Calibration Method for Microscopic Simulation Model of Urban Expressway Using Internet Traffic Operation Data

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Abstract. To develop a calibration method for microscopic simulation model of urban expressway using internet traffic operation data, a practical calibration process is proposed in this study. In this process, a sensitivity analysis was conducted to detect those parameters that impose the most influence on simulation model. Then the Latin Hypercube Sampling Method is used to generate workable amount of parameter sets for simulation run. The parameter set that produces the least discrepancy between the simulation model and the actual condition would be the calibrated parameter values. To demonstrate the feasibility of the proposed method, an example of the Inner Loop Expressway network in Wuxi City is modelled and calibrated using VISSIM. After calibration, the simulation model can accurately represent real-world condition.

1. Introduction

It is always challenging to analyze and evaluate the performance of a traffic system before the implementation of any new mitigation solutions. The current evaluation method, such as Highway Capacity Manual (HCM), the most widely used transportation engineering guidebook in USA, can’t offer a detailed and sufficient analysis before implementation. Alternatively simulation becomes a valuable aid in assessing the performance of a traffic system [1]. Currently, a number of microscopic simulation software have been produced to model real-world traffic conditions. However, certain procedures need to be done before a microscopic simulation model can generate unbiased results.

An important step after any simulation model is created is to make sure that it can recreate the same traffic operation conditions as the real-world. Therefore, sufficient data are needed to prepare a simulation model. Some data (e.g. geometric design, traffic volume, travel speed) are easy to obtain, but some (e.g. driver behavior, desire speed) are rather difficult to observe from field study. A common practice is to calibrate those microscopic parameters using macroscopic performance measures which are much easier to observe. This process of adjusting and fine-tuning simulation model parameters by using real-world data to reflect actual traffic conditions is called model calibration [2].

Rigorous calibration is quite complex and time-consuming considering that there are many parameters in a microscopic simulation model. Some engineers can adapt a certain number of parameters based on their experience to make the simulation model runs as close to the actual situation as possible, but this kind of calibration is rather opportunistic and it depends much on the users’...
personal experience. Park and Schneeberger [3] proposed a general calibration procedure based on a linear regression model. However, they fail to consider the combined effect of those simulation parameters.

Some researchers introduced an optimization method called Genetic Algorithm (GA) to calibrate simulation models [4]. GA is an optimization method that mimics the mechanism of natural selection and evolution. It can take the combined effect between parameters into consideration, and also reduce the risk of converging to local minima instead of global minima. GA has been successfully applied to many aspects of transportation engineering: traffic flow simulation modeling [5], traffic signal timing [6] and even infrastructure maintenance planning [7]. However, GA method is too complicated and often requires a lot of time for it to converge. Therefore, GA is normally used by researchers, while not common in engineering practice.

In this paper, a systematic and practical procedure for calibrating microscopic simulation models is proposed. Taking a widely used microscopic simulation software VISSIM as an example, a model of urban expressway in Wuxi City is calibrated based on the proposed procedure using internet traffic operation data. The calibrated model can satisfactorily replicate actual traffic system.

2. Calibration Method

2.1. Calibration Objective

The objective of calibration is through adjusting and fine-tuning simulation parameters to minimize the discrepancy between simulation models and actual situations. Calibrated parameters in simulation models include driving behavior parameters, traffic control parameters, traffic flow characteristics parameters and so on. The accuracy rate can be defined in following equation:

\[ \alpha = \left| \frac{M_S - M_A}{M_A} \right| \]  

(1)

Where, \( \alpha \in [0, 1] \);
\( M_S \) stands for performance measure of simulation model;
\( M_A \) stands for performance measure of actual situation.

Therefore, when accuracy rate \( \alpha \) gets closer to 1 after calibration, the simulation model would better represent real-world conditions.

2.2. Calibration Procedure

The calibration process has been studied by many researchers before. In 1998, Hellinga has proposed a calibration procedure including 7 steps [8]. However, this procedure only provide an overall guidance for simulation calibration. In this paper, a more detailed and practical simulation calibration procedure is proposed, as shown in Figure 1.
Determine Calibration Objective

Select Performance Measures

Data Collection

Determine Calibrating Parameters

Experiment Design and Determine Initial Parameter Set

Simulation Model Run

Results Evaluation

Adjusting Parameters

Results Acceptable?

Y

Calibration Finished

Figure 1. Calibration Procedure

Detailed procedure is explained as follow:

**Step 1:** Determine calibration objective. Normally, the objective of calibration is to minimize the discrepancy between simulation models and actual situations.

**Step 2:** Select performance measures. Performance measures are used to evaluate the performance of the simulation models and real-world traffic system. Therefore, performance measures should be easy to collect in real world. Normally, speed, traffic volume, queue length etc. are chosen as performance measures.

**Step 3:** Data collection. After selecting performance measures, on-field data collection can be arranged. Collected data should include peak-hour data and non-peak hour data.

**Step 4:** Determine calibrating parameters. A large number of parameters in simulation models are calibratable. It would be too time and effect consuming if we calibrate every parameter in simulation model. Based on their influence on the results of simulation models, sensitive parameters should be selected to be calibrated.

**Step 5:** Experiment design and determine initial parameter set. Considering all the sensitive parameters and their acceptable ranges, it is impossible to evaluate all those parameter combinations. Thus a statistical experimental design is desirable to reduce parameter sets needed to be evaluated. Default values of those parameters are normally used as the initial parameter set.

**Step 6:** Simulation model run. Multiple simulation runs should be conducted to reduce random effects.

**Step 7:** Results evaluation. Simulation results should be evaluated to check whether the performance measures are as close as possible comparing to real-world condition. If the discrepancy is within acceptable range, the calibration process should be finished, otherwise, more parameter sets should be evaluated.

3. Example Verification

3.1. Simulation Model Preparation

In this study, the microscopic simulation software – VISSIM is used. VISSIM is a microscopic, time-step and behavior based multi-purpose traffic simulation package, which was developed at the
University of Karlsruhe, Germany during 1970s [9]. It is capable of simulating traffic operations on urban streets and freeways, with a special emphasis on public transportation and multimodal transportation.

To illustrate how to calibrate an urban expressway network model, the Inner Loop Expressway in Wuxi City, China is modeled in VISSIM. This expressway network is about 30 kilometers long, and has over 80 entering and exiting ramps. The digital map and simulation model for this expressway network are shown in Figure 2 and Figure 3.

![Digital map for the Inner Loop Expressway in Wuxi City](image1)

![Simulation model for the Inner Loop Expressway in Wuxi City](image2)

3.2. Simulation Model Calibration

**Step 1: Determine calibration objective.**
In this study, the objective of calibration is to minimize the discrepancy between real-world network condition and simulation model.

**Step 2: Select performance measures.**
In this study, travel time is selected as performance measure, since it is easy to collect in real world and it is an output of VISSIM evaluation.

**Step 3: Data collection.**
Internet traffic operation data are used in this study for calibration. Data are provided by Gaode Map, which is the leading digital map in China. Gaode Map can provide travel speed and travel time in major roadways in Wuxi City. Therefore, average travel time around the Inner Loop Network in Wuxi City is used as performance measure.

**Step 4: Determine calibrating parameters.**
To improve the efficiency of calibration process, only sensitive parameters should be calibrated. Therefore, paired t-test is used to selecting those sensitive parameters. The paired t-test is designed to handle correlation among matched pairs of measurements or data points. In this all adjustable parameters in VISSIM are chosen, and by changing the parameter value one by one, their influence on the simulation results can be known. For each adjustable parameter, 5 times multi-run are conducted.

In statistics, those parameters with small p-values are significantly different, which means they are sensitive parameters. The type I error is chosen as 0.10 in this study, and eight parameters in the simulation model are found sensitive, as shown in Table 1.
Table 1. Sensitive Parameters for Calibration

| Sensitive Parameters | CC 0 | CC 2 | CC 9 | Maximum Deceleration | Deceleration Resolution | Emergency Stop | Lane Change | Mean of Desired Speed |
|----------------------|------|------|------|----------------------|-------------------------|-------------------|-------------|----------------------|
| Average Output Change| 4.71%| 5.56%| 2.59%| 2.80%                | 2.01%                   | 1.49%            | 2.67%       | 7.72%                |
| P Value              | 0.01 | 0.00 | 0.03 | 0.08                 | 0.09                    | 0.06             | 0.08        | 0.01                 |

Step 5: Experiment design and determine initial parameter set.
Considering eight sensitive parameters and their acceptable ranges, it is impossible to evaluate all those parameter combinations. Thus a statistical experimental design is desirable to reduce parameters sets needed to evaluate. In this study, Latin Hypercube Sampling Method is applied. Latin Hypercube Sampling Method is a space-filling design method that can spread the points as evenly as possible around the operating space. This design should be used when there is little or no information about the underlying effects of factors on responses. In this study, 20 parameter sets are generated for calibration. For each parameter set, 5 times multi-run are conducted. The default values in the simulation model are used as the initial parameter set.

Step 6: Simulation model run.
For those 20 parameter sets, 3 times multi-run are conducted for each set. Therefore, 120 multi-run in total are conducted in this study.

Step 7: Results evaluation.
The results of each simulation run are recorded and compared with the real-world data. In this study, the performance measure is the average travel time around the Inner Loop Expressway. The parameter set that generates the least discrepancy between simulation model and real world condition would be the calibrated parameter set. The calibrated parameter values are shown as Table 2.

Table 2. Calibrated Parameter Values

| Sensitive Parameters | CC 0 | CC 2 | CC 9 | Maximum Deceleration | Deceleration Resolution | Emergency Stop | Lane Change | Mean of Desired Speed |
|----------------------|------|------|------|----------------------|-------------------------|-------------------|-------------|----------------------|
| Default              | 1.5  | 4    | 1.5  | -3                   | 200                     | 5                 | 200         | 60                   |
| Calibrated           | 3.9  | 4.9  | 4.3  | -2.5                 | 287                     | 5.3               | 132         | 71                   |

3.3. Simulation Model Verification
To verify the accuracy of the calibrated model, the Inner Loop Expressway is divided into 5 segments and the average travel of the calibrated model, un-calibrated model and actual condition for each segments are compared. The results shows that the accuracy of the calibrated model is clearly better than before, as illustrated in Figure 4.

Figure 4. Calibration Procedure
4. Conclusion
The objective of this study is to develop a calibration method for microscopic simulation model of urban expressway using internet traffic operation data. To this end, a practical calibration process is proposed. To demonstrate the feasibility of the proposed method, an example of the Inner Loop Expressway network in Wuxi City is modeled and calibrated using VISSIM. After calibration, the simulation model can accurately represent real-world condition.

However, more multi-runs in sensitivity analysis and simulation run process are needed to reduce the impact of random nature of simulation model. An automated program may be better solve this time-consuming process and thus is recommended for future study.

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