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An application to model traffic behaviour on freeways with Getram/AIMSUN2

A calibration procedure for micro-dynamic traffic modelling

Graduation thesis
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A calibration procedure for micro-dynamic traffic modelling has been designed and applied to the micro-dynamic software package Getram/AIMSUN2 (in this study referred to as AIMSUN2). Another involved party of this study is the Barcelona University of Technology (UPC), since AIMSUN2 is originating from UPC. DHV Environment and Infrastructure is developing the AIMSUN2-software for traffic modelling in the Netherlands.

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KEYWORDS

Model development; Calibration; Tuning; AIMSUN2; Fixed Parameters, Model Dependent Parameters and Location Dependent Parameters; Multi-criteria analysis; Calibration procedure.

LIST OF USED EXPRESSIONS

Verification
The process to check whether the theoretical model has been implemented correctly.
Calibration
Determining the set of model parameters that lead to the best fit between model predictions and available observations.
Validation
Checking whether the predictions of a calibrated model correspond to new traffic observations.
Calibrated model
A model consisting of adjusted parameter values.
Validated model
A model that sufficiently approximates a real system.
Network component
Basic network element (section), classified by number of input and output directions.
Criterion variable (also referred to as outcome variable of interest)
Simulation outcome which is used to value the performance of the simulation. (in this study: flow, density, speed, travel time and location/position traffic-jams).
Scenario
Representation of a simulation run for which the criterion variables are judged (accepted or rejected).

SUMMARY

To study traffic flow characteristics at freeways, traffic models are used. One of these traffic models is the micro-dynamic traffic model Getram/AIMSUN2 (in this study referred to as AIMSUN2) developed at the Barcelona University of Technology (UPC). DHV Environment and Infrastructure is using this software package for traffic modelling in the Netherlands. To achieve sufficient accuracy between simulation outcomes and observations traffic models need to be calibrated. At this moment, a procedure to perform the calibration process for AIMSUN2 does not exist. The objective of this study is to design such as procedure. This study focuses on the driver behaviour on freeways.

The objective of a calibration process is to estimate the unknown model parameters and to optimise the overall model performance. By definition, a simulation model generates output on multiple aspects such as flows, density and travel time. Each of these aspects is associated to it is own performance indicator. The overall performance of a model can be defined as a weighted sum of these indicators. The weights depend on the priorities of model experts, but are seldom made explicit. In this study a procedure is applied to determine these weights from revealed preferences of model experts.

First, a problem analysis is performed to distinguish typical aspects of the calibration process. Possibilities to estimate unknown model parameters and optimisation processes to compute the distance between simulation outcomes and observations are defined. The optimisation processes is divided into a one dimensional and a multi-criteria analysis. During the one dimensional optimisation single criterion variables are observed while during the multi-criteria analysis the total performance (all examined criterion variables) of a model is examined. Various estimation techniques are distinguished to determine the model parameter values which are used within the mentioned optimisation processes.

Next, a description of the micro-dynamic traffic model AIMSUN2 is given. The computation of the driving speed for vehicles at sections is discussed. Also, the sub models defining the individual driver behaviour are described and examined. A qualitative analysis is performed to define the influences of model parameters on criterion variables.

Parameters are classified into fixed parameters, model dependent parameters and location dependent parameters. Basic network configurations for simulations are proposed. A stretch, a fork and a join are distinguished as basic configurations By means of this classification, specific driver characteristics are related to network configurations.

An objective function is proposed to compute a distance measure between observations and examined criterion variables. The following criterion variables are included in this objective function: flow, density, speed, travel time and location/length traffic-jams. It is proposed to compute the mentioned distance measure by a mean absolute error proportional (MAEP) function. Experiences of model experts are used to define the weights of examined criterion variables

A sensitivity analysis (quantitative analysis) is performed to define the sensitiveness of model parameter values on criterion variables.

A calibration procedure is proposed based on experiences obtained during this calibration study. In later versions of AIMSUN2, it should be possible to combine the findings of this study into a network wide applicable calibration model.

An important aspect of this study has been the study of the categories to which model parameters are assigned. In the AIMSUN2 (version 3.2 which is not publicly available and used for this study) various model parameters used in the model implementation are assigned to a category which is less suitable for calibration. This classification implies that there are only limited possibilities for tuning the model during the various phases of the calibration process.

CONTENTS

1 INTRODUCTION

1.1 Background

At this moment no systematic procedure to calibrate micro-dynamic simulation models exists. Many explanations can be given why such a procedure is not available at the moment. Next, some of these explanations are given:

- It is difficult to perform a calibration process of micro-dynamic models;
  In general, simulation models consist of many mathematical functions representing the driver behaviour. These functions consist model parameters. For each of these model parameters, values must be estimated to obtain a sufficient fit between simulation outcomes and observations. Defining which model parameters influence specific simulation outcomes is very difficult.

- Diversity of micro-dynamic traffic models;
  Designing a generic calibration process for micro-dynamic traffic models is almost impossible because these models often differ in the process of modelling the driver behaviour. For example different theoretical models may be used to simulate the lane-changing behaviour of drivers which result in different implemented model parameters.

- Single model parameters may influence more than one simulation outcome;
  As mentioned in this section it is difficult to define which model parameters influence specific simulation outcome. However, single model parameters may also influence more than one simulation outcome. Next, the sensitivity of simulation outcomes for the model parameter must be defined.

- Availability of multiple simulation outcomes and criterion variables;
  A micro-dynamic simulation model produces many simulation outcomes. However to judge the performance of a simulation model, criterion variables must be obtained of these simulation outcomes. So, there must be decided which criterion variables are used to judge the simulation performance.

- No or limited availability of observations;
  During the calibration process model parameter values are adjusted to fit criterion variables to observations. However, to perform such a process sufficient observed data must be available. It may be concluded that the limited availability of adequate observations is one of the most important problems of performing a calibration study at this moment.

- Difficulty to judge the simulation performance statistically;
  To judge the performance of simulations, statistical functions can be used to compute a distance measure between criterion variables and observed data. However it difficult to define which function computes this distance measure best.

- The traffic process is not deterministic but stochastic;
  Traffic processes are stochastic processes. So, during a calibration study several simulation runs should be performed to include the stochastic aspect of traffic processes. This

stochastic aspects should also be applied to the observed data. Using observations obtained during different moments (hours/days) will include the stochastic aspect in the calibration study.

1.2 Framework of the study

In this study the micro-dynamic traffic model AIMSUN2 is examined. This type of traffic models simulates individual driver behaviour in road networks, including route choice decisions.

AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) is developed at the Barcelona University of Technology (UPC) and DHV Environment and Infrastructure is using this software to support them in their (Dutch) traffic studies and consultancy. At this moment the software package AIMSUN2 has been applied for several studies in London, Barcelona and various Dutch studies.

Until now, the model has not been calibrated sufficiently for Dutch traffic situations due to a lack of a suitable calibration procedure. To make AIMSUN2 suitable for traffic modelling in the Netherlands, a systematic, user-friendly calibration procedure is needed. The process to determine the optimal combination of model parameters to obtain the desired accuracy between criterion variables and observations is called calibration. In this study, the vehicle behaviour (based on driver and car characteristics) on freeways is examined

1.3 Research objectives

The main objective of this project is to develop a systematic and user-friendly calibration procedure for micro-dynamic traffic modelling, especially with the AIMSUN2-software. This procedure must be a tool to create quickly valid traffic models. Further, there has to be a possibility to expand this procedure in the future. The calibration procedure has also to be verifiable and repeatable such that results can be reproduced.

To design such a procedure, the following research aspects must be examined and defined:
1. Classification of model parameters; Here, parameters will be classified into fixed parameters (parameters corresponding to behavioural or fixed constants), model dependent parameters for freeways (parameters used for the calibration process which is applied once to estimate the parameter value) and location dependent parameters (valid for specific local infrastructure settings only).
2. Definition of parameter values (minimum, maximum, mean and variation);
3. Definition of performance criteria and thresholds to determine whether or not simulation results are sufficiently in line with observations;

A secondary objective is to identify shortcomings or opportunities for model improvements.

1.4 Assumptions

During this study, only the vehicle behaviour on freeways will be examined. Several network components of which freeways are build of (such as on-ramps and off-ramps) will be studied. The vehicle behaviour is modelled by mathematical functions. These functions describe specific aspects of the driving task such as car following, lane-changing and gap acceptance, so that most of the circumstances a driver will face will be studied.

The specifications of sub models to model the vehicle behaviour on freeways as these are currently available will not be changed during this study. This calibration research will only focus on adjusting the parameters values of given models.

For this study AIMSUN2 (version 3.2) is used. This version is not available for commercial use. It is used for this study and test purposes of DHV Environment and Infrastructure. Recommendations of this study are implemented in the new publicly available release.

1.5 Set up of study

In chapter 2, a description of the general calibration problem is given. This model development process will be examined and applied to the traffic model. Therefore, the implemented model specifications will be observed. It is assumed that models are implemented correctly. In this study these implemented theoretical models will not be adjusted.

The examination of the software package AIMSUN2 is discussed in chapter 3.

Chapter 4, defines the study approach. A three phases approach, containing calibration and tuning phases, is proposed. Chapter 4, specifies a method to value multiple outcome variables.

Chapter 5 describes a qualitative analysis of AIMSUN2. Specific simulation characteristics are discussed such as the zone definition of sections for network components. The vehicle behaviour for the components stretch, fork and join is analysed.

After the model parameters have been classified, different estimation techniques are suggested to establish the parameter values. This process is discussed in chapter 6. For example, parameter values can be obtained by literature study, calibration or common sense.

The suggested approach of defining separate network components is discussed in chapter 7. This classification is suggested because most of the model parameters of AIMSUN2 are global parameters and therefore it is difficult to calibrate entire networks. A multi-criteria analysis has been performed to define the priority of criterion variables. The outcome of an interview with model experts resulted into a definition of the weights of these variables. This process is discussed in chapter 8.

Chapter 9 contains the results obtained from a sensitivity analysis. With this analysis, some parameter values have been varied to determine the influences on the examined criterion variables.

The recommended calibration procedure is discussed in chapter 10. Conclusions and recommendations for model improvement are given in chapter 11.

2 PROBLEM ANALYSIS OF CALIBRATION METHODS IN GENERAL

2.1 Introduction

The objective of a calibration study is to define the optimal model parameter values implemented in the model. These optimal model parameter values are obtained by fitting criterion variables to observed data.

In general a calibration study is illustrated by:

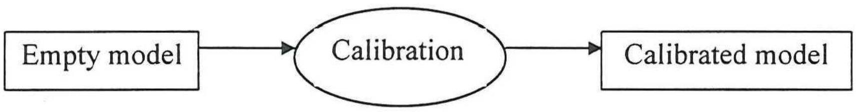


Figure 1. Objective of calibration study

An empty model contains theoretical sub models with undefined model parameters. After a calibration process is performed, a calibrated model is obtained. The aspects defining the calibration are discussed in this chapter.

As mentioned in Chapter 1, performing a calibration process is difficult. A generic calibration procedure does not exist at this moment. There different modelling processes (theoretical models) are applied in micro-dynamic traffic models, defining a generic calibration process is difficult. Before a calibration process can be started, a general mathematical description of the calibration objective should be defined. First, main aspects of the calibration process are defined in section 2.2. Model parameter values can be derived by calibration study or by importing values from literature or other traffic models. This subject is discussed in section 2.3. Secondly, in section 2.4 the method of one dimensional optimisation is introduced. The aspect of valuing multiple objectives is discussed in section 2.5. Also, the properties and availability of observations should be considered. In section 2.6, this subject is discussed. Estimation techniques to compute the model parameters are described in section 2.7. Finally, in section 2.8 a causal and a statistical traffic models are discussed.

2.2 Calibration of a traffic model

The objective of a calibration study is to determine the optimal model parameter values which result in finding an optimum of the model performance. During the calibration study must be determined which model parameters influence specific criterion variables. Most model parameters influence more than one criterion variable. This is a complex aspects of a calibration study. As mentioned in Chapter 1 a general calibration approach does not exist at this moment. Due to the fact that most models are based on different theories and theoretical models which result in different calibration approaches it is difficult to design a generic calibration procedure. Collecting sufficient and useful observed data is another complex aspect of the calibration study. In the next section specific aspects of the calibration process are discussed.

2.3 Calibration versus importing of parameters

To model traffic, mathematical representations are implemented in software packages. A simple example of a mathematical representation of a certain phenomenon is given in Equation (1):

$$y = \alpha \cdot x + C \qquad (1)$$

In this model y is the outcome variable of interest, e.g. distance to the next car (headway) whereas x is the explanatory variable, e.g. speed. α and C are model parameters of the (car following) model. C for example is the minimum headway between vehicles during congestion (speed, x, is zero).

The simple example given in Equation (1) can be replaced by a simple traffic model, defining the relation between (minimum) headway and driving speed:

$$d_i = L_j + z_1 + z_2 \cdot v_i + z_3 \cdot v_i^2 \qquad (2)$$

In Equation (2), four parameters need to be calibrated. Here, L_j, defines the minimum distance between vehicles being stopped (in congestion). This a typical example of an imported parameter. The value can be derived from literature study. The procedure to define the value of this parameter differs compared to the approach of defining other parameter values. The values of the parameters (z_1, z_2 and z_3) can derived by a calibration process using specific observations.

The above example illustrates that one of the problems during the calibration process is the classification of model parameters according to the way they might be obtained.

2.4 One-criterion analysis

In general, the difference between observed data and a single criterion variable in a calibration process is expressed as a distance measure D:

$$D(y, \hat{y}(\theta, x)) \qquad (3)$$

where:

x : vector of input data (e.g. OD-demand);

y: vector of observations ; $y = [y_{t1}, y_{t2}, .., y_{tn}]$;

$\hat{y}(\theta, x)$: vector of model criterion variables; $\hat{y}(\theta, x) = [\hat{y}_1(\theta, x), \hat{y}_2(\theta, x), .., \hat{y}_n(\theta, x)]$;

θ : vector of model parameters; $\theta = [\theta_1, \theta_2, .., \theta_m]$;

m : number of parameter values which need to be calibrated;

n : index indicating the observation number.

For a series of observations (*t1-tn*) the distance measure D between observed data y_n and model predictions $\hat{y}_n$ is computed. See Table 1.

# Observation	Observation y_m	Model prediction $\hat{y}_m$	$D(y_n, \hat{y}_n)$
1	y_1	$\hat{y}_1$	$D(y_1, \hat{y}_1)$
2	y_2	$\hat{y}_2$	$D(y_2, \hat{y}_2)$
:	:	:	:
:	:	:	:
n	y_n	$\hat{y}_n$	$D(y_n, \hat{y}_n)$
			$\sum_{i=1}^{n} D(y_i, \hat{y}_i)$

Table 1. Computing distance measure for one criterion variable with vector θ.

The optimal values for vector θ components to minimise D is given by:

$$\hat{\theta}(y,x) = \underset{\theta}{\arg\min} \sum_{i=1}^{n} D(y_i, \hat{y}_i(\theta, x)) \tag{4}$$

i.e. $\hat{\theta}(y,x)$ is the value of θ that minimises this expression.

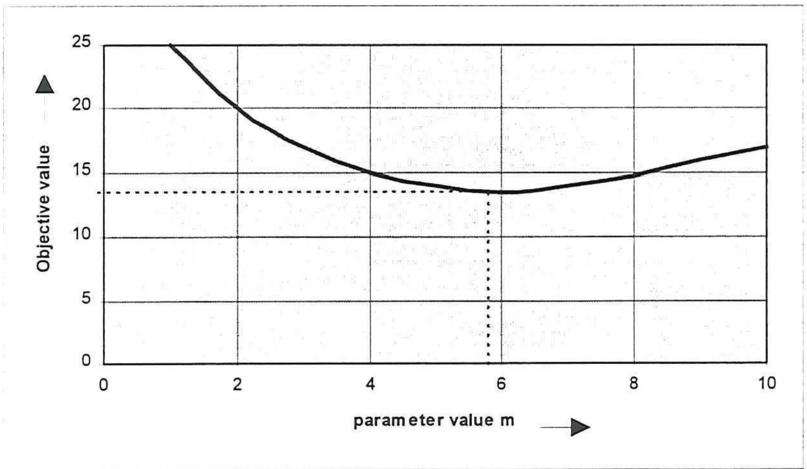


Figure 2. Minimum of distance measure *D* for parameter m.

A distance measure should always be positive and only equal zero if two elements are equal.

$$\begin{aligned} D(y,\hat{y}) &\geq 0, \qquad \forall y, \hat{y} \\ D(y,\hat{y}) &= 0 \qquad \Leftrightarrow y = \hat{y} \end{aligned} \tag{5}$$

The difference D between outcome variables and observations can be computed by different functions. Here, examples of these functions are given.

$$D(y,\hat{y}) = \frac{1}{n}\sum_{t=1}^{n}(y_t - \hat{y}_t)^2 \qquad \text{(mean square error)} \qquad (6)$$

$$D(y,\hat{y}) = \sum_{t=1}^{n} y_t \cdot \log(y_t / \hat{y}_t) - y_t + \hat{y}_t \qquad \text{(entropy distance measure function)} \qquad (7)$$

$$D(y,\hat{y}) = \frac{1}{n}\sum_{t=1}^{n} |\hat{y}_t - y_t| \qquad \text{(absolute error function)} \qquad (8$$

where:

t :an index indicating the observation number.

For a single criterion variable, y, different combinations of model parameters, θ, can be specified describing the examined variable. See also Figure 3, describing observed data of variable y and two possible model specifications of this variable. An important aspect of the calibration is to determine which representation describes the phenomenon best. Therefore, the term 'best' has to be specified. In Figure 3, the following theoretical model is used to describe the examined phenomenon: $y = \alpha \cdot x + C$

For both model specifications the following model parameters are defined:

Model specification	***parameter value*** α	***parameter value C***
(1)	1.5	4
(2)	2.5	-5

Table 2. Example of model parameter values of model specifications.

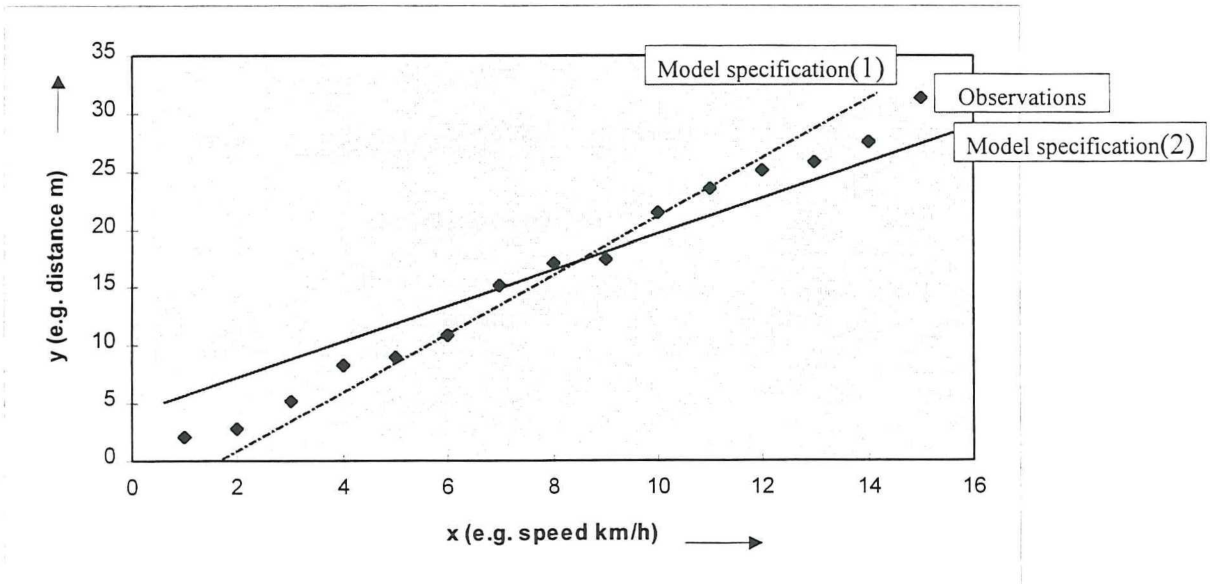


Figure 3. Example of mathematical model specifications of a certain phenomenon.

This subject of performing an one-criterion analysis is discussed in more detail in section 4.8.

2.5 Multi-criteria analysis

In the previous section equations are given defining the distance measure D between series of observed data and a single criterion variable. However, simulations often generate (series of) many types of outcome variables. These complex vectors of observations and criterion variables result into a more complex objective function D. First, a method to value these observations need to be designed. Next, observed data of the examined variables of interest need to be collected Such a process is called a multi-criteria analysis. Equation (9) is an example of a function calculating multi-dimensional the distance between observations and criterion variables where a weight w_i is included.

$$D(y,\hat{y}) = \sum_{t=1}^{n} \sum_{i=1}^{m} \frac{(y_{ti} - \hat{y}_{ti})^2}{w_i} \tag{9}$$

where:

t :index indicating the observation;
i :examined criterion variable.

The weights in the distance function between criterion variables and observations must be defined. For example, the difference between 1500 vehicles simulated and 1525 vehicles observed, 25 (vehicles) and 120 km/h simulated and 95 km/h observed=25(km/h) must be correctly interpreted.

A method to judge the different outcome variables at the same time can be based on a process where priority factors for each outcome variable are defined. These priority factors can be obtained by interviewing experts on traffic modelling. Experiences obtained by these experts can result in a priority factor list. Also, the client for which the study is performed can be asked to define the priority factors based on own preferences.

A gradual process where the several outcome variables are examined separately is another possibility to examine the outcome variables. In such an approach, feedback to already examined outcome variables need to be performed for each observed variable. The definition of the order in which criterion variables are examined is an important aspect for this approach.

In Chapter 0, this subject of performing a multi-criteria analysis is discussed in more detail.

2.6 Type and size of observations

To judge the performance of a simulation model, the outcome variables must be compared to traffic observations. This requires the specification of outcome variables that need to be examined and what observations need to be obtained by the available measurement equipment. The available traffic observations determine the outcome variables that can be used to value the performance of the simulation run.

Another aspect of the performance judgement of a simulation run is the required minimum size of observation data. The observations can be obtained in different ways: By means of traffic counts (manually or automatically by detectors), video or other observation equipment.

Related to the 'observation size'-aspect is the definition of the locations where the observation data must be collected. For network components such as on-ramps, off-ramps and weaving sections there must be defined whether or not different observation locations are determined. During this calibration study it is assumed that sufficient observed data is available. In section 4.6 this aspect is discussed in more detail.

2.7 Estimation techniques

The implemented sub models of AIMSUN2 (route choice, lane-changing, car following and gap acceptance) represent the simulated vehicle behaviour. These sub models are mathematical equations built of explanatory variables and modelling parameters. In the calibration process the values of these modelling parameters must be determined. Several estimation techniques are available to establish the modelling parameter values. As mentioned in section 2.3 and illustrated by equation (2) model parameter values can be imported or obtained by a calibration process. Estimation techniques can be related to the way they might be obtained.

Various estimation techniques are available to determine the modelling parameter values. Here, some of the estimation techniques are given:

- statistical techniques;
- trial and error;
- brute force;
- literature;
- interviews with experts;
- common sense.

However, the characteristics of these estimation techniques differ a lot. For example, parameter values obtained by means of statistical techniques will mostly result into outcome variables of interest which correspond best to available observed data compared to other estimation techniques. However, most of these statistical techniques take a lot of time to perform. Choosing the most suitable estimation technique is another important aspect.

Other techniques to estimate parameter values such as trial and error or brute force can be performed within less time compared to the statistical techniques. The parameter values obtained with the trial and error or brute force techniques may result into a lower performance level of the simulation run. Based on the available time, budget and chosen boundaries to perform these two techniques, the quality of the criterion variables is determined.

Examples of estimation techniques where no simulations are performed are literature research, interviews with experts and common sense. Based on own experiences or experiences obtained by others, parameter values can be defined. The process of checking whether or not experiences obtained by other studies (for example with other simulation models) is an important aspect by these last mentioned techniques which make use of simulation experiences.

In Chapter 6, this aspect is discussed in more detail.

2.8 Causal versus statistical models

The optimum combination of model parameters can be derived in two different ways, depending on whether the model for which parameters are estimated is considered as a statistical or a causal one. Statistical models just describe an observed relation between dependent and independent variables. Causal models describe a theoretical relation between dependent and independent variables.

A statistical approach optimises the objective function by adjusting the model parameters irrespective of their exact meaning. The total performance is valued. So, it is possible that in an optimising process unrealistic parameter estimates are obtained.

In the causal approach of optimising the objective function, the meaning of the parameters is taken into account. Unrealistic parameter values are not accepted in a causal calibration approach although even if they lead to statistically better values for the objective function.

Choosing whether the model is considered as a statistical or a causal one depends on the preferences of the client of the study. In this study a traffic model is considered to be a causal one. Section 4.4 discusses this subject.

2.9 Summary

It is concluded that at this moment no general calibration procedure exists. Performing a calibration study in general is difficult due to the fact that traffic behaviour is a stochastic process. Different simulations need to performed and different observations need to be obtained to model the stochastic aspect of the traffic behaviour. Obtaining sufficient and useful observations is one of the most complex aspects of the calibration study. The diversity of micro-dynamic models is also an aspect what makes it difficult designing a generic calibration procedure.

Different theories resulting in different model parameters are implemented in micro-dynamic traffic models. So, for each traffic model the influence of specific model parameters on criterion variables must be specified. Therefore, a qualitative and a sensitivity analysis must be performed to define the mentioned influence factors. In sections 4.4 and 4.7 these analysis's are discussed in more detail. Chapters 5 and 9 discuss the results obtained during both analyses.

As mentioned in section 2.3, model parameter values can be obtained differently (importing or by calibration). Therefore, it is proposed to classify model parameters. In section 4.3 this subject is discussed in more detail. The proposed classification of model parameters is described in Chapter 6.

For a single criterion, series of observations are obtained during a simulation run. To define the distance measure between series of observations and model predictions a function must be determined. Many functions are available computing a distance measure between predictions and observations. During a calibration there must be decided which function is used to compute the mentioned distance measure for a single criterion. This aspect of the calibration study is discussed in section 4.8.

Different simulation outcomes are obtained by performing a simulation run. Out of these simulation outcomes must be determined which criterion variables are used to judge the simulation performance. After the criterion variables are defined, related observations must be collected to perform a calibration study. The required minimum of observed data must be specified. In this study, locations for measurement equipment are proposed. It is assumed that sufficient data is available to perform a calibration study.

To judge the overall performance of a simulation run (the total of criterion variables), weights need to be defined defining the priority of the defined criterion variables. A multi-criteria analysis must be performed to define a distance measure for the overall performance of a simulation run. Several techniques, from statistical ones and trial and error to interviews with model experts can be applied. For each calibration study must be defined which technique is used to judge the overall model performance. The subject of multi-criteria analysis is discussed in section 4.8 and Chapter 0 in more detail.

The calibration process can be performed by a statistical approach or a causal approach. In a statistical approach, the total performance of the simulation is valued. The meaning of parameters is not observed, so unrealistic parameter values can be obtained. In a causal calibration approach, unrealistic parameter are not accepted. In this calibration study the traffic model is considered as a causal model. Section 4.4 discusses this subject.

Observations are used in a calibration process to judge the simulation performance. Although it is assumed in this study that sufficient observations are available, some aspects concerning this subject are discussed in section 4.6.

3 DESCRIPTION OF THE AIMSUN2 MODEL

3.1 Introduction

This chapter discusses the micro-dynamic traffic model AIMSUN2 in more detail. Information is given about the performance of the software package and its main sub models used to model the traffic flow in sections 3.2 and 3.3. Also, general modelling issues such as vehicle distribution over the network are discussed.

Descriptions are given of the calculation of the speed for vehicles at a specific section and the vehicle behaviour at specific network components such as off-ramps and weaving sections in relation the sub models in sections 3.4 and 3.5.

3.2 Application area of AIMSUN2

Traffic control is an important tool to improve the capacity of traffic networks. With the help of traffic control systems the utilisation of the network and the safety for drivers can be improved.

The micro-dynamic traffic model AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) is used to perform traffic studies to examine above mentioned traffic measures.

AIMSUN2 is a simulation model to model the traffic flow on urban and non-urban networks. The software package simulates the behaviour of each single vehicle. By means of sub models, each representing specific vehicle manoeuvres, the total vehicle behaviour is modelled. It is possible to simulate the behaviour of several user groups differently. Examples of these user groups are cars, trucks, buses ambulances, bicycles. See also Appendix 6, for detailed information of user-groups. The user groups are defined by characteristics such as vehicle length, acceleration and deceleration length and minimum distance between vehicles.

Statistical output of the simulation runs can be obtained for the entire network or for selected locations, periods and user groups. In general the following statistical output can be obtained. See also Figure 4.

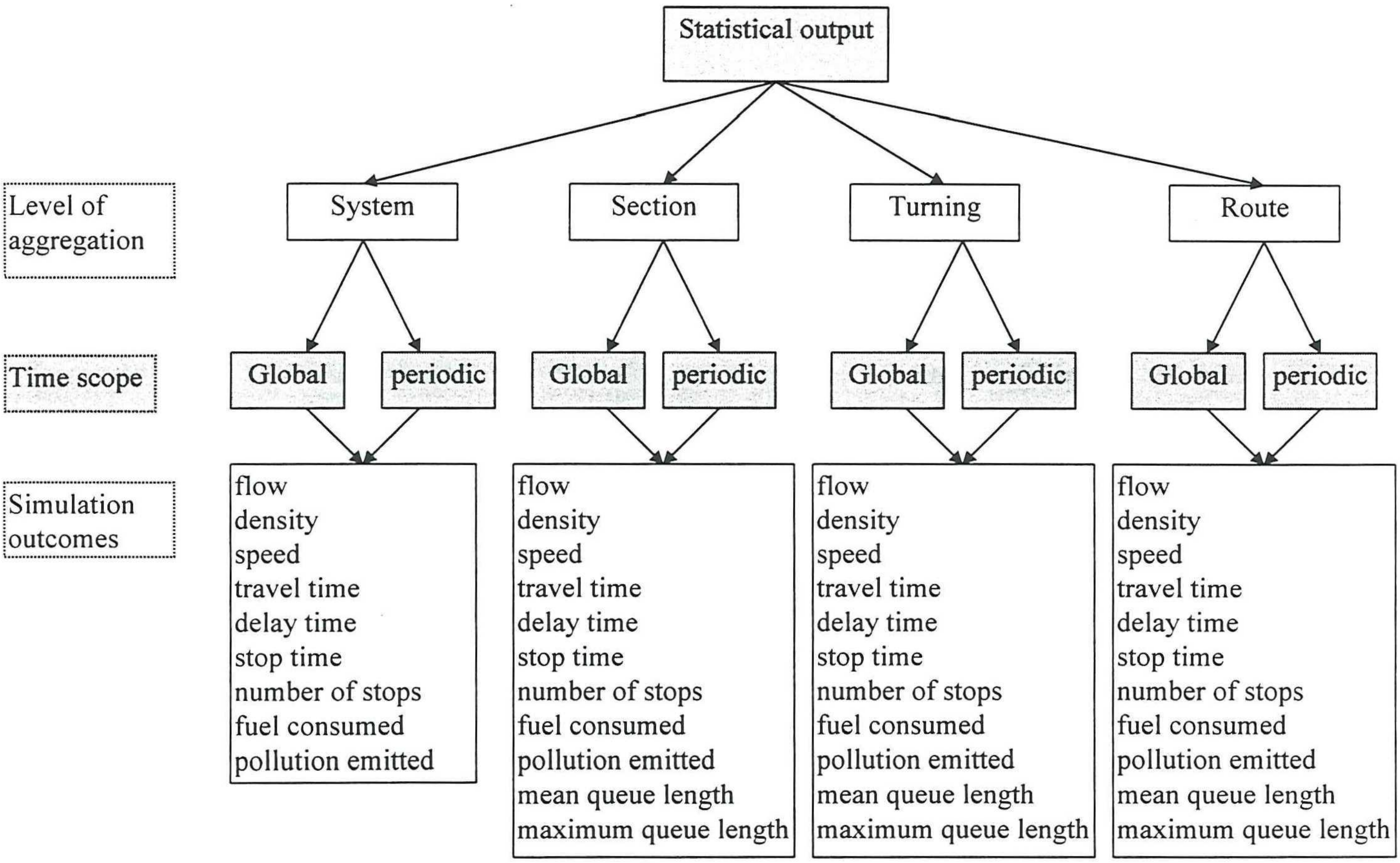


Figure 4. Simulation outcome characteristics.

A simulation run can be performed in different ways by choosing different options. There is a possibility to perform a simulation run where the traffic flow can be observed by means of an animation. Such an animation run can be performed at two different speeds. One, where the flow is simulated real time. A run option is the other possibility to perform an animation run. Based on the size of the network and number of vehicles and the performance of the used computer, simulations are performed.

If the user is interested in the statistical output of a simulation, it is possible to perform a batch simulation. In this situation, there is no animation shown but the simulation run is much faster.

Simulation type	*Options*	*Advantage*
• animation	real time run	visualising traffic flow
	run	visualising traffic flow with reduced simulation time
• batch	run	quickly obtaining simulation outcomes

Table 3. Simulation types and options.

3.3 Sub models of AIMSUN2

The modelling process of AIMSUN2 can be described by different modelling processes. Within AIMSUN2 the following sub models are available:

- the route choice sub model;
- the lane-changing sub model;
- the car following sub model;
- the gap acceptance sub model.

For simulating traffic flow at freeways the route-choice, the lane-changing and the car following sub models are used. The gap acceptance behaviour at freeways is implemented within the lane-changing sub model.

AIMSUN2 can be divided in three main modules:

- input module; the network is specified and the simulation characteristics are defined.
- simulation module; the simulation process of individual drivers is modelled by means of the available sub models.
- simulation module; the presentation of the simulation results is showed.

In Figure 5, the relation between the main modules is given.

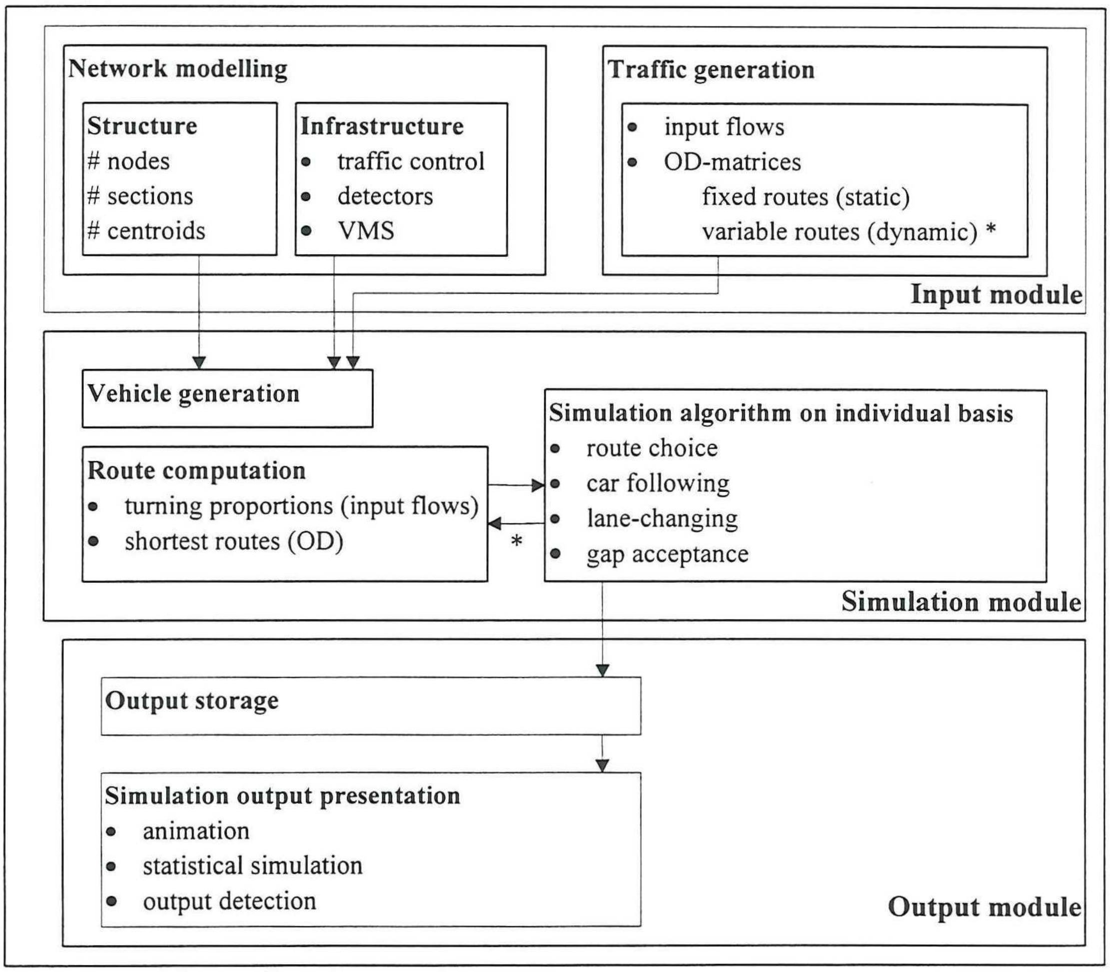


Figure 5. AIMSUN2 modules.

In the following sub sections, the sub models will be discussed in more detail.

3.3.1 The route choice sub model

The generation process of vehicles isn't examined in this calibration study. It is mentioned that a Binomial Distribution or a Multinomial Logit Model is used for this process. For more information about this subject it is recommended to read the Getram/AIMSUN2 user's manual version 3.1.

After vehicles have been generated, they will be placed into the designed network. This distribution process can be carried out in two different ways, based on:

- input flows and turning proportions;
- origin-destination matrices and route criteria.

In the first method, vehicles are generated and input into the network through the input sections, following a random generation model based in the mean input flows for those sections. The vehicles are distributed randomly around the network in accordance to the turning proportions which are defined at each section of the network. So vehicles do not have 'knowledge' about their complete path along the network, but only about their next turning movement. So, it is possible that vehicles are driving the same route over and over again.

With the second method, first an OD-matrix is defined. This matrix specifies for each combination of origin and destination the number of trips that should be assigned to the network. Subsequently these trips are assigned to routes for which a route choice model is used. See Appendix 1, for an example of this computation.

Several route search models have been implemented. In both models the travel costs are expressed in travel time. So, the route with the lowest estimated travel time is the shortest route.

In AIMSUN2 two types of route search models have been implemented.

- Pre-defined fixed routes;

Shortest path trees are computed at the beginning of the simulation. The costs of the path are defined as the travel time between origin and destination by travelling with maximum section speed. During the simulation no new path will be computed. Vehicles will follow their initially shortest paths.

- Variable routes;
  Two variable route search models have been implemented. First, a static route model. Here, new shortest paths are computed each time a vehicle is introduced into the network. Along the trip, no new routes are computed. The second variable route model is the dynamic model. Each simulation step new shortest routes are computed for all simulated vehicles on-route and all vehicles introduced onto the network. So decisions are made whether or not to change path en-route if this option is selected.

The options in computing routes are summarised in Table 4.

Route option	*Type*	*Shortest route computed*	*Shortest route based on*
fixed		once, for all OD-pairs before simulation is started	travel times while driving with maximum allowed speed
variable	static	every simulation cycle, for all vehicles being introduced onto the network	travel times based on traffic conditions while vehicle is introduced
	dynamic	each simulation cycle, for all simulated vehicles on-route and introduced onto the network	travel times based on present traffic conditions

Table 4. Route choice models AIMSUN2.

3.3.2 The lane-changing sub model

The lane-changing sub model is an adaptation of the Gipps lane-changing model[1986]. This sub model will be applied in infrastructure settings where there is a desire or a need to change lanes (also referred to as discretionary and mandatory lane-changes). This desire will arise if the speed in the current lane (= speed of the preceding vehicle) is not acceptable. In situations where a driver is forced to change lanes we speak of a mandatory lane-change. Both lane-changing types can only be performed on certain conditions.

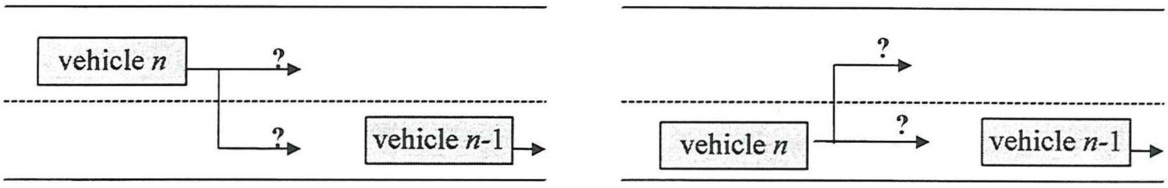


Figure 6. Car following or discretionary lane-changing.

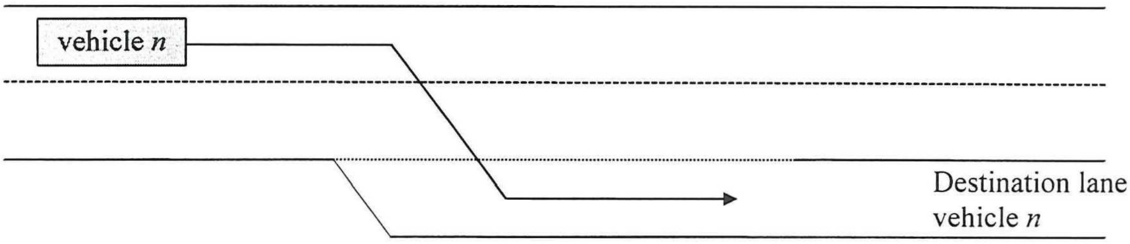


Figure 7. Mandatory lane-changing to reach destination lane.

The condition whether or not to change lanes for discretionary lane-changes in AIMSUN2 (3.2) is computed by:

$$\left(\left(\dot{x}_{n-1}(t) > v_n\right)\mathbf{or}\left(x_{n-1}(t) - x_n(t) > 1.5 \cdot \mathbf{distance\_restrict}\right)\right)\mathbf{and}\left(\dot{x}_n(t) > 0.8 \cdot v_n\right) \quad \mathbf{(10)}$$

where:

$\dot{x}_{n-1}$(t):the current speed of vehicle n-1;[m/s].
$\mathbf{v}_\mathbf{n}$:the desired speed of vehicle n;[m/s].
$x_{n-1}(t)$:the current position of vehicle n-1;[m].
$x_n(t)$:the current position of vehicle n;[m].
$\dot{x}_\mathrm{n}(t)$:the current speed of vehicle n.[m/s]

The distance restrict is computed in AIMSUN2 (3.2) by:

$$\mathbf{Distance\_restrict} = \dot{x}_n(t) \cdot \sqrt{\frac{2 \cdot \dot{x}_n(t)}{a_n}} \quad \mathbf{(\ 11)}$$

where:

$\dot{x}_n(t)$:the speed of the examined vehicle n;[m/s].
a_n :the maximum acceleration rate of the examined vehicle n;[m/s^2].

This distance_restrict function is not implemented correctly. This subject in discussed in chapter 5.5.2.

In Equations (10) and (11) the following parameters can be distinguished:
There, the articles describing the derivation of these models couldn't be found not all parameter units are obtained.

Model parameters discretionary lane-changing	Default values
v_n	120 (km/h)
1.5	1.5
0.8	0.8
a_n	2.8 (m/s2)

In Chapter 5, a sensitivity analysis is performed for these model parameters.

The mandatory lane-change conditions are mainly defined by a zone definition within a section. This subject is discussed later in this section.

For both lane-changing types conditions will be checked by answering three questions.

Each time a vehicle is updated, this first question will be drawn:
Is it necessary to change lanes?
To answer this question several factors have to be examined:

- turning feasibility at the current lane;
- distance to next turning;
- traffic conditions in the current lane (these conditions measured in terms of speed and queue length).

To succeed in lane-changing we also have to answer the question:
Is it desirable to change lanes?
Will the lane change result into an improved driving condition? This improvement will be measured in terms of speed and distance. If the speed in the neighbouring lane(s) is higher than in current lane or the queue length is shorter, the lane change will be an improvement.

If previous questions are answered positive, this last question will be drawn:
Is it possible to change lanes?
Is the gap to change lanes big enough to change lanes with complete safety? Fist, the braking imposed by the future downstream vehicle to the changing lanes will be computed and the braking imposed by the changing vehicle to the future upstream vehicle is also computed. If both braking ratios are acceptable then lane-changing is possible and also accepted.

During the lane-changing processes, network sections are divided into zones. However, this zone definition is related to the lane-changing type. For a discretionary lane-change, where the driver has the desire to change lanes, a section consists of only zone 1. For a mandatory lane-change, driver is forced to change lanes to reach destination lane, a section is divided into a zone 1, zone 2 and zone 3.

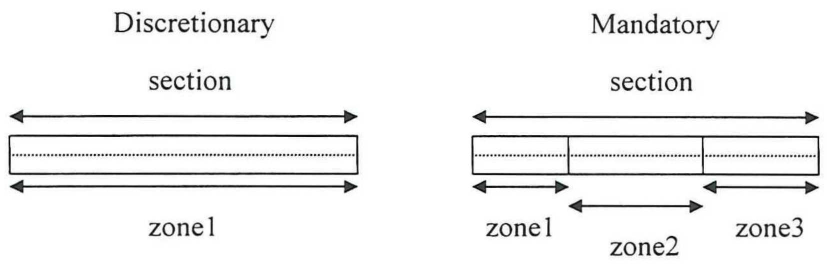


Figure 8. Schematising zone definition of one section for discretionary and mandatory lane-changing.

zone1: changing decisions governed by traffic conditions of the involved lanes.
Considered parameters by the lane-change to the nearest left lane:

- desired speed of driver;
- speed and distance of the current preceding vehicle.

Considered parameters by the lane-change to the original lane:

- speed and distance of future preceding vehicle.

zone2: the drivers look for a gap, but do not affect the behaviour of other drivers in the adjacent lanes (drivers hesitate).

zone3: vehicles (drivers) are forced to reach their desired lanes. If necessary the driver will reduce his speed to succeed the lane-change. For further information about the definition of these zones, see also section 3.5 and chapter 5.

3.3.3 The car following sub model

Several flow regimes on uninterrupted freeways can be distinguished. These regimes are related to the driver behaviour and also to the car following sub model. So first these regimes will be discussed. The following regimes may be distinguished (see Figure 9):

- free flow, nearly all drivers can maintain their desired speed;
- partly constrained flow, a part of the drivers is constrained by other drivers;
- capacity flow, unstable flow (drivers cannot maintain high speeds for long periods);
- congested flow, (nearly) all vehicles are forced to follow a vehicle in front and adapt their speed.

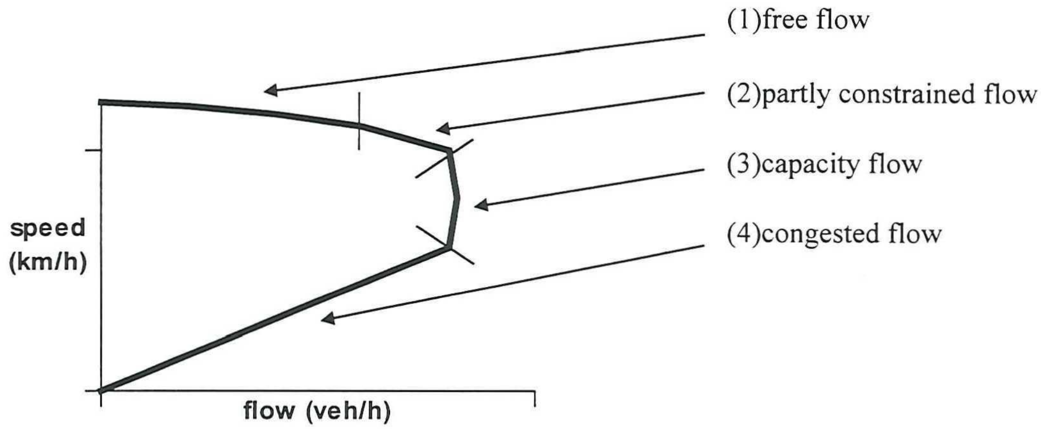


Figure 9. Traffic regimes.

The implemented sub model in AIMSUN2 for the simulation of car following behaviour is based on the Gipps model[1981]. This model consists of two equations each calculating a different speed:

- the *acceleration-speed* , represents the intention of a driver to achieve his desired speed (so influences of other vehicles are not included in this calculation);
- the *deceleration-speed*, represents the limitations imposed by the preceding vehicle when the driver tends to drive at his desired speed.

Both these acceleration and deceleration speeds are computed. The definitive speed $\dot{x}_n(t+T)$ of vehicle n during the time interval $(t, t+T)$ is:

$$\dot{x}_n(t+T) = \min\left\{\dot{x}_n^a(t+T), \dot{x}_n^b(t+T)\right\} \tag{12}$$

where:

$\dot{x}_n^a(t+T)$:the speed (accelerating) of vehicle n at time $t+T$;[m/s].
$\dot{x}_n^b(t+T)$:the speed (braking) of vehicle n at time $t+T$;[m/s].

The minimum value is used in the computation of the new speed (or position) of vehicle n because the computed speed values are related to the current traffic conditions. For safety purposes the minimum value is applied.

Finally the position $x_n(t+T)$ of vehicle n is updated by using the above computed definitive speed and is given by:

$$x_n(t+T) = x_n(t) + \dot{x}_n(t+T) \cdot T \tag{13}$$

where:

$x_n(t)$:the position of vehicle n at t ;[m]
T is the cycle time (simulation interval);[s]

The *acceleration-speed* $\dot{x}_n^a(t+T)$ of vehicle *n* of car following:

$$\dot{x}_n^a(t+T) = \dot{x}_n(t) + 2.5 \cdot \alpha_n \cdot T\left[1 - \frac{\dot{x}_n(t)}{v_n}\right] \cdot \left[0.025 + \frac{\dot{x}_n(t)}{v_n}\right]^{\frac{1}{2}} \quad (14)$$

where:

a :the index for acceleration;

$\dot{x}_n(t)$:the speed of vehicle n at time t ;[m/s].

v_n :the desired speed of vehicle *n* for current section;[m/s].

α_n is the maximum acceleration for vehicle *n*;[m/s^2].

Articles describing the derivation of these models couldn't be obtained, therefore it is assumed that Equation (14) consists of the following model parameters. The units for two model parameters couldn't be obtained.

Model parameter	**Default values**
'parameter 2.5'	2.5
v_n	120 (km/h)
α_n	2.8 (m/s2)
T	1 (sec)
'parameter 0.025'	0.025

In Figure 10, the speed-acceleration for vehicle *n* is given with $\dot{x}_n(0) = 0$, *T*=1 sec, α_n=2.8 m/s^2 and $\dot{x}_n$ = 120 km/h. (in Figure 10 speeds are computed in km/h instead of m/s) .

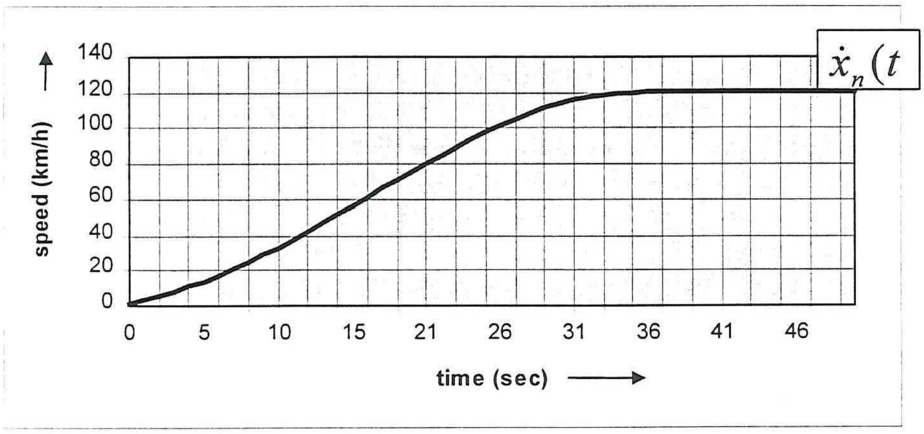


Figure 10. Acceleration-speed $\dot{x}_n^a(t+T)$ vehicle *n*.

The *deceleration-speed* $\dot{x}_n^b(t+T)$ of vehicle *n* of car following:

$$\dot{x}_n^b(t+T) = \beta_n \cdot T + \left([\beta_n \cdot T]^2 - \beta_n\left\{2[x_{n-1}(t) - l_{n-1} - x_n(t)] - \dot{x}_n(t) \cdot T - \frac{\dot{x}_n^2(t)}{\hat{\beta}}\right\}\right)^{\frac{1}{2}} \quad (15)$$

where:

b: the index for braking;

β_n (<0): the maximum deceleration of vehicle n ;[m/s^2].

$x_{n-1}(t)$:the position of preceding vehicle n-1 at time t ; [m].

l_{n-1} : the effective length of vehicle n-1;[m].

$\hat{\beta}$: an estimation of vehicle n-1 desired deceleration.[m/s^2].

The deceleration function is a very complex one. The computation of the new speed of vehicle n is related to the maximum deceleration, the distance between vehicle *n-1* and vehicle n , the current speed of vehicle n and the estimated desired deceleration of vehicle *n-1*. There is no derivation of this function given because of this complexity and the fact that the articles describing the Gipps models couldn't be obtained. Also, in this study the theoretical models are considered to be given and unchangeable. It is assumed that Equation (15) consists of the following model parameters.

Model parameter	Default values
β_n	7 (m/s2)
T	1 (sec)
l_{n-1}	4 (m)
$\hat{\beta}$	4 (sec)

See for units in above mentioned Equations (14) and (15) Appendix 5.

3.4 Computation of the speed for a vehicle at a section

In the previous section a description of the computation of the acceleration and deceleration speed is given. However, before the definite speed of a vehicle n is computed section properties and characteristics of individual drivers are computed which are used as input variables for the computation of the acceleration and deceleration speed.

A driver who is driving in a free flow regime (see Figure 9) where no other vehicles affect his driving behaviour would try to drive with his desired speed ($v_{desired}(n)$).

However, the maximum speed, $v_{limit}(s)$, allowed at a section may be less than the driver's desired speed, $v_{desired}(n)$. In AIMSUN2(3.2) a speed acceptance model parameter, $\theta(n)$, indicates the level of acceptance of the maximum speed for a section. The definite desired speed, $v_{desired}(n,s)$, is computed as the minimum of the driver's desired speed, $v_{desired}(n)$ and the maximum speed of a section multiplied by the speed acceptance, $v_{limit}(s) * \theta(n)$.

The computed definite desired speed is used as input variable of the acceleration speed function, see equation (14).

The process of computing the definite speed of vehicle n for section s is given by Figure 11.

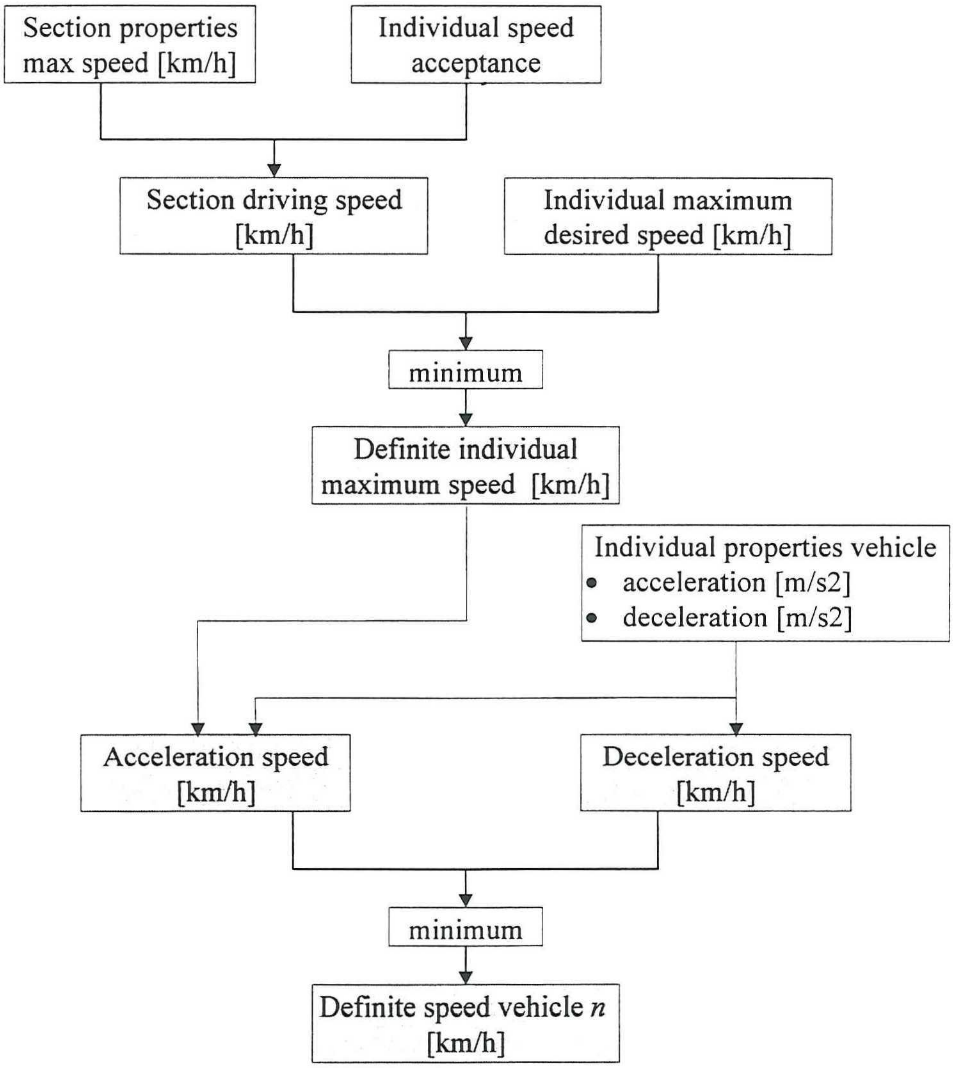


Figure 11. Computation of definite speed vehicle *n* for section *s*.

Summarising, the maximum speed of driver *n* related to the speed limit of a section is computed based on two parameters:
$\theta(n)$: the speed acceptance of the driver n;
$v_{\lim it}(s)$: the speed limit of the section *s*.

The speed limit for vehicle *i* on a section *s* is computed by:

$$v_{\lim it}(n,s) = v_{\lim it}(s) \cdot \theta(n) \tag{16}$$

Note:
The speed limit for each section is computed by the speed acceptance of drivers for that specific section. Therefore, the speed acceptance has been classified as a tuning parameter. The

acceptance of the speed limit for freeway locations differs. Due to the lay-out of infrastructure settings (sharp curves) or speed controls at specific freeway sections, drivers will accept the speed limit (speed penalties influence the acceptance of speed limits)

Finally, the maximum desired speed of a vehicle *n* on a section *s*, $v_{desired}(n,s)$ is:

$$v_{desired}(n,s) = \min[v_{\lim it}(n,s), v_{desired}(n)] \qquad (17)$$

So, the minimum value of the computed speed limit and the desired speed of the driver will be used to model the driving speed of a vehicle.

This speed is used in the car following sub model.

3.5 Lane-change behaviour at specific network components

On behalf of the lane-changing decision process each section created in AIMSUN2 is sub divided into three zones. In each of these zones the lane-change behaviour is simulated differently. Different zone length values for the margins to accept gaps are implemented. There is no function implemented defining the relation between the speed of vehicles and accepted gaps. In each zone, a single value is used to simulate the vehicle behaviour. These zones are only used in situations where a forced lane-change is performed (in this study referred to as mandatory lane-change. We speak of a forced lane-change if a vehicle has to change lanes in order to reach its destination lane. On the other hand we distinguish desired lane-changes (in this study referred to as discretionary lane-change). Based on desired speed a driver decides to perform a desired lane-change if the preceding vehicle is driving too slow. (see section 3.3.2).

In the first zone (zone 1), located at the beginning of a section, lane-changing actions are performed based on the desirability of the drivers to overtake. Based on their own desired speed and the speed of the preceding vehicle, the lane-change will be executed. Here, vehicles will not be influenced by the feasibility of the next turning. A lane-change will only be applied in situations where other vehicles are not influenced.

In zone 2, located down-stream next to zone 1, lane-changing actions will be performed based on the desired turning lane. Vehicles that are not driving on a valid lane (another destination lane), will reduce if necessary their speed to get closer to the desired lane. Their driving style can be described as hesitating to perform the lane-change.

In the last zone, zone 3, vehicles are forced to change lanes to reach the destination lane. If necessary, other vehicles will be affected by these lane-changing processes. In Figure 12 and Figure 13, zone definitions for both lane-changing types are given.

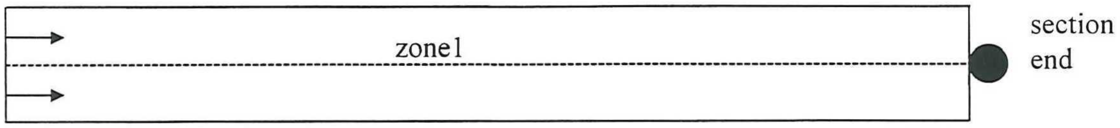


Figure 12. Zone definition of discretionary lane change.

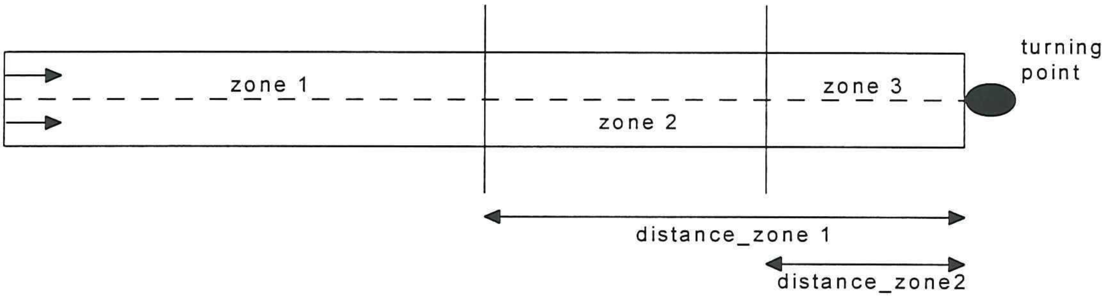


Figure 13. Zone definition of sections for a mandatory lane-change.

Summarising, the following relation between type of lane-change and zone definition is defined:

Type of lane-change	*Definition of section zones*	*Vehicle behaviour*
discretionary lane-change	whole section as zone 1	desired speed versus speed preceding vehicle to decide whether or not to change lanes
mandatory lane-change	section divided into:	
	zone1	desired speed versus speed preceding vehicle to decide whether or not to change lanes
	zone2	hesitating behaviour to reach destination lane
	zone3	behaviour to force lane- change to reach destination lane.

Table 5. Lane-change behaviour versus zone definition.

Within AIMSUN2, the name definition of these zones might be misunderstood. It is possible to define the lengths of distance_zone 1 and distance_zone 2 (see enclosed Figure 13). These lengths are expressed in meters. Because the zone length is a global parameter, valid for all sections, these zone values are applied to freeway sections, arterial sections etc.

This is illustrated in the next example.
Given:
Length of total section 500 meters (will be defined by drawing the examined network)
Chosen:
Length of zone 1 is 250 meters.
Length of zone 2 is 150 meters.

So, in this example the length of zone 3 is 100 meters. To model this setting the following parameters must be defined. Distance_zone1 (equals zone 2 + zone 3) = 250 meters and distance_zone2 (equals zone 3) = 100 meters.

This zone definition is an important aspect by the lane-changing behaviour of vehicles at on-ramps for AIMSUN2 version 3.2. As mentioned in this section, vehicles will apply a lane-change in zone A in situations where other vehicles will not be influenced by this lane change. So large gaps are needed to apply the lane-change within zone 1. So, in situations with high intensities on the lateral lanes, hardly any lane-changes will be applied within this zone 1. Eventually, a vehicle enters zone 3 and will force the lane-change. Vehicles driving at the lateral lanes might be stopped by this mandatory lane-change.

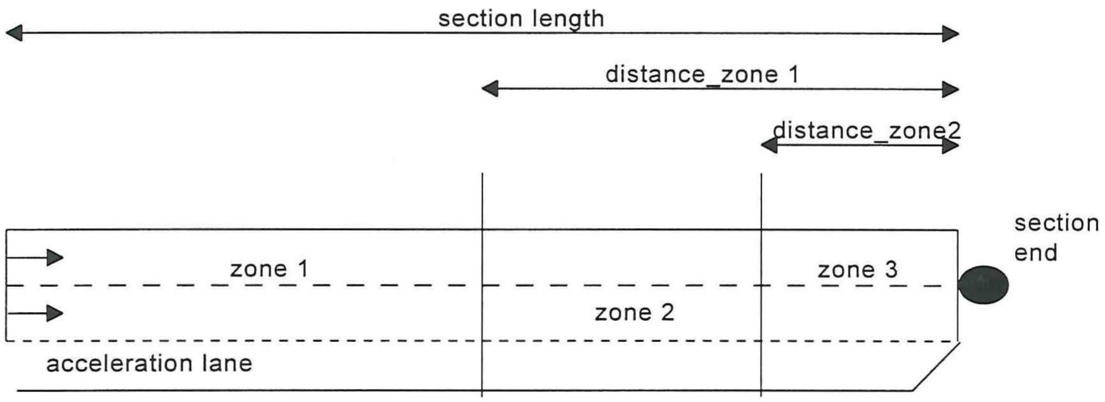


Figure 14. Zone definition at on-ramp settings.

Note: the zone definition of zone 1, 2 and 3 are actually only applied to the acceleration lane because there the mandatory lane-change is applied.. Therefore, this situations could also defined as given in Figure 15

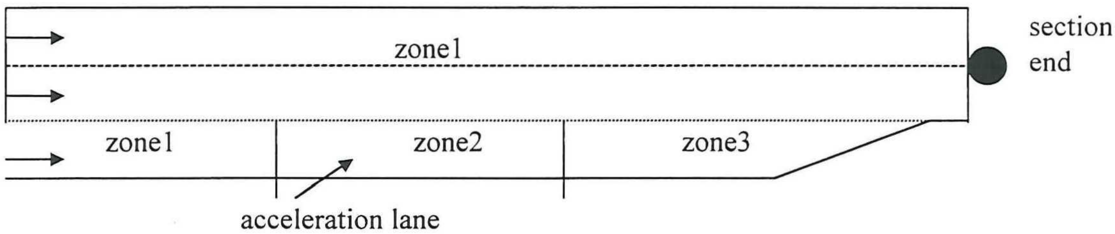


Figure 15. Zone definition at on-ramp settings(2).

3.6 Discussion

As discussed in previous section, vehicles force al lane-change entering zone 3. This may result in stopped vehicles at the lateral lanes. To improve the performance of the simulation for these on-ramp settings, new zone definitions are introduced in new AIMSUN2 versions.

The definition of a distance_restrict is one of these adaptations. This distance_restrict is an estimation of the distance at which the computed deceleration-speed component starts to affect the behaviour of the vehicle. So, in situations where a vehicle is approaching another vehicle, a distance is computed in which the following vehicle will adjust his speed while it is influenced by it's preceding vehicle. Actually, the question is raised whether or not a vehicle is following another vehicle.

Also a distance_restrict zone is introduced at the acceleration lane. In new AIMSUN2 versions (after May 98) of AIMUN2, the zone length is expressed in seconds instead of meters. By using the unit seconds, the driving speed defines the length of a zone. Therefore, the zone definition differs for section types such as freeway, arterial etc. although it is a global parameter. In chapter 5, these modelling aspects are discussed in more detail.

3.7 Summary

AIMSUN2 can be used for modelling urban and non-urban networks or combined urban-non urban networks. The vehicle behaviour is modelled by four sub models: the route choice model, the lane-changing sub model, the car following sub model and the gap acceptance model. In this study, the gap acceptance sub model is not examined because this behaviour is implemented in the lane-changing sub model for freeway traffic modelling. Fixed or variable routes can be applied. The variable routes can be subdivided into a static and a dynamic simulation option. Shortest routes are computed based on estimated travel times. Finally, AIMSUN2 can be divided into three main modules (input, simulation and output) defining the simulation process (section 3.2).

The simulation algorithm applied in each simulation cycle can be summarised by:
if it is necessary to change lanes than apply lane-changing sub model. If a lane change is not necessary apply car following sub model. To apply a lane-change, necessity, desirability and possibility questions are raised and examined (section 3.3.2).

For the car following sub model, both an acceleration and a deceleration-speed component are computed. The acceleration-speed is related to the desired driving speed of the vehicle while the deceleration-speed is related to the driving speed of the preceding vehicle. The minimum value of both computed speeds is applied to define the new driving speed. An overview of the computation of the definite driving speed is given in section 3.4.

Although articles describing the derivation of the Gipps models couldn't be obtained it is tried the distinguish the model parameters of these sub models (sections 3.3.2 and 3.3.3).

To model the driving behaviour a discretionary lane-changing and a mandatory lane-changing process are distinguished. The vehicle behaviour for a certain section is related to the lane-changing type. Two zone definitions for sections determine the driving characteristics for both lane-changing processes (sections 3.3.2 and 3.5).

In new versions of AIMSUN2 (after May 98) improvements of the definition of zones is implemented (section 3.6).

The distinguished sub models and related model parameters are used to perform a qualitative analysis. The results are discussed in Chapter 5. Also, a simulation based sensitivity analysis will be performed where the influences of model parameters on criterion variables are examined (see Chapter 9).

4 CALIBRATION APPROACH

4.1 Introduction

In this chapter, a structured calibration approach will be defined. In the following chapters this approach will be applied.

First, the calibration approach in general is discussed in section 4.2. In this section also the proposed calibration strategy is described. Following to this section, the approach of model parameter classification is given in 4.3. In section 4.4, the objective of a qualitative analysis of AIMSUN2 is given. This analysis already results in conclusions on the network components that can be correctly simulated based on the AIMSUN2 sub models and model parameters.

Section 4.5, discusses why network configurations have been distinguished for the proposed calibration procedure. The subject of defining the influence of model parameters on the driver behaviour is discussed in section 4.7. Proposed is to perform a sensitivity analysis. Finally, section 4.8 gives a more detailed look at the problem of one dimensional optimisation (time series of one criterion variable) and valuing multiple outcome variables of interest by performing a multi-criteria analysis..

4.2 Calibration approach in general

The calibration process should be seen against the background of the general development process of a traffic model. So, first a description of a general traffic model development process is given.

4.2.1 General development process of a traffic model

To increase the knowledge of traffic flows, traffic simulation models have been designed. Several sub models are distinguished such as the car following, the lane-changing models and the gap acceptance, each representing a specific model aspect of driver behaviour. After having calibrated these sub models at microscopic level (separately) and at macroscopic level (combined), the model will be applied to a complete new study area. If the simulation results of the calibrated and tuned model correspond sufficiently to the traffic observations, we assume the model to be valid for practical analysis applications.

In the development process towards a validated model, we distinguish the following steps: *the theoretical model*, a (mathematical) representation of vehicle behaviour, expressed in undefined variables, constants and parameters; *the local application model*, a (mathematical) representation of vehicle behaviour designed for a specific situation; *the calibrated model*, a (mathematical) representation of vehicle-driver behaviour in which parameters have been adjusted until desired accuracy is reached between simulation results and the traffic observations, and finally the *validated model*, a simulation model that has proven to approximate a real system reasonably well. This process is shown in Figure 16.

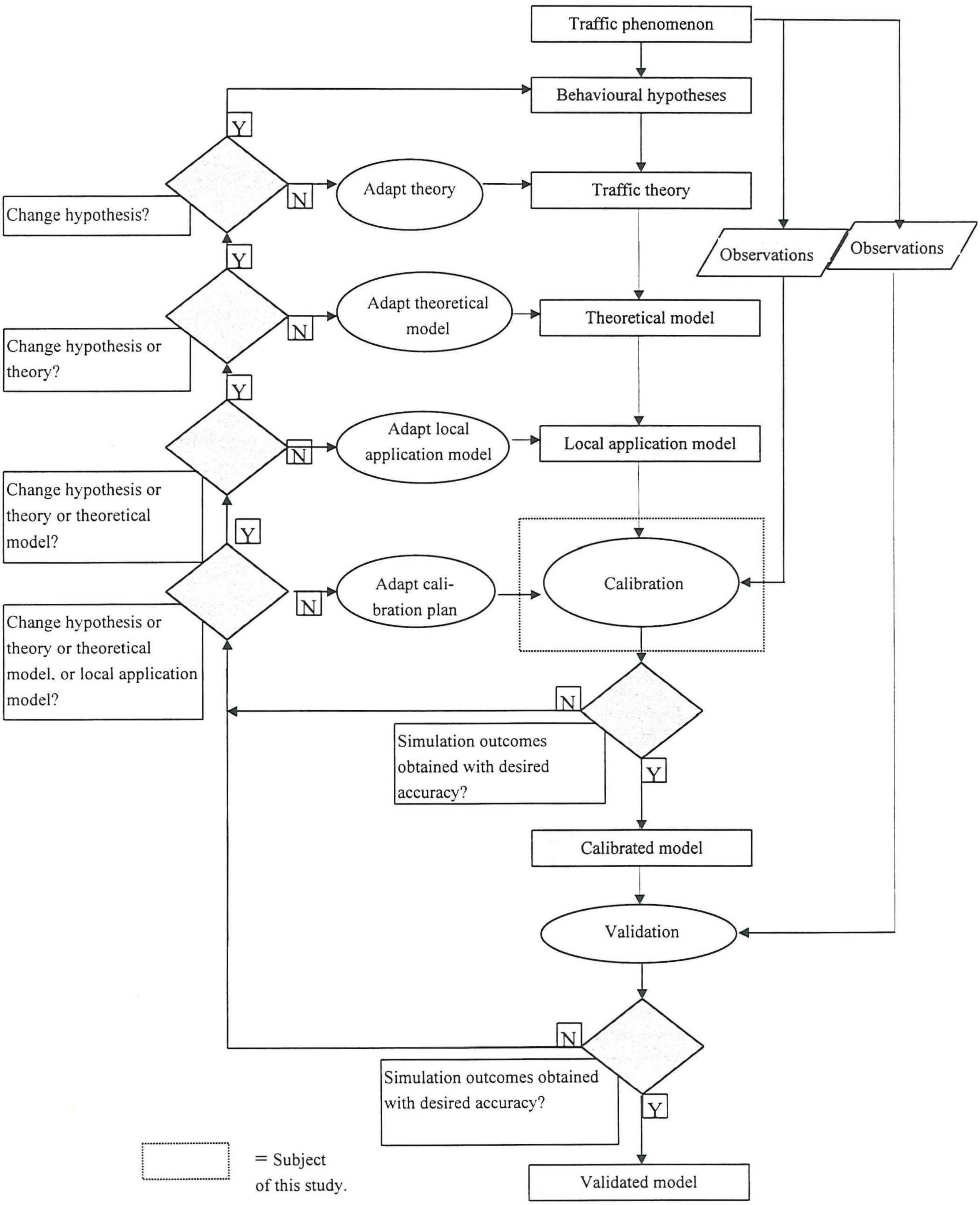


Figure 16. Development process of a traffic model.

The development process of a traffic model starts with defining the *traffic phenomenon* and formulating *behavioural hypotheses*. These hypotheses are combined into a *traffic theory* from which a *theoretical model* is derived. This step involves selecting which theory is applied and which theory is ignored. The next step is making the theoretical model specific to particular network elements, resulting in the *local application model*. This model is then *calibrated*. Section 4.2.2 will zoom in on this calibration process. Finally, to test the calibrated model it is applied to a new traffic area, and if sufficient accuracy between model predictions and observations is achieved a *valid model* is obtained.

The feedback processes depicted in
Figure 16 will be briefly discussed.

The process of adapting the *calibration plan* might be required in situations when during the calibration of a model it is concluded that some simulation outcomes need to be studied which have not been included in the original calibration plan. Based on experiences obtained during other calibration studies or literature study a (definite) calibration plan can be designed.

The *local application model* can be adapted in situations where it is concluded that acceptable simulation outcomes can not be obtained. For example, new parameter values must be included/changed in sub models which were not available for the calibration.

It is also possible that the implemented *theoretical models* do not describe the driver behaviour with desired accuracy. In such cases, the theoretical model must be adapted. For example, the sub model to simulate the driver behaviour at on-ramps can be changed (this happened e.g. during the development process of AIMSUN2 where a new zone definition was introduced).

New developed theories defining the vehicle behaviour can be used while these new theories describe the vehicle behaviour 'better' than the current theories. Actually, this will result in a complete new modelling package.

4.2.2 Calibration strategy

This study only deals with the calibration aspects of the model development process. Therefore, the other processes mentioned in
Figure 16 will not be examined. In this study, the calibration strategy for the calibration process is defined. In Figure 17, the calibration strategy of this study is described:

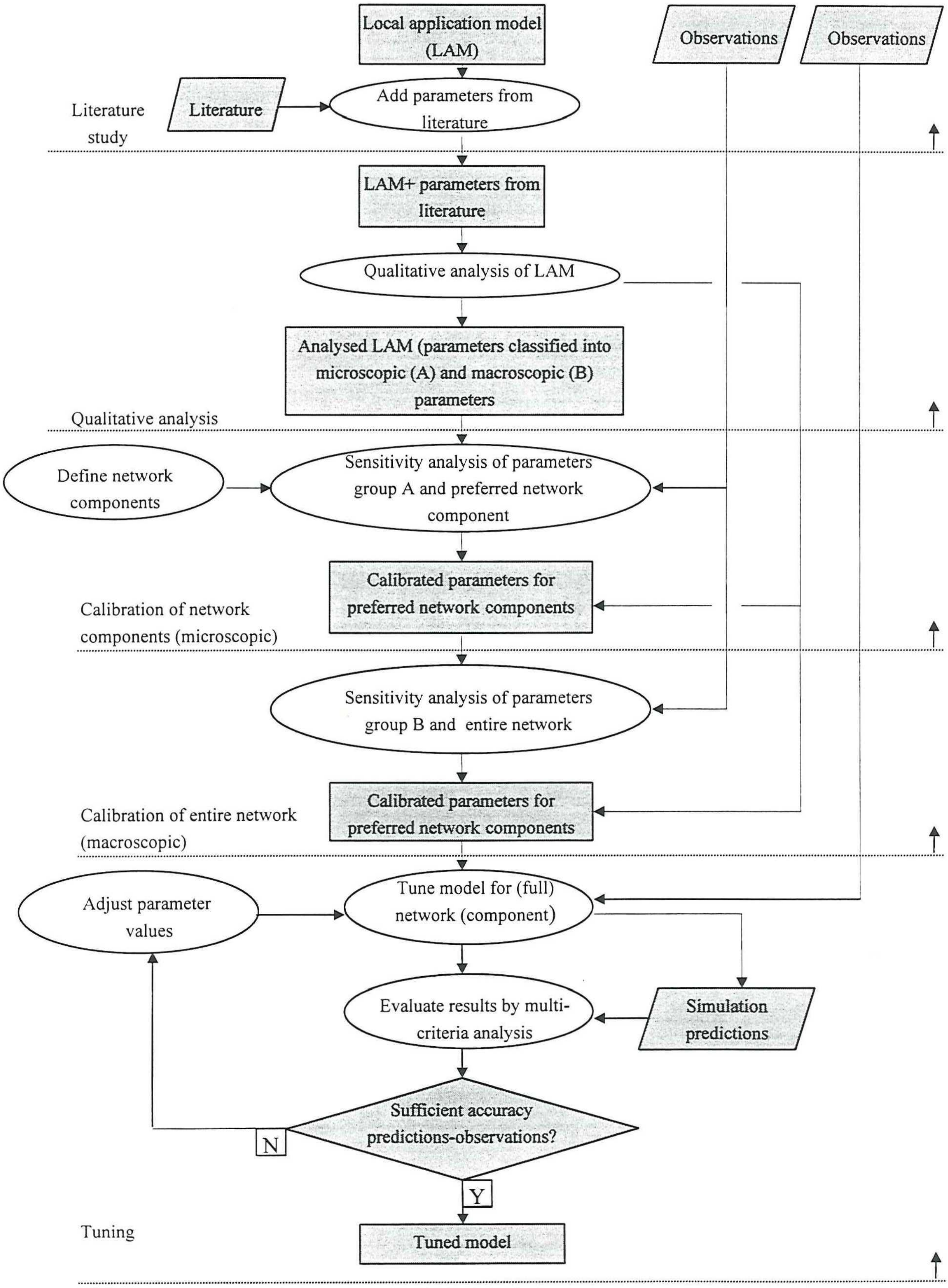


Figure 17. Calibration strategy.

The main difference between the calibration phase and the tuning phase is that the tuning phase must be performed for each new application. Another difference between calibration and tuning is that tuning is always performed for an entire network while calibration process may be applied to network components and the entire network. For new study areas, specific settings and parameter values need to be adjusted. On the other hand, the calibration is performed only once. The results of these phases, parameter and setting values will be kept constant during the tuning phase.

The motivation for distinguishing two calibration levels is based on the complexity of the implemented sub models. For example, the simulation process of AIMSUN2 is based on four sub models, respectively the route choice sub model, the car following sub model, lane-changing sub model and the gap acceptance sub model.

As a consequence, it is very difficult to determine which outcomes of the total system behaviour are the result of which sub models. By defining network components the influence of specific implemented model-parameters can be observed and determined per sub model. The calibration study of single sub models is called the *calibration at microscopic level.* It is possible to analyse the sub models theoretically or/and by simulation. By adjusting parameter values, the influences on the driver behaviour and macroscopic characteristics can be determined.

After having observed and studied single sub models, the overall impact of all implemented sub models should be analysed. This is the second phase of the three phase approach called the *calibration at macroscopic level.* At this level, especially simulation outcomes such as mean speeds and flows for specific road sections should be compared with empirical observations.

In the *tuning* phase, model parameters are adjusted to fit the criterion variables to the available observed data. It is recommended that all performance criteria are unified in a single objective function. Criterion variables have been implemented within this objective function. A gradual tuning process is not recommended because it is difficult to define the priority in which criterion variables need to be examined.

Figure 18 describes the proposed tuning process where one objective function is used. This subject is discussed in section 4.8.

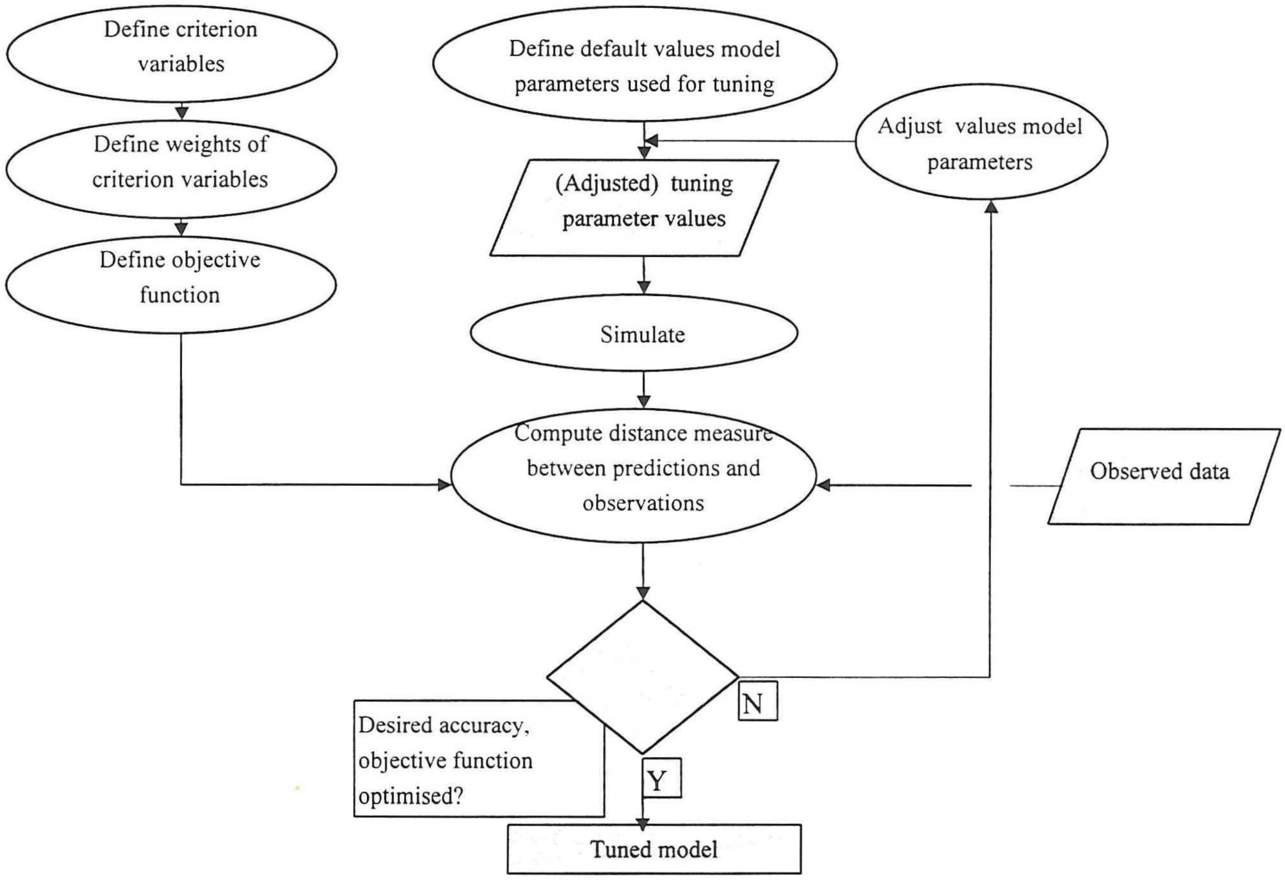


Figure 18. Tuning procedure using one objective function.

4.3 Approach of model parameter classification

In the calibration process, parameter values need to be specified. However, different parameter types are present in traffic simulation models which can be calibrated differently. Therefore, the parameters will be classified into several groups.

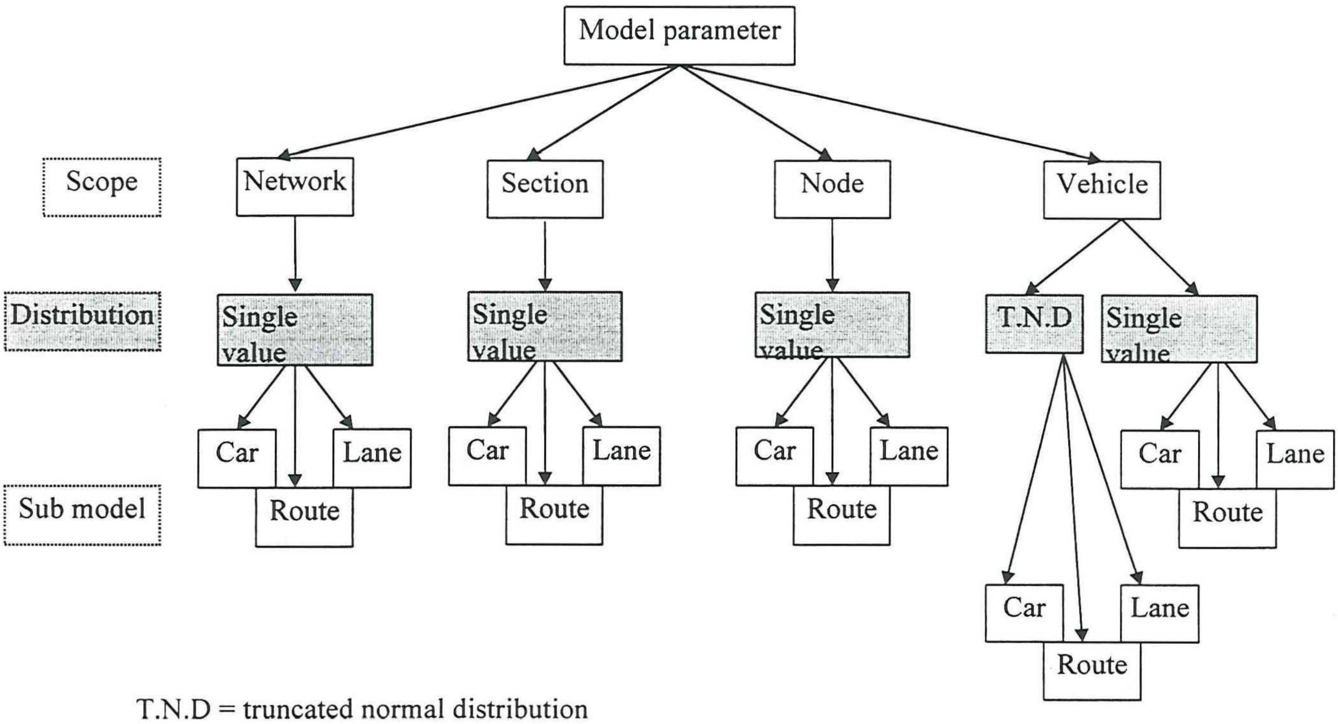
First, parameters can be classified based on their scope. For example, in AIMSUN2, parameters are implemented which are used over the whole network. These so-called global parameters are valid for all link types (urban links, freeway links etc.). On the other hand, parameters applied to specific sections or nodes are distinguished. These parameter values are valid for specific local settings. Finally, some parameters can be grouped as vehicle/driver parameters. These parameters describe vehicle/driver characteristics.

Parameters can also be classified based on the distribution type of the parameter. For example, AIMSUN2-parameters values can either be defined by one single value or by a (truncated) normal distribution where minimum, maximum, mean en deviation values must be specified.

Another classification divides the parameters based on the related sub model. For example, the AIMSUN2-parameter defining the length of vehicles (*l*) is used in the car-following sub model while the 'give way time' parameter (δ) is related to the lane-changing sub model.

Specifying which parameter units are to be used in the different sub models is also an important aspect by studying the model parameters.

Summarising, the following properties of model parameters can be distinguished:



T.N.D = truncated normal distribution

Figure 19. Distinguished parameter properties.

After having considered all relevant properties of a parameter, a choice has to be made about how this parameter is to be calibrated. Three possibilities are considered:

- fixed parameters (also referred to as constants);
- sub model dependent (also referred to as behavioural parameters);
- location dependent (also referred to as tuning parameters).

In chapter 6, the classification of implemented parameter values of AIMSUN2 is dealt with in more detail.

4.4 Objective of a qualitative analysis

As mentioned in section 2.8, traffic models can be considered as causal or statistical ones. In general causal traffic models are considered. For this type of model only realistic model parameter values are accepted A statistical traffic model may contain unrealistic model parameters values while a better simulation performance is obtained. However such a model is less useful in a development process because unrealistic parameter values do not increase knowledge of the simulation process. Another reason to choose to develop a causal traffic model is that clients of traffic simulation studies demand a verifiable calibration approach.

4.5 Decomposing into network configurations

It is very difficult to analyse the total vehicle-driver behaviour of an entire network correctly. Parameter values need to defined for specific network settings such as on/off-ramps. Therefore, the network is decomposed into sub networks. The vehicle/driver behaviour defined by the sub models for specific network components can be calibrated separately. This is called calibration at microscopic level. Finally, the functioning of the total model for the entire network is analysed. (the total vehicle/driver behaviour determined by all sub models). The process of calibrating the total driver behaviour (for an entire network) is called the calibration at macroscopic level. See also Figure 20.

		Network components (local parameters)			**Full network (global parameters)**
		A *(e.g. off-amps)*	*B* *(e.g. on-ramps)*	*C* *(e.g. weaving)*	
Sub models	*route choice*	param. set A	param. set B	param. set C	param. set D
	lane-changing	param. set E	param. set F	param. set G	param. set H
	car following	param. set I	param. set J	param. set K	param. set L

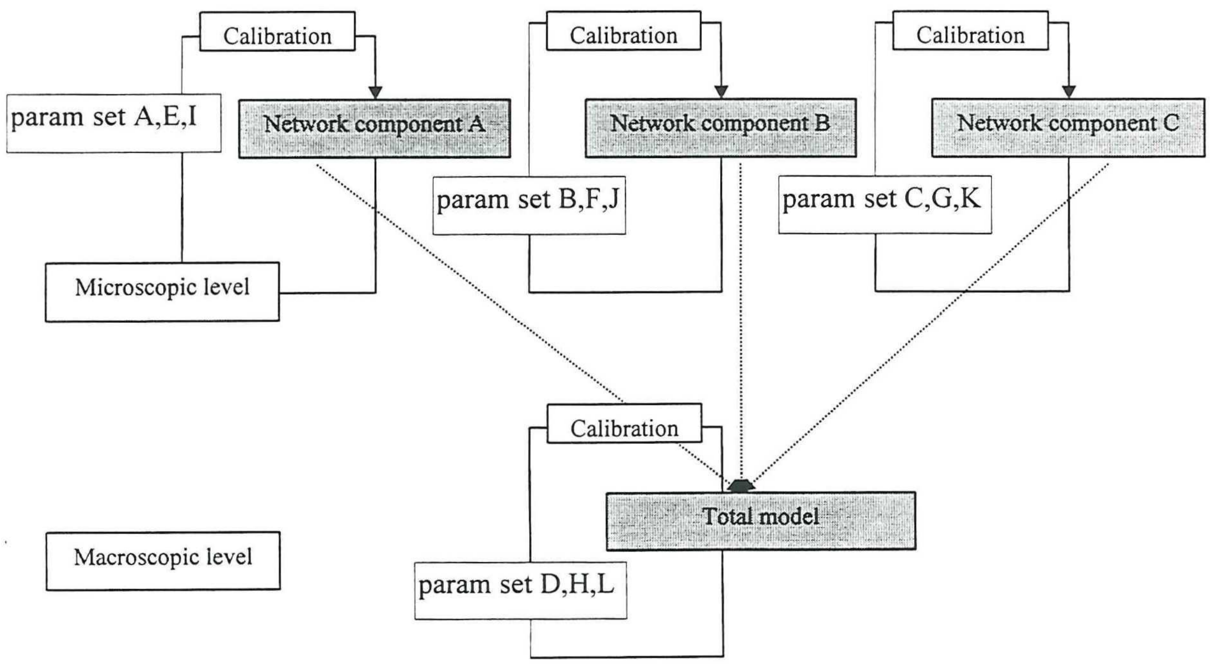


Figure 20. Calibration levels.

4.6 Observations versus calibration

Some short remarks will be given concerning the aspect of observations. In first instance it must be invested whether existing sources of information on the study topic are available. If not, direct observation of traffic volumes may be considered. The basic method is to send an observer to the site to record the number of vehicles passing, over a sequence of time intervals (performed manual or automatic). It is also possible to use automatic counting machines for counts over longer periods.

While traffic counts are obtained there must be dealt with variations occurring as a result of the combination of random, cyclic and trend effects. Some of the variations are due to:

- daily variations;
- weekly variations;
- seasonal variations.

Errors in traffic counts may arise from three main sources:

- the collection of raw count data;

Both manual and machine counts aren't free of possible errors. It may be concluded that completely accurate counts don't exist. Manual counts do underestimate traffic volumes due to missed observations. On the other hand time clock errors in machine counters may result in 'time shifts' of peak demand periods.

- the estimation of a mean count from series of observed counts;

A common and useful assumption is that traffic counts estimates will have a normal probability distribution about the true traffic volume (Bowyer and Fry 1972).

- the period over which continuous counts are taken.

These aspects concerning the process of obtaining observations should be taken into account in a calibration study. However, in this study it is assumed that observations are sufficient observations are obtained with no or corrected errors.

4.7 Sensitivity analysis

The various network components must be studied separately in order to determine the best parameter values for each situation. The best parameter values can be obtained by means of a microscopic calibration process. Literature study and sensitivity analysis can be used to define parameter values. As mentioned in section 4.4, the traffic model is classified as a causal simulation model and therefore the best parameter values must be realistic values. Result of the sensitivity analysis increase the knowledge of the influence of model parameters on criterion variables. The results of the sensitivity analysis can also be used during the tuning process.

For traffic models containing many global parameters (valid over the entire network), the best parameter values for specific network components can be defined. By studying separate network components global parameters are actually considered as local parameters. Defining a best global model parameter value valid for all network settings is also a possible approach by performing a sensitivity analysis. However, it will be difficult to obtain sufficient accuracy between observations and model predictions by this last approach.

Based on literature study, interviews with experts and common sense the ranges of examined model parameters are determined. By means of a trial and error method the influences on specific outcome variables of interest are obtained.

4.8 Single criterion optimisation and multi-criteria analysis

A simulation model produces many (series of predicted values of the) criterion variables which all need to be compared to their corresponding observed values. In addition, the simulation results depend on many parameters, and the influences of specific model parameters on specific criterion variables are difficult to determine.

The distance measure D (expressed in %) between time series of observed data and criterion variable predictions is computed by the mean absolute error proportional (MAEP) function (single criterion optimisation):

$$D_j = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{|A_{ji} - E_{ji}|}{\overline{E}_{ji}} \qquad \text{(MAEP)} \tag{18}$$

where: A_{ji} :the i^{th} observation of examined criterion variable j;

E_{ji} :the i^{th} simulation outcome of examined criterion variable j;

$\overline{E}_{ji}$:the mean value of n simulation outcomes of examined criterion variable j;

n :the number of observations for variable j.

Next, multiple criterion variables must be optimised. Based on literature study of other calibration studies and interviews with model experts the following criterion variables to value the simulation performance are determined:

- flow;
- speed;
- travel time;
- location/length traffic-jams.

Weights of these criterion variables need to be defined to define the performance of the total model. With these weights an objective function can be designed.

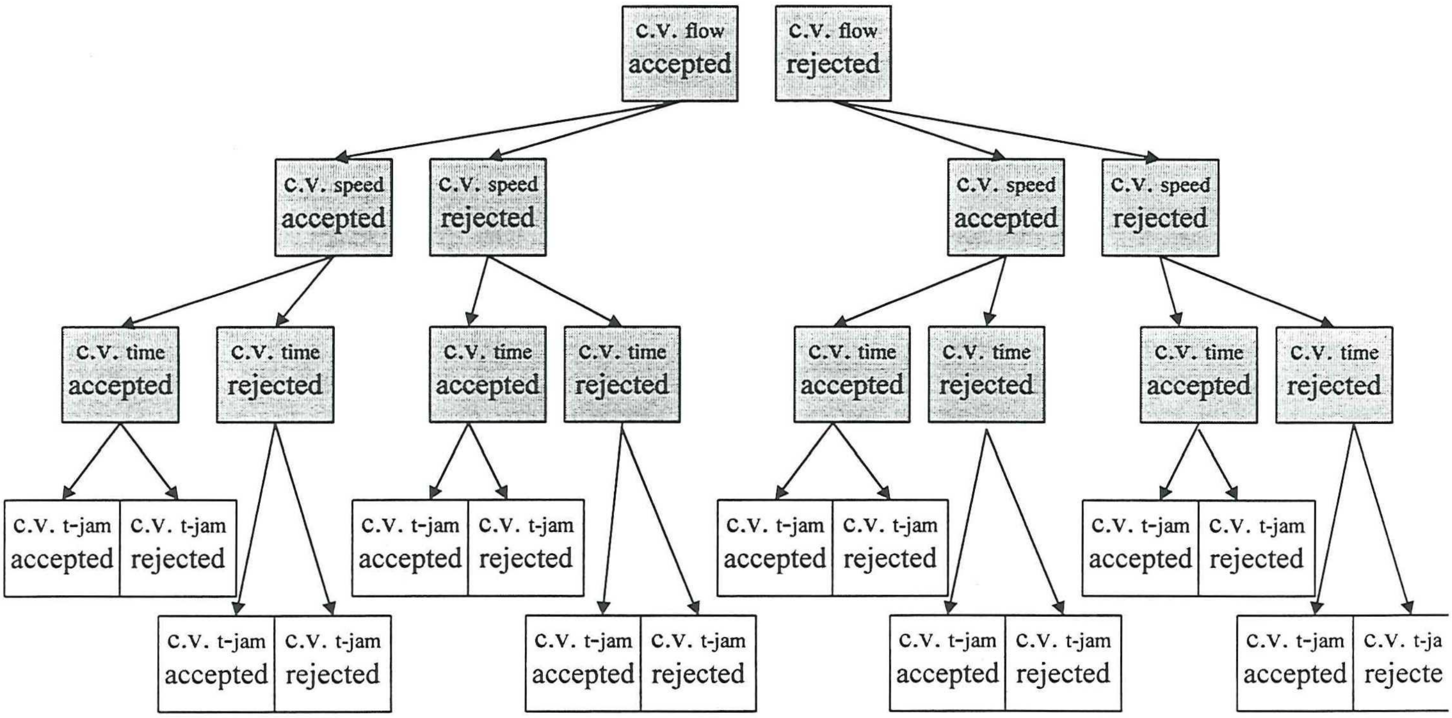
The general form of the proposed objective function is given in Equation (19).

$$\begin{aligned} Obj_{param} &= \alpha_{flow} \cdot D_{flow}(obs_{flow}, sim_{flow}) + \alpha_{speed} \cdot D_{speed}(obs_{speed}, sim_{speed}) + \\ &\alpha_{time} \cdot D(obs_{time}, sim_{time}) + \alpha_{traffic-jam} \cdot D_{traffic-jam}\left(obs_{traffic-jam}, sim_{traffic-jam}\right) \end{aligned} \tag{19}$$

This objective function consists of four sub functions, $D_{flow}, D_{speed}, D_{time}, D_{traffic-jam}$, each calculating the difference between observation data and simulation outcomes for a specific outcome variable of interest.

To define the weights $\alpha_{flow}, \alpha_{speed}, \alpha_{time}, \alpha_{traffic-jam}$ of the objective function, the simulation predictions must be observed. Simulation predictions can be accepted or rejected based on the difference between model predictions and observations. It is difficult to define a general criterion for the maximum distance D value which is used for calibration studies. Due to the time constraint of this study, a 10% maximum distance deviation (as computed by Equation (18) is proposed to decide whether to accept or reject simulation outcomes. However, it is recommended that more research need to be performed about this deviation subject.

In a calibration study observing 4 criterion variables and two prediction classes, accepted or rejected, of model outcomes 16 ($=2^4$) simulation scenarios can be distinguished. A scenario defines for each examined criterion variable the distance measure (accepted or rejected).



c.v. = criterion variable

Figure 21. Scenarios (16) for model predictions.

By means of an interview of model experts these scenarios can be ordered. Computed weights must result in objective function values for the scenarios in the ordering as defined by the model experts.

Two approaches are proposed to define these weights of the criterion variables. First, a trial and error approach is applied. If weights are obtained which order the scenarios are defined by the model experts, these weights may be accepted.

To define the weights of the criterion variables, it is proposed to design an application which automatically computes the weights by performing a brute force estimation technique.

4.9 Summary

Based on the general process of model development, a calibration approach for AIMSUN2 is proposed. This approach focuses on the separate calibration and tuning processes in the model development. The approach consists of a literature study, a qualitative analysis, a calibration process of decomposed network components, and a tuning phase (sections 4.2.1 and 4.2.2).

Model parameters are classified in order to be adjusted correctly in the calibration process. Calibration parameters (model dependent parameters) and tuning parameters (location dependent parameters) are distinguished within this process. A group of fixed parameters (also referred to as constants) is the last distinguished parameter group (section 4.3).

It is found that most model parameters in AIMSUN2(3.2) are global parameters which makes calibration of the model difficult.

Therefore, the focus in this study is on calibration of network components only. To define the influences of parameters on criterion variables a 'trial and error'-sensitivity analysis is suggested. The complexity of the simulation process and the available time are the main reasons to recommended this type of sensitivity analysis. It is recommended in the future that DHV Environment and Infrastructure create a possibility to define a batch input parameter file for AIMUNS2. Such a file contains calibration parameters which may be adjusted with a certain step size. With this batch file a 'brute force'-estimation technique can be performed automatically (sections 4.5 and 4.7).

By interviewing model experts a priority in the model outcomes is defined. The weights of the examined criterion variables (flow, speed, travel time and location/position traffic-jams) can be derived from the results of these interviews. By means of an objective function the values of the parameters can be determined (section 4.8).

Developing a causal simulation model is suggested because the AIMSUN2-software still develops. Also clients of studies demand an causal simulation model instead of a statistical one. The objective of performing a qualitative analysis is discussed. By means of such an analysis the influences of (accessible) model parameters on the simulation process can be defined (section 4.4). Some remarks concerning the process of obtaining sufficient observations used in the calibration process are given. However, in this study it is assumed that sufficient, error free by correction observations are obtained (section 4.6).

In following chapters the calibration processes mentioned in this chapter are discussed in more detail. Chapter 5 discusses the performed qualitative analysis of AIMSUN2(3.2). in this chapter also recent adaptations of the modelling processes are discussed. Chapter 6 describes the proposed model parameter classification. In Chapter 7, network components are distinguished. Each of these basic components are related to specific driver behaviour (and also specific sub models). The proposed definition of judging simulation outcomes by means of a multi-criteria analysis is discussed in Chapter 0. The results of the sensitivity analysis are discussed in Chapter 9. Finally, all obtained experiences of this calibration study are implemented in a calibration procedure (chapter 10).

5 QUALITATIVE ANALYSIS OF AIMSUN2

5.1 Introduction

To develop a causal simulation model, separate network components are examined. Calibrating model parameters for these network components separately will result in more realistic parameter values.

In this chapter specific characteristics of the modelling process of AIMSUN2 are discussed which increases the knowledge of certain modelling processes and the influences of model parameters on model predictions . First, a sensitivity analysis for accessible and non-accessible model parameters is performed. Although some examined model parameters are not accessible for the user (AIMSUN2 version 3.2), the parameter values are examined. Obtained results of these sensitivity analysis may be used to calibrate new versions of AIMSUN2.

Next, a general zone definition of sections is given in relation to the characteristics of the section. In this study, three main network components are distinguished:

- stretch;
- join;
- fork.

For a roadway stretch, no forced lane-changing processes are applied because there is only one origin and one destination direction. Here, only desired lane-changes are applied. For join and fork network components, the number of origin directions does not equal the number of destination directions. Therefore, besides desired lane-changes also forced lane-changes must be applied. In section 5.3, the zone definitions for the distinguished section types are discussed. The classification of main network components is discussed in more detail in Chapter 7. Section 5.4, discusses the definition aspect of simulation cycle, updating interval and reaction time . These aspects are defined by a single parameter value in AIMSUN2(3.2) which may strongly influence the calibration process. An analysis of the car following sub model is given in section 5.2. Finally, recent adaptations of the AIMSUN2 model are discussed in section 5.5.

5.2 Sensitivity analyses sub models

5.2.1 Acceleration-speed model

For the acceleration-speed computed by Equation (14), the influence of (non)-accessible model parameters on the acceleration speed is examined. It isn't possible to define the influence on criterion variables because most examined model parameters aren't accessible.

$$\dot{x}_n^a(t+T) = \dot{x}_n(t) + 2.5 \cdot \alpha_n \cdot T\left[1 - \frac{\dot{x}_n(t)}{v_n}\right] \cdot \left[0.025 + \frac{\dot{x}_n(t)}{v_n}\right]^{\frac{1}{2}} \qquad \textbf{(12)}$$

There, articles discussing the Gipps-models couldn't be obtained, it is assumed that the examined values are model parameters and no constants. Therefore, it is recommended that obtained results are checked in relation to mentioned articles.

First, the relationship between time and speed is defined. Model parameters are adjusted and the same relationship is depicted in the same figure. In all cases a default parameter value is used to compute the time-speed relationship. In most cases a '0.75*default'-value and a '1.25*default'-value are also used as parameter value to compute the time-speed relationship.

First the influence of 'parameter value 2.5' in Equation (14) is examined.

Model parameter value
2.5 (default)
1.875 (0.75* default)
3.125 (1.25*default)

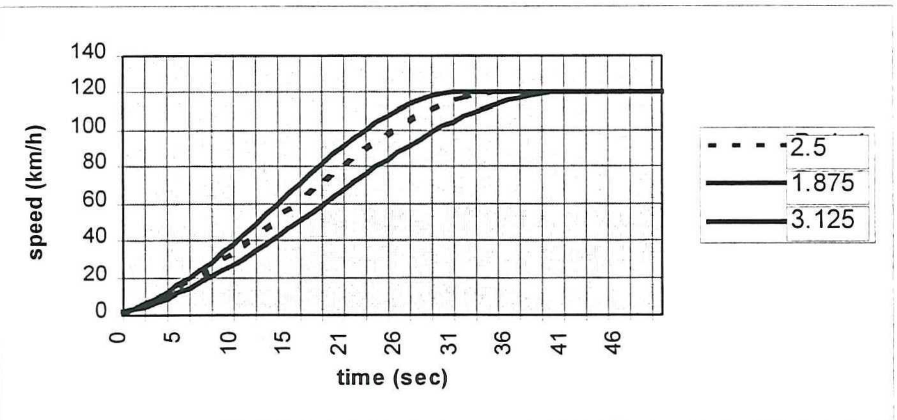


Figure 22. Time versus speed according to acceleration-speed(1).

It is concluded that this model parameter influences the acceleration characteristics of the driver. For higher parameter values the driver will reach its desired speed quicker.

Next, the influence of the acceleration-parameter α_n is examined. The following model parameters are used.

Model parameter value
2.8 (default)
2.1 (0.75* default)
3.5 (1.25*default)

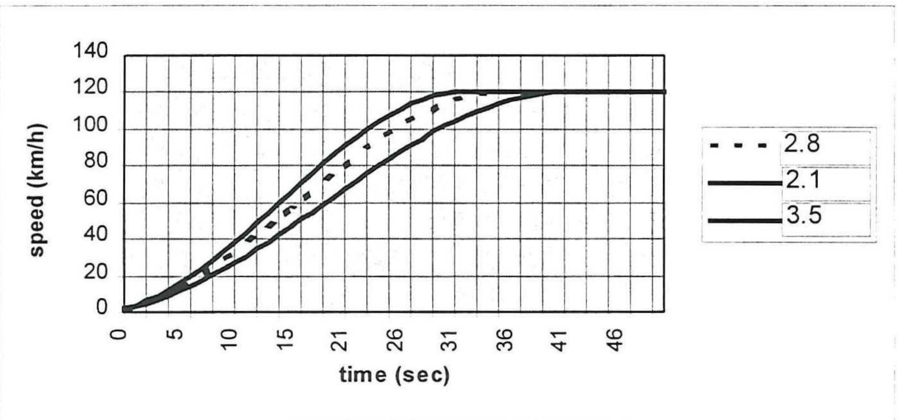


Figure 23. Time versus speed according to acceleration-speed(2).

The same influence of the parameter value on the relationship time-speed as computed for the 'parameter value 2.5'. In both situations a model parameter value is multiplied by factors. Therefore, the obtained results are logical.

Next, the influence of the reaction time parameter *T* on the time-speed relationship is computed. The following values are used:

Model parameter value
1 (default)
0.75 (0.75* default)
0.5 (0.5*default)

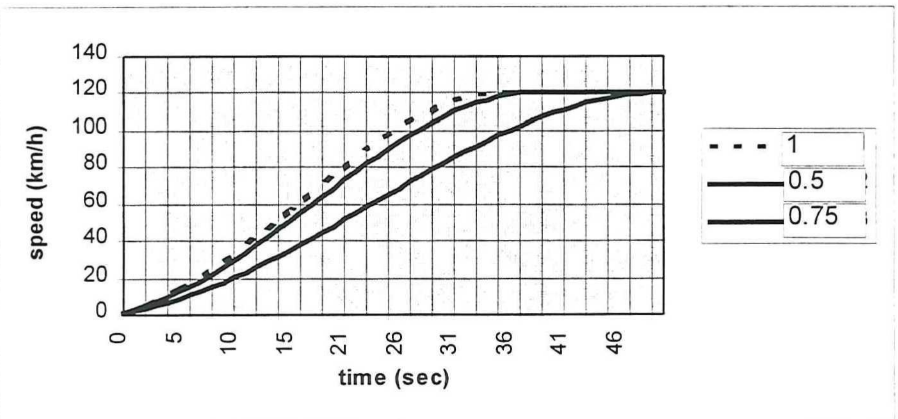


Figure 24. Time versus speed according to acceleration-speed(3).

It is concluded that if the reaction time parameter value is decreased, the desired speed is obtained later compared to the default value. The distance between default simulation outcomes and the 0.75*default simulation outcomes is smaller than the distance between the 0.75*default and 0.5*default simulation outcomes.

Next, the model parameter value 0.025 is examined. The following parameter values are used:

Model parameter value
0.025 (default)
0.018 (0.75* default)
0.031 (1.25*default)

The following results are obtained.

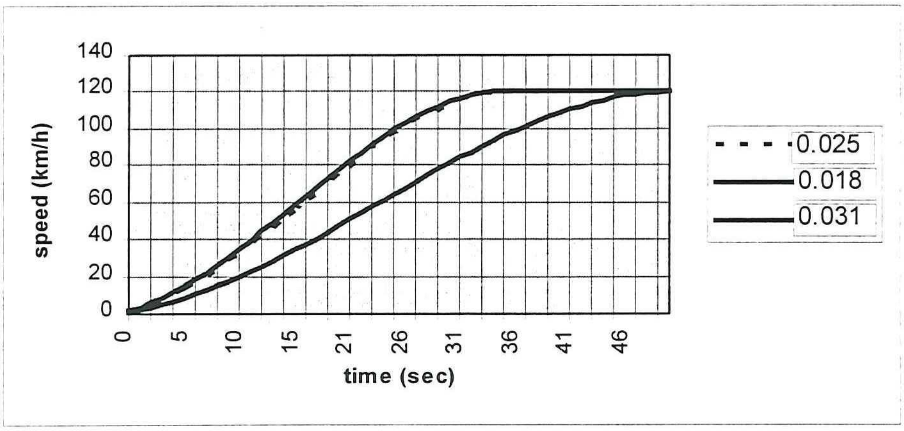


Figure 25. Time versus speed according to acceleration-speed(4).

It is concluded that increasing the parameter value will hardly influence the driver's time-speed relationship. For parameter values lower than the default value, the desired speed is obtained later compared to the default value.

5.2.2 Deceleration-speed model

As mentioned in Chapter 3, the deceleration-speed model is a very complex sub model. There the articles describing the derivation of this Gipps model couldn't be obtained it wasn't possible to perform a qualitative analysis of the computation of the deceleration-speed model. Another important aspect that this model isn't examined in more detail that the model parameters as distinguished in section 3.3.3 are not accessible. So, it is not possible to define the influences of these model parameters on the examined criterion variables. It is recommended that in future studies (when the model parameters are accessible) these influences are defined.

5.2.3 Distance_restrict model

This distance_restrict is computed by the following Equation:

$$\textbf{Distance\_restrict} = \dot{x}_n(t) \cdot \sqrt{\frac{2 \cdot \dot{x}_n(t)}{v_n}} \qquad (20)$$

where:

$\dot{x}_n(t)$:the speed of the examined vehicle n;[m/s].

v_n :the desired speed of the examined vehicle n;[m/s^2].

The model parameter v_n is adjusted. For the following parameter values the relationship between speed and distance_restrict is computed.

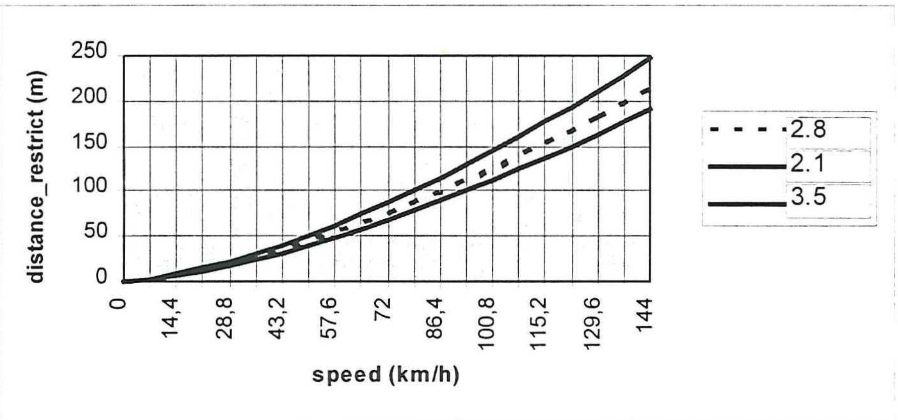


Figure 26. Speed versus distance_restrict (1).

It may be concluded that the distance_restrict increases for decreasing desired speed model parameter values.

The influences of the model parameters defining the conditions whether or not to change lanes as mentioned in section 3.3.3 are not accessible for this calibration study. Therefore, it is recommended to perform a qualitative analysis to define the influence of these model parameters on the criterion variables.

5.3 Section definitions

5.3.1 'Stretch'-section

For stretch components only desired lane-changes will be applied because no merging or splitting of directions is possible within these sections.

So, vehicles decide to change lane in situations where their preceding vehicle is driving too slow compared to their own desired speed. Vehicles search for a gap which is big enough for a save lane-change. A desired lane-change is only applied in situations where other vehicles are not influenced by this lane-change.

Figure 27. Stretch.

If no gaps are available, the driver will reduce its speed and follow its preceding vehicle until a big enough gap is available to change lanes.

In AIMSUN2, drivers only observe their preceding vehicle by estimating their speed. Depending on their own (desired) speed, a driver considers an overtaking process. So, other vehicles downstream are not observed. A vehicle observes congestion when his preceding vehicle is stopped.

So, a stretch-section where at the end of the section no splitting or merging points are located is build of one zone, defined as zone 1. See also

Figure 12. An exception is a stretch-section containing a dropped lane. Such situations still contain one origin and one destination direction. However, while driving on the leftmost lane a driver needs to perform a mandatory lane-change due to the dropped lane. See also Figure 28. In these situations three zones are defined. In each of these zones the driver behaviour is modelled differently as discussed in section 3.5.

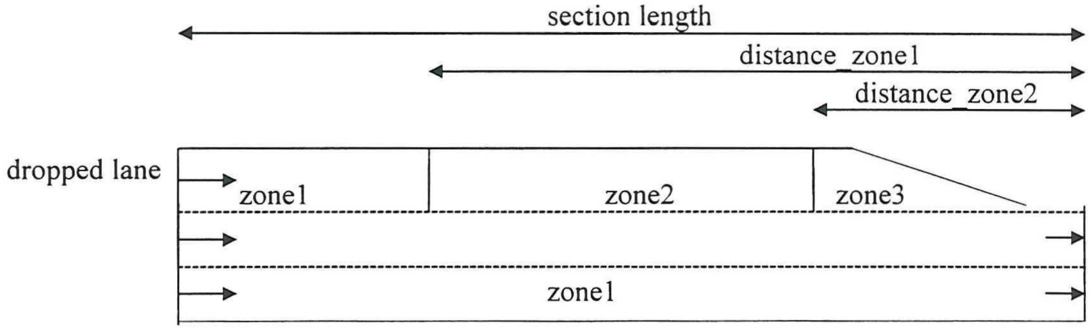


Figure 28. Zone definition for dropped-lane situation (special stretch-component).

In AIMSUN2 the end of zone 3 is defined by the end of the entire section. For modelling dropped lane situations the end of the section must be located next to point A (end of dropped lane). Otherwise, the driver may notice the dropped lane to late while zone 3 is located downstream of the dropped lane.

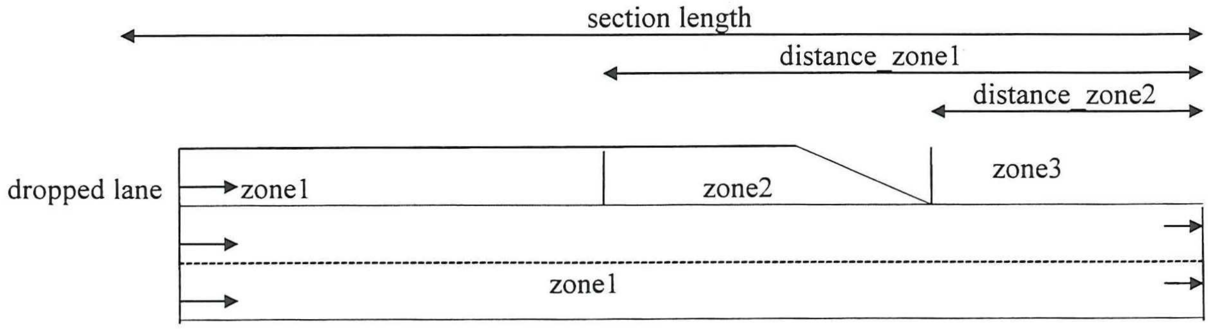


Figure 29. Zone definition for dropped-lane situation (wrong modelling approach).

5.3.2 'Join'-section

For 'join'-network components the number of origin directions is higher than the number of destination directions so that forced lane-changes may be performed. See also Figure 30.

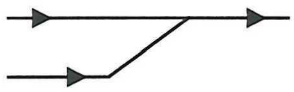


Figure 30. Join.

In these situations a section is divided into three zones. In each of these zones, a different vehicle behaviour is modelled. See Figure 31.

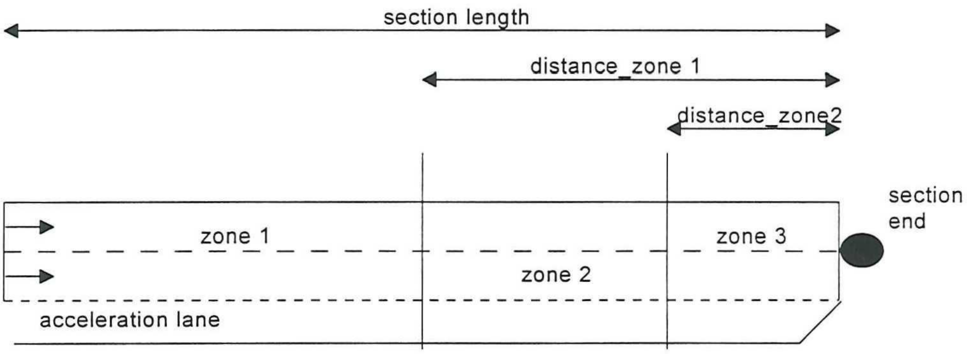


Figure 31. Zone definition on-ramp (mandatory lane-change)

The difference of the vehicle behaviour for the three zones has been discussed in section 3.5. In situations where a mandatory lane-change is performed three zone are considered while for discretionary lane-changes the entire section is considered as zone 1. In above mentioned situation (Figure 31) mandatory lane-changes are only performed at the acceleration lane and for this lane tree zones are considered. The adjacent lanes are characterised by one origin and one destination direction and therefore the lanes are defined as zone1.

5.3.3 'Fork' section

A 'fork'-section models network settings containing more than one destination lane. An off-ramp is an example of such a setting. In Figure 32, a representation of this setting is given.

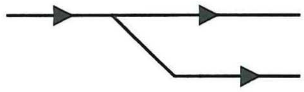


Figure 32. Fork.

In these situations also a forced lane-change to reach the destination lane may be applied. So, for this type of settings also a three-zone definition is defined. An example of a zone definition is given in Figure 33.

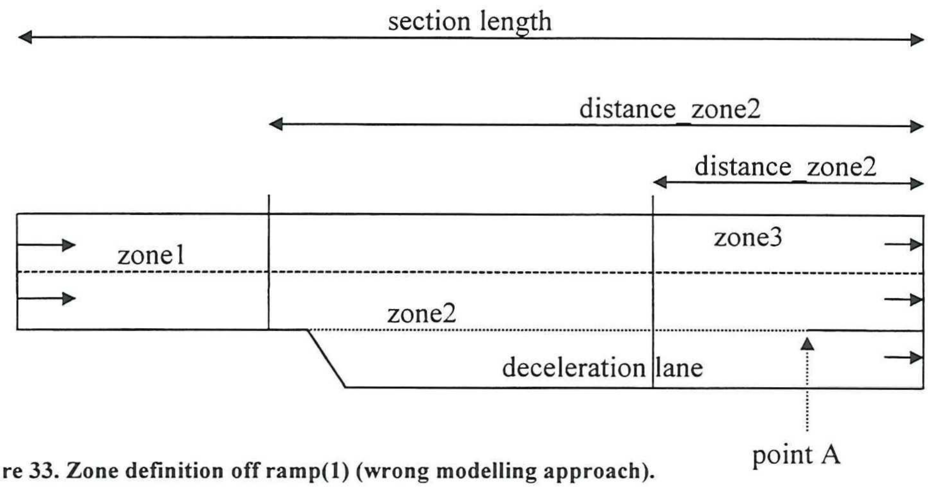


Figure 33. Zone definition off ramp(1) (wrong modelling approach).

As depicted in Figure 33, zone 3 is defined by the end of zone 2 until the section end. However, a lane-change is not possible after a vehicle has passed point A. Therefore, another zone definition is recommended to avoid the above mentioned situation. The end of zone 3 must be located at the end of the section. See also Figure 34.

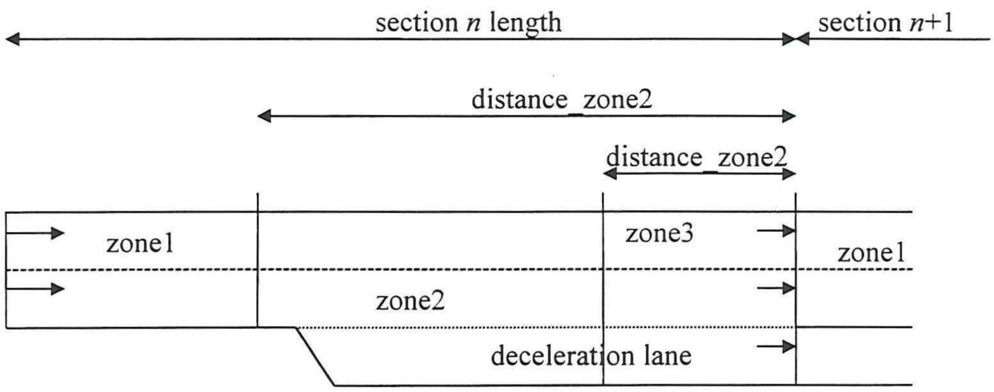


Figure 34. Zone definition off-ramp(2) (appropriate modelling approach).

5.4 Simulation cycle versus reaction time versus updating interval

In the examined version of AIMSUN2 the following simulation characteristics have been integrated into one single parameter value (*T*):

- simulation cycle;
- updating interval;
- driver's reaction time.

For implementation ease, these different parameters are integrated. However, in a calibration process driver's reaction time may be calibrated. The reaction time is related to traffic conditions and to the type of driving process. In capacity flows or congested flows (see Figure 9), drivers are more alert compared to free flow situations. Adjusting the reaction time parameter value would also result in a changed parameter value for the simulation time and the updating interval. The change of these last two parameters may not be necessary or desirable. The simulation time increases when the reaction time is decreased.

The smaller the updating interval, the better drivers can react on traffic conditions for example by the lane-changing process. Therefore, it is desired to introduce three different model parameters to define simulation cycle, updating interval and reaction time.

5.5 Recent adaptations in the AIMSUN2 model

During this calibration study, new AIMSUN2 versions are developed. Main changes on the simulation process of the vehicle behaviour are discussed. However, AIMSUN2 version 3.2 is used during this study.

5.5.1 Change in zone definition

In previous sections, zone definition aspects are discussed. Both for on- and off-ramps the same zone definition is applied because distance_zone1 and distance_zone2 are global parameters. To be able to influence the vehicle behaviour for these specific settings, the zone definition for on-ramps has been changed for new AIMSUN2 versions (after may 98).

Zone 1 still exist, within this zone the desired lane destination will not be taken into account, so a driver does not consider his direction lane after. Zone 2 and zone 3 have been integrated. Within this integrated zone, vehicles only will overtake when enough gap is available and consider their destination lane. Within the last zone, located at the end of the acceleration lane, vehicles are queued and will drive to the end of a section. When the examined vehicle is first in queue, the lane change will be forced.

Summarising, in situations where a weaving section is located downstream an on-ramp, vehicles in zone 1 apply a lane-change while the planned direction at the weaving section is not considered. The lane-change will be applied in zone 1 when enough gap is available. Other vehicles might be influenced by this lane-change. If vehicle is driving in zone2/3, the planned direction at the lane-change is considered. So, the behaviour on the on-ramp will be influenced by the planned direction at the next turning point. In the last zone (=distance_restrict zone= d.r.zone), the first vehicle in the queue arriving at the end of this zone forces a lane change considering his destination lane at the next turning point. See also Figure 35.

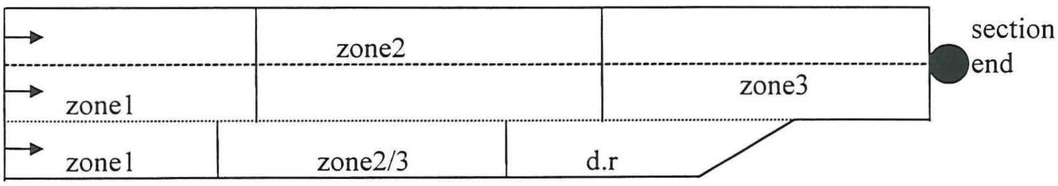


Figure 35. Zone definition on-ramp (version after may 98).

5.5.2 Changes in right lane-change conditions

Distance_restrict (not to be confused with the distance_restrict zone) is the distance between observed vehicles in which the examined vehicle is considered to be following his preceding vehicle. This distance is computed when a vehicle is not driving on the rightmost lane (for one destination). A driver has to decide whether or not to return to the rightmost lane based on driving characteristics of his preceding vehicle.

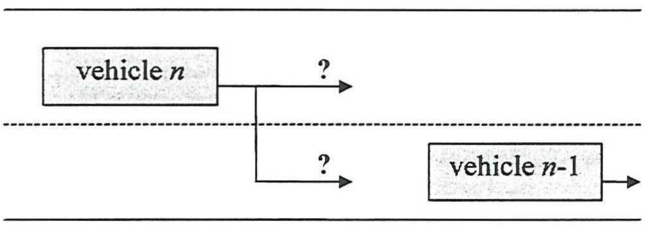


Figure 36. Distantce_restrict-condition determining to return to rightmost lane.

Within AIMSUN2, this distance_restrict is computed by the following Equation:

$$\text{Distance\_restrict} = \dot{x}_n(t) \cdot \sqrt{\frac{2 \cdot \dot{x}_n(t)}{v_n}} \qquad (21)$$

where:

$\dot{x}_n(t)$:the speed of the examined vehicle *n*;$[m/s]$.

v_n :the maximum acceleration rate of the examined vehicle *n*;$[m/s^2]$.

The above given function does not compute the distance-restrict correctly. Checking the units used in this function gives:

$$[m] \quad \neq [m/s] \cdot \sqrt{\frac{[m/s]}{[m/s^2]}}$$

UPC confirmed that this distance_restrict function as not implemented correctly. Within AIMSUN2 (version after May 98), the function computing the distance_restrict is changed. This new implemented distance_restrict is calculated by the following formula given in Equation (22) :

$$\text{Distance\_restrict} = \left(\frac{\dot{x}_n(t)^2}{2 \cdot v_n} - \frac{\dot{x}_{n-1}(t)^2}{2 \cdot v_{n-1}} \right) + \dot{x}_n(t) \cdot T \qquad (22)$$

where:

$\dot{x}_{n-1}(t)$:the speed of the preceding vehicle *n*-1;$[m/s]$.

v_{n-1} :the maximum acceleration rate of the preceding vehicle *n*-1;$[m/s^2]$.

T :the reaction time of the examined vehicle(=driver) *n*.$[s]$.

Note:

In Equation (21) the speed and acceleration rates of the preceding vehicle was not included!

This new formula computing the distance_restrict is likely to improve the simulation outcomes because in this formula speed and acceleration rate of the preceding vehicle is implemented. Future simulation runs must confirm this remark.

To gain more insight in the distance_restrict computation, some values are determined. The distance_restrict for vehicle *n* is computed for three different preceding vehicles. The speeds of the preceding vehicles are respectively 80,108 and 120 km/h. In Figure 37, the relation between driving speed and distance_restrict for vehicle *n* is given for mentioned preceding vehicles

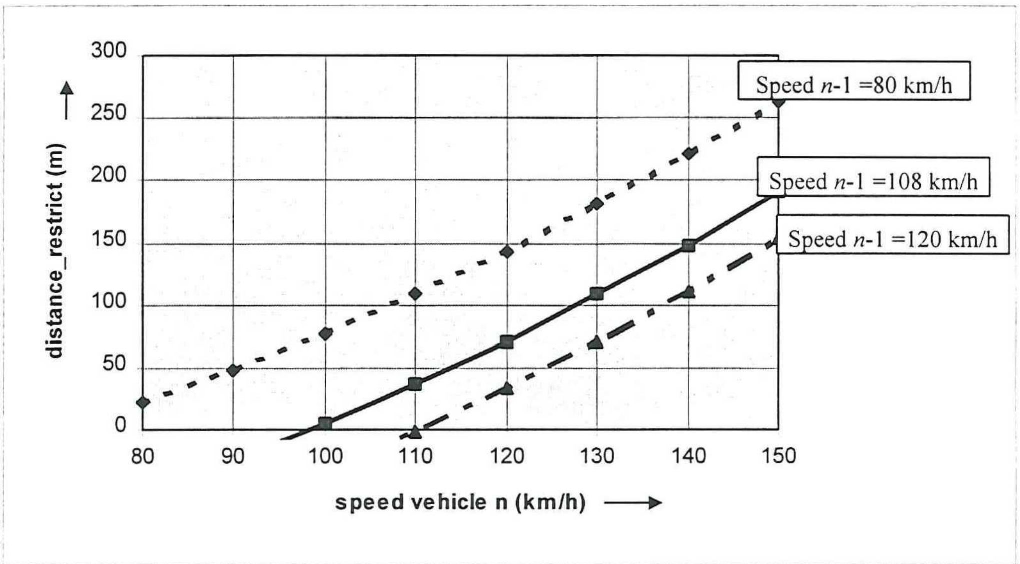


Figure 37. Distance_restrict versus speed vehicle *n*.

In Figure 37 it is visible that the distance_restrict increases for an increasing difference between the both speed values. In situations where vehicle *n* is driving slower than vehicle *n*-1, a very small speed_restrict value (some meters) is considered because the preceding vehicle is driving faster.

Within the AIMSUN2 (vs3.2), there is no possibility to influence the computation of the distance_restrict. It is not possible to adjust the implemented Equation (21).

In AIMSUN2, the following conditions for returning to the rightmost lane have been implemented:

$$\left(\left(\dot{x}_{n-1}(t) > \dot{x}_n\right) \text{or} \left(x_{n-1}(t) - x_n(t) > 1.5 \cdot \text{distance\_restrict}\right)\right) \text{and} \left(\dot{x}_n(t) > 0.8 \cdot \dot{x}_n\right) \quad \textbf{(23)}$$

where: $\dot{x}_{n-1}$(t):the current speed of vehicle *n*-1;$[m/s]$.

$\dot{x}_n$:the desired speed of vehicle *n*;$[m/s]$.

$x_{n-1}(t)$:the current position of vehicle *n*-1;$[m]$.

$x_n(t)$:the current position of vehicle *n*;$[m]$.

$\dot{x}_n(t)$:the current speed of vehicle *n*.$[m/s]$

So, vehicle n will return to the rightmost lane if both conditions are satisfied. The first condition demands that the preceding vehicle is driving faster than the examined vehicle or the distance between both vehicles is larger than (estimated) distance_restrict multiplied by 1.5. The second condition defines that the current speed of the examined vehicle is higher than 0.8 * the desired speed. If so, the vehicle will recover to the rightmost lane. The parameter values, 1.5 and 0.8, are defined by UPC and it is not possible to adjust these values)

In new AIMSUN2 versions(after May 98), new conditions have been implemented to determine whether or not to return to the rightmost lane.:

$$\begin{aligned}&\left(\left(\dot{x}_{n-1}(t) > \dot{x}_n\right)\text{or}\left(x_{n-1}(t) - x_n(t) > 1.5 \cdot \text{distance\_restrict}\right)\right)\text{and}\left(\dot{x}_n(t) > 0.8 \cdot \dot{x}_n\right)\\&\text{or}\left(\dot{x}_n(t) > 0.9 \cdot \dot{x}_n\right)\\&\text{or}\left(x_{n-1}(t) - x_n(t) > 2.0 \cdot \text{distance\_restrict}\right)\end{aligned} \quad \textbf{(24)}$$

The first part of the conditions is the same as implemented in AIMSUN2 (v before May 98). For the two new conditions the simulation outcomes speed and distance have been separated. So, in situations where the current speed of vehicle n is higher than 0.9*desired speed of vehicle n, the vehicle will return to the rightmost lane. Here, the distance between both vehicles is not examined. The speed difference between desired and current speed is not examined in situations where the distance between both vehicles is larger than the distance_restrict multiplied by 2.

Within AIMSUN2 (v3.2) it is not possible to influence the above mentioned conditions. Also, here the parameter values 0.9 and 2.0 (as given in equation (24) can not be adjusted.

5.5.3 Changes in reaction time handling

In new versions (July 98) of AIMSUN2, the reaction time parameter is separated from the simulation cycle and the updating interval. New research is needed to determine the consequences on the simulation performance and the value definition of this new parameter.

5.5.4 Adjusting the Gipps models

Recently discussions between DHV Environment and Infrastructure and Gipps started concerning the validity of the used Gipps-formulas and particularly its parameter values in relation to the changes of the current traffic flows at urban and non-urban networks. It is concluded by Gipps that the current values of model parameters need to be examined concerning their validity.

5.6 Summary

A network can be divided into three basic network components: stretch, join and fork. The driver behaviour is affected by the type of network component. For a stretch component only the car following and discretionary lane-changing behaviour is applied. For the join and fork network components also a mandatory lane-changing is performed.

For implementation reasons the reaction time, simulation cycle and updating interval parameters are integrated and defined as one model parameter. There, the reaction time is a parameter which need to be calibrated (is related to flow conditions and network component) the integration may influence the calibration process.

The car following sub model consists of some parameters which are not available for the user. Influencing the car following behaviour during the calibration process can only be achieved by adjusting model parameters describing the car/driver characteristics.

Recent adaptations of the modelling process of AIMSUN2 resulted into more local model parameters. For example, new model parameters for the definition of the zone of on-ramps are introduced. Also the reaction time is introduced as a separate modelling parameter.

6 APPROACH TO THE CLASSIFICATION OF PARAMETERS

6.1 Introduction

The sub models of AIMSUN2 describe the relation between it's input and output variables. This description is completely specified except for a number of parameters. The parameters can be classified based on different characteristics. Parameters are classified into the following groups:
- fixed parameters;
- model dependent parameters;
- location dependent parameters.

The following properties can help with this classification:
- scope (e.g. network, node, section, vehicle);
- distribution;
- related sub model (e.g. car following, route choice, lane-changing);
- directly or indirectly observing the parameter values.

These parameters can be classified to determine which of these are fixed, model dependent and location dependent. In the following section, these properties will be discussed. Also a section is included where the parameters of AIMSUN2 are discussed and classified.

6.2 Classification of parameters

6.2.1 Scope

The first classification characteristic divides the parameters into the following groups:
- network;
- section;
- node;
- vehicle.

Network parameters are valid for the entire network (applied to all network components). Section and node parameters are applied to specific network components. Vehicle parameters are used to define the characteristics of the simulated vehicles.

6.2.2 Distribution

The second classification characteristic divides the parameters into two groups based on the parameter value definition. Within AIMSUN2, some parameter values can be defined by a single value while others need to be defined by a parameter value distribution set:
- single value;
- parameter value set.
    1. minimum parameter value;
    2. maximum parameter value;
    3. mean parameter value;
    4. deviation value.

The probability distribution of parameters is given by a truncated normal distribution, i.e. random values are generated by sampling from a normal distribution and rejecting all values that violate the specified minimum and maximum parameter value

$$N(\overline{m}, \sigma^2)$$

where: $\overline{m}$: the mean value of the distribution;
σ: is the deviation of the distribution.

6.2.3 Related sub model

Another possibility to classify the parameters is by grouping the parameters based on the related sub models. Within AIMSUN2 three sub models have been implemented. So, parameters can be classified into groups which are related to the implemented sub models. In this study where only the vehicle behaviour on freeways is observed, the following classification based on the implementation level is defined by:

- route choice level;
- car following implementation level;
- lane-changing implementation level.

6.2.4 Directly or indirectly observing the parameter values

The approach how to obtain the definite parameter value can also be used to classify parameters. As mentioned in section 2.7, different estimation techniques are distinguished such as:

- literature study;
- common sense;
- calibration study AIMSUN2.

Some parameter values can be defined directly by literature study or common sense while other parameters must be defined indirectly by a calibration study of the software package. For this last group of parameters different techniques can be used to define the parameter values such as brute force, trial and error or statistical techniques.

6.3 AIMSUN2-parameters

In this section a more detailed description of the AIMSUN2-parameters related to modelling traffic flows at freeway is given. Within AIMSUN2 the following parameters which can be adjusted by AIMSUN2-users have been implemented:

Parameter name	*Symbol*	*Unit*
1drivers reaction time	T	sec
2 vehicle length	l	m
3 vehicle width	(1)	m
4 desired speed	$\dot{x}$	km/h
5 max acceleration	α	m/s2

6 max deceleration	β	m/s2
7 distance zone1	dz_1	sec
8 distance zone2	dz_2	sec
9 normal deceleration	$\hat{\beta}$	m/s2
10 speed acceptance	θ	-
11 min dist. between vehicles	η	m
12 give way time	δ	sec

Table 6. Implemented parameters of AIMSUN2 (version 3.2).

A closer look at Table 6, shows that the speed limit of a section is not defined is this table although it is classified as parameter in the AIMSUN2-manuals. Actually, the speed limit is a setting which will be defined by the observed location (= section). Therefore, the speed limit will not be classified as model parameter used for calibration or tuning purposes.

6.4 Classification of AIMSUN2 parameters

In Table 7, an overview is given of all available parameters implemented in AIMSUN2 to model the driver behaviour at freeways. This is total group of parameters available for the calibration and tuning processes. In Table 8 and Table 9 an explanation of the proposed classification is given

Classification Parameter	*Scope*	*Distribution*	*Related sub model*	*Directly/ indirectly*	*Classification group*
T	network	set	car	literature/calibration	location depend
l	vehicle	set	car	literature	model depend
$\dot{x}$	vehicle	set	car	literature	model depend
α	vehicle	set	car	literature	model depend
β	vehicle	set	car	literature	model depend
dz_1	network	single	lane	calibration	location depend
dz_2	network	single	lane	calibration	location depend
$\hat{\beta}$	vehicle	set	car	literature	model depend
θ	vehicle	set	lane / car	calibration	location depend
η	vehicle	set	car	literature	model depend
δ	vehicle	set	lane	literature	model depend

Table 7. Properties and classification of AIMSUN2-parameters.

All parameters are related to the entire network or to the vehicle scope. It is concluded that all modelling parameters are global parameters. From the last column of Table 7 it is concluded that there are only a few parameters available to perform a calibration study. Most parameters (related to vehicle characteristics) must be obtained by literature study and not be used in the calibration process. In Table 8 and Table 9, the model parameters are classified into parameters used for calibration (model dependent/ behavioural parameters) and parameters used for tuning (location dependent/ tuning parameters).

For each classified parameter an explanation for the classification into model dependent and location dependent parameters is enclosed.

Parameter name	*Symbol*	*Used for calibration because:*
2.vehicle length	l	Parameter values (mean, distribution etc) can be obtained by literature study.
3. vehicle width	(1)	See remarks vehicle length. Note: this parameter has yet not been implemented in the sub models of AIMSUN2 (v before May98). Therefore, this value does not need to be calibrated.
4.desired speed	$\dot{x}$	This parameter describes the population of drivers. So, aggressive and reserved drivers must be represented. The same population is distributed over each infrastructure network setting. Therefore this parameter value set needs to be calibrated (once).
5.max acceleration	α	Parameter values (mean, distribution etc) can be obtained be literature study.
6.max deceleration	β	Parameter values (mean, distribution etc) can be obtained be literature study.
9.normal deceleration	$\hat{\beta}$	Parameter values (mean, distribution etc) can be obtained be literature study.
11.min distance between vehicles	η	Parameter values (mean, distribution etc) can be obtained be literature study and observations.
12.giveway time	δ	See remarks of desired speed.

Table 8. Explanation of classification of calibration parameters.

The next parameters are classified as location dependent parameters.

Parameter name	*Symbol*	*Used for tuning because:*
1drivers reaction time	T	(= simulation step). Defines the calculation step where position of vehicles is determined. This parameter value can be used to influence the measure of being alert of other vehicles (especially in capacity or congested flow regimes). This aspect in not implemented in AIMSUN2 and can be used to influence the capacity of sections.
7 distance zone1	dz_1	Influences the decisions of drivers when to change lanes in situations where a lane-change is needed to reach destination (lane). For single situations this parameter can be used to influence the vehicle behaviour for specific settings and so be used for tuning processes.
8 distance zone2	dz_2	See remarks zone1.
10.speed acceptance	θ	This parameter defines the acceptance of the speed limit defined by parameter13. The speed acceptance differs for each infrastructure setting. For local infrastructure settings this parameter can be used to influence the simulation outcomes and therefore can be used for the tuning process.

Table 9. Explanation of classification of tuning parameters.

The definition of several users-groups is an important aspect which has not been discussed at this moment. It is possible to define different vehicle modalities such as cars, trucks, bus, ambulances, bicycles, taxis etc. Characteristics of each of these modalities must be defined such as vehicle length, acceleration and deceleration rates. In Appendix 5, an overview is given of the implemented vehicle types. In Table 10, the characteristics of the modality cars are given. These values have been determined by experiences obtained by DHV Environment and Infrastructure, literature study and common sense.

Parameter name	***Unit***	***Symbol***	***Mean value***	***Deviation***	***Minimum value***	***Maximum value***
1 drivers reaction time	sec	T	tuning			
2 vehicle length	m	l	4	0.25	3.5	4.5
3 vehicle width	m	--	2	--	--	--
4 desired speed	km/h	$\dot{x}$	115	7.5	85	125
5 max acceleration	m/s2	α	2.8	0.15	2.4	4
6 max deceleration	m/s2	β	7.0	1.5	5	9
7 length zone1	sec	dz_1	tuning			
8 length zone2	sec	dz_2	tuning			
9 normal deceleration	m/s2	$\hat{\beta}$	4.0	0.5	3	5
10 speed acceptance	-	θ	tuning			
11 min dist. between vehicles	m	η	2	0.5	1	3.5
12 give way time	sec	δ	30	5	10	50

Table 10. Parameter values of user group car.

Each network component can be schematised by the following three basic network components:

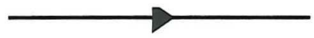


Figure 38. Stretch.

The 'stretch' network component describes settings with one input direction and one output direction, therefore classified as group 1.

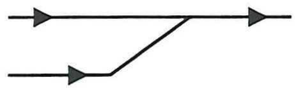


Figure 39. Join.

A 'join' network component describes settings with two input directions and one output direction. So, 'joins' are categorised as group 2.

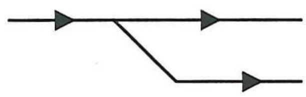
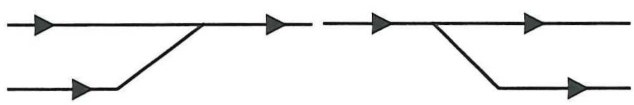


Figure 40. Fork.

A 'fork' represent network components with one origin direction and two destination directions and is therefore classified as group 3.

The three basic network components can be distinguished by the number of input and output directions. All network components can be described by above mentioned representations. For example, a weaving section is defined by a combination of a fork and a join.



Next, the three main groups of infrastructure settings will be discussed in more detail.

7.3.1 Network component 'stretch'

Within this first group the following situations can be determined. See Figure 41. The first network component type describes a stretch of a freeway with a constant capacity value. The freeway can consists of one, two, three or more lanes.

The next, second, representation describes a freeway stretch where the capacity at the beginning of the section is smaller than the capacity at the end of the section. This situation may appear in settings containing a bottleneck or in situations where the speed limit will increase. The freeway can consists of one, two, three or more lanes. It is important to emphasise that the capacity value of a section is not an input parameter! Such a situation need to be obtained by a calibration process.

The third situation is almost the same as the second setting, although here the capacity value will decrease at the end of a section. The freeway may consist of one, two, three or more lanes.

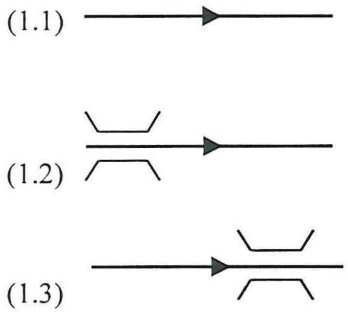


Figure 41. Detailed schema's network component 'stretch'.

7.3.2 Network component 'fork'

The second group of basic network components settings are forks. Examples of such settings are off-ramps. An important aspect during the simulation of these settings is the distribution of the flow between the available directions and the capacity values of each of these directions. The capacity values must be obtained by a calibration process.

Possible types are given in Figure 42.

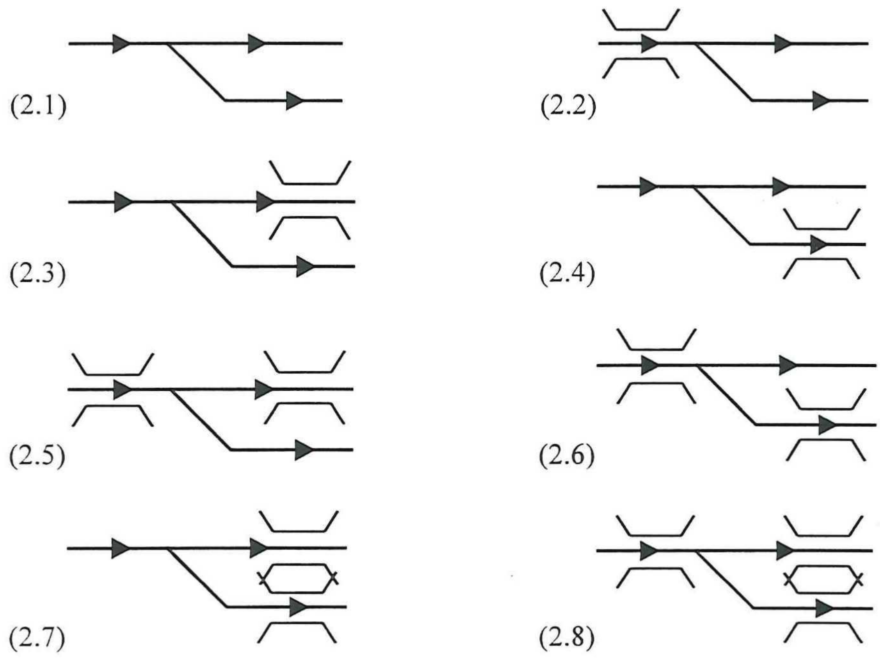


Figure 42. Detailed schema's of network component 'fork'.

7.3.3 Network component 'join'

The third, and last group of network components are joins. Also, here the distribution of vehicles in each direction is an important aspect during the simulation of these infrastructure settings. Capacity problems might exist down-stream the merging of two directions or even at the acceleration lane.

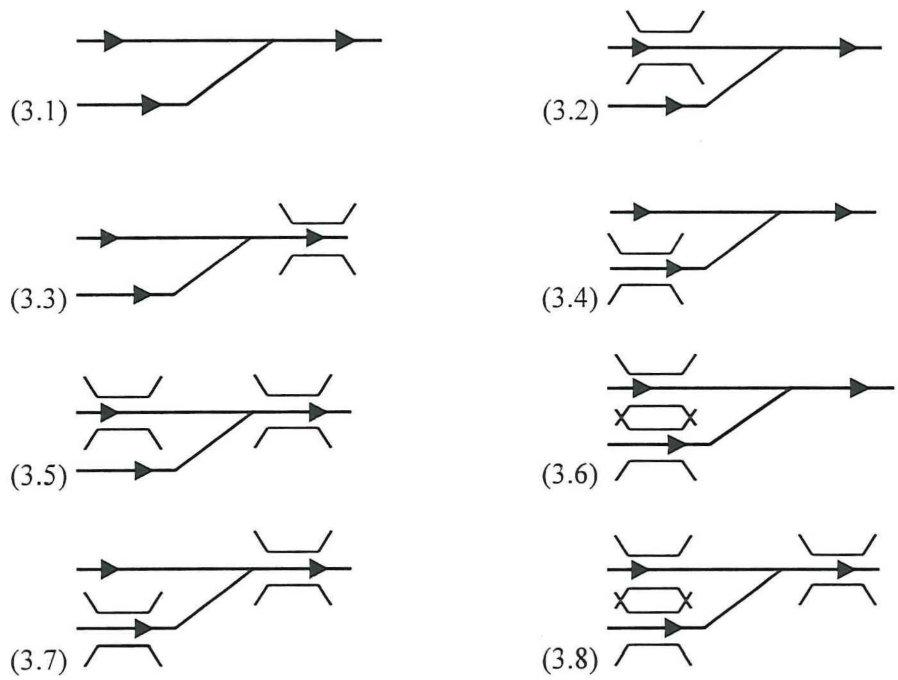


Figure 43. Detailed schema's of network component 'join'.

These situations describe all possible network components. So, if calibration procedures can be designed for these representations of infrastructure settings, a simulation model can be calibrated at microscopic level.

7.3.4 Network component selection for simulation study

A more detailed look at the above described setting will result in a reduction of possible settings. For example setting (2.3) and setting (2.5) look actually the same because the input flow will not directly influence (=here no congestion can be modelled) the vehicle behaviour at the output directions. The maximum input flow is the capacity flow. Therefore, the capacity of the bottleneck determines the input flow. This situation can also be modelled by setting (2.3). So, for each setting where only a bottleneck is defined at one or more input directions, the setting can be described by another setting. Most important aspect during the calibration process is to determine the capacity flow of the different input directions. The same explanation may be applied for example to settings (2.4) and (2.6). Other similar combinations are settings (2.1) and (2.2), settings (3.1) and (3.2), setting (3.1) and (3.4), settings (3.3) and (3.5).

Finally, in Table 13 the remaining network components which will be examined are listed.

remaining infrastructure setting	*similar infrastructure settings*
(1.1)	(1.2)
(1.3)	
(2.1)	(2.2)
(2.3)	(2.5)
(2.4)	(2.6)
(2.7)	(2.8)
(3.1)	(3.2), (3.4) and (3.6)
(3.3)	(3.5), (3.7) and (3.8)

Table 13. Reduced network components.

As depicted in Table 13, a reduction to 8 different network components can be made.

7.4 Summary

To perform a calibration study at microscopic level, separate network components must be examined. These components are classified based on the number of input and output directions. The following main network components are distinguished:

- stretch;
- join;
- fork.

Specific driver behaviour is related to each of these groups. For a 'stretch'-component, no mandatory lane changes are performed because such a setting consists of only one input and one output directions. For such settings the zone definition does not influence the driver behaviour. Only discretionary lane-changes are performed (if component contains more than 1 lane).

However, for the 'join' and 'fork' network components, mandatory lane-changes will be applied. For these components, the zone definition must be tuned to fit criterion variables to observations.

The main network components can be schematised in more detail. Observations can identify bottlenecks which need to reproduced by the traffic model.

observations is proposed as criterion whether or not to accept simulation outcomes. This 10% deviation is adopted for each criterion variable.

It is proposed to compute the difference D between observations and model prediction of examined criterion variable j by a mean absolute error proportional (MAEP) function :

$$D_j = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{\left| A_{ji} - E_{ji} \right|}{\overline{E}_{ji}} \qquad \text{(MAEP)} \tag{25}$$

However, may other functions might be used to compute the difference between observations and predictions. More research must be performed to define the required characteristics of these functions.

An important aspect of the judgement of outcomes is the definition of the objective function's weighting factors. It was found that the criterion variables depend on the traffic regime.

However, it must first be emphasised that the availability and size of observed data is the most important aspect of the calibration study. Here, it is assumed that the availability and size of observations is sufficient to perform a calibration study.

==> for the traffic regimes: free flow, partly constrained and capacity flow

- flow/capacity (= q); $[veh / h]$;
- mean speed (= v); $[km / h]$.

Note:
The simulation outcome density is not included because in situations where network is correctly defined (distances, lengths of sections) and the flow and speed outcomes are tuned, the density is automatically tuned based on the relationship as given by Equation (26):

$$q = k \cdot v \tag{26}$$

where: q :the flow of a section $[veh/h]$;
k :the density of a section $[veh/km]$;
v :is the speed in a section $[km/h]$.

Based on this relationship, two out of the three (q, k, v) elements are used. The following combinations can be chosen:

(1) $q + v$ (2) $q + k$ (3) $v + k$

Combination (1) is chosen because it is much easier to obtain flow and speed observation data compared to density observation data. Flow and speed data can be obtained by detectors (automatically) while density data must be obtained by video or photo.

==> for the traffic regime: congested flow

- q: flow/capacity $[veh / h]$;
- v: mean speed $[km / h]$;

- t: travel time $[sec]$;
- L: traffic-jam length $[m]$.

For some infrastructure settings it is not possible or desirable to obtain a congested flow regime. An example of such a setting is a double lane carriageway which is not influenced by downstream traffic. So, in these situations it is not necessary to include the simulation outcomes travel time and length traffic-jams in the objective function. When a network is correctly defined within the network editor and congestion situations do not appear, tuned speed values also result in tuned travel times. This relation is given in Equation (27):

$$\text{distance} / \text{(mean)speed} = \text{(travel)time} \quad (27)$$

To define the weights of the examined criterion variables, the following process is performed.

Each simulation outcome will be compared to observation data. The first important aspect is the unit difference of these simulation outcomes. For example, the difference between 1500 vehicles simulated and 1525 vehicles observed, 25 (vehicles) and 120 km/h simulated and 95 km/h observed=25(km/h) must be correctly interpreted. Therefore, all simulation outcomes will be related to the observed mean value of a section/network. In previous example this will result in a difference (with mean flow 1525 veh/h and mean speed 95 km/h) of:

$$\left|((1500-1525)/1525)\cdot 100\right| = 1.64\%$$
$$\left|((120-95)/95)\cdot 100\right| = 26.32\%$$

In situations where as example the criterion of 10% is used, the flow difference would be accepted while the speed acceptance is not simulated with desired accuracy.

A graphical representation of the acceptance of a variable is proposed. First, the following two classes are defined:

- accepted simulation outcome, illustrated by ⬭;
- rejected simulation outcome, illustrated by ⊠.

The criterion whether or not simulation outcomes are accepted is 10% maximum deviation of the mean value of the examined outcome.

Applying four variables gives us a total of 16 (=2^4) possible outcomes, or so-called scenarios. See Table 14. A scenario describes the performance of a simulation run for specific criterion variables. In this study, the model predictions for each criterion variable can be accepted or rejected.

Simulation outcome / *Scenario number*	*Flow (veh/h)*	*Speed (m/s)*	*Travel time (s)*	*Traffic-jam length (m)*
1	○	○	○	○
2	○	○	○	⊠
3	○	○	⊠	○
4	○	○	⊠	⊠
5	○	⊠	○	○
6	○	⊠	○	⊠
7	○	⊠	⊠	○
8	○	⊠	⊠	⊠
9	⊠	○	○	○
10	⊠	○	○	⊠
11	⊠	○	⊠	○
12	⊠	○	⊠	⊠
13	⊠	⊠	○	○
14	⊠	⊠	○	⊠
15	⊠	⊠	⊠	○
16	⊠	⊠	⊠	⊠

Table 14. Possible scenarios of an examined infrastructure setting.

○ : 7% (<10) MAEP

⊠ : 20% (>10) MAEP

To define the weights of Equation (19), estimates of the mean value for accepted and rejected model predictions must be made. A mean value of 7% deviation between observations and criterion variables of accepted and of 20% for rejected model predictions is estimated. With these values the weights of the objective function are computed.

8.3 Priority of outcome variables of interest

To order the distinguished scenarios, an interview with current AIMSUN2-users is performed. The experience of these calibration experts is used to define a priority for examined outcome variables of interest. The outcome of the interviews resulted in the following priority of outcome variables.

Simulation outcome / *Scenario priority*	*Flow (veh/h)*	*Speed (km/h)*	*Travel time (sec)*	*Traffic-jam length (m)*	*Qualitative judgement*
1	○	○	○	○	very good
2	○	○	○	⊠	
3	○	⊠	○	○	↑
4	○	○	⊠	○	
5	○	⊠	○	⊠	
6	○	○	⊠	⊠	
7	○	⊠	⊠	○	
8	○	⊠	⊠	⊠	
9	⊠	○	○	○	
10	⊠	○	○	⊠	
11	⊠	⊠	○	○	
12	⊠	○	⊠	○	
13	⊠	⊠	○	⊠	
14	⊠	○	⊠	⊠	
15	⊠	⊠	⊠	○	↓
16	⊠	⊠	⊠	⊠	poor

Table 15. Scenario priority .

Based on the result of Table 15, the following may be concluded:

$$\alpha_{flow} > \alpha_{time} > \alpha_{speed} > \alpha_{traffic-jam} \qquad \textbf{(a)}$$

8.4 Definition of priority weights

In order to determine the set of weighting factors which can appropriately be applied in the objective function some assumptions must be made.

First, an assumption about the difference between observations and criteria outcomes must be made. The mean difference of accepted simulation runs is estimated at 7%. (The criterion whether or not simulation outcomes are accepted is 10% maximum deviation between observations and criterion variables). The mean difference of not accepted simulation outcomes will be estimated at 20%. The sensitivity of these proposed values on the judgement process need to be studied later.

Suggestions can be made concerning the weighting values of the objective function. The first guess to define these four weighting values is given Table 16. The ratio between the weights is as follows:

$$\alpha_{flow} > \alpha_{time} > \alpha_{speed} > \alpha_{traffic-jam}$$

(8) (4) (2) (1)

(estimated smallest weight:1, the other weights are multiplied by 2 based on criterion variable priority of (a).

This process is illustrated by the following example.

Two weights are examined: α_{flow} and α_{speed} .with respectively ranges of [2.0-4.0] and [1.0-4.0] and step size 1. The following 12 combinations are computed

Combi	α_{flow}	α_{speed}	**Combi**	α_{flow}	α_{speed}	**Combi**	α_{flow}	α_{speed}
1	2	1	5	3	1	9	4	1
2	2	2	6	3	2	10	4	2
3	2	3	7	3	3	11	4	3
4	2	4	8	3	4	12	4	4

The combinations are expressed in percentages (otherwise combinations cannot be compared to each other. The sum of the weight combination values must be 1.

Combi	α_{flow}	α_{speed}	**Combi**	α_{flow}	α_{speed}	**Combi**	α_{flow}	α_{speed}
1	0.67	0.33	5	0.75	0.25	9	0.8	0.2
2	0.5	0.5	6	0.6	0.4	10	0.67	0.33
3	0.4	0.6	7	0.5	0.5	11	0.57	0.43
4	0.33	0.67	8	0..43	0.57	12	0.5	0.5

Model experts defined the following (fictive) scenario priority:

Flow (veh/h)	**Speed (km/h)**
○	○
○	☒
☒	○
☒	☒

The objective function value for the first 4 combinations is computed.
(mean deviation value between accepted model predictions and observations is: 7%, the mean deviation value between rejected model predictions and observations is 20 %).

Flow (veh/h)	**Speed (km/h)**	**Objective function value**	**Objective function value**	**Objective function value**	**Objective function value**
		Combi1	Combi2	Combi3	Combi4
○	○	7	7	7	7
○	☒	11.33	13.5	14.8	15.7
☒	○	15.67	13.5	12.2	11.3
☒	☒	20	20	20	20

Combination 1 obtains objective function values according to the defined scenario priority while the other combinations obtain an other scenario priority. In this example only combination 1 is used for the computation of the definite weight values. For all combinations is it checked whether the defined scenario order is obtained. The results are given in Table 20.

Combination	*Objective values according to defined scenario order*	α_{flow}**-value**	α_{speed}**-value**
1	y	0.67	0.33
2	n	-	-
3	n	-	-
4	n	-	-
5	y	0.25	0.75
6	y	0.4	0.6
7	n	-	-
8	n	-	-
9	y	0.67	0.33
10	y	0.57	0.43
11	y	0.5	0.5
12	n	-	-
	mean value	0.51	0.49

Table 20. Computation of weighting values (example).

End of example.
For the computation of the definite weight values the following assumptions are made:

- a regular grid is defined (depending on the step size);
- the area of possible solutions (combinations of weight values) is convex (=A);
- A is an area of feasible model parameter combinations;
- a model parameter combination is feasible if the ranking such as defined by the model experts is reproduced.

The computation of the definite weight values is based on the ranges as given in Table 19.
This process is described by:

$$\alpha_{flow,h} = 0.40 + 0.01 \cdot h \qquad h = 0,1,...,300$$
$$\alpha_{speed,i} = 0.10 + 0.01 \cdot i \qquad i = 0,1,...,200$$
$$\alpha_{time,j} = 0.10 + 0.01 \cdot j \qquad j = 0,1,...,250$$
$$\alpha_{traffic-jam,k} = 0.00 + 0.01 \cdot k \qquad k = 0,1,...,200$$

$\tau_{hijk} = 1$ when the ranking of model experts is reproduced;
$\tau_{hijk} = 0$ otherwise.

$$\bar{\alpha}_{flow} = \sum_h \sum_i \sum_j \sum_k (\alpha_{flow,h} \cdot \tau_{hijk}) / N$$
$$\bar{\alpha}_{speed} = \sum_h \sum_i \sum_j \sum_k (\alpha_{speed,i} \cdot \tau_{hijk}) / N$$
$$\bar{\alpha}_{time} = \sum_h \sum_i \sum_j \sum_k (\alpha_{time,j} \cdot \tau_{hijk}) / N$$

$$\hat{\alpha}_{traffic-jam} = \sum_h \sum_i \sum_j \sum_k (\alpha_{traffic-jam,k} \cdot \tau_{hijk}) / N$$

where:

$$N = \sum_{hijk} \tau_{hijk} \,.$$

The following weights of the objective function are proposed (mean values of obtained weights). It is assumed that these values are defining the weights best because mean values are computed. The weight values computed in Table 18 are obtained by single computations while the values of Table 21 are obtained with a brute force estimation technique.

Weight	*Proposed weight value*
α_{flow}	0.55
α_{speed}	0.17
α_{time}	0.21
$\alpha_{traffic-jam}$	0.07

Table 21. Proposed weighting values

8.5 Summary

Simulations generate (series of values of) many types of variables. To judge the performance of a simulation run, an objective function containing the following criterion variables is proposed

- flow;
- speed;
- travel time;
- location/position traffic-jams.

The objective function calculates a weighted sum of the mentioned criterion variables. To estimate the weight values model experts are interviewed. By ordering scenarios describing possible simulation runs, and a brute force-estimation technique the following weights are proposed:

flow	: 0.55
speed	: 0.17
travel time	: 0.21
location/position traffic-jams	: 0.07

9 SIMULATION BASED SENSITIVITY ANALYSIS

9.1 Introduction

Most of the model parameters of AIMSUN2 are global parameters (model dependent parameters). These values are related to vehicle characteristics and imported from other calibration studies or literature study. The classified local dependent parameters (also referred to as tuning parameters) of Table 9 are used to adjust model predictions to obtain (sufficient) accuracy between criterion variables and observations.

In this chapter, these tuning parameters are examined for specific network components by means of a sensitivity analysis. With this analysis, criterion variables are not compared to observations. Only, the impact of parameters on the criterion variables is examined. Performing such a sensitivity analysis is a time consuming activity, so that not all network components that were distinguished in 7.3.4 are examined.

The organisation of this chapter is as follows. Section 9.2 lists the parameters that are involved in the sensitivity analysis and their default values. Section 9.3 describes the experiments and their results.

9.2 Model parameter values

For network components, two simulation runs are performed. One with default parameter settings defined by UPC/DHV and one by defined parameter values determined in this calibration study. In Table 22 the model parameter values for both simulation runs are given.

Parameter	*Symbol*	*Unit*	*Default*		*Defined*			
			mean	set	mean	set		
						min	max	dev
drivers reaction time	T	sec	0.75	--	tuning			
vehicle length	l (	meter	4	--	4	3.5	4.5	0.25
vehicle width	(1)	meter	2	--	2	-	-	-
desired speed	$\dot{x}$	km/h	90	--	115	85	125	7.5
max acceleration	α	m/s2	2.8	--	2.8	1	4	0.15
max deceleration	β	m/s2	8	--	8	6	9	1
distance zone1	dz_1	meter	120	--	tuning			
distance zone2	dz_2	meter	40	--				
normal deceleration	$\hat{\beta}$	m/s2	4	--	tuning			
speed acceptance	θ	-	0.8	--	tuning			
min dist. between vehicles	η	meter	1.2	--	2	1	3.5	0.5
give way time	δ	sec	30	--	30	10	50	5

Table 22. Parameter values for default and defined settings.

9.3 Experimental set-up of network components for sensitivity analysis

To be able to judge simulation outcomes, detectors are used to obtain automatically network and section information about simulation outcomes. The following lay-out definitions for the basic network components are proposed to perform the sensitivity analysis. In this section recommendations for detector locations and location dependent parameters for the defined network components are given.

9.3.1 Network component 'stretch'

As mentioned in Chapter 7 different types of the main network component 'stretches' are considered. These types will be discussed in more detail.

9.3.1.1 Basic 'stretch'

The zone definition does not influence the vehicle behaviour because no mandatory lane-changes are performed for this component type. Here, only car following and discretionary lane-change behaviour is applied by drivers for this section type.

Two detectors are used to obtain information about traffic flow characteristics of the input and output of section *n*.

At each detector the following indicators are computed: flow, speed, density and travel time. The indicator for the sensitivity analysis is computed by averring these values.

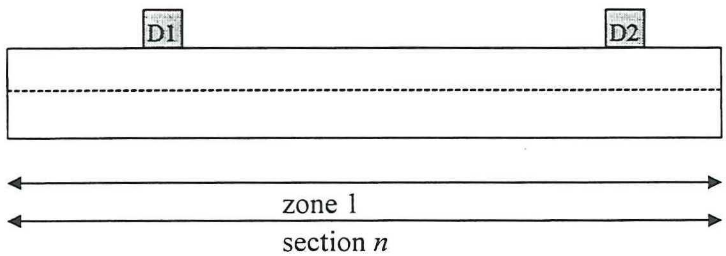


Figure 44. Basic 'stretch'.

Criterion variables can be fit to observations by adjusting the following location dependent parameters.

Tuning order with	*Default value*	*Min value*	*Max value*
reaction time	0.8 sec	0.1 sec	1sec
speed acceptance	1	0.8	1.2

Table 23. Location dependent parameters.

Reaction time can be used to influence the capacity and flow values because drivers react more or less accurate by adjusting the reaction time value. The speed acceptance parameters can be used to influence the speed and the travel time criterion variable.

9.3.1.2 Network components 'stretch' with lane-drop

For this network component the sub models car following, discretionary and mandatory lane-change behaviour are applied. Therefore, also the zone definition may be used to fit criterion variables to observations. The available animation option is a tool to observe and judge the lane-changing behaviour.

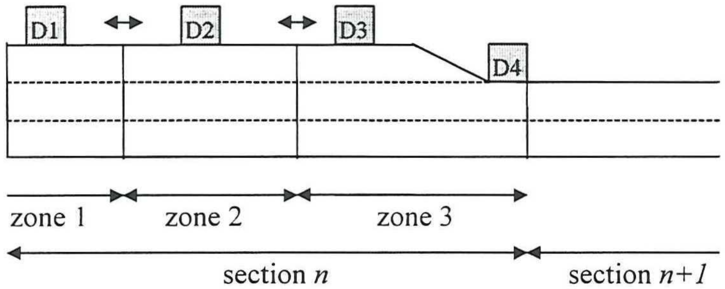


Figure 45. Stretch with lane-drop.

Tuning order with	*Default value*	*Min value*	*Max value*
distance zone 1	120 m	0	section length
distance zone 2	40 m	0	section length
reaction time	0.8 sec	0.1 sec	1sec
speed acceptance	1	0.8	1.2

Table 24. Location dependent parameters.

First, it must be checked whether or not the driver behaviour around the lane-drop corresponds to observations. To influence the lane-changing behaviour the distance zone 1 and zone 2 parameters may be adjusted. With these parameters location and position of traffic jams can be adjusted. This will also influence the flow and speed characteristics. If the driver behaviour is modelled correctly the flow, speed and travel time variables may also be influenced by adjusting the reaction time and the speed acceptance model parameter.

It is proposed to locate in each defined zone a detector because within each of the zones the driver behaviour is differently. By means of the animation option, an visual judgement can be given of the driver behaviour for this setting.

9.3.1.3 Network component 'stretch' with extra lane

In this setting no mandatory lane-changes are performed, therefore the zone definition will not influence the driver behaviour. This setting must be tuned by adjusting the reaction time and/or the speed acceptance model parameter. Defining two detectors, located up-stream and down-stream of point A is proposed.

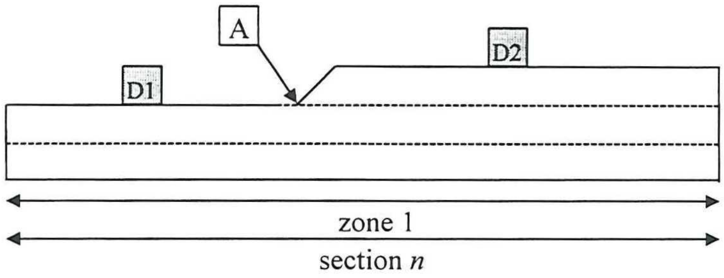


Figure 46. Stretch with extra lane.

For the tuning order of location dependent parameters see Table 23.

9.3.2 Network component 'join'

This type of network components describes setting where a splitting of directions is simulated. First, the mandatory lane-changing behaviour must be correctly modelled by adjusting the distance zone 1 and zone 2 model parameters. The animation option of the simulation run may be used to judge the mandatory lane-changing behaviour. See for the tuning order also Table 24. Defining four detectors is proposed to obtain traffic flow information. The first 2 detectors are located up-stream of point A (in each zone a detector is located). The last two detectors are located down-stream of point A.

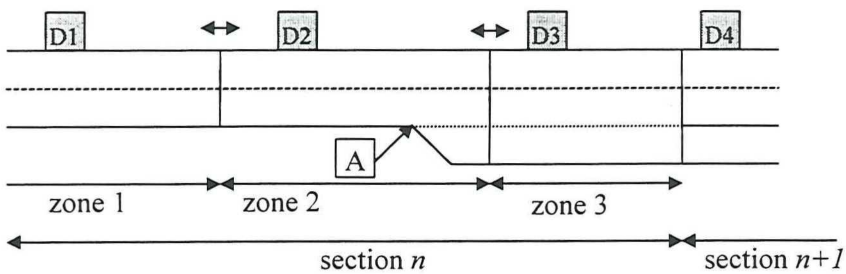


Figure 47.Network component join.

9.3.3 Network component 'fork'

The same remarks for a fork can be made to fit model predictions to observations as given by the network component join because there are only four location dependent parameter available.

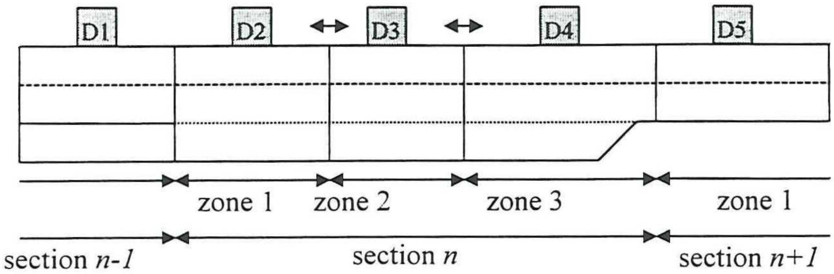


Figure 48. Network component fork.

9.4 Simulated results

In Chapter 7 an elaborate description of possible test networks is given. Due to the time constraints only a limited number of test networks could be examined. The experimental set-up of network components and obtained results are described in this section.

9.4.1 Single lane carriageway

This infrastructure setting corresponds to figure (1.1) of a network component as mentioned in chapter 7. So, over the whole network the same type of network type was used.

The free flow situation is modelled with default values (defined by DHV). Because no parameter value distribution has been defined (only one (mean)value), no congestion was modelled. A network consisting of four sections (with length of 500 meters) was used. The following results have been obtained at detector *D*.

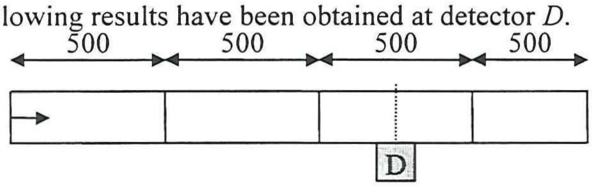


Figure 49. Schematises of single lane carriageway.

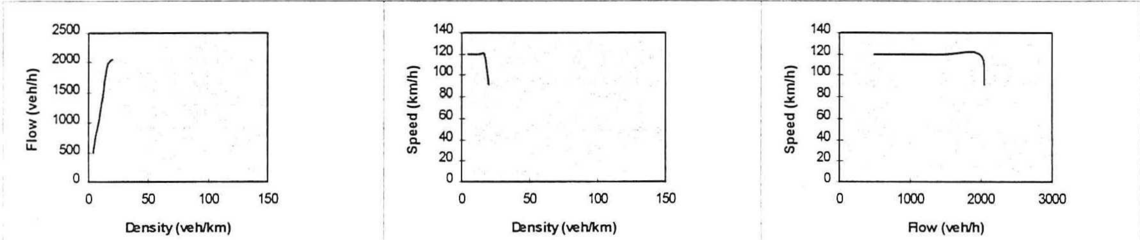


Figure 50. Fundamental diagram for single lane carriageway with default parameter settings.

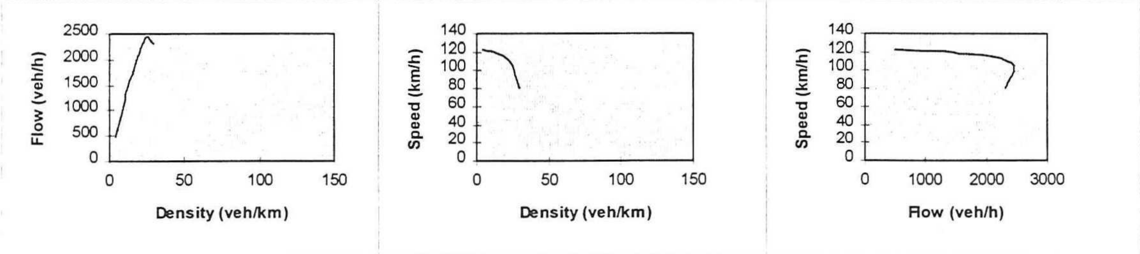


Figure 51. Fundamental diagram for single lane carriageway with defined parameter settings.

<u>Reaction time</u>

For increasing values of the reaction time, speed will decrease. This phenomenon is easy to explain because vehicles (=drivers) react slower to changes in traffic characteristics. This late reaction will cause more extreme driving actions which result in decreasing speed values and increasing density values.

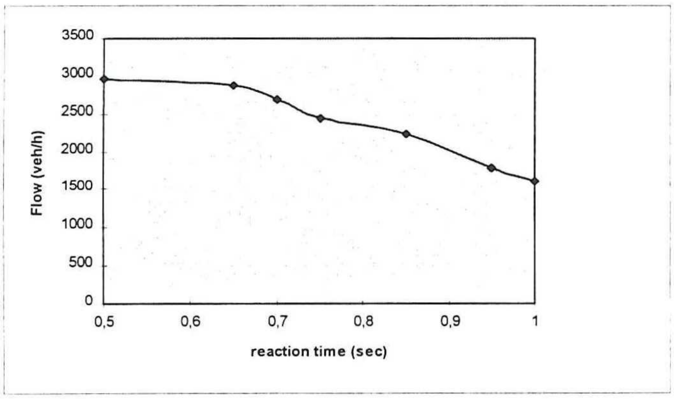


Figure 52. Relation between reaction time and flow for one lane carriageway.

Speed acceptance

For networks consisting of single lanes, this parameters hardly influences the traffic outcomes. Mainly the mean speed is determined by the slow driving vehicles because no lane-changing possibility is available. So, here the distribution of the speeds in more important because of the fact that there is no possibility to change lanes. In the default simulation no distribution was used.

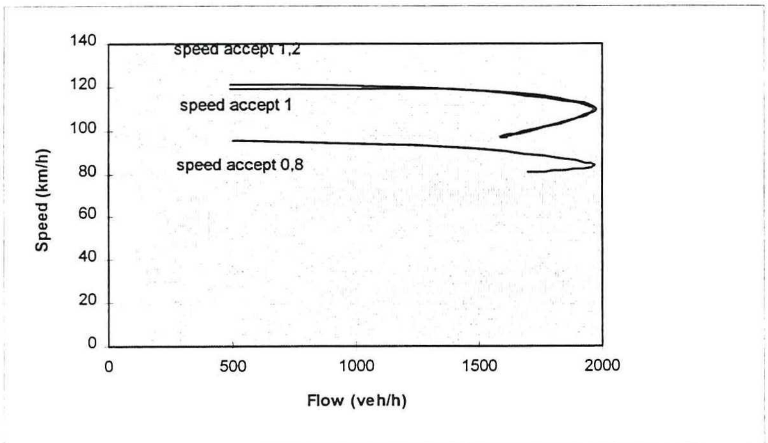


Figure 53. Speed-flow diagrams for different speed acceptance values.

Zone 1 and Zone 2

The zone definition is used in the lane-changing process where vehicles determine their destination direction to the next turning point. In a infrastructure setting where only one destination direction is modelled, vehicles are not forced to change lanes. Therefore, the zone definition is not important in infrastructure settings with only one destination direction.

Single lane carriageway	
conclusions	To adjust flow and capacity rates, reaction time, speed acceptance can be used. Congestion cannot be modelled in situations where no up-stream influences are available. Note: only vehicle type car.
examined parameters	reaction time, desired speed, zone 1 and zone 2, speed acceptance

Table 25. Results simulation single lane carriageway.

9.4.2 Double lane carriageway

The following infrastructure setting which will be examined is the double lane carriageway. First a simulation run is performed with default parameter settings (defined by DHV). So, no distribution of vehicle characteristics is implemented. The following simulation setting was used:

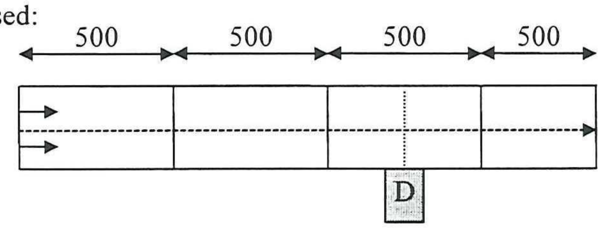


Figure 54. Schematising of double lane carriageway.

Next, obtained simulation outcomes of detector *D* are given.

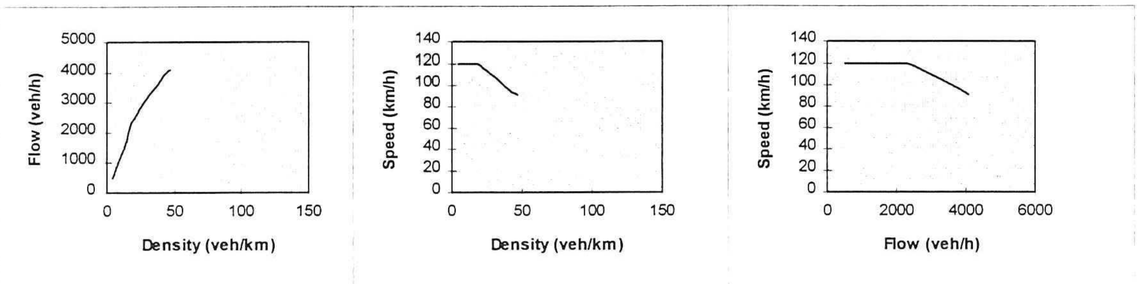


Figure 55. Fundamental diagrams for double lane carriageway with default settings (for free and partly constrained flow regimes).

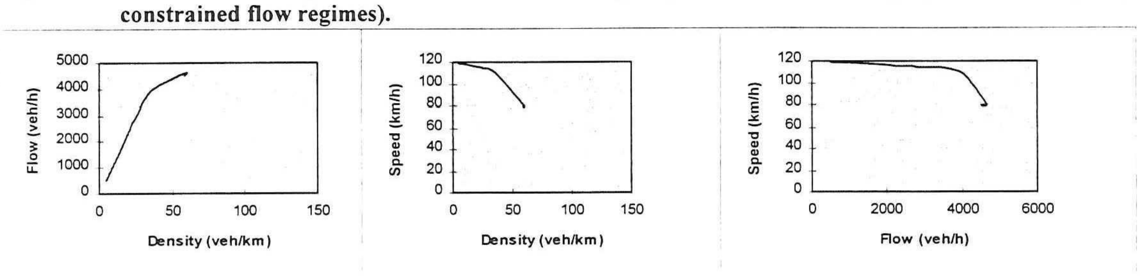


Figure 56. Fundamental diagrams for double lane carriageway with proposed settings (for free and partly constrained flow regimes).

Due to the fact that no congestion could be modelled, the influences of parameter values on the simulation can be compared to the previous infrastructure setting. A stream of vehicles is visible driving with the same speed (due to the fact that no distribution of the desired speed value was implemented).

Subsequently, a simulation run was performed where a distribution of vehicle characteristics (based on Table 10) was implemented resulting in the following figure:

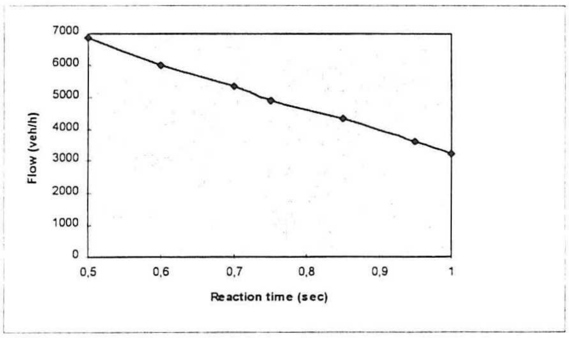


Figure 57. Relation between reaction time and flow for double lane carriageway.

Double lane carriageway	
conclusions	To adjust flow and capacity rates, reaction time, speed acceptance can be used. Congestion can not be modelled in situations where no up-stream influences are available. Note: only vehicle type car.
examined parameters	reaction time, desired speed, speed acceptance, zone 1 and zone2

Table 26. Results simulation double lane carriageway.

9.5 Discussion

Simulation runs for the defined stretch network component with lane-drop or extra lane, the 'fork' and the 'join' network components have not yet performed so that no conclusions can be given about the tuning process of these settings.

9.6 Summary

To perform a sensitivity analysis for AIMSUN2(3.2), model dependent parameter values are specified by literature study, common sense and studying other traffic models. Lay-out network settings for defined basic network components are proposed to perform the sensitivity analysis. For each basic network component type, suggestions are given where to locate detectors and which location dependent parameters to use for the tuning process.

For some basic components a sensitivity analysis has been performed. However, more simulation runs are needed to define the specific influences on the driver behaviour by adjusting the location dependent parameters.

10 RECOMMENDED CALIBRATION PROCEDURE

10.1 Introduction

In this chapter, findings of the study are implemented in a general calibration procedure for traffic models. This calibration procedure is designed for calibration of entire networks. However applying this procedure to AIMSUN (3.2) is not possible because most AIMSUN2(3.2)-model parameters are applied to the entire network, so that tuning specific network components to fit model outcomes to observations also influence other components.

The calibration procedure is divided into two main processes (see section 4.2.2):

- a calibration process;
- a tuning process.

The calibration process is performed once and established model parameter values will not be adjusted afterwards. The tuning process is performed for each application again. Here, model parameters are adjusted to fit criterion variables to observed data.

The generic calibration procedure can be divided into 6 steps which are discussed in following section.

10.2 A 6-step generic calibration procedure

An overview of the generic calibration procedure is given in Table 27.

Step	*Activity*
1. Examination of the traffic model	Distinguish sub models are classify model parameters
2. Definition of the network and subject of calibration	Divide network in network components
3. Collecting observation data	
4. Calibration at microscopic level	Define local dependent model parameter values
5. Calibration at macroscopic level	Define model dependent model parameter values
6. Tuning process	Fit model predictions to observations

Table 27. Generic calibration procedure.

Next, the steps will be discussed in more detail.

Step 1 Examination of the traffic model
Examine the traffic model and distinguish the sub models which compute the different aspects of the vehicle behaviour. In general, traffic models contain sub models for route choice, car following, and lane- changing behaviour of drivers.

Next, classify the available model parameters into the following classes:

- fixed; (also referred to as constants)

Parameters in this group should not be adjusted and are related to behavioural and physical constants.

- model dependent (also referred to as calibration parameters);

These parameters are specific to a model, they are calibrated only once. This group of parameters can be subdivided into parameters valid for the entire network (global) and parameters valid for specific network components (local).

- location dependent (also referred to as tuning parameters).

This group of parameters are related to specific locations. (for example for each modelled on-ramp this value may be changed).

Fixed and model dependent parameters are used in the calibration process while location dependent parameters are used in the tuning process.

Car characteristics such as acceleration rate and length are global parameters and therefore classified as model dependent parameters.

For each model parameter must be decided how values are defined and which criterion variables are used in the calibration process.

Step 2 Definition of the network and collecting observed data.
Make a precise network description. Each network can be subdivided into the following main network components:

- stretch;
- join;
- fork.

To judge the performance of the simulation, observed data is needed of the examined network. Without this data, a calibration and tuning process can not be performed. It is assumed that sufficient observations are available to perform the calibration process.

Step 3 Collecting observation data

Step 4 Calibration at microscopic level
Before simulation runs can be performed fixed and model dependent parameter values must be specified.

For each of the defined basic network components, the following driver behaviour classes can be distinguished:

Basic network component	Related driver behaviour
stretch	car following discretionary lane-change
join	car following discretionary lane-change mandatory lane-change
fork	car following discretionary lane-change mandatory lane-change

Table 28. Network components versus related driver behaviour.

Fixed parameters
This group of parameter values is also referred to as constants must be specified by literature study.

Model dependent parameters
The classified model dependent parameters must be related to the basic network components and parameter values must be specified. Once specified, these parameter values will not be adjusted.

1. Car characteristics

Model dependent parameter values defining the car characteristics must be specified by literature study and are related to all distinguished driver behaviour types. For each user-group (cars, trucks, busses etc.) parameter values must be specified. The following parameters are examples of car characteristics:

- length;
- width;
- acceleration (normal/maximum);
- deceleration (normal/maximum).

2. Model dependent parameters related to the car following behaviour.

For each main network component, the same car following sub model is applied. Therefore, parameter values are specified only once.

Some of the parameters used in the sub models are not accessible for the software-user. These values are already specified in the used theoretical models.

3. Model parameters related to discretionary lane-change behaviour.

Parameters related to discretionary lane-changing conditions must be determined. The following conditions may be implemented in the traffic model and must be specified.:

- distance vehicle n versus preceding vehicle $n-1$.

- desired speed vehicle *n* versus current speed vehicle *n-1*.
- current speed difference between vehicle *n* and *n-1*.

The speed difference between vehicle *n* and *n-1*, determines the distance condition whether or not a vehicle is following his preceding vehicle or not.

4. Model parameters related to mandatory lane-change behaviour.

Here, the lane-change behaviour the reach destination lanes at merging or splitting points is observed. The distance between vehicle *n* (expressed in meters or seconds) to the end of merging or splitting point determines the driver behaviour.

A function can be implemented defining above mentioned relation. It is also possible to specify zones in which specific driving characteristics are defined.

Location dependent parameters
Default values for this tuning parameter group must be specified. These values can be obtained by literature study and a sensitivity analysis.

Next, the order of examined network settings is given. Also, information for the calibration process is given.

<u>Calibrate a single lane carriageway</u>
Simulate a single lane carriageway and specify the capacity flow rate for this lane.
If the capacity flow is lower than 2500 vehicles/h, model parameters of the car following sub model must be adjusted to obtain this capacity value. Here, mandatory and discretionary lane-changes can not be performed.

<u>Calibrate a double lane carriageway</u>
Simulate a double lane carriageway and specify the capacity flow. For each lane at least a capacity flow of 2500 vehicles/h must be obtained. If this is not obtained adjust parameter values for discretionary lane-changing. Capacity values can be influenced by adjusting model parameters related to discretionary lane-changing conditions as given by remark 3. of step 3 of the calibration procedure.

<u>Calibrate double lane carriageway with lane-drop</u>
Simulate this setting, and observe the animation of the traffic flow. Judge by common sense whether or not the forced lane-change behaviour is simulated correctly. By adjusting model parameters related to this mandatory lane-change, the driver behaviour can be adjusted. So, the judgement of this setting is performed by observing the animation.

Judgement aspect: gap acceptance; distance between location lane-change and endpoint of on-ramp.

<u>Calibrate on-ramp setting for double lane-carriageway</u>
For models where the same mandatory lane-changing behaviour for a lane drop and for on-ramps is used, mandatory lane-changing parameter values are already determined. Also, here the judgement of the mandatory lane-change is based on common sense and observed by the animation of the traffic flow.

Judgement aspects: gap acceptance; distance between location lane-change and endpoint of on-ramp.

If the lane-changing behaviour at off-ramps is not modelled correctly, the model parameters related to the mandatory lane-change are adjusted. However, this may also influence the lane-changing behaviour for situations with a lane-drop. If it is not possible to obtain model parameter values which simulate both situations (on-ramps and lane-drop) correctly, it is proposed to adjusted to parameters to model the on-ramp correctly. This approach is recommended because on-ramps may appear more frequently compared to dropped lanes.

The calibration of the lane-changing behaviour at on-ramps for traffic models with a separate on-ramp lane-changing sub model will be performed as above mentioned situation. However, this time adjusting parameters will not influence the lane-changing behaviour at a lane-drop.

Calibrate off-ramp setting for double lane-carriageway

See remarks for calibration on-ramp setting for double lane-carriageway. However, here model parameters related to the off-ramp must be adjusted.

If these basic network components (and related driver behaviour characteristics) are calibrated, the total performance of the traffic model can be observed.

Step 5 Calibration at macroscopic level

The total of driver behaviour definitions at microscopic level define the driver behaviour at macroscopic level. So, step 4 of the proposed calibration process is included to check to overall performance of the traffic model.

In general, the total driver behaviour is judged based on the available animation option of the software. By means of common sense, the observed driver behaviour is analysed. For locations where the simulated driver behaviour is judged to be not correctly, the related basic network component(s) must be determined. The calibration process at microscopic level for these components must be performed again.

Step 6 Tuning process

The performance of a simulation is computed using the defined objective function. Perform a simulation run with fixed and model dependent parameter values and default location dependent parameter values for free, capacity and congested flow regimes.

Compute deviation between criterion variables and observations. Table 29 illustrates how the deviation of the examined criterion variables is computed.

Time	*q*			*v*			*t*			*jam*		
	sim	obs	dev	sim	obs	dev	sim	obs	dev	sim	obs	dev
t1												
t2												
:												
:												
tn												
total			$\overline{D_q}$			$\overline{D_v}$			$\overline{D_t}$			$\overline{D_{jam}}$

Table 29. Computation of separate criterion variable deviations.

The objective function value can be computed with proposed weighting values. If desired preferences of the client can be implemented by computing new weighting factors by using available software: 'weight definition'.

If an objective function value less than 7 is obtained, the simulation is obtained with desired accuracy and the tuning process can be stopped. If a higher objective value than 7 is obtained, model parameters need to be adjusted. (see section 8.4)

First, it must be defined where the deviation of the criterion variable flow and observation flow is highest. In this study, the weight of this variable is estimated highest and therefore it will be the major influence on the objective function value.

After localising the highest 'flow' deviation, the related network component and traffic flow regime must be defined. Available location dependent parameters for network components can be adjusted in relation to the traffic flow regime.

If the criterion variable flow is modelled with desired accuracy (deviation less than 7) , the other variables need to be examined by localising the highest deviation values. This process must be performed in the following order (flow, travel time, speed and finally, location/position traffic-jams).

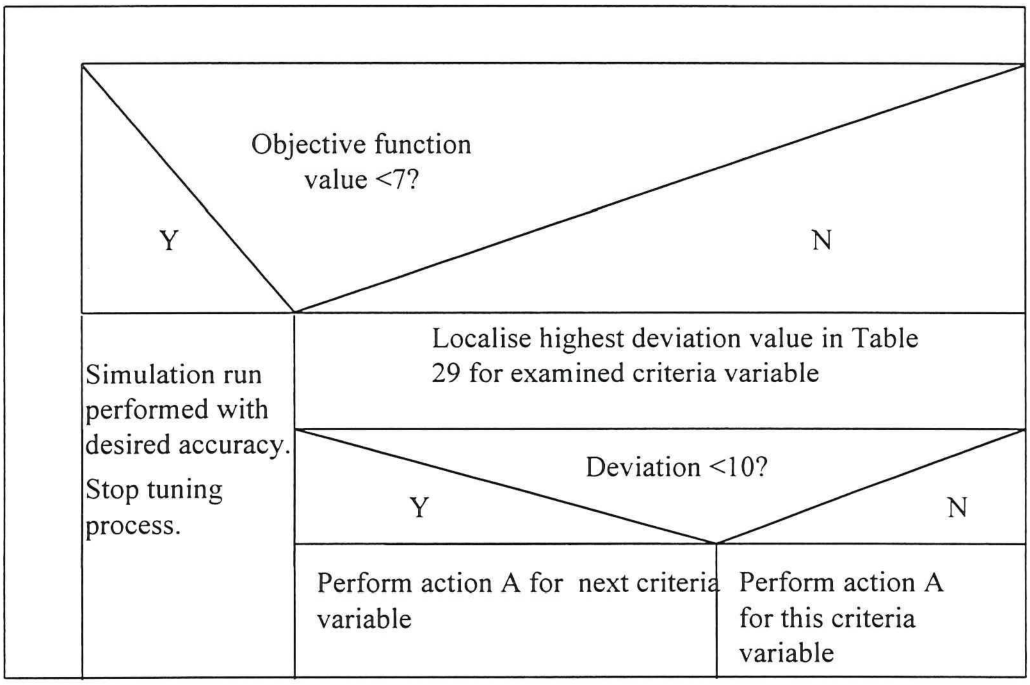


Figure 58. Tuning algorithm

Action A

- Determine related location dependent parameter.
- Adjust location dependent parameter value.
- Simulate with new model parameter values.
- Compute new deviation values (Table 29).

10.3 Proposed calibration procedure versus AIMSUN2 (3.2)

AIMSUN2(3.2) is built of global model parameters only and therefore it is not possible to perform a calibration procedure to fit criterion variables to observations for specific network components. The separate network components can be calibrated by performing the proposed calibration procedure presented in section 10.2 .

If an entire network is examined, general model parameter values must be defined. The performance of the simulation may not be obtained with desired accuracy because the calibration possibilities are very limited.

The car following sub model consists of two main functions computing an acceleration and a deceleration speed. Some parameters are not available to the user and therefore it is not possible to influence the car following behaviour except for the model parameters defining the car characteristics.

Conditions to define whether discretionary lane-changes are performed are not available for the AIMSUN2-user. These conditions define the distance difference and speed difference between vehicle *n* and vehicle *n-1*. Therefore it is not possible to influence the conditions for discretionary lane-changing.

A mandatory lane-change is defined by a zone definition of each section. Two model parameters, distance zone 1 and distance zone2, are available for the user and can be used in the calibration procedure. However, the same two parameter values are applied for all network component types. Therefore, single network components can be calibrated for the mandatory lane-change behaviour. If an entire network is examined, the 'best' global parameter values must be defined. It is most likely that in these situations criterion variables are not obtained with desired accuracy.

10.4 Summary

A 6-step calibration procedure is proposed to calibrate micro-dynamic traffic models. First, a detailed examination of the simulation process must be performed. Implemented sub models defining the route choice, car following, mandatory and discretionary lane-change behaviour must be analysed. Model parameters (available for the user) must be classified into fixed, model dependent and location dependent parameters.

Secondly, the network aspect must be defined. A classification into three basic network components (stretch, join, fork) is proposed to calibrate specific driver behaviour aspects. For each of these basic network components, observations must be collected to fit the model predictions to these observed data.

Next, the calibration at microscopic level must be performed. The driver behaviour aspects car following and lane-changing (discretionary and mandatory) are related to the basic network components.

The calibration process at macroscopic level is performed to judge the total driver behaviour (combination of car following and lane-changing) for an entire network. By means of observing the driver behaviour available by the animation run option, it is decided whether or not specific network components need to be calibrated (at microscopic level) again.

Finally, a tuning process is proposed to fit the criterion variables to observations for specific studies must be performed for each model application. It is proposed to judge the performance of the simulation by means of an objective function. A weighted sum of four criterion variables (flow, speed, travel time and location/position traffic-jams) is computed. Available location dependent parameters are used to fit criteria outcomes to observations.

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 Introduction

This chapter summarises the findings obtained from this calibration study of AIMSUN2. Some of the mentioned conclusions or recommendations have already been implemented in new versions of AIMSUN2. First, conclusions about calibration in general are given. Next, this proposed calibration procedure in relation to the characteristics of the AIMSUN2 modelling process is discussed. Finally, conclusions concerning the proposed general calibration procedure are given.

11.2 Conclusions

By means of the proposed objective function, it is possible to express the performance of a simulation into an objective function value. Weights of the criterion variables flow, speed, travel time and congestion length are defined and implemented in the objective function. Several simulations can be easily compared and judged by comparing the objective function values.

A first (global) maximum difference value between observations and predictions of 10% whether simulation predictions are accepted is proposed. With this value, the weights of the criterion variables are defined.

It is proposed to compute the distance between model predictions and observations by means of a mean absolute error proportional (MAEP) function. This function expresses the distance between predictions and observations in percentages and therefore is easy to implement in the objective function.

11.2.1 General findings AIMSUN2(3.2)

In AIMSUN2 (version 3.2) there are very limited possibilities to perform a calibration process for an entire network. In this model version, most model parameters are defined as global ones implying that adjusting parameter values will influence more than one network components.

To calibrate specific network components (such as 'stretches', 'joins' and forks') the calibration possibilities are still limited due to the fact that most accessible model parameters are related to car and driver characteristics. In AIMSUN2(3.2) most model parameters implemented in the sub models are not accessible which result in very limited possibilities for calibrating the sub models of AIMSUN2 (3.2).

It is not possible to define a batch input file. Such a file may be an useful tool to perform a calibration study. A batch file, consisting of several commands needed for performing a simulation run, can be used to perform simulations containing different parameter values. The sensitivity of model parameters on criterion variables can be defined quickly by performing simulations automatically. Simulations with AIMSUN2 (3.2) can only be performed on-line.

It is difficult to export the simulation outcomes to other software (for example databases). Computing the distance between observations and simulation predictions is therefore a time consuming activity.

Yet, there is a great practical need to be able to use deviating behavioural model parameters at local level. By deviating from the defaults the model operator may express knowledge on the network that cannot be specified otherwise. Knowledge on which deviations to apply is part of the expertise of the operator of the model.

The extensions of AIMSUN2 that allow specifying more model parameters at local level is an option that was realised on behalf of DHV Environment and Infrastructure during the course of this study.

11.2.2 Generic proposed calibration procedure

A generic calibration procedure is proposed to perform calibration studies for traffic models in general and including current versions of AIMSUN2.

The calibration process is part of the total development process of traffic models. It is proposed to divide the calibration process into two phases:

- a calibration phase;
- a tuning phase.

In both phases model, model parameters are adjusted to fit observed data to model predictions. It is proposed to distinguish the following model parameter groups:

- fixed parameters (also referred to as constants);
- model dependent parameters (also referred to as behavioural parameters);
- location dependent parameters (also referred to as tuning parameters).

First, the calibration phase must be performed. During this phase, two sub phases are distinguished:

- calibration at microscopic level;
- calibration at macroscopic level.

To calibrate a traffic model at microscopic level, specific network components are distinguished. These main network components are classified based on the number of input and output directions. It is proposed to define the following main network components:

- stretch;
- join;
- fork.

For each of these main network components, driver behaviour characteristics can be defined. Which result into the following relations:

Basic network component	*Related driver behaviour*
stretch	car following discretionary lane-change
join	car following discretionary lane-change mandatory lane-change
fork	car following discretionary lane-change mandatory lane-change

Table 30. Network components versus related driver behaviour.

Each of these sub models defining the driver behaviour consists of model parameters. These model parameter values can be obtained by statistical estimation techniques or by heuristic procedures such as literature study, interviews with model experts, and trial and error.

After the separate network settings are examined and related model parameters values are determined, the calibration at macroscopic level is performed.

To fit the model predictions to observations, a tuning process is performed. It is proposed to define an objective function to compute the accuracy between all criterion variables and observations at the same time. This objective function calculates a weighted sum of the following criterion variables:

- flow;
- speed;
- time;
- length traffic-jams.

It is proposed to compute the distance measure *D* (expressed in %) between time series of observed data and a criterion variable by the mean absolute error proportional (MAEP) function (one dimensional optimisation).

To derive the set of weighting factors which can be appropriately applied in the objective function, a brute force estimation technique was applied. By means of this function a multi-criteria analysis can be performed. The following weighting factors are proposed:

flow	0.55
speed	0.17
time	0.21
location/position traffic-jams	0.07

It is proposed to accept a maximum 10% deviation between observations and a specific criterion variable. Therefore, the tuning process will be repeated until this defined accuracy is obtained. It is possible that the this accuracy can not be obtained with the software. In these situations a higher deviation must be accepted.

11.2.3 Proposed calibration procedure versus AIMSUN2

AIMSUN2 version 3.2 contains many global model parameters. Some model specific parameters are treated as fixed, some location dependent parameters are treated as global parameters-network specific. There are only limited capabilities to calibrate the model and in some studies it is not possible to reach the desired fit of 10% with this current classification of model parameters.

Specific network components such as on/off-ramps can be calibrated at microscopic level and tuned to fit the criterion variables to observed data.

In AIMSUN2 version 3.2, four model parameters are classified as location dependent parameters. These parameters can be used to fit the criterion variables to observations. It is proposed to use the following parameters for the tuning process:

Used for tuning	*Symbol*	*Default value*
distance_zone1	dz_1	*120 m*
distance_zone2	dz_2	*40 m*
reaction time	T	*0.85 s*
speed acceptance	θ	*1*

11.3 Recommendations

11.3.1 General proposed calibration procedure

A mean absolute error proportional function (MAEP) is proposed to compute the distance D between time series of observations and model predictions. More research is recommended to derive the most appropriate distance measure function to perform the one-criterion optimisation process.

To judge the performance of simulation runs, an objective function computing a weighted sum of criterion variables is designed. To define the weights of this function model experts are interviewed to order scenarios describing different simulation runs. It is recommended to define more scenarios. For example, scenarios containing three classes (very good, mean, not acceptable) in stead of two (accepted or rejected) which are applied in this study. This may result in a more precise ordering of the criterion variables and also in better estimations of the weights used in the objective function.

11.3.2 Suggestions for improving AIMSUN2

Performing a calibration study is a time consuming activity. It is recommended to automated specific processes of the calibration process. It is suggested to define a batch file module. With this batch file the sensitivity analysis of model parameters can be automated. For AIMSUN2 (3.2) the sensitivity analysis must be performed on-line and therefore can't be performed with desired accuracy in a relative short period.

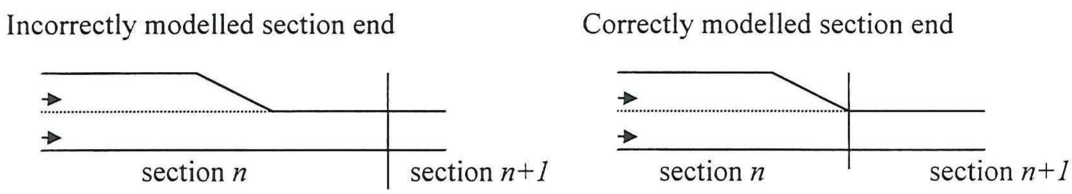
In AIMSUN2 (3.2) exporting simulation outcomes isn't possible. For performing an automated sensitivity analysis it is essential that simulation outcomes can be easily exported to databases.

It is recommended to introduce a number of model parameters in AIMSUN2 that are related to specific network components.

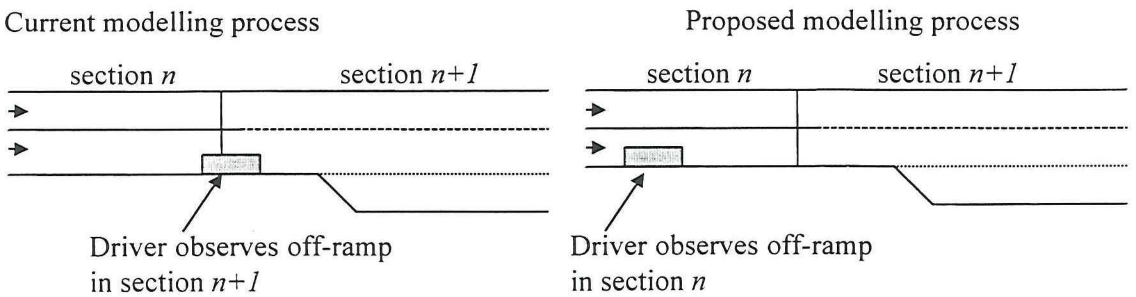
The driver behaviour is defined by the following aspects:
- car following behaviour;
- discretionary lane-changing behaviour;
- mandatory lane-changing behaviour.

Since the AIMSUN2-user now has no influence (=calibrate) on the conditions for the car following and discretionary lane-changing (version 3.2), it is proposed to make all model parameters available to create the possibility to influence these conditions.

The mandatory lane-change should be related to the network component. Therefore specific model parameters should be introduced to define the zone definition for join and fork network components respectively. For situations where a lane-drop is modelled (example of a stretch network component) the section end must be located just behind the lane drop. At the moment it is still possible to model a lane-drop and draw the end of a section freely. This should be changed. A separate zone definition for a dropped lane is proposed



In AIMSUN2 (3.2) drivers only observe the traffic condition of the section they are using. Traffic conditions or network lay-out of the next section is observed after entering this section. It is proposed that drivers may overlook more than one section.



Introduce separate model parameters for reaction time, simulation cycle and updating interval. It is proposed to relate the reaction time to the traffic regime and the network component. In capacity and congested flow regimes drivers are more accurate than driving in free flow situations. Drivers located at or around fork and join network component are more accurate than driving at a stretch network component.

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12 COLOPHON

Client	:	
Project	:	A calibration procedure for micro-dynamic traffic modelling
File	:	
Length of report	:	103 pages
Author	:	Mark van Raaij
Contributions	:	
Project Manager	:	
Project Director	:	
Date	:	31 August 1998
Authorization	:	

APPENDIX 1 VEHICLE DISTRIBUTION

A simple network consists of 3 origin/destination locations. The travel costs (expressed in travel time or distance) are given by:

Origin/Destination	*1*	*2*	*3*
1	12	3	5
2	8	4	10
3	3	5	7

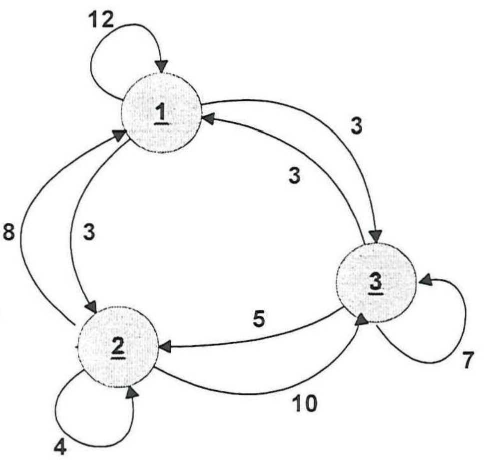
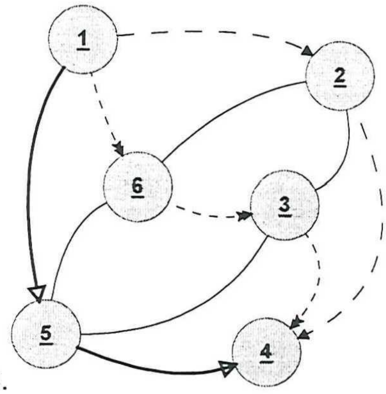


Figure 59. Example of vehicle distribution for a simple network.

To travel from one origin to another only one shortest route is available. Therefore, the route choice of the driver is not very difficult.

In more complex networks, alternative routes to travel from one origin to one destination might be possible. See also Figure 60. So, a shortest route path must be computed to define which route will be followed. To travel from origin 1 to destination 4, more logical routes might be used. For instance:

- route 1-2-4;
- route 1-5-4;



• route 1-6-3-4.

Figure 60. Example of logical routes between origin-destination in a more complex network

To compute the shortest path between origin and destination, route selection models have been implemented. The travel costs are expressed in travel time. So, the route with the lowest estimated travel time is the shortest route.

APPENDIX 2 CALIBRATION MODEL DEPENDENT PARAMETERS

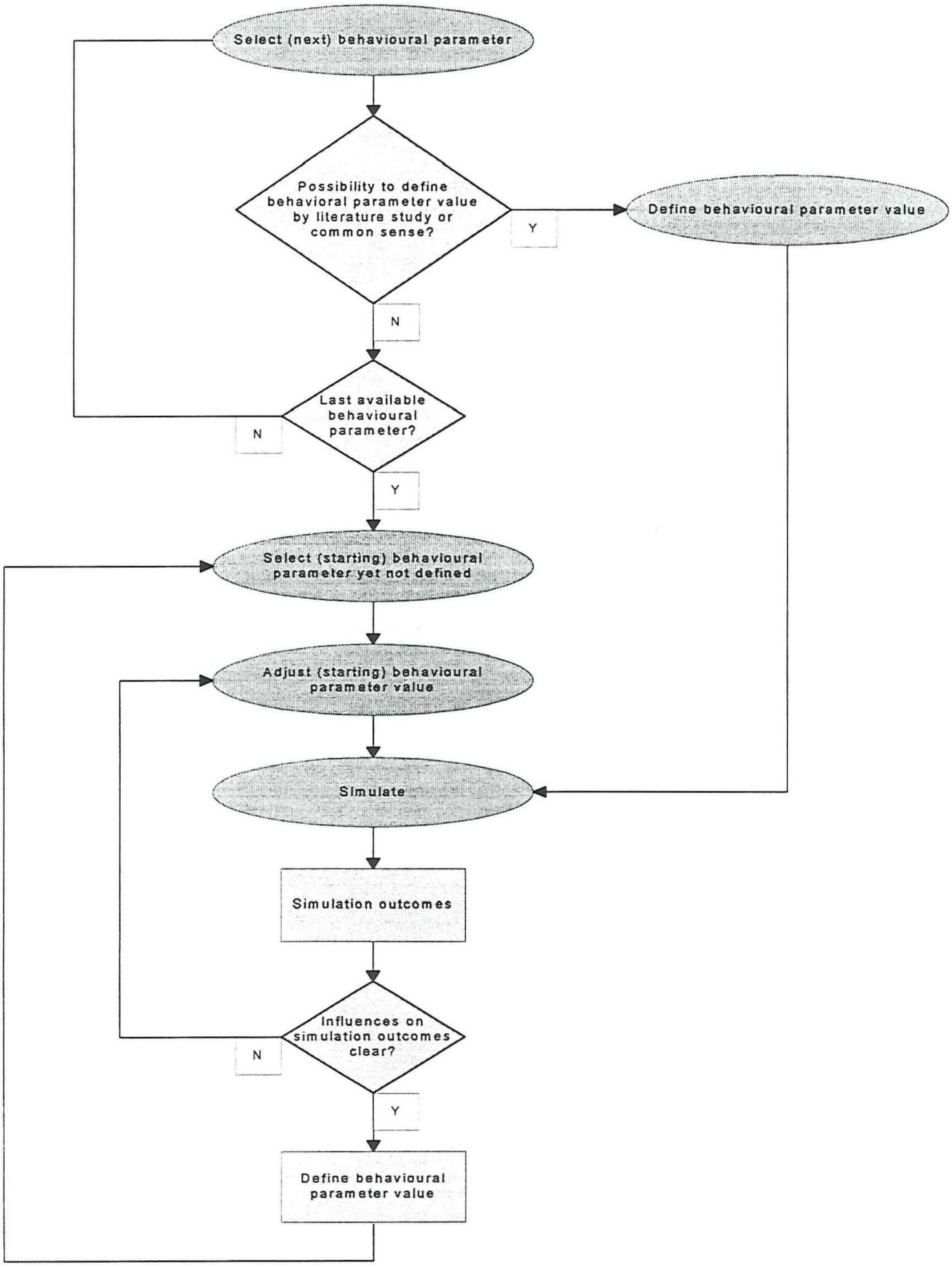


Figure 61. Process of calibrating model dependent parameters.

APPENDIX 3 GRADUAL TUNING PROCESS

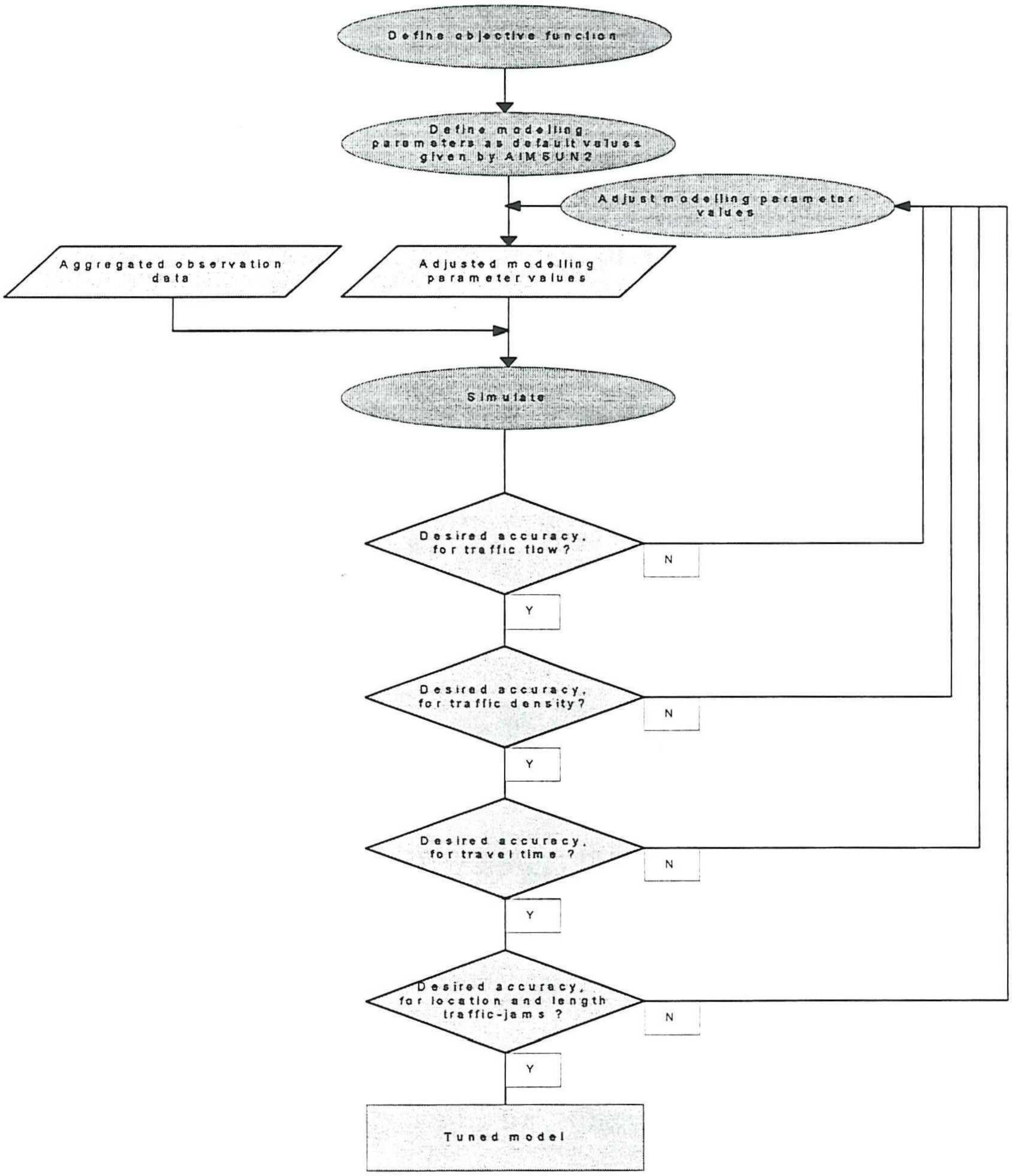


Figure 62. Gradual tuning process

The depicted order of tuning criterion variables may be subject of discussion. Based on preferences of clients this order may be changed. However, in this study it is proposed to perform a tuning process which makes use of an objective function so that all criterion variables are tuned at the same time.

APPENDIX 4 TUNING A SUB MODEL

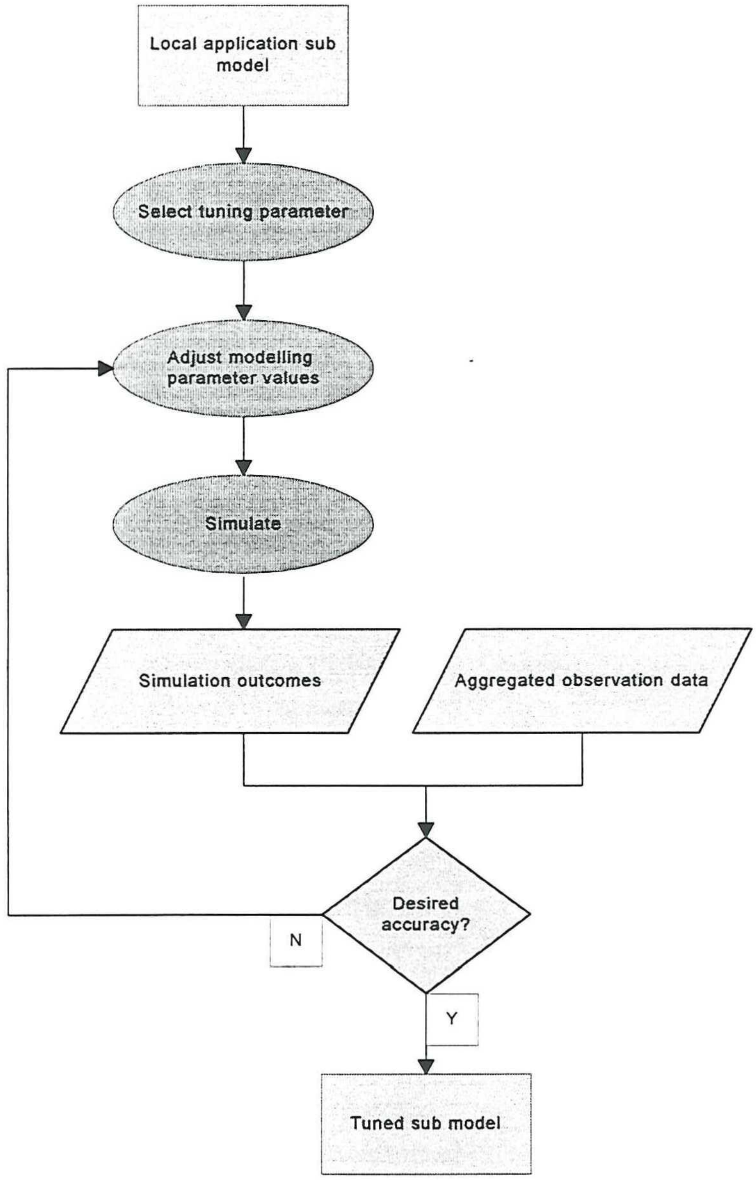


Figure 63. Process of tuning a sub model.

APPENDIX 5 CAR FOLLOWING SUB MODEL

The used car following models are complex functions. Therefore the units are given in this appendix.

For the acceleration-speed component:

$$\dot{x}_n^a(t+T) = \dot{x}_n(t) + 2.5 \cdot \alpha_n \cdot T\left[1 - \frac{\dot{x}_n(t)}{v_n}\right] \cdot \left[0.025 + \frac{\dot{x}_n(t)}{v_n}\right]^{\frac{1}{2}}$$

$$[m/s] = [m/s] + [m/s^2] \cdot [s] \cdot \left[\frac{m/s}{m/s}\right] \cdot \left[\frac{m/s}{m/s}\right]$$

For the deceleration-speed component:

$$\dot{x}_n^b(t+T) = \beta_n \cdot T + \left(\left[\beta_n \cdot T\right]^2 - \beta_n\left\{2\left[x_{n-1}(t) - l_{n-1} - x_n(t)\right] - \dot{x}_n(t) \cdot T - \frac{\dot{x}_n^2(t)}{\hat{\beta}}\right\}\right)^{\frac{1}{2}}$$

$$[m/s] = [m/s^2] \cdot [s] + \left(\left[m/s^2\right]^2 \cdot [s] - [m/s^2] \cdot \left\{[m - m - m] - [m/s] \cdot [s] - \left[\frac{\left[m/s\right]^2}{\left[m/s^2\right]}\right]\right\}\right)^{\frac{1}{2}}$$

$$\Rightarrow [m/s] = [m/s] + \left([m/s]^2 - [m/s^2] \cdot \left\{[m] - [m] - [m]\right\}\right)^{\frac{1}{2}}$$

APPENDIX 6 CHARACTERISTICS OF USER-GROUPS

The following table has been designed by DHV Environment and Infrastructure.

modality / *characteristic*	*car*	*truck*	*bus tram*	*ambu -lance*	*bicycle*	*bus*	*long car*	*long truck*	*motor bike*	*taxi*	*pedes -trian*
length (m)	4	8	10	7	2	9	6	-	2	4	-
width (m)	2	2.3	3	2	0.6	2.2	1.8	-	0.7	1.6	-
desired speed (km/h)	90	70	55	50	20	60	70	-	50	70	-
max acceleration (m/s2)	2.8	1.0	2.0	1.5	1.5	2.0	2.5	-	1.5	2.5	-
normal deceleration (m/s2)	4	3.5	3	2.5	2.5	3	3.5	-	2.5	3.5	-
max deceleration (m/s2)	8	7	6	5	5	6	7	-	5	7	-
speed acceptance (-)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	-	0.8	0.8	-
min dist between vehicles (m)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	-	1.2	1.2	-
giveway time (sec)	30	30	30	30	30	30	30	-	30	30	-
guidance acceptance (-)	-	-	-	-	-	-	-	-	-	-	-

Table 31. Characteristics of user-groups.

APPENDIX 7 BRUTE FORCE COMPUTATION OF THE CRITERION VARIABLE WEIGHTS

To compute the criterion variable weights implemented in the proposed objective function an is designed to perform automatically a brute force estimation.

Input parameters are

- the ranges (start and end values)of the examined variables
- the step size of these ranges.
- the ordered scenarios containing the estimated mean deviation values for accepted and rejected criterion variables.

Start- and end values:

	start	end
a1	0,00	10,00
a2	0,00	10,00
a3	0,00	10,00
a4	0,00	10,00

Stepsize:

ST	0,50

Mean deviation values of criterion variables:

a1*	a2*	a3*	a4*
7,00	7,00	7,00	7,00
7,00	7,00	7,00	20,00
7,00	7,00	20,00	7,00
7,00	7,00	20,00	20,00
7,00	20,00	7,00	7,00
7,00	20,00	7,00	20,00
7,00	20,00	20,00	7,00
7,00	20,00	20,00	20,00
20,00	7,00	7,00	7,00
20,00	7,00	7,00	20,00
20,00	7,00	20,00	7,00
20,00	7,00	20,00	20,00
20,00	20,00	7,00	7,00
20,00	20,00	7,00	20,00
20,00	20,00	20,00	7,00
20,00	20,00	20,00	20,00

Current computed values:

a1	a2	a3	a4
0,00	0,00	3,00	6,50

Stop by pressing the ESC-button !