VERIFICATION PROCESS AND ITS APPLICATION TO NETWORK TRAFFIC SIMULATION MODELS

Ryota Horiguchi
Dr. Eng., President, i-Transport Lab. Co., Ltd.
2-12-404 Agebacho Shinjuku 162-0824 Tokyo Japan
Phone: +81-3-52613077, Fax: +81-3-52613077, E-mail: horiguchi@i-transportlab.jp

Masao Kuwahara
Professor, Institute of Industrial Science University of Tokyo
IIS-Building-C-Cw504 4-6-1 Komaba Meguro 153-8505 Tokyo Japan
Phone: +81-3-54526419, Fax: +81-3-54526420, E-mail: kuwahara@nishi.iis.u-tokyo.ac.jp

ABSTRACT

This paper summarizes a standardized verification process for network traffic simulation models. After the general introduction of philosophy of verification, we explain detailed processes of the verification and its application to several well-known simulation models. "Verification" here means several examination tests of simulation models using virtual data on a simple network so as to confirm their fundamental functions. In the course of model development, the developers have to examine whether the model performance is consistent with the specifications that they intend and also with the well-authorized traffic engineering theory. Because of several constraints in putting the model specifications into the computer programming such as discretizing of time and space and simplifying vehicle behaviors to some degree, the intended model specifications may not be fully achieved in a computer. Therefore, we strongly recommend the verification before applying the models to a real network.

INTRODUCTION

Necessity of Standardized Verification

Nowadays, quite a number of network traffic simulation models are available in all over the world. Sometimes, however, we face difficulties in understanding model performances. For instance, a maximum discharge flow rate from a bottleneck link is not consistent with the input link capacity, vehicles cannot be generated as the input OD data, merging and diverging ratio cannot be achieved as we want, and so on. A part of the reasons would come from incapability of users who do not know what parameters should be adjusted, but the causes would also be found in modeling itself. In the course of model development, a model has to be examined whether the performance is consistent with the specifications developers intend and also with the well authorized traffic engineering theory. Because of several constraints in putting the model specifications into the computer programming such as discretizing of time and space and simplifying vehicle behaviors to some degree, the intended model specifications may not be fully achieved in a computer.

Thus, we recommend the verification of models, where "Verification" means several examination tests of simulation models so as to confirm their fundamental functions such as 1) vehicle generation, 2) bottleneck capacity at simple road sections, 3) capacity of merging/diverging areas, 4) traffic jam growing/shrinking with propagation of shock waves, 5) capacity of left/right turn at an intersection, 6) drivers' route choice behavior, and so on. This verification is useful for model developers to confirm the model functions. For systematic as well as overall tests, a standardized verification process is needed. Same time, the verification would be also helpful for model users to receive results of the verification to get familiar with model characteristics as well as model parameters to be adjusted, since users may frequently have difficulty in fully understanding the contents of the model from only the literature and the manual. Many of users in fact have felt the hearts of models are "black box".

One way to verify a model is to apply simulation models to real traffic data and to examine their reproducibility. Although the examination using real field data is important, complex traffic conditions in the real world would mostly get bogged down individual model functions. Furthermore, the model performance would be different by ways of the application such as parameter adjustment and input data quality. Thus, we in principle suggest verifying the models using virtual data on a simplest network so that we could examine each of the functions separately.

Stages of Model Development

In order to clarify the standpoint of verification, let us start with stages of the model development. We consider the following five stages:

<u>Framework</u>
According to purposes of model applications, we have to first construct the model framework; that is, what the model input and output are, what kind of traffic phenomena should be described, and so on. Then, we have to conceptually decide vehicle motions as well as travelers' behavior to be incorporated so as to reproduce the traffic phenomena concerned.

<u>Specification</u>
The model framework defined above should be specified in more detailed way. For instance, we should decide how long the scanning interval is, and what kind of car-following models as well as route choice models should be employed, etc.

<u>Implementation</u>
This process consists of programming to run the model contrived in the previous stage on a computer and debugging to check if the computer operates according to the algorithm. Debugging is just the fixing coding errors and it must be distinguished from verification described in the next.

<u>Verification</u>
Verification is a series of simple tests to confirm that fundamental model functions are properly programmed as in the specification. As mentioned earlier, the simulated result is compared with what the result should be obtained from the well authorized theory. In order to individually examine each of functions and also to get the theoretical solutions to be compared, we should use virtual data on a simplest network.

Validation

"Validation" seems quite similar to "Verification" in general. However, in this paper, "Validation" must be clearly distinguished such that it is the evaluation of the model specification using real field data. Even if the model is verified as in the specification, the model specification (or the model framework) itself may not be adequate to describe real traffic phenomena. The model cannot be practically applicable, if actual traffic situations are not sufficiently reproduced due to the incomplete model specification. Furthermore, the model performance as a system should also be confirmed, such as whether the execution of the model can be finished within a practical computing time.

Japanese Activity for Standardization of Traffic Simulation

Although this paper mainly focuses on verification, we have been working for standardizing several stages mentioned above. Our first outcome is the verification manual, which describes the standard verification procedure so as to be applied to various different types of models. The second output is the benchmark datasets, which are real field data relatively well observed and processed. The benchmark datasets have been gathered so that developers can utilize them to validate their models, since in general acquisition of real field data is substantially expensive and time consuming.

These our activities can be found in "Clearing-House" at an Internet website:

http://www.jste.or.jp/sim/ (in Japanese).

The developers and users of simulation models can also publish their experiences on verification and validation through the clearing-house. Followings are brief introduction of materials available on the clearing-house at present.

Draft Version of the Manual of Standard Verification Process for Traffic Simulation Models

This manual describes minimal verification items mainly for so-called network simulation models [JSTE, 2001]. The subsequent chapter of this paper explains the main purport of the verification manual and an outline of the substantive verification steps.

Standard Benchmark Data Set for Validation of Traffic Simulation Models

Validation requires data on simulation inputs including traffic demand and operation as well as highly reliable data representing the traffic situation to be compared with the simulation result. Such data collection has been a substantial burden for model developers. With this background, we have proposed the desirable validation process using common benchmark data sets, which is collected from real world with highly reliable preciseness [Horiguchi, 1998]. Currently, five data sets for different categories of road networks like urban streets, inner-city highways, etc. are available.

MANUAL OF STANDARD VERIFICATION PROCESS

Fundamental Concept

Verification is a sort of virtual test using ideal network and demand configurations to qualify basic phenomena on road traffic. Generally, we do not expect a simulation model to reproduce real traffic situation perfectly, since some simplification in vehicle motions and user behaviors have to be made and also discretization of time and space is required to some degree. Accordingly, in the verification, the simulation result is not expected to exactly agree with the theoretical results. When the simulated result is far different from the theory, we should revise the programming. However, in most of the cases, the simulation would perform slightly different way. In these situations, we should utilize the verification to understand the model characteristics. Establishing this linkage will provide us very helpful information to understand the model characteristics. At the same time, it is considered important to define the relationship between certain model parameters and model behavior.

We may now find two categories of network simulation models. One is that maintain traffic flows with vehicle lists or fluid approximation according to the macroscopic flow characteristics, like flow-density or density-speed relationship, given to each link or section. Another type of simulation models is employing vehicle driving behaviors including car following and lane changing. Here, let us say former as the Q-K type and latter as the C-F (car following) type.

The biggest difference of these two types is that the Q-K type explicitly, or implicitly, gives the capacity to a link or a section, while the C-F type basically does not have a parameter directly implies the capacity of link. As the concept of verification is to compare the simulation model behavior with the established theory that is normally on macroscopic view, the detailed description of verification step would be separately defined for each category, i.e.:

a) For the simulation models of the Q-K type, the verification implies that the simulation result really agrees to the given flow characteristics. In this sense, the verification process of this type is to be said as a kind of self-consistency check.
b) For the simulation models of the C-F type, the model parameters are concerning to individual driver's characteristic. Therefore, the verification process of this type should make clear the relationship between those model parameters and the flow characteristic reproduced by the simulation. In this sense, we may say the verification is a sort of sensitivity analysis. Although it is not possible and not efficient to examine flow characteristics under all combinations of several model parameters, we should understand the influence of major parameters on resulted flow conditions.

Features to be considered through Simulation

We have included six basic features in the verification manual, which should be at minimum considered by the network simulation models.

<u>Generation of Vehicles and Flow Conservation</u>
For implementation of simulation, it is necessary to generate the traffic at the entry end according to the arrival distribution of vehicles from outside the study area. Most of the simulation models seem to assume random arrival at a network boundary section, but there might be some other arrival patterns to be adopted by considering the objective of the simulation study. For example, the uniform arrival may be assumed in some cases of the analysis for over-saturated traffic conditions, in order to avoid the undesirable tendency of pseudo-random series. The verification process here requires whether the generation pattern assumed in the model really achieved. It should be also checked whether the number of vehicles generated in a certain time period is equal to or different from the given volume.

Once a vehicle generated, it must not disappear until it reaches its destination. Even in the case that vehicle queue spills out of study area, newly generated vehicles are added to the end of the point queue outside the network and will flow into the network after sufficient time period. Simulation models, so that, must keep this flow conservation law not only at every links but also outside of network.

Bottleneck Capacity / Saturation Flow Rate at Link's Downstream End

As the discharging flow rate from a bottleneck section like sags or tunnels contributes to the reproduction accuracy of the delay caused by the congestion at the bottleneck, it is essential that the capacity of the bottleneck should be reproduced in a stable manner during the simulation.

Even on surface streets in under-saturated conditions, a vehicle may have the delay caused at signalized intersections. The outflow from an intersection continues at the saturation flow rate till a vehicle queue developed during the red vanishes. It is important to clarify how the saturation flow rate is reproduced in the simulation model as for the bottleneck capacity.

Growing and Shrinking Traffic Jam Consistent with Shock Wave Theory

When traffic jam beginning at a bottleneck grows to the upstream link, even traffic that does not need to pass through the bottleneck may be also affected. As a difference in the jam's growing/shrinking speed results in difference in the degree of influence on the total delay upon whole network, it is important to reproduce this phenomenon by using physical-queue to reasonably maintain the traffic density of congestion. The verification of these phenomena is made by comparing the shock wave speed simulated with the one based on the shock wave kinematics, as shown in Figure 1.

For surface streets, on the other hand, even if a signalized intersection is under-saturated, the vehicle queue grows and shrinks in every cycle. The tail of the queue moves with some time lag at the begging of the green phase due to drivers' response delay at departure. Because of this time lag, when two signalized intersections are close and the queue heading to the one intersection spreads beyond another, there may be the case that the vehicles in the tail of the queue cannot pass through the near intersection depending on the signal offset. Therefore, the simulation model that is considering signal control effect must reasonably reproduce this phenomenon including shock wave propagation.

Capacity of Merging and Diverging Section

Not only sags or tunnels but also merging and diverging sections can be the most remarkable bottleneck of highways. At a congested merging section, the travel time on each approaching branch may vary with the merging ratio even if the capacity of the merging section stays constant. Contrary, the capacity of the diverging section is constrained by the capacities of downstream links and may change depending on the proportion of the demand to each branch. The verification step includes these merging and diverging configurations.

Gap Acceptance of Right (Left)-Turn at a Signalized Intersection

In ordinary streets, it is daily observed that vehicles waiting for right (left)-turn in the signalized intersection sometimes obstruct travel of followers and cause congestion. Such vehicles are waiting to find an acceptable gap in the opposing straight-through traffic in the green phase, and consequently the right (left)-turn capacity declines according to the opposing traffic volume. A simulation model that treats a signalized intersection would be required to describe such relationship between the turning capacity and the opposing traffic volume by some set of gap acceptance parameters.

Drivers' Route Choice Behavior
Modeling for drivers' route choice behavior considered in simulation will be classified as follows:

a) No route choice,
b) Dynamic User Optimal (DUO) principle,
c) Dynamic User Equilibrium (DUE) assignment,
d) Probabilistic route choice.

Of these models, the one using a) above is considered applicable to evaluation of the short-term traffic management that need not consider routes of drivers, or to a network without any alternative routes. Verification of these models is not necessary because it is equivalent to the verification at a merging/diverging section.

On the other hand, the simulation model using principles of b), c) or d) let a driver select an appropriate route according to the presented information for routes. This type of models is frequently used to evaluate the operational policy such as dispersing the traffic spatially by means of informative service or road construction. Models with route choice can be verified using a simplified network, e.g. with two routes for one O-D pair, to avoid the difficulty to figure out the theoretical flow pattern to be compared with the simulation result. It is also interesting to examine results by changing settings of simulation model such as an update interval of route costs and locations where the drivers can receive the travel cost information.

Difference in the Verification Procedure by the Types of the Flow Model

As mentioned before, the detailed verification procedure is separately described for Q-K type and C-F type with different fashion. In order to show how the verification of these two types is different, the verification of bottleneck capacity is illustrated as an example here.

Verification of Bottleneck Capacity for "Q-K type" Simulation Models
Given the sufficiently large demand to the bottleneck, according to the procedure described below, verification is made whether the flow ratio on the downstream side is stable at the given bottleneck capacity. We may read the meaning of "self-consistency check" from the last step iv).

i) A corridor network to be used consists of links as shown in Figure 2(a). The most downstream link will be the bottleneck. Set the model parameter so that the bottleneck capacity becomes 800, 1000, and 1200 [pcu/hr]. The capacity is set to be 2000 [pcu/hr] for other sections.
ii) The traffic demand of 1500 [pcu/hr] is provided so that congestion occurs always in the bottleneck.
iii) Simulation is made for one hour using respective model parameters and the throughput volume on the downstream of the bottleneck is recorded.
iv) As shown in Figure 2(b), the cumulative curve of throughput from the bottleneck is plotted to see if the given bottleneck capacity is really achieved.

Verification of Bottleneck Capacity for "C-F type" Simulation Models
The purposes of this verification step are:

i) To identify the "average" flow characteristics under the popular parameter settings for the model.
ii) To get general understanding how the changes on each model parameters will affect the "average" flow characteristic.

Before starting verification, the major model parameters should be listed up with their default values and plausible setting ranges. They are roughly classified into those related to the driving behavior and those associated with a location or a road section. Here, the C-F type model which has the major parameters shown in Table 1 is assumed as an example.

The verification is made for a simple road network as shown in Figure 3. The average Q-K curve is derived according to the subsequent steps by changing the parameter settings for "all combination" of their default, minimum and maximum values.

i) Set the traffic demand at some level and start simulation.
ii) Wait till the link becomes a “steady state”, and then observe the cumulative throughput volume at upstream and downstream ends of the link during some time period.
iii) Take the average number of vehicles on the link from these two cumulative volume curves, and calculate the average traffic density on the link. Then, plot the result on the Q-K plane.
iv) By superimposing all plots on the same Q-K plane, we may find a family of plots of which the parameters on driving behaviors are the same.
v) Draw a curve along the plots. Each family of plots has a different parameters set on link performance. The curve, therefore, represents the average Q-K curve for the parameter setting on driving behavior.

From this procedure, we may find a nuance of "sensitivity analysis".

Other steps in the verification of C-F type use these "average" Q-K curves identified here. This verification step, therefore, must be made at first.

MODEL COMPREHENSION THROUGH THE VERIFICATION RESULTS

Several simulation models that are practically used in Japan have been evaluated based upon the proposed verification process. We have verified seven pilot models, such as AVENUE [Horiguchi, 1996], SOUND [Yoshii, 1995], tiss-NET [Sakamoto, 1998], Paramics [Paramincs, on WWW], NETSIM [NETSIM, on WWW], REST [Yoshida, 1999], and SIPA [Yokochi, 1999] along the verification manual and validated with benchmark data set. Figure 4 illustrates the rough model classification according to their spatial resolution in vehicle motions and the size of the network for their usual application studies.

In this chapter, let us introduce several verification results to understand how the verification process put into practice. We also state some implications from the result in order to show how the verification helps to comprehend the model characteristic.

Generation of Vehicles

For the verification of vehicle generation, the headways of arriving vehicles at a network entry point are accumulated for certain travel demand. Figure 5 and Figure 6 illustrate the distributions of the headways of AVENUE and SIPA under the demand = 1000 [veh./hr]. As both models assume random arrival in the vehicle generation, the headways must obey the exponential distribution. However, the result of AVENUE estranges from the theoretical distribution, while the result of SIPA seems to fit. In the case when the result of simulation shows the difference from the theory, the tester of the verification required to explain why such result could arise.

In this case, both AVENUE and SIPA are implemented as time-periodic scanning models. They calculate the number of generated vehicles within each scanning interval according to Poisson arrival. Therefore, the headway between the vehicles generated at the same scanning interval is considered as 0 second.

While the time is continuum in the theory, the theoretical headway will be rounded up or rounded off the fraction with the scanning interval. As shown in Figure 7, the theoretical headway of 1.5 second may be rounded in the simulation as 1 second for some time or as 2 second for the rest, so that the headway appearance in the simulation may be distorted more or less by the effect of the discrete time interval. As the unit range of the headway in Figure 6 is 1 second and the unit time interval of AVENUE is also 1 second, the headway of which interval is [0,1) will be counted up to 0 or 1 second, and the appearance shape estranges from the theoretical distribution. On the contrary, as the unit time interval of SIPA is 0.2 second, only headway of which interval is (0.8,1.0] will be counted up to 0 or 1.

Adding to the above, the total number of generated vehicles is to be verified. Figure 8 and Figure 9 indicate the results with different random seeds for AVENUE and tiss-NET, both of which assume random arrival in vehicle generation. AVENUE always generates the same number of vehicles as the given demand level, on the other hand tiss-NET varies its results with each random seed.

The results coming from the difference in the attitude of their "specification" stages can be known only through the qualify tests in verification, and can give the meaningful implications that the literatures would not tell us. For this case, a user of the simulation model that has the same nature as tiss-NET in vehicle generation should realize that he or she has to repeat the simulation for the same network and demand configuration with different random seeds. The user also has to be careful in choosing the set of random seeds not to be biased in the number of generated vehicles against to the given demand setting. Subsequently, the user must evaluate the variation of the number of generated vehicles for each calculation.

Traffic Flow Characteristics and Bottleneck Capacity of C-F type Models

According to the procedure described in the previous chapter, the traffic flow characteristics of each C-F type simulation model must be identified in its verification process. Here, let us introduce the verification of Paramics and SIPA as examples, both of which have a dozen of model parameters concerning the driving behavior and the link performance.

The major parameters of each model are listed in Table 2. The meanings of some are clear, e.g. maximum acceleration or limit speed, but not all. For instance, how is the "minimum headway" of Paramics difference from the "target headway" of SIPA, what is the "headway coefficient" of Paramics, or is the inverse of "allowable minimum headway" of SIPA equal to the link capacity? Even if their software manuals or technical papers state the meanings of the parameters, they are mostly conceptual explanations. It is still mysterious how each of the parameters effects on the bottleneck capacity.

Our interest here is to understand the quantitative relationships between the model parameters and the bottleneck capacity reproduced in the simulation. Furthermore, we would like to find the most sensitive parameters through the verification process, because it must be the most efficient strategy to fit the simulation result to an actual traffic condition by changing the most sensitive parameters.

Figure 10 shows a portion of the results of Paramics. The dots in the figure indicate the volume-density plots observed with varying major parameters. The shape of the dots is associated with the sort of varied parameters. The remarkable point is that the decline of the flow rate is found only when the "headway coefficient" of the bottleneck link is 1.5 (dots surrounded by the circle) and otherwise there are no effects. This implies that only the changes on the "headway coefficient" of the bottleneck link does affect to the bottleneck capacity while others have less influence.

Figure 11 shows the result of SIPA in the case that the "minimum headway" of the bottleneck link changes from 2.0 seconds to 3.0 seconds. Theoretically, the minimum headway must be equal to the inverse of the capacity, so that the bottleneck capacity must be 1200 pcu per hour if the minimum headway is 3.0 seconds. However, the bottleneck capacity reproduced in the verification is slightly grater than the theoretical value. We may realize that the "minimum headway" of SIPA is similar but different parameter from the link capacity.

There are common findings through the verification of bottleneck capacity for the C-F type models:

i) Most of them have the parameters that affect to the minimum headway of each link.
ii) Such parameters have strong influence on the bottleneck capacity but others have less influence.
iii) Such parameters are not exactly equivalent to the inverse of the bottleneck capacity.

There are some implications obtained from i) and ii). Even if we use so-called micro-scopic simulation models, we have to be rather careful in calibrating the link parameters related to headways than those to driving behaviors. In this sense, such micro-scopic simulation models are essentially equivalent to the macro-scopic simulation models that require the capacities of links.

For the reason to iii), the tester of SIPA reports the study on the effects of the length of bottleneck sections. Figure 12 illustrates the reproduced bottleneck capacities that increase as the length of the bottleneck link gets shorter. This phenomenon may be considered as follows; when a vehicle with the minimum headway allowed in the upstream section enters the bottleneck link, the headway achieved by the vehicle does not immediately shift to the new minimum headway. If the length of a bottleneck link is so short that a vehicle passes through the link before its headway will shift to the new headway, the capacity of the bottleneck link will not decline as expected. The users of C-F type models should realize this phenomenon because it is found among most of the models, not only in SIPA.

Saturation Flow Rate at an Signalized Intersection

For the verification of the saturation flow rate at a signalized intersection, the tester is required to show the profile of discharging traffic within a signal cycle. Let us introduce the result of SOUND, which has the combined flow model: car following for expressways (SOUND/express) and queuing vehicle lists for arterial roads (SOUND/A-21). The former calculates each vehicle speed according to the spacing-velocity (S-V) function given to each link. The S-V functions can be identified through macro-scopic surveys of traffic flows. On the other hand, the latter assumes the point-queue at the downstream end of each link. The point-queue of each link accepts vehicles up to the jam density and discharges them at the saturation flow rate of the link within the green signal.

Figure 13 illustrates the profile of vehicle discharging for SONUD/A-21. As SOUND/A-21 is a sort of "Q-K type" models, the discharging flow rate at saturation is expected to strictly agree with the given saturation flow rate. Now we may confirm from the figure that the simulation result attains the given saturation flow rate (1600 pcu/G1hr) in average.

There is another point to be discussed in Figure 13. The discharging flow rate of SOUND/A-21 immediately goes up to the saturation flow rate when the signal turns to green. In the actual situation, it takes some time to discharge the flow at the saturation flow rate because of the response delay of drivers. The tester of SOUND gives the reason to this point as follows:

- Instead of neglecting the starting delay, a vehicle cannot flow out during yellow signals in order to adjust the effective green time.
- At normal intersections, the duration of green signal is nearly equal to the effective green time so as to take the yellow interval as much as the starting delay.

CONCLUSION AND FUTURE TOPICS

In this paper, the concept and the outline of the manual of standard verification process currently prepared in Japan is introduced. The verification manual is distributed through the "Clearing House" of simulation models on the Internet <http://www.jste.or.jp/sim/>.

Several simulation models that are practically used in Japan have been evaluated based upon the proposed verification process. We have verified seven pilot models, such as AVENUE, SOUND, tiss-NET, Paramics, NETSIM, REST, and SIPA along the verification manual and validated with benchmark data set. However, only some results are available on the Internet at present [AVENUE, on WWW] [SOUND, on WWW]. We are now discussing how we encourage model developers to open their verification results to the public. Basically, we expect the verification process to be "de-fact standard" by educating the necessity of the verification to practitioners and also to people in public sectors who order consulting jobs using simulation models.

The further discussion in our activity is expected that for to comprehend the results of the verification studies, and to estimate the characteristics of each model. Also, we will afford the movement of this standard certification process for other simulation models worldwide.

ACKNOWLEDGEMENT

We would like to state special thanks to the members of the simulation research group under the sponsorship of Japan Society of Traffic Engineers, who contributed to meaningful discussions on the verification manual.

REFERENCE

AVENUE. Verification of AVENUE. *http://www.i-transportlab.jp/products/avenue/verification* (in Japanese).

Horiguchi, Ryota. et. al. 1998. A Benchmark Data Set for Validity Evaluation of Road Network Simulation Models. *Proceedings of 5th World Congress on Intelligent Transport Systems*. Seoul.

Horiguchi, Ryota. et.al. 1996. A Network Simulation Model for Impact Studies of Traffic Management 'AVENUE Ver. 2'. *Proceedings of the Third Annual World Congress on Intelligent Transport Systems*. Orlando.

JSTE (Japan Society of Traffic Engineers). 2001. A Manual of Standard Verification Process for Traffic Flow Simulation Model (Draft in English). *http://www.jste.or.jp/sim/verification/manual/VfyManE.html*.

NETSIM (CORSIM): *http://www.fhwa-tsis.com/*.

Paramics: *http://www.paramics.com/*.

Sakamoto, Kunihiro. et.al, 1998. Traffic Assignment Method Considering Car-by-car Behavior for Traffic Impact Studies -Development of the tiss-NET System-. *Proceedings of 8th World Conference on Transport Research*. Antwerpen.

SOUND. Verification of SOUND. *http://www.i-transportlab.jp/products/sound/verification* (in Japanese).

Yokochi, K. et.al. 1999. Development of Microscopic Traffic Simulator for AHS Evaluation. *Proceedings of 6th World Congress on Intelligent Transport Systems*. Toronto.

Yoshida, T. et.al. 1999. A Basic Study for the Planning of ETC-dedicated Highway Interchange using a Traffic Simulator REST (in Japanese). *Proceedings of Infrastructure Planning*, No.22 (2). pp.231-234.

Yoshii, Toshio. et.al. 1995. An Evaluation of Effects of Dynamic Route Guidance on an Urban Expressway Network. *Proceedings of the 2nd World Congress on Intelligent Transport Systems*. Yokohama.

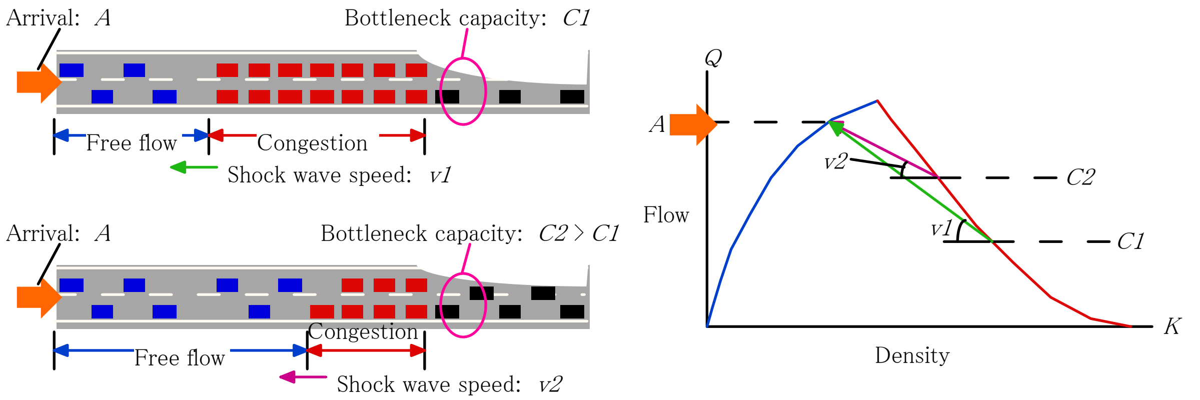
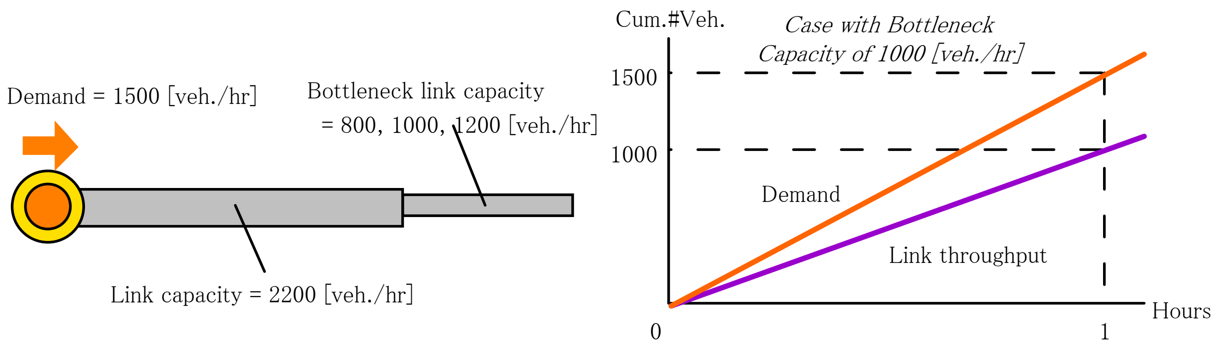


Figure 1: The growing speed of jam is determined by the arrival demand and the bottleneck capacity.



(a) Network and demand configuration (b) Expected cumulative curve of traffic volume

Figure 2: Verification for the bottleneck capacity for Q-K type simulation models

Parameters	Default	Minimum	Maximum
a) For driving behavior of vehicles			
a1) Response delay	1.0 sec	0.7 sec	1.5 sec
a2) Desired headway	2.0 sec	1.7 sec	3.0 sec
a3) Max acceleration	2.0 m/s^2	1.7 m/s^2	3.0 m/s^2
a4) Desired speed	60 km/hr	40 km/hr	100 km/hr
b) For traffic demand			
b1) Composition ratio of drivers groups of which the driving behaviors are different		Set freely as required	
c) For link performance			
c1) Limit speed	60 km/hr	40 km/hr	100 km/hr
c2) Gradient	0 %	-6 %	6 %
c3) Lane width	3.0 m	2.75 m	3.5 m
c4) Curvature radius	Inf.	100 m	-

Table 1: An example of the model parameter set of C-F type simulation model

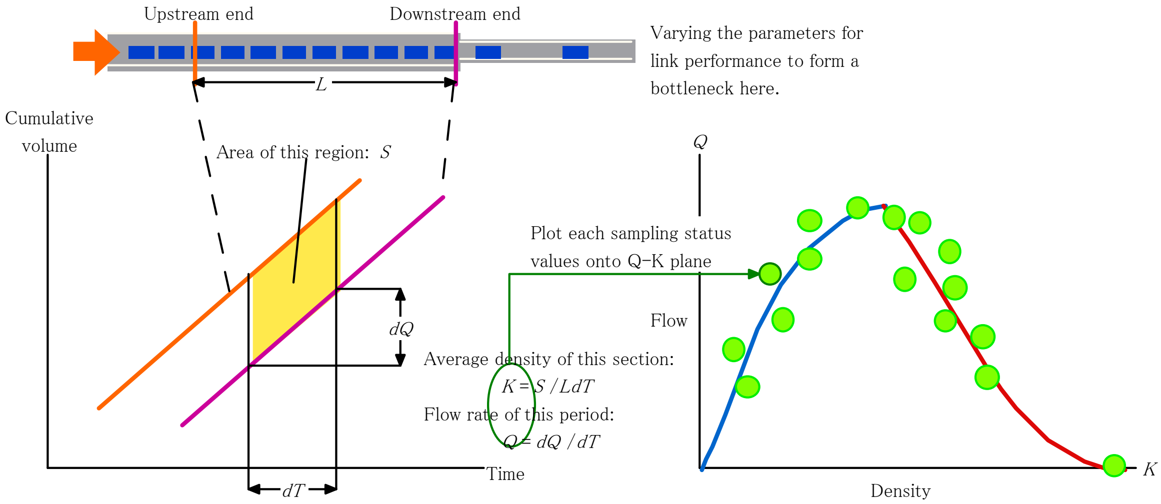


Figure 3: Verification of bottleneck capacity for C-F type simulation models

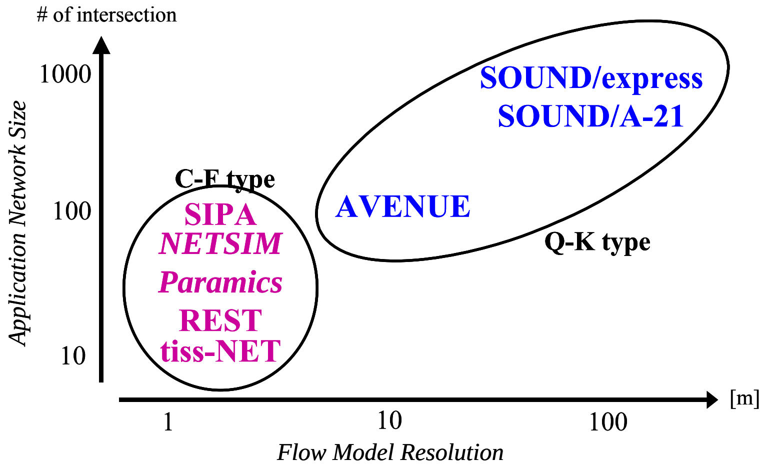


Figure 4: Classification of seven pilot models (block -- Japanese model, Italic -- foreign model)

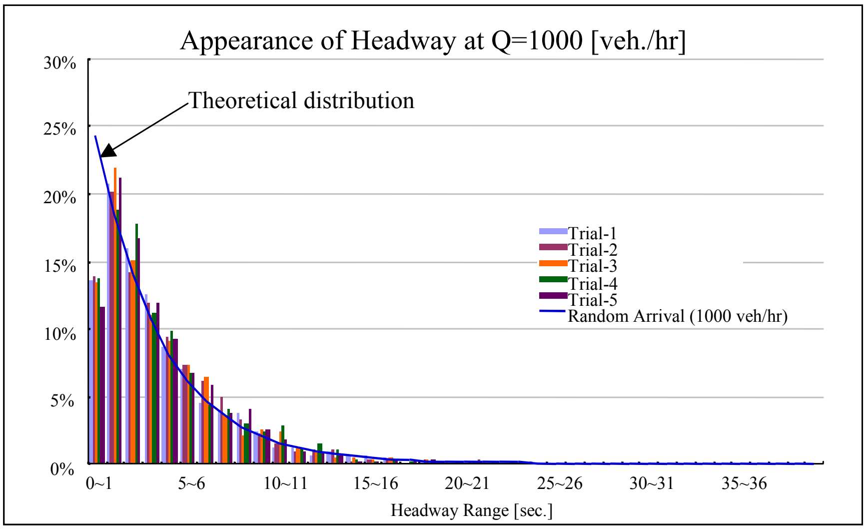


Figure 5: Headway appearance of each trial with 1000[veh./hr] demand -- AVENUE

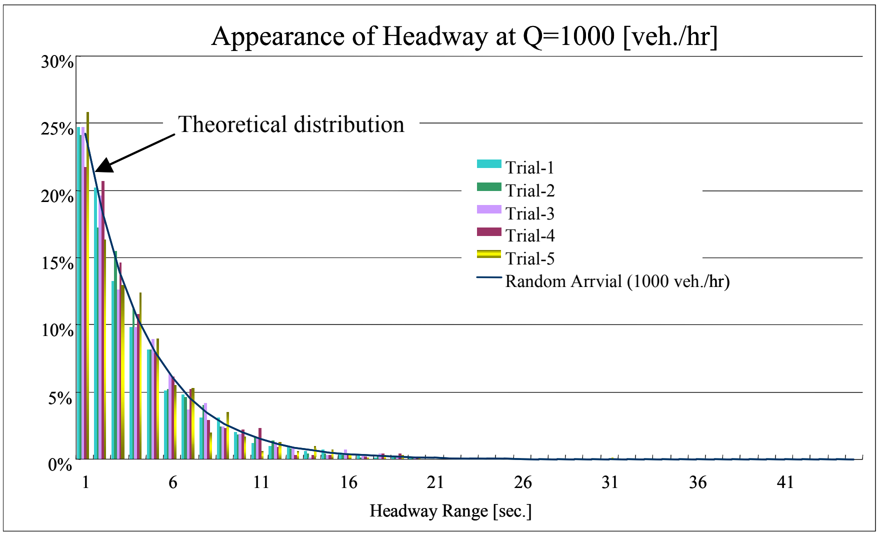


Figure 6: Headway appearance of each trial with 1000[veh./hr] demand -- SIPA

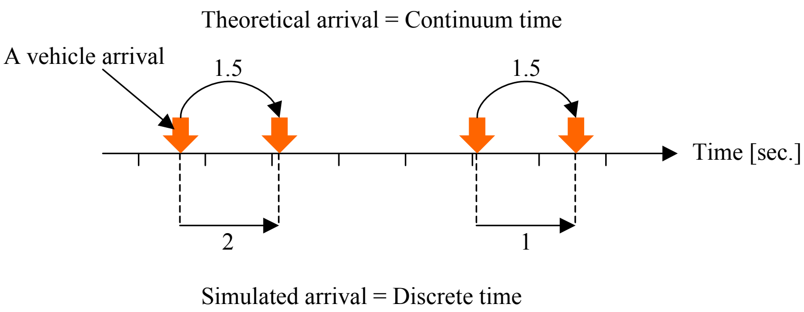


Figure 7: Effects of time discretion on headway distribution

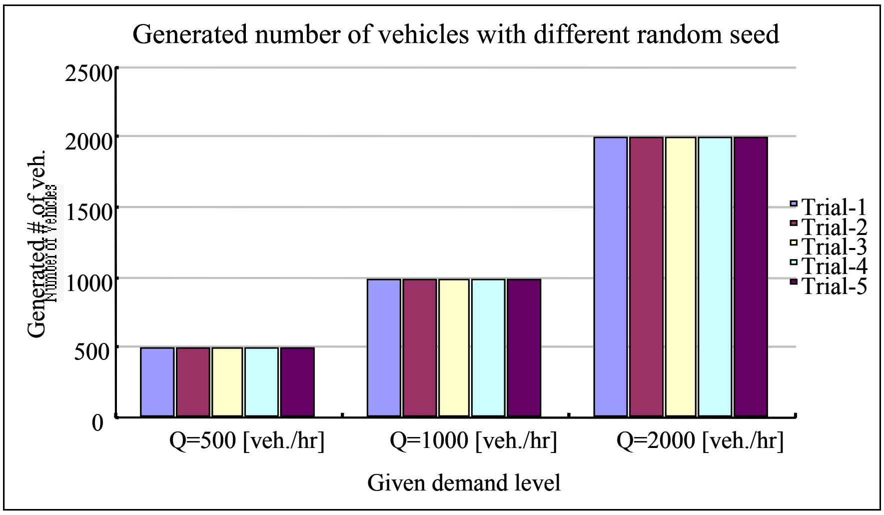


Figure 8: Total number of generated vehicles -- AVENUE

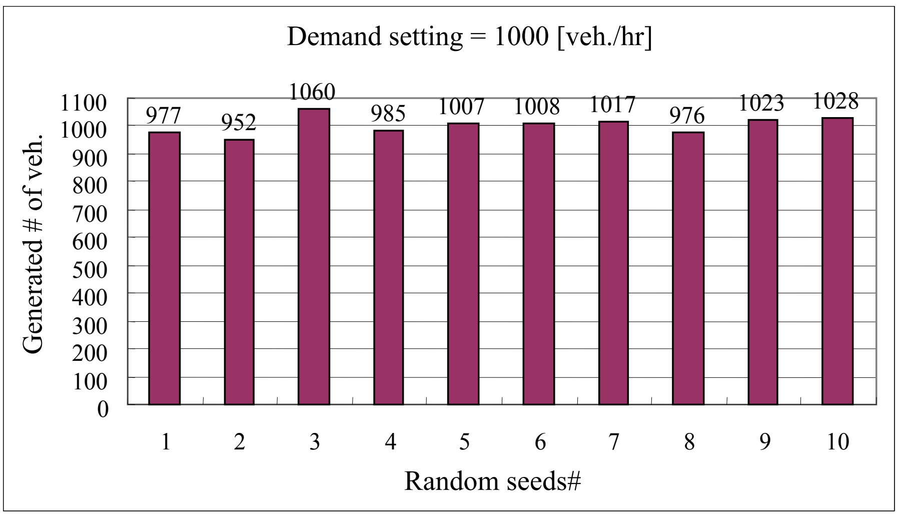


Figure 9: Total number of generated vehicles -- tiss-NET

Model	Driving behavior	Link performance
Paramics	minimum headway, maximum acceleration, driving aggression, etc.	headway coefficient, limit speed, gradient, etc.
SIPA	target headway, target speed, maximum acceleration, response delay, etc.	allowable minimum headway, limit speed, gradient, etc.

Table 2: Major model parameters of Paramics and SIPA

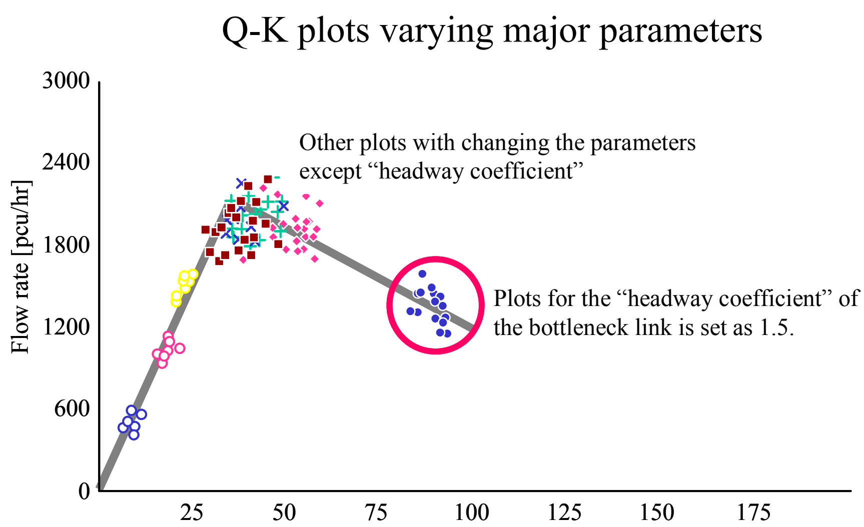


Figure 10: Bottleneck capacity and traffic flow characteristics of Paramics

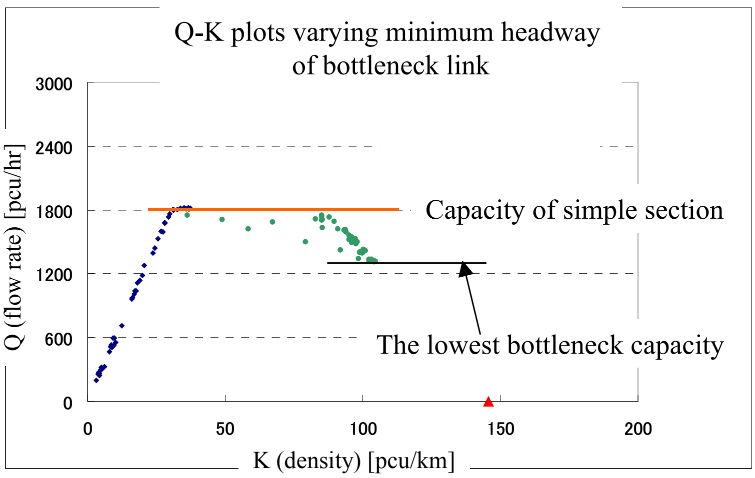


Figure 11: Bottleneck capacity and traffic flow characteristics of SIPA

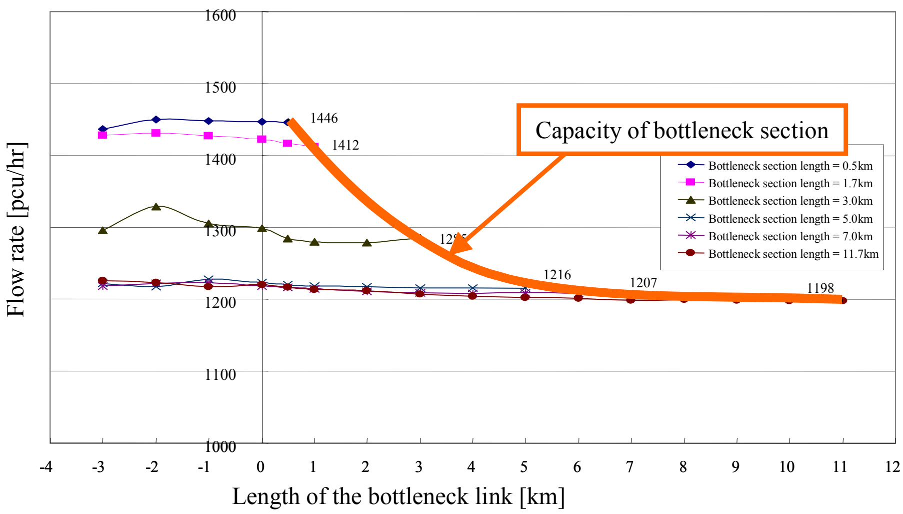


Figure 12: The capacity varying with the length of bottleneck section (SIPA)

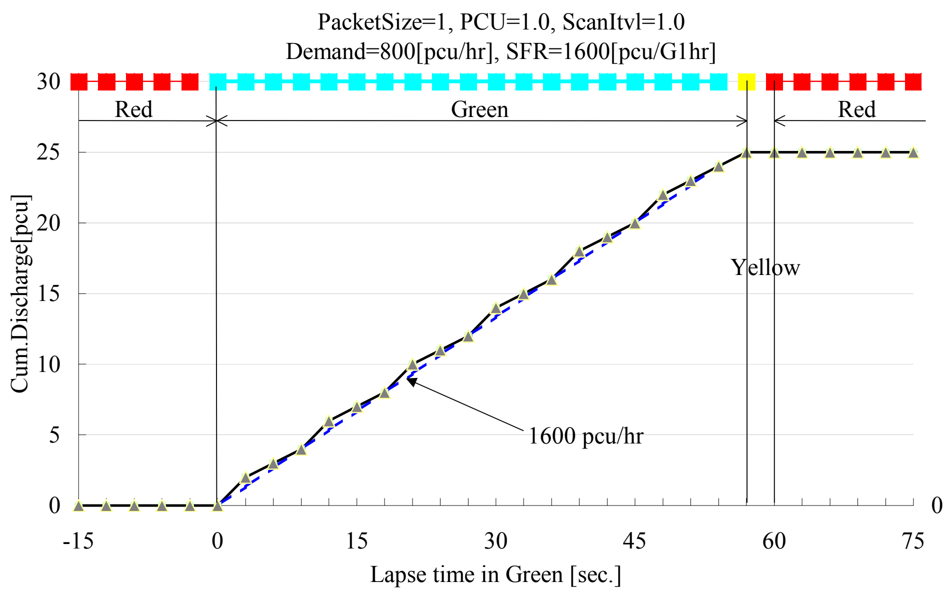


Figure 13: Link discharging profile at a signalized intersection -- SOUND/A-21