# AUTOMATIC TUNING OF PARAMETERS IN A NETWORK TRAFFIC SIMULATION MODEL

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# SUMMARY

This study proposes a method that automatically tunes parameters in a network traffic simulation and examines its validity through applications to a real network. Quite a few simulation models have been developed to evaluate in advance not only conventional traffic policies and regulations but also recent ITS applications such as impacts of AHS, ETC, TDM, etc. Network simulation models are thus needed for the further ITS R&D and deployment. Since the simulation models deal with dynamic traffic phenomena, they can directly consider traffic queues which are vehicles accumulated in the network. However, for their applications to real networks, experts have to spend quite a lot of efforts to calibrate the parameters inside the models. Therefore, for more frequent use of simulation models, the parameter calibration should be not only systematic but automatic.

# INTRODUCTION

These days, technique of Intelligent Transportation System(ITS) has been developed rapidly such as VICS (Vehicle Information and Communication System), ETC (Electric Toll Collection) and so on. Many traffic simulation models, which are effective tools for quantitative evaluation of ITS impacts, have been also actively developed. The process of applying traffic network simulation models is generally as in *Fig.-1*.

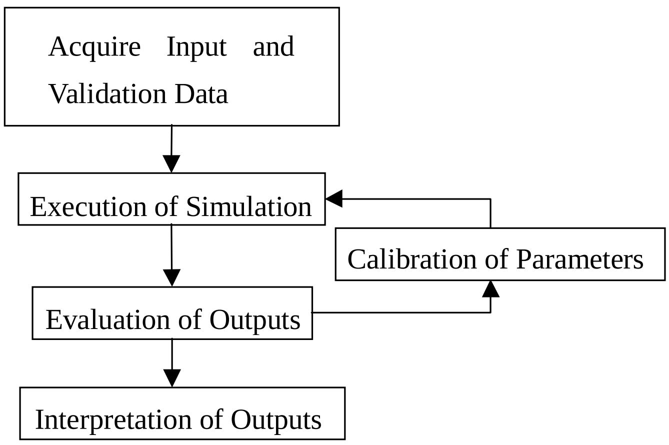


*Fig.- 1 Process of Application with Traffic Simulation*

First, input data such as link-node connection data, traffic demand data, etc are needed. Then, the traffic simulation is executed and the outputs are obtained. In order to obtain reasonable result, we have to however calibrate model parameters (link capacities, individual drivers' characteristics, etc.). For this parameter tuning, experts likely spend quite a lot of efforts to calibrate the parameters. Therefore, for more frequent use of simulation models, the parameter calibration should be not only systematic but automatic. This research proposes an algorithm of automatic calibration of parameters in a network traffic simulation model, and examines the validity of the algorithm.

# OUTLINE

## EMPLOYED SIMULATION MODEL

This study uses SOUND(a Simulation On Urban Network with Dynamic route choice)[1] which incorporates vehicles' route choice and can be applied a network with thousands of links and nodes and parameters to be calibrated are link capacities. The model has been well verified and validated using the Tokyo Metropolitan network data.

## EVALUATION OF REPRODUCIBILITY

The parameters are tuned so that simulated average travel time of the bottleneck section agrees with the observed one as shown in *Fig.-2*.

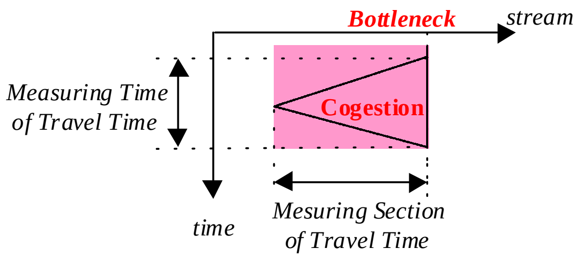


*Fig.- 2* ***Measuring Time and Section of Travel Time***

The simulated average travel time $TT_s^{sim}$ is defined as follows:

$$TT_s^{sim} = \int_0^T \sum_i \sum_j \delta_{ij}^{\ s} T_{ij}^{sim}(t) dt / T \quad , \qquad (1.)$$

where

$TT_s^{sim}$ = simulated average travel time to pass through section $s$ , (2.)

$T_{ij}^{sim}(t)$ = simulated travel time on link ($i$,$j$) for a vehicle entering the link at time $t$ , (3.)

$T$ = end of the simulation time period, (4.)

$$\delta_{ij}^{\ s} = \begin{cases} 1, & \text{if link } (i, j) \text{ is in section } s \\ 0, & \text{otherwise} \end{cases} \quad . \qquad (5.)$$

As well, the observed average travel time $TT_s^{obs}$ is defined as follows:

$$TT_s^{obs} = \int_0^T \sum_i \sum_j \delta_{ij}^{\ s} T_{ij}^{obs}(t) dt / T \ , \qquad (6.)$$

where

$T_{ij}^{obs}(t)$ = observed travel time on link ($i$,$j$) for a vehicle entering the link at time $t$ . (7.)

# PARAMETERS TO BE CALIBRATED

The parameters to be calibrated in this research are traffic capacities of bottleneck links and merging capacity ratios. In the simulation model, traffic capacity of each link must be specified, but not all of them have large effects on simulated traffic condition. Simulated traffic condition is much influenced by traffic capacities of only bottleneck links. Thus, even by tuning traffic capacities of only bottleneck links, the simulation is expected to well reproduce current dynamic traffic situation. In this research, bottleneck links are assumed known.

The $r_{ij}$ does not mean the ratio of merging flows at merging node *j* but stands for the share of downstream link capacity allocated to upstream link (*i*,*j*) when both upstream merging links have queues. When all merging links have queues (all merging links have sufficient demand), we may assume a static value of $r_{ij}$ is determined from the geometric design of the merging section. Parameters to be treated is described as follows:

$$\vec{\alpha} = \text{parameter vector} = (\alpha_1 \cdots, \alpha_j, \ \cdots\cdots) = (\cdots, \mu_{ij}, \cdots, \ \cdots, r_{ij}, \cdots) \tag{8.}$$

where

$$\mu_{ij} = \text{traffic capacity of bottleneck link } (i,j) \tag{9.}$$

$$r_{ij} = \text{merging capacity ratio of link } (i,j) \text{ at merging node } j \tag{10.}$$

# OBJECTIVE FUNCTION

In dynamic traffic simulation, bottlenecks influence each other. Change in departure flow rate from a bottleneck affects the arrival flow rate of bottlenecks downstream. Consequently, the change in traffic condition downstream influences drivers' route choices to their destinations. In this way, a little change in a bottleneck parameter may affect traffic on the whole network. Hence, bottleneck parameters cannot be calibrated one by one, but all the parameters should be simultaneously calibrated.

We now formulate the optimization problem with the objective function of sum of squared errors of average travel times:

$$Z(\vec{\alpha}) = \sum_s \left\{ TT_s^{\,sim}(\vec{\alpha}) - TT_s^{\,obs} \right\}^2 \tag{11.}$$

Since bottleneck capacities and merging capacity ratios can be approximately prespecified based upon the geometric designs at bottlenecks. We therefore decide to search the parameter values within 5% ranges of the prespecified values as shown below:

$$\begin{aligned} &0.95\mu_{ij}^{\ 0} \le \mu_{ij} \le 1.05\mu_{ij}^{\ 0}, \\ &0.95 r_{ij}^{\ 0} \le r_{ij} \le 1.05 r_{ij}^{\ 0}, \end{aligned} \tag{12.}$$

where

$\mu_{ij}^{\ 0}$ = initial prespecified value of traffic capacity of bottleneck link (*i*,*j*),

$r_{ij}^{\ 0}$ = initial prespecified value of merging capacity ratio of link (*i*,*j*) at merging node *j*.

## OPTIMIZATION METHOD

Generally, the optimum solution is found by searching it along the descendent gradient direction. From an output of the simulation run, we should estimated the gradient direction:

$$\frac{\partial Z(\vec{\alpha})}{\partial \alpha_j} = 2\sum_s \left\{ TT_s^{sim}(\vec{\alpha}) - TT_s^{obs} \right\} \frac{\partial TT_s^{sim}(\vec{\alpha})}{\partial \alpha_j} \tag{13.}$$

And, the next simulation run should be executed with new parameters updated from the estimated gradient vector. Repeating this process, we could expect to obtain the optimal solution. The difficulty here is how to find the descendent gradient direction, since the objective function cannot be analytically differentiated by unknown parameters.

# ESTIMATION OF NEW PARAMETERS

Let us discuss a numerical method which estimate the descendent gradient direction. After running the simulation, we get simulated arrival and departure flow rates on every link for any time.

$\lambda_{ij}^{sim}(t)$ = simulated arrival flow rate at link (*i*,*j*) at time *t* (14.)

$\mu_{ij}^{sim}(t)$ = simulated departure flow rate at link (*i*,*j*) at time *t*, (15.)

Using these arrival and departure rates, we propose a method to estimate the gradient direction of parameters.

## ASSUMPTIONS

For the simplicity, following two assumptions are made for the update:

### Assumption-1.

"Change of drivers' route choice due to a small change of one parameter is negligible."

### Assumption-2.

"Change of shockwave propagation due to a small change of one parameter is negligible."

Under the assumption-1, the diverging ratio at every diverging section does not change even if a certain parameter alters. So, the arrival flow rate at a diverging section after change of a parameter is described as follows:

$$\lambda_{ij}(t) = \frac{\lambda_{ij}^{sim}(t)}{\sum_{j'} \lambda_{ij'}^{sim}(t)} \sum_{j'} \lambda_{ij'}(t), \tag{16.}$$

where $\lambda_{ij}(t)$ = arrival flow rate at link (*i*,*j*) at time *t*. (17.)

Under assumption-2, the capacity of a congested link, to which a shockwave is propagating from a downstream bottleneck, does not change even after change of the parameter. This is expressed as the capacity depending on time *t*:

$$\mu_{ij}(t)=\begin{cases}\mu_{ij}, & \text{if link}\,(i,j)\,\text{is a bottleneck} \\ (1-\delta_{ij}^{sim}(t))\mu_{ij}+\delta_{ij}^{sim}(t)\mu_{ij}^{sim}(t), & \text{otherwise}\end{cases}, \tag{18.}$$

where $\mu_{ki}(t)$ = departure flow rate at link ($k$,$i$) at time $t$, (19.)

$$\delta_{ij}^{sim}(t) = \begin{cases} 1, & \text{if } T_{ij}(t) > T_{ij}^{F} \text{ or } \lambda_{ij}(t) > \mu_{ij}, \\ 0, & \text{otherwise,}\end{cases} \tag{20.}$$

$T_{ij}^{F}$ = free flow travel time in link ($i$,$j$).

# CONSTRAINTS TO BE SATISFIED

## Flow Conservation at Nodes

Flow conservation at a node must be always satisfied. It can be described as follows:

$$-\sum_h \mu_{hi}(t)+\sum_j \lambda_{ij}(t)-R_i(t)+S_i(t)=0, \quad \forall i, \tag{21.}$$

where

$R_o(t)$ = vehicle generation rate at node $o$ at time $t$ (22.)

$S_d(t)$ = vehicle attraction rate at node $d$ at time $t$ (23.)

## First-In-First-Out Discipline

The FIFO (First In First Out) discipline is satisfied in every link as follows:

$$A_{ij}(t)=D_{ij}(t+T_{ij}(t)) \tag{24.}$$

where

$A_{ij}(t)$ = cumulative arrivals at link ($i$,$j$) by time $t$ = $\int_0^t \lambda_{ij}(x)dx$, (25.)

$D_{ij}(t)$ = cumulative departures at link ($i$,$j$) by time $t$ = $\int_0^t \mu_{ij}(x)dx$, (26.)

$T_{ij}(t)$ = travel time of a vehicle entering link ($i$,$j$) at time $t$. (27.)

# EVALUATION OF EFFECT BY CHANGE OF A PARAMETER

Given simulated arrivals $\lambda_{ij}^{sim}(t)$ and departures $\mu_{ij}^{sim}(t)$, we evaluate how to revise them when one bottleneck parameter changes based upon assumptions and constraints above.

Suppose the capacity of bottleneck link ($i$,$j$) is changed such that $\mu_{ij} := \mu_{ij} + \Delta\mu_{ij}$. For the bottleneck link, the arrival rate does not change because of assumption-2: $\lambda_{ij}(t) := \lambda_{ij}^{sim}(t)$ for all $t$. Then, departure rate from the bottleneck link can be revised from FIFO as follows:

$$\mu_{ij}(t+T_{ij}(t)) = \begin{cases} \mu_{ij}, & \text{if } \delta_{ij}^{sim}(t)=1, \\ \end{cases}$$

(28.) $\lambda_{ij}(t)$, otherwise,

On the other hand, at a merging section shown below, suppose the merging capacity ratio of link ($i$,$j$) is changed such that $r_{ij} := r_{ij} + \Delta r_{ij}$. The departure rate is determined as follows:

$$\mu_{ij}(t+T_{ij}(t)) = \begin{cases} r_{ij}\mu_{jk}, & \text{if } \delta_{ij}^{sim}(t) = \delta_{lj}^{sim}(t) = 1, \\ \lambda_{ij}(t), & \text{otherwise,} \end{cases} \tag{29.}$$

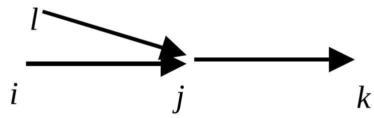


*Fig.- 3* A Merging Section

For other links downstream of the bottleneck, the arrival and departure rates are sequentially obtained from the bottleneck to the downstream. The arrival rate of a link ($i$,$j$) is obtained from the flow conservation and (16):

$$\lambda_{ij}(t) = \frac{\lambda_{ij}^{sim}(t)}{\sum_{j'} \lambda_{ij'}^{sim}(t)} \sum_{j'} \lambda_{ij'}(t) \qquad \text{where} \quad \sum_{j'} \lambda_{ij'}(t) = \sum_{h} \mu_{hi}(t) + R_i(t) - S_i(t)$$

And, the departure flow rate is evaluated in the same way as for the bottleneck link; that is, from (28) or (29).

In this way, arrival and departure rates of all links are evaluated and by integrating the rates over time, the cumulative arrival and departures are also evaluated as shown in figure below. Then, link travel times are determined and consequently the gradient directions can be evaluated from (13): $\dfrac{\partial Z(\vec{\alpha})}{\partial \alpha_j} = 2\sum_{s} \{TT_s^{sim}(\vec{\alpha}) - TT_s^{obs}\} \dfrac{\partial TT_s^{sim}(\vec{\alpha})}{\partial \alpha_j}$.

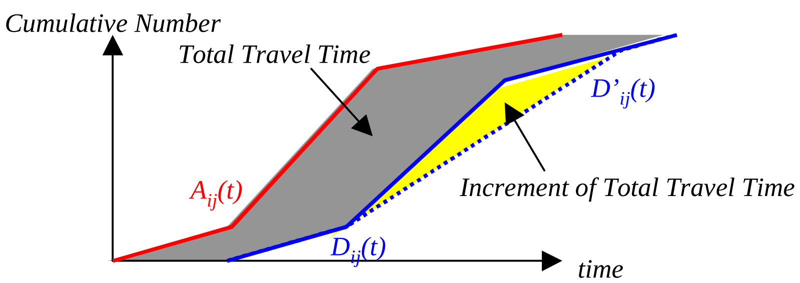


*Fig.- 4 Evaluation of Increment of Total Travel Time*

# APPLICATION OF THIS ALGORITHM

This algorithm is applied to a dynamic traffic network simulation: SOUND. The network applied with SOUND is Metropolitan Express way in Tokyo consisting of 1114 links. Traffic volume from origin to destination observed on 21st September 1995 is used. And observed average travel time of each section is measured from traffic detector data. The number of bottleneck links is 16, and the number of merging capacity ratios is 13.

*Fig.- 5 Network of Metropolitan Express way*

*Fig.-6* shows the decreasing trend of the objective function as the iteration number. We see that the objective function converges after about 20 iterations.

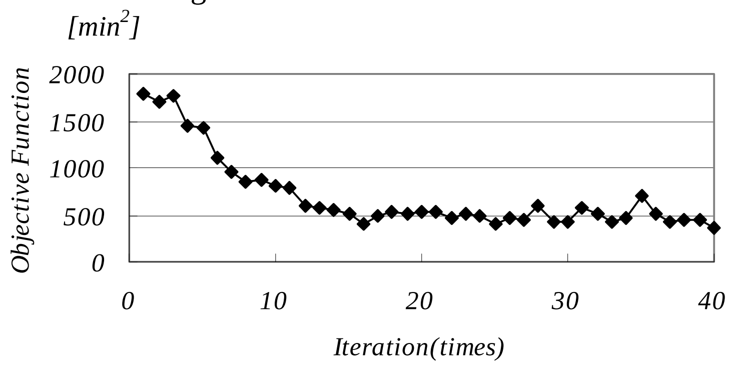


*Fig.- 6 Relationship between Objective Function and Iterations*

*Fig.-7* shows the relationship between average travel times before and after calibration. It shows average travel times is reasonably improved by the calibration. The coefficient of correlation is improved from 0.58 to 0.90.

# CONCLUSION

This research proposes a algorithm which calibrates parameters included in dynamic network traffic simulation, and applied to the algorithm to a real network to examine its validity. First, the optimization problem, which consists of the sum of squared errors of average travel times to pass through the congested sections is defined. To solve the optimization problem, we need to evaluate descendent gradient direction of the objective function with respect to unknown parameters. Since the problem includes the traffic simulation, the gradient vector cannot be analytically estimated. Therefore, we propose an algorithm to evaluate the gradient vector based upon the cumulative arrivals and departures of every link under the point queue concept.

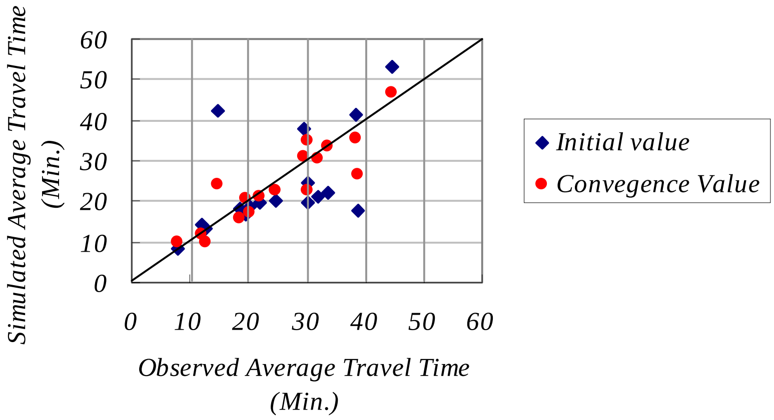


*Fig.- 7 Observed and Simulated Average Travel Times*

An application to the Metropolitan expressway shows that the unknown parameters are almost converged after about 20 iterations, and that parameters calibrated reproduce realistic simulated traffic condition.

For further work, we should improve the algorithm so that not only bottleneck travel times but also other MOEs such as queue lengths, travel speeds, and traffic flow rates are simultaneously fitted with the observed ones. Also, an automatic tuning of other parameters would be also future research needs.

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