Integration of road traffic noise model (ASJ) and traffic simulation (AVENUE) for built-up area

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Abstract

Road traffic noise prediction model (ASJ MODEL-1998) has been integrated with road traffic simulator (AVENUE) to produce Dynamic areawide Road traffic NoisE simulator-DRONE. This traffic-noise-GIS based integrated tool is upgraded to predict noise level in built-up area. The integration of traffic simulation with noise model provides dynamic access to traffic flow characteristic hence automated and detailed prediction of traffic noise. The prediction is not only on spatial scale but also on temporal scale. The linkage with GIS gives visual representation to noise pollution in the form of dynamic areawide traffic noise contour maps. The application of DRONE on a real world built-up area is also presented.

Keywords: traffic noise in built-up areas, areawide noise simulation, dynamic noise simulation, DRONE, noise contour, GIS for traffic noise, noise pollution.

1 Introduction

Traffic noise prediction methods are important tool to assess the effects of noise mitigation measures. A number of noise prediction models have been developed which can predict noise level at a receptor point. Traditionally these noise predictions are limited to road side area, where the affect of building and other infrastructure as a barrier to noise propagation is not considered. None of the current models are efficiently able to consider multiple diffraction, reflection and

scattering of noise when it propagates through densely located buildings. Road traffic noise affects the quality of life in the residential areas adjoining the road. In order to impose effective and cost efficient noise abatement policy it is necessary to grasp the effect of attenuation by buildings. Uesaka *et al* [1] introduced a statistical method to estimate noise level in built-up area. This method was adopted into Acoustical Society of Japan's 1988 road traffic noise prediction model (ASJ Model-1998).

DRONE (areawide Dynamic ROad traffic NoisE simulator), has been developed by integrating traffic simulator with noise model [2]. The integration provides dynamic access to traffic flow characteristic hence automated and detailed road traffic noise prediction. The integrated tool has been linked with GIS to provide areawide noise contour maps. There is a need to upgrade DRONE, to estimate noise level in built-up area where a) it is difficult to calculate multiple diffraction and reflection between buildings; and b) it is not practical to survey the parameters for the prediction such as scale, shape and position of the buildings.

This study fulfils the need to automate the noise prediction in a built-up area. An engineering solution to the real world problem of estimating areawide dynamic noise prediction in built-up area is proposed.

DRONE can be applied to any areawide road traffic network to predict noise at any number of receptor points (even in densely arranged buildings). Areawide dynamic road traffic noise prediction by DRONE can be applied to:

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

    b.   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.

    c.   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 cost-benefit analysis for new projects [3]. This will have a dramatic impact on the planning of projects such as construction of a new freeway.

2   Noise Prediction Method (ASJ Model- 1998)

ASJ Model-1998 predicts equivalent continuous A-weighted sound pressure level according to energy-based calculation. In this model, the first step is to calculate the time history of A-weighted sound level at the receptor 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. By squaring and integrating the unit pattern, total sound pressure exposure 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 is sound exposure level (L_{AE}). By

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

$$L_{Aeq}(without\ buildings) = 10\log_{10}(10^{L_{AE}/10}\frac{N}{t})$$ (1)

where, N is traffic volume (vehicles/ second) and t is time interval in seconds.

The calculation mentioned above is carried out for all the lanes of the road under consideration and for all vehicle type, and finally L_{Aeq} is calculated by combining these results on energy base (for detailed calculation procedures refer to Tachibana [4], Oshino [7] &Yamamoto [8]).

Precise calculation of multiple scattering, diffraction and reflection, is practically very difficult in built-up areas. The problem is approached by statistical methods to predict noise level in such area. In this case ASJ Model-1998 provides a method for estimating sectional energy-averaged equivalent continuous A-weighted sound pressure level ($\overline{L_{Aeq}}$) which is calculated by the next equation:

$$\overline{L_{Aeq}} = L_{Aeq,T} + \overline{\Delta L_{builds}}$$ (2)

where, $L_{Aeq,T}$ is the predicted noise level assuming no buildings are present (see eqn (1)) and $\overline{\Delta L_{builds}}$ is the sectional energy-averaged excess attenuation by the buildings. $\overline{\Delta L_{builds}}$ is calculated according to the density of the buildings and the distance from road to the evaluation section, by summing the sound-energy contributions from the sound paths propagating through the buildings and over them . In this model the buildings are classified as first row of buildings (FRB) directly facing a road and the rear group of buildings (RGB) behind it.

$$\Delta L_{builds} = \log_{10}(\frac{C_1 + C_2 + C_3}{C})$$ (3)

where,
- C is the sound-energy contributing from the line source without buildings;
- C_1 is the contribution from Path 1 which propagates through both FRB and RGB;
- C_2 is the contribution from Path 2 which propagates over FRB and through RGB;
- C_3 is the contribution from Path 3 which propagates over both FRB and RGB; (see fig. 1)

Detailed calculation procedure can be found in Uesaka [1]. The method has been validated by field survey in Tokyo. The values calculated by the method are in good agreement with the measured data [1].
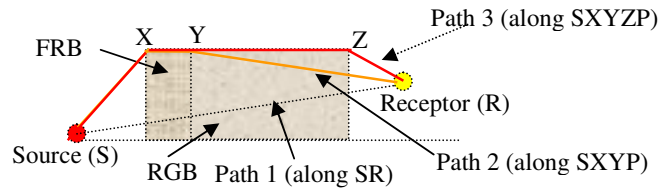
Figure 1: Three sound propagation paths in the build-up area

3 Road Traffic Simulation, AVENUE

AVENUE (an Advance and Visual Evaluator for road Networks in Urban arEas) is a microscopic simulation model based on Multi-Scan Hybrid Block Density Method and the Multi-Layered Route Choice Model to model traffic movements on a road network. The details of which can be found in Horiguchi [5]. The model has been validated for a real road network in Toyota City [6].

4 Methodology for DRONE

DRONE integrates the dynamic output from traffic simulator-AVENUE, with noise prediction model-ASJ Model-1998, to predict noise pollution level on spatial (areawide) as well as on temporal (dynamic) scale (see fig. 2). AVENUE can provide dynamic traffic flow at a minimum resolution of one second for each lane of the road. ASJ Model-1998 has the flexibility to predict L_{Aeq} for any time window such as 15 min, 30 min and one hour. For the prediction of noise levels in built-up area each lane is divided into a number of small sections and the built-up strip formed by the section and prediction point is considered (see fig. 3). Each section is considered independently to predict its contribution in noise level at the reception point, which is calculated using eqn (2).

The flow of data between traffic simulator and GIS-based noise model is presented as a flowchart in fig. 4. DRONE first sets the entire road network along with road and building 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 are searched. For a hypothetical no building situation, noise level calculations based on B-Method of ASJ Model-1998 [8] are performed for a particular source and reception point. The dynamic traffic flow and traffic speed distribution for different classes of vehicles are taken into consideration while performing noise prediction calculations for the selected link-section and receptor point. Then based on the built-up strip between source and receptor point, built-up attenuation calculations are performed.

The equivalent continuous A-weighted sound pressure level ($\overline{L_{Aeq}}$) at the receptor point due to that particular source is calculated using eqn (3). The above mentioned 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.
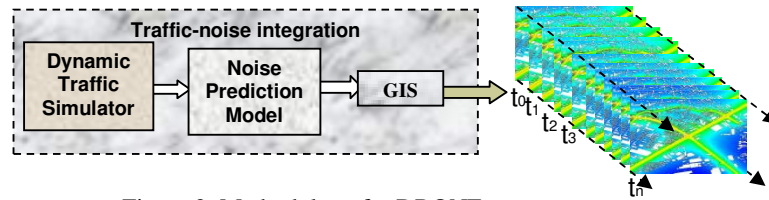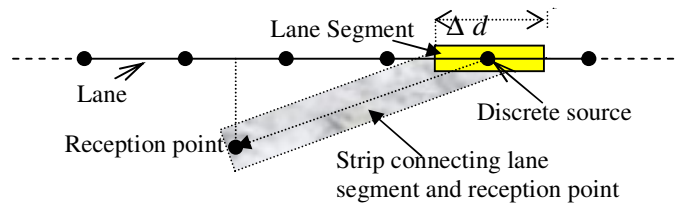

Figure 2: Methodology for DRONE

Figure 3: Illustration of lane, lane segment, discrete source and strip

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.

5   Implementation on a real world situation

DRONE is applied to a real world situation at Ikegami-Shinmachi area in Kawasaki and areawide dynamic noise contour maps are generated for the study area. Route No. 18 of Metropolitan Expressway (MEX) (2 lanes, both directions) is located along SW-NE diagonal of the study area around Ikegami-shinmachi intersection in Kawasaki (see Figure 5). One side of MEX is residential area and other side is industrial area. There are two major cross-diagonal roads-one local highway (3 lane, both directions) running parallel to MEX along SW-NE diagonal and the other is a major arterial road (2 lane, 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 small amount of traffic flow.

Input / Output

Noise Model

TRAFFIC SIMULATOR (AVENUE)

Road Network → Setting of road infrastructure and road conditions

Receptor point properties; Study area boundary coordinates; and Spacing of receptor points. → Setting of a receptor point

Search for road which contributes noise to the receptor point

· OD table
· Signal Control parameters
· Tuned simulator

Setting lane position; Setting discrete source position (each lane is divided into sections with discrete source)

Setting of strips (strip formed by lane section and receptor point)

Building infrastructural configuration

Calculation of noise propagation for each source to receptor point (for each strip without considering buildings)

Sectional energy averaged excess attenuation by the buildings (Calculated based on density of the building and distance between receptor point and link section) (As per Uesaka (2000) [1])

Ground Properties

Road Surface Condition

Power level of vehicle noise, bases on vehicle type and running condition (for each vehicle class) (as per ASJ Model-1998)

Unit Pattern for each strip and for each vehicle class

Dynamic Vehicle running speed (for each lane)

Dynamic Traffic volume (for each lane)

LAeq,T for each vehicle class (for each strip, without considering buildings)

LAeq for each vehicle class (for each strip)

LAeq for all lanes of selected road at receptor points

LAeq for all roads contributing noise at receptor point

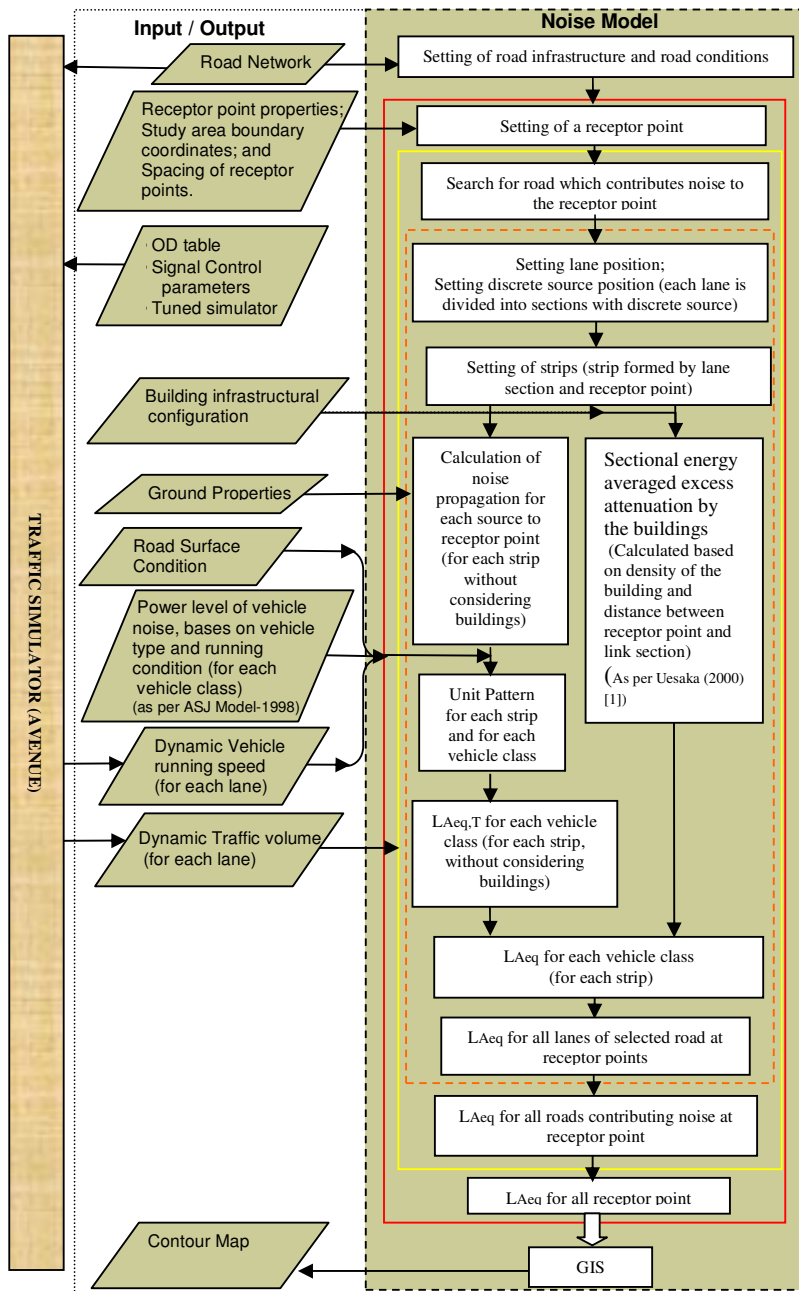LAeq for all receptor point

Contour Map ← GIS

Figure 4 Flow of data in DRONE

In order to effectively reproduce the flow in the study area, field data was collected for a bigger network. Traffic counts along with turning ratios for four types of vehicles i.e. 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 controls at the intersections were also observed and noted. For the purpose of simulation validation, queue volume data at major intersections was also collected. Data was collected for 10-15 signal cycles for each major flow direction during morning and evening peak hour.
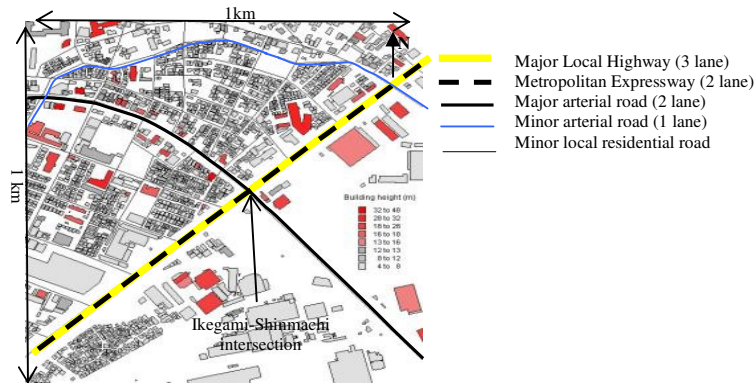
Figure 5: Area around Ikegami-Shinmachi intersection, Kawasaki (1km x 1km)
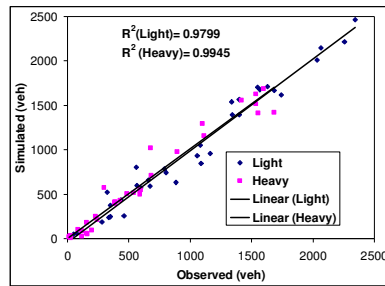
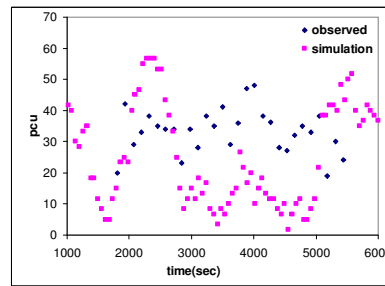Figure 6: Observed and simulated throughputs in the study area

Figure 7: Observed and simulated queue volume at Ikegami-Shinmachi Intersection (link from Tokyo towards Yokohama)

5.1 Traffic simulation validation

Simulated traffic flows at major intersections are compared with those of observed. The observed versus simulated throughputs in study area are shown in fig. 6 for morning peak hours. According to which, the simulated traffic flow is

satisfactory (correlation coefficient R^2 for both types of vehicles is greater than 0.97). We can conclude that the traffic simulator has properly reproduced the observed traffic conditions.

Additional check to ensure that the simulated traffic behave in the same way as the observed traffic, observed queue volume and simulated queue volume on links at observed intersections are compared. The results of the comparison of queue volume on highway links at Ikegami-Shinmachi intersection are shown in fig. 7. From the figures it can also be concluded that traffic simulator is able to properly represent the real traffic behaviour, 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 different for AVENUE and field observation. The simulated queue volume for AVENUE 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.

6   Results

6.1 Necessity of built-up area consideration

Fig. 8 shows the contour maps with and without consideration of building attenuation. Built-up area severely affects the noise propagation. As shown in fig. 9, the difference in dB(A) for cases with and without building consideration may vary from 1dB(A) for receptor points close to the road to 10 dB(A) for receptor points shielded by the buildings. A receptor point at the road side of a road may be hindered by buildings for noise propagating from source on another road (that is why we have a difference of approximately 1dB(A) calculation at a road side in a network).

The Ministry of Environment in Japan enforces "Environmental Quality Standards for Noise" [9] in which the problem of environmental noise in areas facing roads is evaluated by obtaining the numbers and the rates of the buildings at which noise levels exceed the environmental quality. Fig. 8 and fig. 9 clearly indicate that required numbers are different for with and without consideration of effect due to built-up area. In order to address the problem it is necessary to grasp the effect of noise attenuation by buildings. In fact noise levels towards the centre of the built-up area are overestimated if effect of built-up is not considered.

6.2 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. 10 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 area near to the roadside are noisy (red colour, 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.
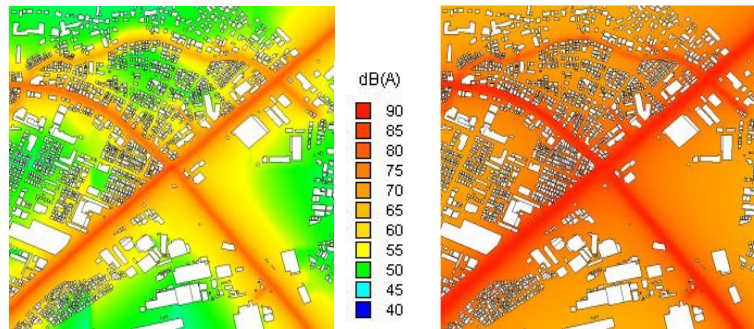
Figure 8: Contour maps with *(left)* and without *(right)* considering building attenuation respectively throughputs in the study area
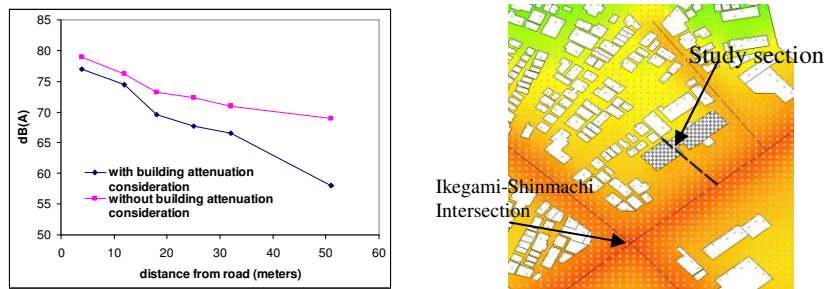

Figure 9: Graph on left show the comparison of noise level with and without consideration of built-up attenuation for different receptor points kept perpendicular to the road (see study section in the figure on right).
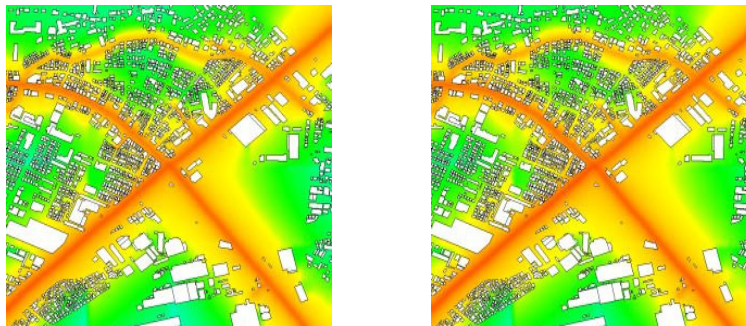
Figure 10: Areawide noise contour maps at 8:00 am *(left)* and 8:15 am *(right)*.
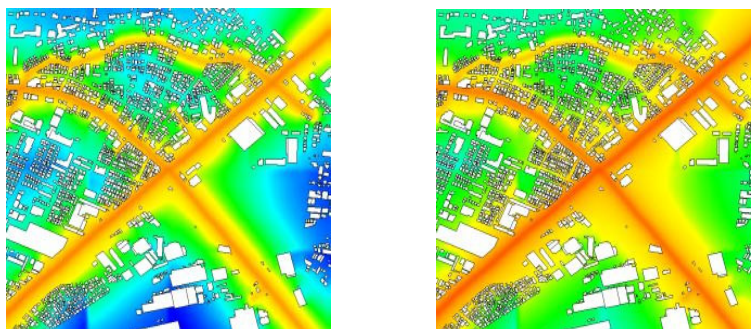

Figure 11: Areawide noise contour maps for contribution of noise (to total noise level) due to light *(left)* and heavy *(right)* vehicles
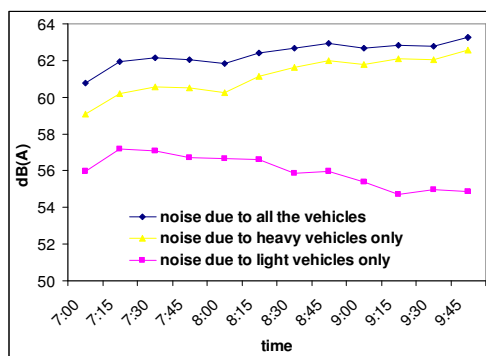

Figure 12 : Contribution from different type of vehicle at a receptor point near Ikegami-Shinmachi intersection.

6.3 Contour maps for noise contribution from different vehicles

Noise contribution from different types of vehicles can be evaluated. Fig. 11 shows noise contour map due to light and heavy vehicles on the study network. In fact noise contour map from light vehicle shows the noise pollution level in the absence of heavy vehicles in the study area. As can be seen from the contour maps, intensity of noise contribution from heavy vehicles is quite high compared to that from light vehicles. The noisy zone (red and orange) around the roads spread to greater distance for heavier vehicles case as compared to light vehicles case. Along the roadside of highway is redder in the contour maps for heavy vehicles, compared to contour map from light vehicles. In contour map from light vehicles, noises is more intense on arterial road compared to that of from heavy vehicles; this is according to the expectation because heavy vehicle flow is mainly on highway and there are very few heavy vehicle flow on arterial road.

Fig. 12 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 vehicle 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 vehicle flow is managed. Moreover, slight increase in heavy vehicle flow will result in significant increase in noise pollution level as compared to similar increase in number of light vehicle 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 the 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.

7 Conclusion and Future Research

DRONE has been developed by the integration of traffic simulator (AVENUE) 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). DRONE is enhanced to predict noise level in built-up area and is applied to Ikegami Shinmachi area in Kawasaki. Areawide noise contour maps are generated which clearly indicate the importance of built-up area attenuation. The difference in noise level at receptor points for cases with and without building consideration may vary from 1dB(A) for receptor points close to the road to 10 dB(A) for receptor points shielded by the buildings. 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

DRONE has been verified (Bhaskar et al., 2004) but further work will be necessary to confirm the accuracy of the methodology for noise prediction in built-up area by conducting field survey. Noise contribution from vehicles using the 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.

8   Acknowledgement

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