Areawide Road Traffic Noise Contour Maps

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Abstract

In this study a framework for developing an object-oriented tool –DRONE (areawide Dynamic ROad traffic NoisE simulator) to generate areawide noise contour maps for a road network is demonstrated. This provides faster access to information for abatement of noise policies. The approach for integrating the dynamic output from traffic simulator to noise model, which predicts traffic noise based on geographical data set for the study area, are described. Noise level at different points of study area is calculated based on integration of noise prediction model, ASJ Model-1998, with traffic simulation model, SOUND. The integration with traffic simulation model provides a dynamic access to traffic-flow characteristics and hence automated and detailed prediction of road traffic noise. Data from the integration of traffic and noise simulation models are used to generating areawide noise contours using GIS. The application of DRONE on a real world situation is also presented.

Keywords: Areawide noise simulation; Dynamic noise simulation; DRONE; Noise contours; GIS for traffic noise; Noise pollution

1. Introduction

Road traffic noise is one of the most widespread and growing environmental problems in urban areas. Noise is frequently overlooked as a form of pollutant because it is ubiquitous, it has no chemical toxicity and there is no attributable death. The effects of traffic noise on people's health are wide ranging and may include; psychological effects (annoyance and behavior reactions); physiological effects (sleep disturbance, hearing loss and general fatigue through sleep loss); and social effects (restrictions on people's social activities and effects on work efficiency) (EPA Victoria, 2002).

Traffic noise analysis and prediction models are important tools while planning for environmental friendly roads and to access the effect of noise mitigation measure. Traditionally road traffic noise exposure is calculated for specific locations only such as school, hospital and airport. The estimated results are available only for a limited number of locations and are generally presented numerically. It is difficult to obtain overview of the variation in noise level for a larger area and gain insight into the effect of possible noise mitigation measures.

A large number of noise prediction models have been developed such as ASJ Model-1998 (Tachibana, 2000), CRTN (Welsh, 1988) and FHWA (Barry and Reagan, 1978), which can predict road traffic noise at a reception point. Researchers have tried to link noise prediction models with GIS by applying spatial operations to geographically located information using GIS. However the current linkage of GIS system with noise model fails to take into account of the following aspects:

a. Application of the current systems is limited to small area around roadside only.
b. These systems do not consider time dependent traffic demand and hence fails to consider inbuilt dynamic traffic characteristics.
c. Noise prediction models used in these systems are not calibrated for small time interval noise prediction, such as $L_{Aeq,15min}$.

The most desired linkage of a noise model with traffic simulation would be an integrated traffic-noise-GIS-system, where GIS based noise tool is developed taking into account traffic simulation. The aim of this research is to fulfill this need and fill the gap between road traffic noise model and road traffic simulation through integration. Our study develops an object-oriented tool to generate areawide road traffic noise contour maps for road network (that can provide adequate support to decision makers) by integrating road traffic simulation with road traffic noise prediction model. This provides dynamic access to traffic flow-characteristics, hence automated and detailed prediction of the road traffic noise.

The application of the tool is illustrated on a study area around Ikegami-Shinmachi intersection, Kawasaki, Japan. The results of the integration are presented in the form of dynamic noise contour maps of the study area. The contour maps provided are for overall noise level and also for different types of vehicles- describing contributed noise pollution by each type.

2. Uses and Benefits of the Research

DRONE can be applied to any areawide road traffic network to predict noise at any number of receptor points and to generate areawide noise contour maps. Areawide dynamic road traffic noise prediction by DRONE can be applied to:

a. Identify hot spots where noise level exceeds the national noise standards.
b. Study the merits and demerits of noise abatement policies based on cost efficiency and effectiveness.

c. Quantify social effects associated with noise pollution. By overlaying daytime population, night time population and other social characteristics on to the noise contour, the social effects of noise pollution can also be studied.
d. Strategic planning where the economic cost of noise pollution can be derived from the reduction in the property values which is an integral component of benefit cost analysis for new projects (McDonnel & Chung, 2001). This will have a dramatic impact on the planning of projects such as construction of a new freeway.
e. Increase general awareness to the people regarding the pollution level in the city. (Noise contour maps used in conjunction with environmental models, such as green house gas emission and air quality, can provide visual effect to the pollution).

3. Literature Review

Manual road traffic noise exposure calculations take time and are costly. A number of researchers have tried to automate traffic noise prediction. Most of the present methods of road traffic noise prediction are limited to noise prediction either at a point or to some specific points only. Ton et al. (1998) developed software library TRANSOOP, for calculation of road traffic noise at a reception point based on CRTN. Jain et al. (1999) developed TNP-MM which predicts noise at a receptor point for the geometry, traffic flow and barrier input. TNP-MM calculation is based on empirical relations calibrated for Delhi, India only. Some commercial packages can predict noise for a large area such as SoundPLAN (Braunstein & Berndt, 1999), TNoiseGIS (Pamanikabud & Tansatcha, 2003). TNoiseGIS can predict noise based on CRTN and FHWA.

All these systems require input data for traffic characteristics i.e. traffic volume, composition of traffic, and traffic speed to be fed externally. These methods currently used, model the traffic as a steady flow. Therefore such models are only able to predict the average noise level generated at the road side for a large time interval. Moreover, the empirical noise prediction models used in these systems (CRTN, FHWA) are not calibrated for smaller time interval (say 15 minutes) noise level prediction, so smaller time window noise level prediction with these noise models is not possible.

Almost all the automated noise simulation systems are based on CRTN or FHWA noise prediction methodology, which is simple to apply but is based on a large number of assumptions. CRTN and FHWA are empirical models not calibrated based on present change of technology, and noise abatement policies for road traffic vehicle.

ASJ-1998 model is advanced and is a semi empirical model. ASJ-1998 model predicts equivalent continuous A-weighted sound pressure level in roadside areas as per energy-based calculation. This model consists of the modules of sound power levels of road vehicles under steady and unsteady running conditions (Tachibana, 2000). These characteristics of ASJ-1998 model provide the flexibility to integrate the noise model with traffic simulation. The integration of the traffic simulation with noise prediction model covers dynamic short term variation in traffic flow hence the detailed (shorter time window e.g. $L_{Aeq,15\ min}$) noise level prediction is possible.

4. Road Traffic Prediction Model (ASJ Model-1998)

ASJ Model-1998 developed by Acoustic Society of Japan, is based on two kind of sound propagation calculation methods denoted by A-method (precision method) in which sound propagation is precisely calculated for each frequency (center frequencies of octave bands from 63 Hz to 4 kHz) and is derived from wave theory; B-method (engineering method) which consists of geometrical acoustics and empirical models (Yamamoto et al, 2000). This method is to separate the propagation factors of road traffic noise prediction into a series of correction terms, each of which has physical significance such as diffraction and reflection of noise propagation. (Oshino et al, 2000).

4.1. Principles for Energy Based Calculation in ASJ Method-1998

In this model, the first procedure is to calculate the time history of A-weighted sound level at the reception point caused by an isolated vehicle passage on the road (lane) under consideration. This gives a "unit pattern" (for each vehicle type and for each lane of a particular road under consideration) at a receptor point as shown in fig. 1. By squaring and integrating the unit pattern, the sound pressure exposure is obtained. Finally by considering the dynamic traffic volume and by averaging the total sound exposure, L_{Aeq}, can be calculated (Tachibana, 2000).

4.2. Calculation Procedure

Each lane of the road under consideration is properly divided into finite number of segments (see fig. 2) and for each segment the sound propagation from the center point of the segment to the receptor point is calculated. This provides a "unit pattern" (see fig. 1) for a particular type of vehicle on the lane under consideration. By squaring and integrating the unit pattern total sound pressure exposure (E) over the time interval during which the source passes the lane under consideration is obtained. The quantity expressed in dB(A) of the total sound pressure exposure E is sound exposure level (L_{AE})

$$L_{AE} = 10\log_{10}\frac{E}{E_o} \tag{1}$$

where, $E_o = 4*10^{-10}$ Pa^{2}s

By considering the traffic volume, equivalent continuous sound pressure (A weighted) level (L_{Aeq}) for a particular lane is obtained as per the following equation

$$L_{Aeq} = 10\log_{10}(10^{L_{AE}/10}\frac{N}{t}) \tag{2}$$

where, N is traffic volume (number of vehicles/ time t(s))
For L_{Aeq} (1- hour), t = 3600 seconds

$$\begin{aligned} L_{Aeq}(hourly) &= 10\log_{10}(10^{L_{AE}/10}\frac{N(veh/hr)}{3600}) \\ &= L_{AE} + 10\log_{10} N - 35.6 \end{aligned} \tag{3}$$

The calculation mentioned above is made for all the lanes of the road under consideration and for all vehicle type, and finally L_{Aeq} is calculated by combining these results based on energy. (For detailed calculation procedure refer to Tachibana, 2000; Oshino, 2000 and Yamamoto, 2000)

There is no restriction in the calculation principle. The validity of the model has been examined for different type of road, vehicle running speed, prediction area and meteorological conditions, the details of which can be found in Tachibana (2000).

5. Road Traffic Simulation

Road traffic simulation model, SOUND (Simulation and Urban road Network with Dynamic route choice) (Yoshii, 1995) can efficiently and accurately reproduce dynamic traffic conditions on a large and complicated road network. The model consists of vehicle simulation and route choice modules, which are alternatively implemented in short time intervals to reproduce the dynamic stochastic user equilibrium flow.

SOUND was used to predict traffic flow characteristics needed as an input to noise prediction model. The input required are road network data (geographical road location including lane configuration, capacity of link, etc); signal control parameters, road traffic regulations and traffic demands for each OD pair.

5.1. Outline of SOUND Model

In the vehicle simulation module, travel time in each link is evaluated by moving vehicles forwarded along routes determined by the route choice module, whereas the route choice module evaluates every driver's choice of route at a regular interval based on travel times estimated by the vehicles simulation module. These two modules are repeatedly implemented to produce dynamic evaluation of traffic flow on a network (see fig. 3).

The probability of choosing a route by a vehicle depends on the cost of the route. The cost function (for a route) is based on preference of a vehicle for travel time and distance to travel on the route. Left and right turns on a route are incorporated by considering penalty for each left and right turn.

Route choice probability for choosing route k, is expressed as following

$$p_k = \frac{\exp(-\theta.C_k)}{\sum_{i=1}^{n} \exp(-\theta.C_i)} \tag{4}$$

Where θ is the logit parameter used in route choice guidance and C_i is the cost of the ith path.

SOUND has been validated for a number of practical conditions (for details of validation refer to Yoshii, 1995).

So far we have discussed about the traffic simulation and noise prediction model used for development of DRONE. In the following section, the focus is on the methodology for development of DRONE and a real world application of the developed model.

6. Methodology for DRONE

DRONE is based on Object-Oriented framework (C++), which features the system with a high flexibility to modify or extend its function. The system developed takes the dynamic output from traffic simulator-SOUND and performs number of calculations based on B-Method (engineering method) of ASJ Model-1998 (Section 3.1), to predict noise pollution level not only on spatial (areawide) scale but also on temporal (dynamic) scale (see fig. 4).

Traffic simulator SOUND can provide dynamic traffic flow on complicated road network with as detailed as one second step. ASJ Model-1998 has the flexibility to predict L_{Aeq} for any time window such as 15min, 30min and one hour. It can also independently predict contribution of noise pollution by different vehicle type. If we consider eqn (3) by adjusting the traffic simulation window to time "t" (say 15 minutes, 1-hour, etc) we can predict $L_{Aeq,\ t}$.

The following section discusses the input required for DRONE.

6.1 Input Data for DRONE

In order to reproduce the complex real world situation, road network and infrastructural data for the study area is needed (such as lane configuration on the road, type of road surface, building location and ground properties). SOUND simulation requires dynamic OD for the network along with various flow regulations such as signal control parameters on the intersections and toll information on a road. Parameters such as capacity, saturation flow rate and free flow speed on each link are to be tuned for proper reproduction of traffic flow conditions and traffic behavior. Contour maps are generated based on prediction of noise at various receptor points which are arranged in a grid pattern with node of the grid as receptor point. Grid spacing is specified based on optimum level of accuracy and simulation time. Smaller grid spacing produces more accurate contour maps at the cost of simulation time. Dynamic contour maps are generated based on the specified time interval (seconds) between two consecutive dynamic noise level prediction (say 15 minutes or 1 hour).

The flow of data between traffic simulator and GIS based noise model is presented in a self explanatory flowchart in fig. 5. DRONE first sets the entire road network along with infrastructural conditions for the study area. Based on receptor point conditions a particular receptor point is chosen. Then based on geographical location and dynamic distribution of traffic on the road network all possible traffic sources which can contribute to noise at the chosen reception point (for that particular time period) are searched. Noise level calculation based on ASJ- Model 1998 is performed for a particular source road and reception point. Dynamic traffic flow and traffic speed distribution for different class of vehicles is taken into consideration while performing noise prediction calculation for the selected source road and receptor point. The process is repeated for all the possible sources and total noise level at the receptor point is obtained by energy based addition of noise contribution from different sources.

For areawide noise prediction the above mentioned process is repeated for all the receptor points in the study area. Finally by linking the noise prediction on all the receptor points with GIS, areawide noise contour map for that particular traffic simulation period is generated. In order to predict dynamic noise level the whole process is repeated for all the time intervals.

7. Verification of DRONE

Noise level was measured at the following investigation areas:
Area A: along national route 16 in Kashiwa city.
Area B: along national route 6 in Fujishiro town.
Area C: along Tokyo ring road 7 in Katsushika ku.
Area D: along Tokyo Mejiro street in Nerima ku.
Area E: along Tokyo Mejiro street in Nerima ku.
Area F: along national route 6 in Mito city.
Area G: along Tokyo ring road 7 in Kita ku.

DRONE is verified by its application on the above mentioned areas. The layout and cross section of the road for investigation area A and area B are shown in fig. 7. (For detailed traffic condition on each area refer to Oshino, 1996). The measured and simulated noise levels were compared. The correlation coefficient for the measured versus simulated traffic noise level is satisfactory ($R^2 = 0.911$) (see fig. 6). The maximum difference between simulated and measured noise level is less than 1 dB(A).

8. Implementation on a Real World Situation

The integrated tool is applied to a real world situation at Ikegami-Shinmachi area in Kawasaki (see fig. 8) and areawide dynamic noise contour maps are generated for the study area. Noise contour maps for different types of vehicle are also presented to focus on contribution of noise pollution by different types of vehicles.

8.1. Site Description

Route No. 18 of Metropolitan Expressway (MEX) (2 lanes, both directions) is located along SW-NE diagonal of the study area around Ikegami-Shinmachi in Kawasaki (see fig. 8). One side of MEX is residential area and other side is industrial area. There are two major cross-diagonal roads-one local highway (3 lanes, both directions) running parallel to MEX along SW-NE diagonal, other is a major arterial road (2 lanes, both directions) running along NW-SE diagonal. Apart from one minor arterial road (1 lane, both directions) all other roads are minor residential roads with very little traffic flow.

8.2. Data Required for DRONE

In order to effectively reproduce the flow in the study area, field data was collected on a bigger network as shown in the fig. 9. Traffic counts along with turning ratios for four types of vehicles-small (passenger vehicles, small trucks); large (buses and big trucks) were observed at 14 major intersections. The data was collected for morning peak (7:00-10:00 am) and evening peak (4:00-7:00 pm) at 10 minute interval. Signal Control at the intersections was also observed and noted.

For the purpose of simulation validation, queue volume data at major intersections was collected. Data was collected for 10-15 signal cycles for each major flow direction during morning and evening peak hour.

Digital Road Network (DRM) for the study area was used to provide geographical data for the road network. DRM and aerial picture of the study area was superimposed by use of MapInfo as a check to DRM. Dynamic OD table for traffic simulation is estimated based on observed traffic counts and turning ratios. Turning ratio at an intersection provides the diversion rate at that intersection, hence probabilities of flow along different route through that intersection. From the diversion rate matrix probability matrix is generated, and by multiplying it with observed traffic count data, dynamic OD for the network is obtained. Real time signal data for all signalized intersections are used for dynamic consideration of signal parameters.

8.3. Traffic Simulation Validation

For validation of the simulation:

a. Simulated traffic flows at major intersections are compared with those of observed. The observed versus simulated throughputs in study area are shown in fig.10 and fig.11 for morning and evening peak respectively. According to the fig. 10 and fig. 11, the simulated traffic flow is satisfactory (correlation coefficient R^2 for both types of vehicles is greater than 0.97). W can conclude that the traffic simulator has properly reproduced the observed traffic conditions.

b. Additional check to ensure that the simulated traffic behaves the same way as the observed traffic, observed queue volume and simulated queue volume on links at observed intersections are compared as shown in fig.12 and fig.13. From these figures we can conclude that traffic simulator is able to represent the real traffic behavior properly as the links on which we have observed congestion are also represented as congested link on the simulation result. Moreover the simulated queue volume is quite comparable with that of observed one. We do not expect one to one correlation in this case as the definition for a vehicle to be a part of queue is entirely different for SOUND and field observation. The simulated queue volume for SOUND is based on number of vehicles whose travel time is greater than free flow travel time on the link. Whereas the observed queue volume is based on surveyor's judgment, that a vehicle is said to be a part of queue if its flow velocity is approx less than 5 km/hr.

8. Results

a) Detailed Noise Contour Maps

Dynamic areawide traffic noise contour maps are generated for the study area. The prediction of noise pollution is not only on the spatial scale but also on temporal scale. Fig. 14 shows dynamic noise pollution level averaged for 15 minutes for morning peak hours. These traffic noise contour maps helps in identifying “hot spots” (area with high noise level) on areawide network. As is evident from the contour maps, the areas near to the roadside are noisy (red color, high noise level) compared to areas far away from roadside (green, low noise level).

Hedonic pricing is often used as a proxy to assess the cost of pollution. The method can be applied to access the cost of noise pollution. The map produced by DRONE can be applied to count number of buildings at every dB(A) above critical threshold and making assessment of noise pollution more precise and easier.

b) Contour Maps for Noise Contribution from Different Vehicles

Noise contribution from different type of vehicles can be studied independently. Fig. 15 and fig. 16 shows noise contour maps due to light and heavy vehicles on the study network. In fact fig. 15 shows the noise pollution level in the absence of heavy vehicles in the study area. As can be seen from the contour maps, noise contributions from heavy vehicles are quite high compared to that from light vehicles. The noisy zone (red and orange) around the roads spread to greater distance for heavier vehicle case (fig. 16) as compared to that of light vehicle case (fig. 15). Along the road side of highway is redder in fig.16 (from heavy vehicles), compared to that of fig.15 (from light vehicles). In fig.15 (light) noises is more intense on arterial road compared to that on fig.16 (heavy); this is according to the expectation because heavy vehicles flow is mainly on highway and there are very few heavy vehicle flow on arterial road.

Fig. 17 represents the dynamic contribution to noise pollution by different types of vehicles at a receptor point near Ikegami-Shinmachi intersection. During the morning peak hour even though light vehicles contribution decreases after 8:00 am the contribution from heavy vehicles is increasing and the overall noise level at the prediction point is governed by the heavy vehicles. This clearly indicates that there will be significant effect on noise level if heavy vehicles flow is managed. Moreover, slight increase in heavy vehicles flow will result in significant increase in noise pollution level as compared to similar increase in number of light vehicles flow.

The contour maps highlight the noise pollution in the study area and indicate that prohibition of heavy vehicles will reduce the noise level in the restricted area. However simply banning heavy vehicle on certain road and at certain time of operation would force the heavy vehicle to use alternative routes, or different type of vehicles may substitute heavy vehicles, thus changing the noise contour map of the area. This is where DRONE can be applied to study the effect on noise level at spatial and temporal scale in order to have more effective and cost efficient solution for road traffic noise abatement policy.

9. Conclusion and Future Research

DRONE has been developed by the integration of traffic simulator (SOUND) with traffic noise prediction model (ASJ Moldel-1998). DRONE provides the flexibility to predict detailed road traffic noise (say $L_{Aeq,15min}$) not only on spatial scale (areawide) but also on temporal scale (dynamic). The model is applied to Ikegami-Shinmachi area in Kawasaki. Areawide noise contour maps are generated which clearly indicate the pollution level in the study area. Dynamic noise contribution from each class of vehicles is also represented through contour maps. The results present better overview of decrease in noise level if heavy vehicles are better managed.

The further research in the development of DRONE is incorporation of module for built-up area attenuation in noise propagation. Noise contribution from vehicles using metropolitan expressway also needs to be incorporate. ASJ noise calculation steps also need to be optimized based on calculation time and accuracy of noise prediction.

10. Acknowledgement

We are thankful to Dr. R. Horiguchi, ITL, Japan for his timely guidance in the calibration of SOUND.

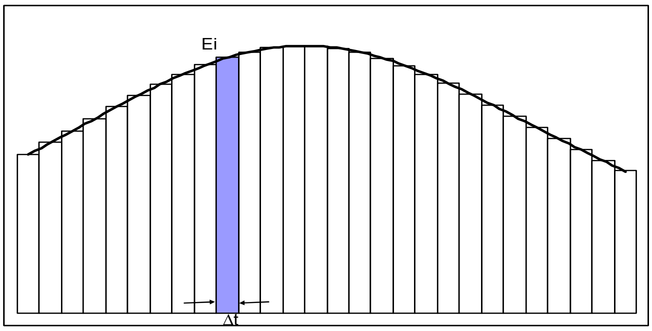


Figure 1: Unit Pattern at the reception point; Ei is the sound power level at the reception point due to vehicle ith discrete source

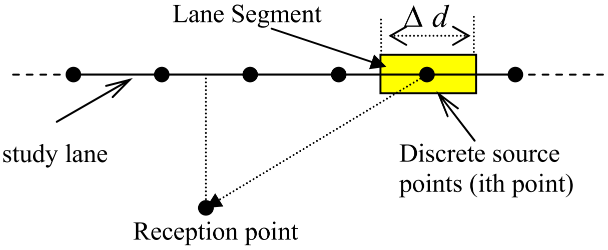


Figure 2: Study lane with discrete source positions

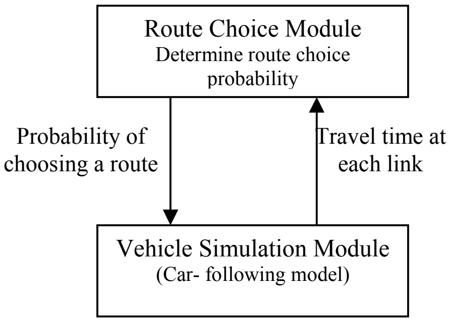


Figure 3: SOUND model structure

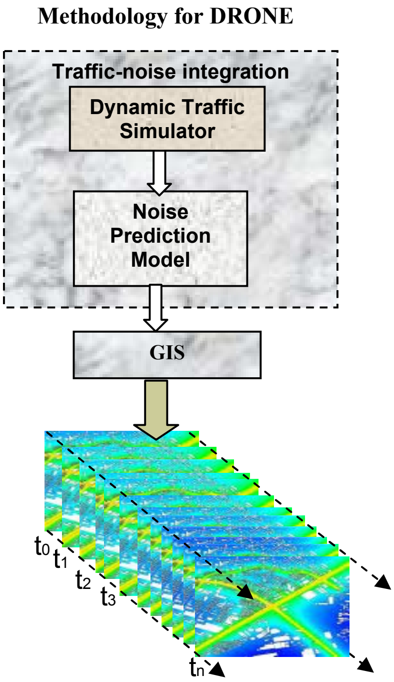


Figure 4: Contour maps are generated on spatial (areawide) and temporal (dynamic) scale

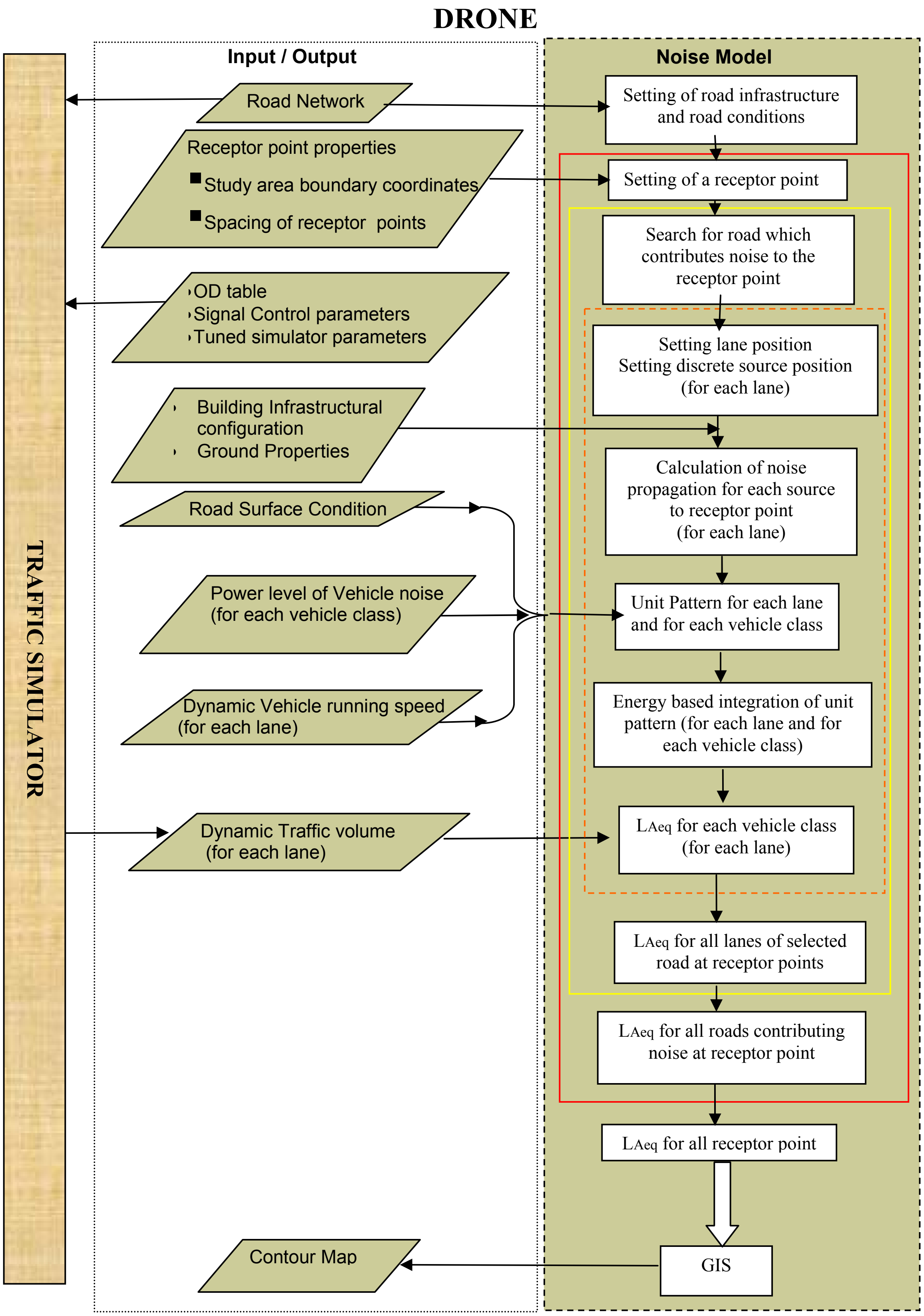


Figure 5 Flowchart for data flow in DRONE

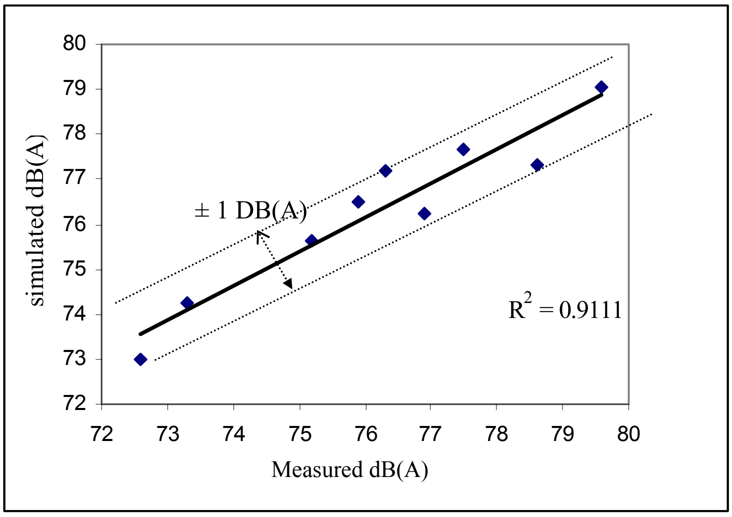
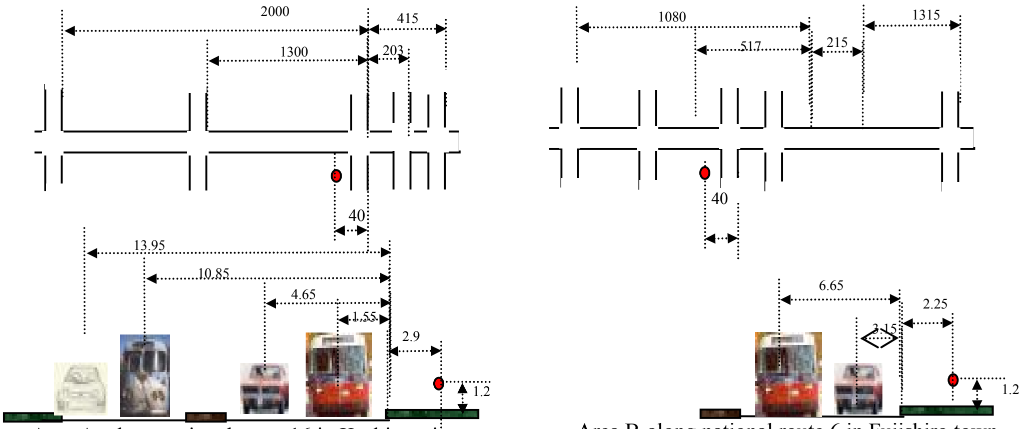


Figure 6: Measured and simulated noise level in different investigation areas



Area A: along national route 16 in Kashiwa city

Area B along national route 6 in Fujishiro town.

Figure 7: Traffic network layout and cross section of the road for different investigation areas (all dimensions are in meters, and figure is not to the scale)

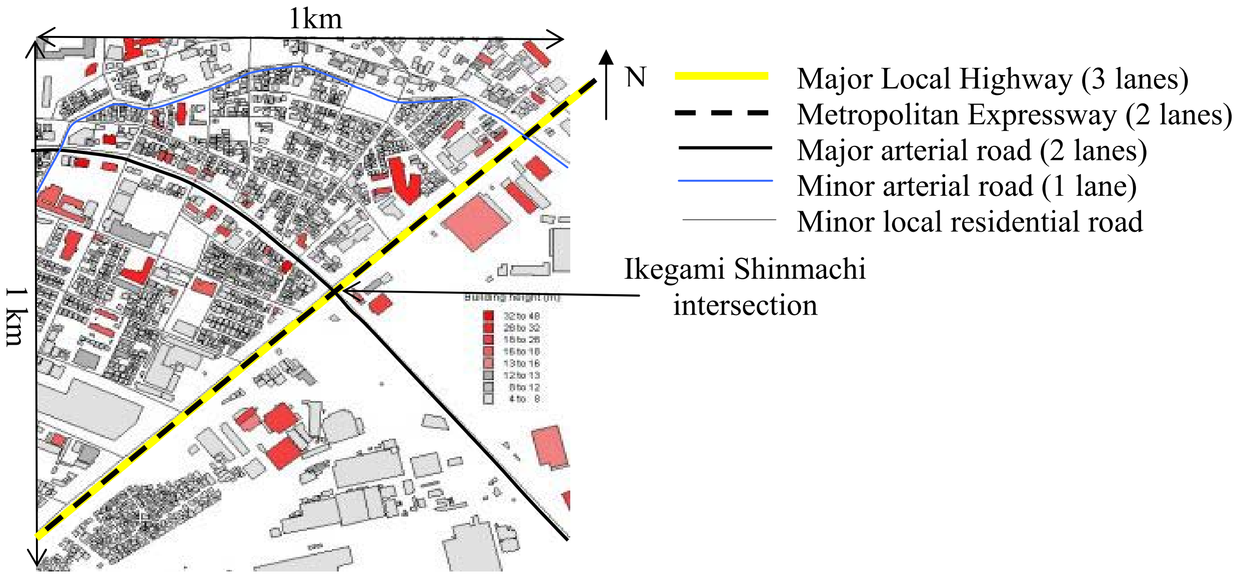


Figure 8: Study area around Ikegami-Shinmachi intersection, Kawasaki (1km x 1km)

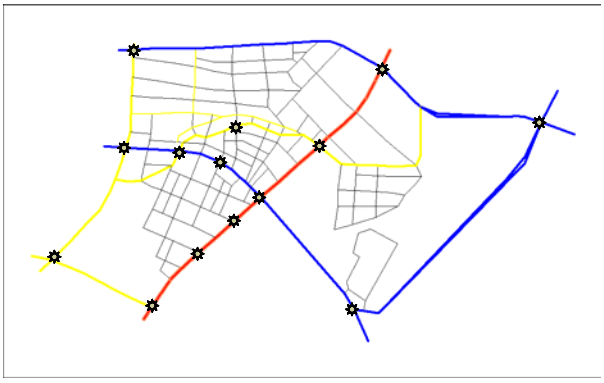


Figure 9: ✵ Observation points at Ikegami-Shinmachi study area.

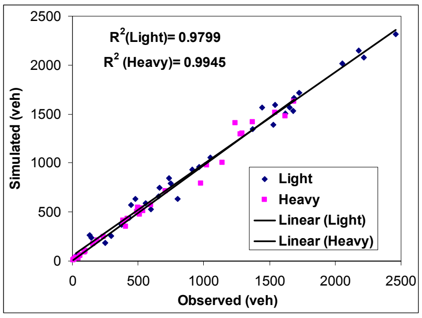


Figure 11: Observed and simulated throughput during morning peak (7:00 am -10:00 am)

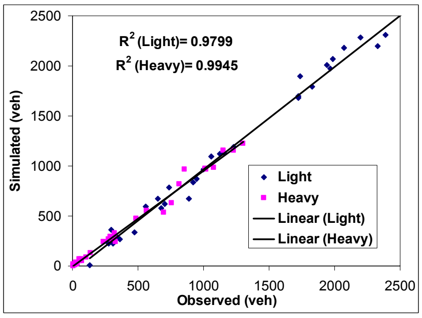


Figure 10: Observed and simulated throughput during evening peak (4:00 pm-7:00 pm)

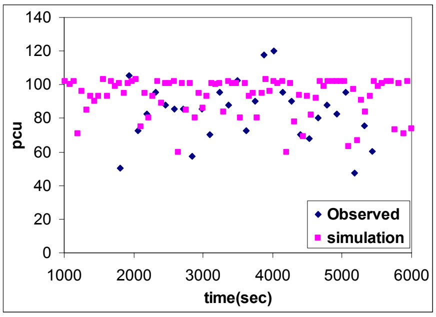


Figure 13: Observed and simulated queue volume at Ikegami-Shinmachi intersection (link from Tokyo towards Yokohama) during morning peak time

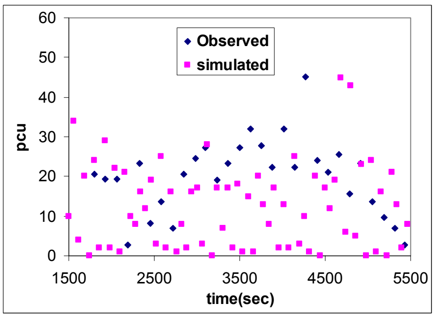
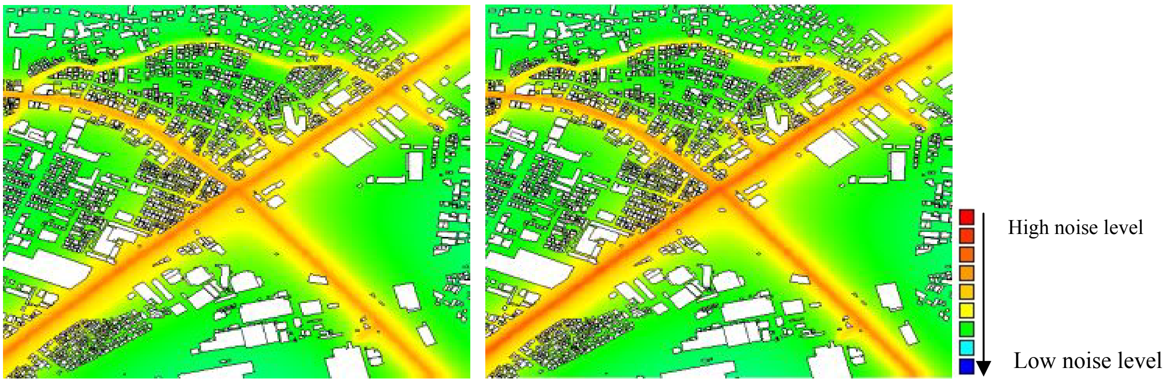


Figure 12: Observed and simulated queue volume at Ikegami-Shinmachi intersection (link from Yokohama towards Tokyo) during morning peak time



$L_{Aeq,15min}$ 8:00 - 8:15 $L_{Aeq,15min}$ 8:15 - 8:30

Figure 14: The visual representation of noise pollution in the form of contour maps where different color represents different intensity of noise.

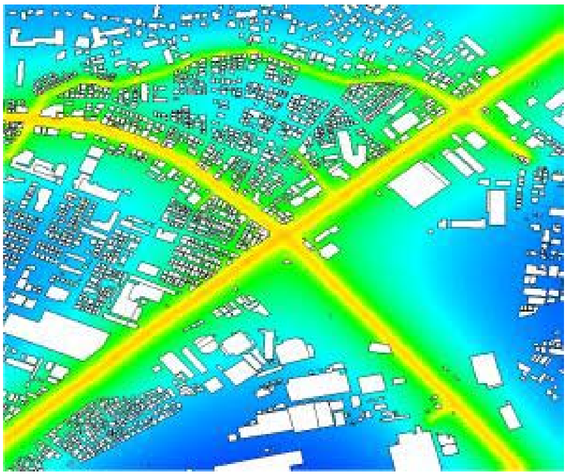


Figure 15: Light vehicle contribution

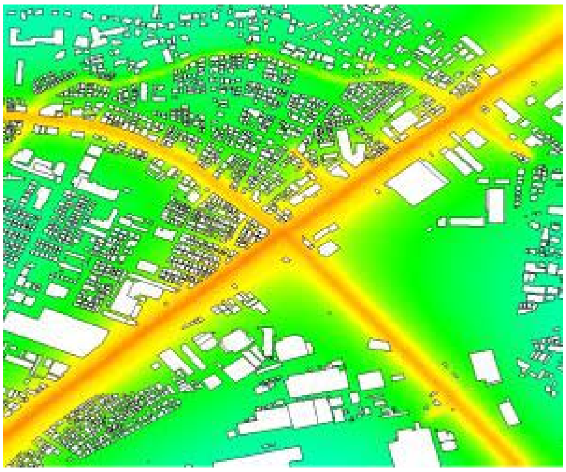


Figure 16: Heavy vehicle contribution

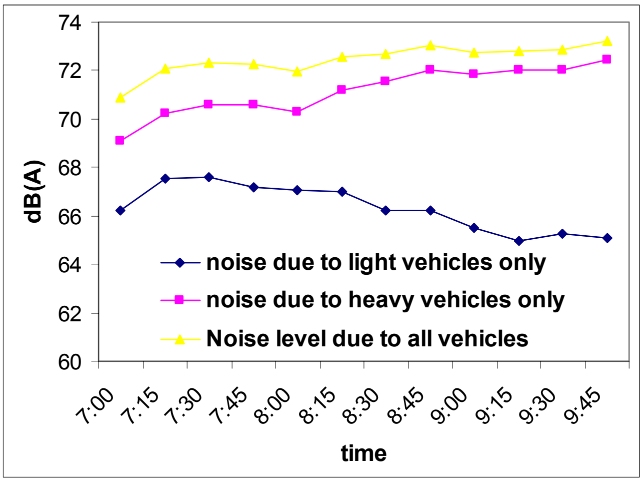


Figure 17: Contribution from different type of vehicle at a receptor point near Ikegami-Shinmachi intersection.

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