TRAFFIC NOISE REDUCTION TOOLKIT

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Prepared for: Project Record: D03B0009-2ac: London road traffic noise map: Initial action planning-related analysis
Client: Greater London Authority and Transport for London

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Executive summary

TRL Ltd have been commissioned by the Greater London Authority (GLA) with the support of Transport for London (TfL) to carry out an assessment of the various noise reduction options that might be used to reduce noise impact in London following the publication of the London Road Traffic Noise Map (LRTNM) in September 2004. The noise reduction measures are published in the Mayor’s Ambient Noise Strategy.

This report focuses on providing advice relating to issues concerning the prioritising and cost-effectiveness of the different measures designed to reduce the noise impact from road traffic. Following an examination of the acoustic performance of each measure the report provides, where possible, the input requirements to the LRTNM model which would allow the effectiveness of such measures to be estimated. Information concerning the overall costs of each noise reduction measure is included where this is feasible.

A number of options for reducing noise have been examined. This ‘toolkit’ comprises a description of a range of measures with an indication of cost where known and the likely effectiveness in terms of noise reduction.

A number of traffic noise prediction models have been used in evaluating the effectiveness of the various measures including the Calculation of Road traffic Noise (CRTN), the Harmonoise vehicle source model and a Boundary Element Method (BEM) numerical method where the evaluation of complex sound fields are required.

A summary of the different options is as follows:

- **Quieter vehicles.** Vehicle noise and tyre noise are governed by type approval regulations and there is no early prospect of any significant change in the status quo. New regulations for vehicle and tyre noise limit values are being considered internationally but it appears likely that limit values will be set at broadly equivalent levels to those currently in force.

  Lowering overall propulsion noise through the introduction of electric hybrid drive units is a long way off (10% penetration predicted by 2020) and even if all passenger cars were fitted with such engines this would only affect traffic noise at the lower speeds (< 30 km/h) by 3-4 dB(A). Motorcycle noise can be a problem especially along relatively quiet suburban streets and this can often be traced to the fitting of illegal silencers. Greater levels of enforcement can assist in reducing the problem including the introduction of roadside tests.

  Tyre noise limits appear unlikely to change substantially in the near future and even if they are improved the effect on UK roads surfaced with materials such as Hot Rolled Asphalt (HRA) may be insignificant. This is due to the fact that the current test for tyre noise takes place on a relatively smooth surface and low levels on this surface do not translate into lower noise levels on rougher roads such as HRA. The implications are that it would only be at local levels that significant changes could be made by, for example, limiting night access to lower noise vehicles in noise sensitive areas and by encouraging the use of lower noise tyres. If all passenger cars were fitted with lower noise tyres yielding a reduction of 5 dB(A) in rolling noise, the net effect on traffic noise would be of the order of 3 dB(A). Encouraging the fitting of lower noise tyres could be through a scheme such as the ‘Blue Angel’ labelling scheme operated in Germany. However, the tests would have to be conducted on a rougher road surface than currently used if the results were to have any relevance to current UK conditions.

- **Road surfaces.** This is potentially the easiest and most cost-effective means of reducing traffic noise. Since urban roads are frequently surfaced with HRA there are significant benefits of the order of 3 to 4 dB(A) to be gained by switching to lower
noise alternatives. These benefits rise with vehicle speed and should be realised at speeds over 35 km/h depending on the percentage of heavy vehicles. Predictions for motorways, where the percentage of heavy vehicles is often far greater indicate that benefits of over 3 dB(A) can be achieved. Where brushed concrete surfaces are currently in use even greater benefits can be expected depending on texture depth. In confined spaces such as city canyons a sound absorptive material such as porous asphalt can be expected to perform even more effectively due to a reduction in number of multiple reflections between opposite facades.

- **Smother driving including road junctions.** Aggressive driving can result in a significant increase in vehicle noise during the acceleration phase and can be perceived as a form of anti-social behaviour. Driver training and encouragements to calmer driving can be realised but there is no evidence that such actions have a long term effect. It is also doubtful whether overall noise levels would be affected by changing the behaviour of the few per cent of drivers who act in this irresponsible manner. However, it is possible that peak levels of noise may be reduced and it is known that this may affect the levels of perceived nuisance.

The presence of road junctions which bring vehicles to a complete stop can increase noise levels in the vicinity. Roadside noise surveys and modelling work have indicated the benefits of switching to roundabouts which allow a smoother speed profile and a reduction in the frequency of high rates of acceleration which increase noise. It is estimated that a reduction of approximately 2 dB(A) within 40 m of a junction can be realised by this single measure.

- **Street works and road maintenance.** It is difficult to generalise about the effects of poorly maintained roads and joints on average noise levels but it is known that peak levels can increase substantially due to the body rattle noise from heavy goods vehicles. The elimination of poor surface profiles and ensuring that patched surfaces do not cause oscillating noise levels will assist in improving the acoustic environment.

- **Noise barriers.** Advice on noise barriers is contained in the companion report entitled; *Noise Barrier Review, TRL PPR 046* (Watts et al., 2005). Larger noise reductions than can be achieved with road surfaces can be realised although local conditions may make the measure difficult to implement effectively, e.g. the presence of side roads and the presence of confined spaces behind the barrier. There is also the problem of vandalism, personal safety issues, especially where light levels are reduced, and there is loss of view. Many attractive designs are available and the use of transparent materials may be appropriate although costs are higher. Vegetative barriers may be considered a solution where an attractive alternative to hard, flat manufactured materials is considered appropriate.

- **Traffic calming.** Traffic calming is primarily introduced to reduce road casualties by reducing speed. The predicted effect based simply on the reduction in average speeds from 50 km/h to 30 km/h is estimated to range up to approximately 3 dB(A) depending on the road surface and percentage of heavier vehicles. Generally where vertical and horizontal deflections are used the character of the sound changes from a fairly constant level before the introduction of the traffic calming feature to a more fluctuating level as a result of vehicles accelerating and decelerating to negotiate the calming feature. Heavy goods vehicles negotiating the features can produce peak levels of body rattle noise which are 10 dB(A) above background. It has been found from predictions based on experimental work that wide cushions and flat topped humps can increase traffic noise significantly, with the actual increase critically dependent on the number of heavy vehicles. In contrast round topped humps were predicted to reduce traffic noise levels by up to 7 dB(A). Despite the reduction in traffic levels recorded at some sites the general reaction of residents has not always been favourable. Clearly, with many current measures, there is a difficult balance to
be struck, having full regard to road safety and a range of other factors besides
noise.

- **Altering traffic flow and composition.** Reducing the numbers of heavier vehicles
can produce significant benefits especially at lower speeds where propulsion noise
dominates. Clearly the size of the effect is critically dependent on the numbers of
these vehicles in the traffic before changes are introduced. Where heavier vehicles
account for approximately one third of the traffic then re-routing these vehicles could
produce benefits of approximately 4 dB(A) at 50 km/h and 6 dB(A) at 30 km/h. These
heavier vehicles would be displaced onto other roads so there may not be a net
benefit unless the displaced vehicles travel on roads where there is little or no
residential development.

The provision of bus routes including park and ride schemes has been predicted to
show benefits if bus patronage is at an adequate level. This has been estimated at
various speeds by calculating the acoustic equivalence of a bus in terms of the
number of cars that are expected to produce comparable sound energy during pass-
by.

- **Improving façade insulation.** Although improved sound insulation can reduce
noise levels inside buildings, making interior environments more pleasant for
occupants, there is no means of accounting for this effect in traffic noise models
which aim to predict exterior levels. Consequently it is at the action planning stage
that the effect needs to be taken into account. This can be achieved by using an
appropriate dose-effect relationship which relates exterior noise exposure to the
numbers of occupants seriously annoyed by noise. For example, different
relationships could be derived for buildings with single glazing, thermal double
glazing and double windows.

- **Combined measures.** By combining two or more mitigation measures it is possible
to reach optimum solutions to noise control. Using mainly prediction models it has
been estimated that the added effects of barriers and a lower noise surface, such as
porous asphalt, measured separately may not be totally realised due to the different
propagation paths involved and the frequency dependence of sound reflection and
diffraction. A similar effect has been predicted for lower noise surfaces and improved
façade insulation. Some results are given which can aid the overall assessment of
the benefits of these particular combined measures.

Where available, cost information is given for various mitigation measures in order to aid the
selection of cost effective solutions for planning purposes or to solve particular problems.
The review has identified the replacement of hot rolled asphalt with lower noise surfaces as
one of the most cost effective measures.
1 Introduction

In June 2002, the European Parliament enacted legislation related to the assessment and management of environmental noise (European Commission, 2002). The legislation called for a uniform approach towards assessing the impact of environmental noise, particularly from all major roads, in each Member State. This would allow the noise exposure in different areas of the European Union to be compared as well as providing a consistent method for assessing the effectiveness of implementing action plans designed to reduce the impact of road traffic noise.

The prescribed method of presenting information on exposure to noise was to construct noise maps showing noise levels at the facades of dwellings in the areas selected. The intention was to provide a visually accessible way of establishing noise exposure information over a relatively wide area and to be able to assess the effectiveness of noise control measures that could be applied. The intention was to update the maps every 5 years in order to estimate the effectiveness of the measures that had been taken to reduce noise from road traffic over the intervening years.

London was selected to be the first city in England to be mapped as a full pilot in work preparatory to the new Directive, although important mapping work had already been carried out in Birmingham. The mapping process requires the use of a model that calculates noise levels from the traffic, road and building layout details. It was decided that the model that would be used in London would be derived from the national UK traffic noise prediction model (Department of Transport and Welsh Office, 1988) suitably adapted to predict the EU noise indices required in the Directive (Abbott and Nelson, 2002). The map produced using this model, known as the London Road Traffic Noise Map (LRTNM) is accessible from the Department for Environment Food and Rural Affairs (DEFRA, 2004), www.noisemapping.org.

TRL Ltd have been commissioned by the Greater London Authority (GLA) supported by Transport for London (TfL) to carry out an assessment of the various noise reduction options that might be used to reduce noise impact in London, using as a basis the LRTNM, published in September 2004. This report provides more detailed information on noise reduction measures in the broad sequence outlined in the Mayor of London’s Ambient Noise Strategy “Sounder City” (Greater London Authority, 2004).

This report provides the results of this study. It focuses on providing advice relating to issues concerning the prioritising and cost-effectiveness of the different measures designed to reduce the noise impact from road traffic. Following an examination of the acoustic performance of each measure, the report provides, where appropriate, the input requirements to the LRTNM model which would allow the effectiveness of such measures to be estimated. Information concerning the overall costs of each noise reduction measure is included where this is feasible. Detailed costs are beyond the scope of this project and will often be conditioned by individual site details.
2 Noise reduction measures

Reducing the impacts caused by road traffic noise ideally involves a combination of measures. The measures include reducing the noise at source through improvements to vehicle and road surface design, reducing the propagation of noise into sensitive areas through road alignment considerations and the use of screening etc., and improving the receiver environment through urban design and improved building insulation. Traffic management can also play a part through measures designed to encourage a more passive, ‘quieter’, style of driving and by re-routing traffic away from more environmentally sensitive areas where possible.

While all of these measures can play a part in helping to achieve an acceptable acoustical environment for people living near to roads, it is often the case that attempts to control noise along the propagation path can only provide a partial solution and, of course, improving the insulation of property only helps to control the noise levels inside buildings. It is also important to understand that not all measures are suited to a particular road or road network. For example, speed reduction measures or changes to the road surface, designed to reduce tyre/road interaction noise, can only be effective on roads where previously tyre noise was a dominant noise source. In other cases, controlling noise through the use of measures designed to screen or contain noise to the immediate vicinity of the road can only have a limited application in urban areas due to the difficulties associated with space restrictions, aesthetics, and the need to allow for pedestrian crossing points.

Clearly in order to arrive at a range of suitable noise control strategies that could be applied in London and elsewhere, it is necessary initially to have a full understanding of the relative merits of each approach and an understanding of the conditions where each measure can be effective. The costs also need to be understood prior to implementation.

The following sections have therefore been set out in a manner that focuses on these main issues. For each noise control option the technical issues are described and the types of situations where the measures can be effective are described. The ways in which the noise control options can be accounted for in the noise model is also described and, where relevant, the costs of implementation are indicated.

2.1 Measures related to source noise

The sources of noise emitted by road vehicles are numerous but can be reasonably categorised to form two main groups. One group of sources tend to be dependent on the operation and speed of the engine and include sources related to the combustion process, gas flow noise and mechanical noise. These are collectively known as power train sources. The second group of sources relates to the speed of the vehicle and is mainly controlled by the tyre/road interaction. Power train noise tends to dominate when vehicles are driven at relatively low speeds and under conditions of acceleration when engine speeds tend to be relatively high. Tyre/road interaction noise tends to dominate at moderate and high road speeds. Measures taken to reduce power train noise are complex involving a wide range of processes that include the structural design of the engine, the control of the combustion process, improved air intake and silencer design and attention to the tolerances associated with moving parts. Reducing tyre noise involves both the design of the tyre and the road surface. Both aspects have to be taken forward with considerable care to avoid affecting issues such as safety (i.e. wet grip), durability and economy.
2.1.1 Quieter vehicles
At first sight it might be argued that a strategy based on quiet vehicle technology is not viable for controlling ambient noise in London as noise levels emitted by vehicles are outside of the control of the GLA, TfL and London boroughs. However, as will be shown below, there is some scope for encouraging the more widespread use of quieter vehicles and there is a way of accounting for this in the LRTNM.

2.1.1.1 Type approval testing
New vehicle noise levels are controlled in the EU through the application of type approval test procedures that require vehicles, when tested according to the specified test, to produce noise levels that are equivalent to or lower than the prescribed limit values. Vehicle types that pass the test are able to be registered and enter service.

There are two types of test. The first, introduced initially in the early 1970s, is aimed at regulating the noise sources on an operating vehicle that are associated with the power unit. The ‘drive-by’ test procedure requires the vehicle to be driven past a microphone at a relatively low speed (normally 50 km/h) but with the accelerator pedal fully depressed. The mode of operation is intended to simulate a harsh acceleration or ‘worst case’ condition in practice. The second procedure, introduced more recently in 2001, focuses entirely on tyre noise levels (European Commission, 2001). It involves coasting a vehicle (engine switched off) past a measurement microphone under a steady speed. The test is carried out at higher speeds than the power unit test to expose the levels of noise generated by the tyres.

Since the regulations were first introduced, in the 1970s the limits imposed have been progressively tightened with the overall objective of reducing the levels of traffic noise and the associated impact of traffic noise on people. Since the tyre noise Directive has only recently been introduced, the limits have not been changed, although it is anticipated that by August 2005 the Commission will propose an amendment to the Directive, including reductions in the permissible noise from vehicle tyres which will include considerations of wet grip adhesion and rolling resistance. It is expected that by 2007 there could be regulations covering all the main performance characteristics of tyres, to include wet grip, rolling resistance, structural safety and noise.

2.1.1.2 Ranges in vehicle and tyre noise levels
Not all vehicles of a particular type emit the same noise levels. In fact there are considerable ranges that are dependent on several factors that include the engine type (diesel, petrol, electric, etc.), the engine power, and the types of tyres used. An example of the ranges of tyre noise levels is shown in Figure 2.1.

The figure shows the relationship between tyre noise levels\(^1\) derived from type approval measurements and tyre tread width. The data was obtained from several surveys and comprises a total of 187 data values. Also shown in the figure are the current nominal type approval limits for each tyre category as defined in the Directive and the actual limits before rounding adjustments are made. It can be seen that currently nearly all the tyres tested would pass the current type approval test. More importantly, it can be seen that for each tyre type examined, there is a large range in noise levels obtained. In each of the main tyre categories the range in levels is about 6 dB(A) which represents a very large change in noise from the noisiest to the quietest tyre. Clearly, from the data given in the figure, there would appear to be considerable scope not only for reducing tyre noise limit values without compromising other important aspects of tyre performance, but also in encouraging the more

\(^1\) All noise levels have been temperature corrected to 20\(^\circ\)C as described in the Directive.
widespread use of existing tyre designs that comfortably meet the type approval limits currently imposed.

A similar result is obtained when car noise levels are examined. A distribution of car type approval levels is shown in Figure 2.2 for vehicles meeting the Euro III and Euro IV emission limits. Approximately 1800 vehicles were included in the analysis for both distributions.

Figure 2.1: Noise levels under type approval for a range of tyres compared with noise limits
The current type approval noise limit of 74 dB(A) for cars is shown on the Figure. The data shows that some 30% of the car population achieve noise levels some 3 dB(A) below the current type approval limit. However, it is not straightforward to relate values obtained under test conditions which involve full throttle acceleration to more typical acceleration rates found in practice and to constant speed driving. This is because propulsion noise often dominates under the current test condition whereas under normal driving conditions tyre/road noise makes a significant contribution and is often more important than propulsion noise. For this reason there are plans to replace the existing test with a procedure which involves testing under moderate acceleration, more representative of urban driving, and at constant speed. The levels obtained under the two conditions are then combined into a single number index $L_{\text{urban}}$.

Unfortunately data for truck noise is relatively scarce at present. However, data from approximately 30 heavy vehicles has been assembled and the distribution obtained is shown in Figure 2.3. In this case the limit value of 80 dB(A) has been added to the Figure. For this category of vehicle, the data suggests about 15% of the fleet produce noise levels some 2 dB(A) below the current limit values. It can also be seen that a significant portion of the vehicles tested gave noise levels that were above the current limit. This can probably be explained by the fact that the vehicles tested in this sample were taken from vehicles in-service and were not new vehicle types. It does, however, emphasise that there are significant differences in the noise levels from heavy vehicles that are currently in-service.
2.1.1.3 In–use testing and certification

The type approval test procedure is clearly aimed at controlling noise from new vehicles prior to registration. However, once vehicles enter service, they deteriorate gradually and in many cases their noise levels increase. For example, exhaust silencer systems may develop faults or holes in the pipework, engine shield gaskets become worn and may leak noise, engine tuning may need adjustment, and moving components will wear leading to higher levels of mechanical noise. There is a case, therefore, for introducing additional test procedures aimed at vehicles that have been registered and are in-service in order to identify vehicles that have become excessively noisy and are in need of maintenance. Suggestions range from procedures that could be used by enforcement authorities to identify noisy vehicles, which would serve as a basis for prosecution, to routine tests that are carried out as part of the annual MOT test.

A further application of in-service testing is to identify quieter commercial vehicles that could be used in noise sensitive areas or at times of the day where noise impact is likely to be high, e.g. at night. This particular application has potential for use as part of local or regional noise control since, although the approval of new vehicles is outside of the scope of the GLA, TfL or boroughs, some method of controlling or incentivising use of appropriately certificated vehicles for operations within defined areas is clearly possible. For example the London Night and Weekend Lorry Control Scheme, which is regulated by the Association of London Government, might be capable of modification. A set of tests has been developed for London Buses Limited which includes lower speed acceleration and stationary testing. A stationary noise test (already in use in Spain and Austria) may also be suitable for assessing ancillary equipment such as on-board compaction units on waste collection vehicles. The costs of additional testing would need to be determined before the viability of any scheme could be assessed.
The observation deduced from the data given earlier, i.e. that there are considerable ranges in the noise of individual vehicles, adds support to the viability of such measures.

The first issue to consider is how to discriminate between relatively noisy and quiet vehicles. Methods based on testing offer the appeal of providing an objective approach but the question arises as to what type of test procedure could be used as a basis for certification. This topic has been the subject of several studies conducted by TRL and the main issues that have emerged from these studies are summarised below.

Firstly, it is important to understand that there are important differences between a type approval test and a test suitable for in-service vehicles. Firstly, type approval testing occurs at registered test sites, where the acoustic conditions are closely controlled and where high quality equipment is available for use by experienced measurement technicians. In this test environment, there are clearly greater opportunities to ensure that the mode of operation of the vehicle, the location of microphones, and the analysis and interpretation of the data is tailored to the overall objectives of the test. Under these conditions, even relatively complex vehicle operations can be undertaken by experienced drivers to produce highly repeatable results. Furthermore, with the strict requirements attached to the quality of the equipment used and the standardisation of the test site itself, the results can be expected to attain a high degree of reproducibility at other type approval test sites.

In contrast, in-service testing needs to be carried out under conditions where it might be difficult to ensure that the standard acoustic conditions occur and using lower cost equipment than that required for type approval testing. Ideally it should be possible to carry out in-service tests in a variety of locations such as a garage forecourt or at the roadside.

Measurements from a stationary vehicle offer potential advantages for in-service testing in that they can safely be taken, relatively close to the vehicle and in an area where space is limited. Tests on a moving vehicle would normally require a reasonable separation between the vehicle and measurement locations and a larger test site to accommodate the chosen mode of operation of the vehicle. The main advantage of taking measurements in close proximity to the test vehicle is that the effect of external parasitic noise is removed. Consequently, as indicated above, it is a technique that is suited to in-service testing where the test would need to be carried out in a variety of non-standard acoustic environments and where background noise might be relatively high. Close proximity measurements therefore provide an opportunity for the development of a procedure that could be used as part of an annual vehicle MOT test, or it could be used to identify excessively noisy vehicles as part of an in-service enforcement programme. Clearly, for these applications the test would need to be very simple and provide reproducible results independent of the acoustic environment. The main disadvantage of close proximity measurements is that they cannot be related simply to the noise from the whole vehicle. For example, a simple tailpipe measurement will not necessarily be a good measure of noise radiated by the engine and vice versa. This raises issues associated with how representative such a test is in relation to the total noise generated by the vehicle in real road situations.

TRL has recently examined a range of possible test procedures that could have an application for in-service testing. A full report of this work will be published in 2005. An objective of the study was to compare the results obtained from both moving vehicle test methods and stationary test methods using a sample of different vehicles. The sample of 26 vehicles included a selection of HGV’s, buses, minibuses, vans and cars. Examples of vehicles powered by Compressed Natural Gas (CNG) and Liquid Petroleum Gas (LPG) were included in the sample to allow a comparison of noise performance from alternative fuelled vehicles.

The data obtained from the study was used as a basis for establishing test procedures that produce repeatable and reproducible results and offer a good degree of representativity with noise emission characteristics in-practice. The test procedures examined included the current standard procedures used for exhaust noise testing but also included tests aimed at
determining noise from all sources on the vehicle including the power unit. Different types of engine operation were also examined that included sweeping the engine speed slowly through the speed range, the use of a rapid acceleration to governed speed, and tests with the engine idling. Measurements were also taken of air brake noise and noise from lifting gear. Refrigeration units were measured where these units were fitted.

The study showed that one of the stationary tests provided results that correlated reasonably well with the results obtained by the more conventional drive-by tests. This test procedure known as the ‘whole vehicle engine sweep test’ involved measuring the noise at an array of 8 microphones arranged around the vehicle (see Figure 2.4). Measurements were taken when the vehicles’ engine speed was gradually raised from idle to either a governed speed, for vehicles fitted with a governor, or, for ungoverned engines, to 75% of the engine speed at which the maximum rated power is obtained. When this point is reached the engine speed is held constant for 1-2 seconds and then the throttle rapidly released to allow the engine speed to return to idle. This type of operation is designed to pick up whole vehicle noise emissions for the range of engine speeds used commonly in normal driving and the slow sweep (15 – 20 seconds duration) provides opportunities to test for exhaust resonances that could develop at particular engine speeds. A more rapid acceleration would not necessarily expose these resonances.

![Figure 2.4: Microphone array positions used in close proximity tests](image)

Although using an array of eight microphones would be too complicated for a viable in-service test, it is highly likely that the test could be simplified to just two microphones located either side of the vehicle at the 2 m position without radically affecting the degree of correlation with drive-by test results. An analysis of the data obtained has shown that there is a high degree of correlation between the results obtained at the 7 m microphone positions with those at 2 m thereby allowing the close proximity positions to be used with reasonable confidence.

Clearly, with this simplification, this type of test could form the basis of a measurement procedure for in-service testing of commercial vehicles operating in noise sensitive locations.
in London and elsewhere. Further work would be needed, however, to examine the effects of reducing the number of measurement microphones from eight to two, determining appropriate limit values for different vehicle types, and addressing sources of noise additional to the vehicle, such as from brake systems, transmission, suspension, tyres, bodies, and load.

A particularly important observation made during the course of this study was the large range of noise levels associated with the engine idling. For the commercial vehicles tested the range in noise levels was of the order of 15 dB(A). In urban areas, idling noise can be intrusive and so identifying vehicles with particularly high levels of noise when idling could be an important discriminator that could be used when granting operation permits in noise sensitive areas. Idling noise is already incorporated as part of the engine sweep test described above and so it would be a simple matter to include this operation as part of an in-service test procedure.

The study also found that noise from operating the air brakes and venting often produced noise levels significantly above the often quoted proposed limit value of 72 dB(A) for this source of noise. Fitting air brake silencers can help in reducing this source of noise and could therefore be a considered as a requirement when considering certifying vehicles for operations in noise sensitive areas. However, it is recognised that they can get damaged or left off during servicing and there is therefore a need to develop a simple procedure that can be used as an in-situ test to check for correct operation.

Vehicles powered by CNG and LPG were compared with their diesel or petrol powered equivalent vehicles. It was found that the differences in noise produced for the different test conditions examined were not significant. The conclusion reached was that CNG or LPG vehicles were not consistently quieter or noisier than vehicles powered with conventional fuels. However, the dataset examined was small and would need to be enlarged before firm conclusions can be reached on this issue. Nevertheless on the basis of current data there is no evidence that fuel type can be used as a basis for discriminating between noisy and quieter vehicles.

Electric vehicles offer potential benefits for noise reduction. These come in a variety of forms including battery powered electric, hybrid electric and fuel cell powered vehicles. Currently fuel cell powered taxis and buses up to 18 tonnes are in service. In recent tests comparing a battery powered electric vehicle and the diesel equivalent it was found that the current type approval value was reduced from 75.6 to 68.8 dB(A) i.e. a reduction of nearly 7 dB(A). The change was due to the significant reduction of the propulsion noise component of total vehicle noise. Currently there are few electric vehicles in use but these results argue for a careful consideration of the merits of promoting their use especially for use in noise sensitive areas in the future. However, there are concerns about tonal noise from large electric motors which may be disturbing even at low levels and this aspect would need to be included in any evaluation of this new technology.

Body noise (i.e. body rattle and suspension noise) is often a source of complaint by the general public. Although the condition of the road surface is an important component governing the generation of body noise, there is a Guide to Good Practice for the control of body noise (Department of the Environment, Transport and the Regions, 1999) aimed at helping operators of commercial vehicles minimise the levels of noise produced. Adherence to the advice given in the guide could also be considered as a pre-requisite for the issue of a noise permit for night operations in the London area.

Although motorcycle noise is unlikely to contribute greatly to average traffic noise levels it is often cited as annoying in questionnaire surveys of noise nuisance. It can be a problem especially along relatively quite suburban streets and this can often be traced to the fitting of illegal silencers. Greater levels of enforcement can assist in reducing the problem including the introduction of roadside noise checks using portable sound level recording equipment.
2.1.1.4 Benefits of reducing vehicle noise

Traffic noise reductions can be achieved by reducing the propulsion and rolling noise components of light vehicles. The size of these benefits can be estimated using an appropriate noise prediction model. The effect on average noise levels of reducing noise from heavy vehicles is likely to be small since they typically make up a relatively small percentage of urban traffic. The effects of banning heavy vehicles or reducing their percentage in the traffic stream can result in some gains, which are examined in Section 2.3.

Reducing propulsion noise

A typical traffic scenario was simulated using the state-of-the-art noise prediction model Harmonoise (Watts, 2005). In this model it is possible to adjust rolling and propulsion noise separately in order to examine the effects on overall traffic noise. A typical urban traffic flow scenario was used based on national statistics (Abbott et al., 2003) i.e. 3% two-axle medium heavy vehicles (4 wheels on rear axle) and 0.6% of heavy vehicles with more than 2 axles. The remainder were light vehicles (96.4%). The road surface was assumed to be a very widely used bituminous surface, hot rolled asphalt (HRA) with a maximum stone size of 20 mm. No reliable figures for HRA are included in the model but the use of a “reference” surface with a stone size of 20 mm gives results which are within the range expected. The average noise level at 7.5 m from the centre of the lane was calculated using a total hourly flow on the road of 1000 vehicles. Figure 2.5(a) shows the average level (equivalent continuous level $L_{Aeq}$) on HRA for different average constant speeds of the traffic for the existing situation and also for the case where the light vehicle fleet has been replaced with vehicles having a low noise propulsion unit e.g. an electric motor. The assumption made for these low noise vehicles was that the propulsion noise was 10 dB(A) lower than for current light vehicle fleet. For simplicity this reduction was assumed to apply across the whole speed range being considered (0 to 80 km/h). Due to the dominance of rolling noise over propulsion noise on this types of road surface it can be seen that the greatest benefits of 3-4 dB(A) are only realised at relatively low speeds of i.e. less than approximately 15 km/h. As can be seen in Figure 2.5(b) on a smoother surfaces such as a stone mastic asphalt with a maximum stone size of 6 mm (SMA6) these benefits are predicted to occur over a wider range of speed (up to approximately 25 km/h) as rolling noise is less important over a wider speed range.

Clearly if the proportion of heavier vehicles is increased the effects of these changes in propulsion noise will be diluted.

The change to electric or other low noise propulsion units will take considerable time and as yet there is no prospect of an early change to this type of propulsion unit. Recent estimates put the percentage of electrically powered vehicles at about 10% in the year 2020.
(a) Hot rolled asphalt (HRA)

![Graph showing differences between traffic noise levels with current vehicles and future vehicles for HRA.](image)

(b) Stone mastic asphalt with maximum stone size of 6mm (SMA6)

![Graph showing differences between traffic noise levels with current vehicles and future vehicles for SMA6.](image)

**Figure 2.5:** Predicted differences between traffic noise levels with current vehicles and future vehicles where the propulsion noise for light vehicles is reduced by 10 dB(A)

Reducing tyre noise

Vehicle noise can also be reduced by an appropriate choice of tyres. Using lower noise tyres it is possible to obtain substantial benefits especially on a relatively rough surface such as HRA. Using the same road traffic scenarios as used above, a 5 dB(A) reduction in rolling noise for light vehicles in the speed range 0 to 80 km/h was assumed within the model to represent the wide use of quieter tyres.

Figure 2.6 shows the effects for the two surfaces used in the previous section i.e. HRA and SMA6. It can be seen that the benefits are greater on HRA than the smoother SMA6 due to the greater dominance of rolling noise over propulsion noise on the rougher surface. On HRA the benefits above 35 km/h are 3 dB(A) or greater while on SMA6 a 3 dB(A) benefit or greater is predicted to occur only above a speed of approximately 80 km/h. Unlike the
situation for propulsion noise the benefits of lower noise tyres are predicted to increase with road speed.

(a) Hot rolled asphalt (HRA)

![Graph showing A-weighted level / Leq vs. Speed / km/h for HRA-current and HRA-future](image)

(b) Stone mastic asphalt with maximum stone size of 6mm (SMA6)

![Graph showing A-weighted level / Leq vs. Speed / km/h for SMA6-current and SMA6-future](image)

**Figure 2.6: Predicted differences between traffic noise levels with current and future reductions in tyre noise for light vehicles**

The use of lower noise tyres could be encouraged by appropriate labelling. The Federal Environment Agency (UBA) in Germany promotes the use of lower noise tyres by “Blue Angel” tyre labelling scheme (Stenschke, 2005). The requirement of 71 dB(A) is by 5 dB(A) lower than the type approval limit for the widest tyres (>215mm section width) currently in force (European Parliament, 2002). It may be possible to control or incentivise use of such low noise tyres on vehicles used in noise sensitive areas as part of a package of vehicle based measures. However, the type approval test procedure utilises a smooth surface with a maximum stone size of 8 mm (ISO 10844) and it has been found that reductions on this test surface do not correlate with the reductions found on HRA. As a consequence noise
reductions would probably only be realised on fine graded material such as SMA6 or SMA8 thus limiting the potential benefits of such a scheme.

2.1.1.5 Implementation in the LRTNM

The implementation of a strategy based on limiting access to noisier vehicles could lead to reduced noise levels. The process of accounting for this in the LRTNM is not, however, straightforward. The LRTNM currently makes use of the traffic noise model CRTN. This model determines source noise levels from inputted values of the total flow, the composition of the traffic stream and the average speed of the traffic. Clearly, changing the noise emission characteristics of individual vehicles will not directly effect the calculation of the source noise levels using the CRTN prediction model.

However these benefits can be converted into reductions in equivalent total traffic flow in order to make use of the LRTNM for estimating area wide changes in noise exposure.

From Charts 2 and 3 in the Calculation of Road Traffic Noise manual (Department of Transport and Welsh Office, 1988) the traffic source noise is a linear logarithmic function of total traffic flow. If $\Delta$ is the change in dB that reflects the benefit then the adjusted flow $Q_{adj}$ that will give this reduction if $Q$ is the measured total flow in a given period (usually 1 hour or 18 hours) is given by:

$$Q_{adj} = Q \times 10^{\frac{\Delta}{10}}$$ (2.1)

For example if the effects of lower noise tyres are to be taken into account then in equation (1) it may be appropriate to set $\Delta$ to -3dB. In this case the adjusted flow required to reflect this change would be $0.5 \times Q$. A similar approach could be taken to estimate the change due to propulsion noise although market penetration of these vehicles is expected to be very slow and therefore there is little prospect of significant benefits in the foreseeable future.

Table 2.1 gives the $Q_{adj}/Q$ values for different values of noise reductions $\Delta$

<table>
<thead>
<tr>
<th>$\Delta$, Change in $L_{Aeq}$</th>
<th>Flow adjustment factor ($Q_{adj}/Q$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.5</td>
<td>0.89</td>
</tr>
<tr>
<td>-1.0</td>
<td>0.79</td>
</tr>
<tr>
<td>-1.5</td>
<td>0.71</td>
</tr>
<tr>
<td>-2.0</td>
<td>0.63</td>
</tr>
<tr>
<td>-2.5</td>
<td>0.56</td>
</tr>
<tr>
<td>-3.0</td>
<td>0.50</td>
</tr>
<tr>
<td>-3.5</td>
<td>0.45</td>
</tr>
<tr>
<td>-4.0</td>
<td>0.40</td>
</tr>
<tr>
<td>-4.5</td>
<td>0.35</td>
</tr>
<tr>
<td>-5.0</td>
<td>0.32</td>
</tr>
</tbody>
</table>
2.1.1.6 Costs for reducing propulsion and tyre noise

The costs of setting up a scheme to control or incentivise low noise vehicles is unknown at the time of writing. Changes to the noise emission of heavy vehicles are unlikely to bring a significant change in average traffic noise levels on most routes. However, in noise sensitive areas where, for example, deliveries are made in the evening or at night, tangible benefits may be realised to the local residents.

It is has not proved possible to obtain information on the costs of lower noise tyres. One problem is that in the UK such tyres are not routinely marked as such. Even if they were, the noise level at type approval would refer to the test results on the ISO 10844 surface which, as remarked above, has little relevance to the noise levels generated on UK roads.

2.1.2 Road surfaces

To estimate the change in traffic noise levels after replacing the road surface is not straightforward. The following sections identify the factors which are most influential. An important aspect is in understanding the various noise sources on a vehicle; how they vary due to changes in vehicle operation and the significance of their contribution to overall traffic noise levels under different traffic conditions. Each vehicle has a number of different noise sources which when combined give the total vehicle noise emission. This section provides background information which describes the various noise sources associated with vehicle noise emissions. In particular, noise sources associated with the interaction of the vehicle tyres with the road surface, often referred to as tyre/road noise, will be highlighted including its generation, propagation and its significance on overall traffic noise. Noise emissions can be affected by meteorological factors such as rain, wind and air temperatures, but these influences fall outside the scope of this report.

2.1.2.1 The sources of vehicle noise

The main noise sources on a vehicle are the power unit (engine, air inlet and exhaust), cooling fan, transmission (gearbox and rear axle), tyre/road interaction, aerodynamic, brakes, body rattles and payload. In general, sources associated with the power unit and transmission up to the lay shaft are referred to as power train noise. All other sources are referred to as rolling noise and providing the vehicle and road pavement are well maintained and vehicles do not greatly exceed the legal speed limit, the dominant rolling noise source is from tyre/road noise.

The relative importance of power train noise and tyre/road noise depends on the type of vehicle and the way the vehicle is driven. Power train sources are primarily controlled by the vehicle engine speed whilst tyre/road noise is controlled by the vehicle’s road speed. For light vehicles such as passenger cars and car-based vans, power train sources are dominant at low speeds in low gears, whereas at higher road speeds in top gear, tyre/road noise is likely to be the dominant source. However, with heavier diesel engine commercial vehicles the contribution from the power train source is dominant under most operating conditions although the tyre/road noise does become significant at the higher road speeds.

The main factors which influence tyre/road noise include the design of the tyre where tread pattern, materials, construction together with the overall width are important contributing elements. However, apart from the influence of vehicle speed, the most influential set of parameters affecting tyre/road noise is that associated with the road surface. In particular, whilst tyre design and vehicle operation affect the levels of noise generated, the design and construction of the road surface can affect both the generation and propagation involving several complex mechanisms. The principal factors are the roughness or texture of the surface, the texture pattern and the degree of porosity of the surface structure.
2.1.2.2 Influence of surface types on traffic noise levels

As explained above, the Harmonoise model allows the effects of changes in rolling noise to be assessed independent from propulsion noise. Thus the effects of changes of road surface type on total traffic noise can be estimated. Using the typical scenarios used in previous sections, these have been modelled using the Harmonoise model to examine the effects of different road surfaces as speed is varied. Thus the percentage of medium heavy vehicles will be 3% and the percentage of heavy vehicles will be 0.3%. Three road surfaces have been modelled i.e. hot rolled asphalt (HRA), stone mastic asphalt with a maximum stone size of 14 mm (SMA14) and an SMA with a 6mm maximum stone size (SMA6). Figure 2.7 shows the trend in traffic noise levels predicted for these three surfaces. It can be seen that by replacing HRA with an SMA surface, this should deliver benefits above 15 km/h. There are advantages of approximately 3 dB(A) at speeds above 35 km/h. At 50 km/h the difference approaches 4 dB(A).

![Figure 2.7: Traffic noise variation with average vehicle speed](image)

At higher speeds than 80 km/h the assumption that all vehicles are moving at a similar speed is inappropriate.

For example on a motorway subject to a 70 mph limit a different scenario needs to be modelled as traffic composition and speeds are different. In this case a typical traffic composition involves 4.5% medium heavy vehicles and 9.1% heavy vehicles. The speed of the heaviest vehicles is restricted to 96 km/h and the average speed of light and medium heavy vehicles is 112 km/h. In this case the predicted traffic noise levels on HRA, SMA14 and SMA6 are 80.5, 78.5 and 77.1 dB(A) respectively. Hence the difference between the quietest and noisiest surface modelled is 3.4 dB(A). The slightly smaller difference than predicted at 50 km/h on urban roads is due to the much larger number of heavy vehicles on motorways (up from 0.6% to 9.1%).

2.1.2.3 Implementation in the LRTNM

It is possible to use Harmonoise to develop algorithms to be used in the LRTNM; however, within the current project only indicative values will be given based on the results of the typical scenarios examined above. At 50 km/h a change from HRA to a lower noise surface
will result in a reduction of approximately 3 dB(A). At 30 km/h this drops to 2 dB(A). As can be seen from Table 2.1 above these adjustments can be implemented by inputting flows of $0.5Q$ and $0.63Q$ respectively into the CRTN based model.

2.1.2.4 Costs for using quieter road surfaces

The cost of HRA, typically 40 to 50 mm thick, is of the range £9 – £10 per m$^2$. A lower noise surface such as an SMA with thickness 20 to 30 mm (thin surfacing) is in the range £6 – £7.50 per m$^2$. These figures include the cost of planing the original road surface estimated at £2 per m$^2$. To meet texture requirements the maximum stone size would be in the range 10 to 14 mm. Another consideration is the useful life of such surfaces. Performance tends to be very variable depending on the quality of laying, the materials and the exposure to heavy traffic. On many urban roads, the life of a road surface may be shortened due to repeated patching following work by the utilities. Experience suggests a life span of 10 – 20 years for HRA. The performance of thin surfacings appears to be much more variable with a range of 5 – 15 years. Hence there is more risk of early failure with the lower noise alternative. Taking the worst case of comparing a HRA surface lasting 20 years and costing £9 m$^2$ with a thin surfacing lasting 5 years and costing £7.50 m$^2$, the ratio of costs per year (SMA/HRA) is 3.3. In the best case the cost ratio reduces to 0.4.

Until more experience is gained with the use of lower noise surfacings in urban areas it is difficult to arrive at a precise figure. However, it could be argued that there is a reasonable chance that the costs of the two surfaces will not prove too dissimilar, and for broad brush comparisons similar costs can be assumed. Therefore the use of thin surfacings to replace HRA in urban areas should be considered as a potentially very cost effective noise reduction measure. It is suggested that monitored trials are carried out in a range of road traffic situations to examine the noise reductions and the pavement condition over time.

2.1.3 Smoother driving including junction design

The noise emission levels from vehicles will of course be influenced by the vehicle operation including whether the vehicle is accelerating or decelerating and on driver behaviour.

Variations in vehicle operation dictated by changes in traffic and road conditions are all part of normal driving and lead subsequently to variations in noise emissions. In addition not all drivers will react in exactly the same way to a given situation, and again as driving styles differ, so the noise emission levels will change.

The following paragraphs review some of the research carried out to examine the effect of a smoother style of driving on noise emission levels and the influence of changes in junction design on overall traffic noise levels.

2.1.3.1 Smoother driving

A comprehensive study of the influence of driving style has been carried out in West Germany (Kemper and Steven, 1984) involving both car and motorcycle drivers. Drivers were instructed to either drive aggressively or drive passively. The results showed that on average the noise emission levels from vehicles driven passively were substantially less than compared with the vehicles driven aggressively. For cars the average noise reduction was about 5 dB(A) and for motorcycles was 7 dB(A).

Similarly, it has been suggested that driving style can influence the noise emission levels from commercial vehicles (Kemper, 1985). Measurements of the noise from commercial vehicles before and after drivers had attended a training course in economical driving indicated reductions in noise level of about 5 dB(A).
More recent studies have been carried out as part of an EU project to develop a common traffic noise model, Harmonoise, to be used in Europe for assessing noise impact from road traffic (Watts, 2005). Table 2.2 shows the influence on total noise emission for both light and heavy vehicles when operating under moderate to excessive acceleration/deceleration conditions compared with when operating under constant speed of 50 km/h. For the range in vehicle operations associated with accelerations, shown in the Table, the corresponding change in total vehicle emissions can increase by as much as 4.5 dB(A) for both vehicle types and in reasonable agreement with that found in the earlier studies carried out in Germany.

The results in the Table also show the change in total vehicle emissions for a range of vehicle operations associated with deceleration. Generally, noise emission levels decrease with increasing deceleration of the order of 1 to 4.5 dB(A) depending on vehicle type and degree of deceleration. However, where deceleration involves heavier vehicles with 3 or more axles, and in particular where the engine brake is used, e.g. on downhill gradients, then noise emission levels will tend to increase compared with noise emissions at a constant speed of 50 km/h.

Table 2.2: The influence on noise emission from vehicles operating under different accelerating / decelerating conditions.

<table>
<thead>
<tr>
<th>Acceleration/deceleration</th>
<th>Vehicle type</th>
<th>Noise influence</th>
<th>Driving style</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m/s²</td>
<td>Light</td>
<td>+ 1.7 dB</td>
<td>Moderate acceleration</td>
</tr>
<tr>
<td>2 m/s²</td>
<td>Light</td>
<td>+ 4.5 dB</td>
<td>High acceleration</td>
</tr>
<tr>
<td>0.5 m/s²</td>
<td>Heavies</td>
<td>+ 2.1 dB</td>
<td>Moderate acceleration</td>
</tr>
<tr>
<td>1 m/s²</td>
<td>Heavies</td>
<td>+ 4.5 dB</td>
<td>High acceleration</td>
</tr>
<tr>
<td>- 1 m/s²</td>
<td>Light</td>
<td>- 0.8 dB</td>
<td>Slow deceleration</td>
</tr>
<tr>
<td>- 2 m/s²</td>
<td>Light</td>
<td>- 1.2 dB</td>
<td>High deceleration</td>
</tr>
<tr>
<td>- 1.5 m/s²</td>
<td>Heavies, 2 axles</td>
<td>- 4.5 dB</td>
<td>Moderate deceleration</td>
</tr>
<tr>
<td>- 1.5 m/s²</td>
<td>Heavies, 3 axles</td>
<td>+ 4.5 dB</td>
<td>Moderate deceleration</td>
</tr>
</tbody>
</table>

(Noise influence is presented relative to constant speed condition of 50 km/h based on the Harmonoise model)

These effects on noise emission levels due to changes in driving style will be reduced at higher speeds above 50 km/h due to the increased contribution from tyre/road noise.

Clearly from the above examination, it is important to avoid, when designing changes to the road network, situations which may provoke aggressive driving styles, particularly at or near residential properties or other noise-sensitive areas.

For the purpose of noise modelling, knowledge of actual driving patterns can be useful as input to the model. Examples of such driving patterns for a medium passenger car are presented in Figures 2.8a and 2.8b below. The first of the two figures show results measured for a residential street and the second for a major urban street (Steven, 1998).
It can be seen that the vehicles are driven with constant speed or very moderate accelerations most of the time. This indicates that on normal straight roads there are no reasons to take accelerations / decelerations into consideration when predicting noise.

Similar studies have been used to examine the influence of different junction designs on overall traffic noise levels and are discussed in the following section.
(a) Residential streets

![Graph showing proportion of time at different speed and acceleration combinations for a passenger car with a 90 kW engine on residential streets.]

(b) Urban main roads

![Graph showing proportion of time at different speed and acceleration combinations for a passenger car with a 90 kW engine on urban main roads.]

Figure 2.8: Proportion of time at different speed and acceleration combinations for a passenger car with a 90 kW engine

2.1.3.2 Junction design

Limited studies carried out in Europe have provided useful information on the change in traffic noise levels that may be expected after alterations to junction design. These studies have focused on where intersections including light-controlled junctions have been replaced by a roundabout.
In 2002 a study was carried out in the city of Basle, Switzerland, where a light-controlled road crossing was replaced by a roundabout (Plüss et al, 2003). Noise monitoring was carried out over a four week period before and after the change in junction design. Average traffic noise levels for the daytime period 06:00 to 22:00 hours and night time period 22:00 to 06:00 hours were compared. The results showed that after the roundabout was installed traffic noise levels were reduced by 1.7 dB(A) over the daytime period and by 2.9 dB(A) during the night time period. It is not known whether there was a significant change in traffic conditions, e.g. flow, composition or speed, which might explain these differences in traffic noise levels. However, the study was carried out at a busy intersection and any changes in traffic conditions would be unlikely to have resulted in such a large reduction in traffic noise recorded. It is more likely that the changes in the way vehicles are driven caused by changes in junction design have had a major influence on traffic noise reductions. The driving style associated with light-controlled junctions will typically promote start-stop traffic conditions, generating high noise levels as vehicles pull-away in low gear, compared with lower noise levels from vehicles under a smoother driving style associated with roundabouts.

Studies carried out in Norway showed similar results (Storeheier and Skaalvik, 1986). Before and after surveys where an intersection (without traffic lights) was replaced by a roundabout showed reductions in traffic noise levels of about 2 dB(A) at locations close to the intersection but little change in noise levels at locations further than about 50 m from the junction. Measurements of speed through the junction showed a 20% reduction after the roundabout was constructed and less variation, significantly contributing to the reduction in noise. The change in junction design had no effect on traffic volume.

In 1991, 21 roundabouts were constructed at intersections on arterial roads in Växjö in Sweden as part of a project to reduce traffic speed, thereby increasing traffic safety (Hydén et al, 1995). The roundabouts were all constructed with only one lane for traffic, and so that heavy vehicles could drive across the elevated central area. Prior to and after establishing the roundabouts, speed was measured at and between intersections, and noise was measured at three intersections, which were judged to be representative in regards to speed in urban areas. The noise was measured for at least 24 hours before and after establishing roundabouts instead of intersections.

Average speed was reduced by 11-18 km/h at intersections provided with roundabouts, and almost all speeding was eliminated. Speed was also reduced on road sections between roundabouts, if the distance between these did not exceed approximately 300 m. The shorter the distance between roundabouts, the greater the speed reduction.

Noise levels at the three intersections were reduced by 1.6, 3.9, and 4.2 dB after establishing the roundabouts as compared to the situation before. These reductions cannot fully be explained by the speed reductions of 11-18 km/h, and it thus seems likely that there is some reduction due to smoother accelerations or other factors regarding driving pattern. Besides the noise reductions measured at the roundabouts, the noise along the sections between the roundabouts must also have been reduced due to the reduced speed.

Results from traffic modelling based on the way vehicles are driven through different junction designs have also indicated similar results. In Uppsala in Sweden, changes in traffic noise were estimated from monitoring vehicle operations through a 4-way intersection (2-lane streets) with no other traffic control than a right-of-way for the major street, as compared to the same intersection after introducing a roundabout in it (with right-of-way for all vehicles already driving in the roundabout). The results showed that a roundabout causes a local decrease of speeds, which results in a reduced noise emission. The total effect is a reduction in traffic noise of around 2 dB along a 100 m street section with the intersection in the middle. However, maximum noise levels over the considered street section were not reduced significantly (Thulin et al, 2003).

In Table 2.3 below some French results are presented (Bérengier) and show that if the volume of traffic is unchanged after the construction of a roundabout, the equivalent noise
level \( (L_{Aeq}) \) will be reduced due to a reduction of the number of acceleration and deceleration periods. On this background the noise reduction depends on the design and layout of a roundabout such as the radius, the number of lanes and the number of entry/exit roads. It is important to reduce the braking and acceleration periods through the optimisation of the radius at the same time as it is important not to create congestion zones along the various roads leading to the roundabout.

### Table 2.3: Noise reductions measured at three French roundabouts in relation to a before situation with different intersections

<table>
<thead>
<tr>
<th>Site</th>
<th>Before situation</th>
<th>Noise reduction in day period ( (L_{Aeq}) ) in dB</th>
<th>Noise reduction in night period ( (L_{Aeq}) ) in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malemort</td>
<td>Intersection with traffic lights</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Namtes</td>
<td>Intersection with traffic lights</td>
<td>3.0 - 4.0</td>
<td>2.0 – 3.0</td>
</tr>
<tr>
<td>Egleton</td>
<td>Intersection with stop signs</td>
<td>1.0 - 3.0</td>
<td>1.0 - 2.5</td>
</tr>
</tbody>
</table>

It can be seen from the measurements before and after the construction of three roundabouts that reductions of the average noise level \( (L_{Aeq}) \) of 1 to 4 dB have been achieved.

An interesting study which compared the subjective responses to noise exposures from a light-controlled intersection versus a roundabout has been published (Notbohm and Schwarze, 2002). The study was part of the European project SVEN.

One part of the SVEN project was to expose a jury to noise recorded at a light-controlled intersection and to noise recorded at a roundabout; both in Paris, and to ask the jury to estimate the annoyance. The noise levels were adjusted in order that the equivalent noise level of both events was the same.

It was quite evident that people prefer the sound from the roundabout. It is probable that this is because the roundabout causes somewhat more smoothly flowing traffic with less intruding acceleration events.

#### 2.1.3.3 Predicting the effects using the Harmonise model

In a recent Swedish study carried out by Sveriges Provnings (Bredenfeldt and Nilsson, 2004) noise measurements were carried out close to roundabouts and junctions with traffic lights. As a reference, a position with free flowing traffic 100 m in front of the roundabout/junction was used. The authors concluded that a roundabout, which is designed to slow down the traffic from 50 km/h to 30 km/h without significant levels of acceleration/deceleration reduced the \( L_{Aeq} \) level to 2.9 dB(A) below that predicted from the Harmonoise model if a steady speed through the junction was assumed. For junctions with traffic lights the trend was similar but the spread in data was greater. It was found that the \( L_{Aeq} \) was always lower close to the crossing than it was at a distance of 100 m before the junction. There were some uncertainties associated with the study, as it proved difficult to correct accurately for the influence of roads crossing the road under study. However, it was quite clear that roundabouts and junctions with traffic lights decrease rather than increase the noise level in the vicinity of the junction. Note that the study sites had a small flow of heavy vehicles and so the results may need to be revised where the percentage is significant.

In order to further examine the likely size of the effect in the present study, a simplification of the situation was carried out to the Harmonoise source model (Watts, 2005). First, the
variations in the horizontal and vertical direction (directivity) were ignored, and secondly, the propagation was assumed to be over hard ground. Directivity in the horizontal direction is not well defined and is not thought to amount to a large effect. For the present simulation a single height of receiver at 1.2m was assumed so that vertical directivity is unimportant when making comparisons. In addition, in many urban situations, the hard ground assumption is not unrealistic.

The junction simulated was a simple junction where all vehicles are required to stop. It was assumed that the effects of the traffic on one arm of the junction was relatively small (due to small traffic flow and screening effects of buildings) and could be neglected in determining the levels on the road considered. The effective vehicle source positions for vehicles approaching and leaving the junction were 5 m apart. Only light vehicles (category 1 vehicles) were simulated and the following approach speeds and deceleration/accelerations rates were chosen for the simulations:

1. 50 km/h approach speed with deceleration/acceleration rate of 2 m/s/s (simulation 1).
2. 50 km/h approach speed with deceleration/acceleration rate of 1 m/s/s (simulation 2).

An acceleration/deceleration rate of 2 m/s/s was chosen as being at the upper end of the range (see Figure 2.8 for driving on main urban roads) and more typically observed at the lower speed range (< 10 km/h) where vehicles are required to stop. A rate of 1 m/s/s was considered a more typical value to compare with results from roundabouts on suburban roads where vehicles are much less likely to stop.

Predictions were made on each side of one arm of the junction with receiver placed at a height of 1.2 m at distances of 7.5 m, 15 m and 30 m from the nearest source line. The distance from the stop line was 0, 5, 10, 20, 40, 60 and 80 m. The line sources consisted of individual non-coherent sources placed 1m apart stretching back to 100 m from the stop line and 110 m beyond. At each individual source position the sound power was calculated using the speed profile based on the assumed acceleration and deceleration rates. With an approach speed of 50 km/h, the distance from the stop line where deceleration commenced was 48 m. It was assumed that vehicles stopped for 10 s at the junction before accelerating away in the same direction. The average level $L_{Aeq}$ was calculated based on a traffic volume of 500 vehicles per hour in each direction. The reference condition was a section of road without a junction, where all vehicles travelled at a speed of 50 km/h without stopping. The difference in $L_{Aeq}$ with and without a junction present was calculated and a contour plotting routine was used to interpolate values.

The contour plots for the differences in $L_{Aeq}$ for the two situations simulated are given in Figures 2.9 and 2.10. Some general trends can be observed from these plots. As expected the noise exposure on the side of the junction where vehicles are accelerating is greater than on the side where they are decelerating. In the case of an approach speed of 50 km/h with acceleration of +/- 2 m/s/s it is clear that noise exposure is always slightly greater than with a vehicle travelling at constant speed. The maximum occurs at the stop line where a maximum increase of 2.2 dB was predicted. At a distance of 60 m or greater from the stop line the level increase is less than 1 dB(A). [Is it justified to say something like: ‘Where vehicle stoplines with relatively hard accelerations persist, it would be worth considering to what extent the planning and design of adjacent land could take account of localised higher noise levels, e.g. through considering changes of use, distribution of uses within new development, and location of sitting out areas within open spaces.’]
For vehicles travelling initially at 50 km/h but then decelerating at a lower rate of 1 m/s/s there are reductions in noise at almost all positions. The greatest reduction of 2.4 dB(A) was predicted at 20 m from the stop line.

Of course the balance of propulsion noise and rolling noise will depend on the road surface and different sizes of effects would be expected on quieter or noisier road surfaces. For the current simulations a two year old SMA 0/16 surface was selected as being fairly typical of surfaces in much of Northern Europe. In addition the presence of heavy vehicles would increase the influence of propulsion noise and would affect the predictions if they were present in a significant amount.

It is interesting to note that the site measurements reported above (Bredenfeldt and Nilsson, 2004), near a roundabout where deceleration rates were judged to be modest, indicated
nearly a 3 dB(A) reduction of noise level near the junction compared with the situation where a steady speed through the junction was assumed. This is similar to the results of the second simulation presented above where a more appropriate acceleration/deceleration rate of 1 m/s/s for this situation was assumed.

2.1.3.4 Implementation in the LRTNM

It is difficult to generalise the results obtained in these studies because much will depend on the balance between rolling noise and propulsion noise. In turn this will depend on the types of road surface and percentages of heavy vehicles. Further work examining a range of scenarios would allow better estimates to be produced for different situations. However it is likely that for roundabouts a reduction of up to 2 dB(A) could be allowed up to 40m from the roundabout entrance. This could be taken into account by incorporating a flow adjustment of 0.63Q (see Table 2.1). Note that although average levels are predicted to fall for some junction designs, the variation in traffic noise levels may well increase, which could cause an increase in annoyance to local residents. For this reason a zero adjustment to traffic flows may be the safest option in the absence of a fuller investigation of the problem.

2.1.3.5 Costs for junction modifications

The cost of introducing a mini-roundabout at a simple junction is of the order of £10,000. However, additional costs arise if additional signing and lighting are required.

2.1.4 Streetworks and street maintenance

The quality of a road surface can affect the noise generation of vehicles travelling over the surface. When there is a change in surface type due to, for example, the replacement of a worn surface with a new one, there may be a perceptible change in noise level as vehicles travel from one surface to another. This case may also arise often in urban areas where there are frequent roadworks for water, energy supplies, or other utilities. This change in noise level may be more obvious where the changes are repeated down the length of the street, so as to produce an oscillating noise level. Of course, such noticeable changes of noise have in the past been exploited by traffic engineers to produce driver alerting devices. However, there has been much opposition to their use in urban areas due to the noise nuisance created. For example, measurements have shown a 6 dB(A) increase at the kerbside as a passenger car travelled over rumble areas composed of pads of coarse textured surfacing (Watts, 1978). It was concluded that such devices should not be installed near dwellings. The frequency of the change is known to affect the alerting properties such that 0.5 seconds of the noisy surface, followed by 0.5 seconds of the lower noise level, produced optimum alerting devices in a simulated driving task (Watts, 1977). Translated into an urban environment with a speed limit of 50 km/h this would mean having lengths of road of about 7 m.

Following local road repairs, it is important to ensure that as vehicles pass by, the patched areas do not lead to significantly different noise compared with the original surface, otherwise the changes in noise level or character may cause annoyance to residents living close by. Such changes in noise are particularly noticeable if the traffic flow is low, and where individual pass-bys can be identified. This situation is most likely to occur in the evening or at night, when residents are likely to be relaxing or sleeping, which will tend to increase the level of disturbance. Note that a patch with a lower inherent noise characteristic compared with the remaining surfacing may also cause a problem as this will create changes in noise level as vehicles pass by which are likely to be annoying.

Changes of road surface type may also introduce road surface profile irregularities. The most usual are a step up or step down at the interface between the surfaces. This can cause
impulsive body rattle noise as vehicles traverse the irregularity. Measurements have shown
that peak levels of noise can be over 10 dB(A) above the original level resulting in some
cases in significant disturbance to those living in the vicinity. In many cases heavy goods
vehicles produce the loudest noises in these circumstances due to a variety of causes such
as a poorly secured loads, loose body components, e.g. tail gates, lifting equipment and
chains, and suspension noises. The remedy is to take special care to avoid irregularities at
the interface. Where differences of surface height are unavoidable a sufficiently long ramp is
required to smooth the profile, or the irregularity should be sited at a sufficient distance from
residential properties, or other sensitive facilities.

Pass-by noise levels have also been shown to increase significantly in the presence of
bridge joints or joints in concrete roads, by 10 to 15 dB(A) depending upon the quality of the
joint. In the case of a noisy joint, the noise peak will be larger on a quiet road surface than on
a noisy one, thus probably making it more annoying. Bridge joints containing elastomers
have been developed recently, that do not cause such noise peaks when vehicles are
passing over, even with a low noise road surface. Note that if long term $L_{Aeq}$ measurements
are performed in the vicinity of a joint, the effect of noise peaks on measured values may be
small and the true impact is not reflected in recorded values. This is because of a number of
factors including the mix of vehicles, background noise and the road surface on either side of
the joint. In addition even if there is an increase in $L_{Aeq}$ the annoyance caused is unlikely to
be fully reflected in the change, due to the repetitive and impulsive nature of the noise that is
created by the joint. Unfortunately, there are no standardised measurement methods for
assessing the true impact of bridge joints. The availability of such a standard would probably
assist the adoption of innovative joint solutions. Where joint noise cannot be otherwise
addressed, it should ideally be taken into account in planning and design of adjacent noise-
sensitive uses.

2.1.4.1 Implementation in the LRTNM

It is difficult to generalise on the effects of poorly maintained surfaces or joints on average
noise levels. In many cases the average level may not be significantly affected; however,
peak levels adjacent to any irregularities in the surface may be relatively high and lead to
annoyance and even complaints. Further work is required to investigate the relationship
between surface profile and noise levels before recommendations can be made. Ideally, the
location of relevant major joints should be recorded to assist in local planning and design.

2.1.4.2 Costs

The costs of maintaining an adequate surface to avoid these problems will depend on many
factors including the frequency of streetworks and the quality of the existing road base.

2.2 Reductions related to noise propagation

2.2.1 Noise barriers

The companion report entitled “Noise Barrier Review” (Watts et al., 2005) contains
information on noise barrier types, their effectiveness in terms of noise screening, and
indicative costs. Also included is a discussion on the appropriateness of the designs for use
in urban areas. Below, the main conclusions from this report are summarised.

- Reflective barriers make an important contribution to reducing noise, although it will
  be necessary to consider angled returns on barriers where it is only possible to erect
  a short length of barrier along the main road. Sound leakage through the barrier
  needs to be considered both at the procurement stage and when installed;
• There is a wide variety of materials available with timber being the lowest cost option and transparent screens at the higher end. Transparent screens alone, or in combination with other materials, are an option worth considering, due to their possible advantage in terms of noise [?]and personal safety perception, and transmission of natural light. Complete covers may be of the order of 20 times as expensive as conventional barriers. However, where housing densities are high, e.g. high rise apartment blocks on both sides of the road, their use may be justified;

• Absorptive barriers add substantially to the cost, but can be justified where reflected noise is likely to be a significant problem. Absorptive materials need to be selected so that they are strongly absorbent at frequencies that are dominant in typical traffic noise, taking into account the traffic composition at the barrier site;

• The use of novel barrier profiles can provide additional screening benefits without raising the height of the barrier. This may be useful where visual impact needs to be limited, or where views need to be preserved. However there are few commercial products world-wide and there is no known supplier in the UK;

• The use of barriers containing photovoltaic (PV) cells for energy production in combination with novel barrier profiles would produce a 'win-win' situation, i.e. additional noise screening and the generation of electricity. Using the Boundary Element Method (BEM) approach some promising improvements in screening have been predicted;

• The robustness of materials needs to be carefully considered in urban areas due to the likelihood of vandalism. Some absorptive panels are not very robust (e.g. timber) and other materials such as wood / cement products may be more appropriate, although costs are significantly higher (estimated to be 70% increase);

• Vegetative barriers are attractive because they can provide a welcome relief to hard man-made surfaces such as brick, concrete and asphalt. However the living willow variants require continuous irrigation and their long-term robustness can be questioned. Similar barriers covered with ivy have the potential for greater useful life as irrigation is not required after the creepers are established. They also do not need annual pruning and can exist in shady conditions. They may be less attractive to graffiti artists than conventional barriers;

• Noise is diffracted around the ends of barriers and short runs of barrier may be ineffective in reducing noise. To overcome the disadvantage of short barrier runs it may be possible to put returns on the barrier, so that the barrier encloses the protected space on three sides, but this will depend on the access required. Where barriers are placed directly in front of buildings, there may be a problem of reflected noise which reduces the effectiveness of the barrier. The BEM modelling has demonstrated the advantage of applying sound absorptive material on the surfaces behind the barrier;

2.2.1.1 Implementation in the LRTNM

The CRTN model can be used to assess the screening by simple barriers. Where novel profile tops are used there is the possibility of adding notional height to the existing barrier to simulate the effects. For example, the average noise level behind a 2 m tall barrier with a 1m wide reflective multiple edge profile has been found to be equivalent to a simple barrier 2.7 m tall (Watts et al., 1994). A 1 m wide absorptive T-shaped profile applied to a barrier 2 m high was found to be equivalent to a simple barrier 2.6 m tall. The receiver heights were 1.45 and 4.5 m above ground level and were at distances of 20 to 80 m behind the barrier. The average levels at these receiver positions were used in the comparisons. With different
receiver positions, different equivalent heights may be found. Modelling work is required to develop appropriate algorithms that could be used to predict for a wider range of situations. Where sound absorptive barriers are used on the opposite side of the road, it may be possible to ignore their presence on the basis that they will probably reflect an insignificant amount of sound energy.

2.2.1.2 Costs for noise barriers

In the companion review (Watts et al., 2005) the costs of various barrier types are given. The costs of different options are reproduced in Table 2.4 below. In attempting to compare costs, some indicative costs for installing a barrier in London have been obtained. Costs are given in terms of costs of supply and erection of a 1 m length of a barrier 3 m high. The costs of barriers and covers of various designs will depend critically on the material, type of construction and dimensions.

It can be seen that the timber barriers are the cheapest option, both for absorptive and reflective options. The concrete option is also relatively cheap but is reflective. A wood cement absorptive or metal absorptive barrier is considerably more expensive. The use of transparent covers, although achieving very large reductions in noise levels, is relatively very expensive when compared with the barrier options. However both sides of the road are protected and the benefits are felt on upper floors of high rise buildings. Table 2.4 shows that costs are of the order of 20 times those for a transparent barrier 3 m tall. However, where housing densities are high, the cost per apartment protected may be more comparable to the cost of protecting two storey homes with conventional barriers.
Table 2.4: Indicative costs of 3m tall barriers per linear metre

<table>
<thead>
<tr>
<th>Barrier type</th>
<th>Type</th>
<th>Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber (single leaf)</td>
<td>Reflective</td>
<td>210</td>
</tr>
<tr>
<td>Timber (double leaf)</td>
<td>Reflective</td>
<td>275</td>
</tr>
<tr>
<td>Timber (single leaf)</td>
<td>Absorptive</td>
<td>350</td>
</tr>
<tr>
<td>Vegetative barrier (living willow)¹</td>
<td>Partially absorptive</td>
<td>360</td>
</tr>
<tr>
<td>Concrete</td>
<td>Reflective</td>
<td>360</td>
</tr>
<tr>
<td>Vegetative barrier (ivy covered)²</td>
<td>Partially absorptive</td>
<td>415</td>
</tr>
<tr>
<td>Aluminium panels</td>
<td>Absorptive</td>
<td>575</td>
</tr>
<tr>
<td>Wood / cement</td>
<td>Absorptive</td>
<td>590</td>
</tr>
<tr>
<td>Transparent acrylic</td>
<td>Reflective</td>
<td>600</td>
</tr>
<tr>
<td>Transparent cover³ over 2 lanes (acrylic)</td>
<td>Reflective</td>
<td>10,350</td>
</tr>
<tr>
<td>Transparent cover³ over 2 lanes (laminated glass)</td>
<td>Reflective</td>
<td>15,870</td>
</tr>
</tbody>
</table>

¹ Not included are costs of water throughout its life and annual pruning
² Not included are costs of water over first 3 years after which no further irrigation is required
³ Maximum height is likely to be of the order of 8m

2.2.2 Effects of street canyons, partial covers and tunnels

The presence of buildings close to the road can alter the sound field and the effects of low noise surfaces on reducing overall traffic noise levels needs further evaluation. Research using a numerical noise prediction model based on a Boundary Element Method (BEM) has indicated the additional benefits of porous asphalt used in narrow canyon streets where all the surfaces are reflective.

In cases of street canyons, parallel barriers, covers and tunnels with reflective surfaces such as concrete, brick or glass, there are likely to be multiple reflections between opposite surfaces and sound waves will propagate over the road surface repeatedly. A highly reflective road surface will contribute to the build up of reverberant energy in such confined spaces. This sound energy has the potential to cause considerable disturbance and has been the subject of a series of modelling and measurement studies (Watts, 1996; Watts and Godfrey, 1996 and Watts et al., 1999). The presence of a sound absorptive road surface such as porous asphalt would be expected to have a greater influence on the total sound pressure level than would be the case for free field propagation conditions. Such a surface may also significantly affect the source strength due to reduction in tyre excitation and air pumping etc. The advantage in terms of noise reduction over a reflective surface is therefore expected to be greater under these conditions.

Predictions were made for a narrow street situation (8m wide) typical of the layout in older areas of towns and cities. Calculations were carried out with and without porous asphalt present on a two-lane road. For these predictions a 2-D BEM was used. This method solves the Helmholtz wave equation numerically and can produce solutions for a wide variety of road cross-sections. The cross-sections are given in Figure 2.11. Note that in order to avoid an infinite series of reflections from perfectly parallel surfaces, which would produce unrealistic results, the building facades (and partial covers where tested) were tilted by a small amount (2.5 degrees from the vertical or horizontal). This was considered to be
appropriate to take into account non-perfect geometry in the real world such as non-parallel facades (both in the vertical and horizontal plane), scattering from window sills and doors, rough surfaces, architectural features and surface absorption. It should also be noted that wider roads could not be modelled due to the limitations on the number of elements that could be used in the program.

The conditions examined were:

- One façade
- Façades on opposite sides of the road
- Façades with partial cover designed to represent the conditions near tunnel entrances

It was assumed that the facades and covers were highly reflective. In addition, the pavements on each side were 1 m wide and highly reflective. Sources were placed 0.01 m above the carriageway in each lane and 1.52 m apart, simulating the sources from tyre noise of a light vehicle which is known to dominate in cruise-by operating conditions. The spectra of these sources for a typical reflective surface (HRA) and porous asphalt concrete (PA) are given in Figure 2.12. These were based on the agreed Harmonoise rolling noise source spectra equations (Jonasson et al., 2004) for a passenger car travelling at 50 km/h and have very recently become available. Note that these spectra do not take account of additional attenuation due to sound propagation over the road surfaces since this is included in the BEM modelling by the selection of the appropriate surface impedance.

Figure 2.11 also shows the points at which the sound field was sampled. Receivers were placed in a grid extending from 5 to 500 mm from the left hand edge of the pavement and from 0.1 to 5.0 m in height in increments of 0.1 m. For the purpose of comparison for typical receivers A-weighted levels were compared at three distances from the façade and at heights of 1.5 m and 4.5 m (representing positions on ground and upper floors) and the average over receivers between 0.1 m and 5 m.

Finally, the average SPL over the entire mesh was calculated. The advantage of applying PA rather than HRA in the three situations was then calculated for each set of 250 receivers and averaged. Contour plots of the A-weighted sound field close to the building façade are given in Figure 2.13 illustrating the variation from 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. These indicate the presence of standing waves due to the interaction of reflected waves. The results show 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 covers increases the benefits substantially to 9.7 dB(A). Multiple reflections of sound waves on the absorptive porous asphalt occur 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, greater improvements than those predicted should be observed.

Work by Hotta et al (2000) using a similar BEM modelling technique, showed that PA reduced average A-weighted noise levels outside a 10m deep reflective cutting of width 25 m by 4.7 dB(A). With no cutting, the reduction was smaller, i.e. 4.0 dB(A). The 0.7 dB(A)
additional benefit compares well with the 1 dB(A) additional benefit found in the current study. Note that a smaller benefit was noted where the sides of the cutting were faced with an absorptive treatment.

Sandberg and Ejsmont (2002) note that in a road tunnel, porous asphalt should be effective in reducing the build up of reverberant noise which bothers drivers and residents near the tunnel portals. A road tunnel under Sydney harbour was surfaced with porous asphalt to reduce the likelihood of such problems. However, there are safety issues related to porous surfaces in tunnels that would need to be considered.

Figure 2.11: Cross-sections used in BEM predictions of city streets and partial covers
Figure 2.12: A-weighted one-third octave spectra for rolling noise of a passenger car at 50 km/h
(a) Single façade

(b) Parallel façades

(c) Partial cover

Figure 2.13 : Contour plots of A-weighted SPL near building facades
2.2.2.1 Implementation in the LRTNM

In such narrow canyons, the additional noise reduction effect of a porous low noise surface could be of the order of 1 dB(A). From Table 2.1 the flow adjustment factor to yield this reduction is 0.79. With partial covers the additional benefit may be of the order of 6 dB(A). However, the performance of porous asphalt varies a great deal and these additional benefits may not be realised where the pores are clogged. Note that alternative low noise surfaces such as SMA offer little sound absorption and the benefits predicted above would not be realised.

2.2.2.2 Costs for low-noise surfaces in city streets and tunnels

The cost of porous asphalt is difficult to determine as it is not widely used in the UK at the present time. Porous asphalt is widely used in the Netherlands and they are currently involved in trialling double layer porous asphalt (through the IPG noise reduction research programme, Vos et al., 2004; Morgan, 2004) which has added absorptive qualities and the potential to reduce noise levels further than conventional porous asphalt. Due to clogging it may be necessary to cleanse the surface with a high pressure water hose. This maintenance may be particularly important in tunnels or under covers where the surface is protected from rainfall which may assist the removal of detritus.

2.3 Reductions related to traffic management

This section deals with noise reduction measures that may be achieved through traffic management. The approach initially deals with the effects of reducing vehicle speeds through traffic calming, which normally includes changes to the road layout. The discussion begins first with a description of the influence of speed on traffic noise levels and highlights the acoustic benefits that may be gained by introducing more stringent speed restrictions. Other forms of traffic management are considered including changes in traffic flow, composition and distribution of traffic across the road.

2.3.1 Traffic calming

Generally traffic calming schemes are introduced to reduce injurious accidents by reducing vehicle speeds. The following sections discuss the additional acoustic benefits that may be achieved through traffic calming schemes. However, there are some types of traffic calming which are known to increase noise levels, for example, rumble strips. The aim of these devices is to alert the driver to reduce speed by inducing a reaction through increased noise and vibration. This type of traffic calming is not appropriate in urban areas or in the vicinity of residential properties and will therefore not be considered in this report.

2.3.1.1 Speed restriction

The acoustic benefits from introducing stricter speed restrictions is dependent not only on the change in traffic speed but also on the traffic composition and the type of road surface. As vehicle speeds are reduced the dominant noise source contributing to overall vehicle noise emission changes from that generated by the interaction between the vehicle’s tyre and the road surface (tyre/road noise) to that produced by the vehicle’s engine, transmission and exhaust (propulsion noise). The relative contribution between these different sources on a vehicle travelling at a given speed is dependent on vehicle type. For passenger cars and car-based vans (light vehicles), the dominance of tyre/road noise can prevail even at low speeds typical in urban driving conditions, whereas, for the heavier commercial vehicles (heavy vehicles), even at motorway speeds the noise from power train sources are
significant. In addition, the balance between the relative contributions from the various noise sources on a vehicle is influenced by the type of road surface.

Generally, for a given speed reduction, the average reduction in the noise emission from light vehicles is greater than that for heavy vehicles and therefore the overall reduction in traffic noise will be dependent on traffic composition. Higher reductions are obtained where traffic consists mainly of light vehicles.

The Harmonoise model was utilised to examine the effects of changes of average speed on noise levels $L_{\text{Aeq}}$. The simplifying assumption was that all vehicles are travelling at the same steady speed. This is not an unreasonable assumption on single carriageway urban roads. However, this assumption will not hold at higher speeds; for example, on motorways there is a speed restriction of 96 km/h for heavy goods vehicles. In addition the composition of traffic changes on higher speed roads is different from that found on typical urban roads. For example, a significantly higher percentage of heavy vehicles are observed on motorways. The steady speed assumption will also be more appropriate where relatively low speeds limits are enforced (e.g. using speed cameras) to reduce speed rather than the use of vertical or horizontal deflections. This is because these latter devices will alter the speed profile and introduce acceleration and braking phases. It should be noted that the above discussion assumes that the restriction in speed does not cause congestion leading to higher noise levels due to a more aggressive style of driving (see section 2.1.3 above).

Figure 2.7 above indicated that a speed reduction from 50 km/h to 30 km/h is predicted to produce a reduction of approximately 3 dB(A) on HRA. On a fine graded surface such as SMA6 the reduction in noise produced by a similar speed reduction would be expected to be just less than 2 dB(A). If the average speed limit was reduced from 80 km/h (50 mile/h) to 50 km/h (31 mile/h) the noise reduction on HRA is predicted to be 4 dB(A) while approximately 3 dB(A) on SMA6. Note that traffic composition has an effect on the relationship and this is examined in section 2.3.2.1.

2.3.1.2 Vertical deflection (changing the height of the road)

Traffic calming schemes have been introduced by many local authorities with the aim of reducing speeds and injury accidents. Various measures have been introduced but one of the most effective measures usually involves some form of vertical deflection such as road humps. While these measures have been effective, there have been concerns raised by some about disturbance to residents from vehicle noise and ground borne vibration as well as discomfort to road users.

The introduction of a speed reduction measure such as a road hump or cushion can influence traffic noise levels in a number of ways. For example, lowering the speed of vehicles may mean that vehicle noise emission levels are lowered. In addition, after the measures are installed, traffic flows may be reduced, leading to further reductions in noise levels. However, vehicle noise emissions may also depend upon the way vehicles are driven: a passive style of driving, at a lower but constant speed, contributes to lower noise levels; an aggressive style, with excessive braking and acceleration between speed control devices, gives rise to a highly fluctuating noise level which can contribute to noise disturbance to residents. In addition, the use of road humps and cushions to reduce traffic speed may give rise to vehicle body noise (e.g. body rattles, suspension noise), which may be a cause of noise disturbance.

The following section deals with the acoustic performance of different designs of humps and cushions typical of those installed by local authorities. The aim is to provide an estimate of the change in traffic noise levels to be expected after the installation of such measures derived from a noise prediction model developed by TRL (Abbott et al, 1995). The model was developed empirically and uses as input average vehicle speeds observed before and after the installation of speed control schemes at a number of different local authority sites.
Figure 2.14 shows the change in traffic noise levels, $L_{Aeq, 1h}$ dB(A), after different types of speed cushions and humps are installed for a range of traffic scenarios: the percentage of commercial vehicles in the traffic stream ranged from 0 to 25 per cent whilst that of buses ranged from 0 to 1 per cent. The total traffic flow and composition were assumed to remain constant before and after the installation of the speed control measures. For the narrow and wide cushions the change in traffic noise level has been calculated from measurements on three examples of the profile. The dimensions of these cushions are given in Table 2.5 below, together with the dimensions of the flat-top and round-top humps.

(a) Narrow cushions (width less than 1700 mm)
Where the traffic stream consists only of cars, reductions in traffic noise of about 5 dB(A) would be expected after the cushions were installed. However, as the percentage of commercial vehicles in the traffic stream increases these reductions become progressively smaller. A small increase in traffic noise is predicted when the percentage of commercial vehicles reaches 10% which increases to about 2 dB(A) when the percentage of commercial vehicles reaches 25%.

(b) Wide cushions (width greater than 1700 mm)
Although substantial reductions in traffic noise levels of about 6 dB(A) may be expected where the traffic stream consists entirely of cars, introducing even a small number of buses and commercial vehicles (of the order of 1%) will rapidly alter the change in noise levels. Where the percentage of commercial vehicles reaches 25%, it is estimated that traffic noise levels will increase by about 9 dB(A) after wide cushions are installed.

(c) Speed control humps (flat-top and round-top)
The effect of both designs of speed control humps on changes in traffic noise levels where the traffic consists of all cars is to produce substantial reductions of about 7 dB(A). As the percentages of buses and commercial vehicles increase then the performance of the two designs differ.

Table 2.5: Dimensions of cushions and humps

<table>
<thead>
<tr>
<th>Type</th>
<th>Overall width (mm)</th>
<th>Overall length (mm)</th>
<th>Height (mm)</th>
<th>On / Off gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow cushions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1600</td>
<td>2000</td>
<td>75</td>
<td>1:8</td>
</tr>
<tr>
<td>2</td>
<td>1600</td>
<td>3500</td>
<td>65</td>
<td>1:8</td>
</tr>
<tr>
<td>3</td>
<td>1500</td>
<td>3500</td>
<td>60</td>
<td>1:8</td>
</tr>
<tr>
<td>Wide cushions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1900</td>
<td>2000</td>
<td>75</td>
<td>1:8</td>
</tr>
<tr>
<td>2</td>
<td>1900</td>
<td>1950</td>
<td>75</td>
<td>1:8</td>
</tr>
<tr>
<td>3</td>
<td>1880</td>
<td>2380</td>
<td>80</td>
<td>1:5</td>
</tr>
<tr>
<td>Flat-top hump</td>
<td>4000</td>
<td>7800</td>
<td>75</td>
<td>1:12</td>
</tr>
<tr>
<td>Round-top hump</td>
<td>4000</td>
<td>3700</td>
<td>75</td>
<td>n/a</td>
</tr>
</tbody>
</table>
The flat-top hump gave similar increases in noise to the wide cushions, i.e. an increase of about 9 dB(A) as the percentage of commercial vehicles approaches 25%. However, the round-top hump profile gave a more gradual deterioration in performance with an increase in the proportion of commercial vehicles. With this hump design a reduction of about 1 dB(A) in traffic noise was estimated when the percentage of commercial vehicles was 10% of the total traffic flow with little change in noise as the percentage of commercial vehicles approached 25% (see comments below).

Results from similar studies carried out in Sweden (Thulin et al, 2002) and in Denmark (Bendtsen et al, 2001) have shown that for round-top humps reductions of between 1 to 3 dB(A) may be obtained depending on traffic composition and are in reasonable agreement with the TRL results. In addition these studies also showed that although overall traffic noise levels were reduced, the variation in noise level from individual vehicle pass-bys increased in the vicinity of the hump compared with before the hump was installed. As vehicles approach the hump, drivers reduce their speed causing noise levels to decrease. After negotiating the hump drivers accelerate away causing noise levels to increase. The increase in noise variation can cause an increase in annoyance beyond that expected from the overall traffic noise level, particularly when drivers adopt an aggressive style of driving.

Further work carried out by TRL have shown that heavier commercial vehicles (i.e. with a gross weight greater than 32.5t) fitted with air suspension systems tended to generate less noise than similar vehicles fitted with conventional steel leaf suspensions. In addition, the variation in noise level between different profile designs was much less for vehicles with air suspension systems, whether unladen or fully laden. Fully loaded vehicles tend to produce less noise than unladen vehicles running over the different measures and this was particularly noticeable for the heaviest vehicles fitted with steel leaf suspension systems.
Vehicles with air suspension tend to be less affected by loading condition although their noise is lower generally than equivalent vehicles fitted with steel leaf suspensions.

It follows from this study that, when assessing the potential noise impacts of traffic calming schemes involving road humps and cushions, consideration should be given to the number of commercial vehicles, particularly those in the heavier category fitted with steel leaf suspensions which are likely to run unladen.

A further point to note in designing schemes involving cushions is to ensure that the incidence of commercial vehicles not straddling the cushions is minimised. When commercial vehicles do not straddle the cushions, noise levels tend to increase depending on vehicle speed, loading, type of suspension and the width of the cushions. It was estimated that increases of up to 10 dB(A) in maximum noise level for not straddling compared to straddling could occur with unladen commercial vehicles fitted with steel leaf suspensions running over narrow cushions at 40 km/h. Parking controls may therefore be required in the vicinity of cushions to avoid the need for vehicles to deviate from the intended line of travel.

2.3.1.3 Horizontal deflections (displacing the vehicle from the main running lane)

Traffic calming measures which are designed to reduce speed by altering the vehicle direction such as chicanes or roundabouts (see also section 2.1.3 above) can provide benefits in noise reduction compared with other calming measures but this is dependent on local traffic conditions and the design of the site.

For example, vehicles that are likely to produce body noise e.g. unladen commercial vehicles with steel suspension systems, may create less noise passing through a chicane than travelling over a road hump. However, chicanes which create high levels of vehicle stop-starting, acceleration and braking noise can be more unacceptable than the noise from the higher speed traffic that existed before the chicanes were installed.

A recent review of the literature has found little published results on the change in noise levels before and after installing chicanes to reduce vehicle speeds. It is likely that although overall traffic noise levels may be reduced due a lowering of vehicle speeds, maximum noise levels from individual pass-by events may increase due to the change in driving style adopted by some drivers.

2.3.1.4 Implementation in the LRTNM

Where a reduced speed limit causes a measurable reduction in mean speed the results predicted by the Harmonoise model can be used. Predictions of traffic noise were made for roads surfaced with HRA. Predictions were made at different speeds and also different traffic compositions. Figure 2.15(a) shows the trends of average noise levels with average traffic speed for different traffic compositions where the total flow remains constant at 1000 vehicles per hour. The percentages of medium heavy vehicles (MHVs) varied from 1 to 30% and the percentages of heavy vehicles (HVs) varied from 0.2% to 6%. MHVs include goods vehicles and buses with 2 axles but with 6 wheels. HVs include large vehicles with more than 2 axles e.g. articulated lorries.

For comparison Figure 2.15(b) shows the trends for speed and percentage of heavy vehicles that are based on predictions using Chart 4 in CRTN. The levels at 80 km/h for the Harmonoise model were used as the reference level.
(a) Predictions made with Harmonoise

![Graph](image1)

(b) Predictions made with CRTN (adjusted to give same levels at 80 km/h)

![Graph](image2)

Figure 2.15: Predictions on HRA of the effects of speed and percentage of heavy vehicles

Comparing (a) and (b) it can be seen that speed effects are generally smaller for the CRTN predictions. Note that CRTN predictions are for $L_{A10}$ and not $L_{Aeq}$ so some discrepancies can occur due to this factor. However, it has been found that there is a good simple relationship between $L_{Aeq}$ and $L_{A10}$ (Brown, 1989)$^2$ such that a reduction in $L_{A10}$ should equate to a comparable reduction in $L_{Aeq}$. For example with the highest percentage of heavier vehicles the predicted reduction in noise level $L_{Aeq}$ when the speed is reduced from 50 km/h to 30 km/h is only 0.2 dB(A) in the case of CRTN but 1.8 dB(A) reduction is predicted with the Harmonoise model. With the smallest percentage of heavier vehicles the corresponding expected reductions in noise levels are 1.8 dB(A) and 3.3 dB(A) for CRTN and Harmonoise respectively.

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$^2$ The relationship for short term measurements is $L_{A10} = L_{Aeq} + 3$. 
Using the Harmonoise model with a lower noise road surface, the predicted changes in noise level with speed will be less because rolling and propulsion noise contributions are treated separately and are subject to different speed functions. In CRTN the speed dependency of the road surface correction is limited to a 1 dB(A) reduction for impervious surfaces below the speed of 75 km/h. Above this speed the correction is dependent on texture depth and surface type (whether bituminous or concrete) although the correction does not change with speed.

Using the Harmonoise model for a fine textured surface such as a Stone Mastic Asphalt with a maximum stone size of 6mm (SMA6) the trend with speed for different traffic compositions are given in Figure 2.16. In this case the benefits of reducing the mean speed of traffic from 50 km/h to 30 km/h composed of 30% of heavier vehicles is 0.9 dB(A). If the traffic is composed of only 1% of these heavier vehicles the reduction is 2.1 dB(A). This is close to the CRTN predictions using a common bituminous surface such as HRA.

![Graph showing noise level vs speed for different traffic compositions](image)

**Figure 2.16: Harmonoise predictions on SMA6 of the effects of speed and percentage of heavy vehicles**

The range of effects can be seen to lie between approximately 0 and 3 dB(A) and it is suggested that the Harmonoise predictions are compared with the CRTN predictions. If the differences between the two methods is small (<1 dB(A)) then the CRTN method can be used. In other cases estimates can be used based on the graphs above and the necessary adjustments made in the CRTN model using the equivalent flow approach (See Table 2.1 and equation (1) in section 2.1.1.5 above).

For vertical and horizontal deflections the situation is more complex and it is suggested that the changes in noise levels given in Figure 2.14 are used. It should be assumed that the calming measures have been installed on a road subject to a 30 mile/h speed limit (48 km/h). Again CRTN predictions should be adjusted using the equivalent flow approach.

### 2.3.1.5 Costs for traffic management measures

Costs of supply and installation will depend on a number of factors but below in Table 2.6 are some indicative total costs based on costs in the year 2000. In the case of humps and cushions the cost estimates are for a single hump or cushion.
### Table 2.6: Indicative costs of traffic calming features

<table>
<thead>
<tr>
<th>Traffic calming feature</th>
<th>Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed cushion</td>
<td>500</td>
</tr>
<tr>
<td>Round topped hump</td>
<td>1,000</td>
</tr>
<tr>
<td>Flat topped hump</td>
<td>1,500</td>
</tr>
<tr>
<td>Traffic island / pedestrian refuge</td>
<td>3,000</td>
</tr>
<tr>
<td>Junction table</td>
<td>5,000</td>
</tr>
<tr>
<td>Chicane / road narrowing / gateways</td>
<td>5,000</td>
</tr>
<tr>
<td>Mini roundabout</td>
<td>10,000</td>
</tr>
<tr>
<td>Speed camera</td>
<td>25,000</td>
</tr>
</tbody>
</table>

In addition white lining at a cost of £0.5/m can be used to reduce the perceived carriageway width and has been found to reduce speed. It can be seen that there is a wide range of costs with the speed cushion providing a low cost solution and speed cameras at the other of the scale. In many cases the need to keep traffic moving at a reasonable speed will mean that calming features that cause a large speed reduction such as humps and cushions may not be appropriate. In these cases traffic islands, white lining to reduce lane width and speed cameras may be the more appropriate. Note that some additional costs may be incurred due to the need to provide additional signing and lighting.

#### 2.3.2 Reducing / rerouting / reallocating space

This section describes traffic management schemes which alter traffic flows with the aim of reducing congestion. The influence of traffic flow on noise levels and the acoustic benefits in reducing the number of vehicles in the traffic stream are examined. Restricting traffic using one part of the road network may generate higher flows elsewhere; rerouting of traffic can have significant effects on noise climate and therefore is included in this discussion.

Reallocating road space is a further tool for controlling traffic flow by redistributing traffic across the road width with the aim of reducing congestion for particular road users e.g. installing bus lanes. The factors which influence changes in traffic noise as a result of introducing this type of measure are discussed.

#### 2.3.2.1 Reducing traffic flow and rerouting traffic

If speed is not likely to increase or traffic composition to change significantly then a reduction of 50% in traffic flow across all vehicle categories implies a reduction of 3 dB(A) (see Table 2.1). However, the situation is more complex if the percentages of medium heavy vehicles (MHV) or heavy vehicles (HV) changes.

Figures 2.15 and 2.16 in section 2.3.1.4 show the trends of average noise levels with average traffic speed for different traffic compositions where the total flow remains constant at 1000 vehicles per hour. The road surface was assumed to be HRA.

The percentages of MHVs varied from 1 to 30% and the percentages of HVs varied from 0.2% to 6%.

Figure 2.15 shows that at a speed of 50 km/h the range in noise levels due to traffic composition was approximately 2 dB(A) while at 30 km/h the corresponding range was about
3 dB(A). Due to the importance of propulsion noise at low speeds the effects of traffic composition increased to 5 dB(A) at 15 km/h.

As noted before, the interaction of speed and traffic composition is also very noticeable. The trend with speed is noticeably less pronounced where the traffic is composed of a relatively high percentage of heavy vehicles. This is a result of the greater importance of propulsion noise which reduces the strong speed effect of tyre / road noise. On a fine graded surface such as SMA6 the range in noise levels for the traffic scenarios examined was larger due to the greater contribution of propulsion noise at all speeds. At 50 km/h the range was approximately 5 dB(A) while at 30 km/h it was close to 6 dB(A).

If a restriction is placed on the medium and heavy vehicles (MHVs and HVs) and only light vehicles (LVs) are allowed then the changes that take place will obviously depend on the percentage of these vehicles in the traffic stream before the restriction is imposed. Figure 2.17(a) indicates the effects predicted using the Harmonoise and CRTN traffic noise reduction on HRA for different proportions of MHVs and HVs.

Where there is a high percentage of medium and heavy goods vehicles (30% and 6% respectively) then the removal of these vehicles produces a relatively large reduction in the average noise level. At 50 km/h the predicted reduction in average noise level is nearly 4 dB(A) and at 30 km/h it is expected to be nearly 6 dB(A). Where the percentages of the heavier vehicles are at a more typical level (3% MHVs and 0.6% HVs) the changes due to the restriction of these vehicles are predicted to be relatively small. For example at 50 km/h the resulting change would be approximately 0.5 dB(A) and would only approach 1 dB(A) at 30 km/h.

The predictions using CRTN are given in Figure 2.17(b) for comparison. The levels are adjusted to the Harmonoise levels at a speed of 80 km/h. In this case with the heaviest flow of heavy vehicles their removal produces changes of approximately 4 dB(A) and 6 dB(A) at 30 km/h and 50 km/h respectively. These are comparable with the reductions predicted with Harmonoise. With the lower flow of heavier vehicles their restriction produces a predicted reduction with CRTN of 0.7 dB(A) at 50 km/h and 1.4 dB(A) at 30 km/h. These are slightly larger effects than predicted by Harmonoise but the differences between the predicted changes are probably insignificant.
(a) Predictions made with Harmonoise

(b) Predictions made with CRTN (adjusted to give same levels at 80 km/h)

Figure 2.17: Effects of imposing a lorry ban on medium heavy and heavy vehicles on HRA

2.3.2.2 Reallocating road space

One means of reallocating road space is to create bus lanes. This has the advantage of giving priority to buses and consequently reducing journey times and encouraging passenger car users to switch to public transport. Schemes which provide park and ride facilities can be attractive in locations where trips involve both ‘line haul’ corridors where congestion is heavy and good bus frequency can be provided, and extensive areas of dispersed development where congestion is light and where it is difficult to provide frequent bus services. Such schemes have apparently been successfully implemented in a number of
cities and cities e.g. Reading, Oxford, Dartmouth, though areas with light congestion are hard to find in London, as is space for parking.

A bus typically emits more noise than an average passenger car so it can be useful to estimate the noise equivalence of a typical bus in order to gauge the number of cars that need to be removed to reach a break even situation. The approach taken was to calculate the Sound Exposure Level\(^3\) or SEL for cars and buses. Within the Harmonoise source model data, the SEL of buses as a separate group is not readily available so an estimate has been made based on the average for category 2 vehicles i.e. medium goods vehicles with 2 axles and more than two wheels on the rear axle. Calculations were carried out for HRA and the relatively quiet surface SMA6 at speeds below 80 km/h. Figure 2.18 indicates the equivalent number of passenger cars to 1 bus as a function of speed.

At the 30 mph speed limit on HRA the equivalent number of cars to a notional bus is approximately two and reduces slowly at higher speeds. Under these conditions the bus would only have to attract relatively few car drivers to reach the break even point in terms of the total contribution to the noise dose. However, as speed decreases the equivalent number of cars increases rapidly and at speeds of 30 km/h the equivalence is estimated to be five and at 10 km/h it is 12. On a lower noise surface the numbers are significantly greater at the higher speeds e.g. seven at 50 km/h. The difference with HRA is due to the greater dominance of propulsion noise on the lower noise surface. At lower speeds the curves for HRA and SMA6 converge as propulsion noise tends to dictate the equivalent values. For example, the equivalent value at 10 km/h on SMA6 is 14. Thus for city driving where average speeds are likely to be low the patronage of the buses in the park and ride-type substitution situation should probably aim for an average at least five i.e. at least five cars should be replaced by the bus.

![Figure 2.18: Estimates of the equivalent number of a passenger car to a bus](image)

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\(^3\) The sound exposure level is the continuous noise level of 1 sec duration which contains the same acoustic energy as the time varying signal during pass-by.
2.3.2.3 Implementation in the LRTNM

The effects on traffic noise of predicting the removal of medium heavy and heavy vehicles from the traffic stream using CRTN are comparable with those predicted using Harmonoise and it appears that there should be little difficulty in implementing such a change in the LRTNM.

It is difficult to be precise about the effects of bus lanes on noise levels. It is likely that there are some benefits especially where bus patronage is very high e.g. at morning and evening peak periods resulting in a relatively larger number of car users opting for bus travel. Some indication of the level of patronage required to provide a benefit is given in the section above. There is a possibility of little or no benefit if levels of patronage are very low.

2.3.2.4 Costs for reducing / re-routing / reallocating space

The costs of setting up a heavy goods vehicle ban using width restrictions can cost up to £8,000 at year 2000 prices. Note that physical width and height restrictions can cause problems for emergency services and removal lorries. Enforcing a purely signed restriction may be difficult and so is not always very effective.

The costs of implementation of bus lanes with and without park and ride are very dependent on the size of the scheme and the number of carriageway alterations and traffic signs and signals required. It is unlikely that the acoustic benefits alone would be worth the considerable costs involved. Therefore the overall case for such schemes would probably depend on reducing gaseous emissions and journey times. A typical single deck bus may hold 40 passengers, a double deck bus approximately 80 and a Red Arrow bendy bus up to 140 passengers. Minibuses hold 8-22 seats and midi buses carry 23-30 passengers. Costs of the larger bus may range between £100,000 and £200,000.

2.4 Reductions related to building insulation

In many countries, legal requirements for noise are expressed in terms of outdoor maximum levels, and the effect of sound reduction techniques like low noise pavements are evaluated by outdoor measurements or predictions. Indoor noise levels are barely estimated, apart from the evaluation of façade insulation properties. Public authorities may be reluctant in specifying indoor noise levels, because of the presence of other noise source inside the buildings, making it difficult to differentiate the part of noise coming from outside. However, indoor levels due to external noise sources are clearly important for determining levels of nuisance and sleep disturbance.

Improved façade insulation can be viewed as a traffic noise mitigation measure. This passive protection is usually used where other mitigation measures are insufficient or too expensive to provide. For instance where a limited number of buildings are concerned, or when the noise barrier would be too high and visually intrusive.

Road traffic noise penetrates to the inside of buildings through the weak points in the façade such as windows, doors, ventilators and roofs.

The acoustic performance of windows depends on a number of factors including the type and thickness of the glass and air leaks between the window and frame. The preliminary treatment of façade insulation consists of improving the window sealing system. For higher insulation, more extensive treatments are required including thicker panes or double glazing, or adding a second window, usually on the inside of the existing window. In some cases additional insulation of walls and roofs are required.
2.4.1 Measured sound insulation

For a continuous road traffic noise, the airborne sound insulation of the façade is described by a standardized level difference:

\[ D_{tr,2m,nt} = L_{eq1,2m} - L_{eq2} + 10 \log(T/T_0) \]  

where \( L_{eq1,2m} \) is the outdoor Sound Pressure Level at 2 m in front of the façade, \( L_{eq2} \) the time and space averaged sound pressure level in the receiving room, \( T \) the reverberation time in the receiving room and \( T_0 = 0.5 \) s. The subscript \( "tr" \) indicates that the sound insulation is expressed for the existing road traffic noise as a source. Similar definitions can be used for other sources of noise, specified by different subscripts: \( "at" \) for air traffic noise, \( "rt" \) for railway noise, \( "ls" \) for measurements performed with a loudspeaker.

Measurements and global rating of sound insulation are described in international standards respectively (EN ISO 140-5) and (EN ISO 717-1).

The sound insulation spectra of a façade depends on many parameters. However, the insulation is usually lower at low frequencies than at high frequencies. The sound insulation often increases with frequency, but some dips may occur in the curve at rather high frequencies (1 to 2 kHz or higher), corresponding to a resonant frequency of the window.

For single casement windows the level difference between inside and outside noise levels (uncorrected for window area and room characteristics) has been shown to average approximately 30 dB at 1 kHz. Using double windows and ventilators, installed under the Noise Insulation Regulations, improves the level difference by over 10 dB at frequencies of 1 kHz and above (Utley et al., 1986). Hence façade insulation can be viewed as an effective mitigation measure.

2.4.1.1 Implementation in the LRTNM

Although improved building insulation can be shown to improve the acoustic environment inside homes and brings relief from traffic noise, there is no means of incorporating this into LRTNM as the levels predicted are outside (free-field) levels. It is possible to take account of the benefits through a simple adjustment to the dose-effect relationship. The predicted numbers of people seriously annoyed at given noise levels could be assumed to be less with improved façade insulation, by an amount equivalent to reducing the external noise level by the level of additional façade attenuation achieved. This may, of course, overstate the benefit, since people’s annoyance may still be influenced by ease of having windows open or use of gardens. Any such adjustment should be made at the action planning stage.

2.4.1.2 Costs for building insulation

The costs of providing double windows (i.e. secondary glazing) in a typical semi detached property is of the order of £3,000. This rises to £8,000 where a high performance package is installed. This package may include sealed double glazing, mechanical ventilation and Venetian blinds. To obtain relief from noise it may be more cost effective to lay a lower noise surface or install barriers especially where housing densities are high. Conversely where densities are low the option of providing improved façade attenuation may be financially attractive.
2.5 Combined measures

2.5.1 Barriers and low noise surfaces

Most of the knowledge on this subject is based on predictions from theoretical models. However these models often overestimate the benefits compared with real data (Watts et al., 1999).

On site data on combined effects are rare, probably because it is very difficult to evaluate the relative contribution of the road surface and the barrier. More experimental data should be obtained.

There is good evidence that noise barriers and low noise road surfaces used together can provide an optimised solution for noise abatement. The latter contributes to reduce noise emitted at the source and affects propagation, whereas the former affects only the sound propagation.

In general, due to the frequency dependence of sound wave propagation, diffraction and absorption, the global efficiency of the combination is lower than the addition of respective benefits. This is confirmed by theoretical predictions as well as on site measurements. In principle, when combining a low noise surface and a sound barrier, great attention should be paid to the spectral efficiency of each in order to optimise the combination.

Modelling work has shown that advantage of a low noise road surface (porous asphalt) over HRA is smaller in the presence of a noise barrier than in the case of unobstructed propagation (Watts, 1999). The decrease in advantage is greatest for a taller barrier, for example with a 4 m barrier the decrease in advantage was in the range 1.6 to 3.2 dB(A) whereas the reduction for a 2 m high barrier was predicted to be less than 1.4 dB(A).

Because they reduce noise emission at the source, low noise road surfaces bring sound reduction in the zones where noise barriers are ineffective (e.g. non-shaded zones, opposite side of the road).

Note that the combination of lower noise surfacings other than porous asphalt with noise barriers has not been examined. It is possible that the change in performance will differ and so it would be unsafe to generalise the results.

The use of low noise road surfaces can, in principle, reduce the barrier cost by allowing reduction in its height or length for equal performance.

2.5.1.1 Implementation in the LRTNM

Although it is difficult to generalise from one or two studies, it does appear that receivers screened by noise barriers will not experience the full benefit of lower noise porous asphalt road surfaces. The appropriate adjustment to the benefits of porous asphalt may therefore be made using the approach outlined in section 2.1.2.3.

2.5.1.2 Costs for combined barriers and low noise surfaces

Costs will be the total cost of the noise barrier and the low noise surface. There may be some savings in traffic management costs if both are installed at the same time.

2.5.2 Building insulation and low noise surfaces

The combination of a low noise road surface that reduces noise at the source, and a façade with enhanced sound insulation that reduces the sound transmitted inside the building, is certainly an effective solution for road traffic noise reduction. But for similar reasons to those
explained previously for combination with noise barriers, the resulting benefit may be less than the addition of respective benefits. The reason is the frequency dependence of sound transmission and of the traffic noise spectrum.

It is useful to know the likely added benefit inside a building that the use of a low noise pavement can achieve taking into account the façade insulation.

As no published results of the indoor effect of low noise road surfaces have been found in the literature search, a basic simulation was performed in order to give an idea of the combination of low noise road surface and façade insulation (SILVIA, 2005). The traffic spectra shown in Figure 2.17 were derived from measurements of passing vehicles at 7.5 m from the road, with both a standard asphalt concrete pavement (AC8) and a double layer porous asphalt DA8. Both pavements were one year old. The sound insulation spectrum taken in the simulation is based on averaged measured values (Vermeir et al., 2004). This had a sound insulation value of approximately 35 dB at 1 kHz which lies near the middle of the range of values that have been measured for all types of windows in dwellings. The basic simulation consists of subtracting the sound insulation spectrum from the road traffic noise spectra to obtain the indoor sound pressure spectrum for both dense asphalt and the porous asphalt. The resulting spectra are shown in Figure 2.17.

![Figure 2.17: Outdoor measured and predicted indoor noise spectra for dense asphalt concrete (AC8-dense) and double layer porous asphalt (DA8-70)](image)

The calculated A-weighted results outside are 72.0 dB(A) for the dense asphalt and 67.5 dB(A) for the double layer porous asphalt, which gives an outdoor advantage of the porous road surface compared with dense asphalt of 4.5 dB(A). However in indoors the calculated levels for dense asphalt are 42.0 dB(A) and 38.9 dB(A) for the double layer porous asphalt (DA), which gives an indoor advantage for the porous road surface of 3.1 dB(A). Thus the physical benefit of the porous pavement is lower indoors than outdoors by 1.4 dB(A). This is comparable with the loss of advantage found when combining noise barriers with porous asphalt of 0 to 3.2 dB(A).
2.5.2.1  Implementation within the LRTNM

As for improved façade insulation used alone it is not necessary to make adjustments in CRTN to take account of the loss of performance. However, when predicting the number of people seriously annoyed at a given level of noise an adjustment can be made.

2.5.2.2  Costs for façade insulation

The costs of improved façade insulation are given in section 2.4.1.2.
3 Conclusions and further research

A number of options for reducing noise have been examined. This ‘toolkit’ comprises a description of a range of measures with an indication of cost where known and likely effectiveness in terms of noise reduction. Suggestions for further research are given to aid the development of policy on noise mitigation and action planning.

3.1 Conclusions

To maintain a logical structure the main conclusions are arranged in the order of presentation in the report.

- **Quieter vehicles.** Vehicle noise and tyre noise is governed by type approval regulations and there appears to be no early prospect of any significant change in the status quo. New regulations for vehicle and tyre noise limit values noise are being considered internationally but it is likely that limit values will be set at broadly equivalent levels to those currently in force. The real pressure for reduced passenger car noise comes from the consumers, who are in general demanding quieter vehicles. It is probably safe to assume that there will be a slow reduction in vehicle noise.

  Lowering propulsion noise through the introduction of electric hybrid drive units is a long way off (10% penetration predicted by 2020) and even if all passenger cars were fitted with such engines this would only affect traffic noise at the lower speeds (< 30 km/h) by 3-4 dB(A). Motorcycle noise can be a problem especially along relatively quiet suburban streets and this can often be traced to the fitting of illegal silencers. Greater levels of enforcement can assist in reducing the problem, including the introduction of roadside tests.

  Tyre noise limits are unlikely to change substantially and even if they are introduced, the effect on most current UK roads may be insignificant. This is due to the fact that the current test for tyre noise takes place on a relatively smooth surface and low levels on this surface do not translate into lower noise levels on rougher roads such as HRA (Phillips et al., 2003). The implications are that it will only be at local levels that significant changes can be made by introducing, for example, controls or incentives for the use of lower noise vehicles entering noise sensitive areas in the evening and by encouraging the use of lower noise tyres. If all passenger cars were fitted with lower noise tyres yielding a reduction of 5 dB(A) in rolling noise the net effect on traffic noise would be of the order of 3 dB(A). Encouraging the fitting of lower noise tyres could be through a scheme such as the ‘Blue Angel’ labelling scheme operated in Germany. However, the type approval tests would have to be conducted on a rougher road surface than currently used if the results are to have any relevance to UK road conditions.

- **Road surfaces** This is potentially the easiest and most cost-effective means of reducing traffic noise. Since urban roads are frequently surfaced with HRA there are significant benefits in the order of 3-4 dB(A) to be gained by switching to lower noise alternatives. These benefits rise with vehicle speed and should be realised at speeds over 35 km/h depending on the percentage of heavy vehicles. Predictions for motorways where, the percentage of heavy vehicles is often far greater, indicate that benefits of over 3 dB(A) can be achieved. Where brushed concrete surfaces are currently in use even greater benefits can be expected depending on texture depth. In confined spaces such as city canyons a sound absorptive material such as porous
asphalt can be expected to perform even more effectively due to a reduction in number of multiple reflections between opposite facades.

- **Smother driving including road junctions.** Aggressive driving can result in a significant increase in vehicle noise during the acceleration phase and can be perceived as a form of anti-social behaviour. Driver training and encouragements to calmer driving can be realised but there is no evidence that such actions have a long term effect. It is also doubtful whether overall noise levels would be affected by changing the behaviour of the few per cent of drivers who act in this irresponsible manner. However, it is possible that peak levels of noise may be reduced and it is known that this may affect the levels of perceived nuisance.

The presence of road junctions which bring vehicles to a complete stop can increase noise levels in the vicinity. Roadside noise surveys and modelling work have indicated the benefits of switching to roundabouts which allow a smoother speed profile and a reduction in the frequency of high rates of acceleration which increase noise. It is estimated that a reduction of approximately 2 dB(A) within 40 m of a junction can be realised by this measure.

- **Street works and road maintenance.** It is difficult to generalise about the effects of poorly maintained roads and joints on average noise levels but it is known that peak levels can increase substantially due to the body rattle noise from heavy goods vehicles. The elimination of poor surface profiles and ensuring that patched surfaces do not cause oscillating noise levels will assist in improving the acoustic environment.

- **Noise barriers.** The advice on noise barriers is contained in the companion report entitled; Noise Barrier Review (Watts et al., 2005). Larger noise reductions than can be achieved with road surfaces can be realised although local conditions may make the measure difficult to implement effectively e.g. the presence of side roads and the presence of confined spaces behind the barrier. There is also the problem of vandalism, personal safety issues where light levels are reduced and there is loss of view. Many attractive designs are available and the use of transparent materials may be appropriate although costs are higher. Vegetative barriers may be considered a solution where an attractive alternative to hard, flat manufactured materials is considered appropriate.

- **Traffic calming.** Traffic calming is primarily introduced to reduce road casualties by reducing speed. The predicted effect based simply on the reduction in average speeds from 50 km/h to 30 km/h is estimated to range up to approximately 3 dB(A) depending on the road surface and percentage of heavier vehicles. Generally where vertical and horizontal deflections are used the character of the sound changes from a fairly constant level before the introduction of the traffic calming feature to a more fluctuating level as a result of vehicles accelerating and decelerating to negotiate the calming feature. Heavy goods vehicles negotiating the features can produce peak levels of body rattle noise which are 10 dB(A) above background. It has been found from predictions based on experimental work that wide cushions and flat topped humps can increase traffic noise significantly with the actual increase critically dependent on the number of heavy vehicles. In contrast round topped humps were predicted to reduce traffic noise levels by up to 7 dB(A). Despite the reduction in traffic levels recorded at some sites the general reaction of residents has not always been favourable.

- **Altering traffic flow and composition.** Reducing the numbers of heavier vehicles can produce significant benefits especially at lower speeds where propulsion noise dominates. Clearly the size of the effect is critically dependent on the numbers of these vehicles in the traffic before changes are introduced. Where heavier vehicles account for approximately one third of the traffic then re-routing these vehicles will produce benefits of approximately 4 dB(A) at 50 km/h and 6 dB(A) at 30 km/h. These
heavier vehicles will be displaced onto other roads so there may not be a net benefit unless the displaced vehicles travel on roads where there is little or no residential development.

The provision of bus priority routes including park and ride schemes is predicted to show benefits but only if bus patronage is at an adequate level. This has been estimated at various speeds by calculating the acoustic equivalence of a bus in terms of the number of cars that are expected to produce comparable sound energy during a pass-by.

- **Improving façade insulation.** Although improved sound insulation can reduce noise insulation noise levels inside buildings making interior environments more pleasant for occupants there is no means of accounting for this effect in traffic noise models which aim to predict exterior levels. Consequently it is at the action planning stage that the effect needs to be taken into account. This can be achieved by using an appropriate does-effect relationship which relates exterior noise exposure to the numbers of occupants seriously annoyed by noise. For example, different relationships could be derived for buildings with single glazing, thermal double glazing and double windows.

- **Combined measures.** By combining two or more mitigation measures it is possible to reach optimum solutions to noise control. Using mainly prediction models it has been estimated that the added effects of barriers and a lower noise surface, such as porous asphalt, measured separately may not be totally realised due to the different propagation paths involved and the frequency dependence of sound reflection and diffraction. A similar effect has been predicted for lower noise surfaces and improved façade insulation. Some results are given which can aid the overall assessment of the benefits of the combined measures.

### 3.2 Suggested further work

Further research has been identified as a result of the lack of information currently available and as an opportunity to trial promising innovative solutions. These include:

- **Lower noise surfaces** that have proven noise advantages on high speed roads could also be tested for effectiveness on residential streets or main urban roads. The use of thin surfacings such as SMA to replace HRA in urban areas is a potentially very cost effective noise reduction measure. It is suggested that trials are carried out in a range of road traffic situations to examine the noise reductions achieved, the pavement condition over time, residents’ perceptions of benefits and costs involved in comparison to HRA. Consideration should also be given to a study of the feasibility and potential benefits of double layer porous asphalt in residential streets. Such surfaces have been available abroad but not in the UK and may offer advantages over more conventional lower noise pavements. This may be due to increased sound absorption properties of the surface.

- **It would be desirable to trial, with industry and public authorities, a demonstration low noise medium heavy and heavy vehicle for delivery to noise sensitive areas.** It is envisaged that this would involve mainly low cost solutions which are brought together in one package, e.g. quieter reversing alarms, low engine idle noise / engine cut-outs, brake noise suppression, low noise tyres, reduced body rattle noise. The use of hybrid-electric propulsion units and the development of retrofit packages for the existing fleet would be other options to consider. The setting up and monitoring of control or incentive measures for such vehicles could be seen as a second phase of
this suggested project. Benefits to residents affected could be assessed by questionnaire surveys.

- It would be desirable to trial, with industry and public authorities, quieter passenger vehicles. The approach could be similar to that suggested for lower noise delivery vehicles, and would pay particular attention to brake squeal, air brake noise and engine idle noise. The trialling of such vehicles could involve measurements of noise emission under different operating conditions and a survey of residents’ satisfaction. The development of retrofit packages would be another option to consider.

- The benefits could be examined of using novel barriers with photovoltaic cells incorporated, and barrier returns to protect three sides of a building or relatively tranquil areas. The advantages of the treatment of confined spaces behind such barriers using porous asphalt and absorptive cladding on the barrier and building façade could also be evaluated.

- To date most of the experience with speed cameras has been on roads with speed limits of 48 km/h (30 mile/h) or greater. A demonstration of the viability of using speed cameras to enforce speeds in low speed areas, e.g. with a speed limit of 32 km/h (20 mile/h) would be worthwhile as there would be a smoother traffic flow and there would be no impulsive sounds caused by some heavy vehicles negotiating calming features. At a lower level of enforcement, active traffic signs which light up when speeds are exceeded could also be trialled in these areas.

- An assessment could be made of the dose-effect relationship between noise exposure at the façade and residents’ satisfaction with noise conditioned by the degree of façade insulation e.g. single glazing, thermal double glazing and double windows, taking account of such factors as having windows open and using gardens, etc. This would aid the development of appropriate action plans in which the number of people seriously annoyed by noise is estimated.
Acknowledgements

The work described in this report was carried out in the Infrastructure and Environment Division of TRL Limited. The authors are grateful to Dr P Morgan who carried out the quality review and auditing of this report.

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