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Dynamic approach for the study of the spatial impact of road traffic noise at peak hours

Arnaud CAN[1]; Pierre AUMOND[1]; Cécile BECARIE[2]; Ludovic LECLERCQ[2]

[1] IFSTTAR, CEREMA, UMRAE, F-44344 Bouguenais, France

[2] Univ Lyon, ENTPE, IFSTTAR, LICIT UMR_T 9401, F-69518, LYON, France

ABSTRACT

A dynamic modelling chain, coupling the Symuvia dynamic traffic model (LICIT, Ifsttar / ENTPE) and the Noisemodelling noise level prediction tool (UMRAE, Ifsttar / Cerema), is developed in this paper to assess the impact of road traffic on noise environments at the scale of an urban traffic network of about 10 km² located in Lyon/Villeurbanne. The simulation, which reproduces 3 hours of a morning rush hour scenario, highlights the increase in noise levels associated with the increase in travel demands. It also highlights that the increase in noise levels is not uniformly distributed over the network and has a greater impact on the streets where traffic is reported. In addition, noise dynamics are modified: background noise is particularly sensitive to the increase in vehicle density on the network, so periods of calm on the network are rare. A more detailed analysis of this dynamic is possible locally through the analysis of the evolution of the $L_{Aeq,1s}$ and the study of specific acoustic indicators. Desirable improvements to the model are discussed, with a view to assessing the currently unknown acoustic impact of road traffic management strategies at the scale of an urban network.

Keywords: Road traffic noise, Dynamic modelling chain, Congestion, Noise dynamics

1. INTRODUCTION

Urban congestion is a major issue as regarding the development of cities. Its cost in terms of time spent, particularly during the morning and evening rush hour, has been the subject of studies (1), giving rise, for example, to policies that spread travel demand. However, the estimation of the environmental externalities that congestion generates, in particular noise pollution, faces scientific obstacles that have not yet been resolved. Conventional approaches to traffic noise modelling do not meet the criteria for evaluating mobility strategies, as they are limited to an overly aggregated traffic description, which relies on average flows and speeds to estimate the sound power of vehicle flows. These traditional models also make simplifying assumptions about the evolution of these flows according to traffic conditions, taking no account, for example, of the assignment of road traffic (distribution of vehicles on the network according to traffic conditions). The detailed estimation of the noise impacts associated with road traffic presupposes the use of: (i) traffic modelling sensitive to traffic conditions, i.e. reproducing vehicle kinematics (speeds and accelerations) and the dynamic assignment of vehicles on the network according to traffic conditions (individual route selection strategies), (ii) acoustic emission modeling itself sensitive to influential variables (vehicle speeds and accelerations, road fleet composition, etc.) (2).

Approaches to traffic noise modeling based on dynamic road traffic modeling have emerged over the past 15 years (3-8). These modeling chains are based on the trajectories provided by the traffic model of the vehicles present on the network, i.e. their position, speed and acceleration at each time step (typically 1 second). These data are used to estimate the sound power of each vehicle at each time step; this is followed by an estimate of the temporal evolution of the noise levels in a receiver map after a sound propagation calculation. Thus, unlike conventional so-called static approaches, this dynamic modelling chain makes it possible to test the impact of traffic regulation strategies that modify vehicle

[1] arnaud.can@ifsttar.fr

kinematics. It also allows the calculation of acoustic indicators describing changes in noise levels, where static methods are limited to the estimation of aggregate noise indicators (e. g. annual average noise levels) (9). This contribution is significant because variations in noise levels, and in particular emergences, have a demonstrated impact on the perception of sound environments (10) as well as on their health impacts (11).

The dynamic modelling chain has been used in the past to compare the acoustic impact of different intersections (12,13), or different traffic light settings on urban corridors (14, 15). These initial studies highlight that traffic control strategies limiting speed variations are beneficial from an acoustic point of view, confirming the results obtained by observations (16). However, the impact of reassignment phenomena, which are very present in the case of congested traffic conditions, has not yet been analysed, as the studies carried out so far have been limited to networks covering only a few intersections.

Recent advances in traffic modelling and acoustic calculations now allow the study of larger networks. In this article, a coupling between a dynamic traffic model, Symuvia, and a noise mapping model, Noisemodelling, is carried out and applied to an urban network located in the city of Lyon, France, covering an area of about 10 km². At this scale, it is possible to study the spatial dimension of urban congestion in terms of its impact on the noise environment.

2. METHODS

2.1 Modeling chain

The dynamic modelling chain implemented for road traffic noise estimation consists of a coupling between the Symuvia dynamic traffic model and the Noisemodelling road traffic noise prediction model.

The architecture of the coupling between the two models is an adaptation of the static models conventionally used: where static models estimate the noise levels emitted by road traffic based on the average flow rates and speeds of vehicle flows per road section, the dynamic approach is based on the vehicle trajectories estimated by the traffic model to determine at each time step the sound power of each vehicle present on the network. The modelling chain is described in Figure 1.

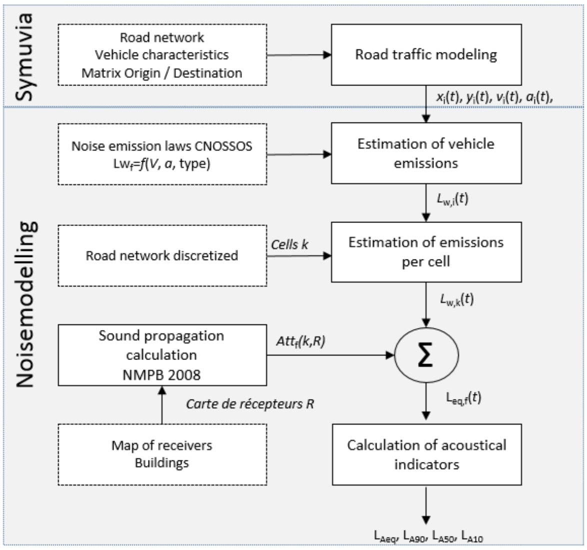

Figure 1 – Dynamic noise modeling chain

2.2 Road traffic modeling

The platform on which traffic simulation is based, Symuvia, is dedicated to the analysis of dynamic traffic simulations. Symuvia includes a tool for editing simulation data sets (flow network and scenarios), a calculation module and tools for analyzing and reporting results. These components are designed to perform traffic simulations over several hours, for an urban area that can cover several km². Symuvia's calculation core includes an assignment module (vehicle route calculation) and a flow module (trajectory calculation). Details on the modeling can be found in (17, 18).

2.3 Noise modeling

NoiseModelling is a free and open-source module of the OrbisGis Geographic Information System, whose initial objective is the production of static road noise maps. The algorithms in the NoiseModelling module take advantage of the spatial analysis methods offered by the GIS environment. The calculation of acoustic indicators from traffic simulation is carried out in three steps:

- Geographic data, from the open Open Street Map (OSM) database, is imported into OrbisGis.
- The trajectories provided by Symuvia in xml format are imported in table form into OrbisGis, via a specific function created for the purposes of this study.
- A set of SQL queries allows acoustic calculations.

The Noisemodelling computation core, called by these SQL queries, dissociates the estimation of noise emissions and the evaluation of noise propagation from sources to receivers. Both the calculation of emissions and sound propagation follow the CNOSSOS methods. Note that the Imagine method is preferred to CNOSSOS for the calculation of the acceleration correction because CNOSSOS, intended to estimate vehicle flow emissions, relies on a distance at intersections correction, which is less appropriate for the dynamic modelling framework.

2.4 Case study and parameters

The case study consists of assessing the acoustic impact of road traffic on an urban network of about 10 km² located in the Lyon conurbation, covering the 3rd and 6th districts of Lyon and part of Villeurbanne (see Figure 2).

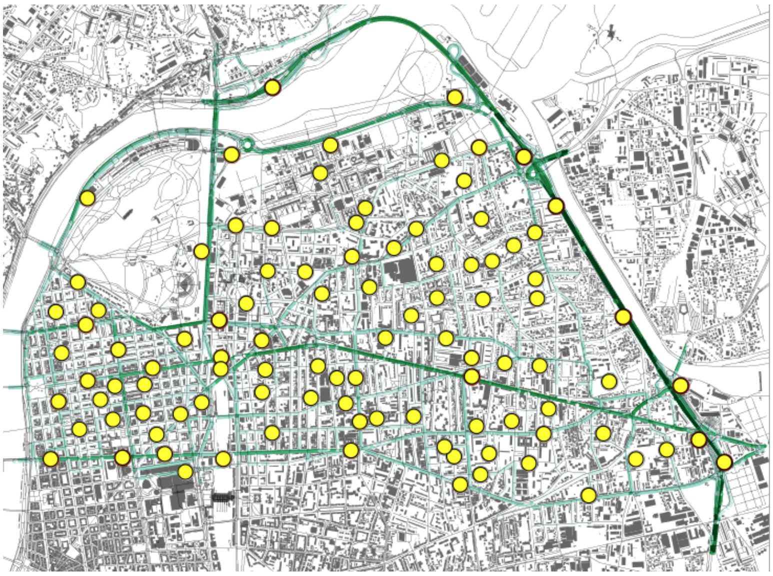

Figure 2 – Network and position of noise receivers

The implemented scenario simulates 3 hours of road traffic during the morning rush hour. Three levels of travel demand are considered, ranging from a P1 period when the level of travel demand is low, to a P3 period when travel demand is almost doubled (morning rush hour). The assignment model was validated to reproduce the flows measured on site during the period of interest in the Magnum project[2].

[2] https://magnum-erc.weebly.com/

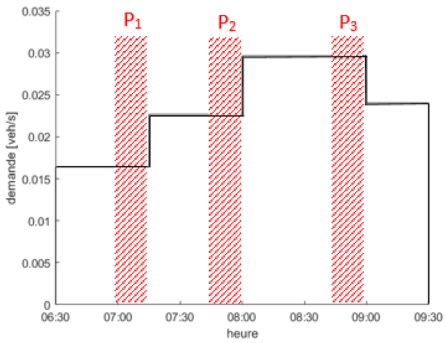

Figure 3 – Demand levels

Three types of vehicles are represented in the traffic simulation: light vehicles (97% of the vehicles generated on the network), heavy vehicles (2.5% of the vehicles generated on the network) and buses (0.5% of the vehicles generated on the network, depending on the bus network and therefore not affected by the assignment processes).

From an acoustic point of view, heavy vehicles and buses are considered as belonging to category 3 of CNOSSOS. Motorized two-wheelers are not included in the simulation.

Three 15-minute periods are used to perform the acoustic calculations: P_1[07:00 - 07:15], P_2[07:45 - 08:00] and P_3[08:45 - 09:00]. Thereafter, the variables relating to the periods Pi will be accompanied by the index i.

Table 1 provides a summary of the parameters that were used for the acoustic calculation for this study. 100 receivers are randomly placed on the network. Noise indicators are the L_{Aeq}, L_{A10}, L_{A50} and L_{A90}.

Table 1 – Parameter values for sound propagation

Parameters	Configuration
Maximal order of reflexion	2
Maximal order of diffraction	1
Maximal distance source-receiver	500m
Building height	10m
Receivers height	1.5m
Ground absorption coefficient	G=0
Walls absorption coefficient	G=0.23
Spatial resolution	D=20m

3. RESULTS

3.1 Period P_1

Period P_1 corresponds to the time range [07:00 - 07:15], during which the flows are already high enough, especially on the structuring axes. Traffic flows relatively smoothly, with average speeds above 30 km/h over a large part of the network. The noise environment is highly correlated to the structure of the road network, with very high noise levels along the ring road. The background noise, materialized by the $L_{A90,P1}$, is also very high, the $L_{A90,P1}$ also exceeding 70 dB(A). This is due to the combined effect of the continuous flow of vehicles and their high speed (average speeds above 70 km/h). The secondary network of small streets is characterized by very low flows, often below 200 veh/h, resulting in relatively low noise levels, with $L_{Aeq,P1}$ of about 50dB(A) and $L_{A90,P1}$ between 40 and 45 dB(A).

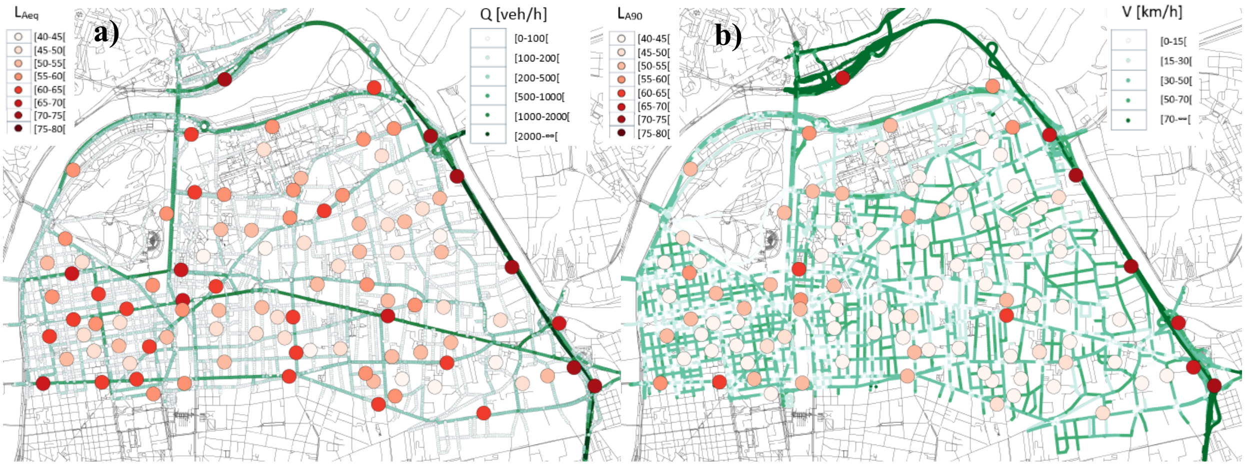

Figure 4 – Period P_1: map of traffic and acoustic indicators

3.2 Period P_2

The P2 period, which corresponds to the time slot [07:45 - 08:00], is marked by an increase in travel demand, which is logically reflected in an increase of the flow rates on the network. This increase is not uniformly spread over the network: some secondary roads see their number of vehicles doubled or even tripled, while traffic flows remain stable or even decrease on some more travelled roads. This is due to a decrease in average speeds, and the resulting route modifications. As a result, the increase in noise levels on the network is itself not uniformly distributed over the network: points near streets where flows have increased significantly see their noise levels increase significantly.

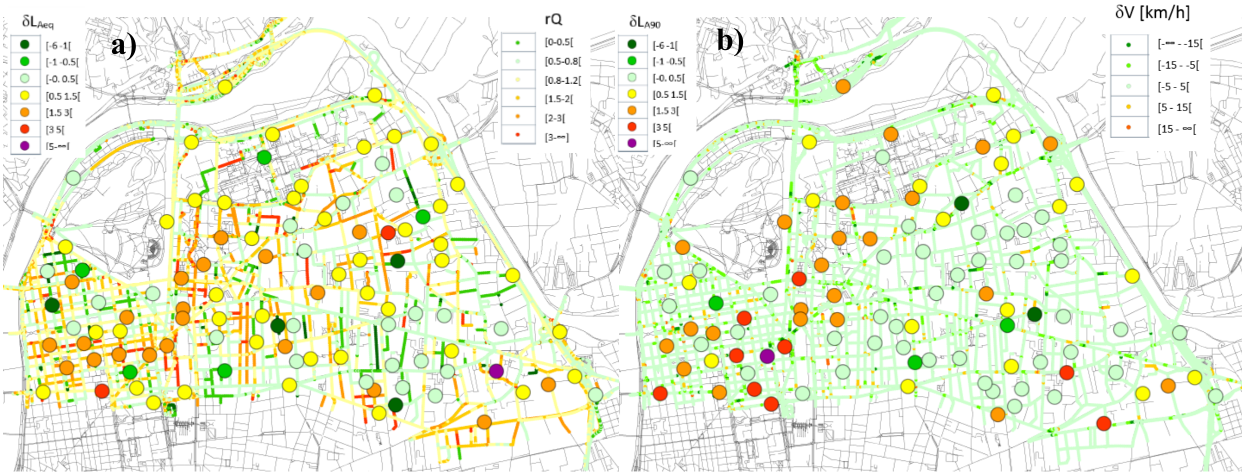

Figure 5 – Period P_2: map of traffic and acoustic indicators relatively to period P_1

3.3 Period P_3

Period P_3 corresponds to the time slot [08:45 - 09:00], marked by the peak of travel demand. The increase in flow rates that was visible during P_2 is accentuated during P_3, and extended over a larger part of the network. Noise levels relative to P_1 increase together, with an increase in L_{Aeq} of more than 3 dB(A) or even 5 dB(A) observed in some areas, particularly to the west of the network where the increase in flow rates is very pronounced. The increase in noise levels on the ring road is contained below 1.5 dB(A), as well as during P_2.

The spatial distribution of the increase in levels remains uneven, with the western part of the network being significantly more affected than the eastern part. The map also shows a distinction in the increase in noise levels between quiet and noisy neighbourhoods. This point is discussed in more detail in the following section.

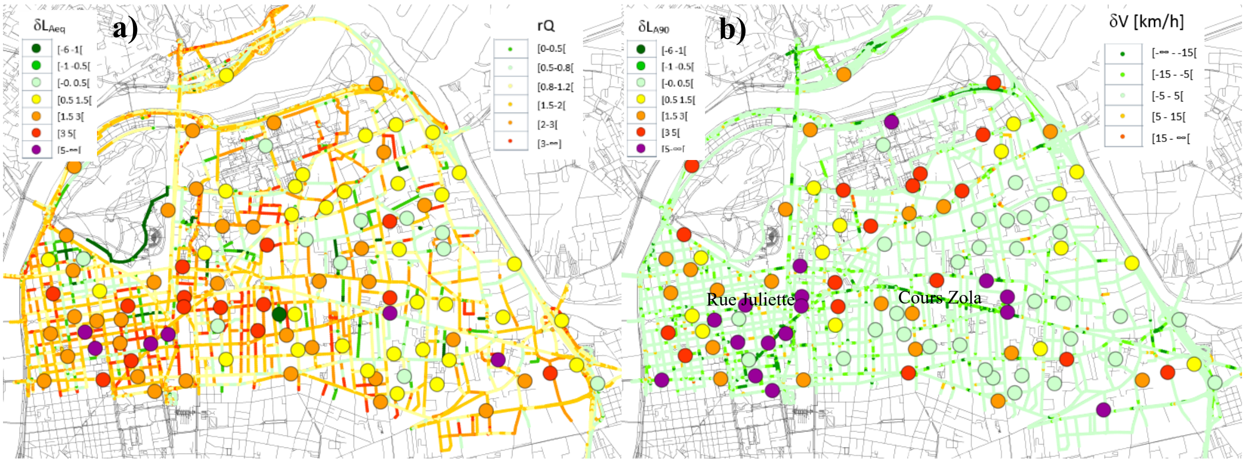

Figure 6 – Period P_3: map of traffic and acoustic indicators relatively to period P_1

3.4 Detailed analysis of noise results

The previous section pointed out that the increase in noise levels was not homogeneous over the network. A closer look into the noise increase shows that for points where $L_{Aeq,P1} > 70$ dB(A), the increase in L_{Aeq} is smaller than 1 dB(A), while for the points where $L_{Aeq,P1}$ is between 65 and 70 dB(A), this increase reaches 3 dB(A). In addition, background noise increases more than high levels, with L_{A90} increases well above L_{A10} increases. Thus, the increase in the number of vehicles on the network tends to compress noise dynamics, increasing background noise more than already high levels. This is due to the rarefaction in the simulation time steps when there are few vehicles in the vicinity of receivers.

The built modeling chain allows the fine analysis of this dynamic, since it gives access to the evolution of the instantaneous levels $L_{Aeq,1s}$. An example of a more detailed analysis is given for receiver n°22.

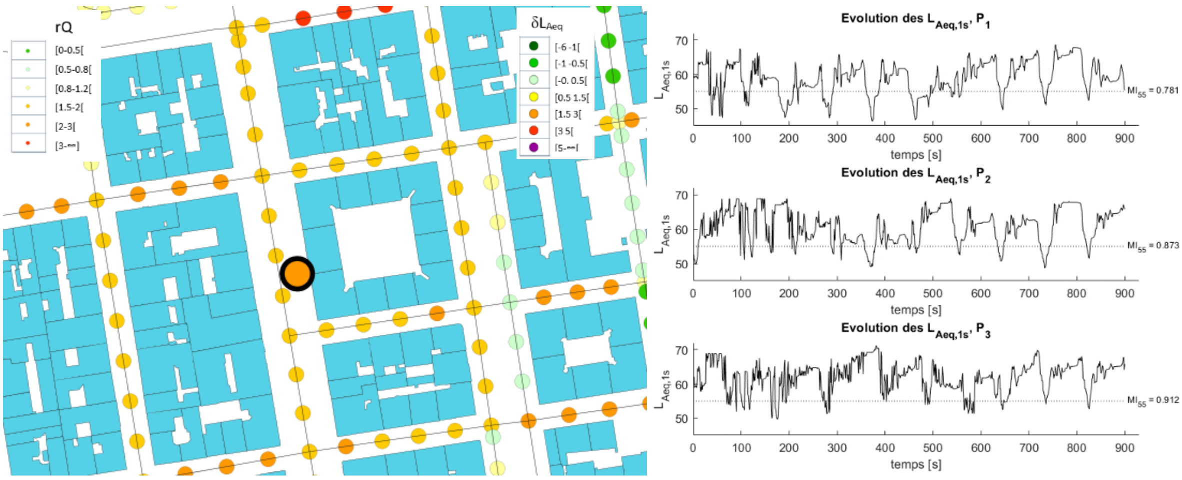

Figure 7 – Sound environment at receiver n°22.

Figure 7 shows the evolution of the $L_{Aeq,1s}$ for each of the three periods. The time series for period

P_1 shows the characteristic evolution of noise levels in streets where road traffic is clocked by traffic lights, marked by a regular alternation between high and lower noise levels.

The quiet periods can be characterized by the indicator MI55, which represents the ratio of time during which noise levels exceed 55dB(A): it is MI55 = 0.78 (22% of the time below 55 dB(A)) for the period P_1. The increase in flows both in the street and the neighbouring streets result in a rarefaction of the periods of calm that were renewed at the scale of the traffic cycle during the P_1 period: the time during which the $L_{Aeq,1s}$ is below 55 dB(A) falls to 13% for P_2, then to 9% for P_3.

4. CONCLUSIONS

A dynamic modelling chain, coupling the Symuvia dynamic traffic model (LICIT, Ifsttar / ENTPE) and the Noisemodelling noise level prediction tool (UMRAE, Ifsttar / Cerema), is developed in this paper to assess the impact of road traffic on noise environments at the scale of an urban traffic network of about 10 km² located in Lyon/Villeurbanne. The traffic model is sensitive to dynamic assignment phenomena depending on traffic conditions, and reproduces the kinematics of the vehicles present on the network. The acoustic model estimates the instantaneous sound power levels as a function of vehicle kinematics, then the noise levels in a receiver map after calculating the noise propagation as a function of data on the building network.

The simulation, which reproduces 3 hours of a morning rush hour scenario, highlights the increase in noise levels associated with the increase in travel demands. It also highlights that the increase in noise levels: i) is not uniformly distributed over the network and has a greater impact on streets where traffic is reported, with noise levels increasing only slightly, for example, on the ring road due to a lower increase in the number of vehicles compared to other streets, ii) has a greater impact on background noise (and in particular the L_{A90}), making quiet periods on the network rare, which is explained by a higher vehicle density. A more detailed analysis is possible locally through the analysis of the evolution of the $L_{Aeq,1s}$ and the study of specific acoustic indicators (here the distribution of $L_{Aeq,1s}$ and in particular the ratio of time when the $L_{Aeq,1s}$ exceeds the 55 dB(A) threshold).

However, some improvements to the model are desirable, and will be the subject of research in the near future, such as the estimation of emergence indicators as long as perceptual assessments. Then the proposed model will make it possible to assess the acoustic impact, currently unknown, of road traffic management strategies on the scale of an urban network: policies for spreading demand, speed limits on a portion of the network, banning certain vehicles (motorcycles, old vehicles, etc.) in a neighbourhood, etc.

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