Dynamic assessment of road traffic noise: elaboration of a global model

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Abstract

Effective noise prediction models are needed to predict the effect on noise of current or planned traffic management systems in the surrounding of populated areas. The currently used noise prediction models are based on a steady representation of traffic flow. Such models are able to predict average noise levels, but fail to evaluate the short-time variations of noise due to interrupted and complex traffic situations. Earlier researches have been conducted to develop an emitted noise estimation model based on a dynamic description of traffic flow and to extend the abilities of this model by taking into account the influence of ground public transport vehicles. This paper describes a first approach of coupling this existing dynamic traffic noise model with a model taking into account the influences of the atmospheric conditions as well as the topography between source and receiver on the sound propagation.

1. Introduction

The traffic noise prediction models are commonly designed to assist in the conception of new roads or for taking into account changes in traffic noise conditions. Usually, the traffic is represented as a steady flow. Therefore, the “static” models are only able to predict average noise levels generated at the roadside. A review of some traffic noise prediction models [1] clearly displayed, that a model able to represent interrupted and complex flow is needed. In a previous paper [1] we have shown the feasibility of a model based on passenger car noise emission monograms associated with a dynamic traffic model. An extension of this model which is able to take into account a mix of various types of traffic is available [3]. The present paper describes a first approach of coupling the existing dynamic traffic noise model emission with a model developed by CSTB [4] taking into account the influences of the atmospheric conditions as well as the topography between sources and receivers on the sound propagation. The possibilities of such a global model are illustrated through a basic scenario describing the noise emitted in an urban neighbourhood for two configurations of traffic management systems.

2. Modelling of the dynamic emission of noise

2.1. Description of the traffic model

To improve the estimation of noise emissions associated to a traffic flow, it is necessary to describe precisely the behaviour of this flow. This can be done thanks to a dynamic traffic model. The one we have chosen uses a two-levels scale for the traffic representation:
- The passengers cars are represented as an continuous flow (macroscopic description);
- Public transport vehicles as buses or others very singulars vehicles are represented individually (microscopic description).

We are going to present briefly how the behaviour of these two kinds of vehicles are characterised by the traffic model.

2.1.1. Modelling of the flow of passenger cars

To model the behaviour of passenger cars we have chosen to use a macroscopic model based on Lighthill Whitham [5] and Richards [6] theory. This model studies car interactions in a global way, by representing the traffic flow as a continuous stream characterised by three variables: the flow $Q$, the density $K$ and the flow speed $V$. The flow is considered to be at any time in a state of equilibrium, described by a fundamental relationship between the flow $Q$ and the density $K$ (cf. Figure 1).

![Figure 1: Equilibrium flow-density relationship](image)

This relationship represents the possible traffic states depending on the network where vehicles drive.
A specific procedure, which modelizes bounded accelerations by limiting, in each point of the network, the maximal speed allowed for the flow has been added to this model.

2.1.2. Taking into account of public transport vehicles

Public transport vehicles are not only different from the others from an acoustic point of view but they also modify the flow of the global traffic because of their singular behaviours (own kinematic characteristics, many stops...). To estimate correctly the acoustic impacts of an urban traffic flow, we have decided to modelize individually the movement of ground public transport vehicles such as buses. Their influence on the surrounding traffic is taken into account by considering the buses as a moving capacity restriction from the other drivers point of view (see [7] for more details on this aspect).

2.1.3. Advantages of the two levels scale for the traffic representation

To conclude the description of the traffic model, we would like to precise the reasons why we have chosen a two-levels scale for the traffic representation. In fact, some other approaches (as [8] for example) to build a dynamic noise estimation model are based on fully microscopic description of traffic flow. It is true that such a representation makes possible a very accurate description of traffic dynamics, but this also results in high computational costs, which make their use difficult for wide networks. They also include a high number of calibration parameters, which makes the model calibration difficult for real field application or, if a precise calibration is not achieved, results in a poor traffic flow description. They also include in most cases a part of stochastic traffic flow description, which results in the necessity of multiple simulation runs to come up with a significant result.

We have so preferred to use a macroscopic description for the passenger cars whose acoustic behaviours are close enough. We can thus directly access to a mean description of the vehicles majority which takes into account the dynamic evolution of traffic. Furthermore, this macroscopic description makes easier the coupling operation with a sound propagation model as we are going to see later in this article.

2.2 The emission laws

The noise emission laws of vehicles have been established in two ways according to their type and their associated description in the traffic flow model.

2.2.1. Case of passengers cars

Acoustic models usually consider vehicles as units (microscopic description) and predict the emitted noise from their individual states. As we have adopted a macroscopic description for the flow of passenger cars, we cannot achieve such an individual description of the passenger cars behaviour. In fact, in our traffic model, each link of the network is divided into cells whose length is \( \Delta x \) (roughly a few ten meters) and where the traffic density \( K \) is supposed to be constant. Thus, each cell contains \( K \times \Delta x \) vehicles at each time step of the simulation. These vehicles are supposed to have the same kinematics characteristics. From an acoustic point of view, we have chosen to take into account the heterogeneity between the different existing passengers cars even if they are described in a homogeneous way by the traffic model. We have so defined the concept of equivalent vehicle (widely described in [1]). The equivalent vehicle synthesises the mean acoustical behaviour of a representative panel of passengers cars depending on its kinematics (speed and acceleration) and its mechanical (gear ratio) characteristics.

2.2.2 Case of “singular” vehicles

The vehicles whose kinematics is appreciably different from the rest of traffic (e.g. buses) have been considered as mobile singularities among the traffic. As we use a microscopic description for this kind of vehicles, the concept of the equivalent bus is not suitable and we have decided to implement real-bus noise emission monograms. The method developed and used to obtain the emission laws consisted of reproducing the different kinematics on an asphalt concrete test track for different types of buses.

2.2.3 Processing of data – implementation of the emission laws

In both cases of passenger cars and buses, the experimental disposition is based on the measurement of the kinematics data (speed, acceleration) and the acoustic data (L1max). A frequency analysis of the signals has been performed and the processing of the L1max levels have led to the elaborate relationship L1max = f(v) in a quadratic form in each third-octave band in the range [63 Hz – 10 kHz]:

\[
L_{1max} = a + b \log_{10}(V/V_{ref}) + c \left[ \log_{10}(V/V_{ref}) \right]^2 \quad (1)
\]

\( V_{ref} \) is fixed at 80 kph. The effect of acceleration/deceleration on the noise emission is taken into account by the mean of a corrective value

\[
\Delta_{acc} = a_{acc} + b_{acc} \log_{10}(V/V_{ref}) + c_{acc} \left[ \log_{10}(V/V_{ref}) \right]^2
\]

or

\[
\Delta_{dec} = a_{dec} + b_{dec} \log_{10}(V/V_{ref}) + c_{dec} \left[ \log_{10}(V/V_{ref}) \right]^2 \quad (2)
\]

added to the relation (1).
Coupling with a sound propagation model

The numerical resolution of the traffic model consists in dividing each link of the network into cells whose length is \( \Delta x \) (roughly a few ten meters) and where the traffic behavior is supposed to be constant. At each time step \( \Delta t \) (we usually use \( \Delta t = 1 \text{s} \)), the traffic characteristics (density, speed...) are calculated for each cell of the network. Then, thanks to the previous emission monograms, we can deduce every second the acoustic power emitted by each cell and for each third octave band. To evaluate the noise received around the road network, we have to couple this information with a propagation model. The propagation model we used was developed by the French CSTB [4]. It takes into account the influences of the atmospheric conditions (wind, temperature) as well as the topography (hills, noise barriers, building...). This model was originally designed to calculate on a receivers grid the mean noise levels corresponding to line sources associated to a static description of the traffic. As we have chosen a macroscopic approach to describe the flow of passenger cars, it is relatively easy to adapt this model to our description of noise emission. Instead of considering only one line source for each link of the network, we have associated to each cell a specific line source, whose length is equal to the cell ones. The propagation model is then charged to calculate the sound propagation between these small line sources and a predefined grid of receivers. This operation is possible because the characteristics of the traffic flow are homogeneous for a given cell. Thus, we can construct a propagation matrix describing the sound propagation between each cell and each receivers (cf. Figure 2).

![Figure 2: Determination of the propagation matrix between transceivers.](image)

As the transmitter cells and the receivers grid are fixed, the sound attenuation between transceivers does not depend on the level of noise emitted by the cells. So, it is possible to calculate the propagation matrix from a fixed level of emission only one time before the simulation. Then, we just have to apply this matrix to the real level emitted by each cell. This solution is very efficient because we do not have to calculate the sound propagation corresponding to the flow of passenger cars at each time step of the simulation.

The contribution to the emitted noise of a given traffic lights synchronization can be evaluated by determining the time/space domains for which the noise levels exceed the statistical index L10. This index is calculated as the level of noise which is exceeded for all the receivers during the time of simulation (240 s). Figures 3 & 4 show these domains of emerging noise in both cases of “red” and “green” waves in the case of the global model, for receivers located at 70 m of the axis of the main road. In the case of the “red wave”, the peaks of noise are visible when the platoon is restarting, i.e. when the traffic lights become green. Figure 5 represents the graphical interface which is proposed by the software “Symubruit”. The dynamic assessment of

Illustration: case of a basic strategy of traffic lights management

This basic scenario consists on a road section where traffic is interrupted by three traffic signals. The entry of this road section is located at \( x = 0 \text{ m} \), the traffic signals are respectively located at 140 m, 300 m, and 820 m. The traffic signals are synchronised according to two different ways. The first one, called “red wave”, is set so as to force the platoon to stop at each traffic light. On the contrary, the second case (“green wave”) allows the continuous flowing of traffic thanks to an adapted synchronization of the traffic lights. Table 1 shows the characteristics of the traffic flow and of the traffic lights.

The flow \( Q \) of the traffic is fixed at 1620 vehicles/hour (in the entry of the road section) for each traffic lights management strategy.

<table>
<thead>
<tr>
<th>Traffic light</th>
<th>Green wave</th>
<th>Red wave</th>
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<tbody>
<tr>
<td>Traffic</td>
<td>Red phase</td>
<td>Shift</td>
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<tr>
<td></td>
<td>2</td>
<td>45</td>
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<td></td>
<td>3</td>
<td>50</td>
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The calculation of the sound propagation associated to public transport vehicles is more complicated because the propagation model we used is not designed to take into account punctual sources which move. We do not deal with this problem for the moment. We need to implement specifically the propagation algorithm corresponding to this situation. We just want to notice here that to take into account such specific vehicles, it is necessary to calculate the sound propagation at each time speed. This results in high computational costs. That is why we have chosen to work globally with a macroscopic description of the traffic and to use the microscopic description only for specific vehicles.
the traffic noise can be visualized in global levels or in bands of octave through this interface.

Fig. 3: “Green wave”, evaluation of the L10 (58.7 dBA) at the distance of 70 m of the axis of the road section.

Fig. 4: “Red wave”, evaluation of the L10 (58.4 dBA) at the distance of 70 m of the axis of the road section.

Fig. 5. Graphical interface of the global model "Symubruit"

4 Conclusion

Traffic noise prediction models are required as aids in the design of new roads and sometimes in the assessment of existing or envisaged changes in traffic noise conditions. The actual models are commonly able to predict “static” noise levels, according to the government authorities, and are not designed for evaluating the noise emitted by an unstable urban traffic. This last point is especially important in the case of interrupted and complex flow, for predicting the effects of various traffic light cycles, traffic routings, pedestrian crossing locations and other controls. This paper describes the basis of a global model which takes account of atmospheric and ground effects, diffraction and reflection due to cuttings; as well as local topography, buildings and screens. The potentialities of this global model are analyzed through the study of a basic scenario involving two traffic lights management strategies.

5 Acknowledgements

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6 References