MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Durability of premium road surfaces

Pratico', Filippo Giammaria[1]
University Mediterranea of Reggio Calabria
Via Graziella, Feo di Vito, 89133 Reggio Calabria, Italy

Briante, Paolo[2]
University Mediterranea of Reggio Calabria
Via Graziella, Feo di Vito, 89133 Reggio Calabria, Italy

Licitra Gaetano[3]
ARPAT – Environmental Protection Agency of Region of Tuscany
Via Marradi, 114, Livorno, Italy

ABSTRACT

Quiet pavement technologies (e.g., Porous asphalt concretes, asphalt rubberised mixtures) have mechanistic, volumetric and surface properties (such as drainability, texture, friction and acoustic performance) that decay over time.
This complex phenomenon depends on many variables and involves many processes that finally affect safety, quietness, and budgets.
In the light of the facts above, the objectives of this study refer to setting up a methodology aiming at optimising the design of the main properties of a premium road surface. Surface and volumetric properties were gathered and analysed.
Results show that the use of road surfaces with low noise emission characteristics such as the rubberized surfaces can increase pavement and acoustic durability.

Keywords: Rubberized pavements, Suface properties, Decay over time
I-INCE Classification of Subject Number: 10
incluir el link http://i-ince.org/files/data/classification.pdf

1. PROBLEM STATEMENT

Premium road surfaces are friction courses that have many "supplementary" properties, such as quietness and drainability.

Quiet pavement technologies (e.g., Porous asphalt concretes, asphalt rubberised mixtures) may be listed among them.

They have mechanistic, volumetric [1,2] and surface properties (such as drainability, surface texture, friction, acoustic absorption, and noise levels) that vary over time.

---

[1] filippo.pratico@unirc.it
[2] paolo.briante@gmail.com
[3] g.licitra@arpat.toscana.it

These complex phenomena affect their durability, depend on many variables, and involve many processes that finally affect safety, quietness, agency budgets, environmental impacts, and user costs. Importantly, this makes the design of such mixtures extremely complicated, because the relationship between design parameters (composition, cf. [3]) and performance is somehow blurry and conflicting. These issues call for an investigation.

2. OBJECTIVES

In the light of the considerations above, the objective of the study presented in this paper is to set up a methodology to design road surfaces from a comprehensive perspective, that is to say, considering not only traditional (e.g., modulus, fatigue resistance, plastic deformation resistance, thermal cracking resistance) but also premium properties (i.e., permeability, noise level) and, particularly, noise-related issues. To this end, the relationships among noise-related properties and their decay over time were analysed.

3.ANALYSIS OF THE LITERATURE

3.1 Introduction

In the pursuit of the objectives mentioned above, a comprehensive literature review was carried out. The variation over time of the following properties was studied: i) air voids content, in-lab and on-site permeability and drainability; ii) surface texture and friction (i.e., Mean Texture Depth, MTD, and Pendulum Test Value, PTV, cf. [4]) iii) acoustic absorption (a_0) and noise level (e.g. CPX, SPB, CPB, OBSI). Furthermore, the variation of the drainability as a function of the position on the carriageway (i.e., inside and out-site the wheel path) was included in this review.

3.2 Air void, permeability, friction, and surface texture

For air void, permeability, friction, and surface texture, Table 1 below summarises the main pieces of information gathered.

Table1. Approximate decay over time (OGFC, PA)

Surface property	Decrease per year	Where	Reference
Air Void content (AV)	0.9%		[5]
Drainability (D)	15% (0.015cm/s)	WT/BWT	[6–9].
Friction Resistance (PTV)	4% (4 units)	WT	[10–13]
Macrotexture (MTD)	8%*	WT	[14–17]

WT: Wheel tracks; BWT: Between Wheel Tracks. * Other authors monitored also periods of increase of macrotexture [14,18]

Note that the hydraulic conductivity (K) increases with the air void content [19–26], ranging from about 10^{-7} cm/s (AV~3%, [23]) where AV stands for air voids content), to about 0.5 cm/s (AV~26%, [26]).

3.4 Mixes Composition, Construction and Noise performance over time

Aggregate (gradation, shape, angularity, etc.), asphalt binder (quantity, quality), and construction affect noise generation. In more detail, they affect texture level and noise absorption. Acoustic absorption mainly depends on resistivity, tortuosity, thickness, and interconnected air voids. Chu et al. [27], following the ASTM E1050-10 [28] standard procedure (corresponding to ISO 10534-2 [29], range of frequency 100 to 2.5 kHz, PAs),

indicated that sound absorption decreases progressively (from about 0.45-0.90 to about 0.15-0.3) as the percentage of clogging increases from zero up to 100%.
Starting from gradation the dynamic modulus of asphalt mixture [30] and the air void content [31] can be estimated. From texture level, several noise indicators can be predicted [32,33] (Figure 1).

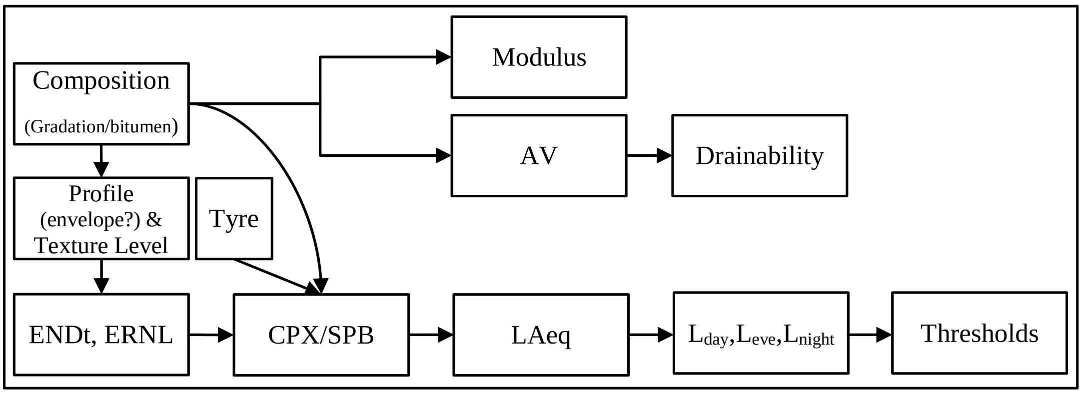

Figure 1. From HMA composition to noise threshold fulfilment

At least in principle, texture level mainly builds on aggregate gradation. For the relationship between texture level and noise the following Equations 1-3 can be listed:

$$\mathrm{ERNL} = 0.5\,L_{tx,80} - 0.25\,L_{tx,5} + 60 \;[32] \tag{1}$$

$$\mathrm{END}_t = 10\log\frac{\sum_i 10^{\frac{\left(L_{mi}+b_i\Delta L_{tx,i}\right)}{10}}}{\sum_i 10^{\frac{L_{mi}}{10}}} - 0.25\cdot\left(L_{tx,5mm} - L_{tx,ref,5mm}\right)[33] \tag{2}$$

$$\mathrm{CPXL} = a_1 + a_2\,\mathrm{Log}\left(\frac{s}{s_0} + \left[a_3 + a_4\,\mathrm{Log}\left(\frac{s}{s_0}\right)\quad L_{tx,16\ \ 63} + \right]\right)\left[a_5 + a_6\mathrm{Log}\left(\frac{s}{s_0}\right)\cdot L_{tx,2\ \ 4}\right] \tag{3}$$

Note that ERNL (Estimated Road Noisiness Level) is the pass-by noise level from a passenger car, estimated from the octave band road surface texture levels $L_{tx,80}$ and $L_{tx,5}$ (at 80 mm and 5 mm texture wavelength, respectively).
END_t (ISO10844) is the Expected pass-by Noise Level Difference [33] due to texture differences between the reference (ref) and the given surface. L_{mi}, b_i, and $L_{tx,\ ref,\ 5mm}$ are reference values. The remaining factors ($\Delta L_{tx,i} = L_{tx,\ \lambda} - L_{tx,ref,\ \lambda}$; $L_{tx,\ 5mm}$) depend on the surface under consideration. ERN_L and END_t are estimated values. CPXL is the predicted CPX [34,35]. In equation 3, s and s_0 are respectively the traffic speed and the reference speed expressed in km/h.
By referring to the prediction of noise levels based on texture levels note that:
1) END_t is the Expected pass-by Noise level Difference from Texture level variation of road surface [33].
2) According to many authors, before deriving texture levels [28–30, forthcoming], road profile must be substituted by its envelope.
3) The actual noise ranking depends not only on pavement texture but also on tyres [39]. Consequently one tyre may be noisier than another on a pavement and quieter than the other on another pavement.
4) Mechanical impedance may affect the production of noise, whatever the texture [40].

From an experimental standpoint, the methods in Table 2 can be used to assess noise outcome.

Table 2. Noise level measurements

Method	Standard	Acoustic Parameter (dB)	N	G	E	G	S (km/h)
Statistical Pass By (SPB)	ISO 11819-1:2004	L_{veh}, SPBI	M	F	I	I	
Controlled Pass By (CPB)	NF S 31-119-2:2000	L_{ref}, L	M	F	I/O	I/O	
Close Proximity (CPX)	ISO 11819-2:2017	L_{CPX}, $L_{CPX:P}$, $L_{CPX:H}$, $L_{CPX:I}$	1	C	I	I	50,80, 110
On-Board Sound Intensity (OBSI)	AASHO TP 360-16	SI_{index}, OBSI	1	C	I	I	56.3,72.4, 96.5
Continuous-Flow Traffic Time-Integrated (CTIM)	AASHTO TP 99-18	L_{eq}	M	F	I	I	
Statistical Isolated Pass-By (SIP)	AASHTO TP 98-18	L_{veh}, $L_{veh,ref}$, SIPI	M	F	I	I	
Coast-by Method (CB)	ISO 13325:2003	SPL	M	F	O	O	60, 70, 80, 90

L_{veh}: Maximum A-weighted sound pressure level determined at a reference speed from a regression line of the maximum A-weighted sound pressure level versus the logarithm of speed, calculated for each vehicle category; SPBI: Statistical Pass-By Index, obtained combining the individual L_{veh} for the different vehicle categories; L_{ref}: noise level resulting from the linear least squares regression for the reference speed velocity V_{ref}; L: measured noise level, either of maximum pressure or of exposure, in overall level or level per band of third party at velocity V; L_{CPX}: time-averaged, A-weighted Sound Pressure Level (SPL) of the tyre/road noise as determined by the CPX method; $L_{CPX:P}$: CPX level for passenger cars and other light vehicles; $L_{CPX:H}$: CPX level for heavy vehicles; $L_{CPX:I}$: CPX index composed of the weighted average of the $L_{CPX:P}$ and $L_{CPX:H;}$ SI_{index}: Sound Intensity Index; OBSI: On-board Sound Intensity; L_{eq}: Average equivalent sound level; L_{veh}: measured vehicle sound level a; SIPI: Statistical Isolated Pass-By Index; SPL: Sound Pressure Level; N: Number of vehicles (1 or more, M); G: Geometry (F as far or C as close) E: Engine (O as Off or I as in); G: Gear (O as Off or I as in); S: Test Speed.

Table 3 refers to the correlations among CB, CPX, SPB and OBSI.

Table 3. Correlations

Noise Measurement Method	Equation	Note	Reference
SPB-CPX	$L_{SPB} = 0.95\,L_{CPX} - 15.6$	v=80km/h, p.c.	[41] (a)
	$L_{SPB} = 0.65\,L_{CPX} + 24$	v=80km/h, h.v.	
CB-CPX	$L_{CB} = L_{CPX} - 20.6$	a.v.s	[42] (b)
SPB-CPX-OBSI	$L_{CPX} = 1.04\,L_{OBSI} - 6.52$	a.v.s.	
	$L_{SPB} = 0.80\,L_{CPX} - 3.23$	a.v.s.	
SPB-CPX	$L_{SPB} = 0.9L_{CPX} - 15.6$	v=50km/h, p.c.	[43] (c)
SPB-CPX	$L_{SPB} = 0.89\,L_{CPX} - 7.95$	v=110km/h, p.c.	[44] (d)
	$L_{SPB} = 0.87\,L_{CPX} - 9.54$	v=80km/h, p.c.	
OBSI-CPX	$L_{OBSI} = L_{CPX} + 3.1$	v=50km/h, p.c.	[45] (e)
	$L_{OBSI} = L_{CPX} + 2.4$	v=80km/h, p.c.	
SPB-CPX	$L_{SPB} = 0.98\,L_{CPX} - 19.8$	a.v.s.	[46] (f)
CPX-OBSI-SPB	$L_{CPX} = 0.7\,L_{SPB} + 48.39$	a.v.s.	[47] (g)
	$L_{OBSI} = 0.43\,LSPB + 68.42$	a.v.s.	
	$L_{OBSI} = 0.87\,L_{CPX} + 13.33$	a.v.s.	
CB-CPX	$L_{CPX} = 0.99\,L_{CB} + 23.03$	v=80km/h	[48] (h)

Statistical Pass By Method; CPX: Close Proximity method; CB: Coast By Method; OBSI: On Board Sound Intensity method; p.c.: passenger car; h.v.: heavy vehicle; a.v.s.: all vehicle speeds.

While CPX, OBSI, CB and SPB refer to specific test conditions and do not represent necessarily real traffic conditions, LA_{eq}, L_{den}, L_{day}, L_{eve}, and L_{night} refer to real traffic [49]. In Figure 4 the main relationships among noise indicators are reported.

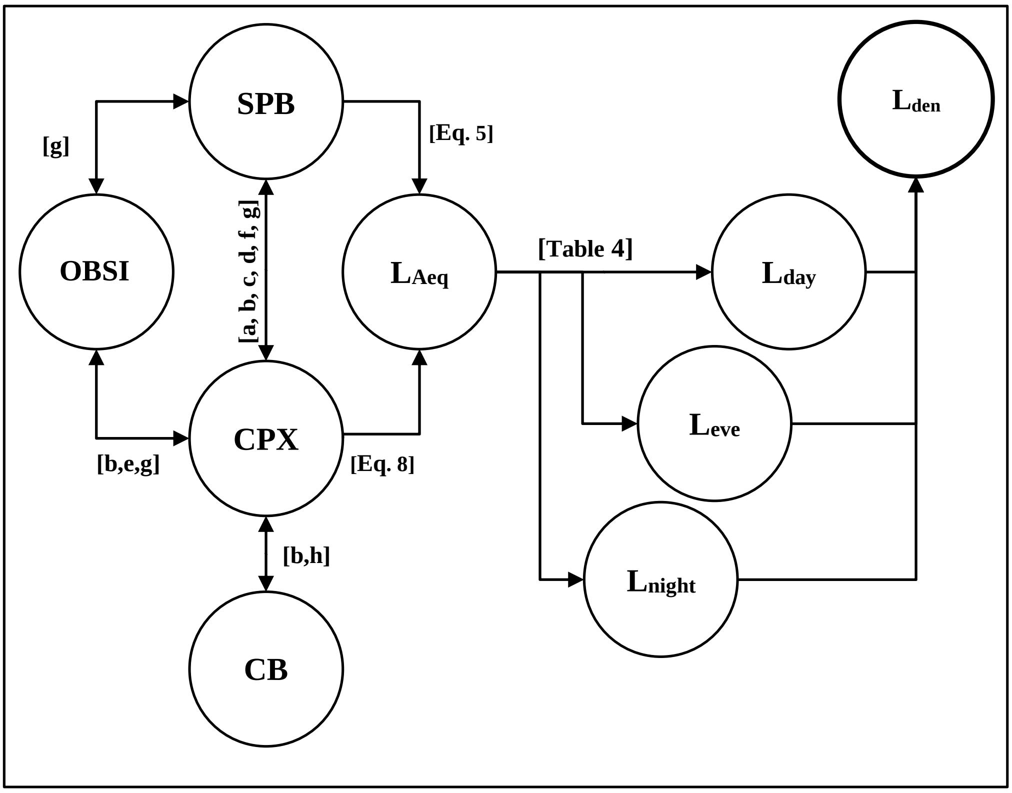

Figure 2. Main relationships among noise indicators (cf. Table 2)

In Table 4, L_{Aeq} is the main input. L_{Aeq} is the Equivalent Continuous Level of a sound source, measured over a specific time period (i.e. 1 hour). L_{Aeq} is the steady sound pressure level which, over a given time period, has the same total energy as the actual fluctuating noise. It can be measured through a sound meter.

Table 4. Noise level indicators

Noise Indicator (dB)	Equation	Time (hour)
L_{day}	$L_{day} = 10\mathrm{Log}_{10}\left[\frac{1}{12}\sum_{6am}^{6pm} 10^{\frac{LAeq(1hour)}{10}}\right]$	6:00-18:00
L_{eve}	$L_{eve} = 10\mathrm{Log}_{10}\left[\frac{1}{4}\sum_{6pm}^{10pm} 10^{\frac{LAeq(1hour)}{10}}\right]$	18:00-22:00
L_{night}	$L_{night} = 10\mathrm{Log}_{10}\left[\frac{1}{8}\sum_{10pm}^{6am} 10^{\frac{LAeq(1hour)}{10}}\right]$	22:00-6:00
L_{den}	$L_{den} = 10\lg\frac{1}{24}\left(12*10^{\frac{Lday}{10}} + 4*10^{\frac{Leve+5}{10}} + 8*10^{\frac{Lnight+10}{10}}\right)$	0:00-24:00

L_{den}: day-evening-night noise indicator in decibels (dB), noise indicator for overall annoyance; L_{day}: day-noise indicator for annoyance during the day; $L_{evening}$: evening-noise indicator for annoyance during the evening; L_{night}: night-time noise indicator for sleep disturbance.

Note that $L_{Aeq,T}$ can be derived as follows (ISO 1996-1, [50]):

$$L_{Aeq,T} = 10\log \frac{1}{T}\int_{0}^{T}(p_A(t)/P_0)^2\,dt \tag{4}$$

Where $p_a(t)$ is the A-weighted instantaneous sound pressure at running time t and p_0 is the reference sound pressure (=20μPa).

According to Berengier et al. [51], LA_{eq} can be derived from SPB measurements through the following parameters: 1) LA_{max} for each vehicle class, obtained through the SPB ISO 11819-1; 2) attenuation; 3) traffic volumes (passenger cars, pc, and heavy trucks, ht).

First the LA_{eq} of the reference period T (i.e., 1 hour), for a single vehicle, running at a certain speed, is estimated through Equation 5:

$$LA_{eq,}T(v_{ref}) = L_{max}(v_{ref}) + 10\log\frac{\pi D_{ref}}{v_{ref}T} \tag{5}$$

where D_{ref} is the distance between the source and the receiver, in metres, T the reference period (i.e. equal to 3600s if T=1 hour), v_{ref} is the average speed in m/s of the vehicle used during the measurements. Note that the A-weighted, pass-by, maximum sound pressure level, L_{Amax}, refers to a reference microphone, located near the road, 7.50 m from the right lane axis and 1.20 m above the road surface, and for each vehicle class (EN-ISO 11819-1).

In a second step, the LA_{eq} at a distance D_{meas} (different from D_{ref}), for a single vehicle, is derived as follows:

$$LA_{eq,}T(v,D) = L_{eq,}T(v_{ref}) + \text{attenuatio n}\,(\text{ground}, \text{top}, \text{meteo}) \tag{6}$$

Equation 5 considers the noise level attenuation caused by the topographical features, the ground effects, and the meteorological conditions.

In a third step, based on $LA_{eq}(pc)$ and $LA_{eq}(ht)$, where pc refers to passenger cars and ht to heavy trucks, the LA_{eq} depending on the traffic volume for each hour is derived:

$$LA_{eq}(T) = 10\log(\frac{1}{T}(n_{pc} * 10^{0.1LA_{eq}(pc)} + n_{ht} * 10^{0.1LA_{eq}(ht)})) \tag{7}$$

where n_{pc} and n_{ht} are, respectively, the number of pcs and hts in the traffic flow during the period T. $L_{Aeq(pc)}$ and $L_{Aeq(ht)}$ are the L_{Aeq} for one representative vehicle of each family on the reference period one hour.

In a fourth step, L_{den} can be derived through L_{day}, L_{eve}, and L_{night}.

Note that the noise indicator L_{den} is obtained by summing all noise contributions on each period of the day (L_{day}), evening (L_{eve}) and night (L_{night}), including the weight of +5 dB for the evening and +10 dB for the night (cf. Table 4, fourth equation). The traffic has a different distribution during the day [6:00-18:00], evening [18:00-22:00] and night [22:00-6:00], for each vehicle class. The noise indicators L_{day}, $L_{evening}$, L_{night} represent the A-weighted long-term average sound level as defined in ISO 1996-2 [52], determined over the reference period.

In terms of durability of noise performance note that noise performance undergoes a decay over time. This decay is probably caused also by the modification of texture levels and, in some cases, of porosity.

To this end note that texture levels over time may become higher in the megatexture range (wavelength between 50 and 500 mm) and lower in the macrotexture range (wavelength between 0.5 and 50 mm) [53,54].

Table 5 illustrates the increase in noise level measured according to different methods. Note that the increase *per* year ranges from 0.1 to 1.3 dB per year.

Table 5. Noise level increase for pavement type

Measurement Method	Pavement type	Increase (dB per year)	Reference
SPB/CPX	PA	0.3-0.5	[55]
	TSL	0.4-0.6	
	1L-PA	0.2-0.3	
SPB/CPX/OBSI	DGAC	0.13-0.72	[56]
	OGAC	0.09-0.80	
	PAC	0.13-0.55	
	RAC-O, RAC-G	0.18-0.40	
	SMA	0.21-1.32	
	UTLAC	0.35-1.06	
SPB/CPX	DPAC	0.24-2.45	[57]
	TSL-PA	0.43-2.39	
	TSL-SMA	0.33-1.52	
CPX/OBSI	ARFC	0.34-0.64	[58]
OBSI	CRM	0.60-0.92	[59]
	DGA	0.06-0.33	
	SMA	0.07-0.67	

CPX: Close Proximity method; SPB: Statistical Pass-By method; OBSI: On Board Sound Intensity method; TSL: Thin Surface Layers; DGAC: Dense-Graded Asphalt Concrete; OGAC: Open-Graded Asphalt Concrete; PAC: Porous asphalt concrete; RAC: Open and Dense Graded Asphalt Concrete with rubber; SMA: Stone Mastics Asphalt; UTLAC: Ultra Thin Asphalt Layers; 1L-PA: Single-Layer Porous asphalt; DPAC: Double-Layer Porous Asphalt Concrete; ARFC: Asphalt Rubber Friction Course; CRM: Crumb Rubber Modified.

The estimate of noise performance can be carried out directly (in terms of measurement of L_{day}, etc) or through correlations between a given type of measurement (e.g., CPX) and the expected output (e.g., L_{den}). In terms of prediction or correlations, speed is very relevant and conversions may be needed. To this end the following equations is given [60]:

$$SEL = a + b \log \frac{v}{v_0} \qquad (8)$$

Where SEL stands for sound equivalent level and v_0 is the reference speed 50 km/h.

Based on experimental results [60], it is possible to have some correlations among the noise level measurement (SPB and CPX) and the noise indicators L_{day}, L_{eve}, L_{night} and L_{den}. Under given assumptions, it may be observed that the measured Statistical Pass-by index (SPBI) shows a quite good correlation with noise levels, namely with L_{den}. On average, the difference between L_{den} and the SPB appears to be smaller (about 5 dB) than the one between CPX and L_{den} (about 21 dB). Furthermore L_{den} results to be quite close to L_{day} and L_{eve} (2-3 dB), rather than to L_{night} (8 dB). Moreover there is often a slight difference between L_{day} and L_{eve} (1 dB) [60,61].

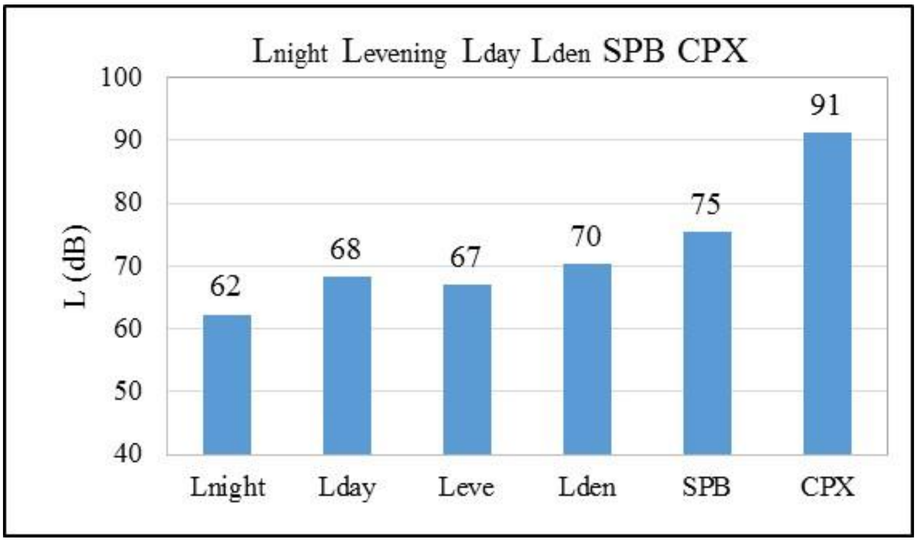

Figure 3. Example of ranking of noise indicators

4. METHODOLOGY

The design of a bituminous mixture (as a layer of a multi-layered system, i.e., a pavement) aims at determining the composition of each mixture.

There are many targets: volumetric ones (e.g., AV), mechanistic (e.g., fatigue, plastic deformation, thermal cracking), resistance (e.g., Marshall stability, cf. [62]), and workability-related properties (e.g., bitumen viscosity), and (for the friction course) surface properties (e.g., friction, surface texture, acoustic absorption, drainability).

A synergetic and concurrent design is needed aiming at having similar expected lives for all the required properties. Not only (for the given layer) the objective above is to accomplish, but also the expected life of the pavement should be n-times (where n is usually 2) the expected life of the friction course (first layer). Consequently, in the case of a new friction course aiming at having, for example, a given CPX [63], the following steps are crucial:

1) Designing the friction course in order to comply with the CPX requirement (cf. Figure 1, equations 1-3);
2) Predicting the corresponding consequences in terms L_{den} [49];
3) Predicting the consequences, if any, in terms of remaining surface-related properties (e.g., drainability, friction, and texture);
4) Predicting the consequences in terms of mechanistic properties (cf. Figure 1);
5) Deriving the expected life for each layer of the pavement system;
6) Deriving the expected life of the pavement (without the friction course);
7) Comparing the expected life of friction course and pavement;
8) Going back to the design of layers (and, particularly, friction course) in order to have the highest expected life of the pavement, the highest expected life of the friction course, being the first n times the second one.

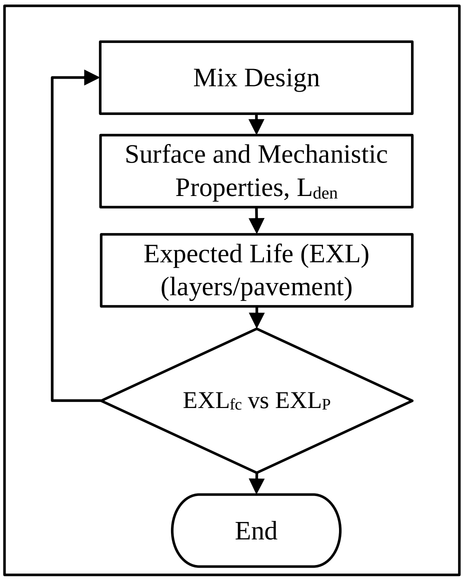

Figure 4. Methodology

5. CONCLUSIONS

The surface properties of friction courses and particularly premium ones (e.g., micro- , macro-texture, and drainability and noise level) are crucial. The evolution over time of these main functional properties is governed by many factors (among which clogging).

In this study, attention focused on the synergetic consideration of different steps of a pavement life and different properties of a pavement structure.

It emerges that the relationships between mix design and outputs is very far from being clearly organised and represented in terms of an implementable algorithm.

Importantly, the first logical step, from design to noise-related properties is only partly understood.

An array of algorithms to help design the noise-related properties has been provided and discussed.

Future research will focus on gathering information and insights on the logical chain from aggregate gradation to noise generation.

6. REFERENCES

1. F.G. Praticò, A. Moro, R. Ammendola, "*Factors Affecting Variance And Bias Of Non-Nuclear Density Gauges For PEM and DGFC*", Balt. J. Road Bridg. Eng., (4) (2009)
2. F.G. Praticò, A. Moro, R. Ammendola, "*Modeling HMA Bulk Specific Gravities a Theoretical and Experimental Investigation*", Int. J. Pavement Res. Technol., (2) 115–122 (2009)
3. F.G. Praticò, "*On the dependence of acoustic performance on pavement characteristics*", Transp. Res. Part D, (29) 79–87 (2014) doi:10.1016/j.trd.2014.04.004
4. F.G. Praticò, R. Vaiana, T. Iuele, "*Macrotexture modeling and experimental validation for pavement surface treatments*", Constr. Build. Mater., (95) 658–666 (2015) doi:10.1016/j.conbuildmat.2015.07.061
5. H. Wang, Z. Wang, T. Bennert, R. Weed, "*HMA pay adjustment*", (2015)
6. T. Isenring, H. Koester, I. Scazziga, "*Experiences with porous asphalt in Switzerland*", Transp. Res. Rec., (1990)
7. L. Ellebjerg, H. Bendtsen, "*Two-layer porous asphalt – lifecycle*", (2008)
8. S. Takahashi, "*Comprehensive study on the porous asphalt effects on expressways in Japan: Based on field data analysis in the last decade*", Road Mater. Pavement Des., (14) 239–255 (2013) doi:10.1080/14680629.2013.779298

9. Y. Brosseaud, F. Anfosso-Lèdèè, "*Silvia Project Report: Review of existing low-noise pavement solutions in France*", in NCHRP Rep. 640, pp. 244–245 (2009)

10. B. Yu, L. Jiao, F. Ni, J. Yang, "*Long-term field performance of porous asphalt pavement in China*", Road Mater. Pavement Des., (16) 214–226 (2015) doi:10.1080/14680629.2014.944205

11. J.-S. Chen, C.-T. Lee, Y.-Y. Lin, "*Influence of Engineering Properties of Porous Asphalt Concrete on Long-Term Performance*", J. Mater. Civ. Eng., (29) 04016246 (2017) doi:10.1061/(ASCE)MT.1943-5533.0001768

12. P.D. Cenek, D.J. Alabaster, R.B. Davies., "*Seasonal and Weather Normalisation of Skid Resistance Measurements*", New Zealand, Wellington (1999)

13. R. Vaiana, F. Praticò, "*Pavement surface properties and their impact on performance-related pay adjustments*", Sustain. Eco-Efficiency, Conserv. Transp. Infrastruct. Asset Manag., 579–587 (2014) doi:10.1201/b16730-85

14. R. Vaiana, G.F. Capiluppi, V. Gallelli, T. Iuele, V. Minani, "*Pavement Surface Performances Evolution: an Experimental Application*", Procedia - Soc. Behav. Sci., (53) 1149–1160 (2012) doi:10.1016/j.sbspro.2012.09.964

15. F.G. Praticò, R. Ammendola, A. Moro, "*A theoretical and experimental investigation on HMA wearing properties*", in 4th Int. Conf. - Mod. Technol. Highw. Eng., Poznan, Poland pp. 156–164 (2009)

16. A. Aavik, T. Kaal, M. Jentson, "*Use Of Pavement Surface Texture Characteristics Measurement Results In Estonia*", XXVIII Int. Balt. Road Conf. Vilnius, Lith. 26-28 August 2013, 1–10 (2013)

17. Y. Miao, J. Li, X. Zheng, L. Wang, "*Field investigation of skid resistance degradation of asphalt pavement during early service Skid resistance degradation of asphalt pavement*", Int. J. Pavement Res. Technol., (9) 313–320 (2016) doi:10.1016/j.ijprt.2016.08.005

18. D. Woodward, A. Woodside, P. Phillips, R. Shammohammadi, I. R.Walsh, "*No TitleDevelopment of early life Skid Resistance*", in 3rd Int. Conf. Bit. Mix. Pav., Thessaloniki, Greece (2002)

19. R.B. Mallick, L.A. Cooley, M.R. Teto, R.L. Bradbury, D. Peabody, "*An evaluation of factors affecting permeability of Superpave designed pavements*", Natl. Cent. Asph. Technol. Rep., 2–3 (2003)

20. W.S. Mogawer, R.B. Mallick, M.R. Teto, W.C. Crockford, "*Evaluation of Permeability of Superpave Mixes NETCR 34. Project No. NETC 00-2.*", (2002)

21. B.J. Putman, "*Evaluation of Open-Graded Friction Courses: Construction, Maintenance, and Performance*", South Carolina (2012)

22. F.G. Praticò, R. Vaiana, M. Giunta, "*Pavement Sustainability: Permeable Wearing Courses by Recycling Porous European Mixes*", J. Archit. Eng., (19) 186–192 (2013) doi:10.1061/(ASCE)AE.1943-5568.0000127

23. K. Kanitpong, C.H. Benson, H.U. Bahia, "*Hydraulic Conductivity (Permeability) of Laboratory-Compacted Asphalt Mixtures*", Transp. Res. Rec. J. Transp. Res. Board, (1767) 25–32 (2001) doi:10.3141/1767-04

24. A. Nataatmadja, "*The use of the hyperbolic function for predicting critical permeability of asphalt*", 1–9 (2010)

25. J. Norambuena-Contreras, E. Izquierdo, D. Castro-Fresno, M. Partl, A. García, "*A New Model on the Hydraulic Conductivity of Asphalt Mixtures*", Int. J. Pavement Res. Technol. Int. J. Pavement Res. Technol., (66) 488–495 (1997) doi:10.6135/ijprt.org.tw/2013.6(5).488

26. M. Aboufoul, A. Garcia, "*Factors affecting hydraulic conductivity of asphalt mixture*", Mater. Struct. Constr., (50) 1–16 (2017) doi:10.1617/s11527-016-0982-6

27. L. Chu, T.F. Fwa, K.H. Tan, "*Laboratory Evaluation of Sound Absorption Characteristics of Pervious Concrete Pavement Materials*", Transp. Res. Rec. J. Transp. Res. Board, (2017) doi:10.3141/2629-12

28. ASTM, "*ASTM E1050 – 10, Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System*", 12 (2010)

29. ISO, "*ISO 10534-2 Acoustics -- Determination of sound absorption coefficient and impedance in impedance tubes -- Part 2: Transfer-function method*", (1998)

30. W.R. Vavrik, W.J. Pine, G. Huber, S.H. Carpenter, R. Bailey, "*The Bailey Method of Gradation Evaluation: The Influence of Aggregate Gradation and Packing Characteristics on Voids in the Mineral Aggregate*", Proc. Assoc. Asph. Paving Technol., (70) 132–175 (2001) doi:10.1103/PhysRevLett.103.054101

31. M. Witczak, O. Fonseca, "*Revised Predictive Model for Dynamic (Complex) Modulus of Asphalt Mixtures*", Transp. Res. Rec. J. Transp. Res. Board, (1540) 15–23 (2007) doi:10.3141/1540-03

32. J. Kragh, L.M. Iversen, U. Sandberg, "*Nordtex Final Repot Road Surface Texture for Low Noisw and Low Rolling Resistance*", (2013)

33. ISO, "*ISO 10844:2014 Acoustics --Specification of test tracks for measuring noise emitted by road vehicles and their tyres*", 45 (2014)

34. M. Losa, P. Leandri, R. Bacci, "*Empirical Rolling Noise Prediction Models Based on Pavement Surface Characteristics*", Road Mater. Pavement Des., (11) 487–506 (2012) doi:10.1080/14680629.2010.9690343

35. M. Losa, P. Leandri, G. Licitra, "*Mixture design optimization of low-noise pavements*", Transp. Res. Rec. J. Transp. Res. Board, (2372) 25–33 (2013) doi:10.3141/2372-04

36. P. Klein, J.F. Hamet, "*Road texture and rolling noise An envelopment procedure for tire-road contact*", (2004)

37. L. Goubert, U. Sandberg, "*Enveloping texture profiles for better modelling of the rolling resistance and acoustic qualities of road pavements*", in Ymposium Pavement Surf. Charact., Brisbane, Queensland, Australia (2018)

38. G. de Leon, A. Del Pizzo, L. Teti, A. Moro, F. Bianco, L. Fredianellia, G. Licitra, "*Evaluation of Tyre/Road Noise and Texture Interaction on Rubberized and Conventional Pavements Using CPX and Profiling Measure*", n.d.

39. G. Licitra, L. Teti, M. Cerchiai, F. Bianco, "*The influence of tyres on the use of the CPX method for evaluating the effectiveness of a noise mitigation action based on low-noise road surfaces*", Transp. Res. Part D Transp. Environ., (55) 217–226 (2017) doi:10.1016/j.trd.2017.07.002

40. V.F. Vázquez, S.E. Paje, "*Mechanical impedance and CPX noise of SMA pavements*", in Proc. Acoust. 2012, Nantes, France (2012)

41. R.S.H. Skov, "*Analysis and comparison of methods, CPX and SPB , for measuring noise properties of road surfaces*", Proc. INTER-NOISE 2016 - 45th Int. Congr. Expo. Noise Control Eng. Towar. a Quieter Futur., 4964–4974 (2016)

42. J. Cesbron, P. Klein, "*Correlation between tyre/road noise levels measured by the Coast-By and the Close-ProXimity methods*", Appl. Acoust., (126) 36–46 (2017) doi:10.1016/j.apacoust.2017.05.005

43. C. Vuye, F. Musovic, L. Tyszka, W. Van Den, J. Kampen, A. Bergiers, J. Maeck, "*First experiences with thin noise reducing asphalt layers in an urban environment in Belgium*", 81–94 (2016)

44. M. Phil, U. Sandberg, G. Van Blokland, "*The Selection of New Reference Test Tyres for use with the CPX Method, to be Specified in ISO/TS 11819-3*", Inter-Noise 2009,

(2009)
45. J. Oddershede, "*CPX – OBSI Relation in Tyre / Road Noise Measurement Results*", (2013)
46. J. Kragh, "*Dutch – Danish Pavement Noise Translator*", Road Directorate, Danish Road Institute, (2007)
47. M. Buret, J. Mcintosh, C. Simpson, "*Comparative assessment for low-noise pavements by means of the ISO 11819 and the OBSI*", Inter-Noise 2014 Melb., 1–9 (2014)
48. D. Bekke, Y. Wijnant, T. Weegerink, A. De Boer, "*Tire-road noise: an experimental study of tire and road design parameters*", 42nd Int. Congr. Expo. Noise Control Eng. 2013, INTER-NOISE 2013 Noise Control Qual. Life, (1) 173–180 (2013)
49. Council of the European Union, E. Parliament, "*DIRECTIVE 2002/49/EC*", Off. J. Eur. Communities, 12–25 (2002)
50. ISO, "*ISO 1996-1:2016 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures*", 47 (2016)
51. M. Berengier, Y. Pichaud, J.F. Le Fur, "*Effect of low-noise pavements on traffic noise propagation over large distances: influence of grounds and atmospheric conditions*", in 29th Int. Congr. Exhib. Noise Control Eng., Nice, FRANCE pp. 6–10 (2000)
52. ISO, "*ISO 1996-2:2017 Acoustics - Description, measurement and assessment of environmental noise -Part 2: Determination of sound pressure levels*", 60 (2017)
53. C. Vuye, A. Bergiers, B. Vanhooreweder, "*The Acoustical Durability of Thin Noise Reducing Asphalt Layers*", Coatings, (6) 21 (2016) doi:10.3390/coatings6020021
54. D. Siebert, "*How wear affects road surface texture and its impact on tire/road noise*", (2017)
55. J. Kragh, B. Andersen, G. Pigasse, "*Acoustic ageing of pavement - DVS-DRD joint research programme – Super Silent Traffic*", (2013)
56. H. Bendtsen, Q. Lu, E. Kohler, "*Acoustic aging of asphalt pavement: A Californian Danish comparison.*", (2010) doi:10.13140/2.1.5166.8803
57. C. Vuye, A. Bergiers, B. Vanhooreweder, "*The Acoustical Durability of Thin Noise Reducing Asphalt Layers*", Coatings, (6) 21 (2016) doi:10.3390/coatings6020021
58. P. Donavan, C. Janello, "*Arizona Quiet Pavement Pilot Program: Comprehensive Report SPR-577-2*", (2018)
59. R.O. Rasmussen, R.C. Sohaney, "*Tire/Pavement and Environmental Traffic Noise Research Study*", 147p- (2012)
60. G. Licitra, E. Ascari, C. Chiari, S. Giannecchini, "*Ante operam noise monitoring within LIFE NEREIDE : methods and results*", in Euronoise 2018 - 11th Eur. Congr. Expo. Noise Control Eng., pp. 2671–2678 (2018)
61. M. Brink, B. Schäffer, R. Pieren, J.M. Wunderli, "*Conversion between noise exposure indicators Leq24h, LDay, LEvening, LNight, Ldnand Lden: Principles and practical guidance*", Int. J. Hyg. Environ. Health, (221) 54–63 (2018) doi:10.1016/j.ijheh.2017.10.003
62. F.G. Praticò, A. Moro, R. Ammendola, "*Potential of fire extinguisher powder as a filler in bituminous mixes*", J. Hazard. Mater., (173) 605–613 (2010) doi:10.1016/j.jhazmat.2009.08.136
63. E. Garbarino, R.R. Quintero, S. Donatello, O.W. Jrc, "*Revision of Green Public Procurement Criteria for Road Design , Construction and Maintenance Procurement practice guidance document*", (2016) doi:10.2791/201271