Sensitivity Analysis and Selection of Check Index of Signal Intersection Simulation Model Based on VISSIM

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Abstract

Selecting check index quantitatively is the core of the calibration of micro traffic simulation parameters at signal intersection. Five indexes in the node (intersection) module of VISSIM were selected as the check index set. Twelve simulation parameters in the core module were selected as the simulation parameters set. Optimal process of parameter calibration was proposed and model of the intersection of Huangcun west street and Xinghua street in Beijing was built in VISSIM to verify it. The sensitivity analysis between each check index and simulation parameter in their own set was conducted respectively. Sensitive parameter sets of different check indices were obtained and compared. The results show that different indexes have different size of set, and average vehicle delay's is maximum, so it's necessary to select index quantitatively. The results can provide references for scientific selection of the check indexes and improve the study efficiency of parameter calibration.

Keywords: *micro traffic simulation; signal intersection; check index; sensitivity analysis; VISSIM*

1. Introduction

Microscopic traffic simulation is one of the most important tools for traffic design, planning and analysis. Before the simulation experiment is carried out, the simulation parameters need to be calibrated to improve the accuracy of the model. It can also guarantee that the program evaluation using simulation model have more referential value. The basic calibration process of the micro-simulation model includes four steps: selecting the check index, measuring road data, designing the simulation experiment and obtaining the parameter scheme in which the index error between the road measurement and simulation is minimum by adjusting the parameters. Selecting the check index quantitatively is the core of the parameter calibration. Recent studies lacks scientific and quantized selection methods of check indexes which cannot guarantee the validity of selecting the check indexes and greatly decreased solution efficiency. Therefore, it is necessary to reasonably select and calibrate the check indexes to improve the calibration accuracy of the micro-simulation model.

The rest of the paper is organized as follows. The second part shows the process of micro-traffic parameter calibration and the selection of indexes on related research, analyzes the shortcomings of these process and proposes the improvement ideas of them. The third part establishes a sensitivity analysis model based on variance and proposed the basis of sensitivity judgment. The fourth part collects the actual data from intersection of Huangcun West Street and Xinhua Street. VISSIM was used to establish the road network model. The final data summary of the whole experiment is displayed in this part. The last part summarizes the full text.

2. Literature Review

The parameter calibration was generally proceeded according to the flow in Figure 1. As the intelligent algorithm matured and was introduced into the traffic simulation field, the workflow changed from Figure 1 to Figure 2. The core idea remained unchanged, but the number of iterations and the calculation accuracy of the model was improved.

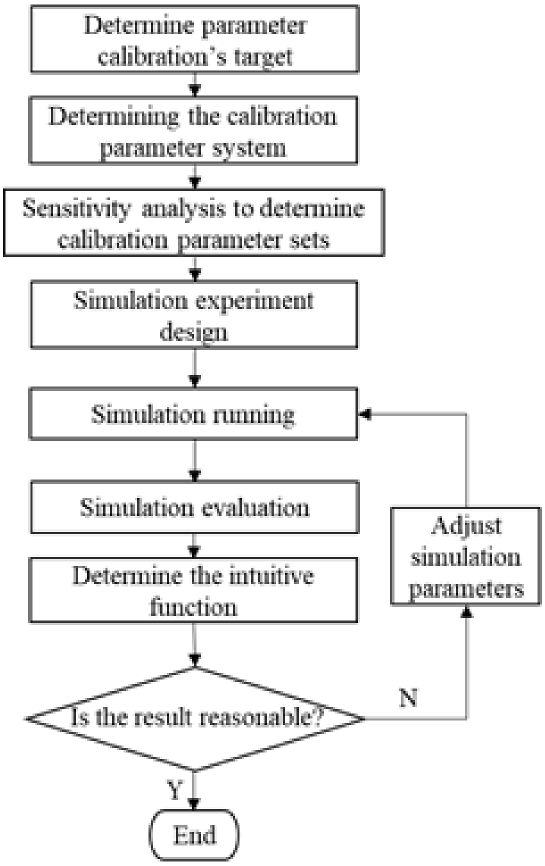

Figure 1. Calibration Process of Experimental Design Parameters

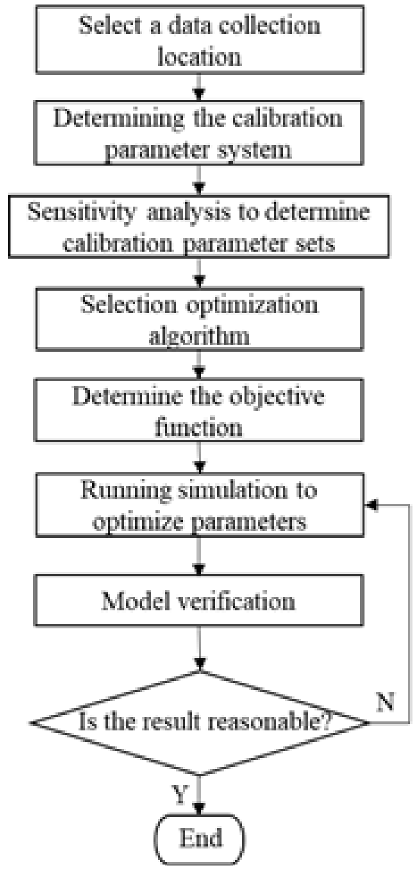

Figure 2 Calibration Process of Intelligent Algorithm Parameters

It can be seen that the step "sensitivity analysis to determine the calibration parameter sets" in both two workflows require a pre-step which is determining the check index. But the researchers often determined the check index based on empirical judgments or qualitative analyses. Li Zhenlong used the average delay deviation of the entrance lane as the check index (Li Zhenlong et al., 2015). Nurlan Muhan chose queue length and travel time as the check indexes for VISSIM simulation model parameter calibration (Nurlan Muhan, 2014). Li Yan analyzed all check indexes qualitatively and selected travel time and maximum queue length as the check indexes (Li Yan, 2014). Xu Yuexin selected the intersection delay, parking delay, as the check index (Xu Yuexin et al., 2015).

In summary, recent studies lacks scientific and quantized selection methods of check indexes which cannot guarantee the validity of selecting the check indexes. Whether the determined check indexes are optimal or not remains to be discussed. Therefore, the sensitivity analysis method based on the variance analysis was proposed to select the optimal check index.

3. Establishment of Sensitivity Analysis Method Based on The Variance Analysis

3.1 Optimization Parameter Calibration Process Establishment

In order to select the check index quantitatively, it is necessary to optimize the parameter calibration process. The optimized micro-simulation model parameter calibration flow is shown as Figure 3.

For improving the accuracy and work efficiency, it is necessary to analyze the parameter sensitivity based on the variance analysis. According to the analysis result, the optimal check index and the calibration parameters set are determined. And then the actual data is collected, the optimization algorithm is selected to establish the objective function. The parameters are optimized by running simulation and finally the model is verified.

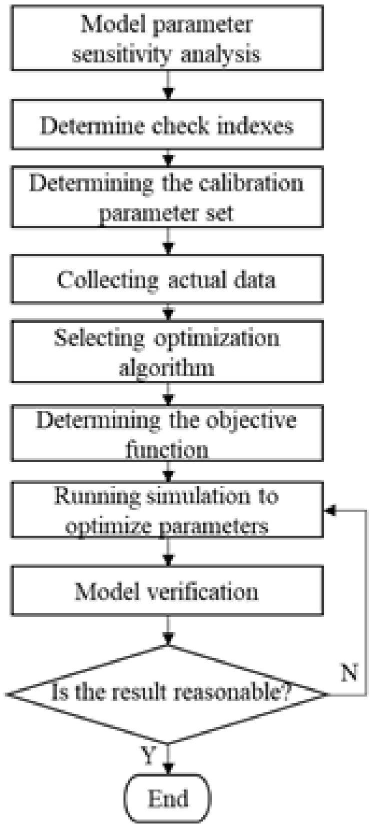

Figure 3 Optimized Process of Micro-Simulation Model Parameter Calibration

3.2 Sensitivity Analysis Method Based on Variance Analysis

The sensitivity analysis method of the model based on the variance analysis is the premise of determining the optimal check index. It is a key step of the parameter calibration optimal process of the micro-simulation model.

The sensitivity analysis method is based on the optimized variance analysis (Zhou Chenjing et al., 2016). The analysis idea is to compare the check indexes' variation changes caused by the simulation parameters with that by the stochastic parameters. The sensitivity relationship between simulation parameters and check indexes are judged. And it is shown as equations (1) - (4):

$$M_{AB} = \begin{vmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{vmatrix} \tag{1}$$

$$I = \frac{\sum_i^X \mathrm{STDEVA}(x_{i1}, x_{i2}, \cdots, x_{in})}{} \tag{2}$$

$$I' = \frac{\sum_j^Y \mathrm{STDEVA}(x_{1j}, x_{2j}, \cdots, x_{mj})}{} \tag{3}$$

$$P = \frac{I}{I'} \tag{4}$$

Where: M_{AB} is the result matrix of the simulation parameter A and the check index B, and i=1，2，3，……，X is the parameter value level of simulation parameters, and j=1，2，3，……，Y is the parameter value level of random seed, and I is the arithmetic mean value of the standard deviation of the change of the check index value caused by the change of the simulation parameter value, and I' the arithmetic mean value of the standard deviation of the change of the check index value caused by the change of the random seed value, and STDEVA（x_i）is a function that finds the standard deviation of x_i, and P is check indicator to judge whether the simulation parameter is sensitive to the check index or not. When P is less than 1, it is considered that this simulation parameter is not sensitive to this check index, not so sensitive when P is between 1 and 1.5, the simulation parameter is not so sensitive to the check index. When P is greater than 1, the simulation parameter is sensitive to the check index.

4. VISSIM Simulation Model for Signalized Intersections

4.1 Selection of Check Index Set

A number of check indexes are provided by VISSIM as shown in Table 1. Those check indexes are divided into three sections according to the evaluation object such as road, node (intersection) and road network. Considering that node (intersection) is usually used to describe the signalized intersection, five indexes in the node (intersection) module such as traffic flow, average delay, travel time, number of stops and queue length are selected as the experimental check index set.

Table 1 Check Indexes

Evaluation object	Check Index
Road	Density
	Average speed
	Traffic flow
	Lost time
Node (intersection)	Traffic flow
	Average delay
	Travel time
	Number of stops
	Queue length (maximum, average)
Road network	Number of vehicles leaving the road network
	Number of vehicles entering the road network
	Total path distance
	Total travel time
	Average speed
	Parking delay
	Number of stops
	Total number of parks

4.2 Parameter Set Selection and Parameter Value Level Setting

Twelve simulation parameters such as maximum forward distance and maximum deceleration in the vehicle following behavior module and lane change behavior module in VISSIM are selected as the parameter set. In order to conduct the sensitivity analysis, it is necessary to set the parameter value level of both the random seed and each simulation parameter.

The greater the number of levels, the closer the sensitivity of the simulation and that of the reality is. Considering the factors such as workload, time and researcher's ability, five levels are set for each parameter including random seed. The parameter value level, which is marked with *, is the default value of the corresponding simulation parameter. All parameter value levels change with equal difference or ratio based on their default values and are kept within their order of magnitude as far as possible. In summary, the simulation parameter levels are shown in Table 2.

Table 2 Parameter Value Levels of Parameter in Set

Module	Parameter	Default	Unit	Level 1	Level 2	Level 3	Level 4	Level 5
Vehicle following behavior	Maximum forward distance	0~250	m	0~150	0~200	*0~250	0~300	0~350
	Number of vehicles observed	2	veh	1	*2	3	4	5
	Average parking distance	2	m	0.5	1	*2	4	8
	Additional part of the safety distance	2		0.25	0.5	1	*2	4
	Multiple of the safety distance	3		0.75	1.5	*3	6	12

Module	Parameter	Default		Unit	Level 1	Level 2	Level 3	Level 4	Level 5
Lane change behavior	Maximum deceleration	-4	-3 (rear car)	m/s^2	*-4; -3	-4; -2	-4; -1	-3; -1	-3; -2
	Acceptable deceleration	-1	-1 (rear car)	m/s^2	*-1;-1	-1.5;	-2; -2	-2.5;	-3; -3
	-1m/s^2	100	100 (rear car)		50; 50	*100; 100	150; 150	200; 200	250; 250
	Waiting time before disappearing	60		s	15	30	*60	120	240
	Minimum headway distance	0.5		m	0.1	0.3	*0.5	0.7	0.9
	Safety distance conversion factor	0.6			0.2	0.4	*0.6	0.8	1
	Maximum deceleration of combined braking	-3		m/s^2	-1	-2	*-3	-4	-5
Other simulation parameters	Random seed	42			10	20	40	80	160

5. Case study

5.1 Data Acquisition

The intersection of Huangcun West Street and Xinghua Street is formed by a trunk road and a secondary road. The entrance lanes are complete and typical. Seen from the signal timing scheme, this intersection uses a typical four-phase (four phases are north-south straight, north-south turn, east-west straight and east-west turn). Its transportation is convenient for on-site investigations repeatedly, so it is selected to provide actual data for model establishment in VISSIM. The lanes composition and road size data of each entrance and exit are shown in Table 3.

Table 3 Lanes Composition and Road Size

	Lanes composition			lane width /m	length of extension section/m	length of gradient section/m
	Left turn	Straight	Right turn			
East entrance	1	2	1	3.5	51.8	20.3
East exit				3.5	52.5	16.1
South entrance	1	3	1	3.5	68.6	7.7
South exit				3.5	0	0
West entrance	1	2	1	3.5	42.7	21
West exit				3.5	43.4	23.1
North entrance	2	3	1	3.5	84	9.1
North exit				3.5	0	0

5.2 VISSIM Modeling and Experiment Conducting

Using the actual data above, the road network is established in VISSIM. According to the calculation method of the traffic intersection capacity specified in Code for Planning of Intersections on Urban Roads, the traffic capacity of each entrance is calculated——Southern entrance: 3,731veh, North entrance: 3,992veh, West entrance: 2,417veh, and East entrance: 2,417veh. The driving path decision is set according to the actual running rules, and finally the detectors on the road are set up to complete the VISSIM model.

The goal of experiment is to prove that the sizes of the sensitive simulation parameter sets of different check indexes are different. The simulation parameters corresponding to each level value of random seed are put into VISSIM for simulation. Stop the experiment when all the results data are finally got.

5.3 Data Calculation

Four detectors such as data collector, travel time detector, queue length counter and delay are provided for users in VISSIM. The output detection data are collected and the result matrixes of the simulation parameters and the check indexes are obtained. The result matrix of -1m/s^2 and the flow is as an example shown in the Table 4. According to formula (3), the P value of the matrixes can be obtained, and the sensitivity can be concluded. P is equal to 0.18 and less than 1 which indicate -1 m/s^2 is considered as insensitive to the flow.

Table 4 Result Matrix of -1m/s^2 and the Flow

Experimental results		-1m/s^2					Standard deviation of parameter influence
		50;50	100;100	150;150	200;200	250;250	
Random seed	10	1006	1014	1019	1018	1015	5.13
	20	1069	1069	1065	1066	1066	1.87
	40	1060	1059	1069	1066	1067	4.44
	80	1078	1084	1078	1077	1064	7.36
	160	1065	1057	1063	1059	1057	3.63
Standard deviation of random seed		28.5	26.1	22.98	22.84	22.04	

5.4 Data Discussion

According to all seventy-two result matrixes, the P value are collected and shown in Table 5. There is a one-to-one correlation between twelve simulation parameters from two core modules in VISSIM and six check indexes in the node (intersection) module, so there are seventy-two groups altogether.

Table 5 Summary of P Values

	Check index simulation parameter	flow	Average vehicle delay	Travel time	Number of stops	Maximum queue length	Average queue length
D	-1	0.18	0.29	0.31	0.48	0.5	0.6
X2	Multiple of the safety distance	0.57	0.42	0.59	*3.63	**1.43	0.22
X1	Additional part of the safety distance	0.31	*3.54	*3.67	**1.18	0.39	**1.41
N	Number of vehicles observed	0.15	0.64	0.74	0.48	0.74	0.26
S	Safety distance conversion factor	*1.59	**1.37	0.7	0.71	0.7	0.52
C2	Acceptable deceleration	0.17	0.28	0.29	0.35	0.3	0.48
R	Maximum deceleration of combined braking	0.1	0.15	0.15	0.24	0.54	0.13
A	Average parking distance	0.77	*4.35	**1.45	**1.32	*1.83	*1.57
T	Waiting time before disappears	0.03	0.1	0.03	0.17	0	0.12
C1	Maximum deceleration	0.1	0.02	0.02	0.16	0.37	0.08
O	Maximum forward distance	0.31	*1.73	0.74	0.74	0.7	0.41
G	Minimum head space	0.24	0.33	0.34	0.88	0.98	0.57

* P is greater than 1.5, ** P is between 1 and 1.5.

It can be concluded from Table 5:

(1) There are three sensitive simulation parameters to average vehicle delay: the additional part of the safety distance (P equals to 3.54), the average parking distance (P equals to 4.35), and the maximum forward distance (P equals to 1.73). And the P value of the safety distance conversion factor is 1.37, which is not so sensitive to the average vehicle delay;

(2) The statistical results show that average vehicle delay has three sensitive simulation parameters, which is the maximum among all check indexes. Secondly, the number of stops has one parameter that is sensitive to it, and two that are not so sensitive to it.

(3) The maximum queue length, the average queue length, and the travel time have two sensitive simulation parameters respectively, one is sensitive to it, and the other is not so sensitive.

(4) Safety distance conversion factor is the only.one sensitive parameters of the flow.

(5) The sensitivity between different check indexes and simulation parameters is different, and the number of sensitive parameters is different. Therefore, before the parameter calibration, it is feasible to use the sensitivity analysis method to

find the optimal check index, and to simplify the experimental steps and improve the simulation efficiency.

Conclusions

In order to improve the accuracy and work efficiency, this paper proposed an optimized parameter calibration process, analyzed the parameter sensitivity of the model based on the variance analysis, and verified the correctness of the process with an actual example.

Five indexes in the node (intersection) module were selected as check indexes set. The basic parameters were used to construct a simulation model of signal intersection based on VISSIM. Selecting twelve simulation parameters in tow core module in VISSIM, the sensitivity analysis of simulation parameters of different check indexes was carried out, and the sensitive parameter sets of different check indexes are compared. Taking the intersection of Huangcun West Street and Xinghua Street in Daxing District of Beijing as an example, the sensitivity calculation method was designed, and the optimized process was verified.

The results show that:

(1) The average vehicle delay has maximum sensitive simulation parameters, followed by the maximum queue length, the average queue length and the travel time.

(2) A sensitivity analysis model based on variance analysis was established, and the basis for judging different sensitivities was given. The study found that the sensitivity of different check indexes to simulation parameters is different, and the number of sensitive parameters is different.

This paper proposed that the optimization process of the sensitivity analysis method to select optimal check index before the parameter calibration can streamline the experimental steps and improve the simulation efficiency.

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