CO_2 and Noise Evaluation Model linked with Traffic Simulation for a Citywide Area

K. Tsukui[*1], H. Hanabusa[*2], H. Oneyama[*3], Y. Oshino[*1], and M. Kuwahara[*4]
Japan Automobile Research Institute[*1]
(2530 Karima, Tsukuba-shi, Ibaraki 305-0822, Japan, +81-29-856-2681, ktsukui@jari.or.jp, yoshino@jari.or.jp)
i-Transport Lab. Co., Ltd. [*2]
(Jimbocho1-4 BLDG 3F, Kanda Jimbocho 1-4, Chiyoda-ku, Tokyo, 101-0051, Japan, +81-3-5283-8527, hanabusa@i-transportlab.jp)
Tokyo Metropolitan University [*3]
(1-1 Minami-Osawa, Hachioji-shi, Tokyo, 192-0397, Japan, +81-426-77-2780, oneyama@tmu.ac.jp)
Institute of Industrial Science, University of Tokyo[*4]
(4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan, +81-3-5452-6419, kuwahara@iis.u-tokyo.ac.jp)

This study develops a system which combines CO_2 emission and road noise models with a traffic simulation model to evaluate the environmental impacts by several traffic management schemes for a citywide area. Despite intensive studies on these three kinds of models, they have been developed almost independently and a few considered a joint use of the models so that environmental impacts could be evaluated from the simulated traffic condition. Therefore, a system combining the ASJ noise model, the NILIM emission model and the AVENUE simulation model is proposed. And, the system is validated by applying to a whole Tsukuba city and outputs from the proposed system get reasonable agreement with the observed traffic flow, travel times, and noise levels. Lastly, an impact analysis of a new road infrastructure reconfirms the difficulty of the noise abatement; that is, the noise levels along major roads are expected to increase due to the higher travel speed though the CO_2 emission would decrease by 2.3%.

Keywords: *Road Noise, CO_2 Emission, Traffic Simulation*

1. Introduction

Environmental protection especially global warming is now the hottest international issue and reduction of CO_2 emission from transport sector is the assignment seriously requested to each of motorized countries. On the other hand, noise abatement is also not negligible issue, since our human beings directly sensate noise and noise exposure could cause not only physical but also emotional health problems such as annoyance, sleep disturbance, hypertension, and so on.

In this study, a system which evaluates CO_2 emission and road noise level for a citywide area linked with traffic simulation is proposed. For transport sector, most of such environmental impacts are realized through traffic changes due to the countermeasures toward environment friendly society. Therefore, it is advantageous to link CO_2 emission model and/or road noise evaluation model with a traffic simulation model that could evaluate dynamic traffic changes.

Historically, CO_2 emission, road noise, and traffic simulation models have been intensively studied by quite a few researchers. However, they have been developed almost independently except for a few studies such as Bhaskar et. al. [1],[2] and Chung et. al. [3], in which a noise model is combined with a traffic simulator. Therefore, in this study, a combined system of not only noise model but also CO_2 emission model linked with a traffic simulator is proposed to evaluate more complete environmental impacts.

For the combined system, model characteristics must be first understood. For instance, several CO_2 emission models with different level of details have been proposed ranging from microscopic one based on driving behavior such as gear changing and brake/acceleration pedal manipulations to macroscopic unit emission model. Similarly, different types of noise evaluation and traffic simulation models are also found. In general, microscopic emission and noise models may request detailed inputs which cannot be supplied from traffic simulation. On the other hand, the macroscopic model such as unit emission model cannot reflect changes in traffic condition but only dependent on travel distance.

Considering these model characteristics, traffic simulator AVENUE is chosen because it can reproduce citywide dynamic traffic conditions and also it has been well validated in our previous studies. Then, the ASJ noise model and average speed based CO_2 emission model by NILIM are selected, since they can reasonably respond to dynamic traffic conditions and request only inputs obtained from the traffic simulator AVENUE.

In this paper, the models employed are first explained briefly, secondly the proposed combined system is validated by applying to Tsukuba city, and finally a case impact study of a new road infrastructure is presented.

2. Outline of the Simulation Model

In recent years, traffic simulation models have been applied to evaluate management schemes such as Intelligent Transport Systems (ITS) and Traffic Demand Management (TDM). And it is also used for a variety of purposes because it can simulate dynamic traffic situations. Therefore, cooperation of environmental evaluation methods and traffic simulation models is efficient for environmental evaluation (prediction) in citywide road networks.

In this study, the traffic simulation model AVENUE (an Advanced & Visual Evaluator for road Networks in Urban arEas) is applied. AVENUE is a network wide traffic simulation model which includes a traffic flow model and route choice behavior models, and is compatible with several models. Figure 1 shows the simulation display with GUI.

Figure 1. Traffic simulation model AVENUE

AVENUE employs the Hybrid Block Density Method (HBDM) as its traffic flow model which is extended from the Block Density Method [4],[5]. In the HBDM, each link is divided into several blocks, and the in/out-flow and the density of each block are revised at every scanning interval based on the flow-conservation law and the Q-K relationships. And there are two types of route choice models: Minimum Path in which everyone chooses the cheapest route and Logit Path in which route choice probability is given by the Logit model based on the generalized path cost.

AVENUE has been verified in accordance with the Verification Manual of Traffic Simulation Model (see http://www.jste.or.jp/sim/index.html) [6], and is also validated using a benchmark data set [7].

3. Noise Evaluation Method

3.1 Calculation Procedure of Noise Index

The calculation of vehicle pass-by noise is mainly divided into two parts: the calculation of sound power level for each vehicle and the calculation of sound propagation from each vehicle to receiving points. It is described as the following equation:

$$L_A^{ik} = L_{WA}^{ik} + \Delta L_{pr}^{ik}, \quad (1)$$

L_A^{ik} = A-weighted sound pressure level at a receiving point propagated from vehicle i during period k[dB],

L_{WA}^{ik} = A-weighted sound power level of vehicle i during period k [dB],

ΔL_{pr}^{ik} = attenuation term regarding sound propagation from vehicle i during period k [dB].

The first term of Eq.(1), L_{WA}^{ik}, ASJ Model explained in the next section is applied. On the other hand, the second attenuation term, ΔL_{pr}^{ik}, consists of the follow components [8]:

$$\Delta L_{pr}^{ik} = \Delta L_{dis}^{ik} + \Delta L_{dif}^{ik} + \Delta L_{grnd}^{ik} + \Delta L_{air}^{ik}, \quad (2)$$

where ΔL_{dis}^{ik}, ΔL_{dif}^{ik}, ΔL_{grnd}^{ik} and ΔL_{air}^{ik} are the correction terms of sound attenuation in distance, diffraction, ground effect and air absorption, respectively. The correction term of sound attenuation in distance ΔL_{dis}^{ik} is calculated by using the theoretical value of sound attenuation on infinite reflective surface. The correction term of diffraction ΔL_{dif}^{ik} is calculated by using the empirical model with the parameter of path length. The correction term of ground effect ΔL_{grnd}^{ik} is calculated for each surface type by using the empirical model with the parameters of heights of sound source and receiver, and propagation distance. The correction term of air absorption ΔL_{air}^{ik} is calculated by using the function of propagation distance on the basis of ISO 9613-1:1993 [9].

The total A-weighted sound pressure level at a receiving point during period k, L_A^k [dB], is then calculated by summing up each vehicle's L_A^{ik} : $L_A^k = \sum_i L_A^{ik}$. And, the final output of Equivalent continuous A-weighted sound pressure level, L_{Aeq} [dB], which is internationally adopted [10], is calculated over the study periods as follows:

$$L_{\text{Aeq}} = 10\log_{10}\left(\frac{1}{N}\sum_{k=1}^{N} 10^{\frac{L_A^k}{10}}\right), \quad (3)$$

where N is the number of time periods from start to end of the evaluation.

3.2 Engineering Calculation Method of Sound Power Level

In order to calculate simply the traffic noise in the citywide road network, the road traffic noise prediction model "ASJ RTN-Model 2003" (ASJ Model) is useful [11]. In this model, sound power levels (L_{WA}) both for steady running condition and transient running condition can be calculated as shown in Fig. 2. In the equations of the figure, C_{T} and C_{S} are regression coefficients. Therefore both equations are only the function of vehicle speed V [km/h].

ASJ Model doesn't have the capability to directly consider the increase of sound power level during accelerating running condition. If more precise analysis of the effect of accelerating running condition is expected, the sound power calculation model applicable to transient running condition (applied in the Dynamic Simulation Method proposed by the authors [12]) is able to be utilized.

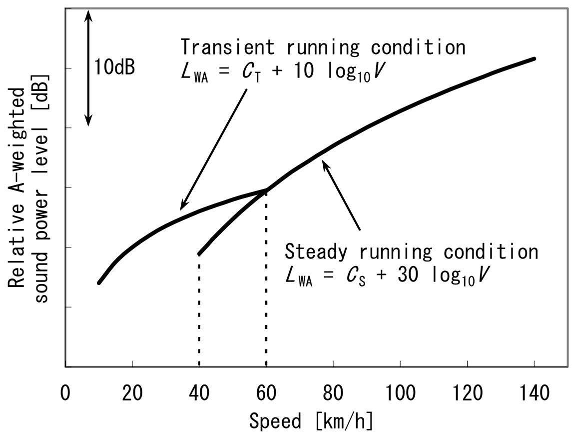

Figure 2. Road vehicles' sound power calculation model of ASJ RTN-Model 2003 [11]

4. CO_2 Evaluation Method

In the study, the average travel speed based CO_2 emission model, proposed by National Institute for Land, Infrastructure and Transport, Ministry of Land, Infrastructure and Transport (NILIM) [13], is used to evaluate CO_2 emission. The parameters in the model, Eq.(4), were calibrated using CO_2 emission data obtained by chassis dynamometer tests for total 43 vehicles: 10 gasoline passenger cars, 10 gasoline trucks, 4 diesel passenger cars and 19 diesel trucks. CO_2 emissions were measured by several real-world driving test cycles with various average speeds. Furthermore, the composition of vehicle types and the average half loaded weight obtained by the roadside plate number survey were taken into account to estimate the parameters.

The equation of the model is:

$$EF_{CO2}(v_i) = a_1/v_i + a_2 v_i + a_3 v_i^2 + a_4 , \quad (4)$$

$EF_{CO2}(v_i)$ = emission factor of CO_2 per unit distance from vehicle i [g-CO_2/km],

v_i = average travel speed of vehicle i within one trip [km/h],

a_1, a_2, a_3, and a_4 = parameters.

Figure 3 shows the relationship between the CO_2 emission and the average travel speed for small and large vehicles, respectively. The method evaluating total CO_2 emission in the whole study area from the output of the traffic simulator is as follows:

a) The average travel speed v_i and travel distance x_i for vehicle i in the whole trip is evaluated from the output of the traffic simulator.

b) The CO_2 emission of the vehicle i, $ECO2_i$, is evaluated by $ECO2_i = EF_{CO2}(v_i)\cdot x_i$.

c) Total CO_2 emission ECO2 is calculated by summing up each vehicle emission: $ECO2 = \sum_i ECO2_i$.

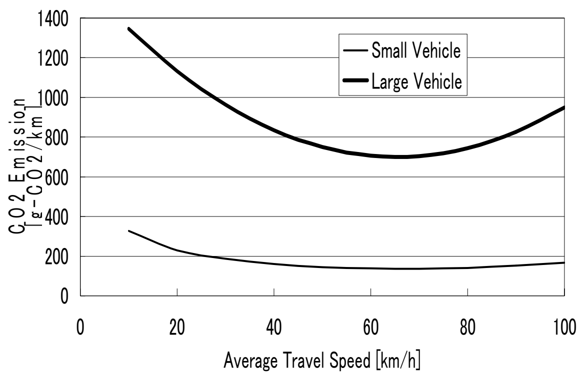

Figure 3. CO_2 Emission Model used in the study

5. Application to Tsukuba City

By using the AVENUE simulation model, the ASJ noise model and the NILIM CO_2 emission model, the citywide road traffic noise and CO_2 emission were estimated.

5.1 Study Area

As a case study, a suburban city in Japan "Tsukuba-city" was selected. A road map of the city is shown in Fig. 4. Tsukuba city is located about 60 km away from Tokyo in the direction of northeast. There are two major roads, the national highway and the Joban expressway.

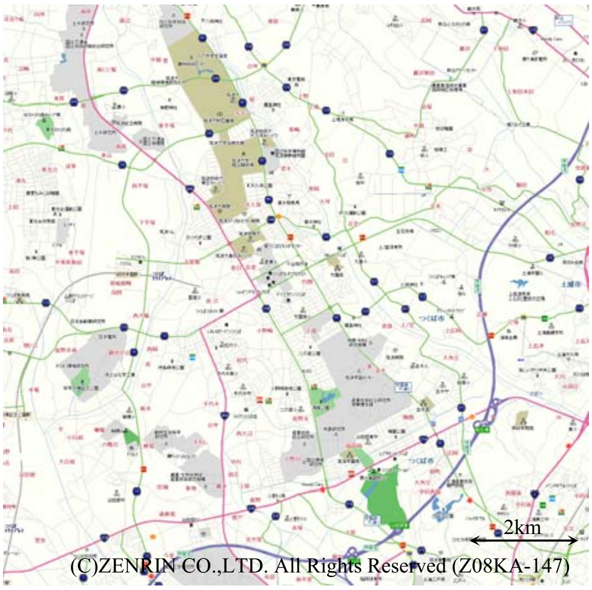

Figure 4. Road map of the study area

In order to predict road traffic noise, it is necessary to grasp the information of the road network in the whole city. From a digital road map, the road network consisting of nodes and links is defined as shown in Figure 5, in which the small squares and the solid lines are the nodes and the links. In this area, the numbers of nodes and links are 1,723 and 4,832, respectively.

In the traffic simulation, each vehicle starts from the origin node, follows the suitable route to the destination based on the traffic condition, and disappears at the destination node. Therefore, in order to predict the traffic flow in the road network, it is necessary to set the OD traffic volume.

However, it is generally impractical to observe the OD traffic volume. Therefore, for the first step of our study, the OD traffic volume was estimated from the roadside traffic volume that was discretely measured in Tsukuba city at 12 main intersections. Then, the OD volume is estimated by the Oneyama's method [14].

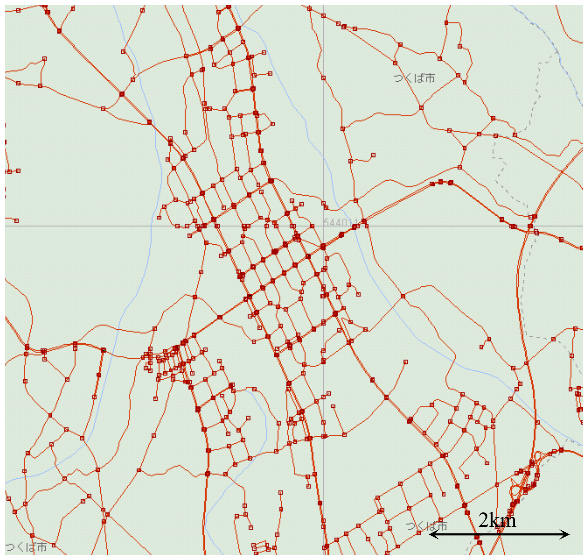

Figure 5. Nodes and links in the study area

5.2 Simulation Result

Figure 6 shows one frame of the simulated traffic flow animation in Tsukuba city. In the figure, the large number of points on the roads are the individual vehicles running on the network. From the computer monitor, individual vehicle movements, route choice behaviors and time variation of congestion points can be examined.

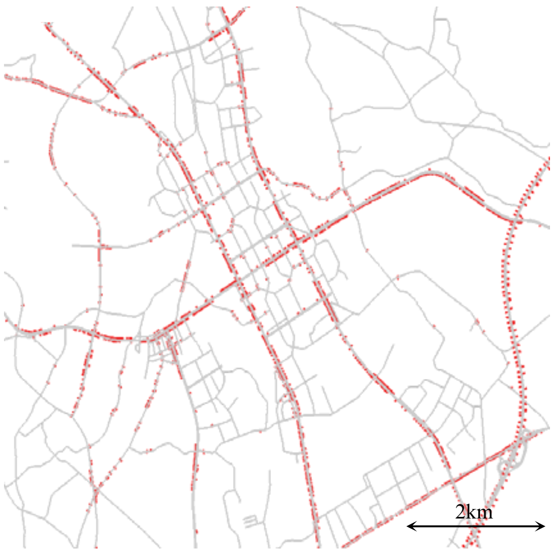

Figure 6. One frame of the simulated traffic flow

By using the estimated traffic flow, the traffic volumes at each intersection and the travel times in congested area were compared to the measured ones. As shown in Fig. 7, the simulated flow agrees with the observed flow with the correlation coefficients above 0.779. In the case of the travel times, the differences between the estimated and measured data are within 23% (9% on average). Though these comparisons cover only the limited situation, the estimated traffic flow seems to reasonably reproduce the citywide traffic condition in Tsukuba city.

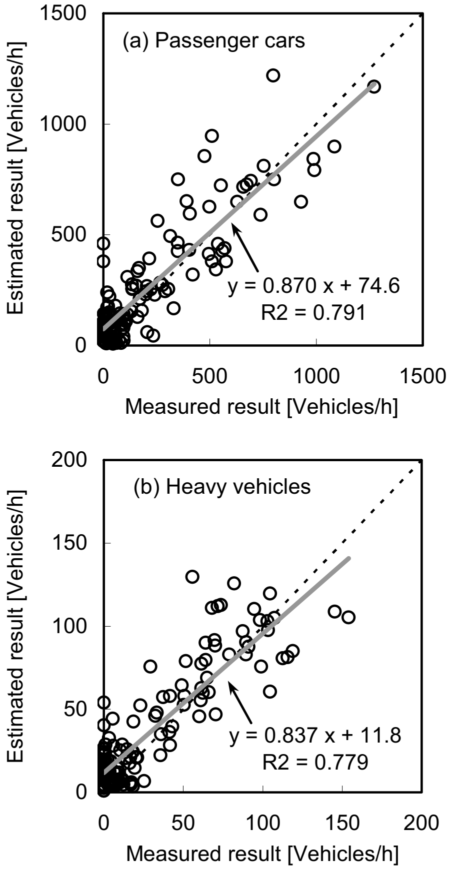

Figure 7. Comparison between estimated and measured traffic volumes

5.3 Noise and CO_2 Evaluation Results

First, the citywide road traffic noise was calculated by introducing the simulated traffic flow into the ASJ Model. The estimated noise map (L_{Aeq} map) in Tsukuba city is shown in Fig. 8. The road traffic noise on the road network including not only the main roads but also the minute streets can be estimated by using this prediction model. From Fig. 8, it is found that the levels in the area along the main urban roads and the expressway are high. In the calculation of the sound propagation, presently, only the sound attenuation in distance (ΔL_{dis} in Eq. (2)) is calculated, and the other correction terms regarding sound propagation (diffraction, ground effect and air absorption) are not considered. Therefore simulated road traffic noise simply decreases according to the distance from each road.

Next, the CO_2 emission from whole road network was also calculated by introducing the simulated traffic flow into our CO_2 evaluation method. As a result, the CO_2 emission in the study area of Tsukuba city was estimated to be 48.2 ton-CO_2/h.

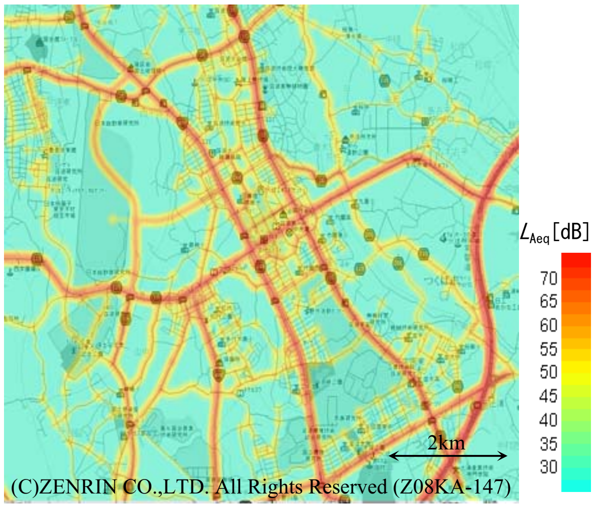

Figure 8. Estimated result of citywide road traffic noise

5.4 Noise Validation

In order to investigate the accuracy of our prediction method, Road traffic noise L_{Aeq} in 15 minutes was measured by using a precision sound level meter (Bruel & Kjaer Type 2231) and compared with the measured L_{Aeq}. The microphone was located in the position of 7.5 m from the center of the outer lane and 1.2 m above the ground. The measurement was conducted in the morning and evening on a weekday (7:30 – 10:30 and 16:00 – 18:15 on September 5th (Tuesday) 2006). The result is shown in Figure 9. The differences between estimated and measured noise levels are within 3.2 dB. This result suggests that our prediction method is able to estimate citywide road traffic noise quite well.

5.5 Policy Impact Evaluation

As an example of the traffic flow managements, the changes of the traffic noise and CO_2 emission caused by the new road infrastructure shown in Fig. 10 in bold lines are examined.

Figure 11 shows the noise maps estimated from the traffic flow before and after the new roads were established. The noise increase along the new roads is clearly seen. However in the other roads, the effect of the noise reduction is unable to be clearly seen due to the speed of the traffic flow being increased. This result indicates the difficulties of the noise reduction measure.

The decrease of the CO_2 emission by the opening of the new roads was predicted to be 2.3% (from 48.2 ton-CO_2/h to 47.1 ton-CO_2/h). This is ascribed to the traffic volume concentrated in the city center being dispersed, thus the traffic flow generally becoming smoother.

6. Summary and Conclusion

In this study, a system in which CO_2 emission and road noise models are combined with traffic simulation model is proposed to evaluate environmental impacts due to some countermeasures for more sustainable road transport. For CO_2 emission, the average speed based CO_2 emission model by NILIM is used. For noise evaluation and traffic simulation, the ASJ Model and traffic simulator AVENUE are employed respectively. The interface between the models is developed so that output from the traffic simulation model could be used as the input to the CO_2 emission and noise evaluation models. The proposed system is then validated by applying to a whole Tsukuba city and the estimated traffic flow, travel times, and noise levels reasonably agree with the observed ones. For instance, the difference between the estimated and observed noise levels, L_{Aeq}, are within 3.2 dB at 11 observed locations in the study area. Lastly, an impact analysis of a new road infrastructure is examined based on the future plan of the Tsukuba city. Although CO_2 emission is estimated to decrease by 2.3%, the noise levels along major roads are expected to mostly increase by the higher travel speed with almost the same noise levels as before at minor roads. The difficulty in the noise abatement is again reconfirmed.

The following items would be candidates for the future study:

- Although the average speed based CO_2 emission model has been individually validated in several previous studies, the validation in this combined system with traffic simulation is required.
- The system is still so primitive that only experts can use. The human-machine interface has to be improved for much more friendly to general users.
- More sophisticated model than the average speed based CO_2 emission model could be also installed in the system, since the emission associated with traffic flow is normally difficult to be explained only by the average speed.
- Since global warming is the international issue, it is needed to establish a proper methodology for the evaluation of CO_2 emission that can be internationally acceptable.
- Other environmental measures such as NOx, particulate matter, and hydrocarbon could be included into the system.

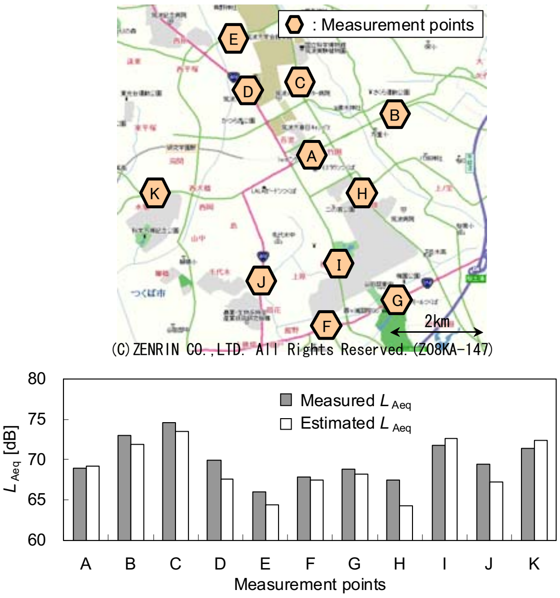

Figure 9. Comparison between estimated and measured L_{Aeq}

Figure 10. The layout of the assumed new roads

(a) Before the opening of the new roads (b) After the opening of the new roads

Figure 11. Change of the noise map according to the opening of the new roads

References

[1] A. Bhaskar, E. Chung, M. Kuwahara and Y. Oshino, "Integration of a road traffic noise model (ASJ) and traffic simulation (AVENUE) for built-up area", *Urban Transport X: Urban Transport and the Environment in the 21st Century*, Edited by C. A. Brebbia and L.C. Wadhwa, 2004, pp.783-794. (WIT Press).

[2] A. Bhaskar, E. Chung and M. Kuwahara, "Development and implementation of areawide dynamic road traffic noise simulator – DRONE", *Transportation Research Part D: Transport and Environment*, Vol.12, No.5, 2007, pp.371-378.

[3] E. Chung, A. Bhaskar and M. Kuwahara, "Large area noise evaluation", *Highway and Urban Environment*, Vol 12. Edited by G. M. Morrison and S. Rauch, 2007, pp.579-589 (Springer).

[4] R. Horiguchi, et al., "A Development of a Traffic Simulator for Urban Road Networks: AVENUE", *Vehicle Navigation & Information Systems Conference Proceedings*, Yokohama, 1994, pp.245-250.

[5] R. Horiguchi, et al., "The Case Studies of the Traffic Assessment Using AVENUE", *IATSS Research*, Vol.18, No.2, 1994, pp.76-79.

[6] R. Horiguchi, "Standardization of Traffic Simulation Models through Verification and Validation", *Proceedings of Best Practices in Road Engineering Conference*, Kuala Lunpur, CD-ROM, 2003.

[7] R. Horiguchi, T. Yoshii, H. Akahane, M. Kuwahara, M. Katakura, H. Ozaki and T. Oguchi, "Constructing a Benchmark Data Set for Validity Evaluation of Road Network Simulation Models", *Proceedings of 8th World Conference on Transport Research*, Antwerp, 1998.

[8] K. Yamamoto and H. Tachibana, "Road traffic noise prediction model "ASJ RTN-Model 2003" proposed by the Acoustical Society of Japan - The framework and the accuracy of the prediction -", *Proceedings of Inter-noise 2004*, 310, 2004.

[9] International Organization for Standardization, "ISO 9613-1:1993. Acoustics - Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere", ISO, Geneva, Switzerland, 1993.

[10] International Organization for Standardization, "ISO 1996-1:2003. Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures", ISO, Geneva, Switzerland, 2003.

[11] S. Kono, Y. Oshino, T. Iwase, T. Sone and H. Tachibana, "Road traffic noise prediction model 'ASJ RTN-Model 2003' proposed by the Acoustical Society of Japan - Part 2 : Calculation model of sound power emission of road vehicles", *Proceedings of ICA 2004*, Kyoto, Japan, 2004.

[12] Y. Oshino and H. Tachibana, "Prediction of road traffic noise taking account of transient running conditions of vehicles", *Proceedings of Inter-noise 93*, 1993, pp.629-632.

[13] N. Ohshiro, M. Matsushita, Y. Namikawa and H. Ohnishi, "Fuel Consumption and Emission Factors of Carbon Dioxide for Motor Vehicles", *Civil Engineering Journal*, Vol.43, No.11, 2001, pp.50-55 (in Japanese).

[14] H. Oneyama and M. Kuwahara, "Estimation of time-varying OD traffic volume by using measured roadside traffic volume", *Traffic Engineering (JSTE)*, Vol.32, No.2, 1997, pp.5-16 (in Japanese).

Keisuke Tsukui is a senior researcher with Japan Automobile Research Institute. He has received Doctor of Engineering Degree from Kanazawa University in 2008. His major is Automotive engineering and Acoustical engineering.

Hisatomo Hanabusa is a engineer of i-Transport Lab. Co., Ltd. He has obtained M.Eng from Chiba Institute of Technology. His major is traffic engineering particularly on traffic simulation, ITS and probe car analysis.

Hiroyuki Oneyama is Associate Professor at Tokyo Metropolitan University. He has received Doctor of Engineering Degree from University of Tokyo in 2003. His major is Traffic Engineering and Traffic Environment.

Yasuo Oshino is a senior chief researcher with Japan Automobile Research Institute. He has received Doctor Degree from University of Tokyo in 1993. His major is Automotive engineering and Acoustical engineering.

Masao Kuwahara is Professor at Institute of Industrial Science, University of Tokyo. He has received Ph.D from University of California, Berkeley in 1985. His major is traffic engineering particularly on highway capacity, traffic simulation, ITS, and highway geometric design.

Received date: January 21, 2009
Received in revised form: June 1, 2009
Accepted date: June 2, 2009
Editor: Der-Horng Lee