AUTOMATIC CALIBRATION OF PARAMETERS IN A TRAFFIC SIMULATION MODEL

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SUMMARY

This study proposes an algorithm which automatically calibrates parameters in a traffic simulation model. We focus on link capacity values to be tuned so as to reproduce both link travel times and link traffic volumes. In this study, the capacity values are iteratively updated based on traffic engineering expert knowledge. Testing the algorithm on a hypothetical network with 104 links, the validity of the proposed algorithm is reasonably confirmed.

INTRODUCTION

This study proposes an algorithm which automatically calibrates parameters in a traffic simulation model so as to reproduce both link travel time and link volume. For simulation parameters, this study tunes link capacity values, which strongly affect traffic condition.

Regarding the automatic parameter tuning, Furukawa and Kuwahara (1) proposed a method in which the objective function was defined as the difference between observed link travel time and simulated one and the point queue model was employed to update the parameters so as to minimize the objective function. Because of the point queue model, the computation time was greatly saved so that the algorithm could be applied to a large scale network such as the Metropolitan expressway network. However, it has sometimes a deficiency in successfully calibrating the parameters, since the point queue model may not produce traffic condition exactly the same as one from the traffic simulation model.

Therefore, in this study, we update the parameters based on traffic engineering expert knowledge instead of the point queue model. Although the new approach would require longer computation time, it is expected to calibrate parameters with which the traffic simulation model reproduces observed traffic condition.

UPDATING SIMULATION PARAMETERS

Link Capacity

Although the link capacity might be defined differently depending upon traffic simulation models dealt with, the capacity here is defined by turning directions as follows:

μ_i^k = capacity of link *i* for turning direction *k*, *k* = 1 (through), 2 (left turn), 3 (right turn)

Algorithm

Link capacity values are calibrated so as to reproduce not only link travel time but also link traffic volume.

(1) Tuning Parameters to Reproduce Link Travel Time

Even if travel time on link *i* is not the same as in the observed travel time, we cannot immediately judge whether capacity of the link should be modified because the link traffic condition may not be controlled by the link capacity. When simulated link travel time is longer than the observed one, the following three reasons could be possible:

Simulated link travel time is longer than the observed one, because of one of the following reasons:
(a) the capacity value of link *i* is too small,
(b) a queue backs up from downstream due to a too small link capacity value of a downstream link, or
(c) higher flow rate arrives at link *i* due to a too large link capacity of an upstream link.

Among these three cases, modification of link *i* capacity is only appropriate for case (a), but downstream and upstream link capacities should be modified for cases (b) and (c) respectively. For case (a), link *i* is a bottleneck link at the head of the queue. As seen here, we should modify capacity values of only bottleneck links, since other link capacities do not directly influence on traffic condition. Focusing on bottleneck links, the updating strategy is proposed for the following four combinations.

	bottleneck link in simulation	non-bottleneck link in simulation
bottleneck link in observation	(1) link capacity should be modified so that the upstream congested condition is agreed with the observed condition	(2) decrease the link capacity so that the link becomes a bottleneck link
non-bottleneck link in observation	(3) increase the link capacity so that the link does not become a bottleneck link	(4) no modification is required

For (1) in the table above, link i is a bottleneck link both in observation and in simulation. The capacity value is therefore modified so that the degree of congestion upstream agrees with the observation. For (2), since bottleneck link i in observation is not bottleneck in the simulation, the capacity value should be reduced so as to be the bottleneck. For (3), link i is a bottleneck link only in the simulation but not in the observation. Two alternative ways exist for the modification: (A) increase link i capacity or (B) reduce capacity of upstream link so that lesser flow rate arrives at link i. In this research, we employ "(A) increase link i capacity" for the following reason. If link i capacity is increased, the degree of congestion heading from link i would gets smaller and case (3) would be expected to shift to case (2). Thus, even if the right modification could have been (B) instead of (A), we could implement (B) after traffic condition shifts from (3) to (2).

(2) Tuning Parameters to Reproduce Link Traffic Volume

Observed and simulated traffic volumes are denoted as:

$f^{sim}{}_{ik}$ = simulated traffic volume on link i for turning direction k,
$f^{obs}{}_{ik}$ = observed traffic volume on link i for turning direction k.

The link capacity value is modified as shown in the table below:

(I) $\mu_i^k \geq f^{sim}{}_{ik} > f^{obs}{}_{ik}$	decrease link capacity
(II) $\mu_i^k > f^{obs}{}_{ik} > f^{sim}{}_{ik}$	increase link capacity
(III) $f^{obs}{}_{ik} > \mu_i^k > f^{sim}{}_{ik}$	decrease link capacity

Since simulated flow $f^{sim}{}_{ik}$ cannot exceed capacity μ_i^k, always $\mu_i^k \geq f^{sim}{}_{ik}$, only three combinations above are possible. For (III), since capacity μ_i^k is smaller than observed volume $f^{obs}{}_{ik}$, capacity μ_i^k should be obviously increased to let simulated volume be closer to observed volume. On the other hand, for (I) and (II), both observed and simulated volumes are smaller than capacity μ_i^k. For (II), if capacity μ_i^k is increased, simulated volume would get larger and consequently condition (II) would shift to (I). While for (I), reduction of capacity μ_i^k would shift condition to (II). As a whole, the above modification strategy shifts condition from (I) to (II) or from (II) to (I). By this modification, $f^{sim}{}_{ik}$ is expected to converge to $f^{obs}{}_{ik}$.

(3) Range of Capacity Value and Step Size of Updating

From the highway geometry, we approximately decide the range of each capacity value. The automatic calibration therefore should be made within the range based on the geometry.

The step size of updating capacity value at the n-th iteration $\Delta\mu_i^k$ is designed as follows so that the step size gradually gets smaller.

$$\Delta\mu_i^k = \Delta\mu^* / n, \tag{1}$$

$\Delta\mu_i^k$ = step size of updating capacity value at the n-th iteration,
$\Delta\mu^*$ = initial step size.

Definition of Bottleneck Links

As explained above, our algorithm basically focus on bottleneck links, which are defined based upon the criteria below. First of all, from link travel time, free flow links and congested links are classified:

$T^{obs}_{ik}(t) \leq \quad TF_i^k$ for all k and t, Link i is in free flow condition (observed) (2)

$T^{sim}_{ik}(t) \leq \quad TF_i^k$ for all k and t, Link i is in free flow condition (simulated) (3)

where,

$T^{obs}_{ik}(t)$ = observed travel time of link i for turning direction k during time interval t,
$T^{sim}_{ik}(t)$ = simulated travel time of link i for turning direction k during time interval t,
TF_i^k = free flow travel time of link i for turning direction k.

Then, the bottleneck links are found based on the following condition:

"Link i is a bottleneck link if link i is congested and all downstream links are in free flow condition."

Using the above definition of a bottleneck link, every link can be classified into either in bottleneck links or into free flow links based on the observed and simulated link travel times.

Evaluation of Link Volume

Since link volume may change over time, f^{sim}_{ik}, f^{obs}_{ik} defined above are evaluated as the maximum traffic flow during time interval t:

$$f^{sim}_{ik} = Max_t\,[f^{sim}_{ik}(t)] \quad (4)$$
$$f^{obs}_{ik} = Max_t\,[f^{obs}_{ik}(t)] \quad (5)$$

where, $f^{obs}_{ik}(t)$ = observed volume of link i for turning direction k during time interval t,
$f^{sim}_{ik}(t)$ = simulated volume of link i for turning direction k during time interval t.

Furthermore, the critical direction is defined as the turning direction with closest turning volume to the capacity value: $Min_k\,[(\mu_i^k - f^{sim}_{ik})/n_k\,]$, where n_k is the number of lanes for direction k.

AN APPLICATION TO A HYPOTHETICAL NETWORK

Network and OD Demand

The hypothetical grid network consists of 104 links, all of which have the same length of 500 m. Every link has lanes but an exclusive right turn lane and an exclusive left turn lane are added at the last 100 meter section; that is, total 5 lanes at the end of each link.

One origin-destination demand from node 1 to node 11 is loaded and the OD demand varies over time during the study period of 5 hours as below but stays at the same demand rate for each one hour period: 1000:2400:1000:1000:1000 [vehicles/hour]. This means that the unit time interval is 1 hour, t = 1, 2, 3, 4, and 5.

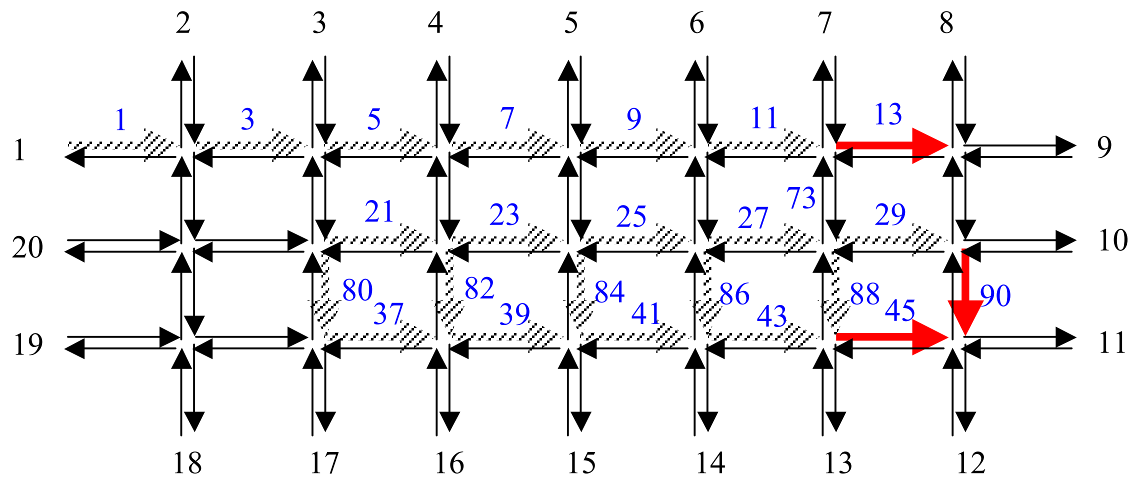

Fig.1 A Hypothetical Network
(shaded arrow = congested links, thick arrows = bottleneck links)

Route Choice Model

The following Logit model is employed as the route choice model:

Generalized Cost [sec] = Instantaneous Route Travel Time [sec] + (1/60)·Toll [yen]
+ 30·the number of left turns + 30·the number of right turns (6)

Logit Parameter $\theta = 0.005$ [1/sec]

In SOUND simulation model (2,3), routes of vehicles are update by implementing the Dial assignment in every 5 minutes based upon the current traffic condition.

Examination of the Algorithm

The observed traffic condition is created using the following capacity values for all links:

Left turn capacity μ_i^2 = 600 [vehicles/hour/lane]

Through capacity μ_i^1 = 800 [vehicles/hour/lane]
Right turn capacity μ_i^3 = 400 [vehicles/hour/lane]

Fig.1 shows the created observed traffic condition using the parameter values and the OD demand. Three bottlenecks exist as shown in thick arrows and shaded arrows shows congested links as defined in section 2.3.

The range of capacity values to be tuned is set as [75%, 125%] of the above true capacity values and the automatic parameter calibration starts from initial capacity values of 75% for bottleneck links and 125% for other links.

In this examination, however, capacity calibration is not carried out by turning direction but the total capacity is tuned by fixing the proportion of the capacity values for each direction. Namely, when the left turn capacity value is modified by a certain amount, the through and right turn capacity values are also modified in proportion of their original capacity ratio. For each of the links, we first identify the critical turning direction as defined in section 2.4 and update capacity value of the critical direction and capacity values for the other direction is proportionally modified.

Figures 2, 3, and 4 show the results. Circle plots show calibrated capacity values so as to reproduce only link travel times, and diamond plots show calibrated values so as to reproduce both link travel times and link volumes. The performance indices as in the vertical axis are defined as follows:

Absolute Difference in Link Travel Time [sec] $$\sum_{i,k}\left|\sum_{t}\{T^{sim}{}_{ik}(t)-T^{obs}{}_{ik}(t)\}\right|/N \qquad (7)$$

Absolute Difference in Link Volume [veh/hr] = $$\sum_{i,k}\left|\sum_{t}\{f^{sim}{}_{ik}(t)-f^{obs}{}_{ik}(t)\}\right|/N \qquad (8)$$

Total Travel Time Difference [veh·sec/hr] = $$\sum_{i,k,t}\left|T^{sim}{}_{ik}(t)\cdot f^{sim}{}_{ik}(t)-T^{obs}{}_{ik}(t)\cdot f^{sim}{}_{ik}(t)\right|/N \qquad (9)$$

The above summations over link i, turning direction k and time interval t are carried out only when Abs$\{T^{sim}{}_{ik}(t)$ - $T^{obs}{}_{ik}(t)\}$ > 0 or Abs$\{f^{sim}{}_{ik}(t)$ - $f^{obs}{}_{ik}(t)\}$ > 0 , and the value of N is the total number of these cases.

For both results, Absolute Difference in Link Travel Time [sec], Absolute Difference in Link Volume [veh/hour] and Total Travel Time Difference [veh·sec/hour] are rapidly improved during the first couple of iterations, but the performance indices stay almost the same level thereafter. The calibration result based on both link travel time and link volume looks a little better.

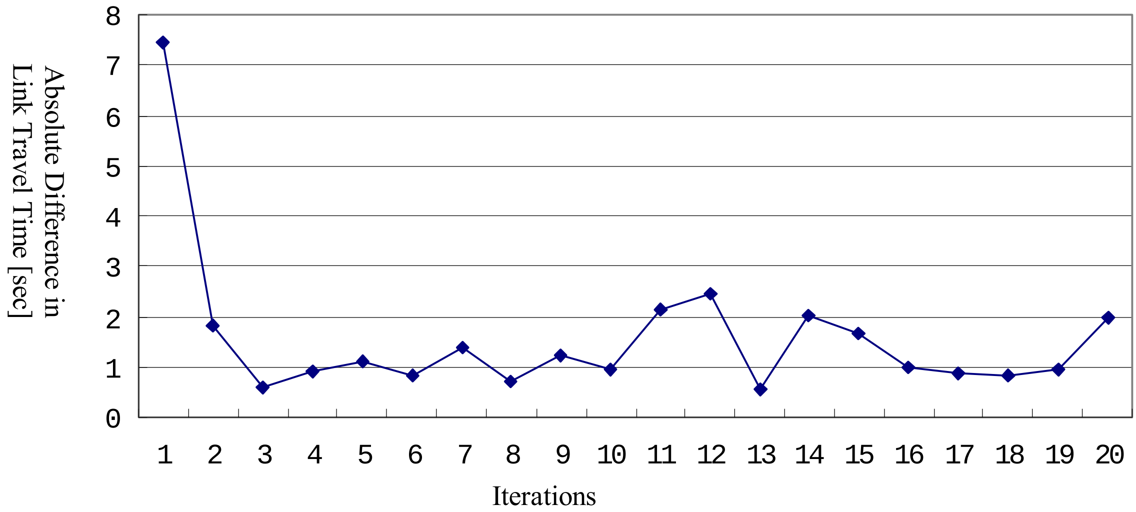

Fig.2 Absolute Difference in Link Travel Time [sec] change over Iteration

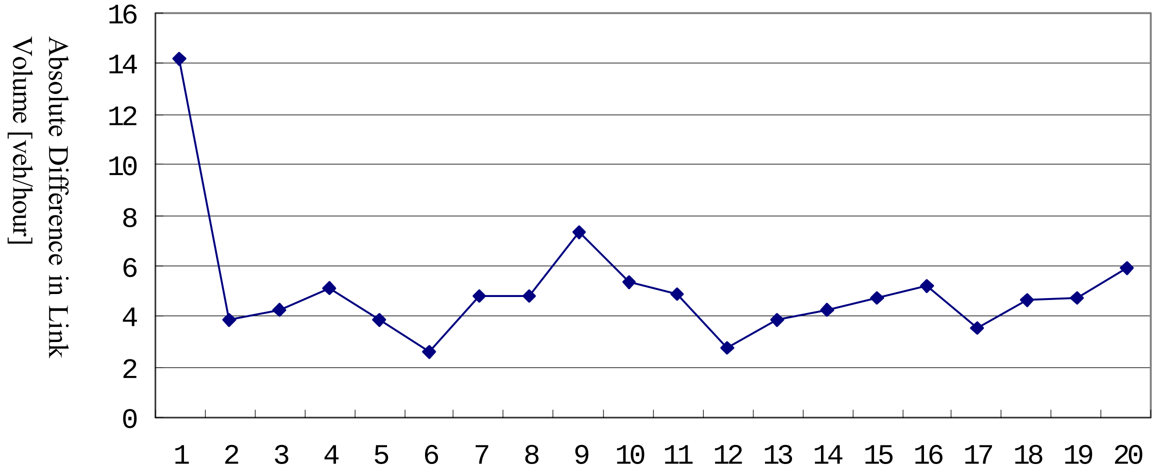

Fig.3 Absolute Difference in Link Volume [veh/hour] change over Iteration

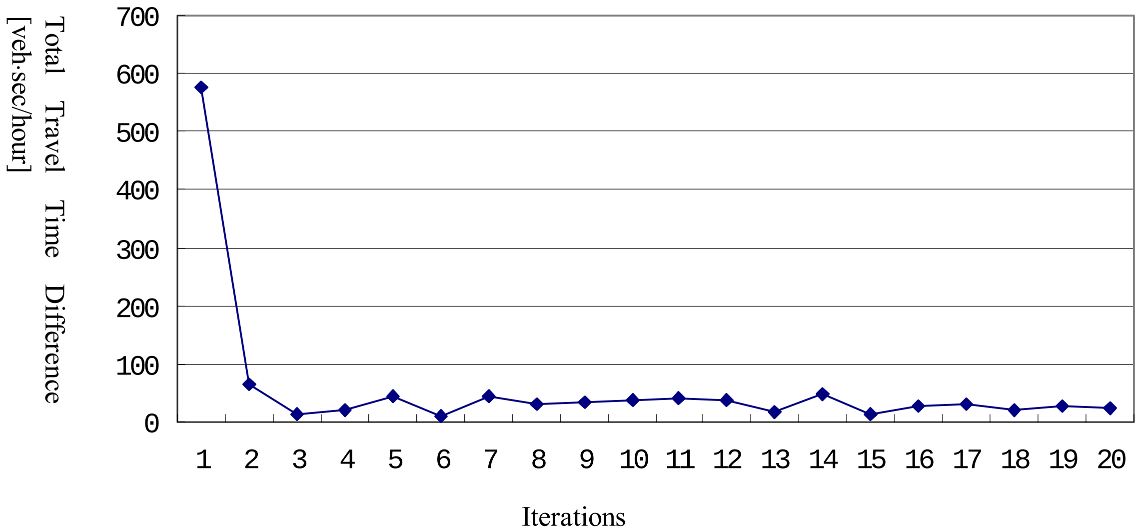

Fig.4 Total Travel Time Difference [veh·sec/hour] change over Iteration

Fig.5 illustrates calibrated capacity values for congested links. The capacity value shown in this figure is converted to the total capacity at the downstream end of each link. Therefore, the true capacity value is 600·1 + 800·3 + 400·1 = 3400 [veh/hour]. (Note that, in the SOUND model, the maximum discharge rate from a link is restricted to capacity of through movement: 800·3 = 2400 [veh/hour]. Hence, the total link capacity defined above is just conveniently used as a referenced value in this analysis.) Calibrated values based on link travel times as well as link volumes converge to the true value except for bottleneck links 45 and 90. Fig.6 shows difference in link travel time for congested links. The maximum difference seems reasonable as about 70 seconds for the 5-hour study period. Figures 7 and 8 respectively show errors in link volumes and total travel times for congested links. They are considerably improved compared with those based on the initial capacity values.

To understand these performances, we test how link travel time is sensitive to the capacity value. For randomly sampled links, link travel time change approximately 3 seconds if capacity values are reduced from 3400 [veh/hour] by 1 [veh/hour]. Considering the sensitivity, the proposed automatic calibration seems to perform quite well.

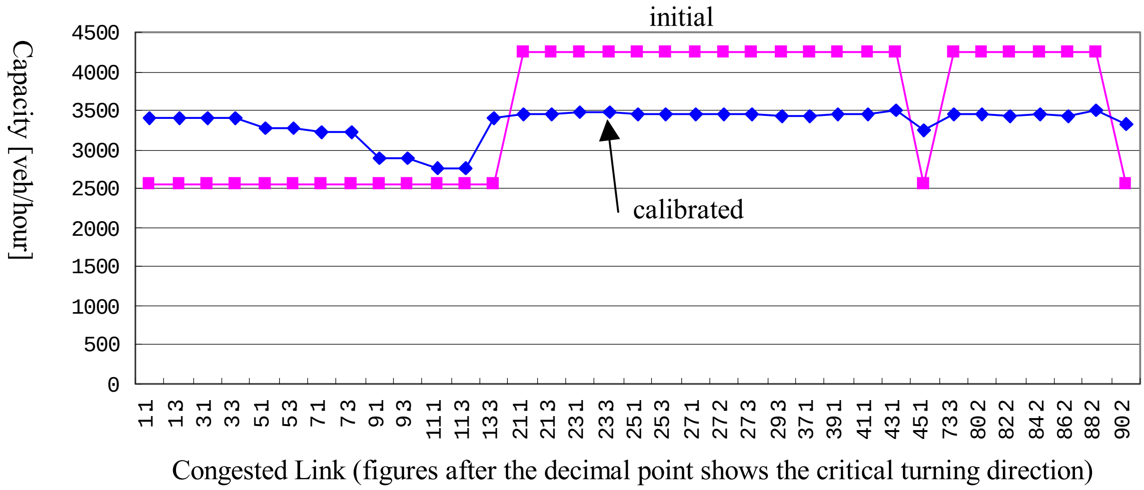

Fig.5 Initial and Calibrated Link Capacity Values

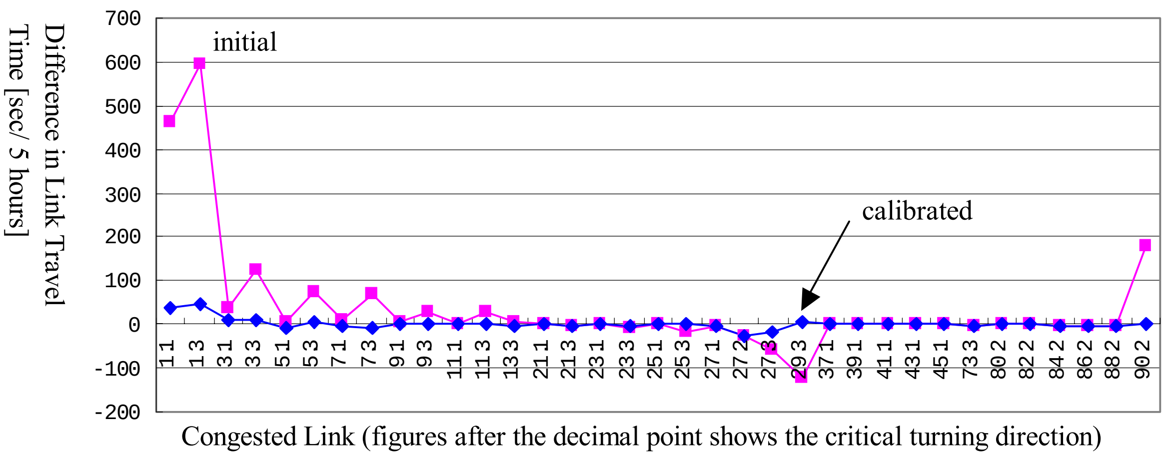

Fig. 6 Difference in Link Travel Time for Congested Links

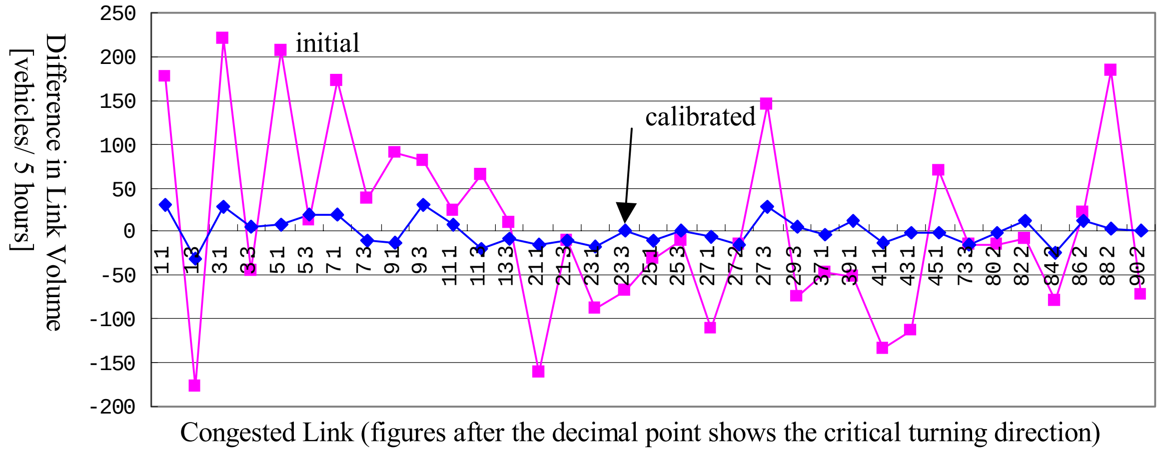

Fig. 7 Difference in Link Volume for Congested Links

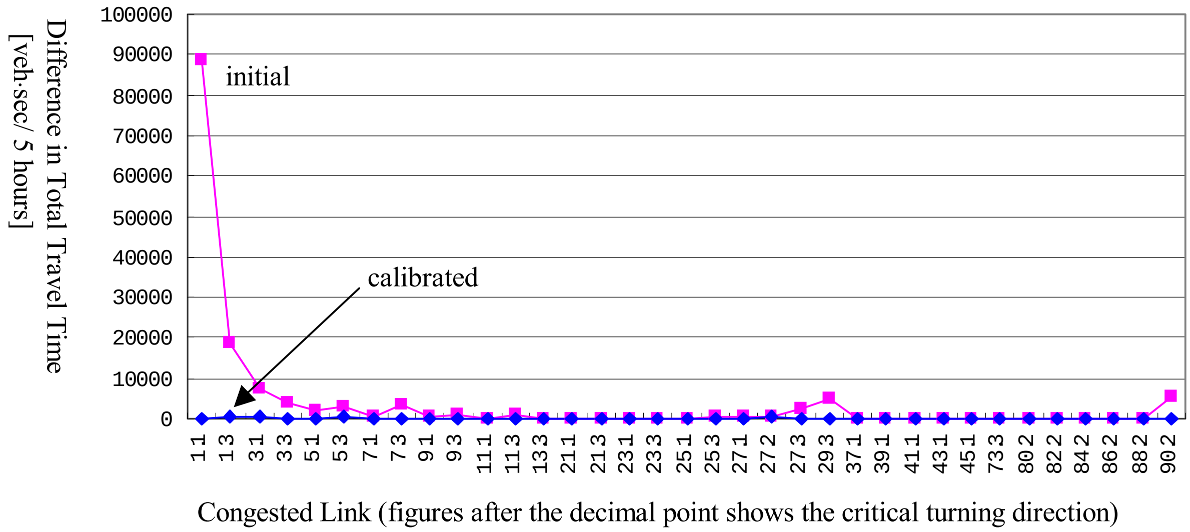

Fig. 8 Difference in Total Travel Time for Congested Links

Figures 9 and 10 illustrate changes of link travel time and link volume over time for the critical turning direction (= through movement) of link 1. The thick solid lines, thin solid lines and dashed lines respectively show observed values, initial simulated values and simulated values with calibrated capacities. Compared to the initial simulated values, the time-dependent link travel time and link volume well agree with the observed ones.

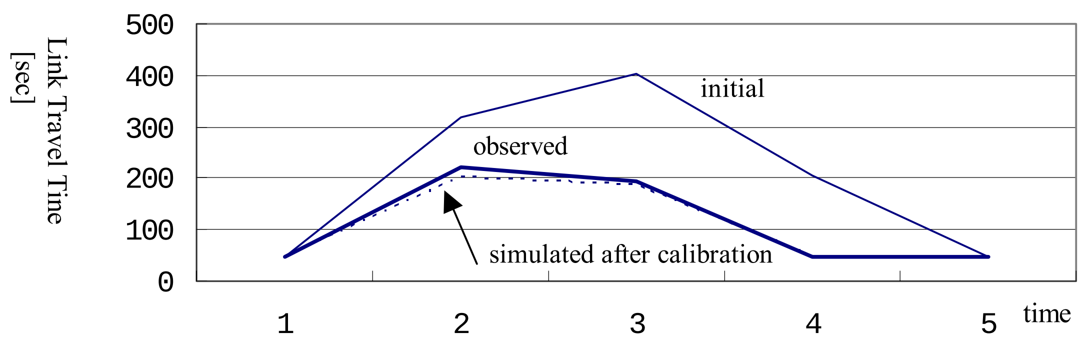

Fig.9 Observed and Simulated Link Travel Times of Link 1

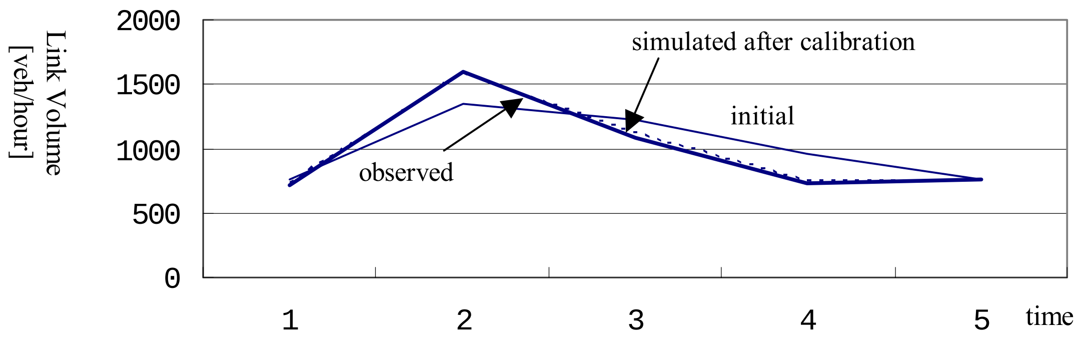

Fig.10 Observed and Simulated Link Volumes of Link 1

CONCLUSION

This research proposes a method which automatically tunes parameters of link capacities in a simulation model so that both observed link flows and link travel times are well reproduced in the simulation model. We employ an empirical tuning methodology based upon traffic engineering knowledge to iteratively update the parameter values. From an application to a hypothetical network composed of 104 links, the proposed method seems quite permissible to adjust the parameters.

For the future study, we would like to tackle a more efficient updating way to tune the parameters. The AI, GA, or other sophisticated tools would possibly be an option for this purpose. An examination of the current method to a real network is required to confirm the validity and robustness.

ACKNOWLEDGEMENT

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