The feasibility of using twin-layer porous asphalt surfaces on England’s strategic road network

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A.1 Current Highways Agency noise policy
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Executive summary

Low-noise surfaces have been in use for over 10 years on England’s strategic road network. Under the requirements of the EU Directive on the Assessment and Management of Environment Noise (END), there may be a need for the Highways Agency to look to implement noise mitigation measures in addition to those already used to address the demands raised by Noise Action Plans produced under the END.

Twin-layer porous asphalt (TLPA) is one such possible measure which has been successfully trialled and/or implemented in some European countries and which offers significant noise reduction benefits. The acoustic performance of TLPA has shown clear advantages over existing thin surfaces. Based on Dutch data, the indication is that an initial Road Surface Influence (RSI) of the order of -11 dB is achievable.

TRL has been commissioned by the Agency to investigate the feasibility of implementing this surface in England, taking into account all issues associated with the surface.

The material specifications for TLPA vary from country to country and there is no mix that stands out as being more prevalent. Discussions with UK surfacing contractors have suggested an equally wide range of potential aggregate specifications and that suitable binders are already available based on previous experiences with porous asphalt pavements. It is considered that TLPA might be achievable using existing thin layer products providing that they are sufficiently porous.

Construction of twin-layer surfaces varies from country to country. The conventional method of laying twin-layer pavements (paving first the lower layer, followed by a tack coat and paving of the upper layer) has problems in less favourable weather conditions with both the tack coats and compaction, as well as there being issues over the time needed to lay the surface.

A method known as “warm-in-warm paving” where the upper and lower layers are laid more-or-less simultaneously offers potentially improved structural durability and increased laying speeds than for conventional TLPA, and the opportunity to lay in colder temperatures, e.g. at night-time. The warm-in-warm technique, with either a single combined paver or two standard pavers in tandem, is considered to be the only viable option for use in England due to the need to keep lane closures to a minimum. This is necessary to reduce maintenance costs and to assist in meeting the delivery of the Public Service Agreement (PSA) for journey time reliability, one of the Highways Agency’s key performance indicators. However it is noted that the use of two pavers in tandem might lead to unevenness in the finished surface.

Measurements of the acoustic performance over the lifetime of TLPA surfaces have been undertaken in some European countries and these have shown a similar degradation in performance to existing thin surfaces. The durability of the acoustic performance is dependant upon keeping the pores within the surface free of detritus.

Structural durability is a significant issue with TLPA. Failure of the surface is generally as a result of ravelling of the upper layer. Based on European experiences, the structural lifetime of the upper porous layer is typically 7-8 years, which is significantly less than that of the thin layers already used on the strategic road network. Research is ongoing to increase this to at least 9 years, although the true durability of such optimised surfaces has yet to be demonstrated. The structural durability of Japanese TLPA has been observed to be 10 years or greater.

In the Netherlands where most sections of TLPA have been laid, a four-stage maintenance cycle is recommended. It is considered that a resurfacing policy such as this in England, based upon the current average structural lifetime, would be unacceptable in terms of cost and lane closures. If longer lifetimes can be achieved, i.e. if the durability of TLPA can be improved, such an approach may possibly be more acceptable.
TLPA is likely to require more intensive winter maintenance than the thin surfaces currently in use on the strategic road network. The surface is only suitable for treating with road salt as the application of grit would result in clogging of the pores of the pavement. This increased salting requirement may have potential implications with regard to the salt reserves available to highways authorities.

One of the main problems affecting the performance of TLPA is clogging of the pores with dirt and detritus. On high-speed roads, the vehicles themselves generate a cleaning effect in the wheeltracks by the action of the tyres passing over the surface. In situations where the emergency lane is also laid with TLPA, there is a need to keep this lane cleaned on a regular basis, e.g. twice a year, since if it becomes clogged then the flow of water away from the running lanes becomes impeded. If the emergency lane is not porous, adequate drainage should be provided. The Highways Agency takes the view that the cleaning of surfaces should be avoided wherever possible.

As with most asphalt pavements, there are issues over early life-skidding resistance until the binder film has been worn away. Any TLPA laid on England’s strategic roads would be required to satisfy the Agency’s skid resistance requirements, which are not based on the skid resistance when new.

Porous asphalt surfaces also offer improved splash/spray performance over traditional dense surfaces.

There are issues which must be considered over the availability of smaller aggregate sizes, e.g. 6 mm, for use in the upper layer of TLPA. This may become a bigger issue if the wider use of smaller aggregates in thin surfacings is accepted. Potentially, it should be possible to use lower quality aggregate in the lower layer of TLPA since it is not in contact with vehicle tyres. The use of recycled materials in TLPA is not widely discussed in the literature.

Porous asphalt pavements can be recycled for use in thin surfaces. A range of processes/methods are available for the recycling. The use of recycled materials in porous asphalt pavements is less well reported.

It is expected that the effects of climate change will lead to an increase in the maintenance issues that are currently experienced with asphalt pavements. However, experience with TLPA in countries with warmer climates is generally restricted to trial sections.

Examination of the basic costs of twin-layer surfaces suggests that a section would cost more to lay than existing thin surfaces. Estimations of the additional cost range from 20-25%, based on UK data. From discussions with surface contractors, these extra costs are likely to be incurred by additional materials, staff resources and machinery. Some of these costs may be greater during the first experiences with the surface type, e.g. investments in specialist pavement equipment, staff training, etc. but in general it is considered unlikely that decreases in the costs associated with materials and staff resources will be any different to those with other asphalt surface types. The whole-life costs of twin-layer porous asphalt, based on European data are significantly higher than dense asphalt pavements, although no comparisons with thin layers have been made.

However, when the costs are expressed in terms of noise reduction achieved per unit spent, a twin-layer surface may be more cost effective than single mitigation measures such as noise barriers, or combined measures such as low-noise pavements and noise barriers. However this will be dependant upon the individual costs considered within the analysis and evaluation on a case-by-case basis is recommended.

It is considered therefore that as long as the Highways Agency’s emphasis is on minimising disruption to journey time rather than on noise reduction potential, the scope for using twin-layer porous asphalt on a widespread basis is low when considered in terms of cost-effectiveness. This emphasis may change with the implementation of Action Plans resulting from the END, but this is not likely to be for some years.
Based on these findings, it is considered that the wide application of TLPA on England’s strategic road network is unlikely, particularly on cost grounds and the need to minimise traffic disruption. However, the following potential applications are proposed:

- Where it is more cost effective to have one very good low-noise surface as opposed to a normal thin surface and noise barriers;
- In locations where high levels of noise mitigation are required but traditional measures such as noise barriers cannot be practically implemented due to, for example, space restrictions.
Abstract
Low-noise surfaces have been in use in the UK for over 10 years and are used on England’s strategic road network. Under the requirements of the EU Directive on the Assessment and Management of Environment Noise (END), there may be a need for the Highways Agency to look to implement noise mitigation measures in addition to those already used to address the demands raised by Noise Action Plans produced under the END. Twin-layer porous asphalt is one such possible measure which has been successfully trialled and/or implemented in Europe and which offers significant noise reduction benefits. TRL has been commissioned by the Agency to investigate the feasibility of implementing this surface in England, taking into account all associated aspects, e.g. construction, maintenance, performance, resource use, costs, and sustainability issues, based on existing knowledge/experiences outside of the UK and the perspective/views of the UK road surfacing industry. This report details the findings from this study, presenting both the benefits and disadvantages, and sets out the resultant recommendations.

1 Introduction
Low-noise surfaces have been in use for over 10 years on England’s strategic road network. The initial reductions in noise level compared with existing surfaces were significant, but recent improvements in design have not led to any further significant reductions.

The implementation of the EU Directive on the Assessment and Management of Environmental Noise (END; 2002/49/EC; Commission of the European Communities, 2002) is likely to highlight areas adjacent to the strategic road network where noise levels are considered to be excessive, even with the policies introduced since 1999 in order to address such areas. Thus, both to meet the expected demand for significantly lower noise levels and to assist in the greater management of existing levels as a result of the Directive, there may be a need for the Highways Agency to look to noise mitigation measures in addition to those already used as a means of meeting this demand.

Twin-layer low-noise (porous) surfaces have been developed in Europe and trialled extensively in the Netherlands. Early results are very encouraging, particularly in terms of noise reduction potential, and the structural durability of the surface is improving.

This type of surfacing has not yet been trialled in the UK, although some sections of single-layer porous asphalt have previously been laid (Nicholls, 1997b). One of these sections was the A31 Bentley Bypass, near Alton, Hants which was opened in 1995. The three kilometre long bypass cost £10 million to build and used a porous asphalt surface to reduce noise for nearby residents. However, winter maintenance proved difficult and Hampshire County Council was forced to resurface the porous asphalt with SMA. This has created an approximation to a twin-layer porous surface, although the upper layer is not porous. Similarly, a further section of porous asphalt on the M4 near Cardiff (Junctions 33-34) was overlaid with a thin surfacing in 2005.

The Highways Agency wishes to consider porous twin-layer surfaces as an addition to its noise mitigation portfolio, whilst taking into account the impact of their use on achieving the Agency’s wider business objectives.

TRL has been commissioned to investigate the feasibility of using twin-layer surfaces on England’s strategic road network. This includes a review of the history of twin-layer low-noise surfaces, a review of the experiences with these surfaces in Europe and consideration of the implications for their use on strategic roads.

This report is a summary of this investigation.
2 The development of twin-layer porous asphalt

This Chapter provides a simple overview of twin-layer porous asphalt, in terms of its physical composition and the advantages/disadvantages associated with the application of the surface, and a brief history of the key stages in its development.

There is no standard way of referring to this surface type, so the terminology varies from country to country. Based on the literature review of international experiences, the most common names appear to be 'twinlay' (in some instances this is used as a proprietary name for a Dutch product), 'two-layer porous asphalt', 'double-layer porous asphalt', 'double porous asphalt concrete' (DPAC), and 'double drainage layer' (DDL). For consistency, the term 'twin-layer porous asphalt' (TLPA) will be used throughout this report.

2.1 Overview of twin-layer porous asphalt

Porous surfaces are defined as those where the aggregate specification results in a high air void content (typically greater than 20%) within the layer (Morgan, 2006). Twin-layer porous asphalt, which is an advance on single-layer porous asphalt (SLPA), comprises two different layers of porous asphalt, namely:

- A coarse, open-graded bottom layer: This typically uses 11-20 mm aggregate and a layer thickness of 35-65 mm;
- A fine-textured upper layer: This typically uses 4-8 mm aggregate and a layer thickness of 20-30 mm.

Figure 2.1 shows this basic structure. Typically the porosity of the surface is 20-25% with a binder content of 5.7-6.0% based on aggregate size and weight. The binder (i.e. the bitumen which binds the aggregate and other components together) is generally polymer modified\(^1\). The benefits of using polymer modified binders include improved structural durability and ageing characteristics.

Figure 2.1: The basic structure of twin-layer porous asphalt

The upper layer acts as a sieve to stop larger particles of detritus from reaching the larger voids in the lower layer and in addition, the lower layer helps to prevent the upper layer from becoming clogged by dirt and detritus from passing traffic (the detritus washes through the upper layer and into the lower layer where the larger air voids allow the detritus to disperse more easily towards the edge of the road). In addition, as a result of the smaller stones used in the upper layer, tyre vibration and hence tyre/road

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\(^1\) The addition of polymer modifiers, e.g. synthetic polymers or natural rubber, to the binder does not chemically change the nature of the binder but rather changes its physical properties, e.g. its softening point and brittleness.
noise is reduced in comparison to surfaces constructed using coarser aggregates. The surface offers increased noise reduction benefits relative to standard SLPA (which will, in general, be comprised of the same size aggregate as the lower layer of TLPA) because of the porosity and fine surface texture of the upper layer.

The inclusion of the upper layer to form the twin-layer surface provides a low-noise surface that is also resistant to some of the clogging (i.e. the blockage of the air voids in the surface by dirt and detritus) that is traditionally observed with single-layer porous asphalt surfaces. As a result, it is feasible to use TLPA in urban areas as well as on high-speed roads as a noise mitigation measure and to improve surface runoff, although a higher level of maintenance will be required compared to the high-speed road situation (as discussed later in the report).

TLPA is known to have a typical structural lifetime of approximately 7 years (based on the structural durability of the upper layer), although sections are known of that have been in place for longer periods. Structural lifetime will be affected by traffic conditions and loads, and local climatic conditions.

Drainage measures must be incorporated at the roadside next to the kerbstones to enable rainwater to flow through the bottom of the porous pavement structure into the sewer.

2.1.1 The potential advantages of twin-layer porous asphalt

The advantages of TLPA are that the high noise reduction performance can reduce the need for other mitigation measures, such as noise barriers or insulation at roadside properties, and it is feasible to use TLPA surfaces in urban areas as well as on high speed roads. Furthermore, because of its open structure, TLPA minimises splash and spray, increasing the level of comfort and safety for road users. The run-off from TLPA also has the advantage of being cleaner than that from dense asphalt concrete due to the filtering nature of the surface.

These issues are addressed in greater detail elsewhere in this report.

2.1.2 The potential disadvantages of using twin-layer porous asphalt

Based on experiences with the surface in Europe, problems have been experienced with the durability of TLPA. For a high life expectancy, care must be taken in selecting where the surface is used, e.g. it should not be used on sharp bends or at junctions (where the increased frequency of vehicle acceleration/deceleration and increased steering leads to an increase in stresses, thereby increasing the likelihood of ravelling3). The costs of TLPA pavements can also be quite high as a result of increased construction and maintenance costs compared to more traditional pavement types. These issues are addressed in greater detail elsewhere in this report.

2.2 The history of twin-layer porous asphalt

Experiences with the use of single-layer porous asphalt in the Netherlands in the 1980’s established that improvements in noise reduction could be achieved by using fine 4/8 porous asphalt mixtures instead of the 6/16 aggregate normally used; this was observed to be particularly the case at low vehicle speeds. However, the problem with these finer aggregates was that they quickly became clogged with dirt and detritus so that the benefits offered decreased more rapidly. A further disadvantage of existing porous asphalt (PA) surfaces was their relatively short surface life in comparison to traditional surfaces.

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2 The noise reduction performance is likely to be reduced on low-speed roads as tyre/road noise is less dominant at lower speeds.

3 Ravelling can be defined as the loosening of stones from the surface of the pavement.
dense asphalt concrete surfaces. The need to find a solution to these problems was the driver in the development of a new concept: twin-layer surfaces.

The two-layered construction surface, known as “Twinlay” was developed by Heijmans Civil Engineering. The first test sections of Twinlay were laid in 1990. Test sections were then laid in 1995 to investigate the reduction of noise from heavy goods vehicles.

Trials of the concept have subsequently been carried out in a number of countries; details of these are presented in the following chapter, although Figure 2.2 summarises some of the key events in the timeline.

Figure 2.2: Some important dates in the development of twin-layer porous asphalt (this time history is not comprehensive and does not include all of the countries addressed in the literature review)
3 Application of twin-layer porous asphalt in different countries

This Chapter of the report provides an overview of how TLPA has been used in other countries. Generally, the surface is not in widespread use on the public road network, so much of the experience relates solely to short demonstration/trial sections.

The review focuses solely on the scale of application in each country rather than a review of performance. Detailed information on the specifications and acoustic/structural/safety performance of individual surfaces or test sections is provided in Chapters 4 and 6 of this report.

3.1 Experiences within Europe

The Netherlands is presently the only country in Europe where the use of TLPA extends beyond the construction of a very limited number of test sections and therefore precedence in the review is given to their experiences. Other countries are then addressed in alphabetical order.

3.1.1 The Netherlands

From 2001, TLPA was introduced onto some provincial roads (local authority roads, generally with a maximum speed limit of 80 km/h) and motorways. However it was not widely applied due to relatively poor structural and acoustic lifetimes. Furthermore, a substantial variation in both the structural and acoustic lifetime had been observed over the test sections. Currently 3% of the Dutch highway network is surfaced with TLPA (VROM, 2006), with most motorways remaining surfaced with SLPA.

The Dutch national noise innovation programme IPG (Innovatieprogramma Geluid, www.innovatieprogrammageluid.nl, e.g. Vos et al., 2004) was initiated in 2002 to help meet national strategic goals up to the year 2030 set by the Ministry of Housing, Spatial Planning and the Environment and the Ministry of Transport, Public Works and Water Management (in the National Environmental Policy Plan, NMP4; VROM, 2001 and the National Traffic and Transport Plan, NVVP 2001-2020; MVW, 2000). The objective of the programme was to deliver ready-to-implement, affordable noise reduction measures and included, as a key element, the testing and further development of TLPA.

As part of the IPG, TLPA trial sections were laid on four roads (one in 2002, one in 2003 and two in 2004) to determine if the best-performing (in terms of structural lifetime), existing TLPA constructions and mixes provided a minimum level of acoustic performance and a minimum structural lifetime (Hofman et al., 2005c). Eight surfacing contractors laid 400 m trial sections at each of the sites (this pattern of surfaces has led the trail sites to be referred to as ‘zebra-sections’). Based on the results from these test sections, a formal decision was taken in 2005 by the Ministry of Transport, Public Works and Water Management to allow the routine application of TLPA on the Dutch highway network. It was also proposed that from 2006 TLPA should be used on the Dutch state road network as a cost-effective alternative for (higher) noise barriers. Guidelines have been prepared within the IPG to advise on its application (Hofman et al., 2005a; Hofman et al., 2005b).

Further work to improve the performance of TLPA, in terms of noise reduction, structural lifetime and early-life skidding resistance has been undertaken within the IPG. Construction issues (a reduction in the restrictions on climatic conditions under which the surface can be laid through using alternative paving technologies) and maintenance issues (cleaning methods) have also been investigated. This has resulted in the construction of additional trial sections of varying length (300 -2000 m) for demonstration purposes.
3.1.2 Austria

Porous asphalt was introduced in Austria in 1984, and by 1992 18% of the main road network was paved with porous asphalt. However, since then the use of porous asphalt has declined substantially mainly due to the surface types susceptibility to ravelling.

Two sections of TLPA (one 500 m section using modified binder, the other 400 m section modified by the inclusion of rubber in the aggregate) were laid on the A12 motorway in the Tyrol, Austria in October 2005 as part of a series of different low-noise surfaces. It is planned to monitor the performance of the surface in terms of acoustic performance, material loss, clogging and traffic safety behaviour over a five year period (Haberl and Litzka, 2006).

3.1.3 Belgium

Belgium ceased using SLPA due to problems with clogging, the expense of cleaning, winter service issues, durability (ravelling in wheel path) and reduced skid resistance. Generally, emulsified asphalt concrete (EAC) pavements and SMA (Stone Mastic Asphalt) pavements are now used. Most newly constructed highly trafficked roads in Belgium are concrete pavements. To date, only a single test section of TLPA has been laid in Belgium to examine its performance over time, including its behaviour in winter. This section is approximately 500 m long and was laid on Road No.988 in June 2002 (Descornet, 2003).

3.1.4 Denmark

Although single-layer porous surfaces were first trialled in Denmark in 1990, twin-layer surfaces were not trialled until 1999 when three different TLPA surfaces were laid on an urban road in Copenhagen with a speed limit of 50 km/h. Each test section was approximately 200 m long. The surfaces were developed based on Dutch concepts but taking into account Danish experiences with materials and durability (Bendtsen et al., 2001). The objective was to optimise noise reduction potential using a high degree of built-in air voids, fine graded materials and thick pavement, and to study the performance of the surfaces over their lifetime. The study included the cleaning of the surfaces biannually to maintain their acoustic durability. Measurements on the surfaces have been continued as part of the DRI/DWW noise abatement programme4 (Bendtsen et al., 2005) which forms an integral part of the Dutch IPG programme (see Section 3.1.1) and the results have been used in the development of concepts and methods to reduce the clogging of porous pavements.

3.1.5 France

SLPA is relatively common in France, with over 60 million m² laid, 90% of which is on motorways and other high speed roads. It is not normally used on low speed roads, due to the risk of clogging. However TLPA is not widely used in France. It has been laid under the framework of a National Program for demonstrating innovative products at three locations between 1997 and 2000 on the A2 toll motorway near Valenciennes in the North of France (the total length of the 3 sections is 5 km) and at two further locations on an Express National Road in 1997 (the RN86 (now RD 386) in the South of Lyon, between Loire sur Rhone and St Romain en Gal; the sections being 280 m and 200 m in length). In each case, different aggregate sizes were used and the performance of the surface has been monitored over an extended period (Brosseaud and Anfosso-Ledee, 2005). A commercially-available twin-layer porous asphalt, EPSIBEL (sold by the

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4 The DRI/DWW Noise Abatement Programme is a collaboration between the Danish Road Institute/Road Directorate (DRI) and the Road and Hydraulic Engineering Institute (DWW) in the Netherlands (Larsen, 2004). The objective of the collaboration is to facilitate and support research activities of mutual interest to both parties within the framework of noise abatement. The main work in the collaboration provides key input into the Dutch IPG programme.
"Eiffage-tp" group, [www.eiffagetp.com](http://www.eiffagetp.com), has been identified (Wilson, 2000); however in practice, there is no market for this product in France due to its poor cost/benefit ratio.

### 3.1.6 Germany

The systematic testing of SLPA on non-urban roads started in the Federal Republic of Germany in 1986 with thirteen test sections. However, SMA is currently the major road surface type used on the German primary road network. Porous asphalt is only used in “noise hot spots” on the network. Only 2% of the Autobahn network is currently surfaced with porous asphalt (Glaeser, 2007). The widespread use of porous asphalt was prevented by the susceptibility of the surface type to raveling, resulting in unacceptably short lifetimes. However, public demand for low-noise surfaces has lead to further research being carried out.

The first trial section of TLPA was constructed in 1998. A thicker layer of TLPA, referred to as ‘fifth generation’ porous asphalt, was constructed in 2003. In spring 2004 a 4 km section of TLPA was laid on one carriageway of the A30 motorway near Osnabrück using the warm-in-warm paving technique (whereby both the upper and lower layer are laid simultaneously – see Section 5.2.3) rather than traditional two-layer paving methods (Ripke, 2006). A section was also laid using conventional methods. In September 2007, the opposite carriageway at the same site was also paved with TLPA using the warm-in-warm technique (see Section 9.4 for further details).

### 3.1.7 Italy

Porous asphalt was first used in Italy in the late 1980s, and now over 30% of the motorways in Italy are paved with SLPA. In September 1995, the first trial section of TLPA (1 km in length) was laid on the A4 Venice-Trieste motorway (Battiato, 1997). The surface, DDL pavement (Double Drainage Layer) was developed by Autovie Road Research Centre (Battiato et al. 1996) with the objective of reducing the production costs of porous pavements, increasing skid resistance and sound absorption, facilitating cleaning and improving durability and drainage performance. Lancieri et al. (2000) also report field trials of a 2 km length of DDL pavement on the A12 motorway.

Other trials have also been undertaken to investigate the use of TLPA for reducing traffic noise in urban environments, based on test sections laid in Florence (Poggi et al., 2000). However no indication is given as to the scale of this trial.

### 3.1.8 Sweden

As part of the EU-funded SILVIA project, single-layer and twin-layer porous asphalt surfaces were evaluated to investigate their performance under severe Nordic winter conditions. In addition to withstanding the climatic conditions, it was necessary for the surfaces to withstand the effects of studded tyres. Consequently, the mix designs were based on local experience and best practice as well as the most recent knowledge/technology available in Europe. The sections were laid on a motorway E18 outside of Stockholm (Morgan, 2006).

### 3.1.9 Switzerland

Porous asphalt has been used on Swiss motorways since 1979 and as of January 2004, 131 km of Swiss motorways were paved with porous asphalt. Trial sections of TLPA are known to have been laid (Poulikakos et al., 2006), although the number and length of the sections is not reported in the literature. TLPA has also been trialled in a project investigating the use of quiet pavements in urban areas (Angst et al., 2006).
3.2 Experiences outside Europe

3.2.1 Japan

Porous asphalt has been used widely in Japan since 1995. Approximately 20% of Japanese national roads are surfaced with porous pavements and more than 50% of toll roads (Nielsen et al., 2005). It is used mainly in urban and densely populated areas, but also in some flat rural locations. Trials of TLPA on urban roads started in 1998. There are now over a 100 test sections in Japan, including some on main trunk roads in Tokyo (Taksumoto et al., 2003). The TLPA is normally laid in a single application using the warm-in-warm process, e.g. Tsukamoto et al. (2003) (see Section 5.2.3). Climatic conditions in Japan have required research and development to develop porous pavements suitable for withstanding the problems associated with cold weather conditions, e.g. structural damage from snow-ploughs.

3.2.2 New Zealand

The standard surfacing for New Zealand highways is chip seal (similar to a surface dressing), with hot rolled asphalt on urban centres (Jackson et al., 2003). However, SLPA is currently used in on the motorway network passing through the densely populated centre of Auckland. A TLPA surfacing called WhispA was developed following a scanning tour to Europe in 2000 and was trialled at three sites on State Highway 1 around Auckland, including a low-speed section with speeds generally < 50 km/h, in 2002/2003. These sites were between 100-500 m in length.
4 Material characteristics of twin-layer porous asphalt

This Chapter describes the physical characteristics of twin-layer porous asphalt and its constituent components. For the surface to be used in England, it must be feasible to manufacture it using materials that are readily available in the UK and which do not require importing. Ideally, these materials should be those with which UK manufacturers are already familiar.


4.1 Mix design

The mixture design for either a single-layer pavement or each layer of a twin-layer pavement is based on striking a balance between the minimum and maximum binder content for a specific (open) aggregate grading. Large maximum aggregate sizes and low fine aggregate content increases the risk of aggregate losses (ravelling) in the pavement (Note: This aggregate loss occurs in the upper layer of TLPA).

If consideration is only given to the surface’s resistance to ravelling, then it is considered that the binder content should be as high as possible as long as binder drainage in the mixing, handling and laying can be avoided. This will give a thick binder film which will help to avoid ageing and provide an adequate resistance against the action of water. It is also important to ensure adequate adhesion between the binder and the aggregate; this can be improved by the use of adhesion agents, e.g. amines, limes and others. The use of modified bitumen and fibres stabilize the mastic and make it possible to increase the binder content. Good quality filler improves the adhesion and the resistance to ageing.

There is no standard mix design procedure in Europe, so a variety of different procedures are used, including specifying the properties of the mix in terms of the properties determined by the Marshall test (British Standards Institution, 2004b). However, in principle, the maximum binder content is selected which will allow the required void content. This may be supplemented with additional tests including binder drainage tests, water sensitivity tests and particle loss tests.

In a review of international experiences related to the ravelling of porous asphalt surfaces in general (i.e. not specifically TLPA), Nielsen (2006) highlighted the following conclusions:

- Large stone mixes (0/16 to 0/20 mm) should be avoided in countries with wet weather conditions such as the UK and the Netherlands;
- The overall development trend for porous surfaces is towards finer mixes (0/8 or 0/6) with a higher binder content and void contents of 22-30%;
- The use of modified binders is recommended. Although there is a lack of data proving improved durability for porous asphalt with modified binders, it is recognised that the higher initial strength might reduce the potential for damage in the first months.

However, it is noted that data for the UK has shown that polymer modified binders (PMBs) can be more durable, as demonstrated by the performance of surfaces on the M4 near Cardiff (Nicholls, 1997b).

5 Binder drainage is defined as when the binder separates from the mixture after the mixing process or during transfer of the mixture to the construction site (BSI, 2004).
The design of single-layer porous asphalt mixtures for use in the UK has been discussed by Nicholls and Carswell (2001) and mix design specifications for porous asphalt surface courses are set out in the Manual of Contract Documents for Highway Works as described above. It is anticipated that these specifications would need to be applied to the top layers of any twin-layer porous asphalt laid in England, or revised for future application based on experiences with trial sections.

Willway et al. (2007) have highlighted some of the potential problems with asphalt pavements in general resulting from changes in rainfall patterns and increasing temperatures, e.g. increased risk of ‘binder stripping’ due to increased exposure to water, increased risk of cracking and fretting due to binder hardening caused by higher temperatures. It should be noted that these climatic changes will take effect over a long period of time. Careful mix design can help to reduce the likelihood of occurrence of such problems in the shorter term. It is suggested by Willway et al. (2007) that one approach for reducing risk from climate change factors would be to use less porous pavements. However, these factors must be considered in tandem with other requirements, e.g. any need for high levels of noise reduction, so that a well designed porous pavement with appropriate modified binders and additives on an impervious base course may be an appropriate solution. Studies are in progress, e.g. the Dutch IPG programme, to address durability issues associated with the use of TLPA and these are referred to in Section 6.2.

4.2 Aggregate specifications

Different sizes and sources of aggregates are used for the lower and upper layers of TLPA. The bottom layer contains a coarse single-grained aggregate (typically 11 to 20 mm) and the upper layer contains smaller (typically 4 to 8 mm) aggregates. In porous asphalt there are normally less fines (and there is minimal mastic content to bind the mix together), compared with SMA-type mixtures in order to create the required percentage of voids (generally 20-28%).

Table 4.1 provides an overview of some of the different aggregate sizes that have been used in TLPA in either trials or routine application, based on the information reviewed in Chapter 3. It can clearly be seen that there is not a common standard. Rather, the selection appears to be based on the requirements of individual countries, e.g. larger aggregate sizes are preferred in Scandinavian countries to withstand wear from studded tyres.

The following information presents other examples of aggregate specifications found elsewhere in the literature.

In addition to the typical Dutch mix designs tested in the IPG (as shown in Table 4.1), trial sections were also laid in the Netherlands in the mid-1990s using TLPA with a 2/4 upper layer and a 11/16 lower layer. This TLPA, known as Twinlay M (where the M stands for ‘micro’) was developed to provide a better resistance to turning heavy traffic (van Bochove et al., 1998). This optimised TLPA met with limited success, since although the initial acoustic performance was excellent, after a few months the noise reduction reduced due to clogging of the upper layer due to the small size of the pores. As a result of these experiences, TLPA with an upper layer of 3/6 was developed; this is still used in some instances in the Netherlands, although a 4/8 upper layer is more common.

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6 Binder stripping is defined as the separation of the binder from the aggregate in the pavement.
7 The following terms are used to classify the sizes of material used in the construction of road surfaces: ‘Aggregate’ is material > 2 mm, ‘Sand’ is material between 0.063 – 2 mm and ‘Fines’ or ‘Filler’ is material < 0.063 mm. The combination of sand and fines is often referred to as ‘Mortar’.
### Table 4.1: Examples of material compositions and technical specifications for TLPA pavements laid in different countries
(Based on the experiences reported in Chapter 3)

<table>
<thead>
<tr>
<th>Country</th>
<th>Upper layer</th>
<th>Lower layer</th>
<th>Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aggregate size</strong></td>
<td><strong>Sand content</strong></td>
<td><strong>Filler content</strong></td>
<td><strong>Modified bitumen</strong></td>
</tr>
<tr>
<td><strong>Netherlands</strong> (Hofman et al., 2005c)</td>
<td>2/6 mm</td>
<td>11/16 mm</td>
<td>4.9%</td>
</tr>
<tr>
<td><strong>Austria</strong> (Haberl and Litzka, 2006)</td>
<td>4/8 mm</td>
<td>6%</td>
<td>25 mm</td>
</tr>
<tr>
<td><strong>Belgium</strong> (Descornet, 2003)</td>
<td>0/7 mm</td>
<td>11/16 mm</td>
<td>4.5%</td>
</tr>
<tr>
<td><strong>Denmark</strong> (Bendtsen et al., 2001)</td>
<td>5/8 mm</td>
<td>25 mm</td>
<td>11/16 mm</td>
</tr>
<tr>
<td><strong>France</strong> (Brosseaud and Anfoss-Lédée, 2005)</td>
<td>4/6 mm</td>
<td>0%</td>
<td>3-4%</td>
</tr>
<tr>
<td><strong>Germany</strong> (Ripke, 2006)</td>
<td>5/8 mm</td>
<td>6.5%</td>
<td>25 mm</td>
</tr>
<tr>
<td><strong>Italy</strong> (Battiato et al., 1996)</td>
<td>0/6 mm</td>
<td>5%</td>
<td>15 mm</td>
</tr>
<tr>
<td><strong>Italy</strong> (Lanceri et al., 2000)</td>
<td>0/10 mm</td>
<td>25 mm</td>
<td>0/18 mm</td>
</tr>
<tr>
<td><strong>Sweden</strong> (Morgan, 2006)</td>
<td>0/11 mm</td>
<td>30 mm</td>
<td>25%</td>
</tr>
</tbody>
</table>
Table 4.1: Examples of material compositions and technical specifications for TLPA pavements laid in different countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Upper layer</th>
<th>Lower layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aggregate size</td>
<td>Sand content</td>
</tr>
<tr>
<td>Switzerland</td>
<td>8 mm</td>
<td>5%</td>
</tr>
<tr>
<td>Japan (Poulikakos et al., 2006)</td>
<td>8 mm</td>
<td>5%</td>
</tr>
<tr>
<td>Japan (Nielsen et al., 2005)</td>
<td>8 mm</td>
<td>5%</td>
</tr>
<tr>
<td>Japan (Tsukamoto et al., 2003)</td>
<td>8 mm</td>
<td>5%</td>
</tr>
<tr>
<td>Japan (Nielsen et al., 2005)</td>
<td>8 mm</td>
<td>5%</td>
</tr>
</tbody>
</table>

*(Based on the experiences reported in Chapter 3)*

(continued...)*
Initial discussions with UK surfacing contractors (see Chapter 9) suggest that a UK-specification TLPA might comprise 20 mm aggregate in the lower layer and either 10 mm or 6 mm aggregate in the upper layer. However, the availability of appropriate size aggregate may affect the selection. It is not clear as to the potential for using recycled material from dense asphalt pavements, e.g. thin layers, as Recycled Asphalt (RA) in new porous pavements.

The TLPA pavements laid in the New Zealand trials reported by Jackson et al. (2003) had a total thickness of 70 mm, with a lower layer comprising 16 mm aggregate and an upper layer comprising 8 mm aggregate; no information is given on the thickness of the individual layers.

Nielsen et al. (2005) reported on a study tour to Japan as part of the DRI/DWW noise abatement programme, a Danish/Dutch collaboration. Japanese TLPA pavements are reported to generally comprise 50 mm thick lower layer with 13 mm aggregate and a 20 mm thick upper layer with 5/8 aggregate; the example pavement shown in Table 4.1 uses a much smaller aggregate size because this was a specification considered to be particularly effective for noise reduction. It is noted that for Japanese single-layer porous pavements, aggregate sizes range from 5-13 mm.

Taksumoto et al. (2003) report the specifications of several different Japanese TLPA pavements designed for different conditions and these are summarised in Table 4.2. For the different conditions the aggregate sizes are constant, and the layer thicknesses are consistent for all but the pavement in the heavily trafficked area (where the lower layer has a greater depth). It is the binder type that varies, each being designed for use in a specific area. No specific details are given in the paper, however it is assumed that each binder uses a different polymer modifier. It is assumed that “usual conditions” implies no extremes in either weather or traffic load; this surface will also use some form of polymer modified binder. It can be seen that the choice of binder has an impact on the acoustic performance.

### Table 4.2: Japanese TLPA mixtures using binders designed for appropriate weather conditions (from Taksumoto et al., 2003)

<table>
<thead>
<tr>
<th>Binder designed for use in specified area type</th>
<th>Usual conditions</th>
<th>Cold area (type 1)</th>
<th>Warm area</th>
<th>Cold area (type 2)</th>
<th>Heavily trafficked area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper</td>
<td>Lower</td>
<td>Upper</td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>Max Aggregate size (mm)</td>
<td>5</td>
<td>13</td>
<td>5</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>20</td>
<td>30</td>
<td>20</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Noise level*</td>
<td>86.8</td>
<td>88.3</td>
<td>88.0</td>
<td>87.0</td>
<td>87.2</td>
</tr>
</tbody>
</table>

*Measured using the Road Acoustic Checker, a CPX-type vehicle (see Section 5.1 for further details)

In addition to the size of the aggregate, other properties must also be taken into account. The aggregate should have a good resistance to crushing and the Polished

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6 It is unclear what the difference is between the two ‘cold area’ binder types.
Stone Value (PSV) of aggregate in the upper layer should be at least 53 (Eijbersen, 2005). Nicholls and Carswell (2001) state that lower quality aggregate can be used in the lower layer because there is no direct contact with vehicle tyres.

DMRB Volume 7, Section 5, Part 1 (HD 36/06 Surfacing materials for new and maintenance construction; Highways Agency, 2006a) sets out the UK requirements for PSV, which are based on a combination of:

- Expected heavy traffic levels (as in CVD (Commercial vehicles per lane per day), where historically a commercial vehicle is anything from a 3.5 tonne van upwards) at the design life of the surfacing;
- The investigatory level (IL) of skid resistance for the site.

The minimum PSV for the lightest traffic and lowest investigatory level is 50, but for heavier traffic and more difficult sites, a PSV of 65 or more is likely to be required. In the context of TLPA, this will most likely be applied to the top layer only, to avoid unnecessary use of premium aggregate in the lower layer.

Volume 1, Series 0900, Clause 938 (Porous asphalt surface courses) of the Manual of Contract Documents for Highway Works (Highways Agency, 2006b) states that the minimum PSV for aggregate in UK specification porous asphalt shall be as declared in Clause 4.2.3 of BS EN 13043 (British Standards Institution, 2002), i.e. a PSV of 44.

Studies are currently in hand through the Highways Agency/Quarry Products Association/Refined Bitumen Association Collaborative Research Programme that are assessing the influence of particle size on skid resistance performance and, possibly, future PSV and texture requirements.

4.3 Binder specifications

Polymer modified binders (PMBs) are normally used in TLPA as they are thought to reduce vulnerability to ravelling by enabling a thicker binder film coating and producing higher viscosity at higher temperatures and higher flexibility at lower temperatures. This is thought to provide a more durable pavement. Binders typically contain 5-8% polymer.

In Japan, special high-viscosity SBS (Styrene Butadiene Styrene) modified binders (with an SBS content as high as 9-12%) have been developed for use in cold regions to provide improved structural durability and reduced ravelling. At these high polymer contents, it is important that the polymer is well homogenised. The use of high viscosity modified binders is widespread in Japan and considered to be a standard, cost-effective method for obtaining more durable pavements (Nielsen et al., 2005).

The Japanese pavements identified by Taksumoto et al. (2003) in Table 4.2 included the use of modified binders; a binder designed for heavy traffic was used in warm areas to ensure resistance against stripping, scattering and flowability, whereas a binder designed for cold snowy weather was used in cold areas to improve resistance to flowability and scattering. The results presented in the Table suggest that the binder type has an impact on the acoustic performance.

The use of modified binders in the lower layer is recommended because of the fact that water can remain in this layer for long periods of time (Eijbersen, 2005).

A higher polymer content allows the binder content of the mix to be increased. It is thought that increasing the binder content from 4.5 to 5.5% increases the durability of the pavement by 2 to 3 years. The examples shown in Table 4.1 generally show the use of 4-6% PMB in each layer. The Austrian and German binder contents are higher than those generally used although the precise nature of the polymer modifiers is not known. In addition, these mixtures generally contain additives (e.g. lime, cellulose fibres, etc.).

Any binder used in twin-layer porous asphalt surfaces in England will be required to have a British Board of Agrément HAPAS Roads and Bridges Certificate. Initial discussions with
UK surfacing contractors (see Chapter 9) suggest that suitable binders are already available based on previous experiences with porous asphalt pavements.

### 4.4 Additives

The durability of an asphalt mix might be improved with appropriate additives. These additives together with polymer modified binders are used to reduce the susceptibility of the mix to hardening (oxidation) and moisture by improving the adhesion between the binder and the aggregate (separation of the binder from the aggregate is referred to as ‘stripping’).

Typical additives are fibres (i.e. mineral or cellulose fibres or a mix of the two) and fillers (e.g. liquid amines and diamines, cement or hydrated lime). The most widely used anti-stripping additive is hydrated lime. Volume 1, Series 0900, Clause 938 (Porous asphalt surface courses) of the Manual of Contract Documents for Highway Works (Highways Agency, 2006b) requires that at least 2% by mass of the total aggregate shall be hydrated lime filler.

Of the surfaces shown in Table 4.1 which include additives, the Austrian surface with the 4/8 upper layer uses cellulose fibres as an additive.

Work undertaken within the Dutch IPG programme has also investigated the use of additives, e.g. glass slag, synthetic fibres to improve the early-life skidding resistance of TLPA surfaces (see Section 6.3.1 for further details).

### 4.5 Summary of findings

The material specifications for TLPA vary from country to country and there is no mix that stands out as being more prevalent. Upper layer aggregate sizes vary from 6-10 mm with a depth variation of 10-50 mm. The lower layer aggregate has an equally wide range from 10-20 mm with a depth variation of 20-80 mm. Polymer modified binders are generally used together with hydrated lime additive. Research in Japan has investigated the development of binders suited to specific climatic or traffic conditions. The use of additives to improve early life skidding resistance has also been demonstrated.

Discussions with UK surfacing contractors have suggested an equally wide range of potential aggregate specifications and that suitable binders are already available based on previous experiences with porous asphalt pavements. It is considered that TLPA might be achievable with existing thin layer products.
5 Construction and maintenance of twin-layer porous asphalt

This chapter deals with construction and maintenance issues, including European experiences with contracts for the construction of TLPA pavements. Whilst there are elements that are specific to TLPA, such as the improved construction procedures, much of the content is applicable to porous road surfaces in general.

One of the considerations in assessing the feasibility of TLPA for use in England is the time required, in terms or road/lane closures, for construction. One of the Highways Agency’s key performance indicators is the delivery of the Public Service Agreement (PSA) for journey time reliability. This is measured by examining the slowest 10% of journeys on the Network and comparing this with the 2004-05 baseline.

From the perspective of the initial construction operation, it is therefore preferable that the time required for paving TLPA should be equivalent to or not significantly greater than that required for conventional surfaces already used on strategic roads. Furthermore, recognition must also be given to the frequency and requirements of any maintenance of TLPA relative to conventional surfaces, as this will also affect the number of lanes open to traffic and the PSA target.

However, in the final analysis, construction and maintenance duration/frequency must be considered alongside any other benefits/disadvantages which may be associated with TLPA.

Another PSA target for the Department for Transport is to reduce the number of people killed or seriously injured in Great Britain. The Highways Agency has a key role in maintaining the network in a safe and serviceable condition. This involves the measurement of road surface condition, which is from surveys of such parameters as rutting, unevenness and skid resistance. By September 2007, the Agency has a target to develop a value for money (VFM) indicator, which will be used to develop improvement plans and eventually set VFM targets (Highways Agency, 2007).

The case for using TLPA for noise reduction should consider its impact upon these wider targets. This may be particularly significant if TLPA were to be used as a mitigation measure in response to Action Plans prepared under the END.

5.1 Procurement of twin-layer porous asphalt – contract issues

In the Netherlands, both SLPA and TLPA pavements are now procured using functional specifications. It is noted that at the present time, these specifications do not include any requirements for acoustic performance. These specifications were introduced at the beginning of 2005. The specifications include requirements to be satisfied initially (when the pavement is new), during the warranty period and at the end of the warranty period9 (residual requirements).

The specifications at the end of the warranty are such that a surface which meets these specifications would be expected to be of sufficient quality to reach the estimated average structural lifetime for the pavement type in the Netherlands, which based on visual inspections, is 7.2 years10 (Morgan, 2007). Under the current system, the warranty period is 5 years and contractors receive a financial bonus at the end of the warranty if the pavement performance is better than the residual requirements.

Based on the work undertaken and experiences gained within the IPG programme, these contract specifications are currently under review for high-durability TLPA surfaces.

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9 A five year warranty for porous asphalt pavements is standard in the Netherlands.
10 It is noted that this average lifetime of 7.2 years was based on data collated in 2004. An assessment of data based on visual surveys undertaken in 2007 suggests a revised figure of 7.9 years for the average structural lifetime.
(defined, for example, as those with a higher bitumen content than standard TLPA; these surfaces have been optimised for improved structural durability). The proposal is that the warranty period would be extended from 5 to 6 years, contractors would be penalised if their surface failed to meet the residual requirements at the end of the warranty period and there would be no bonus for surfaces that were better than the residual requirements.

In Japan, performance-based contracts have been trialled since 1998 and ‘comprehensive evaluation’ contracts have been trialled since 1999. Both include tyre/road noise as a performance indicator (Nielsen et al., 2005). This is determined using a CPX type measurement\(^\text{11}\) taken with a standardised specialist vehicle (the ‘Road Acoustic Checker’; 5 such vehicles are currently in service in Japan) rather than SPB measurements\(^\text{12}\) which is the standard approach in Europe.

In England, the Highways Agency has operated a two-year warranty for low-noise pavements. This has now been extended to 5 years although it is not rigorously policed. Any TLPA system would need a departure or BBA-HAPAS accreditation under current arrangements. If a UK-specification TLPA were derived from existing thin layer products, this should potentially not be a significant issue.

### 5.2 Construction procedures for twin-layer porous asphalt

#### 5.2.1 General considerations during construction

Eijbersen (2005) notes that the following aspects must be considered in relation to the construction of TLPA:

- For durable noise reduction performance, it is important that the lower layer of TLPA has good draining characteristics. The dense subgrade beneath the TLPA should also have a sufficient slope towards the drainage system. It is noted that if this not the case, then water remaining in the bottom layer during winter periods could freeze and cause damage to the layer;

- The total layer thickness is of importance for sound absorption. The minimum thickness of the bottom layer should, in general, be at least 40 mm in order to achieve sufficient acoustic absorption at low frequencies;

- Prior to construction of the upper layer of TLPA, driving on the lower layer should be avoided as far as practically possible. This minimises mechanical damage, pollution and the risk of poor bonding between the upper and lower layers of the surface;

- Under no circumstances should the lower layer be opened to general traffic;

- The thickness of the upper layer means that its thermal capacity is low. This in combination with the open structure of the layer means that it cools down quickly during construction. This is a critical aspect during construction and can result in problems as described below.

The quality of TLPA during construction is mainly affected by the logistics of transferring the hot asphalt mixture for the upper layer to the construction site, by weather conditions and by the surface condition of the lower layer. A narrow temperature window is often the limiting factor during the construction of twin-layer porous asphalt.

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\(^{11}\) CPX (Close-proximity) noise measurements are those where the noise level is measured by microphones positioned in close proximity to a test tyre. These measurements are usually carried out using specialist vehicles or trailers where the test tyre and microphones is enclosed in a semi-anechoic (soundproof) enclosure to prevent contamination from other noise sources. The method is set out in ISO/CD 11819-2 (International Organisation for Standardisation, 2000).

\(^{12}\) SPB (Statistical pass-by) measurements involve the measurement at the roadside of the maximum noise levels from individual passing vehicles together with the vehicle speed and performing a regression analysis to determine the maximum level at a given reference speed. The method is set out in ISO 11819-1 (International Organisation for Standardisation, 1997).
conditions and by the quality procedures applied during the actual construction process (Eijbersen, 2005). The following conditions are recommended:

- TLPA and especially the upper layer should not be laid when there is precipitation and/or an air temperature of < 10°C;
- When the air temperature is between 10-15°C, the wind speed should not exceed 4 m/s;
- When the air temperature is above 15°C the wind speed should not exceed 8 m/s.

Volume 1, Series 0900, Clause 938 (Porous asphalt surface courses) of the Manual of Contract Documents for Highway Works (Highways Agency, 2006b) states that:

- Porous asphalt shall not be laid during rain or when standing water is present;
- Laying shall not be permitted at any temperature if the average wind speed over the preceding hour exceeds 50 km/h at a height of 10 m (40 km/h at 2 m height);
- Porous asphalt containing modified binders are subject to their own wind and temperature limits as set out in the text of the Clause.

### 5.2.2 Traditional construction procedures

Traditionally TLPA is laid using conventional methods, paving first the lower layer, followed by a tack coat and then paving the second layer. However this is obviously a time intensive operation requiring extended periods of road closure. It is reported that using conventional methods, it takes approximately twice as long to pave TLPA as it does a single-layer porous asphalt.

This approach also has limitations in terms of the climatic conditions under which it can be carried out: at low temperatures, problems can occur with ensuring that the upper layer has bonded with the tack coat and furthermore, rapid cooling of the thin upper layer can occur resulting in poor compaction and the surface having a poor resistance to ravelling. It is noted that the same applies to thin surfacing systems that are currently used on the Highways Agency’s strategic road network. TLPA laid under these conditions therefore has a reduced lifetime. This can be addressed in part by having strict conditions under which the surface can be laid. In the Netherlands, for example, TLPA has to be laid with an outside air temperature of at least 10°C. This means that construction is restricted to the period 1st May to 1st October and generally not possible at night-time. This rule is also specified in the guidance issued on TLPA as a result of the IPG programme, stating the temperature and wind speed conditions recommended by Eijbersen (2005; see above). This temperature limit is of particular relevance in this review since resurfacing in the UK generally takes place during night-time to minimise traffic disruption.

Furthermore, there can be difficulties in laying a homogeneous surface or in achieving homogeneity between surfaces laid at different sites.

Therefore, within a number of different studies, alternative methods and improved procedures have been developed to try to overcome these restrictions/problems as described in the following sections.

### 5.2.3 Warm-in-warm paving techniques

To overcome the problems with rapid cooling of the upper layer in low temperatures, an approach has been developed whereby the two porous layers are laid simultaneously; the upper layer is heated by the lower layer, thereby slowing the cooling rate of the upper layer. This method is known as “warm-in-warm” or “hot-in-hot” paving and can be undertaken in two ways:
- **Using standard pavers, one directly behind the other.** The first paver lays the binder course. The second paver lays the wearing course on the still-hot binder course, which will have been pre-compacted by the first paver. Finally, both courses are compacted by rollers in a single process. There are however, a number of disadvantages to this method as follows:

  (i) the lower course is still hot when the wearing course is laid, so there is the risk of deformation of the lower layer as a result of the passage of the second paver;

  (ii) an additional lane/track is required parallel to the road section in order to feed the second paver, as the transporters cannot be driven on the lower layer, i.e. the transporter requires to be driven alongside the paver;

- **Using specialist ‘compact modular’ pavers:** These are single pavers comprising two mix hoppers and two compacting screeds which enable the two asphalt courses to be laid in a single passage. The paver is combined with a mobile feeder which serves the two hoppers in turn. This approach eliminates the problems arising with standard pavers, but requires greater organisational and process control. Compact modular pavers are currently used in Japan, Germany and, to a more limited extent, in the Netherlands, China and Russia. An example of a compact modular paver is shown in Figure 5.1.

  It is noted that many of these compact modular pavers are designed so that the part of the paver designed for laying the second layer is a second module which can be mounted onto a standard paver. In that way, the paver can be used with or without that module depending upon the mode of operation.

![Figure 5.1: Example of ‘compact asphalt paver’ (manufactured by Dynapac)](from www.joempr.com/companies/dynapac/dynapac111.htm)

It would need to be established whether such modules could be directly mounted onto pavers used by surfacing contractors in the UK or whether the pavers would require any particular modification.

It is noted that from discussions with several UK surfacing contractors (see Chapter 9), that the initial system preference for paving trials of TLPA using warm-in-warm
techniques would be to use two pavers or hire in any specialist equipment. Even if the trials prove successful, it was considered that there might need to be some form of guarantee as to the quantities of TLPA that might be laid before specialist compact modular paver apparatus is invested in. This is considered particularly important since the surface is most likely to be less widely used than existing thin surfaces.

Japanese compact modular pavers are currently used to lay a range of different specification TLPA pavements. Nielsen et al. (2005) reported that the Japanese ‘Double Layer Paver’ manufactured by WIRTGEN permits a paving speed of 4-5 m per minute, with a paving width of 2.5-4.75 m. In Germany, compact modular pavers have been used to lay TLPA with an 11/16 lower layer and a 5/8 upper layer (Ripke, 2006). In the Netherlands, compact modular pavers have been used to lay TLPA trial sections with an 11/16 lower layer and a 4/8 upper layer (Morgan, 2007).

A state-of-the-art review prepared for the Dutch IPG project (Gharabaghy et al., 2005), based on an assessment of 5 pilot trials (3 in the Netherlands and 2 in Germany) concluded that this type of paving method offers the following benefits:

- It offers an increase speed of construction in comparison to standard paving techniques for TLPA. Trials within the framework of the Dutch IPG programme have demonstrated that the TLPA paving operation is one and a half times faster than conventional laying;
- It offers a wider range of climatic conditions under which TLPA can be laid, extending the general time window in terms of the time of year as well as allowing night-time construction;
- With improved temperature retention in a twin layer, a higher compaction factor of the material is possible in cooler laying conditions. This higher compaction is considered to provide improved resistance to ravelling;
- There is no need for a tack/bond coat between the layers.

However, the following points must also be taken into account (Gharabaghy et al., 2005):

- The enhanced thermal capacity offered by the application of the method means that it may not be possible to open the road to traffic as quickly as when using traditional paving methods;
- Requirements on the evenness of the subgrade are higher than for conventional laying to avoid any problems with unevenness of the final surface; this point has been further reiterated by the experiences of recent Dutch trials described below. It is also important to ensure continuous paving rather than a stop-start operation;
- More rollers are required than for paving using conventional methods. This is because initial compaction should be with light tandem rollers so that the heavy rollers which follow (used for the final compaction) do not sink in too deeply and cause either intermixing of the two layers or unevenness;
- As of 2005, it was considered that the method is only cost-effective for large projects; studies suggest that economic benefits are only achieved when paving areas in excess of 12,500-15,000 m². This area is approximately equivalent to 3 lane miles. From a UK perspective, it would need to be considered whether such benefits are achievable if the surface is potentially not adopted for widespread use on the Highways Agency’s strategic road network.

In the same report, it was also recommended that small compact asphalt pavers should be avoided for highway construction; in such cases the use of pavers with a large paving width (up to 12 m) was suggested to avoid longitudinal seams, provide better bonding between the courses and a higher compaction factor.
As part of the Dutch IPG project, additional trials have been undertaken using the warm-in-warm approach and compact asphalt pavers. A section was laid at night-time during April/May 2006; this was considered to be equivalent to paving during the day during October/November. The test section comprised a 25 mm thick 4/8 upper layer and a 45 mm thick 11/16 bottom layer. The trial section was 2 km in length and extended across four lanes and the emergency lane. It was laid over 12 nights in temperatures as low as 8°C (Morgan, 2007). After paving, a quality review of the surface (Siedenburg, 2006) reached the following conclusions:

- Noise reductions were in accordance with those observed on TLPA laid using conventional techniques;
- Layer thickness and porosity were in accordance with the design specifications. The permeability of the section was high, suggesting that intermixing at the interface between the two layers was not an issue.

However, there was an unevenness to the pavement that could be felt by drivers which was sufficient for complaints to be received by the Road Authority. The contractors had experienced similar problems at another test site and discussions have been held with the paver manufacturer and German surfacing contractors who have more experience with these pavers. These discussions yielded a wide range of possibilities for the cause of the unevenness, including the hydraulics on the paver being too sensitive, the temperature of the bottom asphalt layer being too high, compaction starting too early, and too much variation in the temperature of the different asphalt deliveries, (van den Pangaard, 2007). There is currently a debate whether contracts for Dutch surfaces paved using this approach should include evenness requirements expressed in terms of the International Roughness Index (IRI) instead of C5\(^{13}\), however the IPG Scientific Board (responsible for the technical auditing of the Dutch IPG programme) consider that the IRI is not suitable for the type of surfaces used on high-speed roads in Europe.

Paving operations to lay a TLPA pavement using warm-in-warm methods and compact asphalt pavers have been observed as part of the project associated with this report. The associated report and observations are included in Chapter 9.4 of this report. The following is a summary of the key conclusions from the site visit.

The **benefits of the warm-in-warm construction method using compact modular pavers** are as follows:

(i) Speed of construction;
(ii) Durability of the laid material (no longitudinal joints, full bond between layers);
(iii) The extended time for compaction (heat retained in the mat);
(iv) The reduced requirement for high PSV aggregates;
(v) The ability to lay TLPA in a wider range of climatic conditions.

**Key requirements for the process to be successful** are:

(i) At least two asphalt plants being available to supply material;
(ii) Transportation of the asphalt to the site; and
(iii) Sufficient road space available to lay wide widths without longitudinal joints

\(^{13}\) C5 expresses the percentage of the road which is 5 mm above or below the mean level. This percentage is expressed per 100 m. Depending on the type of road construction Dutch specifications generally demand a maximum of 2 or 3%
5.2.4 Other innovative paving methods

Hosokawa et al. (2006) have reported on a new technology concept which instead of using hot in-place recycling (HIPR)\(^{14}\) involves “hot in-place transforming” (HIPT), i.e. the transformation of dense asphalt concrete (DAC) pavements into two layers of porous asphalt for the surface layer and a mastic gap asphalt as the underlying layer. Figure 5.2 shows the HIPT train which comprises 5 machines; two pre-heaters, a heater/miller, a separator and a mixer/tandem paver. The system has been used to lay TLPA on a Japanese highway at a speed of 2m/minute, but no details on the composition of the porous asphalt layers could be identified from the paper.

![Figure 5.2: Hot In-Place Transforming (HIPT) Train](from Hosokawa et al., 2006)

5.2.5 Methods for improving homogeneity during construction

Work has been undertaken as part of the Dutch IPG project to improve the homogeneity of TLPA during construction, in terms of both the homogeneity of a section laid within a single paving operation and the consistency between surfaces laid during different operations. A trial has been organised to demonstrate different methods for improving homogeneity (DWW, 2006a). From an initial submission of ten proposals, three were selected for full demonstration during April 2007, as follows:

- **Shuttle buggy**: This equipment, as shown in Figure 5.3, is used to reduce the influence of interruptions/ pauses to the paving process caused by an intermittent asphalt supply. The Shuttle Buggy is used to provide a “buffer capacity” during construction and can be considered as an extra hopper that can be positioned in between the paver and truck containing the warm asphalt. The size of the Shuttle Buggy allows a truck to completely discharge its asphalt load into the Buggy. A further advantage is that the Buggy is fitted with equipment which allows re-mixing of the asphalt before it is fed into the paver, avoiding segregation and providing a uniform temperature and hence compaction across the laid mat.

Initial experiments performed by the developer have demonstrated that it improves the speed of construction because the number of stops made by the asphalt paver is reduced (van Beers and van Buël, 2007);

---

\(^{14}\) Hot in-place recycling is defined as a process to correct asphalt pavement distress by softening the existing surface by heating, mechanically removing the pavement surface, mixing the reclaimed asphalt with a recycling agent, possibly adding new asphalt and/or aggregate, and relaying. A train of machines working in succession performs the recycling (Sanders, 2005).
• Megapave: This is a proprietary surface which includes EOS-Edelsplit (a slag formed from angular particles with a high specific density) in the upper layer. As such, the upper layer cools down at a slower rate than porous asphalt made with traditional aggregate types, making the surface less susceptible to low air temperatures during construction (Laureijssen et al., 2007);

• Total process optimisation: In this proposal, a number of measures to improve quality are combined. It includes, for example, use of the Shuttle Buggy, the two-layer (compact modular) paver, lowering the humidity of the aggregate that enters the asphalt plant, and continuous measurement of the asphalt temperature in the paver.

The results of the trials indicated that all three approaches offer positive benefits in terms of improved homogeneity, although the results from the Megapave trial require further investigation to establish the true scale of benefits. The shuttle buggy not only improved the homogeneity of the surface (by providing a homogeneous temperature asphalt and a more even surface) but also improved the speed of the paving, resulting in an operation 1.5 times faster than conventional paving. The total process optimisation also resulted in a more even top layer.

5.2.6 Other considerations during construction

It is noted that TLPA will most likely be used in England at locations previously laid with thin surfacings. It will therefore be necessary to establish a strategy for paving of the emergency lane and whether this will also be paved with TLPA or a thin surfacing. In the latter case, consideration will have to be given to the installation of drainage to prevent the ponding of water within the structure of the pavement. The choice of approach may have a significant impact on the costs of using TLPA.

5.3 Maintenance of twin-layer porous asphalt

Road pavement surfaces do not last indefinitely. Maintenance is required when signs of wear such as polishing, rutting and cracking are judged to affect the standard of service provided to the road user and the integrity of the pavement structure. To accomplish this task in the most cost-effective manner, DMRB Volume 7, Section 3, Part 3 (Maintenance Assessment Procedure) (Highways Agency, 1999) states it is necessary to use a logical assessment procedure to enable the correct maintenance treatment to be carried out at the most advantageous time. Where there is a need for strengthening, a thorough structural investigation is essential to identify how this should be implemented, particularly when major expenditure is being considered.

Within the UK, routine assessments determine whether the condition of the pavement has deteriorated to a state that may require remedial action and are also used to establish a database of information from which trends in carriageway condition can be established. The CHART system (MARCH in Northern Ireland) provides information about visible physical defects, such as cracking and rutting, which are of major importance in assessing the condition of flexible and flexible-composite pavements.

5.3.1 General maintenance

Porous asphalt is more exposed to the atmosphere than other non-porous surfaces, so the binder is more susceptible to oxidation. This results in the binder becoming brittle and cracking of the surface/loss of aggregate. When this occurs, major maintenance may be required. In some cases, the life of the binder can be extended through the application of rejuvenators which remedy the detrimental effects of ageing (see also Section 5.3.4). This is generally undertaken before ravelling of the pavement begins to occur, i.e. before structural maintenance is required, and can therefore be considered as
‘preventative’ maintenance. An extension of the lifetime of TLPA laid on an urban street in Copenhagen, Denmark by approximately 2 years has been achieved using this technique. Based on the Danish results, it is considered that on TLPA, a preventative rejuvenation after perhaps 4 years, before heavy ravelling occurs, may be a good method for increasing the structural lifetime (Ellberg et al., 2008). However it is not clear whether this recommendation applies to TLPA on all road types or only on urban roads. The costs of such maintenance against the extended durability would need to be fully assessed before any application on strategic roads.

The application of ‘open-graded emulsion asphalt’, which is a mix of bitumen emulsion, cement, filler and a mixture of sand/stone aggregates of a suitable grading (Kneepkens et al. 2004), is used in the Netherlands as an ‘intermediate’ or ‘temporary’ maintenance. This is applied as a thin protective layer on TLPA that is exhibiting light or moderate ravelling. Road trials have indicated that this can enhance the service life of porous asphalt surfaces by 4 years or more (van Gent and Sule, 2004).

If the binder has reached the end of its service life then it is necessary for the whole of the surface layer to be removed. This is normally achieved by cold milling of the porous asphalt layer and applying a new surface course layer to the planed surface.

The maintenance procedure used for TLPA in the Netherlands is a four-stage process known as ‘variable pavement maintenance’. The details of the procedure are set out in Table 5.1, together with the corresponding schedule for SLPA for comparison. It should be noted that the timings shown in the Table are not mandatory, i.e. it is not a fixed maintenance schedule: the timings are representative of the average lifetimes for TLPA (and form the basis of Dutch cost-effectiveness calculations). In practice, maintenance is undertaken when the surface is deemed to have failed, which may be sooner or later than these figures.

It is noted that on England’s strategic road network, the emergency lane may never be resurfaced.

### Table 5.1: Summary of the Dutch four-stage maintenance process on single-layer and twin-layer porous asphalt (timings are illustrative, based on the average lifetimes)

<table>
<thead>
<tr>
<th>Maintenance Stage</th>
<th>Single-layer porous asphalt</th>
<th>Twin-layer porous asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>Replace:</td>
</tr>
<tr>
<td>1</td>
<td>11 years</td>
<td>Slow lane only (i.e. most heavy vehicles)</td>
</tr>
<tr>
<td>2</td>
<td>15 years</td>
<td>All lanes</td>
</tr>
<tr>
<td>3</td>
<td>26 years</td>
<td>Slow lane only</td>
</tr>
<tr>
<td>4</td>
<td>30 years</td>
<td>All lanes and strengthen base course</td>
</tr>
</tbody>
</table>
It is noted that the basis for performing Stage 1 and Stage 3 maintenance on the slow lane of SLPA 11 years after laying, instead of after a shorter period, say 8 years, to have a longer period between Stages 2 and 4, is to stimulate surfacing contractors to improve structural durability.

A similar type of maintenance approach (in terms of first replacing only the nearside lane, then replacing all lanes in the next phase of maintenance) is often used for surfaces on the UK highway network.

5.3.2 Winter maintenance

Winter maintenance generally refers to the treatments needed to prevent ice and bonded snow formation during cold periods in the winter. Many countries have reported special problems concerning winter maintenance on porous asphalt surfaces which can be summarised as follows (Morgan, 2006):

- The thermal conductivity of porous pavements is lower which results in more rapid and deep temperature drops during autumn and winter. Compared with dense asphalt pavements, porous asphalt pavements are approximately 1°C colder. This leads to a longer persistence of freezing conditions on the road surface and, as a result, a higher consumption of road salt;
- The thermal sensitivity of the surface can lead to an earlier formation of ice and frost. The time for which salt stays on the surface is very short as a result of the high void content and rapid drainage;
- In slushy conditions, the performance of porous asphalt is slightly poorer than dense surfaces as the slush is first forced in the pores of the surface by snow ploughs but then wells back up again after a short time. This necessitates another salting pass to avoid freezing again and again, leads to a higher use of road salt.

This means that porous asphalt surfaces require more extensive de-icing measures than conventional dense asphalt layers to maintain skid resistance requirements. They have to be treated with salt more frequently and with higher application rates. The importance of using suitable snow-removal equipment is also important; very aggressive snow-ploughs must be avoided as these can cause significant damage to the surface. Nielsen et al. (2005) report that in cold regions of Japan, where the number of snow removal operations can vary between 150-300 per year, data has shown a 40 mm porous pavement being reduced to a thickness of 5 mm in the wheel tracks and 24 mm between the wheel tracks as a result of the use of snow ploughs with steel scrapers. Significant quantities of loose aggregate were found at the roadside. Partial repair works in such cases were generally performed with dense asphalt. Hybrid pavements which are constructed as a hybrid of SMA and porous pavements have been developed to reduce splash and spray and provide high skid resistance whilst having a high structural resistance to snow ploughs.

In the Netherlands, it is common practice to scatter salt on roads before they become icy (Eijbersen, 2005). However, research in Austria (Pracherstorfer and Litzka, 1994) has shown that preventative salting of porous surfaces may not be effective as precipitation carries the salt into the pores. However once there, it may counteract the freezing of the pavement. It is therefore considered better to use several applications of smaller quantities of salt than using a single pass with a large quantity. This means that more accurate, continuous monitoring of the road may be necessary.

The application of grit in winter maintenance is not recommended with porous pavements as this would result in clogging of the pores. Porous asphalt can therefore only be used on roads exclusively treated with road salt.
5.3.3 Cleaning of twin-layer porous asphalt

As already noted in Section 2.1, during its service life, the pores of porous asphalt tend to become clogged by dirt, dust and general detritus arising from the wear of both the surface and vehicle tyres. Eijbersen (2005) notes that the effective depth of TLPA is decreased by pollution of the layers/clogging of the pores. It is important to initiate cleaning regimes before the pores become totally clogged to help maintain noise reduction and drainage properties.

On high-speed roads, the vehicles themselves generate a cleaning effect in the wheeltracks by the action of the tyres passing over the porous surface. This effect has been observed to occur even more effectively when vehicles travel at speed during heavy rainfall due to effects that occur at the leading and trailing edges of the tyre contact patch (Sandberg and Ejsmont, 2002). However, if the emergency lane is also laid with TLPA, this will need cleaning as part of a regular maintenance programme.

The faster the speed of the traffic, the greater the cleaning effects; clogging is therefore a bigger problem on low-speed roads or roads in an urban environment.

Cleaning of porous pavements has been performed in Japan since their introduction in 1995. However it has been observed from practical experiences that the effect of cleaning is not durable (i.e. its effects do not last long-term). Long periods of dry weather can cause these cleaning processes to be less effective; in such cases it is recommended that the surface be pre-wetted in order to improve the effectiveness of the cleaning.

Where surfaces are cleaned with water, it may be necessary for the cleaning water to be treated before it can be released back into the cleaning system. If it is untreated, then the filtrate has to be disposed of as chemical waste (James, 2003).

Specialist cleaning equipment has been developed in Europe and Japan to help reduce the build-up of dirt and detritus on porous road surfaces. Different low-speed cleaning machines (which run at 1-2 km/h) have been developed which use high pressure water (e.g. Figure 5.4a). However, the effects on noise reduction of using these machines is not consistent. In Japan, these first-generation cleaning machines are referred to as ‘function recovery’ machines since they were used to recover the function of clogged pavements (e.g. noise performance or drainability). New cleaning systems have been developed which allow cleaning at higher speeds 2-10 km/h; the highest speeds can only be used when the pavement is partially clogged; for more densely clogged pavements, the lower speeds are required.

(a) Cleaning TLPA using high-pressure water    (b) Cleaning TLPA using high-pressure air

Figure 5.4: Examples of Japanese TLPA cleaning systems
The latest generation of Japanese cleaning machines are referred to as ‘function maintenance’ machines since their application is intended to maintain the noise reduction function of the pavement at all times. The latest development is a cleaning machine which uses high-pressure air (i.e. no water; see Figure 5.4b) and operates at speeds of 10-20 km/h. The work on this system has indicated that the most cost-effective usage is achieved by running a single cleaning operation every week, beginning one week after the surface has been laid. This is estimated to cost approximately €4/m² of paved area per year, as shown in Table 5.2 (from Nielsen et al., 2005); it is estimated that this cost will be halved with the next version of the system (Sandberg, 2005).

Table 5.2: Effectiveness and costs of TLPA cleaning in Japan
(from Nielsen et al., 2005)

<table>
<thead>
<tr>
<th>Cleaning machine</th>
<th>Conventional type</th>
<th>High-speed with high-pressure water</th>
<th>High pressure air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collected mass/cycle (g/m²)</td>
<td>100</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Frequency (times/year)</td>
<td>3</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Cleaning costs (€/m²)</td>
<td>6.90</td>
<td>0.22</td>
<td>0.08</td>
</tr>
<tr>
<td>Cleaning costs (€/m²/year)</td>
<td>20.70</td>
<td>6.60</td>
<td>4.00</td>
</tr>
</tbody>
</table>

A maintenance study proposed for porous surfaces by OECD in 1995 (Organisation for Economic Cooperation and Development, 1995) suggested initial cleaning two years after paving and then periodic cleaning every two years.

It is noted that unless cleaning is carried out as part of regular scheduled maintenance, it may be preferable to assess the degree of clogging before implementing cleaning. Studies carried out in the Netherlands have suggested that on main highways and motorways, the cleaning of porous asphalt surfaces in the driving lanes is unnecessary, due to the self-cleaning action following rainfall described above; only the emergency lane requires cleaning to maintain the drainage capacity of the driving lanes (on Dutch highways surfaced with porous asphalt, the emergency lane is also surfaced with PA and since this is not trafficked, artificial cleaning must be used). The need for cleaning the emergency lane if TLPA is used in the UK may be dependant upon whether the lane is paved with TLPA or a thin surfacing.

As part of the Dutch IPG programme, a trial to demonstrate different cleaning methods has been undertaken (DWW, 2006a). From an initial submission of ten proposals, three were selected for full demonstration. The trials were undertaken in both the running lane and emergency lane of a TLPA test section which had been open to traffic for five years. The three methods were as follows:

- **Vacuum cleaning**: Instead of blowing the dirt from the TLPA pores of the upper layer into the bottom layer, this technique uses a powerful vacuum to suck the dirt from the TLPA. Two methods exists (i) a rapid cleaning method which uses air to transport the dirt from the TLPA and which is suitable for regular application; (ii) a slow cleaning method which uses water to transport the dirt from the TLPA and which is suitable for extensive cleaning of the TLPA. Only the second approach was the one selected for trial in the IPG (Figure 5.5; van Bochove et al., 2007).
Ultrasonic cleaning: The surface is first vacuumed to remove any loose dirt and then wetted so that the dirt within the TLPA can be removed. This is achieved by using ultrasonic noise to first loosen the clogged dirt within the upper layer and then a vacuum to extract the loosened dirt. The prototype system is shown in operation in Figure 5.6 (a);

Steam cleaning: First the surface is vacuumed to remove any loose dirt and then steam is blown into the TLPA so that any dirt in the upper layer is blown through to the bottom layer. The dirt is then transported away from the road in the same manner as any other normal dirt in the bottom layer, i.e. by the action of rain water. The system is shown in Figure 5.6(b).

The trials demonstrated that both the steam cleaning and the slow vacuum cleaning methods are suitable for cleaning TLPA. The vacuum cleaning was performed with an upgraded system which proved to be more effective than existing vacuum systems. The ultrasonic cleaner was less effective than the other systems, but also operated at a low speed and only covered a small area due to the small-scale, prototype nature of the apparatus. It was therefore concluded that the ultrasonic cleaner was not suitable for cleaning TLPA. It is noted that measurements indicated that the trial section was not heavily clogged, despite having been open to traffic for 5 years. All three methods operated at speeds lower than those demonstrated elsewhere, e.g. in Japan.

The overall results also indicated that a regular two-stage cleaning approach is required: the first pass removes dirt from the upper layer (caking) whilst the second pass, which should be performed two-three days after the first pass but no later than one week after, removes dirt which was transported from the lower to the upper layer by the first cleaning pass and further loosened by the action of passing traffic and any rainfall in the intervening period.

Information relating to the performance of other clogged TLPA surfaces is reported in Section 6.2.1.

5.3.4 Rejuvenation

An alternative approach to removing the surface is to improve the properties of the existing aged bitumen by applying a rejuvenating agent to the surface which is designed
to soften the bitumen as noted in Section 5.3.1. Rejuvenators, which are often applied as diluted emulsions, are penetrative and carry the active ingredients into the top 5-10 mm of the surface and usually modify the binder so that its ductile and binding properties are restored. They may also seal the surface which helps to prevent stone loss. It is often claimed that the life of the surface can be increased by up to five years (Schiavi, 2001).

By prolonging the surface life with a relatively quick and non-disruptive rejuvenation treatment, structural maintenance of the rejuvenated section can be postponed and carried out with other major works at a later date, thus minimising overall disruption to the public. Section 5.3.1 includes details of trials where emulsions have been applied for preventative maintenance.

The following liquids and admixtures can act as rejuvenators, because of their known action in softening the binder:

- A soft bitumen;
- A cut-back oil such as a creosote type liquid, or a flux oil such as a diesel type liquid;
- Emulsions;
- Proprietary liquids.

Cut-back or flux oils do not ensure durable solutions for ageing problems since they may evaporate or in some cases even destroy the cohesiveness of the asphalt. Soft bitumens, cut back or flux oils and proprietary liquids can also be used in hot recycling processes (Sanders, 2005).

A review of rejuvenation procedures prepared as part of the EU SILVIA project concluded that rejuvenators are effective in some circumstances for design purposes. However more work is required to establish the products that are effective in different circumstances because there are many possible combinations of rejuvenating agents, asphalt materials, environmental conditions and traffic loading to consider (Sanders, 2005). No information was included on the report on any potential adverse environmental effects of using rejuvenators which might negate any structural lifetime benefits.

It is noted that some studies, e.g. Schiavi and Nunn (2001), Schiavi et al. (2003), tend to suggest that rejuvenators may have a negligible and sometimes even a detrimental effect on binder properties. In one instance their application had a negative effect on skid resistance and friction properties of the aged asphalt.

No information on the effects of rejuvenation on acoustic performance has been found in the literature.

5.4 Summary of findings

Construction of twin-layer surfaces varies from country to country. The traditional methods of laying a single layer, allowing it to cool, applying a tack coat and then applying another layer has problems with tack coats and compaction of thin layers in less favourable weather conditions, as well as there being issues over the time needed to lay the surface.

A method known as “warm-in-warm paving” where the upper and lower layers are laid more-or-less simultaneously (i.e. the upper layer is laid while the lower layer is still warm) can be used either by two pavers working in tandem or a single paver applying both layers. Such a method offers potentially improved structural durability and increased laying speeds (potentially between 1.5-2 times faster) than for conventional TLPA, and the opportunity to lay in colder temperatures, e.g. at night-time.
The warm-in-warm technique, with either a single machine or two in tandem, is considered to be the only option viable for use in the UK due to the need of keeping lane closures to a minimum. UK surfacing contractors have indicated that for small sections, two paving machines, with one travelling behind the other, could be used. For any large scale operations and commitment to future operations then a single paver would need consideration. However, there are operational issues that would need to be considered in discussion with contractors and Highways Agency Traffic Operations.

In the Netherlands where most sections of TLPA have been laid then based on the typical structural lifetime of 7.2 years for the upper layer, the recommended maintenance cycle involves the upper layer in the nearside lane being replaced every seven years, regardless of condition. This is then followed by the replacement of both layers after a further four years. However, very few twin-layer surfaces are presently old enough to have undergone a complete cycle of maintenance.

TLPA is likely to require more intensive winter maintenance than the thin surfaces currently in use on the strategic road network and the surface is only suitable for treating with road salt as the application of grit would result in clogging of the pores of the pavement. This increased salting requirement may have potential implications with regard to the salt reserves available to highways authorities. Furthermore there may be potential water quality issues resulting from the increased salting (see Section 7.2).

One of the main problems affecting the performance of TLPA is clogging of the pores with dirt and detritus. On high-speed roads, the vehicles themselves generate a cleaning effect in the wheeltracks by the action of the tyres passing over the surface. Consequently, in general TLPA laid on high-speed roads is never cleaned (except that laid in the emergency lane, since if that lane becomes clogged then the flow of water away from the running lanes becomes impeded; in the Netherlands, it is recommended that the emergency lane is cleaned twice a year using high-pressure water). A range of different cleaning methods and systems have been developed in Japan and elsewhere which are used/have been trialled on lower-speed roads where existing maintenance policies require the cleaning of surfaces. No such policies exist for England’s strategic roads.

The effects of rejuvenation of porous surfaces through the application of chemical rejuvenators to restore the properties of the binder have not been widely investigated.
6 Performance characteristics of twin-layer porous asphalt

This Chapter addresses acoustic, structural and safety performance of twin-layer porous asphalt. The bulk of the literature identified during the review focuses on the acoustic performance of TLPA. For TLPA to be adopted in England, its performance characteristics should ideally be equivalent to or better than those of the low-noise surfaces currently used on the Highways Agency’s strategic road network.

6.1 Acoustic performance

The primary mechanism for noise reduction by TLPA is the porosity of the surface. However the small aggregate in the upper layer provides a smooth pavement texture which minimises vibration and noise from vehicle tyres.

The acoustic performance (noise reduction) of low-noise pavements is generally specified relative to a reference surface, for either individual vehicle categories or a specific traffic composition, based on SPB (Statistical Pass-By) measurements carried out in accordance with ISO 11819-1 (International Organisation for Standardisation, 1997). However there is presently no standard Europe-wide (or world-wide) reference surface. Individual Member States specify performance relative to a surface type which has been adopted as their own national reference surface, e.g. HRA (Hot rolled asphalt) in the UK, DAC (Dense Asphalt Concrete) 0/16 in the Netherlands, Gußasphalt (mastic asphalt) in Germany. This makes any direct comparison of results difficult unless absolute noise levels are reported. The performance is generally given in terms of the reduction when the surface is new. This section collates performance data from some of the TLPA surfaces identified in Chapter 3, and where possible, includes comment on the change in acoustic performance over the lifetime of TLPA.

6.1.1 Predicted performance of twin-layer porous asphalt in the UK

The performance of low-noise surfaces on high speed roads in the UK is specified in terms of the Road Surface Influence (RSI) in accordance with HAPAS (the Highway Authority Products Approval Scheme; British Board of Agrément, 2004). This is determined when the surfaces are relatively new (12-24 months old) and defines the acoustic performance in terms of the noise reduction provided relative to the reference surface in the standard UK road traffic noise prediction model CRTN (Department of Transport and Welsh Office, 1988); this reference surface is effectively HRA.

Typical RSI values for other surface types are as follows:

- SMA: -2.5 dB
- Thin Layers: 14mm; -4dB, 10mm; -5.5 dB
- Single-Layer Porous Asphalt: -5 dB

Based on SPB data from two of the zebra test sections (see Section 3.1.1) that were measured as part of the Dutch IPG programme, an RSI_H value (i.e. the RSI value for a high-speed road) has been calculated for TLPA. In addition, the RSI_H for a Swedish TLPA test section, which was laid as part of the EU 5th Framework project SILVIA (Sustainable Surfaces for Traffic Noise Control; Morgan, 2006) has also been determined. These results are given in Table 6.1.

15 A ‘virtual’ reference surface has been proposed by the European 5th Framework project ‘HARMO NOISE’ which was initiated to develop harmonised noise prediction models for transport and industry noise sources (Jonasson et al., 2004). This virtual reference is the average of SMA 0/11 and DAC 0/11 (Dense Asphalt Concrete) of age one year or older but not at the end of its lifetime. This virtual reference has not yet been formally adopted within Europe.
Table 6.1: RSI values for Dutch and Swedish TLPA test sections

<table>
<thead>
<tr>
<th>Location</th>
<th>Age</th>
<th>Upper layer</th>
<th>Lower layer</th>
<th>Noise level, RSI&lt;sub&gt;H&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Aggregate size</td>
<td>Layer depth</td>
<td>Aggregate size</td>
</tr>
<tr>
<td>A59, The Netherlands</td>
<td>12 months</td>
<td>4/8</td>
<td>25mm</td>
<td>11/16</td>
</tr>
<tr>
<td>A59, The Netherlands</td>
<td>12 months</td>
<td>2/6</td>
<td>25mm</td>
<td>11/16</td>
</tr>
<tr>
<td>E18, Sweden</td>
<td>1 month</td>
<td>11</td>
<td>30mm</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>23 months</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It should be noted the data for heavy vehicles on the Dutch surfaces was only supplied for the largest category of heavy vehicles (i.e. those with 3 or more axles). In order to calculate an RSI, data is also required for the 2-axle category. Therefore the value for the largest category of heavy vehicles was also used for the 2-axle group. Since the noise from the larger group of heavy vehicles is invariably higher than that of the 2-axle group, the RSI<sub>H</sub> value could be even lower if the noise for the 2-axle group was known. A similar exercise was undertaken for the data from Sweden.

It can be seen that the test sections on the A59 offer significant improvements in noise reduction to surfaces currently used in the UK. The results from the Swedish surface are not quite as favourable, although the levels calculated are still very good in terms of noise reduction. One possible explanation for the difference between test A59 sections is the aggregate size of the top layer, and this is shown again when comparing the Dutch sections with that laid in Sweden.

6.1.2 Measured early-life performance of twin-layer porous asphalt in Europe

Within the framework of the SILVIA project, noise reduction performance data was collected and analysed for a wide range of low-noise pavements of different ages including TLPA (Andersen et al., 2005). The results from different countries were grouped into pavement “families” which were presumed to have homogeneous characteristics. However there was no separation according to aggregate size or the age of the pavement.

The family of reference pavements comprised DAC, SMA, Gußasphalt and EACC (Exposed Aggregate Cement Concrete) surfaces. Relative to the average noise level for the reference pavements, TLPA was found to provide an average noise reduction of 4 dB(A) for both light and heavy vehicles. By contrast, thin surfaces provided a reduction of 3 dB(A) for light vehicles and 1 dB(A) for heavy vehicles. For reference, noise levels on HRA tended to be 2-3 dB(A) higher than those on the reference surfaces for the different vehicle categories. Table 6.2 provides a summary of the absolute noise levels on TLPA; it must be noted that these values are not derived from surfaces that are necessarily the same age.

The following paragraphs report the results from individual measurement programmes. Where absolute levels are available, these are summarised in Figure 6.1. If should be noted that the surface specifications and reference speeds used vary from country to country and these are also indicated in the Figure. For reference, noise levels on two UK specification SMA surfaces (14 mm and 10 mm) are also shown.
Table 6.2: SPB results and surface details for TLPA collated within the SILVIA project (from Andersen et al., 2005)

<table>
<thead>
<tr>
<th>Vehicle type &amp; speed</th>
<th>Average $L_{A_{max}}$ (dB)</th>
<th>Minimum $L_{A_{max}}$ (dB)</th>
<th>Maximum $L_{A_{max}}$ (dB)</th>
<th>Average aggregate (mm)</th>
<th>Minimum aggregate (mm)</th>
<th>Maximum aggregate (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars, 50 km/h</td>
<td>66.7</td>
<td>62.9</td>
<td>70.4</td>
<td>6.2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Cars 80 km/h</td>
<td>72.9</td>
<td>68.3</td>
<td>78.2</td>
<td>7.6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Cars, 110 km/h</td>
<td>78.9</td>
<td>76.4</td>
<td>82.5</td>
<td>7.7</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>2-axle heavies, 85 km/h</td>
<td>81.8</td>
<td>79.7</td>
<td>83.8</td>
<td>7.3</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>3+ axle heavies, 70 km/h</td>
<td>84.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3+ axle heavies, 85 km/h</td>
<td>83.2</td>
<td>80.3</td>
<td>86.6</td>
<td>7.5</td>
<td>5</td>
<td>11</td>
</tr>
</tbody>
</table>

Figure 6.1: $L_{A_{max}}$ noise levels for passenger cars on different TLPA surfaces. Aggregate specifications are shown for both layers together with the reference speed used for the measurements.

In the Netherlands, the standard reference surface is DAC16 (Dense Asphalt Concrete). SLPA provides an initial noise reduction relative to DAC16 of 4 dB(A) for a traffic composition of 85% light vehicles at 115 km/h and 15% heavy vehicles at 85 km/h;

Figure 6.2 compares SPB indices for passenger cars at 85 km/h (microphone height = 5 m, rather than the 1.2 m height specified in ISO 11819-1) measured on different TLPA surfaces with a 4/8 upper layer, with the bulk of the data measured during the early life...
of the surface; this corresponds primarily to the IPG zebra-sections. It is noted that there is a significant spread in the data. The red dashed line in the Figure shows the SPB index corresponding to the standard Dutch reference surface (DAC 0/16) and the blue lines show the SPB indices corresponding to the expected noise reductions when new for SLPA and TLPA used prior to the IPG.

Figure 6.2: SPB Index on TLPA sections with a 4/8 upper layer as a function of the age of the surface (traffic composition: 85% light vehicles at 115 km/h, 15% heavy vehicles at 85 km/h; microphone height = 5 m) (from Morgan, 2007)

Reference level for new DAC16 = 81.3 dB(A); reference level for new SLPA = 77.3 dB(A); reference level for new TLPA = 75.3 dB(A)

Results presented by Goubert et al. (2005) from periodic noise measurements on both Dutch and other European TLPA surfaces (laid on low-speed roads) indicated that on average, the noise levels on TLPA increase by approximately 1 dB(A) in the first year and a further 1 dB(A) within the second year after application. This effect can be explained by the pores in the surface becoming partially blocked during the first years of service, thereby decreasing sound absorption and increasing noisiness. It seemed likely from the results presented that, on average, the acoustic performance remains relatively stable between 3 years of age and the end of the pavement’s technical lifetime, although this assumption was based on a very limited dataset.

Belgian measurements on TLPA (a trial section with a 14 mm lower layer and a 7 mm upper layer) showed initial noise levels of 68.3 dB(A) for passenger cars at 80 km/h (Bendtsen et al., 2005). This absolute level increased by 1.2 dB(A) after one year and by a further 1.4 dB(A) after the second year. No measurements are reported for heavy vehicles. Although measurements were taken on a reference surface in order to determine the noise reduction for the TLPA, the condition of the reference pavement was poor and the same section was not used for reference measurements in the subsequent years. Therefore the levels on the reference surface cannot be included in the analysis.

Swedish trials of TLPA (with a lower layer of 16 mm and an upper layer of 11 mm) within the framework of the SILVIA project gave an initial reduction of 9.1 dB(A) relative to an SMA 0/16 reference surface for passenger cars at a speed of 110 km/h; this decreased to a reduction of 7.6 dB(A) after two years (Morgan, 2006). It was noted that using smaller aggregate in the upper layer would enhance the noise reduction performance of the surface, but the 11 mm aggregate was chosen as the overall objective was to optimise noise reduction without sacrificing durability (due to the effects of studded
winter tyres). By contrast, an 11 mm thin layer gave an initial noise reduction of 3.3 dB(A), decreasing to 2.6 dB(A) after two years, while a single-layer porous asphalt gave an initial reduction of 4.1 dB(A) increasing to 7.4 dB(A) after 2 years. For heavy vehicles at 85 km/h, the initial noise reduction for TLPA was 9.0 dB(A), decreasing to 8.2 dB(A) after 2 years. By contrast the thin layer gave an initial noise reduction of 1.4 dB(A) increasing marginally to 1.6 dB(A), and the single-layer porous asphalt an initial reduction of 3.4 dB(A) increasing to 5.2 dB(A). The reason for the unexpected increases in noise reduction for the single-layer porous asphalt was due to the shift in the peak of the absorption spectra for the surface as a result of clogging; when the surface was new, the peak in the absorption spectra was occurring at a frequency that was not ideal with respect to the peak in the traffic noise spectrum, after clogging, the frequency of maximum noise reduction shifted to a more favourable match with the peak in the traffic noise spectrum.

Results from the French trials of TLPA only report initial noise levels for one of the trial sections on a toll motorway (that with a 10/14 lower layer and a 4/6 upper layer). For passenger cars at 90 km/h, an initial level of 71.3 dB(A) was reported (Brosseaud and Anfosso-Ledee, 2005). The French database of road surface noise performance data held by LRPC Strasbourg reports that a traditional DAC 0/10 gives an average level of 76.1 dB(A). After 1 year, there was no significant change in the noise levels on the TLPA, a slight decrease to 71.0 dB(A) being reported. The next reported measurements were taken when the surface was 4 years old at which point the level had increased to 73.9 dB(A).

German TLPA sections with a 0/8 upper layer and a 0/16 lower layer were constructed on the A30 using both conventional and warm-in-warm paving methods (Ripke, 2006). Noise emission measurements were conducted in accordance with the standard German procedure described in GEStrO-92 (these are SPB-type measurements but involve additional microphone heights). Initial noise levels of 77 dB(A) for passenger cars at 120 km/h were recorded on the section constructed using warm-in-warm techniques. On the section constructed using conventional paving techniques, speed restrictions meant that the performance could only be determined for a speed of 100 km/h; noise levels of 75.2 dB(A) were recorded. An SPB level of 76.5 dB(A) for passenger cars at 110 km/h at this site after 3 months is reported by Bendtsen et al. (2005), but it is not clear whether this is for the conventional or warm-in-warm paved section. An initial noise level of 78.7 dB(A) passenger cars at 110 km/h on a TLPA surface with a 0/5 upper layer on the A3 is also reported by Bendtsen et al. (2005).

The acoustic performance of Italian TLPA trial sections is not easily compared with that of TLPA in other countries, since the results reported (Battiato, 1997) are not based on the SPB measurements but rather on measurements of acoustic absorption using impulse-type measurement methods as described in ISO 13472-1 (International Organisation for Standardisation, 2002). In addition to absorption measurements, Lancieri et al. (2000) reported that a TLPA laid on the A12 motorway with a 0/18 lower layer and a 0/10 upper layer provided an L_{Aeq} of 65.4 dB. For the test sections laid on urban streets in Florence, the TLPA provided and average noise reduction of 3.5 dB(A) L_{Aeq} relative to a traditional asphalt surface.

Noise levels on Japanese surfaces are generally measured using a ‘Road Acoustic Checker’ (RAC, a CPX-type vehicle) rather than SPB measurements. This makes comparison with surfaces laid in other countries difficult. However, Nielsen et al. (2005) report that SPB noise measurements on porous pavements have shown noise reductions of 4-7 dB(A) for passenger cars and 2-5 dB(A) for heavy vehicles relative to a 13 mm dense asphalt concrete pavement, the highest reductions being observed for TLPA.

Tsukamoto et al. (2003) report an initial noise reduction of 10.4 dB(A) (measured using the RAC) relative to a dense asphalt concrete for a TLPA laid in Japan using a compact modular paver with a lower layer comprising 13 mm aggregate and an upper layer...
comprising 5 mm aggregate. After twelve months, the noise reduction had decreased to 8.5 dB(A).

Measurements on three TLPA sections in New Zealand (Jackson et al., 2003) were taken one week after the surfaces were opened to traffic and are expressed in terms of $L_{A_{eq,24h}}$. On the low-speed section (vehicle speeds less than 50 km/h), a reduction in the $L_{A_{eq,24h}}$ of 4.2 dB(A) was observed relative to the 20 mm Open Graded Porous Asphalt (OGPA) that was in place prior to the test section being laid. This OGPA was visibly clogged, but still free-draining. At the 2nd test site (a 4-lane motorway with speeds around 100 km/h), the TLPA was laid as one of 7 different low-noise surfaces; the precise performance was not reported in the paper but noise levels were stated as being similar to those on the low-speed section and the third site. At the third trial site, the TLPA was trialled along with a 14 mm OGPA and noise reductions of 3 dB(A) $L_{A_{eq,24h}}$ were measured for the TLPA relative to the OGPA.

Danish measurements on the low-speed road Øster Søgade near Copenhagen resulted in an average noise reduction of 6 dB(A) for the TLPA with the 2/5 upper layer two weeks after the surface had been opened to traffic, relative to a DAC 8mm for a traffic composition comprising 90% light vehicles (Kragh, 2007). For the other surfaces, the average noise reduction was 4.5-5 dB(A).

### 6.1.3 Changes in acoustic performance over time

The majority of results reported in the literature focus on initial performance or performance during the early life of TLPA. Relatively few studies have been identified which have taken noise measurements over an extended period or over the full lifetime of a TLPA section, largely because the test sections are relatively new. Brosseau and Anfosso-Ledee (2005) have reported measurements on surfaces up to 4 years old (see previous section). Long-term measurements in Japan using the Road Acoustic Checker have shown that traffic noise on porous pavements in Japan increases by approximately 4 dB(A) over a 5 year period (Nielsen et al., 2005).

Within the IPG, there has been some attempt to investigate performance over lifetime. Figure 6.2 compares SPB indices for passenger cars at 85 km/h (microphone height = 5 m, rather than the 1.2 m height specified in ISO 11819-1) measured on different TLPA surfaces (Morgan, 2007). It should be noted that the data falls largely into two groups: the IPG zebra-sections for which measurements have been taken only during the early years (due to the age of the test sections), and non-IPG sections where data has been measured on surfaces approaching the end of their life but almost no corresponding data exists to show performance during early lifetime. It is considered that changes in the performance after seven years are largely attributable to ravelling; changes during the mid-life of the surface are considered to be attributable to clogging of the surface. The effects of clogging and cleaning of porous surfaces are addressed in Sections 0 and 6.2.1.

The most extensive long-term measurement programme on TLPA is on the Danish low-speed test sections in Copenhagen (Kragh, 2007) which were laid in 1999. To date, measurements over a 7 year period have been recorded and the surfaces have been cleaned twice a year using high-pressure water/air suction. The surfaces also underwent preventative maintenance in 2005 using emulsion sealing techniques; the rejuvenation was successful, stopping the ravelling process and based on visual inspections, it appeared that the structural integrity of the pavement was recovered to some extent (Ellebjerg et al., 2008). The voids in the porous pavements have gradually become clogged and after 7 years, the noise reduction had reduced to only 1 dB(A) on two of the test sections and had completely disappeared on the third section. The noise reductions on the surface with the 2/5 upper layer decreased more than those on the surfaces with 5/8 upper layers. It is noted that this experiment also included the laying of a reference pavement, the performance of which has also been recorded so that the noise reductions...
of the TLPA at any given age could be directly related to a reference pavement of the same age. It is noted that the reference was smoother than anticipated so that so that the noise levels on this surface were lower than initially expected. Table 6.3 summarises the noise reductions measured on three surfaces.

Table 6.3: Performance of TLPA on low-speed roads (Øster Søgade, near Copenhagen, Denmark) (from Kragh, 2007)

<table>
<thead>
<tr>
<th>Age</th>
<th>TLPA1</th>
<th>TLPA2</th>
<th>TLPA3</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>4.5</td>
<td>4.9</td>
<td>6.0</td>
</tr>
<tr>
<td>1 year</td>
<td>4.6</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td>2 years</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>3 years</td>
<td>2.4</td>
<td>2.2</td>
<td>1.0</td>
</tr>
<tr>
<td>4 years</td>
<td>2.8</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>5 years</td>
<td>1.7</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>6 years</td>
<td>1.4</td>
<td>1.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>7 years</td>
<td>1.4</td>
<td>1.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

TLPA1: 70 mm thick, comprising 25 mm 5/8 upper layer, 45 mm thick 11/16 lower layer
TLPA2: 55 mm thick, comprising 20 mm 2/5 upper layer, 35 mm thick 11/16 lower layer
TLPA3: 90 mm thick, comprising 25 mm 2/5 upper layer, 65 mm thick 16/22 lower layer
DAC reference: 30 mm thick 0/8

6.2 Structural performance

Goubert et al. (2005) reported that experience with TLPA which has served a full life-cycle and been replaced only exists in the Netherlands. The average lifetime of the surface is seven years (in terms of the structural durability of the upper layer), but Dutch surfaces exist which are 10 years old and still in structural good condition.

Within the Dutch IPG project, work has been undertaken to improve the durability of TLPA by focusing on developing an understanding of the processes and mechanisms that are responsible for ravelling (the loss of stones from the top surface of the pavement). This has included microscopic analysis of ravelled TLPA using CT-scanning techniques and thin section analysis. The outcomes from this investigation have been combined into a model, referred to as a Lifetime Optimisation Tool (LOT), which has been specifically developed for porous asphalt pavements. This model includes a deterministic element which predicts the failure type and the number of vehicle passages required to cause such a failure (Huurman, 2007), and a probabilistic model which relates ravelling to the distribution of material constituents, production conditions and service life conditions and calculates the effects on lifetime of changes to these distributions/conditions. The objective of the LOT is to promote the optimization of TLPA without the need for rigorous manufacture of test samples and test sections. It is intended that a surfacing contractor will be able to use the LOT to develop a TLPA surface with a structural lifetime (in terms of the upper layer) that it is at least two years longer than that of the TLPA currently in use on the Dutch highway network; such an improved TLPA was one of the key objectives within the IPG, however it is noted that it has not been possible within the timescale of the IPG to practically demonstrate that such an improvement is achievable.
The structural durability of porous pavements in Japan is generally comparable to dense asphalt mixes. In the warm regions of the country, structural durability is 10 years or greater. A number of high performance surface treatments have been developed which are applied to porous pavements to prevent ravelling and also help to prevent clogging of the pavement, thereby reducing the necessity for cleaning. These treatments include (Nielsen et al., 2005):

- Permeable Resin Mortar System (PERMS) which is an epoxy resin mortar with a fine (porous) ceramic material (aggregate size 1.5 mm). This fills the voids of the porous pavement but retains most of the permeability of the surface (a loss of only approximately 10% occurs). Two types of resin are used: one for use in summer conditions and one in winter conditions. The resultant skidding resistance is equivalent to or better than that for porous asphalt. The treatment has been mainly used on urban roads as a way of improving shear resistance;

- “Top Coat” which uses a methyl-methacrylic resin (sprayed onto the porous surface in two coats) with a fine silica sand that is scattered on the surface after each application of the resin.

### 6.2.1 Clogging of porous surfaces

During its service life, porous asphalt tend to become clogged by dirt, dust and general detritus arising from the wear of both the surface and vehicle tyres. Also, based on observations in the Netherlands and Denmark, it has been reported (Bendtsen and Larsen, 2002) that tyres can transport dirt onto porous pavements from adjacent pavements. Furthermore, surfaces become compacted over time by traffic which leads to a reduction in void content. As the pore volume is reduced, so the noise reduction benefits and drainage performance of the surface is degraded. The effects of clogging on noise reduction performance are described in the previous chapter.

The literature identifies two types of pore-blocking (Morgan, 2007). The initial build-up of dirt particles in the pores is referred to as ‘caking’; this is completely reversible by cleaning of the surface. A film formed by the drying of particles in water suspended in the pores then begins to accumulate; this grows in thickness until it forms a complete plug which cannot be removed by cleaning. This irreversible accumulation is referred to as ‘clogging’.

The cleaning of porous surfaces to tackle the problems of clogging, with the aim of restoring the acoustic performance and durability of the surface is discussed in Section 0.

One method for measuring the degree of clogging of the pavement is to measure the permeability, generally using a falling head-based method, similar to that described in DD229:1996 (British Standards Institution, 1996). It is therefore recommended that the permeability of the surface is measured prior to the opening of the road to traffic in order to provide a reference level which can be used for comparison with measurements over the lifetime of the surface.

Hamzar & Hardiman (2005) state that there is a significant loss in permeability of porous pavement after two to three years in service because of clogging of voids by de-icing materials or other debris. In one field study in Europe, the initial drainage times of porous asphalt surfaces in the range of 25-75 seconds increased to 80-100 seconds after 3 years and to 160-400 seconds after 9 years (Kraemer, 1990).

Work investigating the processes resulting in the ravelling and clogging of TLPA has been carried out within the Dutch IPG programme (under the framework of the DRI-DWW Noise Abatement Programme (Larsen, 2004) to improve understanding and aid the development of concepts and methods to overcome these problems.

As part of that study, investigations have been undertaken on TLPA test sections laid on an urban road at Øster Søgade in Copenhagen. A DAC 0/8 was also constructed to serve
as a reference surface. Noise and permeability measurements have been taken annually to investigate the effect of ageing, wear, and clogging of air voids in the porous asphalt. The porous asphalt has been cleaned biannually by high-pressure water/air suction. (Bendtsen et al., 2005). The results for the northbound lane and the southbound lane are reproduced in Figure 6.3. It was observed that there was a strong tendency for clogging on the pavements with 5 mm aggregate (which were clogged after 15-20 months), whereas the pavement with 8 mm aggregate stayed in a much better condition. The reason for the accelerated clogging in the surfaces on the southbound porous surfaces is believed to be dirt and fine material from the adjacent dense asphalt concrete pavement having been dragged onto the porous pavements by vehicle tyres, since clogging first appeared at the position nearest to the reference section. This is an issue that is difficult to mitigate against, but is also one that is fairly localised. It was generally not possible to see significant reductions in the level of clogging from before to after the cleaning of the pavements.

![Figure 6.3: Permeability (s/10 cm) in the wheel track as a function of pavement age in months on Danish urban TLPA trial sections (from Bendtsen et al., 2005)](image)

Permeability measurements have been reported for the French TLPA trial sections by Brosseau and Anfosso-Ledee (2005) for when the surfaces were new and either after a period of 4 years or on an annual basis. These results, together with the associated noise levels on the surfaces (measured using the Controlled Pass-By method) are shown in Figure 6.4. The decrease in permeability after 1 year is in the range 29-35%.

For SLPA it is stated that typical permeabilities are in the range 0.6-1.2 cm/s; a residual permeability of 0.5 cm/s is stated as being sufficient to retain the drainage performance of the surface as well as some noise reduction. No indication is given in the report as to whether the TLPA trial sections were cleaned at any stage during the measurement programme, and no explanation is offered as to the sudden changes in noise level after 5 and 6 years; in view of the steady decrease in permeability, it is considered that the noise level increases are most likely to be a result of ravelling of the surface and that some form of maintenance might have been undertaken prior to the noise measurements in year 6.
For the TLPA trial sections in Japan described by Taksumoto et al. (2003), a decrease in porosity of between 15-35% was observed after 12 months. For a TLPA pavement in general use on a highway carrying more than 3000 vehicles/day in one direction, a loss in permeability of 14% was observed after 12 months. This corresponds to a decrease in noise (measured using the Road Acoustic Checker) of approximately 2 dB(A). It was concluded that the permeability was comparable to that of a standard SLPA.

6.3 Safety performance

Porous asphalt surfaces are widely used across the EU, primarily for their noise reduction benefits. However, they also offer additional safety-related benefits relative to traditional dense surfaces. These benefits are addressed in the following sections. It is noted that much of the information is applicable to porous surfaces in general, and not specifically TLPA.

6.3.1 Initial skidding resistance

“Early life” skidding phenomena occur with all types of asphalt. This can become a concern where some European countries have specific requirements for skid resistance to be met by new road surfacings.

Consideration of any potential UK-specification TLPA would require meeting UK skidding resistance specifications as stated in Volume 7, Section 3, Part 1 (Skidding Resistance) of DMRB (Highways Agency, 2004). The standards are based on “equilibrium skid resistance” which is that achieved after the initial period in which the binder film on the surface is removed and the aggregate has been polished by traffic action.

The skid resistance of TLPA in early life has not been specifically studied in the UK. If, as suggested by discussions with UK surface manufacturers (Chapter 9), a UK TLPA was based on existing thin layers, then it is unlikely that there would be any differences compared to existing surfaces. Experts at TRL also consider that TLPA is likely to exhibit similar effects to those observed on other asphalt surfaces (Roe and Lagarde-Forest, 2005), namely:
• Dry locked-wheel skid resistance may be reduced by the presence of a thicker binder film, but the effects will probably be similar to those on other newly-laid asphalt surfaces;

• Wet skid resistance will generally be similar to that accepted on older surfaces. At low speeds, wet skid resistance can sometimes be relatively high compared to older polished surfaces;

• The lower levels of skid resistance reached at high speeds on old well-polished surfaces may be achieved at relatively lower speeds while there is bitumen present to mask the aggregate microtexture. However, it is likely that these effects could be offset by the porous nature of the texture and the smaller aggregate sizes, although there have been no direct tests on materials of this type.

In the UK, skid resistance is controlled by requiring an appropriate PSV and texture depth. A clear issue with TLPA is what happens if the surface clogs and the texture is filled on a surface with smaller aggregate particles. This is one area that will form part of ongoing research on the use of smaller-size aggregates in thin surfacings.

The following paragraphs summarise the skid resistance information that has been identified for TLPA trial sections in various locations in Europe measured using a variety of methods. It is noted that measurements of skid resistance in the UK are taken using a Sideway-force Coefficient Routine Investigation Machine (SCRIM) in accordance with the specifications of DMRB Volume 7, Section 3, Part 1 and the results reported in terms of the Characteristic SCRIM Coefficient (CSC).

Measurements in the Netherlands have shown there to be a large scatter in the level of initial skidding resistance measured on TLPA. In some circumstances skidding resistance as measured in accordance with Dutch standards was observed to be below the acceptable safety limits when the surface was newly laid. The skidding performance of TLPA (as well as other surfaces) is likely to be poorer than expected until the binder film has worn off from the top layer of stones. In some instances, signs are placed after construction to warn road users of longer braking distances. These signs are then removed after a couple of weeks or months (Eijbersen, 2005).

As part of the IPG programme, research has been undertaken to investigate methods for improving the early-life skidding resistance. These methods included both post-laying treatments and in-mix treatments. The latter approach was found to be the most effective. While a number of different additives were observed to be beneficial for wet braking performance, only one of these, 0/1 glass slag, also proved beneficial for dry braking performance. Drainability, noise reduction and texture characteristics were not affected by the use of the glass slag and no additional costs were incurred through using this additive (Morgan, 2006).

On the French TLPA trial sections, Brosseaud and Anfosso-Ledee (2005) only report skid resistance measurements for one of the sections, namely the 4/6-10/14 TLPA with upper and lower layer thicknesses of 20 mm and 30 mm respectively. Values are stated for 1997 (the year in which the surface was laid) and it is assumed that this is an initial measurement. At 90 km/h, a Brake Force Coefficient (BFC) of 0.38 was recorded. Measurements were also taken at two other speeds, resulting in a BFC of 0.56 (40 km/h) and 0.45 (60 km/h). Results are also reported for 1998 and 2001 (assumed to be at 1 year and 4 years); at 90 km/h, the BFC was 0.40 and 0.34 respectively.

On the Italian trial section of TLPA laid on the Venice-Trieste motorway, Battiato et al. (1996) reported that SCRIM measurements taken 30 days after the surface was laid resulted in a mean skid coefficient value of 0.72 in lane 1. After 12 months the skid coefficient value was 0.70.

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16 The UK Highways Agency is examining the use of 6mm surfaces through a project from 2005 to 2007.

17 Skid resistance measurements under wet conditions are carried out at 50 km/h and 86% wheel resistance, in accordance with Dutch Standard RAW2000, Test 150 (minimum requirement: 0.38).
Japanese contractors are known to use special surface treatments, such as fine silica sand, where TLPA is used on intersections in urban areas to improve, amongst other properties, skidding resistance (Nielsen et al., 2005).

An evaluation of skidding resistance and stopping distances on single-layer porous asphalt compared to dense asphalt (Delanne et al., 1991) showed no differences in stopping distances. A separate study showed that the sideway force coefficient 3 weeks after opening was the same for both SLPA and dense asphalt pavements (Nicholls, 1997b). However evidence has been reported that new porous asphalt has lower skidding resistance values when braking with locked wheels. When braking hard, the thicker bitumen film on porous asphalt can 'melt' and become slippery which leads to braking distances that are 20-40% longer than on dense asphalt (PIARC, 1995). It is not known whether TLPA exhibits the same characteristics.

6.3.2 Splash/spray effects

Providing that the porous surface has a sufficient water bearing and drainage capacity, it can have a significant effect on splash and spray. The properties of the pavement which affect this performance are the thickness of the open layer, the percentage of air voids in the mixture, the extent to which these voids are connected, and the slope and evenness of the dense subgrade beneath the porous surface.

Nicholls (1997) reported that the spray on newly-laid single-layer porous asphalt was reduced by 95% compared to dense asphalt. This benefit reduced with time, stabilising at a reduction of one third after a period of 5-10 years.

The effects of wet weather on driving speeds on single-layer porous asphalt and dense asphalt have been compared. One study (Nicholls and Daines, 1992) showed that on high-speed roads, car drivers appear to reduce speed in wet weather by 10 km/h on dense asphalt compared to 7 km/h on porous asphalt. HGVs were observed to reduce speed by 2 km/h on both surfaces. However, it was considered that the speed reductions were conservative because the length of the porous sections were relatively short and that the reduced slowing down of vehicles in wet weather might have an adverse impact on safety. In a different study (Edwards, 2002), motorists speeds in wet weather were reduced on average by 4 km/h on both surface types compared with dry conditions, however the average speeds on porous asphalt were 10 km/h higher under both wet and dry conditions.

UK experiences have shown that porous asphalt remains pervious for over 6 years, equivalent to a permeability measurement of 50 seconds (Davies, 1992). However, even when the hydraulic conductivity of PA approaches zero, the spray will still only be half that of HRA (Nicholls and Daines, 1992).

The choice of surface used in the emergency lane may also indirectly have an effect on splash/spray. If a dense surface is laid in the emergency lane, adequate provision for drainage must be made to prevent the ponding of water within the structure of the pavement and associated damage; if such drainage is inadequate, then under particularly wet conditions, the surface may become saturated resulting in water ponding on the surface of the pavement.

6.3.3 Accident reduction potential and the effects on risk factors

A survey on the effects on road safety of porous asphalt surfaces was undertaken as part of the EU SILVIA project, based on accident data. However the results were generally inconclusive, with some studies estimating a reduction in the number of accidents and others estimating an increase. Overall no statistically significant effect on the reduction of accidents by using porous surfaces could be determined.
As part of the same project, a review of the effect of using porous asphalt on risk factors associated with accidents was carried out to determine if this could be a more effective approach. The open-graded structure of porous asphalt affects several different factors and the effects are summarised in Table 6.4 (Elvik and Greibe, 2003). The net effect of the impacts on risk factors is difficult to assess, since it depends on the relative magnitude of the effects. It was concluded that the mix and complexity of the effects on risk factors make it impossible to predict a corresponding change in accident rate.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Effect of using porous asphalt on risk factor compared to dense pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Splash and spray – visibility in wet weather</td>
<td>Favourable</td>
</tr>
<tr>
<td>Risk of aquaplaning</td>
<td>Favourable</td>
</tr>
<tr>
<td>Rutting – unevenness</td>
<td>Favourable</td>
</tr>
<tr>
<td>Light reflection</td>
<td>Favourable</td>
</tr>
<tr>
<td>Friction – stopping distance</td>
<td>No effect</td>
</tr>
<tr>
<td>Speed</td>
<td>Adverse*</td>
</tr>
<tr>
<td>Performance in wintertime</td>
<td>Adverse</td>
</tr>
<tr>
<td>Need for more frequent resurfacing</td>
<td>Adverse</td>
</tr>
</tbody>
</table>

* Further studies required to confirm this

### 6.4 Summary of findings

**Acoustic performance:** The acoustic performance of TLPA has shown clear advantages over existing thin surfaces. Based on Dutch data, the indication is that an initial Road Surface Influence (RSI) of the order of 11 dB is achievable.

Measurements of the acoustic performance over the lifetime of TLPA surfaces have been undertaken in some European countries and these have shown a similar drop-off in performance to existing thin surfaces. The durability of the acoustic performance is dependant upon keeping the pores within the surface free of detritus.

**Structural performance:** Structural durability is an important consideration with TLPA. Failure of the surface is generally as a result of ravelling of the upper layer. Based on European experiences, the structural lifetime of the upper porous layer is typically 7 years which is significantly less than that of the thin layers already used on the Highways Agency’s strategic road network (typically 8-12 years, 10 years on average). Research is continuing in the Netherlands to increase this to at least 9 years, although the true durability of optimised surfaces has yet to be demonstrated. The structural durability of Japanese TLPA has been observed to be 10 years or greater.

**Safety performance:** As with most asphalt pavements, there are issues over early life-skidding resistance until the binder film has been worn away. Work in the Netherlands has been undertaken to investigate the use of additives such as glass slag to improve
early life skidding resistance. Any TLPA laid in the UK would be required to satisfy UK skid resistance requirements, which are not based on the skid resistance when new. Porous asphalt surfaces also offers improved splash/spray performance over traditional dense surfaces.
7  Wider environmental impacts

The Department for Transport has an overriding target to improve the environmental performance of transport. Under this overall target, the Highways Agency must mitigate potentially adverse impacts from the network and take opportunities to enhance the environmental benefits, taking into account value for money. This chapter covers the key areas that may be affected through the use of TLPA. It should be noted that air quality issues have not been considered within this project, however it has been remarked (James, 2003) that the drainage properties of porous asphalt contribute to reducing the amounts of airborne pollutants from roads.

7.1  Resource use

One of the most significant differences between the surfaces currently laid on the UK highway network and TLPA is the overall thickness of the two layers. This will result in a more rapid use of aggregate supplies, particularly if the upper layer is comparable to that used in existing thin layer surfaces, e.g. 10 mm aggregate. The reduced structural lifetime of the upper layer of TLPA relative to existing thin surfaces would further accelerate the use of aggregate supplies. It may be possible to use aggregate in the lower layer with a lower PSV value since there is no direct contact between the lower layer and the vehicle tyres (Nicholls and Carswell, 2001), although this would need to be investigated since no detailed information has been identified within the literature. It will become a problem, however, if the upper layer strips away in significant quantities but such stripping is likely to result anyway in failure of the surface through rutting.

The long-term availability of suitable aggregates would need to be discussed with suppliers to assess the potential scale of application of TLPA on the network. Concerns were raised during discussions with one of the contractors (see Section 9) regarding the availability of high quality 6 mm aggregate and the amount of waste material generated during its manufacture. At present, there is a potential surplus because it is a by-product of producing larger sizes for most modern asphalts. However, it is also possible that 6 mm material may be accepted for wider use in thin surface courses in future, which will mean that there will be even less high PSV premium aggregate available.

The importance of being able to use recycled materials is therefore a key feature in the potential long-term use of TLPA. The potential for using recycled materials in TLPA is not one that is discussed widely in the literature. Most studies/reviews, e.g. Pucher et al. (2004), Sanders (2005), focus on the differences between recycling dense asphalt surfaces and porous asphalt surfaces.

It is not clear as to the potential for using recycled material from dense asphalts, e.g. recovered aggregates from 10 mm and 14 mm thin surfaces, as Recycled Asphalt (RA) in new porous pavements. The development of hot in-place transformation techniques for recycling dense asphalt into twin-layer porous asphalt pavements has been discussed by Hosokawa et al. (2006). Section 7.3 includes further information on recycling.

In terms of the wider implications of using porous asphalt surfaces, Veisten and Saelensminde (2004) reported as part of the EU-funded SILVIA project that with current technologies the use of porous asphalt (not specifically TLPA) instead of dense asphalt may involve the following changes in resources:

- More material use in surfacing and resurfacing;
- A lower usage of recycled material;
- Increased use of energy/transport in repairing, eventual cleaning, and eventual dumping;
- Eventual additional activity/care (involving energy, transport, etc) in waste handling. This also includes the handling of waste water from the cleaning of porous surfaces (James, 2003).
The need for increased de-icing on porous road surfaces will require greater use of salt; over 2 million tonnes of salt are already spread onto the UK roads each year (Salt Union Ltd, undated). According to the UK Salt Manufacturers Association, proven UK salt reserves are extensive, with an estimated 500 years capacity at current extraction rates (Salt Manufacturer's Association, undated), however highway authorities should still be prudent in their use.

7.2 Water run-off and roadside pollution

The impact of pollutants will be dependant upon traffic volume and the use of near-by waterways but also on the extent to which these pollutants reach these waterways. James (2003) compiled a summary of road pollutants, their sources and possible negative impacts, and identified that the run-off of pollutants can be greatly affected by changing from a traditional (dense) asphalt pavement to a porous pavement. The draining of rainwater through the pores in the surfaces produces a filtration effect which removes the majority of particulates suspended in the rainwater. Road pollutants such as heavy metals and PAHs (polynuclear aromatic hydrocarbons) attach to particles of dirt so are quite effectively removed by this filtration process; porous asphalt has been found to remove around 90% of the PAHs and heavy metals present in water run-off. The pollutants are trapped in the pores of the surface; allowing them to build up makes the surface more difficult to recycle at the end of its lifetime.

The laying of porous asphalt pavements can affect flooding and draining. Compared to dense asphalt, it has been argued (Berbee et al., 1999; Pagotto et al., 2000) that the absorption properties of porous asphalt allow a more gradual run-off of water as well providing the filtering effects outlined above. It has been also been estimated that 80% of rainfall is removed by evaporation on porous asphalt compared to 15% on conventional asphalt pavements (van Bohemen and van de Laak, 2003).

The issue of providing adequate drainage is an issue that must also be acknowledged. If the emergency lane is not paved with TLPA, then artificial drainage must be incorporated in the emergency lane to prevent ponding of water within the structure of the pavement.

The reduction of splash and spray has a significant effect on the degree of pollution dispersed by that mechanism (James, 2003). The effects of splash and spray reduction on safety is discussed in Section 6.3.2.

The main potentially negative effect on water pollution from a change to porous asphalt is related to winter maintenance. The thermal properties of porous asphalt demand a more extensive use of de-icing salting (James, 2003). This may have an adverse effect on run-off partly because of the increased concentrations of de-icing chemicals but also because increased acidity increases the secretion of heavy metals which are trapped within the pores of the surface. However, the reported necessary increase in use of de-icer, relative to ordinary dense asphalt, varies considerably. The percentage increase in the frequency in applying de-icer varied from 30% to 100 % and the quantity of de-icer from 30% to 450%.

In the short term therefore, while the voids in the pavement remain unclogged, there will be positive effects from using TLPA on water run-off (in terms of absorption and filtration) but negative effects due to de-icing. The run-off effect will be of greater importance in those areas which combine exposed watersheds and high populations/traffic volumes. This issue will become increasingly important as a result of the EU Water Framework Directive; further research may therefore be needed, and the issue should be one of the factors considered in assessing the use of TLPA in different locations.
7.3 Recycling of surface courses

Sanders (2005) summarised the different methods available for the recycling of surface courses as follows:

- **Hot in-place recycling:** Defined as a process to correct asphalt pavement distress by softening the existing surface with heat, mechanically removing the pavement surface, mixing the reclaimed asphalt with a recycling agent, possibly adding virgin asphalt and/or aggregate and relaying. This is normally performed by a train of machines working in succession;

- **Cold in-place recycling:** This involves pulverising an existing pavement, sizing the reclaimed asphalt pavement (RAP), incorporating additives before placing and compacting the material and overlaying with new material;

- **Hot off-site recycling:** The recovered material is mixed with virgin aggregates in specified mixing blends;

- **Cold off-site planning:** A process where asphalt layers are removed by scarification to a specific depth and the surface restored to a desired grade and slope, free of bumps etc, e.g. to roughen or texture the pavement to restore skid resistance properties. The reclaimed material is taken away from site and stockpiled for future use.

Socelit Autostrade investigated a technique for recovering the functionality of porous pavements without substantially modifying the structure (Peroni *et al.*, 1996). This involved a hot removal of the material using infra-red preheaters and rejuvenation of the binder by the addition of polymers to recover the properties lost due to environmental ageing and during the hot recovery process. Alteration of the aggregate grading due to the recovery process was corrected by adding natural quarry material or expanded clay, which also provides a high resistance to polishing.

Another similar experiment was conducted in France when a porous asphalt layer was recovered and replaced by a new porous layer containing up to 50% of the old porous layer (Alvarez *et al.*, 1996).

The properties of any reclaimed asphalt used in new porous asphalt layers are governed by ISO 13108-8:2005 (International Organisation for Standardisation, 2005).

It may be considered that the potential for recycling is lower with porous asphalt than with other surfaces, due to accumulated debris and contaminants in the pores. For example the accumulation of pollutants like heavy metals and PAHs in the worn porous pavement could impede recycling since it may need to be handled as hazardous waste. Descornet *et al.* (1998) reported that the quantities of pollutants in worn porous asphalt are generally low and that in Belgium, for eventual dumping the worn porous asphalt could be allowed at certain sites without cleaning.

However, it seems possible to recycle a large share of worn porous asphalt, although possibly to a slightly lesser degree than for dense asphalt types. Pucher *et al.* (2003) estimate an average recycling rate of roughly 80% or higher for dense asphalt and 50-80% for porous asphalt.

Discussions with UK surfacing contractors (see Chapter 9) have identified that porous asphalt surfaces can be recycled for use in thin surfaces. Carswell *et al.* (2005) reported an investigation into the feasibility of recycling thin surfacings and other asphalt pavements (including porous asphalt) back into thin surfacing systems. Samples of porous asphalt planed off the M40 in 1994 were investigated. The aggregate properties were reasonably close to what would be expected based on values for the original constituent materials; the similarities indicated that the suitability of an aggregate for recycling can be assessed either from prior knowledge of the component materials or testing samples of recovered aggregate. After recovery of the binder, the grading composition showed an increase in the quantity of fines for sizes 3.35 mm and below.
The recovered binder content was less compared to the original specification, considered to be a result of binder being worn off the aggregate surface through trafficking and a build up of detritus within the layer. Significant binder ageing was observed in the recovered binder. The maximum theoretical proportions of recycled 20 mm asphalt that could be used in a 14 mm thin surfacing were reported as being between 25-47%, although the precise result was dependant upon the type of pavement that the material was to be recycled into and the laboratory where the analysis was performed. A successful trial was carried out using 10% and 30% RA (Recycled Asphalt) mixtures in both a proprietary 14 mm thin surfacing and a 14 mm SMA surfacing using the porous asphalt plainings.

The following points need to be considered when recycling porous asphalt into new surfaces:

- The penetration of the binder in the old material can be very low down to values of 10pen. There could be problems regarding blending such a bitumen with the new binder;
- If a modified binder is used in the old porous asphalt there could be compatibility questions about the use of the modified binder with the newly added binder;
- Through the pollution of the old porous asphalt, which can consist of an accumulation of organic as well as inorganic materials (such as heavy metals), environmental specifications for the surface may be exceeded.

Despite these problems there are reports from several countries about recycling of old porous asphalt. Adding low percentages of this material into new asphalt has generally worked well (PIARC, 1995).

### 7.4 Fuel consumption

As part of the SILVIA project, a literature review and measurement programme were undertaken in order to investigate the possible effect of road surface effects on rolling resistance and thereby fuel consumption. The literature review (Bendtsen, 2004) identified no specific data for porous pavements on the effects on rolling resistance. The measurement programme (Ejsmont et al., 2005) was carried out on a range of surfaces including TLPA with 2/6 (two test sections) and 4/8 (four test sections) upper layers. For a patterned tyres at 70 km/h, the average reduction in rolling resistance relative to a DAC 0/16 reference surfaces was 12.5% for the TLPA with a 2/6 upper layer, 7.5% for a TLPA with a 4/8 upper layer; this compared with a reduction of approximately 35% for SMA 0/8 and a reduction of 2.5% for single-layer porous asphalt.

The rolling resistance of tyres on low-noise surfaces, with a particular interest in TLPA, has been undertaken within the Dutch IPG programme. A round-robin test of measurement systems for determining the rolling resistance of road surfaces and the energy consumption of vehicles was performed by a group consisting of partners from the Netherlands, Belgium and Poland (Roovers et al., 2005). Table 7.1 ranks the surfaces tested based on their measured rolling resistance. The Table has been expanded to include some indication of the corresponding fuel consumption on such surface; these values have been derived using a conversion based on French data provided by Descornet (1990).  

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18 The penetration value 'X pen' for a binder is defined by the depth ('X' tenths of a millimetre), to which a standard needle having a 100g load on it will penetrate a standard sample cup of bitumen at 25°C centigrade in 5 seconds. For example a 10pen binder is one where the needle penetrates 1 mm. The method is described in BS EN 1496 (British Standards Institution, 2007). The smaller the number, the stiffer the material.

19 It should be noted that the minimum rolling resistance coefficient reported by Descornet was 1%, measured on a very smooth artificial surface (constructed from pure epoxy); 1.13% was the smallest coefficient measured on a real pavement.
Table 7.1: Rank ordering of road surfaces based on rolling resistance measurements

<table>
<thead>
<tr>
<th>Road surface</th>
<th>Location</th>
<th>Rolling resistance coefficient cR (%)</th>
<th>Fuel consumption (ml/10 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement concrete with burlap – smooth</td>
<td>Germany, A4</td>
<td>0.86</td>
<td>630</td>
</tr>
<tr>
<td>Stone mastic asphalt (SMA) 0/8</td>
<td>Germany, A4</td>
<td>0.86</td>
<td>630</td>
</tr>
<tr>
<td>Twin-layer porous asphalt (TLPA) 2/6*</td>
<td>Netherlands, A15</td>
<td>0.97</td>
<td>640</td>
</tr>
<tr>
<td>Twin-layer porous asphalt (TLPA) 4/8*</td>
<td>Netherlands, A15</td>
<td>1.02</td>
<td>640</td>
</tr>
<tr>
<td>Cement concrete transversely brushed – rough</td>
<td>Netherlands, A59</td>
<td>1.04</td>
<td>640</td>
</tr>
<tr>
<td>Single-layer porous asphalt (SLPA) 6/16</td>
<td>Netherlands, A59</td>
<td>1.05</td>
<td>640</td>
</tr>
<tr>
<td>Dense asphalt concrete (DAC) 0/16</td>
<td>Netherlands, A15</td>
<td>1.09</td>
<td>650</td>
</tr>
<tr>
<td>Gußasphalt 0/11</td>
<td>Germany, A4</td>
<td>1.18</td>
<td>660</td>
</tr>
</tbody>
</table>

* Figure refers to aggregate size in upper layer

Even based on this limited dataset, it is foreseen that TLPA would be considered to be unfavourable in any examination of carbon emissions that are required in air quality assessment. A more detailed assessment of TLPA in comparison to the thin surfaces currently used on the strategic network would be required in order to assess its suitability for application in the UK in respect to this issue.

7.5 Effects of climate change on pavement use and maintenance

The major effects of climate change on asphalt pavements in the UK, based on a study of local highways (i.e. not the Highways Agency’s strategic road network), have been summarised by Willway et al. (2007) and are shown in Table 7.2. Highway engineers are already faced with some of these maintenance issues, but it is expected that the frequency of occurrence and the areas of the network affected will increase.

Table 7.2: Summary of climate induced effects on UK asphalt pavements (from Willway et al., 2007)

<table>
<thead>
<tr>
<th>Excess water</th>
<th>Soil moisture deficit</th>
<th>High temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>o Binder stripping</td>
<td>o Subsidence</td>
<td>o Increase rutting</td>
</tr>
<tr>
<td>o Surface scouring</td>
<td>o Cracking</td>
<td>o Fatting</td>
</tr>
<tr>
<td>o Scouring at saturated asphalt layer interfaces</td>
<td></td>
<td>o Reduced skid resistance</td>
</tr>
<tr>
<td>o Hydroplaning in water filled ruts</td>
<td></td>
<td>o Increased cracking</td>
</tr>
<tr>
<td>o Increased run-off</td>
<td></td>
<td>o Contribution to heat island effect</td>
</tr>
</tbody>
</table>
By 2080, climate models indicate that the UK climate could have similarities to that currently experienced in more southerly countries. However, caution needs to be exercised when using spatial analogies as precise comparisons can be misleading. Any experiences from countries with porous pavements should be taken into account in future, to avoid problems that have already been addressed elsewhere. However at the present time, the use of TLPA in southern Europe has been largely restricted to trial sections, so little practical information is available.

7.6 Summary of findings

There are issues which must be considered over the availability of smaller aggregate sizes, e.g. 6 mm, for use in the upper layer of TLPA. This may become a bigger issue if the wider use of smaller aggregates in thin surfacings is accepted. Potentially, it should be possible to use lower quality aggregate in the lower layer of TLPA since it is not in contact with vehicle tyres.

Whilst porous asphalt pavements can be beneficial in the removal of PAHs and heavy metals from surface water run-off, the increased requirement for winter salting may have an adverse effect on run-off. There will be an increased demand for salt reserves for winter maintenance.

Porous asphalt pavements can be recycled for use in thin surfaces. A range of processes/methods are available for the recycling. The use of recycled materials in porous asphalt pavements is less well reported.

It is expected that the effects of climate change will lead to an increase in the maintenance issues that are currently experienced with asphalt pavements. However, experience with TLPA in countries with warmer climates is generally restricted to trial sections.

Further investigations relative to thin surfaces used in the UK are considered beneficial, particularly in relation to rolling resistance, full consumption and emissions.
8 Whole life costs of twin-layer porous asphalt

An important consideration in recommending whether TLPA should be introduced in the UK is the costs associated with the use of the pavement. This encompasses not only the costs of the materials, but also construction, maintenance and other associated costs.

Based on a review of information collated during the EU-funded SILVIA project, Veisten and Saelensminde (2004) reported that there are likely to be extra costs associated with the use of porous asphalt surfaces (not specifically TLPA) in comparison to dense asphalt, related to:

- The increased amount of new material required;
- The reduced use of recycled material and relatively more expensive recycling technology;
- The increase in maintenance (repairing/repaving, in addition to cleaning to prevent/recover from clogging, and increased salting in winter climate);
- A higher degree of dumping of waste materials.

Davis (2006) reports that the costs of twin-layer porous asphalt are typically 25 to 35 per cent higher than conventional costs.

The following sections relate to specific cost-effectiveness and cost-benefit calculations that have been carried out specifically related to the application of TLPA on high-speed roads in the Netherlands and on low/medium speed roads in Denmark.

8.1 Dutch calculations

To best understand whether the use of twin-layer porous asphalt is cost-effective, it is necessary to consider the whole life costs of the pavement rather than the initial costs.

Whole life cost effectiveness or (life-cycle cost analysis) is calculated using the Net Constant Value (NCV) method. In this method the total costs, i.e. a combination of both construction and maintenance costs, is determined. As part of the Dutch IPG programme (see Section 3.1.1), a lifecycle cost analysis has been assessed to determine if TLPA is a cost-effective alternative for (higher) noise barriers. Within the calculation,

- Resurfacing costs were based on the actual costs of recent works in the Netherlands where TLPA was used. All costs associated with resurfacing were included, e.g. removal of the existing top asphalt layer, any erection of safety fences placed during maintenance;
- Maintenance costs were based on the maintenance procedures that are used in the Netherlands for SLPA. This involves a major maintenance cycle based around 4 lifetime phases for the pavement which extends over a period of approximately 22 years; at the end of the first and third lifetime phases only (7 and 18 years respectively) the porous asphalt of the nearside lane (i.e. the lane carrying the bulk of the heavy traffic) is replaced, at the end of the second phase (11 years) the porous asphalt in all lanes is replaced and at the end of the fourth phase (22 years) the porous asphalt in all lanes is replaced and the sub-layers are reinforced (See Table 5.1).

In the case of TLPA at the end of the first and third phases, only the upper layer is replaced.

Minor maintenance work is not included in the calculations, because the costs are negligible and are equivalent for SLPA and TLPA. In addition, no social or user costs are included as it was considered that they are arbitrary and depend much on the size and type of the construction (Hofman et al., 2005c). It is noted that in the UK information no such costs have been calculated.
The data used for SLPA and noise barriers was based on data available in the manuals of Rijkswaterstaat (the Dutch Directorate-General for Public Works and Water Management). In the NPV method future expenditures are discounted to present value; in this instance, the current analysis a discount rate of 4% was used. Table 8.1 shows the results of the analysis comparing the NPV for TLPA with that for DAC, SLPA and noise barriers (Note that this Table has been updated from that presented in the original reference based on 2007 data provided by RWS DWW).

Table 8.1: Cost Effectiveness of SLPA & TLPA in comparison to that of noise barriers (based on 25 m wide roads which comprise 2x2 lanes and 2 emergency lanes)

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Construction Costs (€/m²)</th>
<th>Yearly Maintenance Costs (€/m²)</th>
<th>NCV over 30 years (€/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAC</td>
<td>19</td>
<td>1.2</td>
<td>30</td>
</tr>
<tr>
<td>SLPA</td>
<td>23</td>
<td>2.15</td>
<td>50</td>
</tr>
<tr>
<td>TLPA</td>
<td>27</td>
<td>3.07</td>
<td>60</td>
</tr>
<tr>
<td>Noise Barrier</td>
<td>No data available</td>
<td>No data available</td>
<td>492</td>
</tr>
</tbody>
</table>

In a separate assessment, the cost effectiveness of TLPA was compared to the use of SLPA in combination with a noise barrier for different situations including whether one or both sides of the road required screening and different height noise barriers. This assessment was included because where high levels of noise mitigation are required, this might be achieved using TLPA instead of the combination of SLPA and noise barriers. Furthermore, it is known that public acceptance of noise barriers is lower than for low-noise pavements due to the increase in visual intrusion.

In all cases the width of the road was fixed at 25 m and the pavement across all lanes was renewed with either SLPA or TLPA depending on the scenario. Figure 8.1 illustrates the results of this investigation.

When a noise barrier is only required on one side of the road, using TLPA can lower the cost of mitigation in that situation by up to 55%. However in some cases, e.g. where the height of an existing noise barrier only requires to be increased by a small amount, e.g. by 0.5 m, using TLPA is a more expensive option. When noise barriers are required on both sides of the road (i.e. for the existing situation there are either no barriers or a barrier only on one side of the road), using TLPA was always found to be more cost effective.

It was calculated that depending upon the content of future noise legislation, with the expected growth in traffic density, an investment of €1-2 billion in noise barriers would be required for the whole Dutch State network (3600 km of motorway) if mitigation were to be provided by the combination of SLPA and noise barriers (Hofman et al., 2005c). In contrast, if TLPA is used where additional noise mitigation is required, it was estimated that the costs could be reduced by €200-500 million.
8.2 Danish calculations of cost-effectiveness

8.2.1 Assessment on low-speed roads, Øster Søgade, Copenhagen, Denmark

As part of the Øster Søgade trials in Copenhagen, Denmark, the costs of using TLPA in an urban environment have been assessed against the costs of other mitigation measures, namely noise barriers, and sound insulation, for a 30 year period (Larsen and Bendtsen, 2001; Larsen and Bendtsen, 2002). The calculations considered a 50 km/h 2-lane central city street, a 70 km/h 4-lane urban ring-road and 110 km/h 4-lane motorway running through a suburban area; in each case each road section was 1 km in length. In all cases, it is assumed that there are no mitigation measures in place at the beginning of the 30 year period, i.e. TLPA or noise barriers or sound insulation will be installed at the beginning of the 30 year period.

The Danish Road Directorate reports that 25-30 years is the expected lifetime for both noise barriers and sound insulation, however no clarification is provided for the basis of these figures. The bottom layer of the twin-layer porous asphalt was assumed to have a lifetime of 15 years, with the upper layer requiring renewal after 7-8 years. The lifetime of a dense asphalt pavement was not specified, but it is greater than that of the upper layer of TLPA. While replacing a dense asphalt pavement with porous asphalt often requires a complete rebuilding of the road because the porous layer is much thicker than the original dense layer, it was considered that since many urban roads in Denmark are old and not built for current traffic loads the major roads would require to be rebuilt regardless. As such, it was only considered necessary to take into account the difference in costs compared to paving a road with DAC.

The costs shown in Table 8.2 were used as the basis for the calculations of NPV for scenarios using DAC and TLPA. Including all of the building and maintenance costs for TLPA and subtracting those for DAC, the increase in the NPV when using TLPA instead of
DAC over a 30 year period was €296,000 for the city street scenario, €360,000 for the ring-road and €477,000 for the motorway.

Table 8.2: Assumed costs for calculating NPV of TLPA pavements over 30 years
(Content from Larsen and Bendtsen, 2001)

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Description of component</th>
<th>Unit cost</th>
</tr>
</thead>
</table>
| TLPA pavement        | Upper layer: 8 mm aggregate, 25 mm thick  
                         Lower layer: 16 mm aggregate, 45 mm thick                              | €5.4/m²  
                         €9.7/m²  |
| DAC pavement         | 30 mm thick                                                                              | €5.6/m²  |
| Foundation           | Saving using TLPA (foundation can be 30 mm thinner than that for DAC pavement)           | -€4.7/m² |
| Drainage             | Pipes and installation of pipes (not needed if road is not in urban area, as no kerbstones) | €53.6/m  |
| Maintenance (renewal)| Renewal of upper TLPA layer, whole TLPA pavement or whole DAC pavement                   | €3.4/m²  |
| Maintenance (cleaning)| High pressure cleaning (twice a year on city streets, annually on ringroads)            | €0.07/m² |
| Maintenance (winter salting) | Winter maintenance on porous asphalt is 50% more expensive than that on DAC      | €4830/km  |

In the 2001 report, the noise reductions for TLPA (relative to DAC) were assumed to be 5, 6 and 7 dB(A) for use in the city street, ring-road and motorway respectively. However these were revised in the 2002 report to 4, 5 and 6 dB(A) respectively and later still, Larsen (2005) reported that the average reduction of the test pavements was 3 dB(A), so that the most realistic assumption would be for noise reductions of 3, 4 and 5 dB(A) for the city street, ring-road and motorway respectively.

Table 8.3 shows the assumed costs used for calculating the NPV of other mitigation measures, namely noise barriers and noise insulation. These costs assume the construction of a new barrier or the installation of new façade insulation; It is not clear precisely what types of materials are assumed for the noise barrier construction or what costs associated with the construction of the barrier are included in the main figures, e.g. the inclusion of any traffic management costs. It is assumed that some basic construction costs (without traffic management) are included in the figures to allow for a valid comparison with the cost of installing TLPA. The need for traffic management in the installation of noise barriers on high-speed roads has a significant impact on the cost of installation. It was assumed that there were 665 apartments on the city street, 399 apartments on the ring-road, and five rows of 87 houses on each side of the motorway.

Based on this information, Table 8.4 compares the 30 year cost (NPV), noise reduction and cost/db/dwelling of the different mitigation measures.

While the figures in the Table indicate that TLPA is the most cost-effective mitigation measure, the noise reduction required when selecting the measure must be taken into account. For example, considering the motorway scenario, then if the required reduction is greater than 5 dB(A), then either noise insulation of a combination of TLPA and barriers must be used; this has a significant effect on cost-effectiveness.
Table 8.3: Assumed costs for calculating NPV of other noise mitigation measures (Content from Larsen and Bendtsen, 2001)

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Description of component</th>
<th>Unit cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise barriers</td>
<td>2.5 m high, high quality noise barrier: Initial cost*</td>
<td>€255/m²</td>
</tr>
<tr>
<td></td>
<td>3.0 m high, high quality noise barrier: Initial cost*</td>
<td>€242/m²</td>
</tr>
<tr>
<td></td>
<td>Maintenance costs</td>
<td>€2.2/m/year</td>
</tr>
<tr>
<td>Noise insulation</td>
<td>For apartments</td>
<td>€4,030/dwelling</td>
</tr>
<tr>
<td></td>
<td>For houses</td>
<td>€6,640/dwelling</td>
</tr>
</tbody>
</table>

* It is not clear what individual costs (if any) associated with the construction of the barriers are included nor what type of materials are used to construct the barrier

Table 8.4: Costs (NPV) and effects of three different noise mitigation measures
(Cost/dB/dwelling is based on linear averages of the noise reductions inside the dwellings). Adapted from Larsen (2005)

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Costs and noise reductions</th>
<th>City street scenario</th>
<th>Ring-road scenario</th>
<th>Motorway scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin-layer porous asphalt</td>
<td>30 year cost</td>
<td>€296,000</td>
<td>€360,000</td>
<td>€477,000</td>
</tr>
<tr>
<td></td>
<td>dB reduction</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Cost/dB/dwelling</td>
<td>€148</td>
<td>€225</td>
<td>€220</td>
</tr>
<tr>
<td>Noise barriers</td>
<td>30 year cost</td>
<td>---</td>
<td>€1,335,000</td>
<td>€1,159,000</td>
</tr>
<tr>
<td></td>
<td>dB reduction</td>
<td>---</td>
<td>0 – 12 (average: 3.9)</td>
<td>0 – 13 (average: 6.2)</td>
</tr>
<tr>
<td></td>
<td>Cost/dB/dwelling</td>
<td>---</td>
<td>€858</td>
<td>€590</td>
</tr>
<tr>
<td>Noise insulation</td>
<td>30 year cost</td>
<td>€2,685,000</td>
<td>€1,607,000</td>
<td>€2,890,000</td>
</tr>
<tr>
<td></td>
<td>dB reduction</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Cost/dB/dwelling</td>
<td>€449</td>
<td>€448</td>
<td>€738</td>
</tr>
</tbody>
</table>

8.2.2 The Danish noise strategy

In 2003, the Danish Ministries of the Environment, Finance, Transport, the Interior and Health, Justice and Economic and Business Affairs published a proposal to reduce noise from road traffic (Ohm and Jensen, 2003). As part of the preparation, a socio-economic evaluation was performed for various road traffic noise mitigation measures, including thin layers and twin-layer porous pavements. This considered the abatement potential, the cost effectiveness and the annual net-benefit in 2020 of implementing the measures. The year 2020 was chosen because this was considered to be the earliest that the full effect of the regulation on vehicle noise emissions and less noisy tyres will be observed. Three different conditions were considered for the scale of use of each mitigation measure: ‘widespread use’, ‘moderate use’ and ‘limited use’ (as defined in Table 8.5).
### Table 8.5: Mitigation definitions the extent of use, from socio-economic analysis associated with the Danish noise strategy (from Ohm and Jensen, 2003)

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Widespread use</th>
<th>Moderate use</th>
<th>Limited use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin-layer porous asphalt pavements &amp; thin layer pavements</td>
<td>- Urban roads: 2,357 km</td>
<td>- Urban roads: 477 km</td>
<td>- Urban roads: 209 km</td>
</tr>
<tr>
<td></td>
<td>- Major urban roads/highways: 1272 km</td>
<td>- Major urban roads/highways: 384 km</td>
<td>- Major urban roads/highways: 102 km</td>
</tr>
<tr>
<td></td>
<td>- Motorways: 325 km</td>
<td>- Motorways: 4 km</td>
<td>- Motorways: 1.5 km</td>
</tr>
<tr>
<td>Noise barriers</td>
<td>- 3 m or 4 m high barriers along 712 km of roads*</td>
<td>- 3 m or 4 m high barriers along 164 km of roads*</td>
<td>-----</td>
</tr>
<tr>
<td>Façade insulation</td>
<td>- 135,000 dwellings (all with noise levels exceeding 65 dB)</td>
<td>- 19,400 dwellings (all with noise levels exceeding 70 dB)</td>
<td>- 2,250 dwellings (all with noise levels exceeding 73 dB)</td>
</tr>
<tr>
<td>Speed reduction</td>
<td>- Reduction of 10 km on ~1690 km of roads with speed limits 50-110 km/h</td>
<td>-----</td>
<td>- Reduction of 10 km on ~164 km of roads with speed limits 50-110 km/h</td>
</tr>
<tr>
<td>Regulation of vehicles</td>
<td>- The full potential using present-day technology is assessed to be 1 dB</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Promotion of low-noise tyres</td>
<td>- The full potential using present-day technology is assessed to be 1.3 dB on high-speed roads and 0.7 dB on low-speed roads</td>
<td>-----</td>
<td>-----</td>
</tr>
</tbody>
</table>

* It is unclear whether barriers are to be put up on one side or both sides of the road, but it appears to be only on one side.

The analysis was done in terms of Noise Exposure Factor (NEF) which is the basis of all Danish cost-benefit analysis of noise from road and rail traffic (the Øster Søgade analysis described above also included NEF calculations).

The NEF is an expression of the accumulated noise load on all dwellings in an area, such that dwellings subject to higher noise levels have a more heavily weighted noise load. The noise load is expressed in terms of ‘annoyance factor’ (determined by a known dose response relationship), the value of which varies according both to the free-field noise level experienced at the property and whether the receptor is indoors or outside. The weighted noise load is this annoyance factor multiplied by a weighting factor, the value of which depends on whether the noise load is outside or indoors (see Larsen 2005 for a detailed explanation of NEF). The higher the NEF, the worse the scale of the noise problem. For England’s strategic road network, a similar type of index, the Noise Severity Index (NSI) is currently used, however a replacement index, the Noise Exposure Index (NEI) is being developed.

The results of the assessment are shown in Table 8.6. The construction of thin layer pavements was estimated to cost 15% more than for dense asphalt pavements and the operating costs for thin layers and dense asphalt concrete pavements were assumed to be the same. By comparison, TLPA pavements involve considerable extra costs for construction, cleaning and winter maintenance and a short expected lifetime (7.5 years compared to 15 years). The costs of twin-layer porous asphalt used were those from the

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20 Area Management Memo No. 43., Prioritisation of category 2, 3 and 4 Noise Mitigation Sites, Highways Agency Controlled Document 65/03.
earlier study by Larsen and Bendtsen (2001). As noted with the previous study, it is not clear precisely what costs have been included in relation to the application of noise barriers. The requirement for traffic management during installation can significantly increase the costs of noise barriers.

Table 8.6: Socio-economic bet-result of various means of noise abatement in 2020 (adapted from Ohm and Jensen, 2003). The NEF reductions are based on the calculated noise levels that are reductions for each abatement method.

<table>
<thead>
<tr>
<th>Means of abatement</th>
<th>Scale of use</th>
<th>NEF reduction</th>
<th>Cost-effectiveness €/NEF/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation of vehicle noise emissions</td>
<td>-----</td>
<td>23,300</td>
<td>3,070</td>
</tr>
<tr>
<td>Promote use of less noisy tyres</td>
<td>-----</td>
<td>19,100</td>
<td>5,020</td>
</tr>
<tr>
<td>Twin-layer porous pavements</td>
<td>• Widespread use</td>
<td>53,100</td>
<td>2,540</td>
</tr>
<tr>
<td></td>
<td>• Moderate use</td>
<td>33,900</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td>• Limited use</td>
<td>22,100</td>
<td>460</td>
</tr>
<tr>
<td>Thin layer pavements</td>
<td>• Widespread use</td>
<td>29,200</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>• Moderate use</td>
<td>19,000</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>• Limited use</td>
<td>12,600</td>
<td>30</td>
</tr>
<tr>
<td>Speed reduction</td>
<td>• Widespread use</td>
<td>22,100</td>
<td>9,280</td>
</tr>
<tr>
<td></td>
<td>• Limited use</td>
<td>15,600</td>
<td>4,720</td>
</tr>
<tr>
<td>Noise barriers</td>
<td>• 3m high: Widespread use</td>
<td>9,700</td>
<td>15,180</td>
</tr>
<tr>
<td></td>
<td>• 3m high: Limited use</td>
<td>6,700</td>
<td>5,030</td>
</tr>
<tr>
<td></td>
<td>• 4m high: Widespread use</td>
<td>10,600</td>
<td>16,980</td>
</tr>
<tr>
<td></td>
<td>• 4m high: Limited use</td>
<td>7,300</td>
<td>5,620</td>
</tr>
<tr>
<td>Façade insulation</td>
<td>• Widespread use</td>
<td>50,900</td>
<td>1,140</td>
</tr>
<tr>
<td></td>
<td>• Moderate use</td>
<td>12,300</td>
<td>680</td>
</tr>
<tr>
<td></td>
<td>• Limited use</td>
<td>2,200</td>
<td>440</td>
</tr>
</tbody>
</table>

The NEF reductions are based on the calculated noise levels that result from the introduction of each abatement measure. It was assumed that the noise reduction potentials for the twin-layer porous pavements relative to dense asphalt concrete were 3, 4 and 5 dB for speeds of 50, 70 and 110 km/h respectively; the corresponding reductions for thin layers were assumed to be 1.5, 2.0 and 2.0 dB respectively.
For the two pavement types, it was assumed that the extent of application is the same, so they are directly comparable.

The Table shows that TLPA produces the greatest benefits in terms of noise reduction (NEF reduction). However, the cost-effectiveness expressed in terms of €/NEF/year is much poorer than for thin layers, and of a similar order to façade insulation in the case of limited use. It is more cost-effective than the other mitigation measures considered.

8.3 General UK cost information

Based on limited information available from UK manufacturers, it is estimated that the costs of twin-layer porous asphalt will be between 20%-25% above that for normal single layer paving, depending on site location.

8.4 Summary of findings

Examination of the basic costs of twin-layer surfaces suggests that a section would cost more to lay than an existing thin surfaces. Estimations of the additional cost range from 20-25% (based on UK estimations). Dutch calculations suggest an additional cost of almost 70% relative to a conventional dense asphalt pavement. From discussions with surfacing contractors, these extra costs are likely to be incurred by additional materials, staff resources and machinery. The whole-life costs of twin-layer porous asphalt, based on European data are significantly higher than dense asphalt pavements, although no comparisons with thin layers are available.

However, when the costs are expressed in terms of noise reduction achieved per unit spent, a twin-layer surface can be more cost effective than single mitigation measures such as noise barriers, or combined measures such as low-noise pavements and noise barriers. The level of cost-effectiveness will be dependant upon the individual costs that are associated with the construction of noise barriers in the calculations, e.g. traffic management costs; this is likely to improve the cost-effectiveness of TLPA in relation to noise barriers.

A general conclusion on the cost-effectiveness of TLPA in relation to noise barriers or combined mitigation measures is not be possible since it will vary depending in the scale of the project and whether barriers are required on both sides of the road. Evaluation is therefore recommended on a case-by-case basis.

Consideration must also be given to the costs associated with ensuring adequate drainage at the roadside when TLPA is used. This will be dependant upon whether the emergency lane is paved with TLPA or a dense surfacing. Artificial drainage will be required if the emergency lane is dense, however cleaning of the emergency lane may be required if the emergency lane is porous. The individual costs of such approaches require investigation.

It is considered therefore that as long as the emphasis is on minimising disruption to journey time rather than on noise reduction potential, the scope for using twin-layer porous asphalt on a widespread basis is low when considered in terms of cost-effectiveness alone.
9  The view of UK surface manufacturers and pavement experts

Although much of this study is focussed on reviewing other countries’ experience with using TLPA, it is necessary to establish whether UK surfacing manufacturers and contractors consider that they would be able to manufacture and construct TLPA pavements. The information from previous Chapters has been discussed with three different manufacturers and their views are reported in the following sections.

9.1  Views of Manufacturer No.1 (from discussions in May 2007)

This manufacturer was familiar with the concept of twin-layer porous asphalt prior to discussions with TRL and amenable to using the surface if the results of the current project indicate it as a feasible option for the Highways Agency. The following is a summary of the key points of the discussions:

Aggregate and mix specifications:

It was the opinion of the manufacturer that the potential basis for a UK-specification TLPA would be a 0/20 mm lower layer and a 0/10 porous friction course (with 24% voids, as used by Defence Estates) as the upper layer. This would use the same aggregate as currently used for thin layers on the trunk road network.

Whilst it was acknowledged that there is a tendency towards smaller aggregates for the upper layer in Europe, e.g. 6 mm, concerns were expressed over the potential long-term difficulties in the supply of high quality 6 mm aggregate in the UK; the manufacture of 10 mm and 14 mm aggregate generates large quantities of 6 mm, but even more > 6 mm waste. Furthermore, the requirement for high quality 6 mm means that many quarries might not be able to supply sufficient quantities. Clearly, this would be dependant upon the level of demand and may be less of an issue if the use of TLPA was restricted solely to areas requiring very high levels of noise mitigation.

In addition, whilst 6 mm surfaces are used on lightly trafficked roads, there are potential concerns with regard to the skidding resistance. Investigation would be needed to determine if aggregate with a lower PSV would provide sufficient skidding resistance\(^21\). The potential wider use of 6 mm material in thin surface courses, especially on high-speed roads, is currently the subject of ongoing research.

It was considered that suitable polymer-modified binders are already available based on previous experiences with porous asphalt pavements.

Construction issues:

Using two pavers for warm-in-warm paving rather than a custom-made single paver (such as that used in Germany) was considered preferable, since the single pavers could be used for standard single-layer operations when not engaged on warm-in-warm. It is not considered that there would be any significant difference in the paving times.

It was also considered easier to guarantee quality when laying using separate pavers. The disadvantage is that side access (i.e. another lane) is required to provide access to the loading hoppers.

It was considered that there would be no significant difference in the footprint of paving operations whether using conventional paving techniques or warm-in-warm due to the size of the paver required for the latter.

\(^21\) These discussions took place prior to the publication of the latest Highways Agency/QPA/RBA research findings
A standard 6 hour paving operation uses 300-400 tonnes of material. TLPA would require more setup time and require further resources (estimated to be approximately 70% more material per hour per machine).

Heat retention and the time required before opening to traffic were considered to be issues. Furthermore, there are risks in hot weather with the compaction and the reduction of voids.

Layer thickness should be the 3rd or 4th priority in terms of quality targets. By far the most significant issue is compaction, as the rolling is the most important part of the paving operation. This is often done based on the expert judgement of the roller operators; they would need additional time to gain experience with TLPA.

**Maintenance issues:**

Maintenance after a period of 7 years was considered to be unthinkable. The general view is that porous asphalt pavements are expensive and insufficiently durable. The 4-phase maintenance approach as used in the Netherlands is similar to that already used in the UK. Careful consideration would have to be given to the formation of longitudinal joints.

**Performance issues:**

It was noted by the manufacturer that the acoustic performance of porous asphalt surfaces is equivalent to or better than thin surfaces.

It was noted that careful planning and consideration would be required in the design and provision of drainage to the roadside for water run-off through the TLPA.

**Resource issues:**

The manufacturer advised that porous asphalt can be recycled into thin surfaces (forming 25% of the new mix). The use of recycled materials in TLPA was not discussed, and this is not a topic widely discussed in published literature on the surface type.

**Construction of trial sections for testing and demonstration purposes:**

It was considered that any potential test section to trial the surface type and the associated paving technology would need to be meaningful. Laying using two pavers might allow a test section of 80-100 m. However, it was considered that a test section of 200-500 m would provide more meaningful data. Three 500 m lengths would be ideal.

**Overall view:**

It was recognised that there are advantages to using TLPA, e.g. noise reduction performance, and particularly TLPA using warm-in-warm paving methods (the elimination of the tack coat and the guarantee of the bond between layers). However the surface offers reduced durability relative to thin layers, and there are a number of issues that must be considered, including the potential investment in paving equipment (a particular issue if TLPA is not to be laid on a widespread basis), the footprint required during paving and safety issues arising through unfamiliarity with the techniques and processes. Clearly this latter issue should not be seen as a barrier to the consideration of TLPA.

**9.2 Views of Manufacturer No.2 (from discussions in May 2007)**

This manufacturer was unfamiliar with the concept of twin-layer porous asphalt prior to the discussions with TRL. The manufacturer considered that unless certain issues can be addressed, the continued use of thin surfaces may be a better option. The following is a summary of the key points of the discussion:

**Aggregate specifications:**
It was the opinion of the manufacturer that the potential basis for a UK-specification TLPA would be a 0/20 mm lower layer and a 0/6 upper layer. This was considered feasible since these gradings are by-products from the manufacture of 14 and 10 mm aggregate. Specifically creating 6 mm aggregate would generate large quantities of waste material.

It was not considered possible to use an existing 6 mm thin surfacing for the upper layer as it may not be sufficiently open – discussions with bitumen suppliers would be required.

**Construction issues:**

Whilst it was acknowledged that a far greater degree of coordination and management would be required to use warm-in-warm paving techniques as against laying a standard single-layer pavement, it was considered that the associated paving times are likely to be similar.

It was considered that using standard pavers for laying TLPA using warm-in-warm procedure might be problematic due to the potential difficulties of keeping the front paver supplied with materials; potentially an additional lane would be needed to provide access to the loading hoppers.

It was the preference of the manufacturer to use standard pavers for laying TLPA if feasible; this would allow the pavers to still be used for laying other pavements for standard surfaces. Investments in warm-in-warm pavers would only be made if a large application was envisaged.

**Maintenance issues:**

It was considered that a durability of 7 years for TLPA was poor. Whilst TLPA on high-speed roads is to some degree self-cleaning (due to the action of the tyres on the surface when it is wet), clogging and cleaning is an issue which needs careful consideration.

**Performance issues:**

It was considered that there may be issues with obtaining sufficient skid resistance if 6 mm aggregate is used for the upper layer. The possible inclusion of glass slag in the mix (as trialled in the Dutch IPG programme) was noted; this material is already used in 20 mm pavements, but it is not widely used due to an inadequate supply.

**Resource issues:**

The manufacturer advised that porous asphalt can be recycled into a proprietary 20 mm surface (forming 20% of the new mix).

**Construction of trial sections for testing and demonstration purposes:**

It was considered that any potential test section to trial the surface type and the associated paving technology would need to be at least 200 m in length.

**Overall view:**

Whilst the concept of TLPA is an interesting one, the issues associated with the surface, particularly durability, are such that the manufacturer considered the continued use of thin layers to be a better option.

### 9.3 Views of Manufacturer No.3 (from discussions in September 2007)

This manufacturer was very familiar with the concept of twin-layer surfaces generally and considered their use to be possible if the results of the current project indicate it as a feasible option for the Highways Agency. More specifically, the use of TLPA was considered to be possible. The following is a summary of the key points of the discussions:
**Aggregate and mix specifications:**

The manufacturer had the opinion that for a standard non-porous twin-layer surface the lower layer could be a 0/10 specification and the upper layer a 0/6 mm. It was considered that one of the most important aspects of laying two surfaces together was the interlock (bonding) between the two surfaces. It was considered that a 6 mm and a 10 mm combination would achieve this interlock.

For a TLPA section this specification is more likely to be 0/14 for the lower layer and 0/10 for the upper layer.

A potential problem was identified in meeting the texture requirements of the surface. This would be caused if the lower layer required extra compaction and this process was undertaken by excessive compaction of the upper layer. The initial skid resistance of the surface was not considered to be a problem.

It was considered that ride quality and durability could be adversely influenced if a two-stage process is adapted for construction. This is discussed in more detail below.

**Construction issues:**

The use of two pavers for warm-in-warm paving was not considered to be a practical option. The use of two pavers could introduce problems with the second paver being required to travel over the lower layer while laying the upper layer. This has a high potential to introduce unevenness that would cause problems with texture depth (due to the need for the upper layer to be rolled excessively to reduce the unevenness in the lower layer), ride quality and durability. It was considered that if the twin-layer principle was used for existing non-porous surfaces, then an ‘Enrobé à Module Élevé’ (EME) asphalt mixture would provide a very stable bottom layer.

It was considered that a single combined paver was the only method that would work in order to obtain the coverage required for a particular job.

Training of staff and the logistics of the operation was considered to be a very key area that would need to be addressed and practised before any paving took place.

**Maintenance issues:**

It was not considered by the manufacturer that there would be any extra issues associated with maintenance of twin-layer surfaces. The manufacturer stated that they considered the self-cleaning action of the tyres on the surface when wet would be sufficient if it was required to clean a surface.

**Resource issues:**

The manufacturer considered that the laying of a twin-layer surface would require more plant on site and also additional staff.

From an aggregate point of view, assuming the layer required was not thicker than usual, it was not considered there would be any additional aggregate usage. Current recycling methods being used would still be applicable for the construction of twin-layer surfaces.

**Construction of trial sections for testing and demonstration purposes:**

It was considered that a trial section should be of at least 500 m. If the durability of the surface is proved then it was suggested that a trial section should be on a relatively heavily trafficked section of road.

**Overall view:**

The manufacturer had undertaken a lot of their own research into the concept of TLPA and was therefore very familiar with the principals. They considered the only method
that would successfully work in the UK was by using a single combined paver. Obtaining a stable lower layer was considered as the most important aspect of the construction process.

9.4 Views of Pavement Expert No.1 (from discussions in September 2007)

The following is a report of a site visit to the A30 at Osnabrück in Germany in September 2007 to view the laying of a twin-layer porous asphalt pavement and the conclusions/views drawn by the expert following the visit.

General site observations:

The section under construction was on the eastbound (Hanover direction) carriageway and was dual 2 lane with an additional lane forming an off slip lane on the A30 between Osnabrück and Bad Oeynhausen. In Germany, there is a requirement to use low-noise surfacings in urban areas, hence the decision to lay porous asphalt. This contract follows a similar contract on the A30 in the opposite (westbound) direction which was constructed using the same technique in August 2004 (Gharabaghy et al., 2005). The noise levels from the surface constructed in 2004 were perceived by the author to be low, albeit with construction activity taking place adjacent to the trafficked carriageway, and the condition of the surfacing was considered to be good (assessed using the TRL/Highways Agency inspectional panel 7-point scale (Nicholls, 1997a)). Figure 9.1 shows the 2004 twin-layer surface.

![Figure 9.1: Twin-layer porous pavement constructed at Osnabrück in August 2004, adjacent to 2007 works](image)

Description of the paving operation:

For the 2007 construction, TLPA was being laid across the full width of the carriageway in echelon using compact (twinlay) pavers from Dynapac and Kirchner. Two lanes in each direction were open to traffic under contra-flow. The full depth pavement construction is shown in Figure 9.2, including details of the TLPA.

The pavers had a capacity to lay up to 13 m width (Dynapac, F300C/S, hopper capacity 45t + 25t) and 8.75 m (Kirchner, Super 2500, hopper capacity 30t + 18t) with the feed
into the pavers provided a separate feed hopper. Figure 9.3 shows the asphalt feed from the lorry into the feed hopper and then into the large lower hopper on the compact asphalt paver. Figure 9.4 shows the two screeds at the back of the paver.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness (mm)</th>
<th>PA Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper PA</td>
<td>35</td>
<td>5-8 mm aggregate, 6.5% binder (with 5% SBS), 0.5 % fibres</td>
</tr>
<tr>
<td>Lower PA</td>
<td>45</td>
<td>11-16 mm aggregate, 5.6% binder (with 5% SBS), 0.4 % fibres</td>
</tr>
<tr>
<td>SAMI</td>
<td></td>
<td>Stress Absorbing Membrane Interlayer (SAMI): Polymer membrane sprayed at 2.5L/m² and with 8-11 mm grit @ 10 kg/m² rolled in.</td>
</tr>
<tr>
<td>Binder</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>Sub-base</td>
<td>250</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 9.2: Twin-layer porous asphalt pavement construction**

**Figure 9.3: Asphalt feed process into compact asphalt paver**
The material supplied to the site on the 5th September appeared hot with some measured temperatures of the material into first hopper recorded up to 190°C.

The target void content for the PA was 25%; measured values of 27% for the lower layer and 25% for the upper layer were recorded.

The compaction was undertaken in two stages to avoid mixing of the upper and lower layers. Initial compaction was undertaken with a Dynapac CC142 roller (4500kg), followed by use of a Hamn DV90 roller (9000 kg), both operated in static mode. Figure 9.5 shows full width echelon paving and initial compaction, and Figure 9.6 shows secondary compaction.
The paver is claimed to have the capability to lay 850 t/h. However, in practice rates of half this are typically achieved. For the full width of the carriageway the forward movement was typically 3-5 m/min, so for a 12 m wide screed and an 80 mm thick PA this translated to about 360-600 t/h.

A view of the completed works on the 5th September is shown in Figure 9.7.

**Conclusions based on the experiences of the site visit:**

The benefits of the construction method were as follows:
(i) Speed of construction;
(ii) Durability of the laid material (no longitudinal joints, full bond between layers);
(iii) The extended time for compaction (heat retained in the mat);
(iv) The reduced requirement for high PSV aggregates

The benefits of the process are clear in terms of the improved workability and durability of the material minimising the risk of cold joints formed using conventional techniques. In addition the technique has been used to lay conventional binder and surface course layers, which enables the surface course layer to be laid thinner without the risk of excessive heat loss during compaction and thus conserving resources of high PSV stone required for surface course layers. Typically in Germany the requirement is for 80 mm of binder course and 40 mm of surfacing. Using the compact paver twin-layer approach means that this can be changed to 100 mm binder and 20 mm surfacing thus saving 50% of the demand on high PSV aggregate.

**Key requirements for the process to be successful are:**

(i) At least two asphalt plants being available to supply material;
(ii) Transportation of the asphalt to the site; and
(iii) Sufficient road space available to lay wide widths without longitudinal joints

Key to the process will be having sufficiently wide access to make the technique viable. Keeping water out of the pavement structure is key to extending pavement life. Minimising the number of joints in the construction is key in achieving this.

The Highways Agency, Quarry Products Association (QPA) and Refined Bitumen Association (RBA) all appreciate the need to maximise the durability of asphalt pavements. Therefore, one of the tasks in their jointly funded research project at TRL entitled “Performance and Durability of Asphalt Roads” was “Durability of Asphalt Pavements”. One of the principal aims of this task was to identify the techniques and procedures currently considered to produce a Best Practice Guide (Full details of this research will be published in Road Note 42).

There are many approaches that can be used when striving for durable pavements. However, there are some universal truths that should be borne in mind at all stages of design and manufacture, including the following:

**The three core principles of asphalt**
- Pavements are designed to act as one layer
- All joints are weaknesses
- Sealing and bonding between layers is essential

**Three things water should not do**
- Get in from the side
- Get in from the joints
- Find its way between un-bonded layers

**The three excellences of asphalt**
- High binder content
- Small nominal size aggregate
- Low air voids

**Three things to remember about drainage**
- It is essential
- It needs to be continuous
- It needs to be maintained.
The compact paving approach can address potential problems by elimination of joints, providing an excellent join between layers and minimising the possibility of water entering the structure of the pavement.

The size of contract and access to the carriageway have an influence on the ability to construct a continuous pavement with minimal joints. That is, a more durable product can be achieved on relatively large contracts.

Minimising the immediate disruption to traffic by requiring a road to be re-opened at peak periods may be detrimental to the long-term traffic disruption because working in small packages may increase the need for maintenance and bring forward the time when replacement is needed. This approach compromises durability to minimise traffic disruption and these differences should be fed into the whole-life costing of the works in order to achieve true value engineering.
10 Conclusions and Recommendations

This chapter provides a conclusion to the study, summarising the findings within each topic area. The potential uses of twin-layer surfaces on England’s strategic road network are then discussed before recommendations are made.

10.1 Conclusions related to specific issues

A review of European and world-wide experiences of using twin-layer surfaces has indicated that TLPA has been trialled in a large number of countries, although its general/wide application is far more restricted. The most notable experience with the surface exists in the Netherlands and Japan.

Overall, the study has indicated that there appear to be no technical barriers preventing the implementation of twin-layer surfaces (either porous or dense) on England’s strategic road network. However, there are a wide range of other factors that need to be taken into consideration when assessing the surface type that may be linked to policy and, as follows:

Acoustic performance:

The acoustic performance of TLPA has shown clear advantages over existing thin surfaces. Based on Dutch data, the indication is that an initial Road Surface Influence (RSl_h) of the order of -11 dB(A) is achievable. At the present time, there is no commitment from the Highways Agency to use low-noise surfaces with an RSI better than -3.5 dB(A).

Measurements of the acoustic performance over the lifetime of TLPA surfaces have been undertaken in some European countries and these have shown a similar degradation in performance to existing thin layers. The durability of the acoustic performance is dependant upon keeping the voids within the surface free of detritus (see ‘Maintenance and rejuvenation’ in following paragraphs).

Maximising acoustic performance could potentially be attractive to the Agency, particularly in relation to helping meet the requirements of the END, however this has to be balanced against wider business objectives such as whole-life costs and journey time reliability.

Specification and materials:

The material specifications for TLPA vary from country to country and there is no mix that stands out as being more common. Upper layer aggregate sizes vary from 6-10 mm with a depth variation of 10-50 mm. The lower layer aggregate size has an equally wide range from 10-20 mm with a depth variation of 20-80 mm. Polymer modified binders are generally used together with hydrated lime additive. Research in Japan has investigated the development of binders suited to specific climatic or traffic conditions. The use of additives to improve early life skidding resistance has also been demonstrated.

Discussions with UK surfacing contractors have suggested an equally wide range of potential aggregate specifications and that suitable binders are already available based on previous experiences with porous asphalt pavements. It is considered that TLPA might be achievable with existing thin layer products providing that they are sufficiently porous.

It is likely that the preference will be for surfacing contractors to develop proprietary TLPAAs rather than for the Highways Agency to provide a single full TLPA specification. However, if the greatest benefit of TLPA is its acoustic performance, a commitment from the Agency for the use of surfaces with an RSI better than -3.5 dB(A) would be
necessary to encourage the necessary research and development. New HAPAS guidelines will also need to be prepared for TLPA rather than use a combination of the existing guidelines for porous asphalt and thin layers.

**Construction of TLPA:**

Construction of twin-layer surfaces varies from country to country. The traditional method of laying a single layer, allowing it to dry, applying a tack coat and then applying another layer has problems in less favourable weather conditions with both the tack coats and compaction, as well as there being issues over the time needed to lay the surface.

A method known as “warm-in-warm paving” where the upper and lower layers are laid more-or-less simultaneously (i.e. the upper layer is laid while the lower layer is still warm) can be used either by two pavers working in tandem or a single paver applying both layers. Such a method offers potentially improved structural durability and increased laying speeds (potentially between 1.5-2 times faster) than for more conventional methods, and the opportunity to lay in colder temperatures, e.g. at nighttime. These benefits provide a positive step in any consideration of TLPA.

The warm-in-warm technique, with either a single machine or two in tandem, is considered to be the only viable option for use in the UK due to the need to keep lane closures to a minimum. This is necessary to reduce maintenance costs and to assist in meeting the delivery of the Public Service Agreement (PSA) for journey time reliability, one of the Highways Agency’s key performance indicators. UK surfacing contractors have indicated that for small sections, two paving machines, with one travelling behind the other, could be used, although one of the contractors consulted considered using two pavers in tandem to be impractical because this might lead to unevenness in the finished surface. For any large scale operations and commitment to future operations then a single paver would need consideration. However, there are operational issues that would need to be considered in discussion with contractors.

It is noted that the use of twin-layer paving techniques is not limited to porous surfaces. Dense twin-layer surfaces can also be laid using this approach. As such, the use of twin-layer paving on the strategic network for dense and porous surfaces could potentially be an important tool in assisting the Agency in minimising traffic disruption caused by road maintenance.

The use of shuttle buggies has been demonstrated to provide improved quality with regard to TLPA. It is noted that there is increasing interest in the use of shuttle buggies when laying thin layers, so they may already been in regular use once any formal decision to lay TLPA is taken.

If the emergency lane is not porous, then the installation of drainage systems would be necessary when laying TLPA for the first time on a road. This will have a negative cost impact relative to the current use of thin layers.

**Structural performance:**

Structural durability is a significant issue with TLPA. Failure of the surface is generally as a result of ravelling of the upper layer. Based on European experiences, the structural lifetime of the upper porous layer is typically 7-8 years which is significantly less than that of the thin layers already used on the strategic road network (10 years on average). Research is going on in the Netherlands to increase this to at least 9 years, although the true durability of optimised surfaces has yet to be demonstrated. The structural durability of Japanese TLPA has been observed to be 10 years or greater. Until the lifetime of TLPA can be increased to be comparable with that of the thin layers already used on the strategic network, this is foreseen as being a potentially significant obstacle.
in the wide application of the surface, except under the most extreme circumstances, e.g. where there is a severe noise issue.

**Maintenance and rejuvenation:**

In the Netherlands where most sections of TLPA have been laid, the recommended maintenance cycle involves first only the upper layer in the nearside lane being replaced (the average lifetime of the upper layer in the most heavily trafficked lane being 7-8 years). This is then followed by the replacement of both layers after typically a further four years. However, very few twin-layer surfaces are old enough to date to have undergone a complete cycle of maintenance.

The Highways Agency does not currently use a fixed maintenance schedule, but would only replace the surface when it failed. It is considered that a re-surfacing policy such as that used by the Dutch would require support from both the surfacing contractors and the Agency, and based upon the current average structural lifetime, would be unacceptable in terms of cost and lane closures. As noted above, this may preclude application except in the most extreme circumstances. If longer lifetimes can be achieved, i.e. if the durability of TLPA can be improved, such an approach may possibly be more acceptable.

TLPA is likely to require more intensive winter maintenance than the thin surfaces currently in use on the strategic road network. The surface is only suitable for treating with road salt as the application of grit would result in clogging of the pores of the pavement. This increased salting requirement may have potential implications with regard to the salt reserves available to highways authorities.

One of the main problems affecting the performance of TLPA is clogging of the pores with dirt and detritus. On high-speed roads, the vehicles themselves generate a cleaning effect in the wheeltracks by the action of the tyres passing over the surface; this is considered sufficient to clean the surface so that manual cleaning is not required. In situations where the emergency lane is also paved with TLPA, e.g. in the Netherlands, this lane must be cleaned on a regular basis, e.g. twice a year, since if it becomes clogged then the flow of water away from the running lanes becomes impeded. If the emergency lane is not porous, then the installation of drainage systems would be necessary when first laying TLPA. Both of these situations have a negative cost impact relative to the current use of thin layers.

A range of cleaning methods and systems have been developed for cleaning porous surfaces. These are generally applied on lower-speed roads and are used/being trialled in countries where existing maintenance policies require the cleaning of surfaces. In the UK, no such policies exist. The Highways Agency takes the view that the cleaning of surfaces should be avoided wherever possible, however the maintenance of drainage paths is very important to the Agency.

The effects of rejuvenation of porous surfaces through the application of chemical rejuvenators to restore the properties of the binder have not been widely investigated.

**Safety performance:**

As with most asphalt pavements, there are issues over early life skidding resistance until the binder film has been worn away. Work in the Netherlands has been undertaken to investigate the use of additives such as glass slag to improve early life skidding resistance. Any TLPA laid in the UK would be required to satisfy UK skid resistance requirements, which are not based on the skid resistance when new.

Porous asphalt surfaces also offers improved splash/spray performance over traditional dense surfaces.
Environmental impacts:

There are issues which must be considered over the availability of smaller aggregate sizes, e.g. 6 mm, for use in the upper layer of TLPA. This may become a bigger issue if the wider use of smaller aggregates in thin surfacings is accepted. Potentially, it should be possible to use lower quality aggregate in the lower layer of TLPA since it is not in contact with vehicle tyres. The use of recycled materials in TLPA is not widely discussed in the literature.

Whilst porous asphalt pavements can be beneficial in the removal of PAHs and heavy metals from surface water run-off, the increased requirement for winter salting may have an adverse effect on run-off. There will be an increased demand for salt reserves for winter maintenance.

Porous asphalt pavements can be recycled for use in thin surfaces. A range of processes/methods are available for the recycling. The use of recycled materials in porous asphalt pavements is less well reported.

It is expected that the effects of climate change will lead to an increase in the maintenance issues that are currently experienced with asphalt pavements. However, experience with TLPA in countries with warmer climates is generally restricted to trial sections.

Cost/benefit issues:

Examination of the basic costs of twin-layer surfaces suggests that a section would cost more to lay than existing thin surfaces. Estimations of the additional cost range from 20-25%, based on UK data. Dutch calculations suggest an additional cost of almost 70% relative to a conventional dense asphalt pavement. From discussions with surfacing contractors, these extra costs are likely to be incurred by additional materials, staff resources and machinery. Some of these costs may be greater during the first experiences with the surface type, e.g. investments in specialist paving equipment, staff training, but in general it is considered unlikely that decreases in the costs associated with materials and staff resources will be any different to those with other asphalt surface types. The whole-life costs of twin-layer porous asphalt, based on European data are significantly higher than dense asphalt pavements, although no comparisons with thin layers are available.

However, when the costs are expressed in terms of noise reduction achieved per unit spent, a twin-layer surface may be more cost effective than single mitigation measures such as noise barriers, or combined measures such as low-noise pavements and noise barriers. The level of cost-effectiveness will be dependant upon the individual costs associated with the construction of noise barriers in the calculations, e.g. traffic management costs. This is likely to improve the cost-effectiveness of TLPA in relation to noise barriers. Generally, the level of cost-effectiveness will vary depending on the scale and type of project and should be evaluated on a case-by-case basis. At the current time, Highways Agency systems are not capable of comparing the cost-effectiveness of different mitigation measures.

The costs of using dense or porous surfaces in the emergency lane also require further evaluation.

It is considered therefore that as long as the Agency’s emphasis is on minimising disruption to journey time rather than on noise reduction potential, the scope for using twin-layer porous asphalt on a widespread basis is low when considered in terms of cost-effectiveness. This emphasis may change with the implementation of Action Plans resulting from the END, but this is not likely to be for some years.
10.2 Potential for application of TLPA in the UK

Based upon the information collated in this report, it is considered that the wide application of TLPA on England’s strategic road network is unlikely, particularly on cost grounds and the need to minimise traffic disruption. However, the following potential applications are proposed:

- Where it is more cost effective to have one very good surface as opposed to a thin surface and barriers. As noted previously, Highways Agency systems are not capable of comparing the cost-effectiveness of different mitigation measures.

- In very noise sensitive locations, e.g. in locations where high levels of noise mitigation are required but traditional measures such as noise barriers cannot be practically implemented due to, for example, space restrictions.

Appendix A sets out current Agency policy with regard to the mitigation of road traffic noise and describes the tools that are currently available to help implement this policy. With the increasing awareness of the problems of road traffic noise, existing policy and measures may be insufficient, particularly in light of potential Action Plans in accordance with the implementation of the EU Directive on the Assessment and Management of Environmental Noise (Commission of the European Communities, 2002).

10.3 Recommendations

Based on the above conclusions, the following recommendations are put forward:

- With regards to the structural lifetime of TLPA, it will be some time before the actual lifetime of optimised TLPA, i.e. that investigated within the Dutch IPG programme to offer improved resistance to ravelling, can be fully assessed based on real road sections. It is therefore considered that any decision on the trial/application of TLPA in the UK will have to be taken before this information becomes available.

- It is recommended that a test section is laid in the UK to allow the Highways Agency to evaluate the surface. UK surfacing contractors have recommended that for a meaningful evaluation to be undertaken, a test section between 300-500 m in length on a trafficked road would be required. However, it was considered that the paving techniques and logistics would first need to be tested away from a highway.

- It is recommended that any test section should be laid on a road where maintenance of the existing surface is already required. Due to the issues associated with the provision of drainage based on the characteristics of the emergency lane, it is considered that any initial trial should be carried out, if possible, at a site where there is no emergency lane.

- It is recommended to examine future Highways Agency commitment under Action Plans that are produced in accordance with the Environmental Noise Directive to determine what pressures they will be put under to do more in terms of noise mitigation. This will decide whether there is any need for the Highways Agency to pursue this any further on acoustic grounds alone. However at this time it is unclear as to precisely what these commitments are likely to be.

- A further review of this work should be undertaken in 2 years time when more data is available from Europe.

- If and when the next round of Highways Agency noise hotspots are assessed for prioritisation, any hotspots to be tackled with a surface and barrier combination should also be assessed to evaluate whether TLPA could be used as an alternative (i.e. a surface correction of -11 dB used for noise calculations).
It is recommended to undertake a trial of the warm-in-warm paving technique independent to any trial of TLPA so that the feasibility of using the approach for laying thin surfacings can also be investigated.
11 Acknowledgements

The work described in this report was carried out in the Noise and Vibration Group of TRL Limited and the technical review and auditing of this report was carried out by Phil Sivell.

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13 Glossary of abbreviations and acronyms

BBA  British Board of Agrément
BFC  Brake Force Coefficient
CPX  Close-Proximity Noise
CRTN  Calculation of Road Traffic Noise
CSC  Characteristic SCRIM Coefficient
CVD  Commercial Vehicles per Day
DAC  Dense Asphalt Concrete
DDL  Double Drainage Layer
DMRB  Design Manual for Roads and Bridges
DPAC  Double Porous Asphalt Concrete
DRI  Danish Road Institute (Denmark)
DWW  Dienst Weg- en Waterbouwkunde (Road and Hydraulic Engineering Institute), The Netherlands
EAC  Emulsified Asphalt Concrete
EACC  Exposed Aggregate Cement Concrete
EME  Enrobé à Module Élevé (an asphalt material which provides a stiff bituminous roadbase)
END  EU Directive on the Assessment and Management of Environment Noise
HAPAS  Highway Authority Products Approval Scheme
HIPR  Hot In-Place Recycling
HIPT  Hot In-Place Transforming
HRA  Hot Rolled Asphalt
IL  Investigatory Level (in relation to UK skid resistance performance)
IPG  Innovatieprogramma Geluid (Noise Innovation Programme, The Netherlands)
LOT  Lifetime Optimisation Tool
NEF  Noise Exposure Factor
NEI  Noise Exposure Index
NCV  Net Constant Value
NPV  Net Present Value
NSI  Noise Severity Index
OGPA  Open Graded Porous Asphalt
PA  Porous Asphalt
PAH  Polynuclear Aromatic Hydrocarbon
PERMS  Permeable Resin Mortar System
PMB  Polymer Modified Binder
PSA  Public Service Agreement
PSV  Polished Stone Value
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>QPA</td>
<td>Quarry Products Association</td>
</tr>
<tr>
<td>RA</td>
<td>Recycled Asphalt</td>
</tr>
<tr>
<td>RAC</td>
<td>Road Acoustic Checker</td>
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<tr>
<td>RAP</td>
<td>Reclaimed Asphalt Pavement</td>
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<tr>
<td>RBA</td>
<td>Refined Bitumen Association</td>
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<tr>
<td>RSI</td>
<td>Road Surface Influence</td>
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<tr>
<td>SBS</td>
<td>Styrene Butadiene Styrene</td>
</tr>
<tr>
<td>SCRIM</td>
<td>Sideway-force Coefficient Routine Investigation Machine</td>
</tr>
<tr>
<td>SILVIA</td>
<td>Sustainable Road Surfaces for Traffic Noise Control</td>
</tr>
<tr>
<td>SLPA</td>
<td>Single-Layer Porous Asphalt</td>
</tr>
<tr>
<td>SMA</td>
<td>Stone Mastic Asphalt</td>
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<td>Statistical Pass-By</td>
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<td>TLPA</td>
<td>Twin-layer Porous Asphalt</td>
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<tr>
<td>VFM</td>
<td>Value For Money</td>
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14 Glossary of terms

*Aggregate grading:*
The term given to the percentages of the different size fractions, after sieving, that go to make up the whole material.

*Aggregate sizes:*
The following terms are used to classify the sizes of material used in the construction of road surfaces:

- **Aggregate (Stone):** > 2 mm;
- **Sand:** 0.063 – 2 mm
- **Fines or Filler:** < 0.063 mm

The combination of sand and fines is often referred to as ‘Mortar’.

*Binder:*
In asphalt pavements, this is the bitumen (asphalt). It serves two purposes, namely to bind the aggregate and other components together and to provide a good adhesion between the surface course and the base course.

*Binder drainage:*
When the binder separates from the mixture after the mixing process or during transfer of the mixture to the construction site (British Standards Institution, 2004a).

*Binder stripping:*
The separation of the binder from the aggregate in the pavement.

*Hot in-place recycling:*
A process to correct asphalt pavement distress by softening the existing surface by heating, mechanically removing the pavement surface, mixing the reclaimed asphalt with a recycling agent, possibly adding new asphalt and/or aggregate, and relaying. A train of machines working in succession performs the recycling

*Interlock:*
The bond between the upper and lower layers of a twin-layer surface

*Gap graded materials:*
A material when one or more of the aggregate sizes in a normal downward distribution of aggregate particle sizes are missing, hence producing a "gap" in the grading where there is little or no aggregate of a particular size to be found.

*Polymer modifiers*
Polymer modifiers, e.g. synthetic polymers or natural rubber, are added to the binder to change its physical properties. It should be noted that they do not chemically change the nature of the binder. The use of polymer modified binders can, for example, affect the ageing characteristics of the surface and improve structural durability

*Ravelling:*
The loosening of stones from the surface of the pavement.
Appendix A  Highways Agency noise policy and tools for the management of traffic noise

This Chapter gives a brief overview of Highways Agency noise policy and the tools currently available to manage traffic noise on the strategic road network.

A.1  Current Highways Agency noise policy

**Low-noise surfaces used as standard**

The Agency is committed to resurfacing over 60% of the strategic road network with low-noise surfacing over the next ten years, as part of the Ten Year Plan (DETR, 2000). For 2007-08, the target is to treat at least 900 lane km of road surface with low-noise surfacing. This target will be achieved by using low-noise surfaces whenever there is a need to resurface a particular section of existing road. Also, any new sections of the network are surfaced with a low noise surface as standard.

**Concrete roads**

Although the Ten Year Plan included a commitment to resurface all remaining section of concrete road with quieter materials irrespective of the need for maintenance by the end of March 2011, this policy has not been funded since 2004. Concrete surfaces are therefore currently only replaced with low-noise surfacing based on maintenance requirements.

**Noise Hotspots**

The Agency is committed within the Ten Year Plan to tackling areas alongside the network where the noise level is considered a problem and where there is no early prospect of achieving noise reductions through resurfacing with quite material on maintenance grounds. Approximately 79 locations have been identified following a screening process, and these have been assessed to determine the most cost-effective means of reducing noise levels. A budget of £5 million each year has been set aside to tackle noise at these locations, and this has been called the ‘Noise Mitigation Programme’.

**New roads schemes and improvements**

Current policy is to ensure that there is a high standard of noise mitigation within schemes and the impact from noise is minimised (DETR, 2000). This is achieved by ensuring that all projects that are put forward for government approval are subject to an environmental appraisal. In addition, large schemes are also subject to environmental assessment to determine the extent of the impact of the scheme/improvement and hence determine the need for/extent of mitigation required to reduce this impact.

**Research**

The Agency commissions research each year to investigate ways of improving the performance of the strategic road network. Some of this research work is directly targeted at reducing noise, while in other research projects noise is a secondary benefit.

A.2  Tools available to the Highways Agency for noise control

The first section below describes the options currently used by the Agency to mitigate the impact of noise. There is then a section of possible measures that could be used to reduce noise levels.
A.2.1 Tools which are currently available

Noise barriers

The use of barriers to reduce the noise level is the most common measure used in situations where resurfacing with a low-noise surface is not an option. To achieve maximum noise reduction, barriers should be placed as close as possible to the source or the receiver. For use on the strategic road network, the former would always be the option used. Traditional barriers made from a timber construction are the most common, but the network does contain some example of concrete barriers. The barriers currently used are a mixture of reflective and absorptive barriers.

However, barriers are only really effective for dwellings within 100 metres of the road. The effect of reducing the noise from heavy vehicles is also a lot less compared with the reductions achieved from car tyres. With some of the strategic road network now containing stretches of road with four or more lanes in each direction, the effect of barriers in these situations is less.

The Agency currently installs barriers as part of the ‘Noise Mitigation Programme’ and also where they are required for mitigation purposes following construction projects.

In addition to barriers, earth bunds can also be used to reduce the noise level. However, due to the size of the footprint of these bunds, they are only really available as an option during the construction of a new road or a major improvement, and even in these cases sufficient space for construction is becoming increasingly scarce.

Surfaces

The surface of a high speed road is the main factor in the level of noise produced by a stream of traffic. As described in Chapter 9.1, resurfacing is used under specific circumstances and very rarely just to control noise.

The benefits of low-noise surfaces are known to reduce over time, and the maximum benefit is usually gained just after resurfacing has taken place of a worn out surface. With low-noise surfaces now common place and used as standard, when these are eventually wear out and are replaced with another low-noise surfaces, the benefits will be less.

The resurfacing of a worn out HRA carriageway would typically reduce tyre noise levels by about 4 dB(A).

Alignment (only at design stage), cuttings and away from dwellings

Changes to the alignment of a road in order to reduce noise levels are only really an option available at design stage of the new road. These would take the form of changes to the horizontal alignment (i.e. moving the road away from dwellings) or vertical alignment (i.e. moving the road into a cutting).

Insulation of dwellings

The insulation of certain dwellings is a statutory duty that the Highways Agency must offer under certain circumstances following the introduction of a new highways or the alteration to an existing one.

A.2.2 Possible policy and tools which are not currently used

Flow or speed restrictions

The two single most important factors in the determining the noise level produced by a stream of traffic is the number of vehicles and their speed.

The noise level from tyres dominates at speeds above 40 mph for most types of vehicle. Reducing vehicle speeds to the legal limit or below is a rapid way to reduce tyre noise levels, given that in 2003 57% of all cars exceed the 70 mph speed limit on motorways,
and 19% of cars and 17% of Light Goods Vehicles (LGVs) exceed 80 mph (Department for Transport, 2005). With all other factor remaining the same, a reduction is speed of 20 mph for cars would reduce noise levels by approximately 3 dB. A halving of traffic flow would also have the same effect (i.e. a reduction in noise level of about 3 dB).

In the short term, high visibility policing could possibly reduce speeds on high speed roads, with the bonus of lower accident rates and savings in greenhouse gas emissions. In the longer term, speed enforcement ‘through the vehicle’ is likely. DfT research has explored speed limiters that adapt the maximum speed of a vehicle to the prevailing local speed limit (Carsten and Fowkes, 2000). Some insurance companies’ now offer ‘Pay As You Drive’ (PAYD) insurance technology deters extreme driving styles. Any Government financial incentives for speed limiters or the fitting of PAYD insurance equipment would create a market, and cause these technologies to permeate the vehicle fleet much more rapidly than otherwise would be the case.

Restrictions on flow would be less easy to put in place than those relating to speed. These would probably have to involve some form fiscal penalty that would make it less desirable to use the strategic road network.

**Encouraging industry to do more**

There are areas, such as tyres, where the technology currently exists to reduce noise levels but these are not being widely used (Watts *et al.*, 2006). However, there is currently no incentive for manufactures to use or for motorists to demand such technology. As an example, if only vehicles fitted with ‘low noise tyres’ were permitted to use the strategic road network at certain times, then this would rapidly create a market for ‘low noise tyres’.

Another area is the development of lower noise road surfaces; although it is recognised that considerable work is currently being undertaken in this area. It is also noted, as with tyres, that safety implications of any new developments need to be considered before noise.

**Different noise barrier designs**

Although the Highways Agency currently uses noise barriers, those used are limited to just the most basic of designs and materials. Alternatives may include transparent barriers, vegetative barriers, tilted or cranked designs, T-shaped profiles or partial covers.

However, it is acknowledged that some of these would perform no better than those currently used, and could increase the cost of barriers.

**Different locations for barriers**

As described above, the scope for the positioning of barriers is limited. However, there is the possibility of improving the design of median barriers (i.e. those along the central reservation of a road) to provide improved noise reduction. Median barriers are typically constructed of concrete and are about one metre high, which does offer some noise screening benefits but improvements could be made through the use of noise absorptive claddings and higher barriers. However, for this type of barrier the safety needs are likely to limit the possibilities for noise reductions.

**Novel surfaces**

A range of different surfaces have been or are presently being developed which offer increased noise reduction relative to the current state-of-the-art surfaces that are already in use. These surfaces are also innovative in terms of the materials or methods that are used for their construction/manufacture and include:

- Poro-elastic surfaces: These are surfaces constructed using rubber granulate rather than traditional stone aggregate. They were first developed in Japan, but have also been trialled in varying capacities in Sweden and the Netherlands (e.g. Sandberg and Kalman, 2005; Meiarashi and Oishib, 2007). At the present time,
the main barrier to their implementation is their relatively poor structural durability;

- Modular surfaces: These are pre-fabricated surfaces which are constructed under factory conditions and brought to the road site for assembly. Much of the development work on modular surfaces has been carried out in the Netherlands within the framework of the Roads To The Future project, and several of the concepts have been tested further within the Dutch IPG programme. These include Rollpave (a prefabricated thin porous layer on a drum, which is transported to site and then unrolled, bonding to the sub-layer being by thermal conduction; DWW, 2007) and Modieslab (a prefabricated porous concrete slab system; DWW, 2006b).
The feasibility of using twin-layer porous asphalt surfaces on England’s strategic road network

Low-noise surfaces have been in use in the UK for over 10 years and are used on England’s strategic road network. Under the requirements of the EU Directive on the Assessment and Management of Environment Noise (END), there may be a need for the Highways Agency to look to implement noise mitigation measures in addition to those already used to address the demands raised by Noise Action Plans produced under the END. Twin-layer porous asphalt is one such possible measure which has been successfully trialled and/or implemented in Europe and which offers significant noise reduction benefits. TRL has been commissioned by the Agency to investigate the feasibility of implementing this surface in England, taking into account all associated aspects, e.g. construction, maintenance, performance, resource use, costs, and sustainability issues, based on existing knowledge/experiences outside of the UK and the perspective/views of the UK road surfacing industry. This report details the findings from this study, presenting both the benefits and disadvantages, and sets out the resultant recommendations.

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