Institution: University of Bradford

Unit of Assessment: B14

Title of case study: Sustainable strategies for noise mitigation through improved assessment of noise impact and enhanced design of noise barriers

1. Summary of the impact

Research at the University of Bradford has resulted in more accurate and efficient predictions of traffic sound propagation and faster determination of sound reflection effects, enabling more effective design and positioning of noise barriers. Software derived from our research is used in 40 countries to map traffic noise and plan evidence-based targeting of Noise Reduction Devices (NRDs), thus increasing efficiency and sustainability. Beneficiaries include the public, through improved quality of life from reduced noise pollution from transport and wind turbine sound, and governments and public administrations through policy tools to influence noise management. The reach of our research is demonstrated by its incorporation into national and EU-wide policy and guidance on sustainability in design and use of NRDs.

2. Underpinning research

A Bradford team comprising David Hothersall (Reader 1993-2000, Professor 2000-2011), Kirill Horoshenkov (PDRA 1993-1995, Lecturer 1995-2002, Senior Lecturer 2002-2004, Professor 2004-2013), Dr Simon Chandler-Wilde (Lecturer 1989-1993) and Greg Watts (Professor 2000-present) conducted the underpinning research between 1993 and 2005. Drawing on the Boundary Element Method (BEM) our team produced a model specifically for application to traffic noise mitigation. BEM is most commonly applied in two-dimensions (2D) for transport noise propagation calculations. Although the true physical problem has distinct differences from the 2D approximation, results from 2D BEM calculations can be successfully and accurately related to physical measurements. Our model offers advantages over ray-tracing methods and other numerical techniques by providing an accurate treatment of the diffraction, scattering and absorption of sound that occurs in the presence of obstacles including noise barriers. Furthermore, complex cross-sections can be modelled and specified with considerable precision and the effects of absorptive surfaces and far-field solutions can be computed much more efficiently (1,2). The research also allowed the noise reducing properties of novel barrier caps and the effects of air gaps in barriers to be quantified and demonstrated accurately for the first time (3).

Hothersall's development of a Fresnel Zone method of calculating sound reflections from mixed ground conditions (4) both enhanced and simplified the model and paved the way for its use in the HARMONOISE (engineering) and NORD2000 (sound propagation) models. A key contribution of our research was to enable calculation of the zone of influence of reflected sound rays where the ground surface is mixed, a frequency-dependent effect. Our work demonstrated that averaging within the Fresnel zone, despite being a simpler method, resulted in agreement with more complex models and significantly reduced computing times. Our method has been shown to be particularly efficient in complex source situations where ray acoustics was previously the preferred approach e.g. in the calculation of the spread of traffic noise from highways into a large urban area where multiple reflections of sound rays are common. Our research on the calculation of surface reflection effects became a core component of the EU HARMONOISE collaborative project (2000-2003) that produced improved sound propagation models for environmental noise predictions used for both accurate traffic noise prediction and for noise mapping in largely urban areas. The research resulted in the development of a sound propagation model and noise prediction models leading to the development of 6 software packages.

The work on NRDs was further extended within the completed EU QUIESST project to improve their sustainability. Dr Oltean-Dumbrava (Lecturer 2003-present), working with Watts, used multi-criteria analysis to develop a novel method for assessing the overall sustainability of roadside NRDs (5,6). The significance of the new work is its demonstration that optimising particular criteria in isolation, e.g. cost and technical performance, does not necessarily increase the sustainability of noise barrier projects. Rather, the research showed that it is the combination of the outcome of all measured criteria (technical, economic, environmental, social) in relation to each other that shows the relative sustainability of the noise reduction project as a whole. The Multi Criteria Decision Making (MCDM) tools produced during the project have been disseminated through an EU guidebook on sustainable procurement of noise barriers.

3. References to the research

1. Chandler-Wilde SN, Hothersall DC. (1995) A uniformly valid far field asymptotic expansion for the Green function for two-dimensional propagation above a homogeneous impedance plane. *Journal of Sound and Vibration* 182(5): 665-675.

2. Chandler-Wilde SN, Horoshenkov KV. (1995) Padé approximants for the acoustical characteristics of rigid frame porous media. *Journal of the Acoustical Society of America* 98(2): 1119-1129.

3. Watts GR, Crombie DH, Hothersall DC. (1994) Acoustic performance of new designs of traffic noise barriers: full-scale tests. *Journal of Sound and Vibration* 177(3): 289-305.

4. Hothersall DC, Harriot JNB. (1995) Approximate models for sound propagation above multi-impedance plane boundaries. *Journal of the Acoustical Society of America* 97(2): 918-926.

5. Oltean-Dumbrava C, Watts G, Miah A. (2013) Transport infrastructure: making more sustainable decisions for noise reduction. *Journal of Cleaner Production* 42: 58–68.

6. Oltean-Dumbrava C, Watts G, Miah A. (2012) Procurement of sustainable noise-reducing devices: state-of-the-art review from EU Project QUIESST. *Journal of Management in Engineering* 28(3): 324–329.

(1), (4), and (5) are the three most significant publications.

4. Details of the impact

Impact from the research has been achieved through three main channels: i) incorporation of our research outputs into internationally-used models (HARMONOISE, NORD 2000), ii) software packages derived from our research, and iii) adoption in national policy requirements. Our research outputs are now used worldwide in mapping and impact assessment of rail, road, and wind turbines noise with results used to plan the design and positioning of NRDs. The targeting of appropriately designed NRDs is a key application of our research findings, resulting in a reduction of the negative impact of noise on human health and associated improvement in quality of life through diminished noise pollution as indicated by World Health Organisation guidelines for acceptable noise exposure (a).

i) Internationally-used sound assessment models: our research was core to the development of both the HARMONOISE and NORD2000 models (b,c). The HARMONOISE noise propagation model (d) has gained acceptance in Europe for the basis of noise mapping (e,f) and is being adopted in other countries, for example in predicting noise from industrial sources in Australia (g).

The importance of our research for the development of the NORD2000 model is described by one of the developers thus: "*The introduction of Fresnel-zones in NORD2000 led to essential improvement compared to earlier methods. The ground effect, for example, is calculated for each type of ground to be found inside the Fresnel-zone and the resulting ground effect is calculated as a weighted average taking into account the fraction of the Fresnel-zone covered by each type of ground surface*" (d,e,h).

Work for recently completed EU FP7 QUIESST on sustainable procurement of noise barriers using multi-criteria analysis, led by Dr Oltean-Dumbrava (5,6), is further extending our impact in this area by involving a novel method for assessing the overall sustainability of noise reducing devices at the roadside. A key output of this work is a tool to support decision-making by policymakers and industry professionals. In addition the work led to the publication of a guidance manual (i) and a further group TG4 has been set up within CEN TC 226/WG6, led by Dr Oltean-Dumbrava, to develop such sustainability standards. This is the first group within CEN TC226 road equipment to address this issue and others are likely to follow our lead (j). A very large industry concerned with the provision of roadside barriers will be impacted by the introduction of such standards. As an example of market size the provision of timber barriers along a 2km stretch of highway to protect a residential area would cost approximately £1.6m (6). If more expensive NRD systems were used costs would rise up to an order of magnitude higher and, to gauge scale, many hundreds of kilometres of NRDs are installed across Europe annually.

ii) Commercialisation through software: the sound propagation and noise prediction models developed and tested in the research led to the development of six software packages, commercialized in over 40 countries and utilized by private enterprises, public administrations and academia (d, e). The HARMONOISE model led to the development of Predictor-LIMA, CadnaA and the NORD2000 model to the development of ExSound2000, SPL2000, SoundPlan and WindPRO noise prediction software packages. Since 2008, use of NORD2000 and HARMONOISE models and software packages has extended from road and railway traffic noise reduction to wind turbine noise, as well as to evaluation of the health effects of noise over a wide spectrum of applications and uses, within and outside Europe (e.g. Brazil, Australia, Canada, Hong Kong, South Korea, Chile, and Taiwan).

Estimates of the annual turnover generated by software retail alone is €600k, based upon an average market price of €1,000 per licence, three licenses sold *per annum* per country with 40 countries involved worldwide. We should also consider the added value made by consultants using the software. Assuming 40% of licences are sold to consultants and they manage three small projects *per annum* worth an average of €3,000 each, we reach a turnover of €2.16m over the REF2014 period. Taken together the total annual turnover generated by software licences is estimated to be a minimum of €2.76m.

iii) Adoption in national policy requirements: the NORD2000 noise prediction model was commissioned by the Nordic Council of Ministries and has been used in both private and public sectors (e,h) including public authorities such as the Federal Department of Health in Canada and Scandinavian national and local administrations. In Denmark the use of NORD2000 is mandatory for strategic noise mapping. In addition, NORD2000 is prescribed for general use with road traffic noise, beyond the already existing guidelines for its use for railway noise, and, more recently, for the prediction of sound propagation from wind turbines.

5. Sources to corroborate the impact

a. Berglund B, Lindvall T, Schwela DH. (eds.) (1999) *Guidelines for community noise*. Geneva: World Health Organisation

b. Strategic Consultant at Dutch consultancy DHV, advises European Committees, government departments, councils and companies on environmental noise pollution and was convenor of the EU Harmonoise project. He can confirm our contribution to the Harmonoise propagation model through use of BEM.

c. Senior Researcher at the Danish Road Institute and previously at the Danish consultancy DELTA. He was closely involved in development of Nord 2000 (environmental noise propagation model used by the Nordic countries) and can vouch for the importance of Hothersall's Fresnel zone approach.

d. Watts G R (2005). *Harmonoise prediction model for road traffic noise*. Published Project Report PPR 034, TRL Ltd, Wokingham, Berkshire (Sections 5, 6 and Appendix B)

e. Nota R, van Leeuwen JJA, Barelds R, Beuving M, Cremezic C, Defrance J, Jonasson HG, Van Maercke D, Taraldsen G, Watts G, Witte J (2004). Harmonoise: simplification of comprehensive source and propagation models into an accurate and practicable engineering method, *Internoise 2004*, Prague.

f. van Leeuwen HJ, de Vos P (2009). The Implementation of a simplified HARMONOISE/IMAGINE Method for Making Noise Maps for Large Areas. *Proceedings of Euronoise 2009*, October 2009, Edinburgh.

g. Bullen R. The Harmonoise noise prediction algorithm: validation and use under Australian conditions. *Proceedings of Acoustics 2012*, November 2012, Fremantle, Australia

h. noiseLab – Nord2000 noise prediction software available at: http://noiselabdk.wordpress.com/more-software/sound-propogation-nord2000/

i. Oltean-Dumbrava C. (2012) Sustainability. In (eds.) Clairbois J-P, de Roo F, Garai M, Conter M, Defrance J, Oltean-Dumbrava C, Durso C. *QUIESST7 – Guidebook to noise reducing devices optimisation*. Presented: final seminar, Brussels, 10th December 2012: www.quiesst.eu.

j. Managing Director of the Belgian consultancy Acoustic Technologies and convenor of European Standards Committee TC226/WG6 on noise reducing devices for roadside application, closely involved in developing CEN standards and QUIESST. He can vouch for important inputs made by University of Bradford including setting up of the new standards group TG4 to address sustainability. He will be able to confirm that TG4 will be the first group in TC226 road equipment to develop sustainability standards and other groups e.g. safety fences, traffic signals and signs, road markings are likely to follow our lead.