MODELING ROAD-TYRE NOISE

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Abstract

The growing awareness by the broader public of the consequences to health and well-being due to road noise has led to a growing number of legal requirements being produced to deal with this matter, both in the design of new or assessment of existing infrastructure. In this article the purpose is to make an up-to-date review of existing studies being carried out to deliver models for predicting noise produced from tyre-road contact, taking account of different methodological approaches which, particularly in Europe thanks to EU sponsored projects, intend to deliver practical solutions regarding different structural solutions and the use of new materials. The main goal of this work is to provide some insight about which approach is better suited to be used in a practical noise prediction model for Portuguese roads, to take into account its specific environmental characteristics and physical features of construction materials.

INTRODUCTION

Different studies throughout several countries have shown the harmful effects of excessive noise levels due to road traffic, not only in terms of health or well being but in other features as well, like reducing productivity of workers or the decrease in real estate value near noisy roads.

Since the first decisions to undertake actions to handle the problem it has been dealt with by different approaches, taking consideration of several factors which affect that noise (SILVIA, 2006):

- Road surface – roughness, porosity (void content), texture, absorption;
- Vehicle – engine type, speed, aerodynamics, torque, acceleration;
- Tyres – pressure, hardness, with, tread pattern, load, diameter;
- Local conditions – slope, humidity, wind, temperature, traffic control.

The knowledge on these issues has increased considerably, and some impressive results have been already achieved, noticeably in the vehicle-related factors, where it is reported (Descornet et al., 2005) that the noise form those sources has decreased by 85 to 95%. However such accomplishments are in many cases, like important urban areas or major roads, upset by the growth and spread of traffic.

Historically the first widespread attempts by the ‘road community’ (*i.e.* not from vehicle or tyre makers) to achieve some degree of noise reduction near more important roads was the construction of noise barriers by the side of those roads, the use of additional noise insulation in nearby buildings or stricter building standards for new construction.

The limited effect of those barriers and the costs of their installation and maintenance as well as the increase in construction prices and uncertainty of the effectiveness of some types of insulation to the specific attributes of different traffic noise have led to efforts in attacking the noise problem at its source.

It’s in this context that research on the subject of low emission pavements has a potentially important role as part of a solution, either to allow the characterization in terms of road noise in an existing location or its forecasting in a planned site as a decision helping tool.

Although there have already been a significant number of studies in this area, which have focused on surface types, construction and maintenance methods and different modelling techniques, there is still development to be carried out.

LEGAL FRAMEWORK

As part of an effort to limit noise, recognised as one of the main environmental problems in most of its countries, the European Union has proposed, in what became known as the Environmental Noise Directive (European Parliament and the Council of the European Union, 2002) the adoption of maximum values for perceived annoyance by the populations near noise sources, for which it suggests the widespread use of common noise intensity indicators, L_{den} and L_{night}, respectively describing overall annoyance and sleep disturbances.

Such indicators are A-weighted equivalent sound levels, referring to the 24 hours (L_{den} which combines the sound levels of day, evening and night periods, respectively L_{day}, $L_{evening}$ and L_{night}) or just the night period (L_{night}), determined over all of the corresponding periods of a year.

It should be noted that those indicators can be used in general assessment and management of different types of environmental noise, and so are not exclusively for uses related to road traffic.

For the overall annoyance indicator the values of evening and night sound levels are increased by a specific amount (respectively 5 and 10 dB) because of the amplified nuisance attributed to noise in those periods, being calculated using the following expression, in the case where the adopted durations of the three relevant periods are 12, 4 and 8 hours each day:

$$L_{den} = 10 \times \log_{10}\left(\frac{1}{24}\right) \cdot \left(12 \times 10^{L_{day}/10} + 4 \times 10^{(5+L_{evening}/10)} + 8 \times 10^{(10+L_{night}/10)}\right) \quad (1)$$

It is pointed out by the above referred EU Directive that it's up to each individual country to settle the actual limit values of the L_{den} and L_{night} indicators as well as the start of the different periods, giving flexibility to shorten the evening period and lengthen the day and/or night period accordingly (and consequently adjusting the coefficients of the expression above), depending on local specificities and needs to maintain the noise levels below a certain amount.

Each country in the EU is expected to implement action plans to ensure that exposure to excessive environmental noise levels is prevented and/or reduced where necessary or where it can induce harmful effects on human health and to preserve environmental noise quality where it is good. Consequently the use of low noise surfaces, and related research, is likely to have a significant increase due to the implementation of those action plans.

In practical terms it is proposed that the determination of L_{den} and L_{night} be made by common measurement or computation methods, although not yet fully developed, as established by the Commission. It is therefore said that until those methods are adopted, Member States may use assessment methods for the determination of those indicators based upon the methods included in their own legislation, verifying it can be demonstrated that such methods give equivalent results.

For the specific case of road traffic noise the recommended computational method, for countries that do not have their own, is the French national computation method '*NMPB-Routes-96 (SETRA-CERTU-LCPC-CSTB)*' which is a process to forecast the sound levels at distances of over 250 meters of the roads taking in account the influence of the meteorological conditions.

As this method is however limited to calculating the sound propagation, it does not provide input data concerning sound emission, for what the use of a different method is necessary. For that purpose the '*Guide du bruit des transports terrestres, CETUR 1980*' is suggested.

EUROPEAN RESEARCH PROJECTS

The pursuit of ways to avoid the harmful effects of noise exposure from different sources and preserve quiet areas, as established by the EU policy behind the legal framework described above, means that intensive research is required to provide a solid base for the efficient limitation of environmental noise in general and road traffic noise in particular.

As stated by one of the investigation groups established in this field of study, the CALM Network, in its Strategy Paper: "The noise research strategy must be in line with the direction of the future noise policy. The main goal of future research is, therefore, to support the implementation of the Environmental Noise Directive and the further development of noise policy."

Although there is a significant amount of research related to knowledge on road traffic noise underway or recently concluded, particularly throughout Europe often funded by the EU and conducted in partnerships between state road administrations, research agencies and the industry, particular reference will be made to some of this investigation projects due to the importance of the work produced related to quiet pavements' use in noise abatement.

HARMONOISE - Harmonised Accurate and Reliable Methods for the EU Directive on the Assessment and Management of Environmental Noise

This project (Voos et al., 2005) was shaped with the intention to produce the common EU model for the prediction of environmental noise levels caused by road (and railway) traffic, in terms of L_{den} and L_{night}, as defined in the END, incorporating into road noise prediction models the source noise level of quiet pavements and thus providing the base information for a generic noise propagation model.

In the process of dividing in separate models the source description from the propagation description of noise it is therefore possible to distinguish the influences of the rolling noise and propulsion noise and so associate them with the influence of the road-tyre mechanism (for the first) and the vehicle's attributes (for the second).

The HARMONOISE project gave special importance to the improvement of the description of weather conditions and their influence on sound propagation, unlike other methods for noise prediction that do not fully account for these effects. This can be understood as the calculation of L_{den} takes in account the noise in three periods of the day which are linked to three levels of activity in average social behaviour (work, leisure and sleep) and it is considered that those periods may coincide with three meteorological periods (wind speeds are generally higher during the day and temperature inversion is more frequent during the night).

Regarding this aspect it is alleged that the methods are valid for any regional climate in Europe, provided that the long term weather behaviour can be described in terms of the frequency of occurrence of certain meteorological classes that have been defined in the project.

As to how the project has translated into actual noise prediction models, the outcome was to create two separate methods: one capable of more comprehensive results (the Reference method) and the other more suited to applications less detailed requirements (the Engineering method).

In essence the rationale is that the Reference method, which consists of a set of advanced sound propagation models, gives a more theoretical description of propagation effects and parameters. The model is used to validate the Engineering methods, in which the source models are coupled to the so-called point-to-point propagation model, which allows for time-efficient computations, to yield L_{den} and L_{night}.

Both models can operate with the same source model, but the propagation modelling methods will differ substantially. The engineering model uses a simplified description of the atmosphere in terms of a limited number of representative classes and so only intends to predict the propagation as a long time averaged value over many similar situations. The Reference model will be designed to achieve the highest possible accuracy, without too much concessions to flexibility of use or short computation times.

The following figure (from the 'Final technical report') is reproduced as it is quite insightful in how the source description is related to the two different approaches proposed.

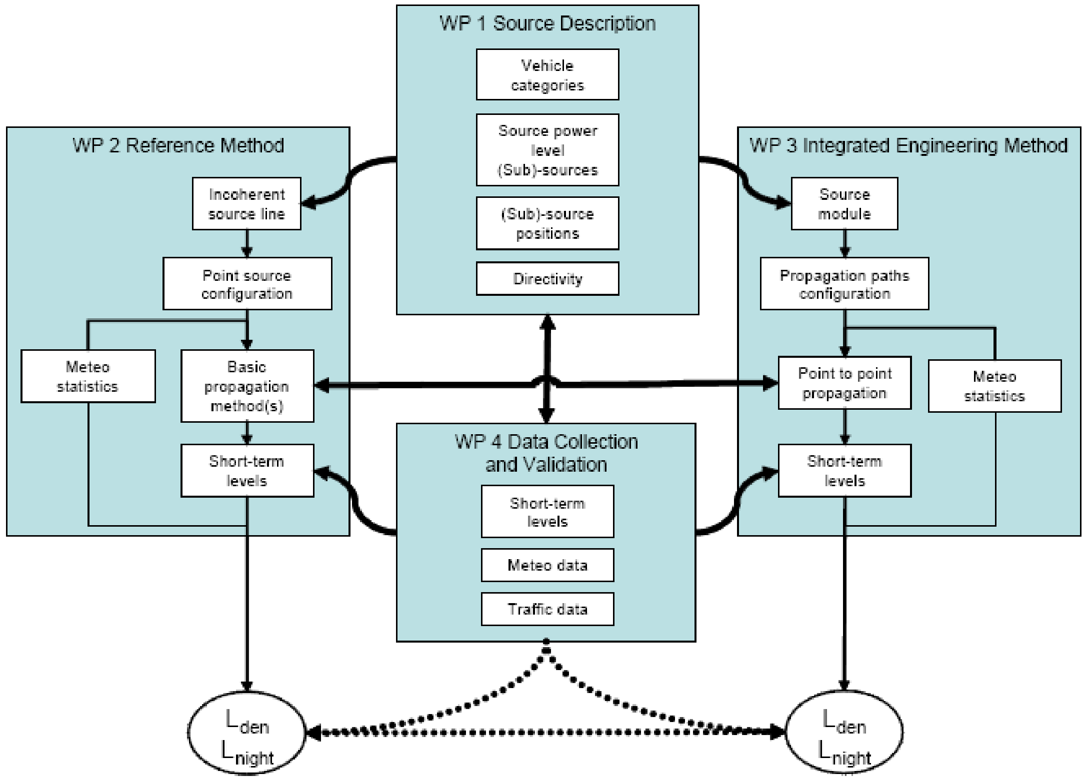

Figure 1- Overall structure of the HARMONOISE project

In conclusion it can be said that one of the most interesting aspects of the results of this project is that, as stated, the HARMONOISE methods allow the level of accuracy to depend on the accuracy of the chosen input parameters, so the methods are then suitable both for mapping purposes, where usually less detailed information about source and mapping area is required or available, as for detailed computations in case of noise assessment studies.

IMAGINE - Improved Methods for the Assessment of the Generic Impact of Noise in the Environment

Within the IMAGINE project (Peeters et al., 2007) part of its work was to conduct further development of the emission model proposed by the HARMONOISE project, notably in the development of a noise emission model for road vehicles that accounted for the characteristics of different vehicle types and that accounted for the variation within the European vehicle population observed in different regions.

The main objective was to develop new and more reliable model coefficients for the road noise emission model developed in HARMONOISE, based on extensive measurement sets and analyses related to the different vehicle categories and road surface types, for a typical fleet of European road traffic and also to provide guidelines on how to deal with situations deviating from the default value.

In order to achieve those objectives, the model is based on some essential features:

- Each road vehicle has two noise source types, one for rolling noise and one for noise from the propulsion system;

- The differences between the sound emission characteristics of road vehicles are distinguished through vehicle categories;
- The effect of the road surface is implemented in the rolling noise and in the propulsion noise level through a procedure developed in the related 6th framework project SILVIA;
- Within categories shifts in vehicle fleet characteristics are taken into account by regional corrections;
- The effect of driving behaviour (speed and acceleration) is taken into account in the formulation of the source strength for both propulsion and rolling noise;
- Effects of environmental conditions are taken into account through meteorological corrections.

The emphasis in IMAGINE was laid towards the development of the complete definition of the emission of the average European road vehicle in 1/3rd octave bands, and although many different parameters that affect the road vehicle noise are included the model is in essence presented as practical and easily used for noise mapping purposes.

SILVIA - Sustainable Road Surfaces for Traffic Noise Control

As with the HARMONOISE project, SILVIA intended to improve the insight in effectiveness of noise reduction measures, but while the first was designed to aid in the calculation the noise impact of the solutions in the second the durability of low-noise solutions is investigated and the solutions are compared to new construction and maintenance techniques.

An important outcome of SILVIA was the proposal of a "Noise classification procedure" that has been developed to provide the most accurate and reproducible characterization of the acoustic performance of a specific pavement. The procedure – with some variations – has different applications among which is the determination of the correction term for the road surface influence in the vehicle noise source model developed by the HARMONOISE project.

On the subject of modelling techniques, it's stated that although those predicting sound emission and propagation models that incorporate the effects of distance, atmospheric sound absorption, meteorological influences (temperature and wind speed gradients) and ground attenuation, are becoming more advanced and increasingly accurate, there are still important methodological problems that require to be resolved for the effects of low-noise pavements to be accurately accounted for.

Therefore the acoustical performance of a given pavement design cannot be adequately assessed at present before the pavement is actually constructed on a large scale as only testing of the finished pavement, either by noise measurements of passing vehicles or using a noise measurement trailer, provides the necessary information about the noise reduction achieved.

In addition, these methods lack the possibility of absolute calibration that would make the results exchangeable throughout Europe. Laboratory tests of small pavement samples are available but their results cannot be translated into an estimation of the noise reduction of a finished pavement in practice. Part of the solution is to establish or improve prediction models relating noise to the relevant road surface parameters, like texture profile or acoustic absorption.

Besides the definition of procedures to determining correction terms (like the one mentioned above) the SILVIA project defines a scheme for labelling a specific surfacing technology and for subsequently contractually checking the conformity of production of that technology once applied on the road.

Such classification system identifies specific measurement procedures necessary for labelling the acoustic performance of a road surface, using one of the two possible labelling procedures referred to as LABEL1 (preferred) or LABEL2.

Consequently a procedure for assessing the noise performance of a given road surface in a representative and reproducible way is necessary. Presently to determine the noise benefit of pavements, different methods are available including Statistical Pass-By (SPB, ISO 11819-1), Close Proximity (CPX, ISO 11819-2), and various Controlled Pass-By (CPB) methods, along with pavement sound absorption measurements.

The different existing measurement methods need then to be harmonised and supplemented with measurements of relevant physical characteristics like surface texture and acoustic and mechanical impedances subsequently requiring that models relating these characteristics to noise be refined and validated.

Results of the project were incorporated in the "Guidance Manual for the Implementation of Low-Noise Road Surfaces" which is expected to help decision-makers to rationally plan noise control measures taking into account full life-cycle costs and integration of low-noise surfaces with other abatement measures.

Other investigation

As above said, several other studies in Europe (SILENCE, TINO, SIRUUS, ROTRANOMO), but also in the USA, Japan and other countries have been dedicated to the diverse components of the tyre/road noise system into developing prediction or simulation models. Although the possibility to be able to observe the effects on that system due to modifications in its mechanisms, source locations and contributions would be very useful for research or design purposes, it’s still thought that a complete model with such capabilities does not exist (Sandberg et al., 2002).

Naturally this hasn’t been an exhaustive review of investigation projects in the area of low noise pavements modelling techniques, but above all a way of pointing out research trends with relevance to support a wider use of such pavements in Portugal.

THE PORTUGUESE SITUATION

Concerning national legislation, the EU Directive related to environmental noise has been incorporated in the present Noise General Regulation approved in 2007. In it the indicators L_{den} and L_{night} are adopted as indicators regarding the environmental noise and its relation to the population’s health and well-being, stating that those values are to be determined according to the methodology recommended by the Directive for cases where a national model does not exist.

In the case of the overall indicator, the duration of the days and evenings has been adapted, from the EU original suggestion, to 13 and 3 hours long, thus resulting in it being calculated by the expression:

$$L_{den} = 10 \times \log_{10}\left(\frac{1}{24}\right) \cdot \left(13 \times 10^{L_{day}/10} + 3 \times 10^{(5+L_{evening}/10)} + 8 \times 10^{(10+L_{night}/10)}\right) \quad (2)$$

In this Regulation, associated to local urban management plans, two separate zones are defined regarding its degree of vulnerability to noise: sensitive and intermediary areas. The first include residential neighbourhoods, schools, hospitals or leisure spaces, and the second comprises other purposes not included in the sensitive areas.

Such classification of areas is used to set up the limits of the sound level indicators. In the intermediary areas the limits are $L_{den} \leq 65$dB and $L_{night} \leq 55$dB while in the sensitive areas the typical limits are $L_{den} \leq 55$dB and $L_{night} \leq 45$dB, although exceptions may be accepted near major existing transportation infrastructures, where those limits can be exceeded.

Overview of past Portuguese experiments

Presently two types of silent road surfaces are used in Portugal: porous asphalt, widely used in motorways, and asphalt with rubberized binder, used either in motorways or in national roads.

As far as noise is concerned, advantages and disadvantages of the use of porous asphalt are well known and documented. The same does not happen for the rubberized asphalt. In Portugal only three studies carried out in motorways focused these types of mixtures. The first compared a gap graded rubber asphalt with a “rough” dense asphalt and with cement concrete, where abatements of 5 to 8 dB(A) and 8 to 10 dB(A) were stated (Ruivo, 2004). The second assessed the noise produced in a porous rubber asphalt mixture, in which a reduction of 3 to 5 dB(A) was reported (Gomes et al., 2006). The last compared porous asphalt with dense asphalt considering two surface conditions: dry and wet. When surfaces were dry, a poor abatement of less than 2 dB(A) for the reference speed of 80 km/h was found, whereas when surfaces were wet the noise abatement doubled (Freitas et al., 2006).

More recently, another study was carried out in national roads. This study addressed a set of 7 surfaces among which three gap graded with rubberized asphalt, one dense asphalt and three unconventional gap graded with a small aggregate size. As opposed to what was expected the mixtures with rubber did not show a significantly better performance compared to the other mixtures (Freitas et al., 2008). In fact, the same performance was achieved with other type of gap graded mixtures.

Figure 2 shows seven typical grading curves used in several types of surfaces, such as dense asphalt (DA), porous asphalt (PA), rough thin layers (TL), smooth thin layers, rough asphalt rubber (RA) and gap graded asphalt rubber (GGAR). For comparison, an additional grading curve of a low noise surface widely used in France was included.

The most important differences between that reference curve and the others regard the maximum aggregate size. This leads to the conclusion that Portuguese conventional road surfaces have a big maximum aggregate size which is likely to control the noise in a great extent.

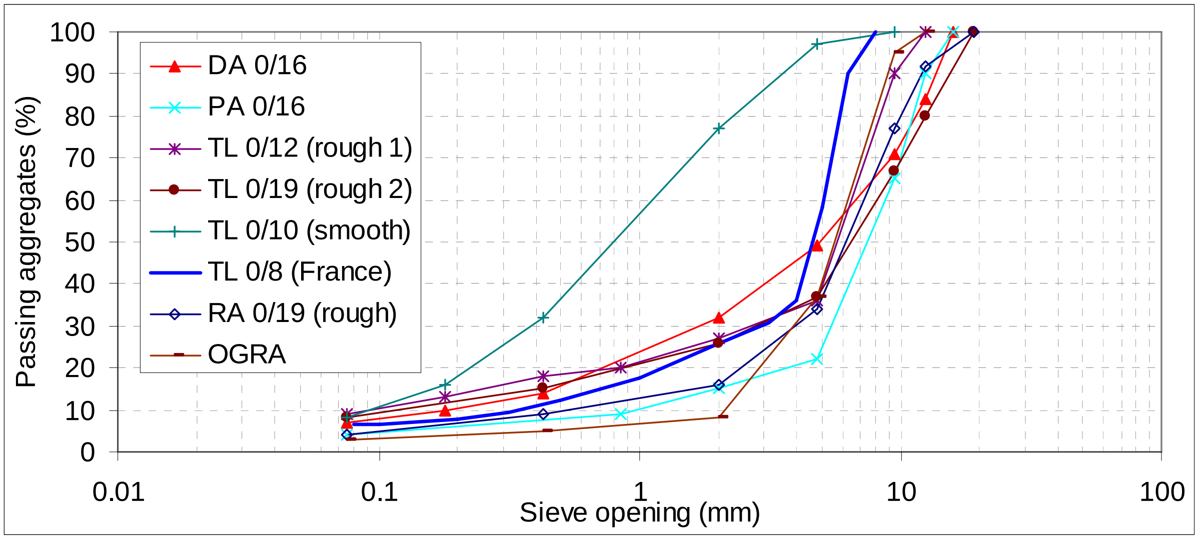

Figure 2 - Common grading curves of Portuguese road surfaces

CONCLUSIONS

As there is no methodology developed nationally to evaluate traffic related noise, and in particular the tyre-road contribution, presently the determination of indicators such as the L_{den} and L_{night} is done by using interim methods, as the French scheme in the case of Portugal.

This situation is likely to be changed in a near future by the expected adoption of the methods proposed by the HARMONOISE project, which will demand some degree of adaptation, for example as to ensuring that the Portuguese climate can be described accurately enough by the meteorological conditions descriptors used in the method.

The specificities of Portuguese practice in buildings construction and the effectiveness of most commonly used types of noise insulation may offer a different performance in abating the traffic noise than those used in other countries. Also the road's pavements characteristics, regarding the materials and production techniques used may introduce some differences in terms of noise predictions.

These are therefore obvious topics of upcoming research, which in turn is expected to provide better knowledge on the performance of national low noise pavements and to promote a more widespread use of such pavements.

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