RWB STEPHENS LECTURE: REDUCING TRAFFIC NOISE DISTURBANCE

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1 INTRODUCTION

In the UK traffic noise is a major source of noise nuisance causing serious disturbance to nearly 10% of the population. Research into mitigation measures has concentrated on a number of areas where worthwhile reductions in noise can be achieved. These can be broadly classified as measures to reduce noise generation and those that attenuate the transmission of sound to the receiver. Topics covered include the design of highway surfaces, the use of novel barriers and the provision of sound absorptive materials in the road cross-section.

It might sometimes be necessary to affect a reduction at two stages. This is a 'combined mitigation' approach e.g. the use of low noise surfaces with noise barriers. Cost-effectiveness is also very important especially when public funds are involved. Much of the research carried out by TRL has been funded by the Department of Transport or the Highways Agency and it has always been a central concern to maximise benefits while keeping costs down. Public acceptability also needs to be considered since a mitigation measure may be highly effective in reducing noise but visually intrusive and therefore unacceptable e.g. a tall noise barrier. Noise nuisance and the choice of appropriate noise indices to reflect disturbance are important areas of study which should not be neglected when mitigation measures are devised. Social survey, full-scale jury trials and well controlled laboratory studies have all been employed to understand more fully the response to noise.

In terms of implementation, the development of appropriate BSI, CEN, ISO and EC and UN-ECE standards and regulations standards are essential and international projects funded by the EC are increasingly important as a means of achieving state-of-the art solutions that can be applied across member states.

2 GENERATION

Tyre/road surface noise is a dominant source of traffic noise especially on high-speed roads. However even on main urban roads subject to a 30 mph limit it is clear that the significant noise source for light vehicles is due to this mechanism. Tyre design has a part to play in the noise generation process and it has long been known that a bald tyre generally produces less noise than a tyre with tread. Skidding resistance depends on a good tread pattern so clearly there are trade-offs that may have to be made to achieve the overall optimum design. Type approval testing of noise from tyres has recently been introduced across the EU which should stimulate further research into this noise generation process. TRL are currently involved with European projects SILVIA[(1)] and HARMONOISE[(2)] with the aims of providing advice to road authorities and a means to accurately predict this contribution. In addition, we are actively involved in developing a new vehicle noise emission standard through ISO WG42 and updating the corresponding UN-ECE regulation R51.02. This involves a consideration of both acceleration and cruise by conditions under realistic urban operating conditions of a wide variety of vehicle types and the development of a composite noise index L_{urban}. The test surface is also under consideration as there are issues concerning reproducibility and whether it represents typical surfacings.

The current noise regulation R51.02 requires vehicles to be tested at relatively high engine revs and can be considered a worst case test of the potential to cause disturbance. It has been successful in reducing propulsion noise although rolling noise has remained largely uncontrolled. Recently a new EC Directive 2001/43/EC(3) involving coast by tests at speeds of 70 and 80 km/h has been introduced to control this noise source although the effect on rolling noise is considered to be small with the current limit values.

2.1 Road Surface Effects

Noise from rolling tyres is caused partly by the generation of vibration in the tyre structure, which is excited by the road surface roughness and block impact, and movement in the contact patch. It is also produced by the movement of air in the cavities of the tread pattern in and around the contact patch ("air pumping"). The degree of macrotexture (i.e. large scale asperities) in the road surface, frictional characteristics between tyre and road and the porosity of the surface are all significant road surface factors.

Air pumping occurs when air is compressed in the grooves in the tyre tread pattern as tread elements deform in the contact patch. The compressed air is then expelled as the tread elements emerge from the contact patch causing noise. Noise due to tyre vibration tends to occur at frequencies below 1kHz while air-pumping noise is thought to be dominant from 1 to 3kHz. If the surface is porous then noise produced by air pumping should be reduced as the air paths in the surface layer help to dissipate the air trapped in the tread grooves. The propagation of noise away from the tyre can also be reduced if a porous layer is present. Both sound absorption and sound interference processes can be involved. The latter can occur when a significant phase change occurs on reflection

As a result of a greater understanding of the importance of rolling noise more emphasis is now placed on the appropriate choice of road surfacing. The use of traditional surfaces such as hot rolled asphalt (HRA) and brushed concrete is now restricted on high-speed roads in England and Wales. Quieter surfaces such as porous asphalt, thin bituminous surfaces and exposed aggregate concrete have also been used in recent years. The bituminous thin surfacings are the most widely used at present and a type approval scheme has been set up to regulate their acoustic performance. TRL have assisted with the setting up of the Highways Authority Product Approval Scheme (HAPAS) which is being introduced by the British Board of Agrément (BBA). The test method was based on TRL's statistical pass-by procedure. This involves the recording of maximum noise levels and corresponding speed of a statistically valid sample of vehicles. Using regression analysis the average levels for different classes of vehicles at standard pass-by speeds are obtained. This normalisation allows the noisiness of different surfaces to be compared at different sites. It can be demonstrated that relative to HRA there is a reduction in pass-by noise of several decibels using these newer surface types.

Despite the usefulness of the statistical pass-by procedure there are some limitations. Because the measurement is made at a specific location, the results can only be related to a relatively short section of road surface. Consequently the variability in noise along the road due to changes in the surface texture pattern cannot easily be determined. To overcome the limitations of the method TRL are currently using a vehicle-based system of measurement where microphones are mounted close to a specified test tyre. This is based on the ISO draft ISO/CD 11819-2 close-proximity or CPX method. A special TRL vehicle called TRITON is used at present to collect data on a wide range of surfaces and can travel at test speeds of 110 km/h. This has greatly facilitated in depth investigations of the effects of texture and tyre tread parameters on noise generation.

Figure 1 shows the CPX levels normalised to 80 km/h for a selection of car tyres on a range of reflective and absorptive surfaces based on TRL measurement programmes(4).

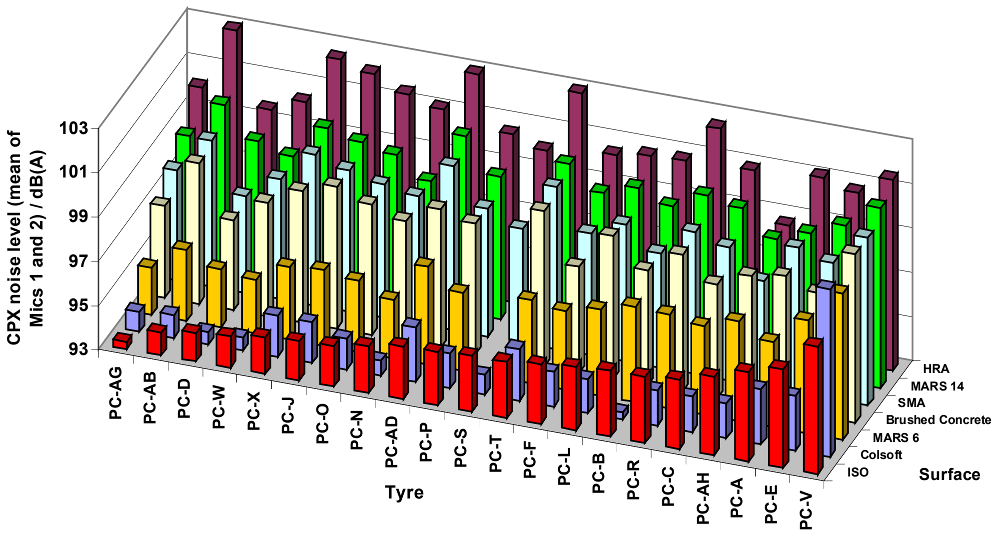

Figure 1: CPX levels at 80km/h by tyre and surface types

The test surfaces were:

- *ISO 10844 test surface* was originally developed as a standard surface for vehicle noise testing and its specification was intended to help reduce the variability in test results. The surface achieves relatively low levels of tyre noise by using a dense bituminous material with a relatively smooth texture and a nominal maximum stone size of 8 mm. The surface has been specified for use with the European tyre noise test procedure.
- *Hot Rolled Asphalt (HRA)* is one of the most common road surfaces in use on high-speed roads in the UK. The surfacing is laid with a maximum aggregate size of 14 mm and pre-coated chippings with a nominal size of 20 mm are then rolled into the surface. The chippings are added to the surface to provide it with good high-speed skidding resistance properties.
- *Stone Mastic Asphalt 0/14 (SMA)* is a monolithic, gap-graded material that has a very high stone content and is a widely used wearing course in Europe. The 14mm SMA has a specification similar to that adopted for UK motorways and has texture characteristics that are close to those that has been proposed for a second, rougher, ISO test specification.
- *Brushed concrete* is created on newly laid concrete surfaces by brushing across the carriageway. The section of brushed concrete chosen for this study has a lighter texture than the type generally used until recently on high-speed roads in England.
- *MARS6 and MARS14* surfaces are bituminous in character and are described as porous surface dressings. The surface with the maximum aggregate size of 14 mm (*MARS14*) was selected for the study since the texture fully meets that required for UK high-speed roads, whereas the surface with the smaller sized aggregate was assumed to have similar characteristics to surfaces found on high-speed road in many European countries and on some medium speed roads in the UK.
- *Colsoft* is a proprietary road surfacing laid by Colas Limited. The surface was originally developed by their French parent company for low noise applications in urban areas and includes a proportion of crumb rubber (approximately 2%) derived from recycled tyres.

Noise levels have been shown to be influenced by the texture characteristics of the road surface. In studies carried out by Sandberg and Descornet[(5)] it was shown that for car tyres running on different surfaces, the effect of the road surface on the generation of tyre noise could be related to periodic features of the surface texture which can be characterised as texture wavelengths. In particular, the texture level at the 63 mm wavelength, referred to as T_{63}, has previously been found to correlate well with overall noise levels.

It was also shown by Sandberg and Descornet(5) that the correlation between noise and the profile of the texture could be divided into two main frequency regions. For tyre/road noise frequencies below 1500 Hz, the strongest correlations were obtained with texture wavelengths greater than 10 mm. Higher frequencies in the noise spectra were correlated with smaller scale texture wavelengths. It was suggested that two separate mechanisms were involved with the resulting tyre noise spectrum being composed of two component or 'partial' spectra. The lower frequency elements of the spectra were attributed to noise resulting from tyre vibration whereas the higher frequencies were related to an air pumping mechanism.

Figure 2 shows for one of the study tyres, PC-O, how different frequencies in the noise spectrum are influenced by each of the texture wavelength components. These figures were generated by correlating changes in one-third octave band noise level with changes in one-third octave band texture level as each tyre was run on a different surface.

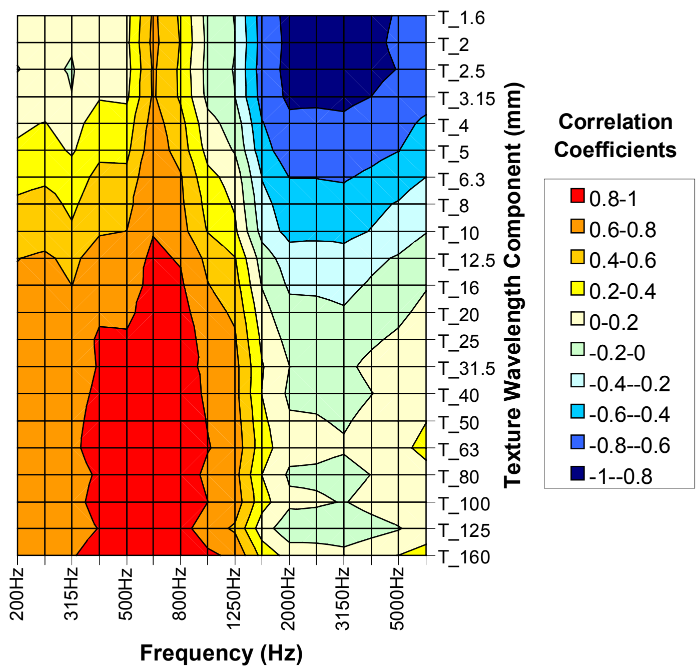

Figure 2: Correlation of texture characteristics with one-third octave frequency band coast-by noise levels for tyre PC-O

As can be seen from the figures, positive correlation between texture levels and noise levels tends to occur for texture wavelengths between 20 mm and 160 mm, and in the frequency range 500-1000 Hz, whilst at higher frequencies, negative correlation with the short wavelength texture components (1.6 mm to 8 mm) was generally found. In practice, positive correlation between T_{20}-T_{160} and the 500-1000 Hz frequency range means that road surfaces with high texture levels in this particular range of wavelengths tend to produce relatively high noise levels due mainly to mechanisms associated with tyre tread block impact and snap-out effects. The negative correlation between $T_{1.6}$-T_8 and frequencies greater than 1000 Hz means that noise levels in this region decrease as short-wavelength texture increases due to reduced air pumping effects.

With such greater insights into the noise generation mechanisms the design of appropriate road surfaces is enhanced. Emphasis is now being placed on examining double layer porous surfaces where the greater depth enables a greater range of lower frequencies to be significantly attenuated. A further development is the inclusion of Helmholtz resonators in a third (bottom layer) to absorb even lower frequencies.

2.2 Tyre Design

Rolling noise can be reduced by the correct selection of tyres but as can be clearly seen in Figure 1 a ‘quiet’ tyre rolling on one surface doe not necessarily deliver the same benefits on other surfaces. For example car tyre PC-AG is quietest on the ISO surface but produces one of the highest levels of any of the tyres on the rougher HRA surface which is common on the UK road network. This is due to the different noise generation mechanisms involved. On a smooth surface it has been found that air pumping noise is relatively important and the importance of tread block design is emphasised. Since much research has been carried out by tyre companies on the relatively smooth ISO 10844 surface in order to comply with the EC directive and UN-ECE regulations on vehicle noise emission the best designs are now thought to be similar in performance to completely smooth designs (‘slick’ tyres) on this surface. However, on rougher surfaces tyre dimensions and construction are relatively more important due to the greater excitation of the whole tyre(6). With this in mind it is hoped to include a rougher surface in the revision of ISO 10844 so that test results are more representative of typical conditions. This may in the long term have the effect of improving tyre design to a point where they are optimal for a range of road surface conditions. However, it may only be possible to optimise successfully for particular combinations of tyre and road surface type. This whole system approach may have implications for tyre selection in different countries reflecting the different proportions of road surface types.

2.3 Speed Effects

The overall noise generated by vehicles is largely governed by vehicle speed. At low speeds the noise from the engine and its ancillaries, gearbox, exhaust, and cooling system, will often dominate over the noise generated by the tyres. However, as the speed of the vehicle increases, the noise generated by the tyres will also increase. Previous work at TRL has shown that tyre noise may increase at rates of between 9 and 13 dB(A) for each doubling of speed, depending upon the type of tyre and road surface. Harland(7) had shown that the general relation between the maximum sound level L_{Amax} and the speed of a passing vehicle for a measurement point located 7.5 m from the centre line of the vehicle path is given by:

$$L_{A\max} = A\log_{10}(V) + B \quad (1)$$

where A and B are constants.

This equation clearly assumes that a linear relationship exists between overall noise levels and the logarithm of vehicle speed. This assumption forms the basis for many forms of vehicle and tyre noise measurement procedures including the CPX method. This relationship allows linear regression techniques to be used, giving a relatively simple method of determining noise levels at any selected speed from random data gathered either at roadside locations or under test track conditions.

The rate at which the overall noise level increases with the logarithm of speed is heavily dependent on the type of road surface. Analysis of the results obtained using the CPX method has indicated that for any particular tyre, the rate of increase is greatest on the Brushed Concrete surface and lowest on the MARS-6. The rank ordering of the other surfaces displays some variation depending on the tyre under test, but by averaging the speed constants (which quantifies the rate at which noise levels increase with speed) for all tyres running on a particular surface, some idea of the influence that each surface has on the rate at which noise increases with speed was obtained. The results of this analysis is shown in Figure 3.

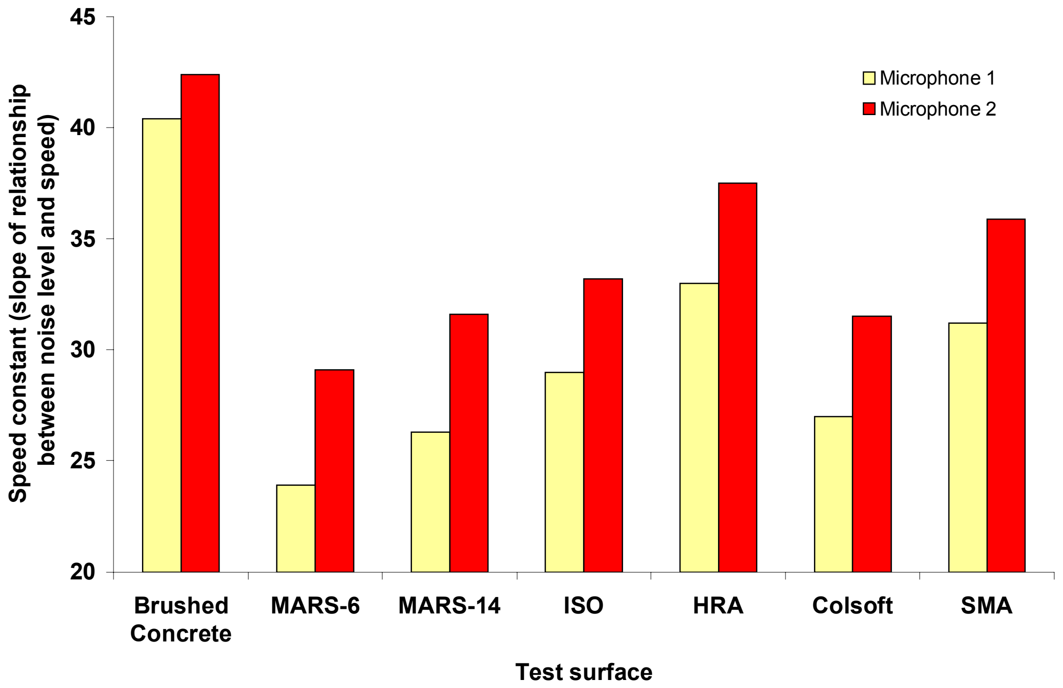

Figure 3: Average rate at which CPX noise levels increase with the logarithm of speed for each of the test surfaces

As can be seen, the speed constant tends to be higher for rougher surfaces, transversely textured surfaces (brushed concrete) and lower for porous surfaces.

The research is continuing to inform the Department for Transport's policy on appropriate road surfaces and the development of regulations on tyre and vehicle noise. TRL is currently actively involved in ISO WG42 (vehicle emission) and WG33 (CPX) and UN-ECE GRB committee on vehicle noise regulation.

3 TRANSMISSION

An obvious way to reduce noise levels is to block the sound in the transmission path from source to receiver using noise barriers, earth mounds, cuttings or covers (both partial and complete). Generally the closer a barrier or earth mound is to the source the more effective it becomes. For simple plane barriers the height and length are the most important factors determining the degree of screening achieved[(8)]. The shadow zone of the barrier is the region where the receiver cannot see the source and here the greatest reductions in noise levels are recorded. Some sound will always be diffracted over the top and around the edges of the barrier into the shadow zone so it is not possible to eliminate all noise from the source. Typical sized barriers of a few metres high can achieve noise reductions of the order of 10 dB(A). This corresponds to halving the subjective loudness of the sound.

Common factors that affect acoustic performance of a wide variety of noise barriers are:

(i) Sound leakage through the barrier
(ii) Absorptive effects – absorptive elements on the traffic face or diffracting edge
(iii) Diffraction effects – basic geometry, elements or caps at the top of the barrier
(iv) Ground surface properties
(v) Meteorological effects

At TRL a noise barrier test facility (NBTF) has been used to test barriers at full-scale under controlled conditions[9,10,11]. The facility consists of a powerful loudspeaker source, road surface and flat grassland beyond the barrier. Additionally, boundary element methods (BEM) have been developed in collaboration with Brunel and Bradford Universities to provide versatile numerical modelling techniques for examining the efficiency of a wide range of designs. Model results have been validated using full-scale and roadside measurements[12]. The BEM method has been used to design and patent a multiple edge diffractor which can be used to enhance screening performance of a plane barrier.

3.1 BEM model

The program used was developed at the Universities of Bradford and Brunel with assistance from TRL. The boundary element method (BEM) program calculates the wave field at a particular frequency by solving a reformulation of the Helmholtz wave equation in terms of an integral equation. For this purpose the surfaces are divided into boundary elements of length in general no greater than $\lambda/5$ where λ is the wavelength. The effects of ground cover and absorptive surfaces are included in the definition of the elements. The vehicle model is two-dimensional which means that the traffic is effectively a coherent line source. Despite this limitation results have shown good agreement with measured values. For the purposes of barrier studies a typical rural dual 3-lane motorway has been modelled. The vehicle sources used in the model were represented by using average vehicle shapes for light and heavy vehicles with sources at heights of 0.05 m and 0.1 m respectively under the nearside and farside edges of the vehicle body. The source spectra for light and heavy vehicles were based on measured peak values for individual vehicle pass-bys at the edge of a motorway[13]. In most cases the road surface was assumed to be acoustically hard and the verge and flat ground beyond the barrier was assumed to be acoustically soft. Suitable parameters were chosen for flow resistivity, porosity, layer depth and tortuosity to represent typical values for reflective and absorptive surfaces including grassland. Predictions were made in terms of the A-weighted levels based on centre frequencies of one-third octave band levels from 100Hz to 5kHz. The calculation method described in ISO 9613-1 was used to take account of air absorption assuming 15^{o}C and 50% humidity.
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3.2 Sound Leakage

An effective noise barrier will reduce the sound energy transmitted through its construction to much lower levels than the sound diffracted over and around the barrier. However, in some cases leakage will occur as a result of shrinkage, warping and splitting of the panels and weathering of acoustic seals. A TRL roadside survey using a novel sound intensity technique indicated that timber barriers had poorer sound transmission performance due to leaks than might be expected from the mass per unit area of the barrier[14]. BEM predictions were made with and without horizontal gaps of various dimensions and spacings in barriers of various heights. These predictions were compared with an approximate but simpler sound intensity approach with generally good agreement[15]. The method assumes that sound spreads evenly from each gap and that logarithmic addition of the secondary sound sources at the gaps on the rear face of the barrier with the sound diffracted over the barrier top can be used to obtain the resultant noise level. It can be shown that the resultant increase in the A-weighted level Δ for a barrier of height *h* is approximately given by:

$$\Delta = 10\log\left[1 + \frac{2Gh}{\pi}\frac{(d_s + d_r)}{d_s d_r}10^{-B/10}\right]$$

where d_s and d_r are the horizontal distances from source to barrier and from barrier to receiver respectively and *G* is the fraction of the barrier area with air gaps. Figure 4 shows predictions for a barrier with realistic air gaps (3% of total area) for a 6 m and 3 m tall barriers.

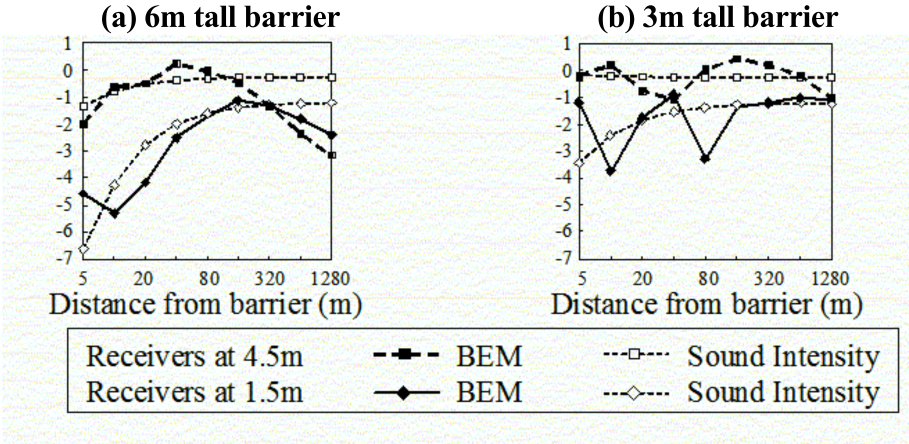


Figure 4: Changes in insertion loss due to 3% gaps

The barrier potential correction *B* (a negative value) was obtained from the CRTN method(8). In general it was found that the reduction in screening performance caused by gaps was greatest close to the barrier and reduced with distance. It follows that a barrier of higher sound insulation than that provided by a typical single leaf timber barrier is required to prevent significant decreases in screening performance at distances behind a tall barrier of less than about 20 m.

TRL have been involved in developing in situ test standards for airborne sound insulation based on the maximum length sequence method (MLS) through the work of CEN TC226/WG6 on anti-noise devices(16). Figure 5 (a) shows the measurement with the barrier sample present and (b) without. The impulse response is obtained by cross correlating the input signal to the loudspeaker with the output signal; from the microphone. To obtain an average over an area of the panel measurements are made at 9 microphone postions.

Using suitable time windowing the required transmitted signal is separated from the diffracted and reflected components. The transmitted component is then Fourier transformed to obtain the impulse response function. The sound insulation value SI at the j^{th} third octave frequency is calculated from:

$$SI_j = -10 1og\left\{ \frac{\sum_{k=1}^{n} \int_{\Delta f_j} \left| F\left[h_{tk}(t) w_{tk}(t)\right] \right|^2 df \left(\frac{d_k}{d_i}\right)^2}{n \cdot \int_{\Delta f_j} \left| F\left[h_i(t) w_i(t)\right] \right|^2 df} \right\}$$

where $h_i(t)$ is the incident reference component of the free-field impulse response; $h_{t,k}(t)$ is the transmitted component of the impulse response at the *k*-th microphone position; $d_i(t)$ is the geometrical spreading correction factor for the reference free-field component; $d_k(t)$ is the geometrical spreading correction factor for the transmitted component at the *k*-th scanning point (k = 1, .., n); $w_i(t)$ is the reference free-field component time window (Adrienne temporal window); $w_{tk}(t)$ is the time window (Adrienne temporal window) for the transmitted component at the *k*-th scanning point; *F* is the symbol of the Fourier transform; *j* is the index of the *j*-the one-third octave frequency bands (between 100 Hz and 5 kHz); Δf_j is the width of the *j*-the one-third octave frequency band; $n = 9$ is the number of scanning points. The geometrical spreading correction factors d_i and d_k are the distances from loudspeaker to microphones. The SIjs are then weighted by a standard traffic noise spectrum to obtain the overall single number rating of airborne sound insulation DL_{SI} .

(a) With barrier sample

(b) Free field

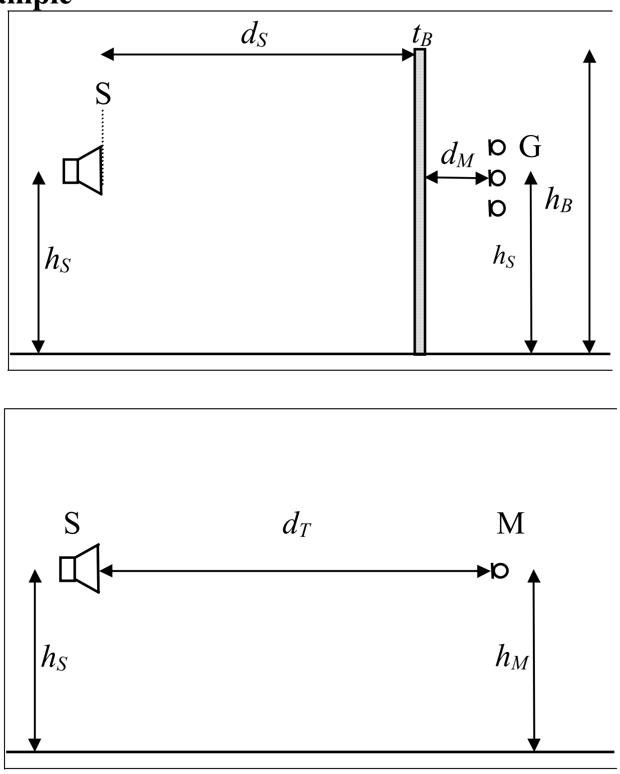


Figure 5: Transmitted components measurement in front of a barrier. S: loudspeaker, G: measurement grid, M: microphone. d_S=1m, d_M=0.25m and the microphones are spaced 0.3m apart in a 3x3 grid. $h_S=h_B/2$

3.3 Sound Absorption

There are a number of situations where sound absorptive materials can be used in the road cross-section to control the spread of noise from the highway.

Where plane vertical barriers exist on both sides of the road there exists the possibility of multiple reflections leading to a loss of screening performance. Sound absorptive panels located on the sides of the barriers facing the traffic can reduce the reflected contribution by absorbing the sound energy from the incident wave. There are several types of system that are used for sound absorbing barriers. Clearly, to be effective the barrier material must be highly absorptive at frequencies that are significant in highway traffic noise spectra and this is recognised in the recent CEN standard EN 1793 (part 1) which gives a test method for deriving a single number rating(17). This method weights the absorption coefficients from 100Hz to 5kHz with a typical traffic noise spectrum (part 3). While most of the absorptive materials perform adequately at mid to high frequencies the absorption at low frequencies varies considerably. Thick layers of absorptive materials or the use of a cavity behind the absorber are possible ways of improving performance. The effectiveness of absorptive materials in reducing noise levels will depend on the distance between parallel barriers/barrier height. Roadside tests by TRL involving reversing barrier panels from absorptive to reflective have shown that the largest reductions from applying good absorbers are generally a few dB(A)(18). Table 1 shows the maximum increases that reflective farside barrier have produced in other well controlled roadside studies where source strength and wind component have been taken into account. Larger effects of > 5dB have been predicted using physical and mathematical models due to the simplifying assumptions that are not realised in practice e.g. screening effects of traffic, reflections from safety barrier and absorption by grassed embankments, influence of road curvature and meteorological effects.

Table 1: Increase in L_{Aeq} dB due to the farside reflective barrier

Experimental design	Barrier separation/height ratio	Maximum increase in L_{Aeq}
Pairwise comparison	8.6 : 1	2.8
Barrier alteration	9.3 : 1	2.3
Barrier erection	15 : 1	1.4

In narrow urban streets a canyon effect can be created by the presence of tall acoustically reflective building facades on both sides of the road. Under such circumstances noise levels can be relatively high due to the reverberant sound field created by multiple reflections. The effect can be enhanced if horizontal covers project from each side of the building facades recreating a partially enclosed space. It has been predicted that in such circumstances the presence of a porous road surface can offer greater benefits than in a free field situation.

Contour plots of the A-weighted sound field close to a tall building façade bordering an 8m wide road are given in Figure 6 using a typical emission spectrum for light vehicles. The SPL varies from relatively high sound pressure (red) to low (dark blues). The appearance and increase in the area of blue for the cases with the PA surface is striking and clearly illustrates the wide extent of the lowered noise levels. Some relatively narrow horizontal bands of higher noise levels are visible in the plots for opposite façades and with partial covers (horizontal covers extending 1.7m from the top of each façade). These indicate the presence of standing waves due to the interaction of reflected waves. The results indicate that PA is more effective in reducing noise levels where the conditions are more reverberant. Overall in the case of the single façade the improvement with porous asphalt is 3.9 dB(A). With an opposite façade the improvements increases by just over 1 dB to 5.0 dB(A). The addition of partial covers increases the benefits substantially to 9.7 dB(A). Multiple reflections of sound waves on the absorptive porous asphalt occurs for the parallel façade and partial cover cases leading to greater reductions of overall noise levels compared with the reflective HRA case. With increasing distance between opposite façades, lower façade heights and where a cover is not present it would be expected that the advantage of PA over a reflective surface such as HRA would tend toward that of a single façade. Conversely inside tunnels and with narrower roads and closer façades with horizontal extensions greater improvements than those predicted should be observed.

Absorptive materials are also useful in controlling noise passing through louvered covers and noise barriers. A range of designs have been examined using scale model tests and BEM modeling. The results can be used to develop appropriate designs[19].

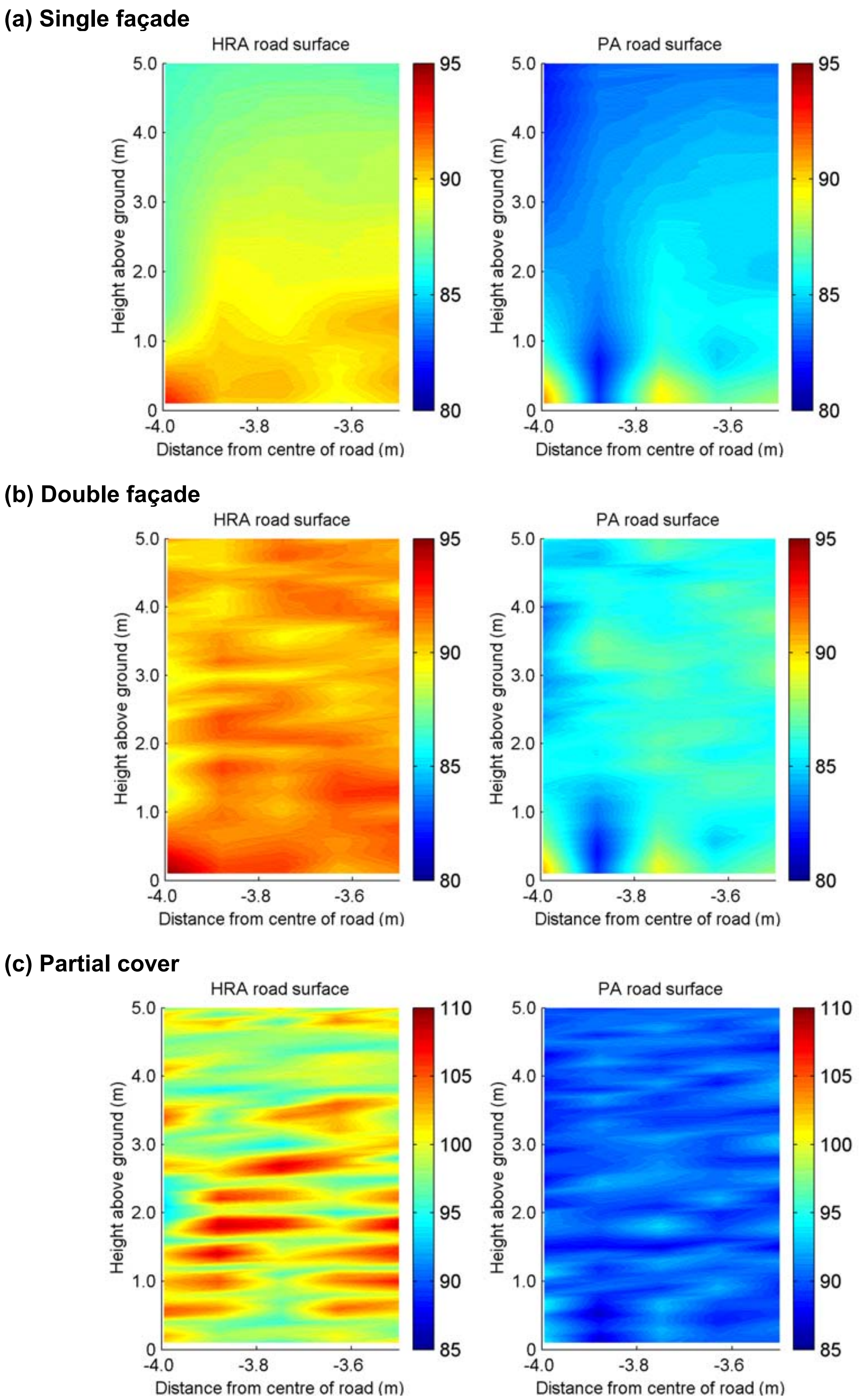


Figure 6 : Contour plots of A-weighted SPL near building facades

3.4 Diffraction Effects

The insertion loss of barriers can be determined in simple cases using the path difference approach. With suitable adjustments this approach was incorporated into the UK traffic noise prediction model CRTN[8]. In the case of more complex shapes the procedure may underpredict performance even when the effective height of thick barriers are taken into account e.g. cranked barriers comprising a simple barrier with an extension overhanging the carriageway. This is illustrated in Figure 7 (a to e) where the maximum insertion loss gains for receivers at 1.5 m above the ground produced by extensions of various lengths are based on BEM and path difference calculations.

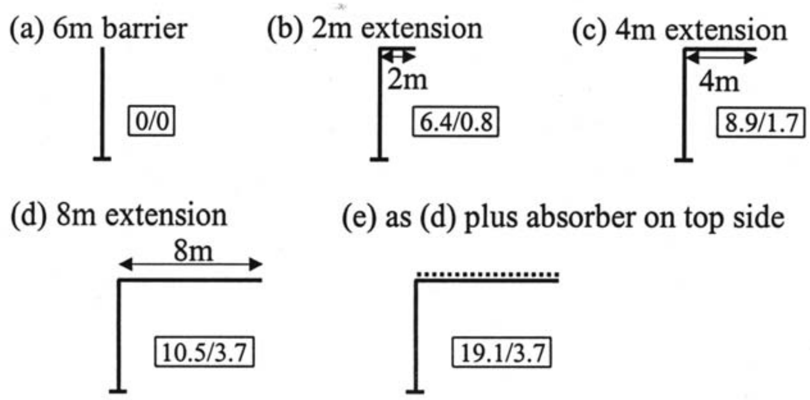


Figure 7: Maximum changes in insertion loss due to extensions (BEM / CRTN predictions in dB(A) posted)

Barriers have been altered in cross-section in an attempt to reduce the noise diffracted into the shadow zone. Many designs have been examined at TRL using mathematical and scale modelling and the more promising designs have been tested at full scale at the NBTF[9,10,11]. Figure 8 (a to l) shows some of the designs in cross-section that have been tested with the average improvement in insertion loss posted.

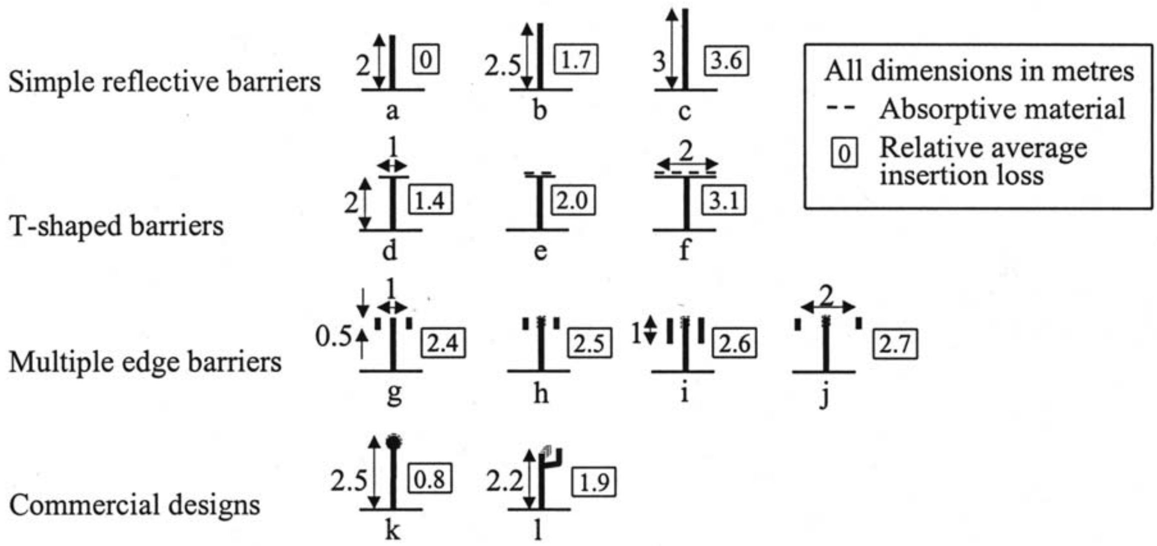
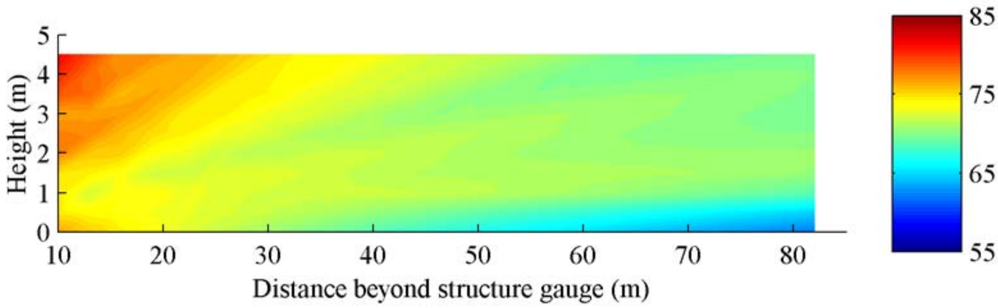


Figure 8: Insertion loss changes due to barrier caps

The designs included T-shaped barriers and multiple edged barriers as well as commercially available designs e.g. a rounded absorptive cap 0.5 m in diameter (k) and a device designed to exploit the principle of sound interference (l). The average reduction in noise levels for barrier profiles compared with a simple reflecting barrier of identical overall height were up to 3 dB. Adding the most efficient profiles has the same effect as raising the height of a simple plane barrier by 0.5-1.0 m. Roadside tests have confirmed that such reductions are possible in practice[12]. Such barrier profiles might therefore be useful for screening traffic noise in situations where the maximum height of barriers needs to be limited because of other environmental considerations (e.g. visual intrusion, reduction in sunlight) or where extra screening is required from an existing barrier and the costs of increasing the height would be excessive. The BEM approach has been used to develop diffractors of even greater efficiency and has also been used to examine the performance of earth berms of various shapes[20], and the spread of sound from cuttings. An advantage of the modelling approach is that it can produce tailor-made solutions for specific noise control problems. For example tall barriers can reduce the view from railway carriages and low barrier solutions are required without compromising noise screening. Figure 9(a) shows contour plot of the predicted A-weighted SPL behind a 3m plane reflective barrier and Figure 9(b) beyond a 2m high barrier with a multiple edge barrier. It can be seen that despite the lower height the multiple edge barrier is predicted to provided significantly better screening performance and could be suggested as a viable alternative to the simple screen for trackside noise control.

(a) 3m high reflective barrier



(b) 2m high absorptive multiple edge barrier

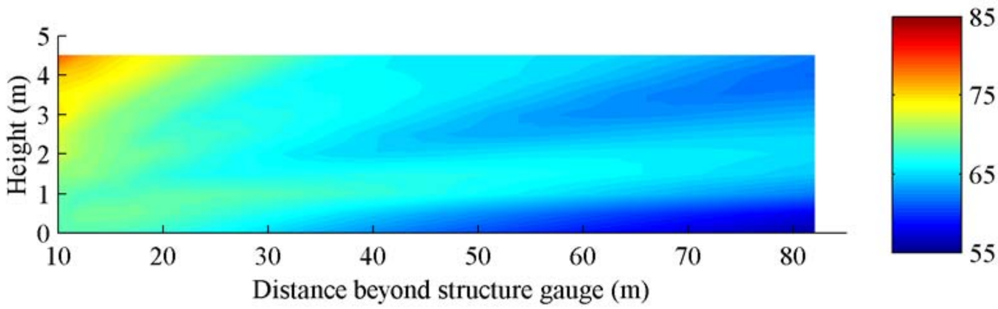


Figure 9: Contour plot of A-weighted SPL behind trackside barriers

3.5 Ground surface effects

The insertion loss of a barrier will depend on the road surface and the ground type in the screened area. It has been possible to model these effects using a combination of BEM modelling and site measurements to calibrate the model. The resulting effect has been shown to be different from the sum of the individual effects[13]. Figure 10 shows the change in insertion loss when 2m and 8m high barriers are placed adjacent to a porous asphalt (PA) road surface compared with a conventional asphalt surface (HRA). Porous asphalt is strongly absorptive in the frequency range 1-1.6kHz. Generally by changing to PA there is a decrease in the performance that depends on the distance behind the barrier and the height of the barrier. The largest decrease in performance for receivers at 1.5m height above grassland was predicted for the 8m high barrier where the loss was nearly 3dB(A) at a distance of 80m behind the barrier. The nature of the ground over which sound passes beyond the barrier also has an important effect on the insertion loss of the barrier. Generally the more absorptive the ground cover the smaller is the insertion loss of the barrier.

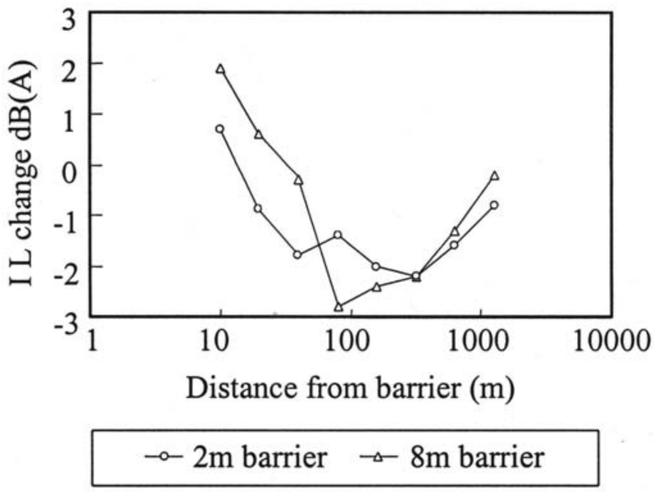


Figure 10: Predicted change in insertion loss from HRA to PA at 1.5m above ground

3.6 Meteorological Effects

Modelling work has indicated that the effectiveness of simple barriers is seriously degraded by wind blowing in the direction from the road to the receiver(21). The problem is partly due to the sound speed profile which is altered around the barrier resulting in greater refraction in downwind propagation conditions. Further research is needed to model these atmospheric effects sufficiently accurately so that it will be possible to predict the performance of barriers under different meteorological conditions. Research is planned involving developments in the BEM approach to include layered atmospheres and the use of other techniques, e.g. the parabolic equation approach, so that the effects on screening of wind and temperature gradient conditions can be calculated. In addition it is likely that air movements over the diffracting edge have a significant effect on acoustic screening performance(22). With greater understanding of the nature of this interaction it may be possible to produce designs that are more efficient than plane barriers across a wide range of wind conditions.

4 FUTURE DEVELOPMENTS

Research will continue into identifying characteristics of tyre design and road surface roughness that affect noise levels. It should then be possible by suitable design to avoid characteristics that cause excessive noise. The benefits of multiple layers of porous surfaces and the incorporation of Helmholtz resonators are currently being explored. This may mean looking at tyres and the road surface as a total system for low noise design purposes rather than in isolation. It may even be possible to use active noise cancellation (ANC) based on advanced signal processing techniques to produce destructive sound interference around the tyre contact patch to reduce noise levels even further although the problems are formidable.

However, it is likely that some residual noise will remain and in the foreseeable future there will be a continuing need to consider other mitigation measures that affect transmission, reception and perception. Recent studies have involved the examination of modified wheel arches and extended hubcaps to reduce propagation away from the tyre by providing additional screening and sound absorption. Research is continuing on improving the design of noise barriers and earth banks that will provide even better screening without increasing height. One possibility is to use a row of ANC devices on or near the diffracting edge of the barrier to produce sound cancellation that might result in significant noise reductions throughout the shadow zone(23).

It is recognised that such devices as noise barriers are not effective under all meteorological conditions. Future research is needed to model these atmospheric effects so it will be possible to predict the performance of barriers under different wind and temperature conditions. It is likely that air movements over the diffracting edge have a significant effect on acoustic screening performance. With greater understanding of the nature of this interaction it may be possible to produce designs that are more efficient than plane barriers across a wide range of wind conditions.

The nature of the ground over which sound passes also has an important effect. For example, ploughed ground and fields with standing crops are more absorptive than grassland and can lead to greater attenuation rates with distance, Stands of thickly planted trees with dense foliage down to ground level can also be effective. The effects of combining barriers with porous road surfaces or tree planting is not well understood and there are possibilities of optimising solutions if effects can be accurately modelled. Treating the hard shoulder and central reservation with sound absorptive material is also a possiblility and BEM modelling has been used to explore a range of options.

Finally the greater understanding of how people respond to noise and the factors in the noise signature of passing vehicles that cause particular irritation needs further research. It has been shown that the A-weighted level is not always a good indicating of noisiness and more sophisticated measures such as loudness on the Sone scale offer some advantages(24,25,26). Visual factors are known to affect the perception of nose(25) but studies are required to optimize any advantages that may be offered by manipulating the visual field.

5 CONCLUSIONS

The following conclusions can be drawn from this overview of TRL research into the generation and transmission of traffic noise.

1. Studies at TRL aim to identify the important characteristics of tyre design and road surface roughness that leads to the generation of significant noise. A special TRL vehicle called TRITON has been used to collect data on a wide range of surfaces. This will greatly facilitate in depth investigations of the effects of texture and tyre tread parameters on noise generation.

2. European co-operation through SILVIA and HARMONOISE are bringing added benefits in terms of access to larger databases and state-of-the-art modelling solutions.

3. Absorptive barriers can be designed to eliminate reflected noise but it is necessary to choose the absorptive material to eliminate the most important frequencies of traffic noise at the site of application. Porous road surfaces are predicted to be even more effective in situations producing reverberant fields e.g. in narrow city streets with tall buildings adjacent to the carriageway.

4. Multiple edge barriers and other barrier shapes are a solution to enhancing the acoustic performance of barriers without raising the overall height of the barrier system.

5. The usefulness of the Boundary Element Method modelling for investigating the spread of noise from the traffic source and designing effective mitigation measures has been

demonstrated. The fruitful cooperation with Bradford and Brunel Universities has facilitated the further development of the model.

6. Future research should include the study of optimising designs of the tyre/road system to reducing rolling noise, meteorological factors on sound diffraction and the use of ground cover to control noise as well as the innovative use of absorptive materials in the road cross-section.

7. The human response to noise is not well understood although some headway has been made on understanding the issues such as the deficiencies in the A-weighted scale for reflecting noisiness and the importance of visual factors. Further research is required so that mitigation measures are correctly targeted.

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