Traffic Simulation and Data

Validation Methods and Applications

Edited by
WINNIE DAAMEN
CHRISTINE BUISSON
SERGE P. HOOGENDOORN

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Preface

This book has been written within work package 1 of the Multitude project. Multitude was a European network funded by COST, an intergovernmental framework for European Cooperation in Science and Technology. The main objective of Multitude was to develop, implement, and promote the use of methods and procedures for supporting the use of traffic simulation models, especially regarding model calibration and validation, to ensure their proper use and the validity of the results and the decisions made on them. In order to reach the objective, four work packages were defined:

1. State of the art of traffic simulation practice and research
2. Highway modelling
3. Network modelling
4. Synthesis, dissemination and training

This book is one of the three deliverables of work package 1. The other two deliverables are a report on the state of the practice and an overview of national guidelines on performing traffic simulations and calibration and validation of traffic models.

We would like to express our thanks to Mark Brackstone (IOMI, United Kingdom), Arie van Ekeren (Delft University of Technology, the Netherlands), Victor Knoop (Delft University of Technology, the Netherlands), Pete Sykes (SIAS, United Kingdom), Tom van Vuren (Mott MacDonald, United Kingdom). Without your contributions and those of the authors, it would have been impossible to deliver this state-of-the-art document.

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Chapter 1

Introduction

Winnie Daamen, Christine Buisson, and Serge Hoogendoorn

Traffic and transportation applications are rapidly expanding in scope due to their potential impacts on community and environmental decision making. These applications range from planning and assessment of road infrastructure to evaluation of advanced traffic management and information systems (e.g., dynamic hard-shoulder running) and testing technologies and systems to increase safety, capacity, and environmental efficiency of vehicles and roads (e.g., cooperative systems and intelligent speed adaptation). The complexity and scale of these problems dictate that accurate and dynamic traffic simulation models rather than analytical methods are used increasingly for these purposes.

Many commercial traffic simulation models are currently available, and even more models have been developed by research institutes and research groups all over the world. However, the simulation results should be interpreted with great care. First, the quality of the simulation models should be considered. In addition, the reproducibility of the simulation results is important. Reproducibility is the ability of simulation results to be accurately reproduced or replicated by a party working independently using the same or a different simulation model. Since more and more parameters must be set in traffic simulation models, situations can be modeled in different ways and models exhibit increasing complexity, the capabilities of a user may affect the quality of the simulation results.

Therefore, it is important to develop methods and procedures to help developers and users to apply traffic simulation models correctly, effectively, and with reproducible results. Motivations and solutions to this problem should be found in the traffic models themselves and in the ways they are applied, following an approach that is often halfway between deductive and inductive, "whereby one first develops (via physical reasoning and/or adequate idealizations and/or physical analogies) a basic mathematical modeling structure and then fits this specific structure (its parameters) to real data" (Papageorgiou, 1998). The fitting process is generally known as model calibration. Validation tests whether a model gives a sufficiently accurate representation of reality (Kleijnen, 1995). As for calibration, during the validation of a simulation tool, predictions from the simulation model are compared to observations from reality, but a data set different from the data set used for calibration should be utilized.

Unfortunately, calibration and validation against suitable observed data are not commonly practiced in the field of traffic simulation. Until now, no standardized methods existed and most efforts and resources focused on model (and software) development.

While researchers recently started working on these topics, the efforts are fragmented, based on different data sets, and motivated by various applications. The problem is further complicated by geographic and cultural differences in attitudes toward driving, road design, and traffic regulations among different countries, resulting in considerable differences in driving behaviors and traffic operations.

The aim of the MULTITUDE project (2013) covering methods and tools for supporting the use, calibration, and validation of traffic simulation models is therefore to develop, implement, and promote the use of methods and procedures to support the use of traffic simulation models, especially in relation to model calibration and validation, to ensure their proper use and the validity of the results and decisions based on them.

Before development and implementation of methods and procedures for calibration and validation can be started, an overview should indicate the information that is currently available on these and related topics. This overview can be used to identify the blank spots in the research and also to provide researchers and practitioners who are new in the field an opportunity to be introduced to existing (theoretical) knowledge about the calibration and validation processes in general and in performed calibrations and validations of specific models in particular. The aims of this state-of-the-art report are to:

- Analyze data collection techniques and estimation methodologies for innovative traffic data, e.g., vehicle trajectory data.
- Consider data reduction and enhancement techniques for standards, i.e., commonly available traffic information such as point detector data.
- Provide an overview of calibration and validation principles.
- Review literature on estimation, calibration, and validation of traffic flow models and corresponding methodologies, including estimating and refining travel demand matrices using traffic data.

First, we will look at the relationship of a real system and a simulated system, as shown in Figure 1.1. As indicated earlier, validation intends to determine how well a simulation model replicates a real system. In calibration, the outputs of the simulation and the real system are also compared, but the parameters of the simulated system are optimized until the difference between both outputs is minimal or at least meets specific minimum

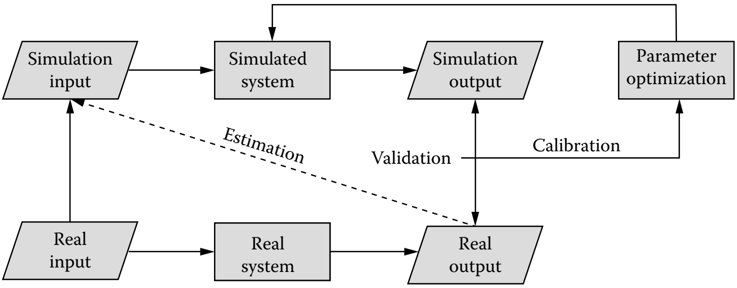

Figure 1.1 Relationship of simulated and real systems and locations of calibration and validation processes. (*Source:* Toledo, T. and Koutsopoulos, H. 2004. *Transportation Research Record*, 1876, 142–150. With permission.)

requirements. Ideally, the inputs of the real and simulated systems should be identical. Therefore, both the input variables and outputs of the real system should be observed. However, not all inputs (e.g., dynamic origin–destination matrices) can be observed directly and thus must be estimated; this introduces an additional source of inaccuracy.

A framework for calibration and validation of traffic simulation models is shown in Figure 1.2. Calibration and validation of traffic simulation models involve two steps (Toledo et al., 2003). Initially, the individual models of the simulator (e.g., driving behavior and route choices) are estimated using disaggregate data. Disaggregate data include detailed driver behavior issues such as vehicle trajectories. These individual models may be tested independently, for example, using a holdout sample. The disaggregate analysis is performed by statistical software and does not involve the use of a simulation model.

In the second step, the simulation model as a whole is calibrated and then validated using aggregate data (e.g., flows, speeds, occupancies, time headways, travel times, and queue lengths). Aggregate calibration and validation are important both in developing the model and applying it. The role of aggregate calibration is to ensure that the interactions of the individual models within the simulator are captured correctly and to refine previously estimated parameter values. In most practical applications, only aggregate traffic measurements are available. Model calibration in such cases must be performed by using aggregate data alone, so as to minimize the deviation between observed and simulated measurements.

Note, however, that the difference between aggregate and disaggregate data from the view of calibration is mostly a practical issue, not a fundamental one. Usually, disaggregate data are not available or are difficult to work with, but nothing forbids disaggregate testing of a simulation model.

This book starts with an overview of the various data collection techniques that can be applied to collect the different data types cited in Chapter 2.

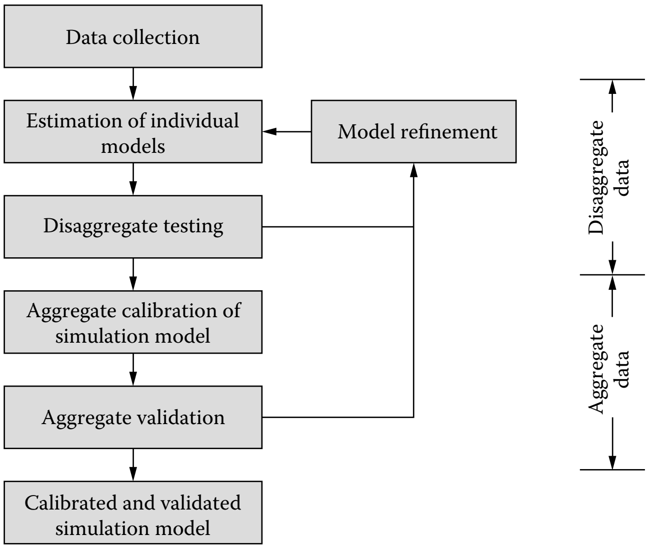

Figure 1.2 Calibration and validation framework of traffic simulation models. (*Source:* Toledo, T., Koutsopoulos, H.N., Davol, A. et al. 2003. *Transportation Research Record*, 1831, 65–75. With permission.)

Chapter 3 shows data processing and enhancement techniques for improving the quality of the collected data. The techniques are introduced according to the type of estimation, i.e., microscopic data enhancement, traffic state estimation, feature extraction and parameter identification techniques, and origin–destination (OD) matrix estimation. In Chapter 4, the principles of calibration and validation are described. In addition to generic procedures, the measures of performance, goodness of fit, and optimization algorithms are discussed.

Before focusing on the calibration and validation processes, Chapter 5 discusses the sensitivity analyses of the parameters in traffic models. These sensitivity analyses indicate the effects of various parameters on simulation results and thus on the importance of determining a correct value for a specific parameter. Chapter 6 gives details on network model calibration studies, while Chapter 7 focuses on the validation of simulation models. The final chapter discusses conclusions.

Chapter 2

Data collection techniques

Jean-Michel Auberlet, Ashish Bhaskar, Biagio Ciuffo, Haneen Farah, Raymond Hoogendoorn, and Axel Leonhardt

CONTENTS

The objective of this chapter is to provide an overview of traffic data collection that can and should be used for the calibration and validation of traffic simulation models. There are big differences in availability of data from different sources. Some types of data such as loop detector data are widely available and used. Some can be measured with additional effort, for example, travel time data from GPS probe vehicles. Some types such as trajectory data are available only in rare situations such as research projects.

This means that a simulation study carried out as part of a traffic engineering project, having a restricted budget, typically must rely on existing loop data or can at most utilize some GPS probe drives. The objective of calibration and validation in a traffic engineering project is mainly to check whether a model of a specific area replicates—at a desired level of detail—the macroscopic traffic conditions (flow, speed, travel time) for a certain traffic demand. Consequently, data for calibration and validation in traffic engineering projects typically need not to be microscopic.

Conversely, data generated with much more effort (e.g., trajectory data) are typically used by researchers to investigate driver behavior in general.

Analysis of driving behavior such as car following and lane changing requires highly detailed data to generate adequate insight into the traffic features to be modeled. These data are typically very expensive and/or laborious to acquire.

Sections 2.1 through 2.7 briefly describe the technical backgrounds of various data types and detection techniques and discuss typical availability and application areas. Section 2.8 draws conclusions about what data to use for specific purposes. An overview table included in Section 2.8.4 may be useful to get a quick view on the various sorts of data that may be used for the calibration of microscopic traffic simulation models.

In accordance with the primary focus of this book, this chapter provides only an overview of data collection. Extensive literature covering the techniques and their performance is available to the public through the World Wide Web.

An interesting point is the expected quality of the data. However, there is some ambiguity in existing studies because "performance of a data collection system" is a result of several factors (hardware and software used, sensor configuration, and environmental and traffic conditions). Therefore, this chapter will not answer questions like "What is the expected accuracy?" and in "What sensor is best to be used?". Specific studies describing detector features and boundary conditions are cited.

Errors in data exert impacts on the calibration of a simulation model and hence, on its results. This impact is twofold. First, a calibration step is needed before a simulation can be performed. In Chapter 4, we show that errors in measuring the variables that are compared with the simulation results impact the optimal parameters set for the calibration process. Second, any simulation tool uses measured (or enhanced or estimated; see Chapter 3) variables as inputs. Therefore, data measurement errors must be kept in mind when performing simulation studies. The reader is invited to consult the available documentation to gain knowledge of limits and error bounds of each type of detector.

2.1 MANUAL RECORDING

Manual recording is not exactly a data collection technology but may become necessary if automatic data collection is not feasible or fails to provide sufficient insight. Manual observations may be especially useful at intersections. The following data can typically be collected manually:

- Traffic volumes
- Turning volumes at junctions
- Delays at signals
- Queue lengths

2.2 LOCAL DETECTOR DATA

This section describes local detector data in detail. First, the data characteristics are described, and then an overview of the various detector types and relevant information is presented.

2.2.1 Data characteristics

Local detector data constitute traffic information collected at a single measurement point on a road. Data can be raw (single vehicle data) or aggregate (information recorded at time intervals, typically 1, 5, 15, or 60 minutes, and in rare cases intervals smaller than 1 minute) covering one or several lanes. Depending on the detector type, raw data collected may include:

- Vehicle presence (time points when it enters and/or leaves the detection zone)
- Vehicle speed
- Vehicle class (truck, bus, etc.)
- True or sensor-specific (e.g., magnetic) vehicle length

Aggregate data based on a specific time interval may show:

- Vehicle count, possibly per vehicle class
- Average vehicle speed, possibly per vehicle class (time mean speed)
- Variance in time mean speed
- Local occupancy (fraction of time when vehicle was present in the detection zone)
- Average time headways and variances of time headways

Local traffic data are the most widely available automatically collected traffic information available now and play a key role in most simulation studies. Such data can be used as input values and boundary conditions to derive demand and route split rates. On the other hand, simulation output can be compared to local traffic data to validate a simulation. Comparing time series of local speeds is a common way to calibrate a simulation model for analyzing congestion development. Automatic origin–destination (OD) matrix correction is another application of local detector data. More details about OD matrix estimation and correction are given in Section 6.2 of Chapter 6.

2.2.2 Detector types

Detectors can roughly be classified as intrusive and nonintrusive. Conventional intrusive traffic collection devices primarily consist of inductive loop detectors. These detectors must be cut into a road surface. This makes them usable only as permanent detectors, as they cannot be used for short data collection periods. Because they are embedded in pavements, intrusive detectors are costly to install and maintain because they require road closures. Furthermore, they deteriorate under the impact of traffic. Loop detectors are well advanced because the technology has been applied for several decades. Another advantage is that they are less prone to vandalism and theft than nonintrusive devices.

Nonintrusive detectors are not in direct contact with vehicles and are usually side firing or mounted overhead. They experience less wear and tear than intrusive pavement-based detectors. Because they are not embedded in road surfaces, they are easier to install and to replace, making them suitable choices for temporary installations. Among the many technologies available are radar, ultrasonic, and video cameras. Some are advanced technologies used in the field for years. Others are still under development or involved in field trials.

Minge et al. (2010) noted that volume and speed measurement performance with state-of-the-art nonintrusive detection technology (radar, video, laser, infrared, and magnetometer) is satisfying, but classification remains a weak point, especially if standardized classification schemes such as FHWA 13 of the Federal Highway Administration in the United States (FHWA, 2001) are applied.

2.2.2.1 Inductive loop detectors

Inductive loops consist of wire loops inside a road surface. The loops are fed electrically with a frequency between 40 and 100 kHz. Any metal objects in the inside area of the loops change the electric inductivity of the loops and can be measured by an electronic device. Vehicle presence is the basic information provided by a loop detector. If two loops are combined in a small distance (typically a few meters), the speed of a vehicle can be measured with good accuracy.

Inductive loops are by far the most common detectors for road traffic. They are used as single loops around signals to provide information for vehicle-actuated control and on freeways as double loops to provide flow and speed information.

From single loops, speed can be estimated with some advanced techniques, but this kind of speed information should be used with care only. Several recent research efforts are aimed at improving the accuracy of speed estimation and vehicle classification with single loops (Coifman and Kim, 2008). Double loops can determine speeds more easily than single loops and are more easily used for vehicle classification (Heidemann et al., 2008).

Specific studies investigating the accuracy of installed dual loop detectors report unreliable results like underestimation of volumes and false classification while stating that the cause of the inaccuracy could be the hardware, software, or underlying algorithm (Nihan et al., 2002). Traffic volume underestimation was also reported by Briedis and Samuels (2010), who cited pavement condition as the factor producing the highest impact on data quality.

Generally, data from a working and calibrated loop detector are rather accurate and reliable. However, since inductive loops are the typical detectors used for long-term installations, many are broken or biased after long-time usage.

2.2.2.2 Magnetic field detectors

These detectors use the earth's magnetic field to detect vehicles. The metallic mass of a vehicle influences the vertical and horizontal components of the earth's magnetic field locally and this influence can be measured by the sensors. For a description of the method, see Mimbela and Klein (2000). To measure speeds, two sensors within a close distance are needed. In modern detection equipment, both sensors are combined in a single unit. The time series of changes in the magnetic field produced by moving vehicles can also serve as the basis for vehicle classification and patterns for vehicle reidentification.

Since the earth's magnetic field can be distorted by influences such as electric cables, it is necessary to consider these error sources when installing the sensors. A sensor is typically mounted in the middle of a lane on a road surface such that installation and maintenance work can be done without road closure. The systematic disadvantage of magnetic field sensors is that they cannot detect stopped vehicles. Since magnetometers are relatively recent measurement technologies, there is no consensus on their measurement quality.

2.2.2.3 Pressure detectors

A pressure detector can measure the presence of a vehicle at a cross section by measuring the impact of the wheels of the vehicle on the detector. The simplest pressure detectors are thin tubes attached to a road surface. When a vehicle crosses a tube, the air pressure is increased and the pressure can be measured by an electronic device. More advanced pressure detectors use fiber-optic tubes or piezoelectric cables.

Pressure detectors remain the most commonly used sensors for short-term traffic counting and vehicle classification by axle count and spacing. Some types gather data to calculate vehicle gaps, intersection stop delays, stop sign delays, saturation flow rates, spot speeds, and other factors. High truck and bus volumes tend to deteriorate axle count accuracy. Pressure detectors are also prone to breakage from vandalism and wear produced by truck tires (Heidemann et al., 2008).

2.2.2.4 Weigh-in-motion systems and piezoelectric sensors

Weigh-in-motion (WIM) systems are used to capture and record truck axle weights and gross vehicle weights as they pass over sensors. The advantage of state-of the-art WIM systems over older weighting systems is that the vehicles do not have to stop to be weighted. WIM systems use piezoelectric