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Auscultation acoustique des aménagements cyclables en milieu urbain

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Les études d'impact acoustique en milieu extérieur sont généralement menées pour des récepteurs situés en façade de bâtiments, comme le demande la réglementation française. Très peu d'entre elles ont été effectuées pour des piétons ou des cyclistes se déplaçant le long d'axes routiers bruyants. Or, dans leur déplacement en ville, les cyclistes sont souvent exposés à des niveaux sonores très élevés, parfois largement supérieurs aux recommandations d'organismes de santé. Dans ce contexte, l'objectif principal de cette recherche est de proposer une méthodologie capable d'évaluer l'exposition d'un cycliste au bruit de trafic, lors de son déplacement en site urbanisé. L'exposition sonore est évaluée par des mesures in situ, ainsi que des simulations. Des indicateurs acoustiques classiques, mais aussi dynamiques, sont ainsi calculés, en prenant en compter le bruit aérodynamique généré au niveau des oreilles.

1 Introduction

1.1 Context

Since the invention of the first "velocipede" in 1861 in Paris by Pierre Michaux, the bicycle has known a growing success with a real democratization during the 20th century. However not before the 80s have the bicycle users gathered to put pressure on urban mobility policies. As for the town of Grenoble it has been one of the pioneers in the bicycle's expansion (perhaps due to its flatness): 115 km of cycle paths today and more than 400 km expected in 2012.

But despite the development of new cycle paths, car is still a king in the city relegating the bicycle to no more than an alternative mean of transportation. Thus cyclists have to cope with dangers of the road as well as comfort problems such as noise. However most of noise annoyance surveys have been dedicated to residents inside or in front of buildings. Only few of them have addressed the aspect of noise annoyance for pedestrians or cyclists, when they are exposed to high and sometimes unacceptable noise levels along their route (due to road traffic). This point shows also the lack of regulation for people exposed outdoors during their daily activities and movements.

In this context we propose to develop a method able to assess the acoustical quality of a cycle path from the cyclist point of view (that it is to say to caracterise the environmental noise impacting him). This approach aims at being used by town planners as well as cycle paths designers in order to improve the well-being of cyclists and to participate to the sustainable development of cities [1].

1.2 Acoustical classification of roads

The French "Noise Law" (Loi Bruit) requires from the local authorities to carry out the acoustical classification of roads whose daily traffic is greater than 5000 vehicles. This classification allows to determine 5 classes of roads depending on the road noise emission level during daytime (6am-10pm) calculated from traffic speed and flow (from class 1 for highest noise levels to class 5 for lowest ones).

Thus a first acoustical assessment of cycle paths in Grenoble has been carried out from the known classification of roads. By superimposing the roads network with the cycle paths one, it is possible to attribute to each cycle path section the classification of the corresponding road section (along it). A sixth category has been created for cycle path sections along non-classified roads (less than 5000 vehicles a day) or located far away from roads. In Figure 1 is shown an example of noise acoustical classification (by sections) of the cycle paths in Grenoble with the 6 classes displayed with different colors.

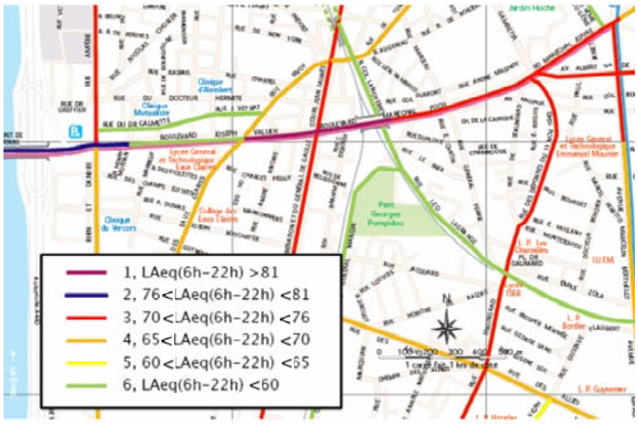

Figure 1: A part of the acoustical classification of cycle paths in Grenoble, determined from the official values of roads acoustical classification

2 Choice of assessed cycle routes

2.1 Quick presentation of the routes

Four different cycle routes (each of them using several cycle paths) have been chosen within the agglomeration of Grenoble:

- The "South Ring Path" route which is the oldest city laying-out and certainly the best cycle path in the agglomeration with many sections away from roads,

- The “Grand Boulevards” route following a 2 km long, wide avenue bordered with 6 floor buildings, where the cyclists are absolutely not protected from road traffic noise with sound pressure level peaks higher than 80 dB(A),
- The “Berriat Street” route along a 2 km long canyon street with many shops, caracterised by an important heterogeneity of soundscapes along it,
- The “University” route going through the large campus of Saint-Martin-d’Hères (close to Grenoble), this campus representing a daily flow of 6800 bicycles; for this reason it seemed interesting to us to keep this route for a more detailed study presented in the next sections.

2.2 Presentation of the “University” route

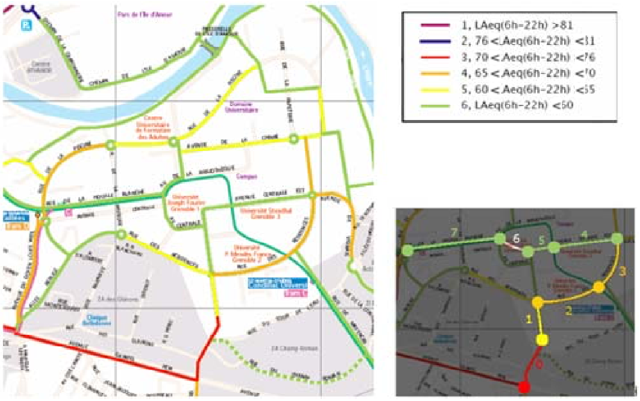

Figure 2: A part of the acoustical classification of cycle paths in Grenoble, determined from the official values of roads acoustical classification

In order to take into account a wide range of cycle path classes, a dedicated route composed of 8 sections (0 to 7) has been created (Figure 2). An experimental study (see section 4) is carried out on this route with a set of acoustic indicators presented hereafter in section 3.

3 Acoustic indicators and index

3.1 Acoustic weighting

In the frame of environmental acoustics, noise if very often evaluated with A-weighting which has been developed from sonies curves at 30 phones [2]. On the other hand works [3] have shown that C- and D-weightings tend to overestimate levels when B-weighting is appropriate to the 70 phones curve. The latter seems to be the most adapted to a cyclist situation in an environment full of vehicles rolling at about 50 km/h. So we propose here to apply the B-weighting to noise exposure of a cyclist in urban area.

3.2 Aerodynamic noise

The cyclist moves in an air flow whose speed is close to its own velocity. The cyclist’ head acts as an obstacle within the flow creating vortex in the vicinity of the ears and making an aerodynamic noise. Kristiansen and Pettersen [4] have measured such a noise for different angles on incidence (vs head position) and different speeds (see Tables 1 and 2).

	Frequency band (Hz)				
Speed (km/h)	31.5	63	125	250	500
13.0	**76**	**76**	**69**	**65**	**-**
18.7	**80**	**80**	**75**	**70**	**-**
23.0	**82**	**84**	**79**	**68**	**-**

Table 1: SPLs in dB (vs speed and frequency band) corresponding to the aero-acoustic noise received at the ears when the head stands in an air flow

	Frequency band (Hz)				
	31.5	63	125	250	500
Mean (over angles)	**10**	**11**	**13**	**16**	**17**

Table 2: Extra sound attenuation in dB due to the head tilting

For acoustical studies of cycle paths it seems necessary to take into account this physical phenomenon. Hence we propose here to use an acoustical mask [5, 6] whose spectrum are calculated from Kristiansen and Pettersen’s data. We consider that the SPL of the aerodynamic noise $L_{aero}(f)$ for an octave-band centered on frequency f brings a contribution of $L_{aero}(f)-12$ on the octave band $2f$, that is the mask level $L_{mask}(2f)$ produced by the aerodynamic noise within the octave bands f and $2f$ writes:

$$L_{mask}(2f) = 10\log\left[10^{\frac{L_{aero}(2f)}{10}} + 10^{\frac{L_{aero}(f)-12}{10}}\right] \quad (1)$$

Using Tables 1 and 2 with Equation 1, one gets the masking SPLs in Table 3.

	Frequency band (Hz)								
Speed (km/h)	31.5	63	125	250	500	1k	2k	4k	8k
13.0	**66**	**66**	**58**	**51**	**39**	**27**	**15**	**5**	**1**
18.7	**70**	**70**	**63**	**56**	**44**	**32**	**20**	**9**	**2**
23.0	**72**	**74**	**67**	**57**	**45**	**33**	**21**	**10**	**2**

Table 3: SPLs in dB (vs speed and frequency band) corresponding of the aeroacoustic mask at the ears when the head stands in an air flow

A linear regression method can be applied in order to determine a general formula of L_{mask} as a function of speed v and frequency f:

$$L_{mask} = av + b \quad (2)$$

where coefficients a and b are given in Table 4.

	Frequency band (Hz)								
coefficient	31.5	63	125	250	500	1k	2k	4k	8k
a	**2,9**	**2,3**	**4,4**	**3,9**	**4,5**	**4,5**	**4,4**	**4,0**	**2,1**
b	**55**	**58**	**42**	**37**	**23**	**11**	**-1**	**-10**	**-7**

Table 4: Coefficients a and b

Thus considering that measured noise $L_{meas,v}$ (with a wind protection) whose B-weighted SPLs are less than $L_{mask,v}$ should not be heard by the cyclist, any SPL less than theoretical masking level should not be taken into account. In this way we propose to use a dedicated indicator $L_{cycle,v}(f)$ integrating all these assumptions and defined as:

$$L_{cycle,v}(f) = L_{meas,v}(f) \quad \text{if } L_{meas,v}(f) \geq L_{mask,v}(f) + 3 \tag{3a}$$

$$L_{cycle,v}(f) = L_{meas,v}(f) - \frac{6 \times \log\left(\dfrac{L_{meas,v}(f)}{L_{mask,v}(f)+3}\right)}{\log\left(\dfrac{L_{mask,v}(f)}{L_{mask,v}(f)+3}\right)} \quad \text{if } L_{meas,v}(f) < L_{mask,v}(f) + 3 \tag{3b}$$

15 km/h appears to be a suited and practical value for *v*.

Finally the $L_{eq,cycle}$ is obtained by energetic summation of the frequency band values using a B-weighting.

3.3 Dynamic noise indicators

We propose to complete the L_{eq} averaged indicator with noise indicators caracterising the dynamics of soundscape such as its roughness. These indicators based on the time evolution of $LA_{eq,1s}$ are presented hereafter [7, 8]:

- The SWI (Spreading width indicator) defined as $\Delta L/30$, where ΔL represents the difference in dB between the highest and the lowest value in the dB-by-dB distribution of $L_{eq,1s}$ (keeping only values above 1%).
- The RPI (Rhythm purity indicator) defined as $[\max(LM) - av(LM^*)]/\max(LM)$ where LM is the Fast Fourier Transform of the $L_{eq,1s}$ "signal" and $av(LM^*)$ is the average of the LM values out of the half-octave band centered on the $max(LM)$.
- The roughness indicators $\delta L_{max,1}$ and $\delta L_{min,90}$, $\delta L_{max,1}$ being the average of the δL_{eq} maximal values preent 1% of time, and $\delta L_{min,90}$ being the average of the δL_{eq} minimal values present 90% of time, where $\delta L_{eq} = L_{Aeq,1s}(k+1) - L_{Aeq,1s}(k)$.
- The noisiness indicator NI70 being the percentile of time when $L_{eq,1s}$ is greater than 70 dB(B) (counting only periods of at least 4 seconds).
- The tranquility indicator TI60 being the percentile of time when $L_{eq,1s}$ is less than 60 dB(B) (counting only periods of at least 4 seconds);

3.4 Noise quality index

Indices are commonly used to assess the ratio of air pollution, integrating several pollutant concentration values. In the European Interreg-IIIB project ALPNAP [10],a first proposal for integrating both air and noise pollution into a single index has been developed. Here we propose to use a scale of 6 values (1 for very good to 6 for very bad) for the characterization of noise quality of a cycle path section. We also propose such an approach for the dynamic indicators as shown in Table 5.

Noise quality index	Acoustical classification of cycle path	$L_{eq,cycle}$	ΔL	SWI	RPI	$\delta L_{max,1}$	$\delta L_{min,90}$	NI70	TI60
1	6	<60	<3	<0.1	<0.1	<3	<1	<10	>100
2	5	60-65	3 - 6	0,1 – 0,2	0.1 - 0.2	3 – 6	1 – 1.5	10 – 25	90 – 100
3	4	65-70	6 - 9	0,2 - 0,3	0,2 - 0,3	6 – 9	1.5 – 2	25 – 50	70 – 90
4	3	70-75	9 - 15	0,3 - 0,5	0,3 - 0,5	9 – 12	2 – 3	50 – 60	50 – 70
5	2	76-80	15 - 30	0,5 – 1	0,5 – 0.7	12 – 15	3 – 4	60 – 100	20 – 50
6	1	>80	>30	>1	>0.7	>15	> 4	>100	<20

Table 5: Proposed indices for $L_{eq,cycle}$ and dynamic indicators

4 Experimental approach

4.1 Results

The experiment is carried out along the University route (see section 2 and Figure 2). The B&K 2250 sound level meter is fixed in the cyclist backpack at ears height. Figure 3 shows the measured levels (L_{eq}, LA_{eq}, LB_{eq}, $L_{eq,cycle}$) for the 8 sections of the route.

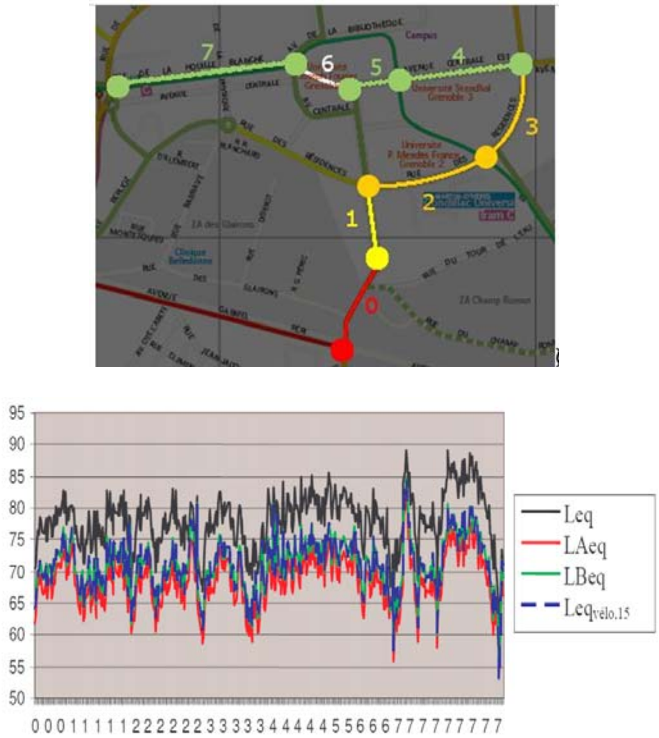

Figure 3 : University route (left) and measured levels (Leq, LAeq, LBeq, $L_{eq,cycle}$) for the 8 sections of the University route (right)

In Table 6 are recapped the indicators results obtained for a set of four measurement campaigns (named 23, 24, 27 and 28).

		Path section N°							
Indicator	Meas.	0	1	2	3	4	5	6	7
$L_{eq,cycle}$ (dB(cycle,15))	23	70	70	69	69	72	72	68	73
	24	72	69	70	72	69	65	65	69
	27	67	67	69	66	71	73	73	72
	28	71	76	74	74	72	74	72	72
ΔL (dB(cycle,15))	23	13	14	20	15	15	5	12	24
	24	16	11	14	11	12	16	13	13
	27	15	11	22	18	18	17	12	12
	28	9	16	23	9	15	14	13	24
SWI	23	0.4	0.5	0.7	0.5	0.5	0.2	0.4	0.8
	24	0.5	0.4	0.5	0.4	0.4	0.5	0.4	0.4
	27	0.5	0.4	0.7	0.6	0.6	0.6	0.4	0.4
	28	0.3	0.5	0.8	0.3	0.5	0.5	0.4	0.8
RPI	23	0.7	0.8	0.8	0.8	0.8	0.7	0.7	0.8
	24	0.8	0.8	0.8	0.8	0.8	0.6	0.7	0.8
	27	0.7	0.8	0.8	0.7	0.8	0.6	0.7	0.8
	28	0.8	0.8	0.7	0.8	0.7	0.7	0.6	0.8
$\delta L_{max,1}$ (dB(cycle,15))	23	5	9	12	5	9	4	6	12
	24	6	6	8	6	7	5	6	8
	27	9	7	8	8	6	11	9	7
	28	5	9	9	8	10	6	6	7
$\delta L_{min,90}$ (dB(cycle,15))	23	1	2	2	2	2	1	2	2
	24	1	2	2	2	2	1	2	2
	27	1	1	2	2	2	3	2	1
	28	1	1	2	1	2	2	3	1
NI70	average	47	57	52	73	59	65	39	58
TI60	average	0	0	0	1	0	0	0	0

Table 6: Indicators obtained from 4 measurement campaigns along the University route

4.2 Analysis

From results in Table 6, we can observe that:

- The Spread Width rather low in all cases, with maximum values in section 7 due to tramways passing-bys along; one may note that in a mapping approach such as the one presented in section 1.B, predominant sound sources other than roads (trams, trains…) should also be taken into account to better determine the acoustical classification of cycle paths.
- Rhythm is quite pure everywhere as RPI shows (close to 1);
- Roughness is of medium intensity, with high values of $\delta L_{max,1}$ (more than 10 dB, due to some noise peaks) but low values of $\delta L_{min,90}$ (around 2 dB);
- Noisiness (NI70) is rather elevated. A cyclist on the University route is impacted in average by 3 noisy events a minute;

Indeed the tranquility indicator TI60 is zero almost everywhere.

5 Conclusions

In this paper we have presented an original experimental approach allowing to assess the acoustical quality of a cycle path from the cyclist point of view. We have proposed a new indicator $L_{eq,cycle}$ using the B-weighting more suited to outdoor noise exposure as well as the effect of the aerodynamic noise mask due to the head's displacement through the air. This level has been completed by dynamic indicators able to describe the characteristic of the soundscape with a time dimension.

In a further work it could be interesting to propose urban sound abatement solutions for the worst sections of each cycle route. One promising idea would be to create innovative low height noise protections (no more than 1 m high) between the cycle path and the road or tram track in order to prevent the cyclist from high sound levels exposure [12].

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