Interpave

Whole Life Cost Analysis for Various Pavement and Drainage Options

Final

Job Name:	Whole Life Cost Analysis for Various Pavement and Drainage Options
Report Type:	Final Report
Job Number:	MP319
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Executive Summary

Whole Life Cost analysis is a useful tool for an asset owner or operator to establish the most appropriate design and maintenance solution for a given asset. Whole Life Cost (WLC) analysis is routinely used within the construction industry to assess a diverse range of assets, from nuclear power stations to street lighting. Scott Wilson have been employed by Interpave to undertake a WLC analysis for three pavement surfaces: permeable block paving (System C), unreinforced concrete and asphalt, for four applications: supermarket car parks, industrial warehouse car parks, distribution roads on a housing estate and distribution roads on an industrial estate, for two subgrade conditions (3% & 6% California Bearing Ratio (CBR)). The designs of the pavements were undertaken as part of the initial Scott Wilson (2006) study.

This report initially describes the general theory behind WLC analysis and explains the need for timely maintenance in order to minimise WLCs, whilst providing the required user serviceability level. The report specifies the required maintenance schedule over the design life of each of the pavement application System Combinations. Each of the pavement applications has different requirements; for example a supermarket will need a smooth, skid resistant surface with good aesthetic appearance, whereas an industrial application will have a more utilitarian focus. The maintenance schedules have been designed to meet these different needs. The maintenance schedules have been costed by Corderoy (Quantity Surveyors). A full description of the 'costing rules' has been provided. The discounted annual maintenance cost data has been combined with initial construction costs (calculated as part of the initial Scott Wilson (2006) study) to provided WLCs.

This study has shown that permeable block paving (System C) has lower WLCs than asphalt and unreinforced concrete for all applications with the exception of the supermarket car park. Regarding the supermarket car park, two cases were analysed for the permeable block paving (relating to a 20 and 40 year block durability), to form upper and lower bound limits to the WLCs. The 20 year block durability (Case I) had slightly higher WLCs than those of the asphalt, whilst the 40 year block durability (Case II) had lower WLCs than those of the asphalt. Permeable block paving (System C) also has significant environmental advantages over the asphalt and unreinforced concrete due to its Sustainable Urban Drainage System (SUDS) and its inherent ability for reuse when being maintained.

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1. INTRODUCTION

The purpose of a Whole Life Cost (WLC) analysis is to calculate the true cost of an asset over its design life. WLC analysis provides a very useful tool for service owners and operators, enabling them to determine the most appropriate solution for their requirements. The monetary costs in a WLC analysis generally comprise three components: i.) initial construction costs, ii.) user costs and iii.) maintenance costs. Where applicable, a WLC analysis should also account for any decommissioning costs. A WLC analysis should also highlight the more intangible non-monetary benefits and drawbacks of the various solutions, which potentially have an important bearing on the service owner or operator. As different solutions have different design lives, the costs are 'normalised' to provide annual costs (discounted to present day values). WLC analysis is commonly used in the construction industry on a diverse range of assets. Major cost savings can be made over the design life of the asset if WLC analysis is used, providing a means to avoid 'short term planning', which can have expensive long terms implications.

Scott Wilson have been employed by Interpave to undertake a WLC analysis for three pavement types (Section 1.4), four different applications (Section 1.5) and two subgrade conditions (Section 1.6). To achieve this objective the study was undertaken in the following stages:

1. A description of general WLC principles, explaining how timely maintenance intervention is required at critical stages in an asset's life to avoid subsequent serious asset deterioration and thus expensive repair work. The study goes onto to consider factors affecting pavement deterioration and WLCs.
2. Identification of the maintenance strategies required for the 12 pavement type application combinations. As there is little published information on maintenance strategies for these pavement type applications, the rationale used to generate the maintenance intervention stategies has been detailed. The subgrade condition does not affect the maintenance strategy but does affect the cost due to the variation in pavement layer thicknesses. The pavement designs for these different applications were taken from an earlier SWPE study (SWPE reference: L276).

3. A summary of the WLCs, comprising a summation of the maintenance strategy costs (undertaken by Cordeory, Quantity Surveyors) and the initial construction costs (undertaken as part of a previous Scott Wilson study).
4. A summary of the study and findings.

This report forms the Final Report as detailed in the proposal (SWPE reference: AEH/FWKC/MP319).

1.1 Whole Life Costs: General Theory

There have been several studies (Shahin *et al*, 1990; Zimmerman *et al*, 2000) undertaken which detail the appropriate intervention junctures to maintain the structural integrity of the pavement at minimum financial cost to the asset owner. A schematic diagram showing the road maintenance costs and condition against time is given in Figure 1. It can be seen that once the condition of the road reaches an ‘intervention’ level it become necessary to spend money on rehabilitation treatment and thus improve the condition of the pavement. The importance of timely maintenance and reconstruction to protect against ‘expensive’ work being required at a slightly later point in time was highlighted by Shahin *et al* (1990), as shown in Figure 2. Figure 2 shows that if maintenance is left for an extra 12% of a pavement’s life, a 40% drop in road condition occurs, resulting in a factor of four increase in maintenance costs. Hence it is important to undertake maintenance works before the occurrence of serious structural damage.

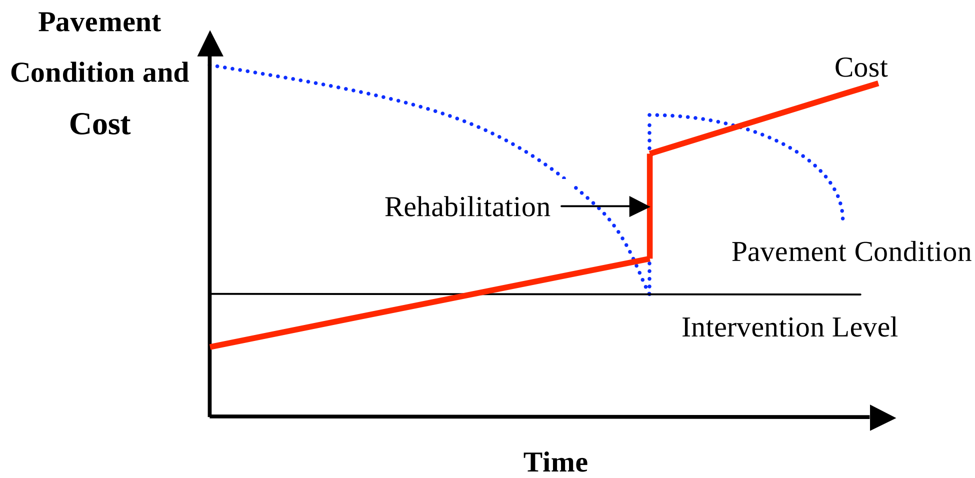

Figure 1 Schematic Representation of Rehabilitation costs and Intervention Levels for a Road

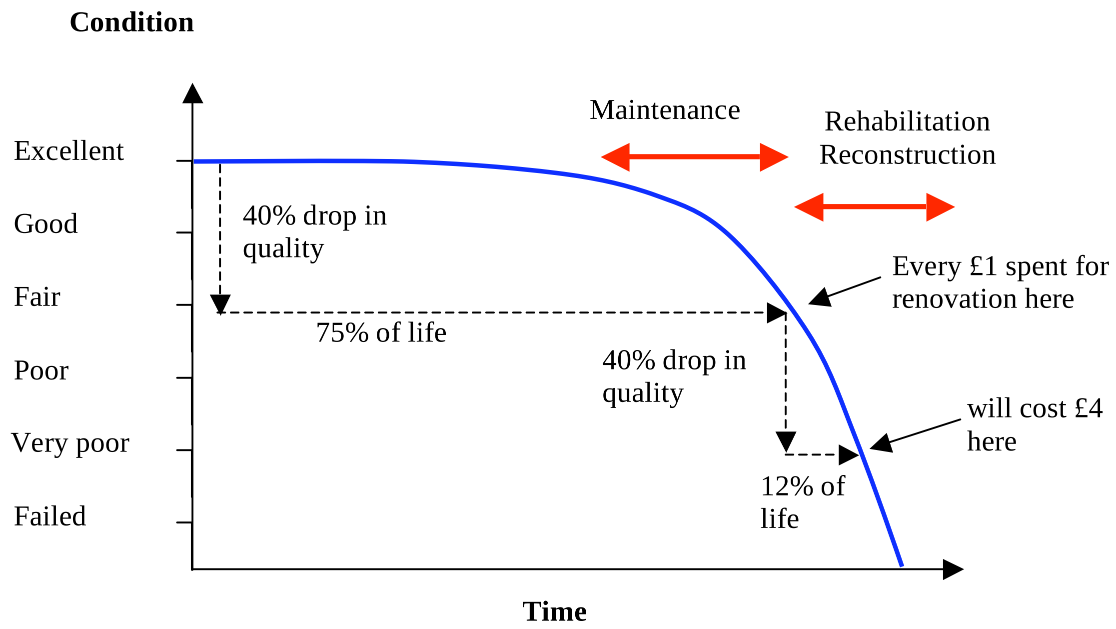

Figure 2 Pavement Deterioration and Optimum Treatment (Shahin *etl al*,, 1990)

1.2 Physical Factors Affecting Pavement Deterioration Rate

Vehicle-Pavement Interaction

The specific vehicle-pavement interaction is dependent on vehicle weight, the number of axle loadings, and the spacing within the axle group. Pavement impacts are also influenced by vehicle suspension, tyre pressure and tyre type, although these are secondary effects (FHWA, 2004). Over time, the accumulated strains (the pavement deformation from all the axles loads) deteriorate the pavement structure, eventually resulting in cracking of both rigid and flexible pavements and permanent deformation or rutting in flexible pavements. Fatigue or fatigue cracking is caused by repeated loadings, and the heavier the loads the fewer the number of repetitions required to reach the same condition of cracking (FHWA, 2004). A series of empirical tests undertaken in the 1950s suggested a 'fourth power law' relationship exists between axle load and road 'damage' i.e. doubling the axle load would increase pavement damage by a factor of 16.

One of the reasons that damage to the road accelerates after a certain time (as shown in Figure 2) can be attributed to a concept called 'spatial repeatability', which assumes that particular locations will be damaged significantly more than others. The reasons behind the development of these specific 'damage locations' are complex, but is in part due to the excitation of the modal response of the vehicles (the frequency and amplitude of vertical motion) and irregularities in the road surface (which can cause a 'bouncing effect').

Design, Materials and Environmental Factors

In addition to the vehicle-pavement interaction, the other primary factors affecting pavement durability are pavement design, material quality, subgrade conditions, weather conditions and importantly, construction quality. As stated earlier, this study uses the results from a previous study (L276, SWPE) to define the pavement design and materials

Life Expectancy

Flexible pavements are generally expected to serve from 10 to 20 years, depending on traffic conditions and construction before major rehabilitation (surfacing) is required. In contrast, rigid pavements may serve up to 40 years. However, when flexible pavements require major rehabilitation, the work is generally less expensive and quicker to perform than for rigid pavements. Block paving is not routinely used for major road applications in the UK, so there is a dearth of information relating to its performance. Reports have confirmed that in 'town centre' roads, block paving can perform with minimal maintenance for in excess of 20 years (Walsh, 2004), and on residential roads for in excess of 40 years.

1.3 Adopted Procedure

A 'maintenance instigator' (MI) is a requirement which forces a maintenance action to be undertaken. Different pavement applications have different MIs. For example, a supermarket car park pavement has a requirement to maintain a reasonable aesthetic quality. As a result it might require regular surface dressing treatments or other largely cosmetic interventions. In contrast, the aesthetics of an industrial warehouse distribution car park are of lower priority, but there are demanding requirements to maintain the structural integrity of the pavement under high loading regimes. This study has attempted to identify the main MIs which are associated with the four pavement applications detailed in Section 1.5.

Once the MIs have been identified for the different applications, the optimum maintenance strategy needs to be specified. The optimum maintenance strategy is defined as that which meets the requirements of the MIs for the minimum financial cost. The maintenance strategy includes the treatment, the scope of the treatment and the anticipated frequency of repair. In this report the 'scope of treatment' is quoted in terms of % area to make the maintenance strategy as generic as possible. The principle reason for this approach is to enable future amendments to be easily incorporated into the WLC model. The expected design life of each pavement type application is also specified. The optimum schedule (maintenance strategy) specifies all the maintenance works over this design life, including the final maintenance works required to rehabilitate the pavements to its 'as built' condition. The information used to develop this WLC model was obtained from a range of sources. In terms of literature, the relevant British and European standards were used as well as proprietary, academic and industrial publications. The 'experience' view point was gained from talking to surveyors and engineers at several local and county councils as well as building service departments of private asset owners (for example national supermarket chains). It should be noted that the nature and extent of the maintenance treatments have been estimated based on this information and are for 'general' cases.

Once the optimum maintenance schedule has been identified for each pavement application System Combination, the costing of the various maintenance interventions can be undertaken. The procedure used to develop the WLCs in this study is shown in Figure 3. In this study the WLC costs have been taken as the summation of the initial construction costs and the maintenance costs. The initial costs were undertaken as part of a previous Scott Wilson study. 'User costs' have not been accounted for in this WLC analysis as they were not thought to be relevant to the service owner / operator.

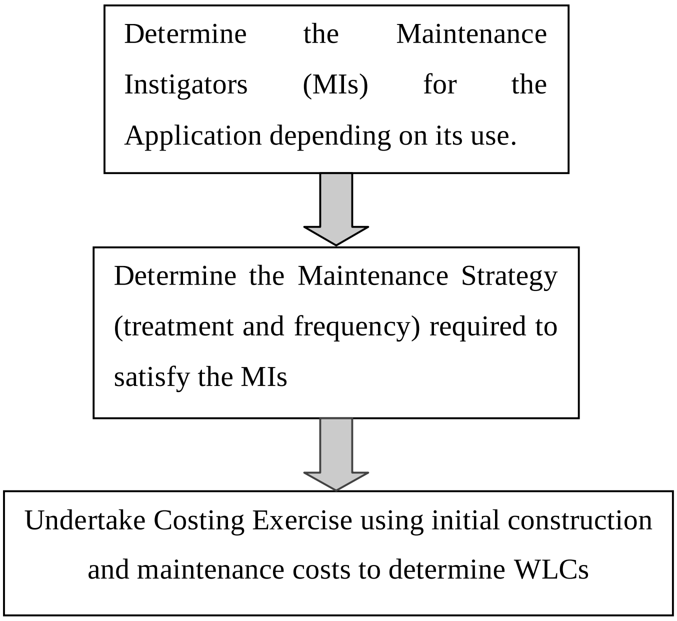

Figure 3 Procedure used for Developing Whole Life Costs

1.4 Pavement Types

The three pavement types selected for whole life costing were:

1. Permeable Block Paving – System C;
2. Unreinforced concrete (referred to as Pavement Quality Concrete in the initial Scott Wilson (2006) report);
3. Fully flexible asphalt surface (referred to as Asphalt in the initial Scott Wilson (2006) report).

It should be noted that there are three types of permeable block paving – Systems A, B and C. System A permeable block paving allows total infiltration of the water into the subgrade. System A permeable block paving is sometimes referred to as 'Zero Discharge' as no additional water from the new development is discharged into traditional drainage systems, therefore the need for pipes and gulleys is eliminated resulting in cost savings. System B permeable block paving allows some water to infiltrate through the pavement, but a series of perforated pipes or fin-drains are also introduced at the formation level to allow the remaining water to be drained to other systems. System C permeable block paving allows for the complete capture of the water using an impermeable, flexible membrane placed on top of the formation level, as shown schematically in Figure 4. It is used in situations where the existing subgrade has a low permeability or low strength and would therefore be damaged by the introduction of additional water. A series of perforated pipes or fin-drains are placed on top of the impermeable membrane to transmit the water to sewers, watercourses or treatment systems. System C permeable paving is particularly suitable for contaminated sites, as it prevent pollutants from being washed further down into the subgrade, where they may be eventually washed into the existing natural water system (Permeable Pavements, 2005). Due to the impermeable membrane and drainage provision System C permeable paving forms the most expensive permeable paving option. In many situations, where the complete capture of the drainage water is not a priority, it is feasible to use Systems A and B permeable block paving, and hence reduce the WLCs. System C permeable block paving was chosen for this study as the four pavement applications (see Section 1.5) could suffer from fuel spillage and other pollutants, hence there is a need to control the drainage water and stop it infiltrating into the natural water system.

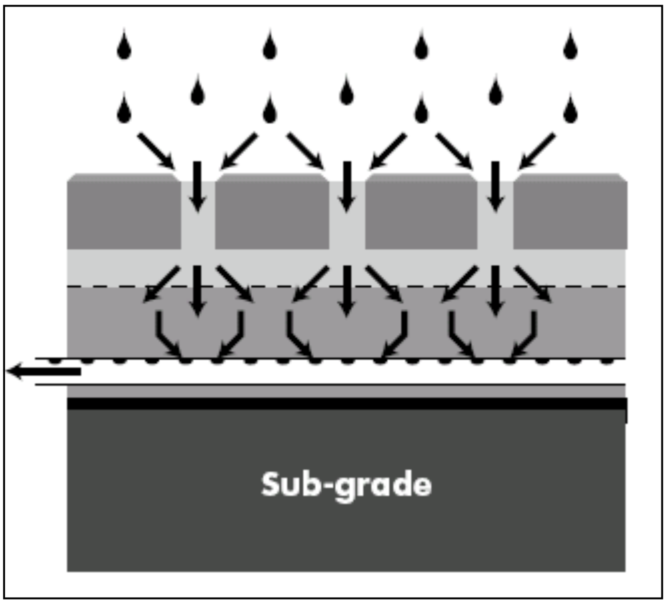

Figure 4 System C Permeable Paving System (Permeable Pavements, 2005)

System C permeable block paving also acts as a semi-porous subterranean reservoir. This enables water harvesting for applications such as flushing toilets (i.e. grey water) or for irrigation.

1.5 Four Pavement Applications

The four pavement applications are shown below:

1. Parking lots suitable for a 24 hour supermarket
2. Parking lots suitable for a typical warehouse distribution centre
3. Distribution roads on a housing estate
4. Distribution road on an industrial estate

The applications were chosen to represent markets which were suitable for block paving and where the value of this type of paving solution is not fully recognised.

1.6 Two Subgrade Conditions

The two subgrade conditions assessed have been classed in terms of their California Bearing Ratio (CBR): 3% and 6%. A 3% CBR value represents a fairly poor quality of subgrade, where as a 6% CBR value represents a subgrade of reasonable quality. The subgrade quality has a direct bearing on the thickness of the pavement layers; it does not usually affect the *type* of works specified in the maintenance schedule, although it could affect the cost i.e. if a pavement layer needs to be replaced, the thicker the layer the higher the cost.

2. SUPERMARKET CAR PARK – 24 HOUR

The main MIs for a '24 hour' supermarket car park are shown in Table 1 along with a brief description of their impact. National supermarket chains are acutely sensitive to the appearance of their stores. As a result there is a need to maintain the 'cosmetics' of the car park, resulting in a more onerous maintenance schedule than that usually required to service purely the utilitarian function.

Most supermarkets will require any major maintenance to be undertaken during off peak hours, usually at night, allowing customers to park (and shop) at peak times. For the same reasons, any maintenance which is perceived as time consuming or requiring a long 'curing' duration is likely to be viewed unfavourably.

Table 1 MIs for Supermarket Car Park

MI	*Description*
Health and Safety	Maintaining a 'safe' car park environment is of prime importance to most national supermarket chains, with the aim of reducing the risk of accidents. In the current litigious environment, supermarket chains are very eager to mitigate the risk of third party claims, especially when related to matters of health and safety negligence.
Aesthetics	Supermarkets place high importance on the aesthetics of the car park as it indirectly forms part of 'branding' and marketing strategy. The image of supermarkets over the past 15 years has been upgraded and competition within this sector is fierce. The car park has significant visual impact and as such needs to fit into the corporate image of the supermarket chain. To meet this requirement a supermarket car park will require maintenance interventions which are largely cosmetic.
Utility Reinstatement	Recent years have seen a significant increase in residential developments and supermarket car parks are not exempt to utility excavations. In addition, many supermarkets will install new CCTV or upgrade existing systems which can require pavement excavations and subsequent reinstatement.
Drainage Maintenance	Drainage channels and fins can become blocked and require a degree of maintenance. The flow rates caused by storm 'flash floods' may result in the drains becoming blocked. The apparent increasing frequency of storms due to global changes in weather patterns can have an impact on this type of maintenance requirement (but is notoriously difficult to predict).
Maintaining Structural Integrity	The structural integrity of any pavement needs to be maintained. The long term maintenance philosophy for layered asphalt pavement constructions involves interventions to the surface layers to protect the lower structural layers of the pavement indefinitely. Similarly, concrete pavements require attention to joints and minor slab cracking before serious damage occurs. The

MI	*Description*
	maintenance plan for block paving tends to be simpler and require less skilled personnel as detailed in the following section. Supermarket car parks are subjected to a variety of point loads. Apart from domestic vehicles (cars, motorbikes), supermarkets often house recycling centres (skips) which impart a high point load onto the pavement surface. In addition, the removal process of the full recycling skips can have a scuffing effect on the pavement surface. All car parks are subjected to a high degree of fuel and oil spillage resulting from the parked vehicles. Certain pavement surfaces are susceptible to chemical damage, as discussed later. Car park surfaces are subject to a high degree of turning forces, normally concentrated on the apex of the entrance routes to the car park lots. In addition, the majority of cars are equipped with power assisted steering which tends to encourage drivers to 'turn on the spot'. This mechanical action intensifies the turning shear stresses and increases the risk of surface damage. This can result in areas of poor skid resistance and so impacts on the 'Health and Safety' MI.

2.1 Permeable Block Paving Construction (System C)

The design of the permeable block paving for a supermarket car park (domestic vehicles only, as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 2.

Table 2 Design of Permeable Pavement Construction (System C) - 24 Hr Supermarket Car Park

Subgrade condition (% CBR)	*Pavement Construction*
3	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregate 500 mm Open Graded Crushed Rock Impervious Membrane
6	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregate 250 mm Open Graded Crushed Rock Impervious Membrane

The next step in the analysis is to assess the pavement types (in this case permeable block paving) generic resistance or susceptibility to the MIs detailed in Table 1. Once the probable effect the MI has on the pavement type is quantified the required maintenance schedule is detailed. Table 3 details the maintenance strategy for a System C permeable block pavement for a 24 hours supermarket car park. It should be noted that the different subgrade conditions (3% and 6% CBR) have no effect on this step of the WLC analysis. There is a degree of overlap in the maintenance treatments for some of the MIs.

The design life for permeable block paving (System C) is difficult to judge due to its relatively new introduction, especially to the UK market. To provide information on this subject a search was undertaken to identify UK block paving supermarket car park construction case histories. Photographs of the oldest supermarket car park block paving constructions (not System C) identified as part of this search are shown in Figure 5 and Figure 6 (in service approximately 23 years). A visual assessment of this pavement indicated that whilst there was evidence of limited surface wear, the structural condition of the pavement was sound, with considerable residual structural life. Whilst the example shown in Figure 5 and Figure 6 is not System C paving, it does provide evidence that the block paving has a design life well in excess of 20 years. To counter the lack of case history in the use of System C block paving two design life cases have been used in the analysis, Case I.) a 20 year design life, forming an extremely conservative guide, and Case II.) a 40 year design life, forming an upper bound to the design life. Oversees experience suggests that if well constructed the paving can easily last in excess of 30 years, thus reducing the WLCs. It should be noted that to achieve these extended design lives, good compaction and construction of the underlying materials is essential.

Figure 5 Photograph (a) showing condition of supermarket block paving, constructed circa 1983

Figure 6 Photograph (b) showing condition of supermarket block paving, constructed circa 1983

Table 3 Maintenance Strategy for Permeable Block Paving (System C) – 24 Hr Supermarket Car Park

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Health and Safety	The main health and safety issue with block paving is the risk of tripping over either i.) raised blocks or ii.) missing blocks. As a result, regular surveys are required to ensure the block paving has not become loose or been dislodged. The wet skid resistance of a permeable block paving can be expected to give a mean reading of 85 (measured in accordance with Road Research Laboratory Road Note 27), meeting the requirements of prEN 1338 : 1996[a]. It is difficult to predict whether the skid resistance will appreciably degrade with time; whilst the blocks are homogenous (and thus no high friction surface layer to degrade), there may be a tendency to polish due to trafficking.	Relocation of block paving using new laying and jointing materials. Visual survey.	2	Case I.) 20, Case II.) 40 Once a year
Aesthetics	Block paving might require cleaning to remove general dirt and detritus (algae is a very wet site). If the colour of the paving becomes masked it may be re-established by scrubbing with soap and warm water, either by hand or by using an industrial cleaner[d]. The block paving should retains its colour for a period of up to 20 years[b].	Cleaning of pavement slabs (mechanical or manual methods)[c].	100	Twice yearly[b]
Utility Reinstatement	One of the advantages of block paving lies in its ability to be reinstated with relative ease, reusing the majority of the original materials. Hence the costs for any reinstatement are primarily reduced to labour costs.	'Full depth relocation': removal of original materials; relay using equivalent depths of new materials (aggregate/crushed	2	20

MI	Effect of MI on Pavement Type	Maintenance Treatment	Car Park Area (%)	Frequency (years)
		rock)[e]. Reuse permeable block paving.		
Drainage Maintenance	The infiltration rate or a permeable block pavement will decrease but stabilise with age, due to the build up of jointing material. However, evidence to date suggest that infiltration rates always remain significantly higher than rainfall intensity, so even without maintenance, there should be sufficient infiltration to accommodate rainfall events[d]. It is important that where drains are used the diameter of the perforations are smaller than the nominal maximum aggregate size of the surrounding material. It is not anticipated that drainage will need replacing for shallow excavations, classed as block paving & laying course (i.e. not 'full depth' relocation).	None.	-	-
Maintaining Structural Integrity	*Overall Durability* The structural durability of all types of concrete block paving, either conventional or permeable, is high. They are resistant to weathering and will retain their integrity (and act as a rainwater drainage system) for a period of 20 years[b].	Complete relocation of block paving (100% new blocks[f]) using new laying and jointing material (no replacement of 500 mm open Graded Crushed Rock).	100	20
	Resistance to Shear Stress If block paving is constructed properly, with the correct boundary restraints and bedding and jointing materials, the block paving will be	None	-	-

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	capable of withstanding the shear stresses imparted by the turning action of vehicles. There are several cases of block paving being used in town centres with relatively high traffic levels without requiring any maintenance even after 20 years[b].			
	Resistance to Fuel Spillage Block paving has a high resistance to fuel; the fuel should penetrate readily into the concrete. Staining of the concrete blocks can occur if any spillage is not removed with an absorbent material.	None	-	-
	Resistance to Point Loads If properly constructed, block paving should be well placed to resist high stationary point loads. By way of example, block paving is regularly used in port applications, and is subjected to extremely high loading regimes resulting from the loading and unloading of containers[g].	Relocation of block paving using new laying and jointing materials.	1	20
Summary of Maintenance Requirements	Complete relocation of blocks (100% surface area) every 20 years (Case i) or every 40 years (Case ii), using 100% new blocks in both cases. New jointing and laying materials used. No replacement of 500 mm Open Graded Crushed Rock. Clean twice yearly. Visual survey once a year. Relocation of 3% of surface area (reusing blocks, using new jointing and laying materials). 'Full depth' relocation of blocks of 2% of surface area (reusing blocks, using new jointing, laying and subbase materials).			

Table footnotes

[a]prEN 1338: 1996 Concrete paving blocks – Requirements and test methods.

[b]'Formpave Paving Blocks', British Board of Agrément, Certificate No 97/3373.

[c]Mechanical sweepers, especially vacuum cleaners, should not be used with block paving in the first six months as they can remove the jointing material in between the paving blocks.

[d]'Permeable Pavements. Guide to the design Construction and Maintenance of Concrete Blocks Permeable Pavements', Edition 3, Interpave, ISBN 0 9536773 4 6, 2005.

[e]'Reinstatement. Guide to the Reinstatement of Concrete Block Paving', Interpave (website publication), 2004.

[f]It should be noted that although the majority of the blocks could be reused, a supermarket chain would probably insist on new blocks

[g]Knapton J. and Meletiou M., 'The Structural Design of Heavy Duty Pavements for Ports and other Industries', British Ports Association, publishers The British Precast Concrete Federation Ltd for Interpave, 1996.

2.2 Unreinforced Concrete Construction

The design of the unreinforced concrete for a supermarket car park (domestic vehicles only, as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 4.

Table 4 Design of Unreinforced Concrete for 24 Hr Supermarket Car Park

Subgrade condition (% CBR)	*Pavement Construction*
3	150 mm Jointed (5 m bays) of Unreinforced Pavement Quality Concrete 300 mm Subbase
6	150 mm Jointed (5 m bays) of Unreinforced Pavement Quality Concrete 210 mm Subbase

The maintenance strategy for the unreinforced concrete is shown in Table 5. The structural life for a concrete pavement is generally considered to be approximately 40 years; hence the maintenance strategy has been normalised for this time span.

Table 5 Maintenance Strategy for Unreinforced Concrete – 24 Hr Supermarket Car Park

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Health and Safety	The main requirements for a concrete pavement in terms of health and safety are i.) maintain the surface texture of the surface to prevent a loss of skidding resistance and ii.) to prevent surface irregularities which could cause people to trip. A loss of surface texture tends to occur in the more heavily trafficked parts of the road or surface, generally due to 'aggregate pop out' and general abrasive wear. A number of defects can cause surface irregularities: joint defects, slab rotation leading to upturned edges, significant cracks particularly around manholes.	The Health and Safety maintenance treatment has been amalgamated with the 'Maintaining Structural Integrity' MI. Visual survey	-	- Once a year.
Aesthetics	Concrete is generally considered to have poor aesthetics when compared to either block paving or asphalt surfacing. This probably forms the biggest intangible drawback of this surfacing type for this application.	None	-	-
Utility Reinstatement	The excavation of concrete slabs is a time consuming and expensive exercise, requiring either pneumatic, hydraulic impact, or diamond coring equipment to break out the concrete.	Break out of concrete, followed by full layer reinstatement.	4	40
Drainage Maintenance	The current drainage philosophy is to utilise surface water channels where possible, thus reducing the chance of blockage and making maintenance easier. However, at points, the surface water channels must feed into the underground drainage system (pipe or fin drains). Literature[a] indicates that subterranean drainage systems should be check and cleaned (if	Visual check of drainage followed by cleaning if necessary.		Once every ten years.

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	required) every ten years.			
Maintaining Structural Integrity	*Overall Durability* There are a number of maintenance operations required if the concrete surface is to maintain its structural integrity. In particular attention should be paid to joint defects (joint seals, spalling, cracks and joint stepping), structural defects (transverse cracks, longitudinal cracks, diagonal cracks, cracks around manholes, compressions failures and punch-outs) and surface defects[c].	Repair of joint sealant	100	40
		Repair of cracks (all types)[b]	30	40
		Repair of surface spalling	10	40
		Repair of surface defects (thin bond repairs)	10	40
		Repair of concrete bays (full depth)	15	40
	Resistance to Point Loads Concrete is well placed to cope with high point loads. It displays high elastic stiffness with no associated rutting.			
	Resistance to Fuel Spillage Concrete has very high fuel resistance; no damage associated with fuel spillage would be expected.			
	Resistance to Shear Stresses One of the main problems with concrete is 'spalling'; this generally occurs at the edge of slabs or in areas subjected to high shear stress. In addition the joints between the concrete slabs often need attention; this generally requires a routing and resealing operation.	Repair of joint spalling	20	40
Summary of Maintenance Requirements	As detailed above under 'Maintaining Structural Integrity', plus 4% of surface area broken out and reinstated over 40 year period, 3 drainage checks and cleaning if necessary over 40 year period, visual surveys undertaken once a year, full reinstatement 40 years after construction.			

Table Notes

[a]'Delivering Best Value in Highway Maintenance', Code of Practice for Maintenance Management, 2001.

[b]Cracking in concretes is usually defined in terms of location and type of crack. However, for this exercise, it was felt that a general category for joints would suffice.

[c]'Concrete Pavement Maintenance Manual', ISBN 0 946691 89 4, Highways Agency, 2001.

2.3 Asphalt Construction

The design of the asphalt construction for a supermarket car park (domestic vehicles only, as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 6.

Table 6 Design of Asphalt Construction for a 24 Hr Supermarket Car Park

Subgrade condition (% CBR)	*Pavement Construction*
3	30 mm Surface course 60 mm Basecourse 300 mm Subbase
6	30 mm Surface course 60 mm Basecourse 200 mm Subbase

The maintenance strategy for the asphalt construction is shown in Table 7. The expected life of an asphalt surface course for this type of application is approximately 20 years; hence the maintenance strategy has been normalised for this time span. As the traffic conditions are relatively low, no replacement of the base/binder course has been accounted for in the following maintenance strategy.

Table 7 Maintenance Strategy for Asphalt Construction – 24 Hr Supermarket Car Park

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Health and Safety	The aggregate on the asphalt surface course can become 'polished' with time, especially in areas/carriageways which are	Surface dressing	100	Once ten years after construction; Once fifteen

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	subjected to concentrated traffic or sharp turning. The most common method of maintaining the surface texture of the road is to 'surface dress'; this may be achieved using either slurry seal, microsurfacing or the more traditional method of 'chip and seal'. These methods will prolong the life of the surface course for approximately 5 years.	Visual Survey		years after construction. Once a year.
Aesthetics	To maintain the cosmetic appearance of the car park surface dressing would probably be required. However this requirement is already met by the health and safety MI.	None	-	-
Utility Reinstatement	Requires excavation of trenches and full reinstatement of material. This type of operation can also have a detrimental effect on the aesthetics of the car park.	Excavation and full reinstatement	2	20
Drainage Maintenance	As detailed in Table 5.	Visual check of drainage followed by cleaning if necessary.		Once every ten years.
Maintaining Structural Integrity	*Overall Durability* As stated earlier, timely replacement of the surface course protects the structural layers of the pavement.	Surface course	100	20
	Resistance to Point Loads Bituminous mixtures are susceptible to rutting due to the viscoelastic properties of bitumen. If the bitumen is loaded at a low frequency (stationary vehicles / recycling skips), the bitumen becomes increasingly viscous (i.e. softer), resulting in rutting and surface deformation. These	Surface course	4	20

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	problems generally occur in the summer, where temperatures are higher.			
	Resistance to Fuel Spillage Bituminous material is susceptible to fuel damage. The surface of the car park might require cleaning if contaminated with fuel.	Surface course	2	20
	Resistance to Shear Stresses Possible damage to the surface course; chance of reducing the surface texture, creating polished surfaces. Can also induce ravelling.	Surface dress	20	20
Summary of Maintenance Requirements	100% of surface area is given some form of surface treatment, once ten years after construction, once fifteen years after construction. Surface course replaced on 106% of surface area (6% over 20 year period, 100% at end of 20 year period). Full reinstatement of 2% of surface area 1 drainage check and possible cleaning			

Table Footnotes

[a]Private communication – Philip Swain – Broxtowe Borough Council

3. WAREHOUSE DISTRIBUTION CENTRE PARKING LOTS

The main MIs for a warehouse distribution centre car park are shown in Table 8 along with a brief description of their impact. The maintenance strategy for a warehouse distribution centre is focussed on maintaining the structural integrity of the pavement. The aesthetics of the surface are of lower priority with the pavement providing a primarily utilitarian purpose. The loading regime for a busy warehouse distribution centre are particularly onerous. The advent of 'super single' tyres on articulated heavy goods vehicles has increased the point loads which the pavements are subjected to and this compounds the rate of 'damage' to the pavement.

Table 8 MIs for Warehouse Distribution Centre Parking Lots

MI	*Description*
Health and Safety	Although the health and safety requirement is not as high as that for a supermarket car park, there is still a requirement to maintain a safe working surface.
Utility Reinstatement	A small amount of utility reinstatement could be expected, although at a reduced rate from that occurring in a residential or commercial zone.
Drainage Maintenance	The drainage maintenance requirements for this application are similar to that for the supermarket car park. Cleaning of the drains will be required at a relevant juncture to maintain the flow capacity.
Maintaining Structural Integrity	This forms the main requirement for this type of pavement application. It is essential that the structural layers of the pavement are maintained, as otherwise deterioration will occur rapidly. The point loads for a warehouse distribution centre are extremely onerous especially if areas of the car park are on an incline or hot weather is routinely experienced (applicable to bituminous mixtures). Fuel spillage is relatively common in this type of pavement, hence ideally the pavement construction will exhibit high resistance to this mode of attack. The turning action of the commercial vehicles imparts significant shear stresses onto the pavement surface. However, cosmetic scuffing on the pavement surface would not constitute a maintenance need for this application.

3.1 Permeable Block Paving Construction (System C)

The design of the permeable block paving (System C) for a warehouse distribution centre parking lot (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 9.

Table 9 Design of Permeable Pavement Construction for Warehouse Distribution Centre Parking Lots

Subgrade condition (% CBR)	*Pavement Construction*
3	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregates 200 mm Cement Stabilised Crushed Rock 400 mm Open Graded Crushed Rock Impervious Membrane
6	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregate 220 mm Cement Stabilised Crushed Rock 75 mm Open Graded Crushed Rock Impervious Membrane

The maintenance strategy for the permeable block paving is shown in Table 10. The design life for this type of paving and application is estimated to be in the region of 20 years.

Table 10 Maintenance Strategy for Permeable Block Paving – Warehouse Distribution Centre Parking Lots

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 3. A reduced degree of block paving relocation would be expected compared to a supermarket application.	Relocation of block paving using new laying and jointing materials.	0.5	20
Utility Reinstatement	As detailed in Table 3. Similarly, a reduced amount of reinstatement would be assumed.	As detailed in Table 3.	1	20
Drainage Maintenance	As detailed in Table 3.	None	-	-
Maintaining Structural	*Overall Durability*			

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Integrity	As stated in Table 8, the main requirement for this application is to maintain the structural integrity and protect the underlying pavement layers. To reflect this requirement, a reasonable level of maintenance is required,	Complete relocation of block paving (75% of blocks reused); new jointing and laying materials used. No replacement of Cement Stabilised Crushed Rock.	100	20
	Resistance to Point Loads The commercial traffic at a warehouse distribution centre will impose a high loading regime (both volumetric and shear stresses) on the pavement. If laid correctly, block paving is highly resistant to deformation. Experience and studies[a,b] have shown block paving to be well suited to heavy loading regimes, resulting in very low rutting rates.	Relocation of block paving using new laying and jointing materials.	1	20
	Resistance to Fuel Spillage As detailed in Table 3.	None	-	-
	Resistance to Shear Stresses As detailed in Table 3; the shear stresses imparted by the commercial vehicles on the pavement surface will be significant. However, a properly constructed block pavement should exhibit high resistance to this type of damage.	Relocation of block paving using new laying and jointing materials.	0.5	20
Summary of Maintenance Requirements	Complete relocation of blocks (100% of surface area) after 20 years; in this case it has been assumed that 75% of the blocks can be reused. However, new jointing and laying material is always required. No replacement of Cement Stabilised Crushed Rock. Relocation of 2% of surface area (reusing blocks, using new jointing and laying materials).			

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	'Full depth' relocation of 1% of surface area (reusing blocks, using new jointing, laying and subbase materials).			

Table Notes

[a]Knapton J, and Meletiou M., 'The Structural Design of Heavy Duty Pavements for Ports and other Industries', British Ports Association, publishers The British Precast Concrete Federation Ltd for Interpave, 1996.

[b]Teiborlang L., Ryntathiang M., Mazumdar M. and Pandey B.B., 'Structural Behaviour of Cast In Situ Concrete Block Pavement', J. Transp. Engrg., Volume 131, Issue 9, pp. 662-668, September 2005.

3.2 Unreinforced Concrete Construction

The design of the unreinforced concrete construction for a warehouse distribution centre parking lot (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 11.

Table 11 Design of Unreinforced Concrete Construction for Warehouse Distribution Centre Parking Lots

Subgrade condition (% CBR)	*Pavement Construction*
3	170 mm Pavement Quality Concrete 300 mm Subbase
6	170 mm Pavement Quality Concrete 210 mm Subbase

The maintenance strategy required for an unreinforced concrete construction in a warehouse distribution centre parking lot application is shown in Table 12. It is estimated that the design life of this pavement type for this application is in the region of 40 years.

Table 12 Maintenance Strategy for Unreinforced Concrete Construction – Warehouse Distribution Centre Parking Lots

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 5. It is not anticipated that any maintenance requirements will arise out of the 'Health and Safety' MI which are not covered by the 'Maintaining Structural Integrity' MI.	The Health and Safety maintenance treatment has been amalgamated with the 'Maintaining Structural Integrity' MI.	-	-
Utility Reinstatement	As detailed in Table 5.	As detailed in Table 5.	2	40
Drainage Maintenance	As detailed in Table 5.	Visual check of drainage followed by cleaning if necessary.	-	Once every ten years
Maintaining Structural Integrity	*General Durability* As detailed in Table 5.	Repair of joint spalling	30	40
		Repair of joint sealant	100	40
		Repair of cracks (all types)[b]	40	40
		Repair of surface spalling	20	40
		Repair of surface defects (thin bond repairs)	20	40
		Repair of concrete bays (full depth)	25	40
	Resistance to Point Loads As detailed in Table 5. Although the loading is regime is more severe than that expected in a supermarket car park this is compensated by the more rigorous design and the increased maintenance defined in the 'Maintaining Structural Integrity' MI.	None	-	-
	Resistance to Fuel Spillage As detailed in Table 5.	None	-	-

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	Resistance to Shear Stresses As detailed in Table 5.			
Summary of Maintenance Requirements	As detailed above under 'Maintaining Structural Integrity'. 2% of surface area broken out and reinstated over 40 years life. 3 drainage checks and cleaning if necessary. Full reinstatement 40 years after initial construction.			

3.3 Asphalt Construction

The design of the asphalt construction for a warehouse distribution centre parking lot (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 13.

Table 13 Design of Asphalt Construction for Warehouse Distribution Centre Parking Lots

Subgrade condition (% CBR)	*Pavement Construction*
3	30 mm Surface Course 60 mm Basecourse 100 mm Roadbase 300 mm Subbase
6	30 mm Surface Course 60 mm Basecourse 100 mm Roadbase 210 mm Subbase

The maintenance strategy required for an asphalt construction in a warehouse distribution centre parking lot application is shown in Table 14. It is estimated that the design life of this pavement type for this application is in the region of 20 years.

Table 14 Maintenance Strategy for Asphalt Construction – Warehouse Distribution Centre Parking Lots

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 7. Although Health and Safety requirements are not as stringent as those for a	Catered for under 'Maintaining Structural	-	-

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	supermarket car park, the risks still need to be managed. However it is likely that the 'Maintaining Structural Integrity' MI will satisfy the Health and Safety requirements	Integrity'.		
Utility Reinstatement	As detailed in Table 7.	Excavation and full reinstatement	1	20
Drainage Maintenance	As detailed in Table 7.	Visual check of drainage followed by cleaning if necessary.		Once every ten years.
Maintaining Structural Integrity	*Overall Durability* As stated earlier, timely replacement of the surface course protects the structural layers of the pavement. Research[a] has indicated 'damage' to an asphalt road is approximately proportional to the weight of the vehicle to a third or fourth power law.	Surface course	100	10
	Resistance to Point Loads As explained in Table 7, asphalt is susceptible to rutting. The advent of 'super single' tyres on commercial vehicles has also increased point loads[b], compounding the problem.	Surface Course Repairs	10	20
	Resistance to Fuel Spillage As detailed in Table 7.	Surface Course Repairs	5	20
	Resistance to Shear Stresses As detailed in Table 7. The damage is likely to be more severe due to the commercial vehicles; hence the required maintenance is likely to be more extensive.	Surface Course	30	20
Summary of	100% of surface course replaced after ten years.			

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Maintenance Requirements	A further 45% of surface course replaced over 20 year period. Full reinstatement of 1% of surface area over 20 year period. 1 drainage check and possible cleaning. 100% of surface course replaced after twenty years.			

Table Footnotes

[a]In the later 1950s the then American Association of State Highway Officials (AASHO) conducted pavement deterioration tests. The tests found that, with increasing axle load, pavements deteriorated at a rate that was roughly equivalent to the relative weight increase raised to the fourth power. More recent research has suggested that the pavement deterioration is less than a fourth power, and the overall relationship between axle loads and pavement deterioration may be closer to a third power law.

[b]'Design of long-life flexible pavements', TRL Report 250, ISBN 0968-4107.

4. HOUSING ESTATE DISTRIBUTION ROAD

The main MIs for a distribution road on a housing estate are shown in Table 15 along with a brief description of their impact. The majority of vehicles on a housing estate distribution road are domestic, transmitting a relatively low load to the surface. The traffic flows obviously depend on the size of the housing estate but would generally be classed as low. Housing developers place great importance on the aesthetics of the houses and the surrounding infrastructure, as market research suggests it is the 'overall feel' which helps secure sales. The MIs detailed in Table 15 are designed to reflect these needs.

Table 15 MIs for a Housing Estate Distribution Road

MI	*Description*
Health and Safety	Although the health and safety requirement is not as high as that for a supermarket car park, there is still a requirement to maintain a safe working surface. Adequate skid resistance needs to maintained as there is a higher probability of child activity, which might necessitate hard braking on occasions.
Utility Reinstatement	Most block paving installations are undertaken on new housing estate developments. New housing developments tend to have adequate service ducts placed at the time of construction, reducing the need for utility driven excavations.
Drainage Maintenance	Cleaning of the drains will be required at a relevant juncture to maintain the flow capacity.
Maintaining Structural Integrity	The maintenance schedule required for a housing estate distribution road is generally low. The vehicles are generally domestic (low load) and the traffic flow is also low.

4.1 Permeable Block Paving Construction (System C)

The design of the permeable block paving (System C) for a housing estate distribution road (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 16.

Table 16 Design of Permeable Block Pavement Construction for Housing Estate Distribution Road

Subgrade condition (% CBR)	*Pavement Construction*
3	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregate 125 mm Cement Stabilised Crushed Rock 400 mm Open Graded Crushed Rock Impervious Membrane
6	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregate 125 mm Cement Stabilised Crushed Rock Impervious Membrane

The maintenance strategy for the permeable block paving is shown in Table 17. The design life for this type of paving and application is estimated to be in the region of 40 years; however this allows for a substantial degree of block relocation.

Table 17 Maintenance Strategy for Permeable Block Paving – Distribution Road on a Housing Estate

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 3. The health and safety requirements for this application may be classed as intermediate (i.e. not as high as a supermarket car park application but greater than those required for a warehouse distribution centre).	Relocation of block paving using new laying and jointing materials.	1	20
Utility Reinstatement	As detailed in Table 3. The predicted degree of utility reinstatement is reduced due to the presence of service ducts.	Full depth relocation. As detailed in Table 3.	1	20
Drainage Maintenance	As the design life is 40 years for this application, it is advised that a mechanical cleaning operation is undertaken after 20 years	Mechanical cleaning		Once after 20 years.
Maintaining Structural Integrity	*Overall Durability* The loading regime for this	Complete	100	20

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Car Park Area (%)*	*Frequency (years)*
	application is low. There are examples of block paving resisting much higher traffic regimes without maintenance in excess of 20 years[a]. Hence the design life for this application (assuming the block paving is correctly installed) is probably in the region of 40 years.	relocation of block paving (75% of blocks reused); new jointing and laying material used. No replacement of 125 mm Cement Stabilised Crushed Rock.		
	Resistance to Point Loads Block paving has high resistance to point loads; this application will not generally generate high point loads, hence the maintenance requirement is correspondingly low.	Relocation of block paving using new laying and jointing materials.	0.5	20
	Resistance to Fuel Spillage As detailed in Table 3.	None	-	-
	Resistance to Shear Stresses It is not anticipated that the shear stresses generated on a typical housing estate distribution will require maintenance work.	None	-	-
Summary of Maintenance Requirements	Complete relocation of blocks (100% surface area), reusing 75% of blocks after 20 years. New jointing and laying materials used. No replacement of Cement Stabilised Crushed Rock. Relocation of 1.5% of surface area (reusing blocks, using new jointing and laying materials). 'Full depth' relocation of blocks of 1% of surface area (reusing blocks, use new jointing, laying and subbase materials). One cleaning operation (mechanical) 20 years after construction.			

Table Footnotes

Walsh I., 'Take the A-Road', Pave-it, Interpave publication, April 2004.

4.2 Unreinforced Concrete Construction

The design of unreinforced concrete construction for a housing estate distribution road (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 18.

Table 18 Design of Unreinforced Construction for Housing Estate Distribution Road

Subgrade condition (% CBR)	*Pavement Construction*
3	160 mm Pavement Quality Concrete Bays (5 m bays) 300 mm Subbase
6	160 mm Pavement Quality Concrete Bays (5 m bays) 210 mm Subbase

The maintenance strategy required for an unreinforced concrete construction of a housing estate distribution road is shown in Table 19. It is estimated that the design life of this pavement type for this application is in the region of 40 years.

Table 19 Maintenance Strategy for Unreinforced Concrete Construction – Distribution Road on a Housing Estate

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 5. It is not anticipated that any maintenance requirements will arise out of the 'Health and Safety' MI which are not covered by the 'Maintaining Structural Integrity' MI.	The Health and Safety maintenance treatment has been amalgamated with the 'Maintaining Structural Integrity' MI.	-	-
Utility Reinstatement	As detailed in Table 5. The degree of utility reinstatement required is reduced due to the presence of service ducts.	Break out of concrete, followed by full layer reinstatement.	1	40
Drainage Maintenance	As detailed in Table 5.	Visual check of drainage followed by cleaning if necessary.		Once every 10 years
Maintaining Structural	*General Durability* As detailed in Table 5. Although	Repair of joint spalling	30	40
		Repair of joint	100	40

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
Integrity	the durability of concrete is generally recognised as good, it is anticipated that a degree of repair will be required over the 40 year design life.	sealant		
		Repair of cracks (all types)[b]	10	40
		Repair of surface spalling	15	40
		Repair of surface defects (thin bond repairs)	10	40
		Repair of concrete bays (full depth)	10	40
	Resistance to Point Loads As detailed in Table 5. Although the loading regime is more severe than that expected in a supermarket car park this is compensated by the more rigorous design and the increased maintenance defined in the 'Maintaining Structural Integrity' MI.	None	-	-
	Resistance to Fuel Spillage As detailed in Table 5.	None	-	-
	Resistance to Shear Stresses As detailed in Table 5.	None	-	-
Summary of Maintenance Requirements	As detailed above under 'Maintaining Structural Integrity' 1% of surface area broken out and reinstated 3 drainage checks and cleaning if necessary Full reconstruction after 40 years.			

4.3 Asphalt Construction

The design of an asphalt construction for a housing estate distribution road (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 20.

Table 20 Design of Asphalt Construction for Housing Estate Distribution Road

Subgrade condition (% CBR)	*Pavement Construction*
3	40 mm Surface Course 80 mm Basecourse 300 mm Subbase
6	40 mm Surface Course 80 mm Basecourse 210 mm Subbase

The maintenance strategy required for an asphalt construction of a housing estate distribution road is shown in Table 19. It is estimated that the design life of this pavement type for this application is in the region of 20 years.

Table 21 Maintenance Strategy for an Asphalt Construction – Distribution Road on a Housing Estate

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 7. It is important that the surface texture of the road is maintained. Discussions with County Councils[a] provided approximate surface dressing maintenance interventions.	Surface dressing or other surface treatment.	100	Once after 10 years; Once after 15 years
Utility Reinstatement	As detailed in Table 7. Minimal utility reinstatement assuming housing development is new.	Excavation and full reinstatement	0.5	20
Drainage Maintenance	As detailed in Table 7.	Visual check of drainage followed by cleaning if necessary.		Once every ten years.
Maintaining Structural Integrity	*Overall Durability* As stated earlier, timely replacement of the surface course protects the structural layers of the pavement.	Surface course	100	20

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
	Resistance to Point Loads Minimal point loads would be expected on a residential housing estate.	Surface Course Repairs	2	20
	Resistance to Fuel Spillage As detailed in Table 7. Minimal fuel spillage would be expected on a residential housing estate.	Surface Course Repairs	1	20
	Resistance to Shear Stresses As detailed in Table 7. Whilst the traffic loading regime for this type of application is relatively low, there is a requirement to maintain a smooth surface.	Surface Course Repairs	3	20
Summary of Maintenance Requirements	100% of the area would require surface treatement; once ten years after construction, once fifteen years after construction. Full reinstatement of 0.5% of surface area. 1 drainage check and possible cleaning. 3% of the surface course would be replaced during the twenty year period. 100% of the surface course would be replaced at the end of the twenty year period.			

Footnotes

[a]Barry Wilcox of Birmingham City Council – private communication.

5. INDUSTRIAL ESTATE DISTRIBUTION ROAD

The main MIs for a distribution road on an industrial estate are shown in Table 22 along with a brief description of their impact. The loading regime on an industrial estate distribution road can be reasonably severe, with a high proportion of heavy good vehicles.

Table 22 MIs for an Industrial Estate Distribution Road

MI	*Description*
Health and Safety	Whilst the health and safety requirements for this type of pavement surface are relatively low (due to the low pedestrian traffic and low speeds) skidding resistance needs to be maintained. In most cases, the Health and Safety requirements will be met by the requirements to Maintain the Structural Integrity.
Utility Reinstatement	Discussions with county councils have revealed that the main driver for utility reinstatement is when a warehouse or industrial unit will change application.
Drainage Maintenance	Cleaning of the drains will be required at a relevant juncture to maintain the flow capacity.
Maintaining Structural Integrity	The loading regime on an industrial road is relatively severe. The majority of the traffic is heavy goods vehicles. They can also park up on the road side, creating sustained point loads.

5.1 Permeable Block Paving Construction (System C)

The design of the permeable block paving (System C) for an industrial estate distribution road (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 23.

Table 23 Design of Permeable Block Pavement Construction for Industrial Estate Distribution Road

Subgrade condition (% CBR)	*Pavement Construction*
3	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregate 150 mm Cement Stabilised Crushed Rock 400 mm Open Graded Crushed Rock Impervious Membrane
6	80 mm Permeable Block Paving & Jointing Material 50 mm Laying Course Aggregate 150 mm Cement Stabilised Crushed Rock 75 mm Open Graded Crushed Rock Impervious Membrane

The maintenance strategy for the permeable block paving is shown in Table 24. The design life for this type of paving and application is estimated to be in the region of 20 years.

Table 24 Maintenance Strategy for Permeable Block Paving – Industrial Estate Park

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 3. The health and safety requirements for this application may be classed as low. It is anticipated that all the health and safety requirements will be met by the 'Maintaining Structural Integrity' MI.	None	-	-
Utility Reinstatement	The degree of utility reinstatement is difficult to estimate for this application. As stated in Table 22 it depends largely on whether an industrial unit changes use.	'Full depth' relocation. As detailed in Table 3.	1	20
Drainage Maintenance	As the design life is 20 years it is unlikely that any drainage maintenance will be required.	None	-	-
Maintaining Structural Integrity	*Overall Durability* The durability of block paving is generally classed as high; it is unlikely that there would be durability requirements.	Complete relocation of block paving reusing 75% of the blocks and new jointing and laying material. No replacement of Cement Stabilised Crushed Rock.	100	20
	Resistance to Point Loads Point loads could be expected in this application due to parked commercial vehicles; however as block paving has high resistance to rutting, the required maintenance schedule would be limited.	Relocation of block paving using new jointing and laying materials.	1	20

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
	Resistance to Fuel Spillage As detailed in Table 3.	None	-	-
	Resistance to Shear Stresses A small degree of maintenance work could be expected to account for turning stresses.	Relocation of block paving using new jointing and laying materials.	1	20
Summary of Maintenance Requirements	Complete relocation of blocks (100% surface area) every 20 years (reusing 75% of the blocks). New jointing and laying materials used. No replacement of Cement Stabilised Crushed Rock. Relocation of 2% of surface area (reusing blocks, using new jointing and laying materials). 'Full depth' relocation of blocks of 1% of surface area (reusing blocks, using new jointing, laying and subbase materials).			

5.2 Unreinforced Concrete Construction

The design of unreinforced concrete construction for an industrial estate distribution road (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 25.

Table 25 Design of Unreinforced Concrete Construction for Industrial Estate Distribution Road

Subgrade condition (% CBR)	*Pavement Construction*
3	150 mm Pavement Quality Concrete 300 mm Subbase
6	150 mm Pavement Quality Concrete 210 mm Subbase

The maintenance strategy for the unreinforced concrete construction is shown in Table 26. The design life for this type of paving and application is estimated to be in the region of 40 years.

Table 26 Maintenance Strategy for Unreinforced Concrete Construction – Industrial Estate Park

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Surface Area (%)*	*Frequency (years)*
Health and Safety	As detailed in Table 5. It is not anticipated that any maintenance requirements will arise out of the 'Health and Safety' MI which are not covered by the 'Maintaining Structural Integrity' MI.	None	-	-
Utility Reinstatement	As detailed in Table 5.	Break out of concrete, followed by full layer reinstatement.	2	40
Drainage Maintenance	As detailed in Table 5.	Visual check of drainage followed by cleaning if necessary.		Once every ten years.
Maintaining Structural Integrity	*General Durability* As detailed in Table 5. Although the durability of concrete is generally recognised as good, it is anticipated that a degree of repair will be required over the 40 year design life.	Repair of joint spalling	30	40
		Repair of joint sealant	100	40
		Repair of cracks (all types)[b]	10	40
		Repair of surface spalling	15	40
		Repair of surface defects (thin bond repairs)	10	40
		Repair of concrete bays (full depth)	10	40
	Resistance to Point Loads As detailed in Table 5. Although the loading regime is reasonably severe, any damage due to point loads should be catered for under 'General durability' above.	None	-	-
	Resistance to Fuel Spillage As detailed in Table 5.	None	-	-

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Surface Area (%)*	*Frequency (years)*
	Resistance to Shear Stresses As detailed in Table 5.	None	-	-
Summary of Maintenance Requirements	As detailed above under 'Maintaining Structural Integrity'. 2% of surface area broken out and reinstated during the 40 year design life, 3 drainage checks and cleaning if necessary. Concrete broken out and relaid 40 years after initial construction.			

5.3 Asphalt Construction

The design of an asphalt construction for an industrial estate distribution road (as detailed by SWPE report L276) for both 3% and 6% CBR subgrade is shown in Table 27.

Table 27 Design of Asphalt Construction for an Industrial Estate Distribution Road

Subgrade condition (% CBR)	*Pavement Construction*
3	30 mm Surface Course 50 mm Basecourse 70 mm Roadbase 300 mm Subbase
6	30 mm Surface Course 50 mm Basecourse 70 mm Roadbase 210 Subbase

Table 28 Maintenance Strategy for Asphalt Construction – Industrial Estate Distribution Road

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
Health and Safety	Any health and safety requirements would be met by the 'Maintaining Structural Integrity' MI.	None	-	-
Utility Reinstatement	As detailed in Table 7.	Excavation and full reinstatement	1	20
Drainage Maintenance	As detailed in Table 7.	Visual check of drainage followed by cleaning if necessary.		Once every ten years.

MI	*Effect of MI on Pavement Type*	*Maintenance Treatment*	*Road Area (%)*	*Frequency (years)*
Maintaining Structural Integrity	*Overall Durability* Due to the relatively heavy traffic it is advised that the surface course is replaced after ten years to protect the Basecourse layer.	Surface course	100	10
	Resistance to Point Loads Due to the resurfacing of the surface course under the 'durability' clause above, further surface course repairs should be minimal.	Surface Course Repairs	2	10
	Resistance to Fuel Spillage As detailed in Table 7. At a minimum due to the 'durability' requirements.	Surface Course Repairs	1	20
	Resistance to Shear Stresses As detailed in Table 7. At a minimum due to the 'durability' requirements.	Surface Course	1	20
Summary of Maintenance Requirements	100 % of surface course relaid ten years after construction. A further 3% of surface course repaired over twenty year period 1 drainage check and possible cleaning over twenty year period. 100% of the surface course would be replaced at the end of the twenty year period.			

6. WHOLE LIFE COSTS

6.1 Costing of Maintenance Strategies

The costing of the maintenance strategies was undertaken by Corderoy (Quantity Surveyors) and used the maintenance strategies identified in Sections 2 through to 5. The 'costing rules' used by Corderoy are listed below:

1. The base date for the costs is 4th quarter 2005.
2. The rates are nett and do not allow for any profit.
3. The rates exclude any site preliminaries except for traffic management. The traffic management component has been included within the rates.
4. The areas on which the costs have been based are:
   - Supermarket Car Park of 3438 m^2
   - Warehouse Distribution Centre of 104871 m^2
   - Housing Estate Road of 7504 m^2
   - Industrial Estate Road of 7504 m^2

   The size of the area does affect the price per square metre for several reasons:
   - Plant hire/running costs become more effective as the area to be paved increases.
   - Materials reduce in cost with bulk purchase.
   - The ratio of the perimeter length to the area decreases with an increase in area. This means that per square metre less 'edge activities' (e.g. gully cleaning) need to be undertaken.
   - Initialisation costs become a smaller component of the total cost as the area to be paved increases.
5. For the warehouse distribution centre, housing estate distribution road and industrial estate distribution road only 25% of the block paving has been costed for replacement (as detailed by the maintenance strategies), using new jointing and laying material (50 mm thick coarse aggregate), in the section named 'Overall Durability'. The remainder (75%) will be lifted, and relocated (relaid) using new jointing and laying material.

6. The design lives for the asphalt and permeable block paving are both 20 years, whereas the unreinforced concrete has a design life of 40 years. To make all the costs comparable, the maintenance component of the WLCs of the asphalt and the permeable block paving have been doubled.
7. It has been assumed that the gullies will only be cleaned once a year.

6.2 Calculation of WLCs

In this study the WLCs were taken to comprise the initial construction costs and the maintenance costs. Pavement user costs were not accounted for as these do not affect the service owner /operator. The initial construction costs were calculated as part of a previous Scott Wilson project and have simply been added to the maintenance costs. It is important to note that the initial construction cost would not be duplicated if the asset was still in service after 40 years, as the maintenance strategies are designed to return the asset to its 'as built' condition after 40 years service.

6.3 WLCs of 24 Hr Supermarket Car Park

The WLCs of all three pavement types and subgrade conditions are shown in Table 29 for the supermarket car park application. In this case, it has been assumed that a charge of £40/day will be made for the loss of a parking space during daytime trading. The analysis has shown that the permeable block paving Case I (block paving replaced after 20 years) has slightly higher WLCs than that of the asphalt, for both subgrade conditions; however, the permeable block paving Case II (block paving durability of 40 years) is the least expensive in terms of WLCs. To reiterate, the reason for undertaking two analyses (Case I and II) for the permeable block paving was to provide upper and lower bound solutions for the WLCs for this paving solution. This was deemed necessary as permeable block paving is a relatively new construction material, and consequently lacks long term performance data relating to its maintenance costs. The paving solution with highest WLCs was the unreinforced concrete. The principal maintenance cost component for the concrete is the 'breaking out' cost. It is apparent from Table 29 that the quality of the subgrade has only a marginal effect on the WLCs of the asphalt and the permeable block paving. A more detailed breakdown of these costs is presented in Table 33 (Appendix A). The WLCs for the various pavement types have been presented as a cost per square metre per year in the bar chart shown in Figure 7 – PB denotes permeable block paving, URC denotes unreinforced concrete and A denotes asphalt, with the subsequent numbers representing a subgrade of either 3 or 6% CBR.

Table 29 WLCs for a Supermarket Car Park

Pavement Type	*CBR (%)*	*WLC Total (£)*
Permeable block paving - Case I	3	434,123.36
Permeable block paving - Case II	3	337,146.62
Permeable block paving - Case I	6	402,741.74
Permeable block paving - Case II	6	305,716.97
Unreinforced concrete	3	697,024.16
Unreinforced concrete	6	539,129.89
Asphalt	3	399,169.54
Asphalt	6	384,661.18

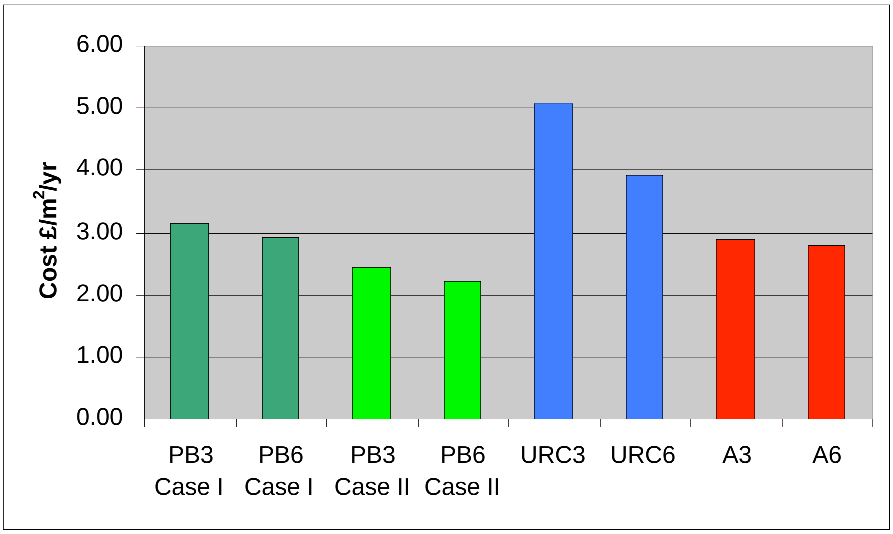

Figure 7 WLCs per square metre per year for a Supermarket car park

6.4 WLCs of a Warehouse Distribution Centre

The WLCs of all three pavement types and two subgrade conditions are summarised in Table 30 for the warehouse distribution centre, with a detailed breakdown provided in Table 34 (Appendix A). The magnitude of the WLCs for all pavement types are high when compared to those of the supermarket; this is predominantly due to the size of area considered. The WLCs for the various pavement types have been presented as a cost per square metre per year in the bar chart shown in Figure 8. It can be seen from this figure that permeable block paving is the most economic paving option when compared to asphalt and unreinforced concrete, and that on this measure, the magnitude of the cost per m^2 is less than for the supermarket application as would be expected (because of the size effect).

Table 30 WLCs over 40 years for a Warehouse Distribution Centre

Pavement Type	*CBR (%)*	*WLC Total (£)*
Permeable block paving	3	9,565,803.84
Permeable block paving	6	8,417,470.40
Unreinforced concrete	3	18,142,383.90
Unreinforced concrete	6	13,560,522.72
Asphalt	3	9,975,592.24
Asphalt	6	9,594,910.51

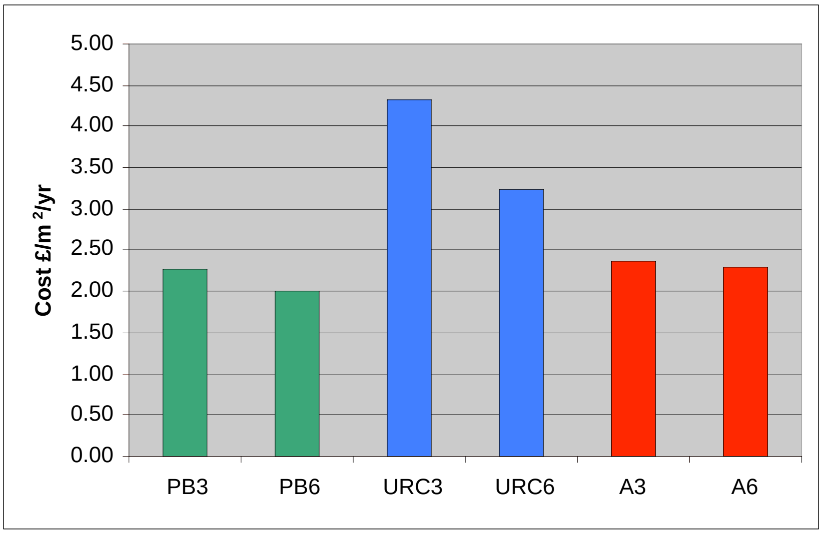

Figure 8 WLCs per square metre per year for a Warehouse Distribution Centre

6.5 WLCs of a Housing Estate Distribution Road

The WLCs of all three pavement types and two subgrade conditions are summarised in Table 31 for the housing estate distribution road, with a detailed breakdown provided in Table 35 (Appendix A). The WLCs for the various pavement types have been presented as a cost per square metre per year in the bar chart shown in Figure 9. The WLCs for this application display a similar ranking to those of the warehouse distribution centre: the permeable block paving is the most economic paving choice, closely followed by the asphalt, with the concrete being by far the most expensive due to its break out costs.

Table 31 WLCs over 40 year period for Housing Estate Distribution Road

Pavement Type	*CBR (%)*	*WLC Total (£)*
Permeable block paving	3	686,372.34
Permeable block paving	6	597,880.22
Unreinforced concrete	3	1,536,240.48
Unreinforced concrete	6	1,107,246.82
Asphalt	3	740,734.96
Asphalt	6	713,495.44

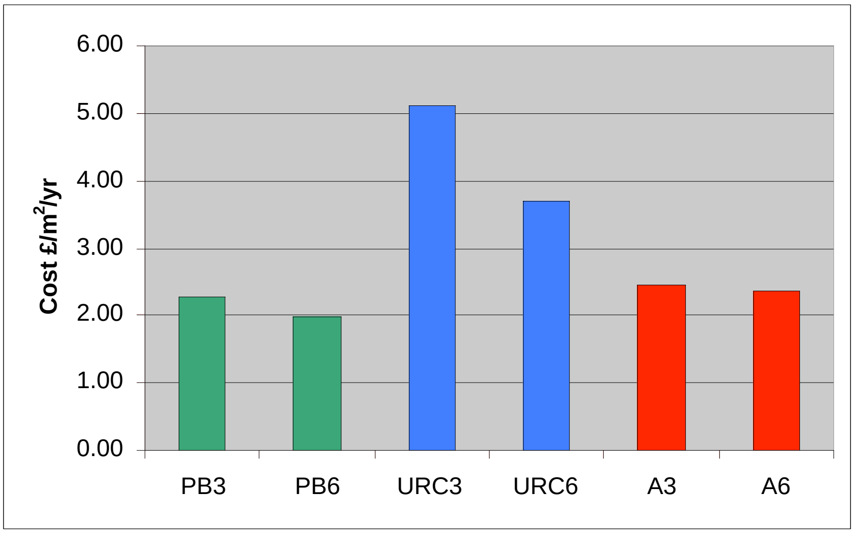

Figure 9 WLCs per square metre per year for a Housing Estate Distribution Road

6.6 WLCs of an Industrial Estate Distribution Road

The WLCs of all three pavement types and two subgrade conditions are summarised in Table 32 for the industrial estate distribution road, with a detailed breakdown provided in Table 36 (Appendix A). The WLCs for the various pavement types have been presented as a cost per square metre per year in the bar chart shown in Figure 10. For this application it is clear that permeable block paving is the most economic paving solution by a significant margin.

Table 32 WLCs over 40 year period for an Industrial Estate Distribution Road

Pavement Type	*CBR (%)*	*WLC Total (£)*
Permeable block paving	3	696,270.92
Permeable block paving	6	607,231.02
Unreinforced concrete	3	1,513,016.94
Unreinforced concrete	6	1,090,477.20
Asphalt	3	823,293.10
Asphalt	6	796,053.58

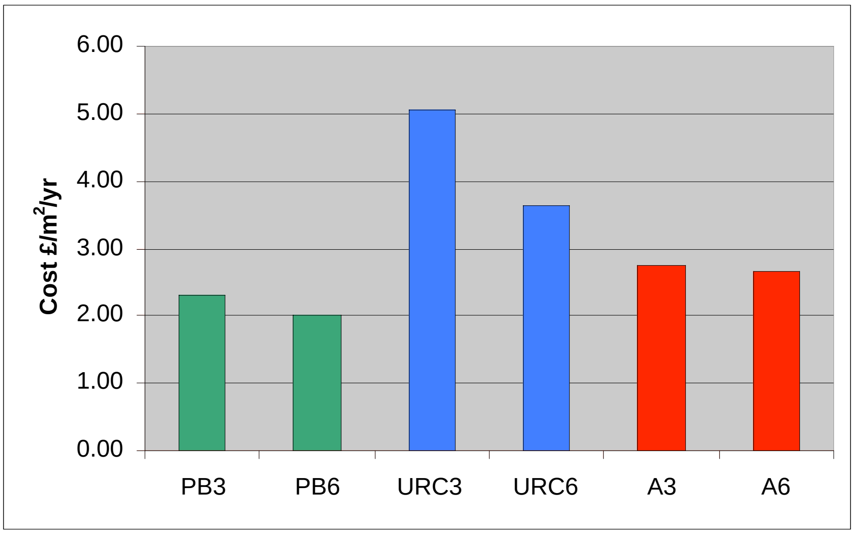

Figure 10 WLCs per square metre per year for an Industrial Estate Distribution Road

7. SUMMARY

Following a request by Interpave, Scott Wilson undertook a WLC analysis on three pavement types (permeable 'System C' block paving, unreinforced concrete and asphalt) for four pavement applications (supermarket car park, warehouse distribution centre, housing estate distribution road and industrial estate distribution road) for two subgrade conditions (having CBR values of 3 and 6%, respectively).

Each pavement application has different maintenance requirements driven by their different needs. For example, a supermarket car park needs to maintain an aesthetically pleasing appearance to satisfy the operators marketing needs and also needs to maintain a 'safe' surface, in order to avoid costly litigation resulting from their customers injuring themselves by tripping. In contrast, a warehouse distribution centre's strategy needs to focus on maintaining the structural integrity of the pavement under onerous loading conditions. These factors have been termed 'maintenance instigators', and the maintenance strategies needed to meet these requirements (for each of the pavement type application combinations) have been documented.

Costing of the maintenance strategies has been undertaken by Corderoy (Quantity Surveyors). These costs have been combined with the initial construction costs to calculate the WLCs. The initial construction costs have been calculated under a previous Scott Wilson study on behalf of Interpave.

The costing exercise has shown that with the exception of the supermarket car park, the permeable block paving (System C) was the most cost effective paving solution. For the case of the supermarket permeable block paving solution, two cases were analysed (20 year and 40 year block durability for Cases I and II, respectively); the WLCs of Case I were slightly higher than those of the asphalt, whilst the WLCs of Case II were lower than those of the asphalt. Based on these results, it is considered that for a 'standard' supermarket car park construction, the WLCs of the permeable block paving would be competitive, if not less than those of an asphalt construction. The WLC of the unreinforced concrete was consistently higher than those of the other two paving options, predominantly due to its 'breaking out cost'. It is important to note that the most expensive block paving option, System C, has been used in this analysis. Systems A and B would allow for further significant reductions in WLCs. In addition, the design lives for permeable paving used in this analysis have intentionally been extremely conservative (with the exception of the supermarket car park where a range was used) and thus form the upper bound of WLCs which could be expected in practice. Permeable pavements also have significant environmental advantages when compared to asphalt and unreinforced concrete, due to their Sustainable Urban Drainage System (SUDS) and their inherent capability for reuse when maintained.

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9. APPENDIX A

Table 33 Detail of WLCs for Supermarket Car Park (Case I and II) – 40 year life

Pavement type	*CBR (%)*	*MI*	*WLC Component (£)*
Permeable block paving - Case I	3	Initial Construction	162,548.64
	3	Health & Safety	35,380.62
	3	Aesthetics	35,001.64
	3	Utility Reinstatement	11,909.70
	3	Maintaining Strutctual Integrity	189,282.76
WLC Total (£)			**434,123.36**
Permeable block paving - Case II	3	Initial Construction	162,548.64
	3	Health & Safety	35,380.62
	3	Aesthetics	31,254.32
	3	Utility Reinstatement	11,957.01
	3	Maintaining Strutctual Integrity	96,006.03
WLC Total (£)			**337,146.62**
Permeable block paving - Case I	6	Initial Construction	132,775.56
	6	Health & Safety	35,380.62
	6	Aesthetics	35,001.64
	6	Utility Reinstatement	10,301.16
	6	Maintaining Strutctual Integrity	189,282.76
WLC Total (£)			**402,741.74**
Permeable block paving - Case II	6	Initial Construction	132,775.56
	6	Health & Safety	35,380.62
	6	Aesthetics	31,254.32
	6	Utility Reinstatement	10,301.16
	6	Maintaining Strutctual Integrity	96,005.31
WLC Total (£)			**305,716.97**
Unreinforced concrete construction	3	Initial Construction	144,946.08
	3	Health & Safety	30,000.00
	3	Utility Reinstatement	15,033.72
	3	Drainage Maintenance	18,056.24
	3	Maintaining Strutctual Integrity	488,988.12
WLC Total (£)			**697,024.16**
Unreinforced concrete construction	6	Initial Construction	131,881.68
	6	Health & Safety	30,000.00
	6	Utility Reinstatement	15,033.72
	6	Drainage Maintenance	18,179.28
	6	Maintaining Strutctual Integrity	475,916.89
WLC Total (£)			**539,129.89**
Asphalt Construction	3	Initial Construction	124,008.66
	3	Health & Safety	81,283.92
	3	Utility Reinstatement	8,420.76
	3	Drainage Maintenance	15,503.16
	3	Maintaining Strutctual Integrity	169,953.04
WLC Total (£)			**399,169.54**
Asphalt Construction	6	Initial Construction	109,500.30
	6	Health & Safety	81,283.92
	6	Utility Reinstatement	8,420.76
	6	Drainage Maintenance	15,503.16
	6	Maintaining Strutctual Integrity	169,953.04
WLC Total (£)			**384,661.18**

Table 34 Detail of WLCs for Warehouse Distribution Centre – 40 year life

Pavement type	*CBR (%)*	*MI*	*WLC Component (£)*
Permeable block paving	3	Initial Construction	5,218,380.96
	3	Health & Safety	22,856.88
	3	Utility Reinstatement	156,646.30
	3	Maintaining Strutctual Integrity	4,167,919.70
WLC Total (£)			**9,565,803.84**
Permeable block paving	6	Initial Construction	4,094,163.84
	6	Health & Safety	22,856.88
	6	Utility Reinstatement	132,529.98
	6	Maintaining Strutctual Integrity	4,167,919.70
WLC Total (£)			**8,417,470.40**
Unreinforced concrete construction	3	Initial Construction	4,201,132.26
	3	Utility Reinstatement	139,492.44
	3	Drainage Maintenance	222,850.09
	3	Maintaining Strutctual Integrity	13,578,909.11
WLC Total (£)			**18,142,383.90**
Unreinforced concrete construction	6	Initial Construction	3,820,450.53
	6	Utility Reinstatement	139,492.44
	6	Drainage Maintenance	222,850.09
	6	Maintaining Strutctual Integrity	13,198,180.19
WLC Total (£)			**13,560,522.72**
Asphalt Construction	3	Initial Construction	4,574,473.02
	3	Utility Reinstatement	107,411.92
	3	Drainage Maintenance	266,498.64
	3	Maintaining Strutctual Integrity	5,027,208.66
WLC Total (£)			**9,975,592.24**
Asphalt Construction	6	Initial Construction	4,193,791.29
	6	Utility Reinstatement	107,411.92
	6	Drainage Maintenance	266,498.64
	6	Maintaining Strutctual Integrity	5,027,208.66
WLC Total (£)			**9,594,910.51**

Table 35 Detail of WLCs for Housing Estate Distribution Road – 40 year life

Pavement type	*CBR (%)*	*MI*	*WLC Component (£)*
Permeable block paving	3	Initial Construction	394,410.24
	3	Health & Safety	6,346.32
	3	Utility Reinstatement	16,908.46
	3	Maintaining Strutctual Integrity	268,707.32
WLC Total (£)			**686,372.34**
Permeable block paving	6	Initial Construction	308,864.64
	6	Health & Safety	6,346.32
	6	Utility Reinstatement	13,961.94
	6	Maintaining Strutctual Integrity	268,707.32
WLC Total (£)			**597,880.22**
Unreinforced concrete construction	3	Initial Construction	401,764.16
	3	Utility Reinstatement	17,030.03
	3	Drainage Maintenance	47,830.45
	3	Maintaining Strutctual Integrity	1,069,615.84
WLC Total (£)			**1,536,240.48**
Unreinforced concrete construction	6	Initial Construction	374,524.64
	6	Utility Reinstatement	17,030.03
	6	Drainage Maintenance	47,830.45
	6	Maintaining Strutctual Integrity	1,042,386.34
WLC Total (£)			**1,107,246.82**
Asphalt Construction	3	Initial Construction	377,526.24
	3	Health & Safety	61,536.90
	3	Utility Reinstatement	10,011.96
	3	Drainage Maintenance	56,602.80
	3	Maintaining Strutctual Integrity	235,057.06
WLC Total (£)			**740,734.96**
Asphalt Construction	6	Initial Construction	350,286.72
	6	Health & Safety	61,536.90
	6	Utility Reinstatement	10,011.96
	6	Drainage Maintenance	56,602.80
	6	Maintaining Strutctual Integrity	235,057.06
WLC Total (£)			**713,495.44**

Table 36 Detail of WLCs for Industrial Estate Distribution Road – 40 year life

Pavement type	*CBR (%)*	*MI*	*WLC Component (£)*
Permeable block paving	3	Initial Construction	403,940.32
	3	Utility Reinstatement	17,309.26
	3	Maintaining Strutctual Integrity	275,021.34
WLC Total (£)			**696,270.92**
Permeable block paving	6	Initial Construction	318,544.80
	6	Utility Reinstatement	13,664.88
	6	Maintaining Strutctual Integrity	275,021.34
WLC Total (£)			**607,231.02**
Unreinforced concrete construction	3	Initial Construction	394,410.24
	3	Utility Reinstatement	4,920.91
	3	Drainage Maintenance	47,830.45
	3	Maintaining Strutctual Integrity	1,065,855.34
WLC Total (£)			**1,513,016.94**
Unreinforced concrete construction	6	Initial Construction	367,170.72
	6	Utility Reinstatement	4,920.91
	6	Drainage Maintenance	47,830.45
	6	Maintaining Strutctual Integrity	1,037,725.84
WLC Total (£)			**1,090,477.20**
Asphalt Construction	3	Initial Construction	407,392.16
	3	Utility Reinstatement	19,070.40
	3	Drainage Maintenance	56,602.80
	3	Maintaining Strutctual Integrity	340,227.74
WLC Total (£)			**823,293.10**
Asphalt Construction	6	Initial Construction	380,152.64
	6	Utility Reinstatement	19,070.40
	6	Drainage Maintenance	56,602.80
	6	Maintaining Strutctual Integrity	340,227.74
WLC Total (£)			**796,053.58**