A microlevel method for road traffic noise prediction

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Abstract

Traffic noise is a major environmental concern and a source of an ever-increasing level of discomfort particularly in urban areas with traffic congestion. In a microscopic noise model for urban areas both the noise sources and the noise propagation have to be modeled. The main objective of our study was the integration of a very detailed traffic microsimulation model (HUTSIM) with an accurate and commonly used model of noise dispersion (Nordic Traffic Noise Computing Model). This integration enables more accurate estimations of traffic noise in changing situations in urban areas. The use of computer simulation rather than case studies or physical models should provide a greater degree of reliability and flexibility to the results achieved.

This study is a part of the DIANA-project (Development of Integrated Air Pollution Modeling Systems for Urban Planning), where the aim is to create a model that would be accurate in modeling urban air quality and its changes depending on the traffic situation. The noise study is made at HUT in cooperation with the Laboratory of Transportation Engineering and the Department of Environmental Sciences at University of Kuopio.

The microsimulation model used in this study is HUTSIM, which is developed at Helsinki University of Technology. The results are analyzed by using graphs produced by HUTSIM-analyzer. The approach of developed noise distribution model is macroscopic and the main input parameters are speed limit, traffic flow and the distribution of vehicles.

The results were calculated in the application phase. Dividing each
approach and departure direction at the intersection area in smaller, ten metres, elements carries out the observation of traffic at the intersections. Each of these elements is then studied separately by using the Nordic Traffic Noise Computing Model. The main benefit of the developed method is that more accurate information is obtained of the traffic situation.

**Introduction**

One of the main concerns about the growth of traffic is the state of the environment, which is deteriorating especially in cities. The ever-growing traffic is a highly topical problem in both industrialized and developing countries; declining air quality decreases the quality of life in cities, and exposes people to different kinds of respiratory diseases. The knowledge of the cause and behavior of emissions helps to evaluate different control strategies in preventing and minimizing environmental strain in cities, where the main cause of pollution is traffic. In modeling emissions it is therefore important to understand the impact of vehicle movements and delays in generating accurate urban emission dispersion models. Furthermore, the opportunity of being able to correctly model emissions and the dispersion of air pollution is a means to a greater understanding of the characteristics of urban environment.

Traffic noise, in addition to other emissions, is an important environmental health problem affecting the health and well being of the people exposed. Growing pressure on road space underlies increasing public concern about the environmental impact of road traffic, particularly in terms of air quality, but also noise and visual intrusion. The amount of people being exposed to road traffic noise is increasing in addition to the growth of traffic. Especially in urban areas the noise environment is totally different than that on highways in general because of changing traffic situations. In urban areas the fluency of traffic units is the key to the noiseless and emission free environment.

The aim of the DIANA-project was to create a comprehensive modeling system that could be used in evaluating traffic volumes, emissions, atmospheric dispersion, and noise in cities. This paper deals with the integration of a very detailed traffic microsimulation model (HUTSIM) with commonly used model of noise dispersion (Nordic Traffic Noise Computing Model). This integration enables more accurate estimations of traffic noise in changing situations in urban areas, like intersections.

**DIANA-study**

This study was done as a part of the DIANA (Development of integrated air pollution modeling systems for urban planning) project. The different sub-models of the program are shown in Figure 1. The bolded arrows show the areas this paper concentrates on.
The organization behind the study was the Finnish Meteorological Institute (FMI). FMI accounted also for the expertise of air quality modeling and management while Helsinki University of Technology (HUT) was in charge of traffic simulation and planning. University of Kuopio was responsible for the noise modeling.

**Traffic simulation**

Road traffic simulation was introduced in the early days of computer-aided calculation of traffic demand and flows in a network system. Computer simulation has become a widely used tool in transportation engineering with a variety of applications from scientific research to planning, training and demonstration. Traffic systems are an excellent application environment for simulation-based research and planning techniques. Traffic systems are also an application area where the use of analytical tools, though very important, is limited to the level of subsystem and sub-problem. The reasons to use simulation in the field of traffic are the same as in all simulation; the problems in analytical solving of the question at hand, the need to test, evaluate and demonstrate a proposed course of action before implementation, to do research (to learn), and to train people.

Traditional traffic simulation has been macroscopic. However, the use of macroscopic simulation requires such generalizations in the traffic environment that, it can sometimes be an inflexible and inappropriate way of modeling traffic. In macroscopic simulation, for example, vehicles are treated as traffic flows, and
individual vehicles are not separated from it. In microscopic simulation of traffic, on the other hand, each vehicle has its own characteristics. This brings in the real dynamics of the traffic phenomenon, and thus increases the sensitivity of the simulation. The planner and researcher can also follow the traffic phenomenon as it develops as a function of time. Visual presentation and animation of real-time (or faster) action gives the viewer a comprehensive view that helps him or her in interpreting statistical printouts depicting the traffic situation and performance.

Model integration

Integration of traffic simulation models to traditional analytic prediction models is a potential way to create new efficient tools to evaluate the harmful effects of traffic more and more accurately. The aim of this study was to find out how a traffic micro simulation model could be used with a traditional noise prediction model. Basically this meant that the micro simulation model HUTSIM [4] was used as a tool in producing the variables the analytic model needed. The analytic model used was The Nordic Road Traffic Noise Prediction Model.

The prediction models are commonly used for traffic noise evaluation. In the models both the noise emission and the noise propagation are modeled. The noise emission of road traffic is modeled mostly for example in The Nordic Road Traffic Noise Prediction Model [1] on a macrolevel as a noise emission of a line source. The model does not take into account that there may be a local increase of noise emission at road intersections courtesy of the influence of driving pattern. The modeling of noise source and propagation on a macrolevel is not very suitable for computer modeling of noise near road intersections and in cities, where the traffic flow and noise emission are not locally steady. In this paper a basis for prediction of traffic noise emission and propagation on a microlevel is described.

The macrolevel road traffic noise prediction models are based on line sources. In the microlevel method each lane is divided into point sources. In this work a ten metres part of a lane forms a point source. The noise emission of each point source is predicted and the evaluation of noise propagation is made using point source models.

The traffic noise emission in macrolevel models is predicted as a noise level for example at 10 m from the centerline of the road, caused by the traffic flow. In the microlevel method the traffic noise emission is predicted as the noise emission level of each point source. The noise emission level is defined as the equivalent A-weighted sound power level during the time interval considered. The noise emission level of each vehicle at each point is predicted by using empiric data. The vehicle noise emission level is normalized to one second. The vehicles are divided in different categories. The relationship between noise emission and speed and acceleration must be determined empirically in each vehicle category. The noise emission level of each point is the sum of the noise emission levels of all vehicles at this point during the time interval considered.

In this state of the art the dependence of the noise emission of light (<3.5 ton) and heavy (>3.5 ton) vehicles on speed is documented. In this first application model of the microlevel method the noise emission levels of light and heavy vehicles were derived from the empiric nomograms and formulas of The Nordic
Road Traffic Noise Prediction Model. The effect of acceleration on noise emission is not documented before. In this study that relationship was predicted supposing that it is alike the effect of the road gradient in the Nordic model. We hypothesized that the effect of acceleration is linear and that 0.4 m/s² corresponds to the road gradient 100 per thousand i.e. +2 dB(A) for light vehicles and +8 dB(A) for heavy vehicles. It was also found that vehicle type approval tests supported this assumption. The possible effect of deceleration on noise emission was eliminated.

Modern automatic traffic counting systems can classify cars into about 10 classes instead of two classes of the Nordic model. For developing the model it is necessary to measure noise emission of different kind of vehicles in different weather and traffic conditions. The statistical distribution of noise emission of different vehicle types must be measured. Using this database the noise emission at any traffic composition can then be more reliably predicted.

In current acoustic theory there are five main sound propagation attributes that are considered to be the most important for the design of a noise prediction model: attenuation due to geometrical divergence, attenuation due to air absorption, attenuation due to screening, attenuation due to the ground effect, and effects of reflections. The acoustic theory is quite advanced and standardized with the factors, which affect the propagation of sound from a point source outdoors [2]. The computer modeling enables the accurate modeling of the basic acoustic forms on which today's acoustic theory is based. That is why the microlevel method is suitable for evaluation of the road traffic noise propagation.

The noise emission of vehicles has a directional pattern. This may be significant for prediction of noise emission in the vicinity of road intersections. The microlevel method makes it possible to utilize also the directivity data of vehicle noise emission. In the microlevel modeling of noise propagation the noise levels in any receiving point are computed integrating the sound levels caused at that point from noise emissions of all the point sources.

The next presented new method of calculating and evaluating the traffic noise emissions enables the observation of a noise emission from single vehicle at each point of the lane. Microscopic variables of each vehicle, which are speed, acceleration and deceleration, can be interpreted from the results of simulation and then used as a part of the analytic calculation. In other words the evaluation of noise emission has jumped from macro level to microlevel, which makes new applications possible.

**Case study**

In this study there were two different intersections under research: a T-intersection and a three-leg-roundabout (Figure 2). In both intersections two legs were chosen to represent the main direction.
The intersection models were constructed very simple, which in some cases turned out to be a little problem. However, the models corresponded well enough to the reality and enabled the production of needed microscopic variables for vehicles simulated.

Because the chosen intersection types were very different on their function it was possible to assume there to be some difference between the noise emissions. Roundabouts contains only accelerating and decelerating traffic while T-intersections also have vehicles with steady speed. However, it can be said that the noise emission of an intersection is dependent on fluency of the traffic in the intersection area. So the more there are stopped vehicles and delays the more there is accelerating and decelerating traffic, which increases the noise emission.

The idea was to find out the noise emissions of the chosen intersections in different traffic situations. Simulations were made for both intersections in six different traffic situations, where the number of vehicles per hour and speed limit varied. The speed limits when approaching intersection area were 50 km/h and 70 km/h and three different traffic situations were then modeled:

- Low demand traffic: main direction 300 veh/hour, minor 60 veh/hour.
- Day traffic: main direction 600 veh/hour, minor 120 veh/hour.
- Rush hour traffic: main direction 800 veh/hour, minor 160 veh/hour.

In simulations the road before the intersection (intersection area) was divided into smaller parts of ten metres and noise emissions were then calculated separately to each part. The total emission of the intersection in question could then be calculated by summarizing the effects of smaller parts. The critical examination intersection was extended up to 50 meter so that each leg had five point sources, which all contained two smaller elements (Figure 3). Each smaller
element contains three different flows, which means different driving situations: steady speed, acceleration and deceleration.

![Figure 3: Dividing intersection in smaller parts and the formation of point sources.](image)

So, each point source contains noise emissions from different flows with different behaviors. Average speed, acceleration, and the amount of heavy and light vehicles was calculated for each flow inside the element. Acceleration was calculated from the speed differences between sequential elements. With this information the effect of each point source was calculated with the new microlevel method where the Nordic Model was modified so that it notices the microscopic variables. In practice the whole calculation process was programmed in Microsoft to make whole process easier and also suitable for future research.

The duration of each simulation was 30 minutes. Both intersections had six simulations where the number of vehicles and speed limit varied. The simulated traffic flows that went through the intersection were manipulated in several ways to correspond to the real traffic situation. First of all, the lanes (pipes) around the intersection were given a speed limit (50 or 70). Speed limits at the intersection were given based on field studies. In this way vehicles observe the geometry of the intersection and some acceleration and deceleration can be found. The vehicle objects simulated in to model also included speed distribution so that 70% of all vehicles aimed at the speed limit and 15% either 10 km/h lower or higher speed. The portion of heavy vehicles was 12%.

The results of the simulations were expressed by using HUTSIM-Analyzer. Analyzer enables the presentation of results in graphic form. From the graphics it was possible to see the trajectory of each vehicle at intersection as function of time, distance or speed (Figure 4).
Results of case studies

The table that was used in the calculations gave directly the equivalent A-weighted sound power level at the distance of 100 meter ($L_{a,100\text{m}}$) from the intersection. So, the noise level that each intersection creates in various cases was observed from that distance.

The noise emission from the intersections was first calculated with the Traditional Nordic model. In this case the simulation process was not needed, because the only input parameters were speed limit, the amount of simulated vehicles and the vehicle type distribution. Because of the macroscopic character of the model both intersections gave the same results for noise level (Figure 5).
Next the noise emission from intersections was calculated with the new microscopic method. The microscopic input variables that model needed were collected from the graphs of HUTSIM Analyzer. This meant that the speed values were more realistic than in the traditional method where they were the same as the speed limit. Also the effect of acceleration on noise emission was now noticed separately for heavy and light vehicles in a way described earlier in this paper.

In cases where speed limit was 50 km/h the noise emission from both intersections was a little bit higher than what the traditional method gave. In cases of higher speed limit the microlevel method gave 2-3 dB(A) higher noise levels than the traditional method (Figures 5 and 6). Acoustically this means a doubling of sound power, which can be considered as a significant result.

![Figure 6: Calculated noise emission from intersections in different traffic situations with the microlevel method.](image)

**Conclusions**

The main objective of this study was the integration of a very detailed traffic microsimulation model (HUTSIM) with an accurate and commonly used model of noise dispersion (Nordic Traffic Noise Computing Model). According to the results, this integration enables more accurate analysis of traffic noise in changing situations at urban areas, like intersections. The use of computer simulation rather than case studies or physical models should provide a greater degree of reliability and flexibility to the results achieved.

The Traditional Nordic model gives too high noise levels in inconstant traffic situations, because in real life the speed in intersection area is lower than the speed limit on the same road. Because of that the noise emission due to vehicle speed, is lower. On the other hand acceleration was supposed to greatly increase the noise emission, but obviously its effect is not as big as the effect of speed or the factor set to reflect the effect of acceleration was too small. In addition to the
comparison results between the traditional and the microlevel method something can be said about the influence of intersection type on noise emission. This is actually one of the main results of this study. Because the traditional method does not make any difference between intersections the conclusions are based on the results from the developed microlevel method.

With lower speed limit, which means lower average speeds, the difference between noise emissions from T-intersection and roundabout was very small. This is interesting, because the operating principle of these two intersections is very different: all vehicles in a roundabout are either accelerating or decelerating at intersection area while a T-intersection also contains vehicles, which are having a steady speed. The reason why there is no difference between intersections with this speed might derive from our inaccurate assumption about the effect of acceleration on noise level.

In case of higher speed limit T-intersection turned out to be much noisier than roundabout. Mainly this is a result of two factors. First, the average speeds in a roundabout intersection area are lower because there are no vehicles with steady speed like at T-intersections. Speed is, however one of the main reasons affecting noise levels. Secondly, the fluency of the traffic in a roundabout was much better than at T-intersection. The amount of stopped vehicles at roundabout was almost zero in all cases while in T-intersection vehicles had to wait for suitable time gap much longer.

References