Influence of noise source representation on the estimation of specific descriptors close to traffic signals

Arnaud Can[a], Ludovic Leclercq[a] and Joel Lelong[b]

[a]LICIT, ENTPE / INRETS - Université de Lyon, rue Maurice Audin, 69518 Vaulx-en-Velin Cedex, France
[b]INRETS, 25 av. F. Mitterrand, case 24, 69675 Bron, France
can@entpe.fr

Considering traffic dynamics greatly improves noise estimation in urban area. This can be achieved by coupling a dynamic traffic model with both emission laws and sound propagation calculation. This paper focuses on the influence of noise source representations with the traffic model. Several representations are tested: point sources and homogeneous line sources of different sizes. We aim at evaluating how these representations correctly estimate classical descriptors (L_{Aeq} and statistical descriptors) and specific descriptors able to capture noise dynamics at a traffic signal scale. Three typical urban situations are studied: in front of, upstream and downstream of a traffic signal. Noise source representation can be coarse for classical descriptors calculation if traffic dynamics are precisely described. On the contrary, noise source representation should be refined to precisely assess noise dynamics.

1 Introduction

Traffic noise prediction models should consider traffic dynamics to precisely assess noise variations in urban area [1][2]. Such variations can be assessed by coupling a dynamic traffic model and both emission laws and sound propagation calculation [3][4][5][6][7].

The traffic model gives position $x(t)$, speed $v(t)$ and acceleration $a(t)$ of each vehicle on the network. The simulation time step is usually 1s. Traffic model outputs feed emission laws to calculate noise emissions $L_w(t)$. Then a propagation calculation provides A-weighted equivalent sound pressure levels $L_{Aeq,1s}(t)$ for a grid of receivers. Classical descriptors but also refined descriptors able to capture noise dynamics at the traffic signal scale can finally be calculated [8][9] (see Figure 1). Thereby this complete modelling chain permits to account for traffic noise dynamics when evaluating urban traffic management policies.

Confidence bounds for the errors generated by each block will help to characterize the accuracy of the whole modelling chain. In this paper we will focus on noise source representation and its influence on descriptors calculation. Indeed, vehicle emission should be gathered on predefined line sources (LS) to reduce calculation times [10]. Line source length but also alignment between line source and receiver can affect noise estimation. Possible alignments are "in front" (receiver is in front of a LS) and "opposed" (receiver is between two LS). [10] has shown that line sources give better results than fixed point sources since it limits alignment influences. Moreover, this study has shown that, for a receiver located in front of a traffic signal and 15m from the road, noise estimation can be reached through quite large line sources provided that traffic dynamics is precisely described. Line sources can length up to 56m for L_{Aeq} estimation and up to 28m for statistical descriptors estimation. However, this study only considered receivers quite far from the road (15m).

This paper will extend this study to receivers located closer to the road (5.5m and 10m), where noise dynamics are higher. Noise descriptors are calculated upstream, in front, and downstream of a traffic signal. Classical descriptors and specific descriptors proposed in [8] are tested to determine line sources lengths that guarantee a precise assessment of noise dynamics.

Background materials on traffic modeling and noise source representation are first provided. Errors generated by different line source lengths are estimated with respect to an exact calculation (moving line sources). A discussion will sum up the main insights of this comparison.

2 Background

2.1 Traffic modeling

A macroscopic car-following model (MCF) is used. This representation enables to capture traffic dynamics close to a traffic signal and to precisely estimate L_{Aeq} and statistical descriptors [10]. In MCF, vehicles are individually represented but obey global rules [11][12] (contrary to microscopic car following models in which each vehicle has its specific behavior [13][14]). The vehicle parameters are the maximum speed V_x, the minimum spacing s_{min} between two vehicles and the wave speed w (speed at which a congestion spills back on the network) [15]. Thus position of vehicle i at the next time step $x_i(t+\Delta t)$ is the minimum between the position it is willing to reach when traffic is free and the position it cannot overpass when traffic is congested:

$$x_i(t+\Delta t) = \min\left(\underbrace{x_i(t)+V_x\Delta t}_{\text{position when traffic is free}} \quad , \quad \underbrace{x_{i-1}(t)-s_{\min}}_{\text{position when traffic is congested}} \right)$$

The numerical time step Δt is settled by the CFL (Courant-Friedich-Lewy) condition $\Delta t = s_{min}/w$ to ensure the scheme stability and minimize numerical diffusion. Speed $v_i(t)$ and acceleration $a_i(t)$ are then deduced from positions $x_i(t)$ and $x_i(t+\Delta t)$.

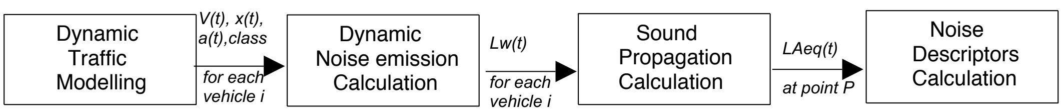

Figure 1: modeling chain of the dynamic noise estimation models

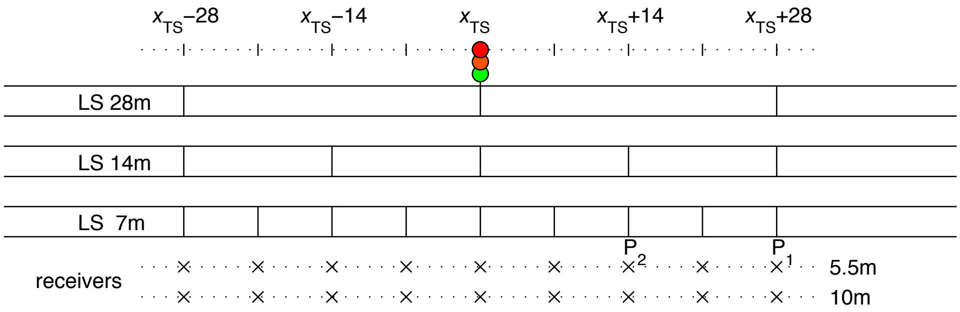

Figure 2: noise source representations and receivers positions

2.2 Noise source representations

Emission laws provide noise power level $Lw_i(t)$ of each vehicle i at time t from its kinematics. The laws used in this study give Lw with respect to speed and cruising mode (accelerating, cruising or decelerating) [16]. All vehicles follow the same emission law. This was validated in [17] for classical descriptors estimation in urban area, provided that traffic dynamics are precisely described. Note that this hypothesis prevents the estimation of noise peaks (L_{max} and L_1) that are due to noisiest vehicles [17].

The reference noise source representation is moving line sources. This is the finest one: each vehicle i forms a segment source whose angle $\theta_{i,\Delta t}(t)$ seen from the receiver is defined by the positions between the receiver and the vehicle i at t and at $t+\Delta t$. This representation is useless in practice for dynamic noise estimation because it is time consuming: propagation calculation should be determined at each time step. Thus, noise sources are gathered on fixed-length lines sources. Then propagation calculation between fixed line sources and the receiver is only performed one time for the first time step. Power noise level LW_j of a line source j is deduced from the power noise level of vehicles on the line source:

$$LW_j(t) = 10\log\left(\sum_{i\in I}\frac{1}{L}10^{\frac{Lw_i(t)}{10}}\right), I \text{ : vehicles on the line source}$$

where L is the length of the line source.

$L_{Aeq,1s}(t)$ can then be determined. Only geometric sound propagation will be considered in this study. Within this hypothesis equivalent noise level $L_{Aeq,1s}(t)$ is given by:

$$L_{Aeq,1s}(t) = 10\log\left(\sum_j \alpha_j 10^{\frac{LW_j(t)}{10}}\right) - 10\log(2\pi d),$$

where α_j is the angle of the line source j seen from the receiver and d is the distance between the road and the receiver.

3 Method

Tests are carried out on a 700m one-lane road section, with a traffic signal TS located at x_{TS}=350m; its characteristics are t_{green} = 60s and t_{red} = 30s. Flow rate is Q = 900veh/h. Under those conditions, no queue remains at the end of the traffic cycle. Received levels are calculated over a 15mn period.

Receivers are located 5.5m and 10m from the section, at 2m height.

Descriptors used for the comparison are classical ones: L_{Aeq} and statistical descriptors (L_{max}, L_1, L_5, L_{10}, L_{50}, L_{90}, L_{min}), but also but also specific descriptors that reveal noise dynamics at the traffic signal scale, based on [8]:

- The mean noise pattern. This is the pattern that repeats on average every traffic signal. It is obtained from acoustic average for each instant t_i of the cycle ($0<t_i<t_{cycle}$) after filtering. Filtering consists in keeping at each instant the sample of $L_{Aeq,1s}$ between L_{90} and L_{10}.
- Specific descriptors that highlight characteristics of noise levels when traffic signal is green or red. Note that these descriptors can only be calculated when the chronology of the traffic cycles is precisely known. An extraction procedure of these levels is proposed in [8] when traffic cycle chronology is unknown. These descriptors are:
  - The green mode x_{green} (respectively red mode x_{red}) of the Gaussian fit of the $L_{Aeq,1s}$ distribution, considering the levels received during the green phase (respectively the red phase). x_{green} and x_{red} correspond to the most frequent levels observed when traffic signal is green (respectively red).
  - The A-weighted equivalent sound pressure levels L_{green} and L_{red} calculated when the traffic signal is respectively green or red.
  - The L'_{green} (respectively L'_{red}), calculated from an acoustic average of the sample of $L_{Aeq,1s}$ between L_{90} and L_{10} during the green phase (respectively the red phase). L'_{green} and L'_{red} correspond to the upper and lower levels of the mean noise pattern in front of a traffic signal, when it is constructed following the procedure above.

The following receiver positions are tested: -28m, -21m, -14m, -7m, 0m, 7m, 14m, 21m and 28 from the traffic signal. Two distances from the road (5.5m and 10m) are considered (see Figure 2). Noise representations are 7m (LS7), 14m (LS14) and 28m (LS28) line sources.

Impacts of line source length and alignment will be jointly evaluated, by considering the influence on descriptors estimation of doubling line source length whether alignment is changed or not.

LS14 and LS28 line sources will be first compared. Only receivers at 5.5m from the road will be considered. Two cases will be investigated:

- P_1 (28m downstream); see Figure 2: comparison between LS14o (opposed) and LS28o (opposed). In this case cell length is doubled without changing alignment;

- P_2 (14m downstream); see Figure 2: comparison between LS14o (opposed) and LS28f (in front). In this case cell length is doubled and alignment is changed.

All the results will then be summarized on a final table to state on the suitable noise representation with respect to the considered descriptor.

4 Results

4.1 LS14o and LS28o comparison; P1($x = x_{TS}$ +28m, d=5.5m)

Energetic noise descriptors (L_{Aeq}, L_{green} and L_{red}) are not affected by line source length; see Table1. On the contrary, differences in high levels estimation are observed with both LS14o and LS28o (L_5 underestimation exceeding 2 dB(A) with both LS14o and LS28o). It is due to the aggregation of energy on the line source, which affects the representation of vehicles passing in front of the receiver (see from t=40s to t=60s on Figure 3a): dynamics linked to vehicle motion are partly lost.

Thus descriptors estimation with LS14o and LS28o are very similar. Nevertheless, estimation of low levels seems affected with LS28o (1.3 dB(A) L_{min} overestimation). Finally, loss of dynamics does not affect specific descriptors estimation (see L'_{green}, L'_{red}, x_{green} and x_{red} estimations; Table 1).

Source Representation	LS length	Alignment	L_{Aeq}	L_{max}	L_1	L_5	L_{10}	L_{50}	L_{90}	L_{min}	L_{green}	L_{red}	x_{green}	x_{red}	L'_{green}	L'_{red}	σ
Vehicle line source			67.4	73.2	73.2	73.0	71.6	65.6	54.6	53.5	68.8	59.1	67.4	56.3	68.1	55.2	-
Grid of line sources	14m	opposed	67.1	72.7	72.7	70.5	70.3	65.4	54.7	53.7	68.5	59	67.5	56.4	67.5	55.9	0.8
	28m	opposed	67.1	72.9	72.8	70.6	70.2	65.5	55.6	54.8	68.5	59.3	67.5	57.1	67.3	56.3	1.9

Table 1: Comparison of noise descriptors estimation at $x = x_{TS} + 28$, for 14m and 28 line sources.

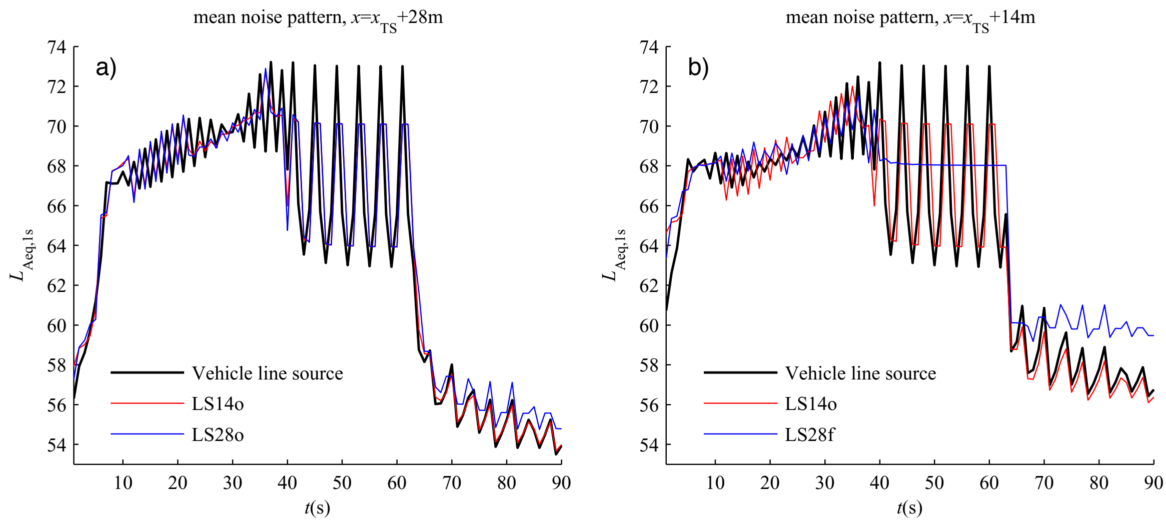

Figure 3: mean noise patterns at $x = x_{TS} + 28$ and $x = x_{TS} + 14$, for the following noise source representations: vehicle line source, 4m line source and 28m line source

Source Representation	LS length	Alignment	L_{Aeq}	L_{max}	L_1	L_5	L_{10}	L_{50}	L_{90}	L_{min}	L_{green}	L_{red}	x_{green}	x_{red}	L'_{green}	L'_{red}	σ
Vehicle line source			67.3	73.2	73.2	73.0	71.4	65.6	57.1	56.4	68.7	59.1	67.7	58.4	68.2	57.7	-
Grid of line sources	14m	opposed	67.1	72.0	72.0	70.4	70.1	66.2	56.8	56.1	68.5	59.2	67.9	58.0	67.2	57.4	1.9
	28m	in front	67.2	71.5	71.2	70.4	69.5	68.0	59.8	59.2	68.5	61.3	68.3	60.5	68.4	59.8	2.5

Table 2: Comparison of noise descriptors estimation at $x = x_{TS} + 14$, for 14m and 28 line sources.

4.2 LS14o and LS28f comparison; P2($x = x_{TS}$ +14m, d=5.5m)

Statistical descriptors estimation is affected by alignment with LS28f (2.4dB(A) L_{50} overestimation), L_{red} is also 2.2dB(A) overestimated – see Table 2, while it remains precise with LS14o (0.6dB(A) L_{50} overestimation and 0.1dB(A) L_{red} overestimation). Mean noise pattern (see Figure 3b) is quite far from the reference's one with LS28f (σ=2.5dB(A), because of low levels overestimation. It is linked to noise level estimation when traffic signal is red. This overestimation is due to vehicles that arrive on the queue and are noisier than stopped vehicles; those vehicles enter sooner on the line source when it is larger. Moreover, dynamics from vehicles motion are totally lost with LS28f (see from t=40s to t=60s on Figure 3b). However, L_{Aeq} remains precisely estimated.

Thus alignment between line source and receiver can influence estimation with large line sources. Noise source representations should imperatively be chosen to ensure a precise estimation of noise dynamics wherever the receiver is located. The results for all receiver locations are now compared. Suitable line source lengths are discussed according to the descriptor to estimate.

4.3 Suitable Line source length

Maximum deviations from vehicle line source representation among the 9 receivers are exposed for all descriptors in Table 3. It should not exceed a fixed value. Two bounds are considered: 1 and 2 dB(A).

10m from the road: all descriptors can be estimated with LS28 within a 2dB(A) error bound. LS28 is still relevant for energetic descriptors (L_{Aeq} and L_{green}) estimation if only a 1dB(A) error bound is allowed, but it is not sufficient for statistical levels estimation. Then LS14 is not sufficient too. LS7 guarantees estimation within 1dB(A) for all descriptors.

5.5m from the road: L_{Aeq} can still be estimated with LS28 within a 1dB(A) error bound. But this representation is not relevant for other descriptors. If a 2dB(A) error is admitted, LS14 is sufficient for descriptors relative to green and red phase estimation. This representation fails in estimating high levels (L_{max} and L_1) accurately. However, high levels estimation was already impossible because of averaging noise emission laws [17].

Finally, LS7 improves estimation and guarantees estimation of descriptors within 2dB(A). It also guarantees estimation of all descriptors except high levels (from L_{10} to L_{max}) within a 1dB(A) error bound.

		L_{Aeq}	L_{max}	L_1	L_5	L_{10}	L_{50}	L_{90}	L_{min}	L_{green}	L_{red}	x_{green}	x_{red}	L'_{green}	L'_{red}
10m from the road	LS7	-0.2	0.6	0.6	0.8	0.6	0.7	-0.4	-0.4	-0.1	-0.5	-0.1	-0.4	-0.4	-0.6
	LS14	-0.3	-1.4	-1.4	-1.4	-1.3	1.0	-0.6	-0.4	-0.2	-0.9	-0.1	-0.7	-0.6	-1.1
	LS28	-0.2	1.2	-1.4	-1.9	-1.3	0.9	1.3	1.4	-0.1	-1.1	0.2	-1.0	-0.7	-2.0
5.5m from the road	LS7	-0.5	1.5	1.9	1.9	1.5	0.9	-0.4	-0.8	-0.4	-0.9	-0.2	-0.6	1.0	0.7
	LS14	-0.6	-2.8	-2.9	-2.9	-2.9	1.7	-0.9	-1.4	-0.4	-1.5	0.2	-1.1	-0.9	-1.0
	LS28	-0.6	-3.0	-3.1	-3.9	-2.9	2.4	2.7	2.7	-0.3	2.2	0.6	2.1	0.9	2.1

Table 3: Maximum errors in noise descriptors estimation (compared to vehicle line source representation), for different line source lengths and distances from the road (5.5m or 10m). in grey: error exceeds 1dB(A), in black: error exceeds 2dB(A)

5 Conclusion

Noise source representations have been tested for dynamic traffic noise estimation close to traffic signals. Estimation is achieved by coupling a dynamic traffic model with noise emission laws. Different line sources lengths have been compared (7m, 14m and 28m) for classical and specific noise descriptors. Alignment between line source and receivers can affect estimation with large line sources (28m). Thus line source length should be carefully set to guarantee accurate descriptors estimation on a grid of receivers.

28m line source lengths seems sufficient for noise descriptors estimation over 10m from the road. Line source lengths should be reduced when receivers are closer to the road (5.5m). However, L_{Aeq} remains precisely estimated close to the road with 28m line sources provided that traffic dynamics are precisely described.

14m line source lengths is sufficient to assess specific descriptors (L_{green}, L_{red}, x_{green}, x_{red}) 5.5m from the road within a 2dB(A) error bound. Finally, peaks of noise (L_1 and L_{max}) cannot be estimated through line source representation. To improve estimation of noise peaks for one given receiver (this procedure is too computational expensive to be extended to a grid of receivers), it is possible to consider individual emission laws and vehicle line source representation for closest vehicles.

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