THE ASPHALT PAVEMENT EMBODIED CARBON TOOL (asPECT): DEVELOPING A CARBON FOOTPRINTING METHODOLOGY FOR ASPHALT PRODUCTS

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ABSTRACT

Specific contributions to climate change - carbon footprints - now feature in the claims of many products, giving a basis for potential customers to procure on environmental as well as economic terms. This paper describes a consistent approach to carbon footprinting devised for asphalt products, developed through a collaborative effort by the UK highways sector, with representation from clients, industry and the research community. The asphalt Pavement Embodied Carbon Tool (asPECT), consisting of protocol documentation and software, takes a life cycle approach that follows the Publically Available Specification PAS 2050:2008 and facilitates assessment of greenhouse gas contributions from raw material acquisition, through to product production, installation, maintenance and end-of-life. The method provides the resolution to allow factors such as individual constituent material contributions, recycled content, energy consumption in heating and mixing and transport modes to be reflected in the overall footprints of asphalt products and applications. This paper describes the development process and some of the key features of asPECT.

***Keywords*:** Carbon, Climate change, Life-cycle assessment.

1. INTRODUCTION

Carbon footprints now feature in the environmental claims of a number of mainstream consumer products [1]. Carbon footprinting is one approach which can be used in the process of measuring and reducing greenhouse gas (GHG) emissions, responding to overarching targets such as the 80% target reductions in GHG emissions by 2050 of the UK's Climate Change Act 2008 [2]. As part of a resource intensive industry, the highways sector was keen to develop a transparent, practical and all-inclusive methodology to measure the GHG impacts of its products and applications.

asPECT, the asphalt Pavement Embodied Carbon Tool, was released in full in May 2011 [3]. asPECT consists of protocol and guidance documents, and accompanying software, which together facilitate the calculation of carbon footprints for asphalt products with a consistent approach. asPECT was produced as a result of collaborative research between the UK's Highways Agency, Mineral Products Association, Refined Bitumen Association and TRL (Transport Research Laboratory), thereby providing a representation of client, suppliers (contractors) and consultant. Collaborative research between these organisations has been undertaken on a rolling three year programme since 1982 and typically investigates a topical subject within the asphalt arena in each phase. For example, past projects have investigated overlays for concrete and have produced best practice guidance for laying asphalt (Road Notes 41 & 42; [4], [5]). This paper provides an overview of the process which was used to develop asPECT, highlighting how some of the more challenging elements were dealt with and the importance of stakeholder involvement in the process. At the time the development process was commenced there was no greenhouse gas emissions calculator in existence specifically for the UK and asPECT has now filled this gap. On the same timescale, a commercially available program "CHANGER" has been developed by the International Road Federation [6] and a method specific to the USA has been developed by AASHTO [7].

2. THE DEVELOPMENT PROCESS

An overview of the development process is shown in Figure 1. The project was conducted over a three year period 2008-2011.

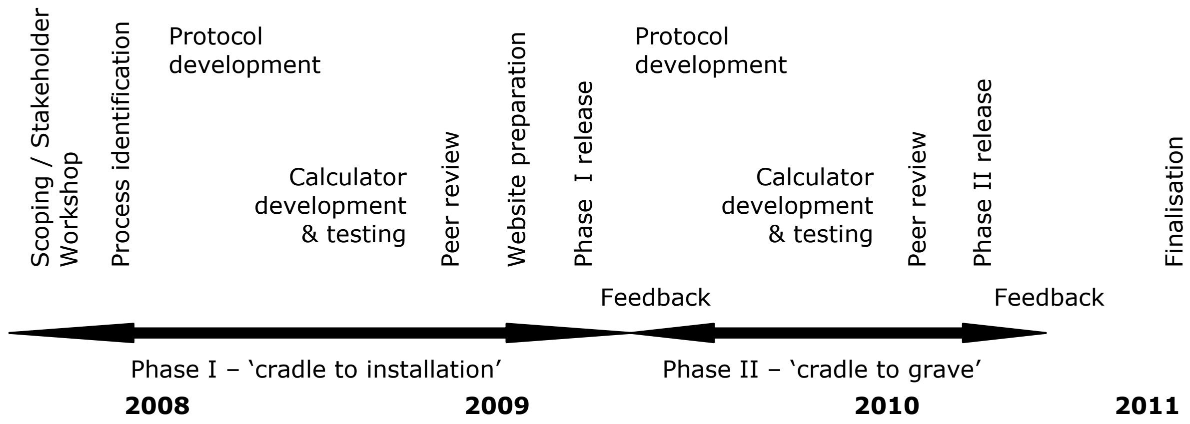

Figure 1 : Development process

2.1 Stakeholder Workshop

The first step in the process was to hold a stakeholder workshop in order to (a) define 'sustainability' or prioritise objectives under its broad umbrella and to (b) raise awareness across the sector that a project was underway that would provide a means for industry to measure its impacts, that would be used and recognised by the principal client (the UK's Highways Agency). Twenty-six stakeholders attended the workshop, clearly prioritising climate change as the primary environmental objective to be addressed. In terms of the other facets of sustainability, it was concluded that economic perspectives were already well considered in road construction through whole life costing procedures such as SWEEP (Software for Whole-Life Economic Evaluation of Pavements; [8]). Additionally, some societal considerations of construction products were being dealt with through "responsible sourcing" initiatives, for example using BS 8902:2009 [9].

2.2 Identifying the life cycle & boundary setting

It was necessary to take a 'life cycle' approach to carbon footprinting, in order to realise where the important environmental impacts exist, cradle to grave. To this end, it was necessary to determine the asphalt life cycle and where processes should lie within the project's boundaries. The asphalt life cycle is presented in Figure 2. The full life cycle from resource acquisition through to end-of-life was considered during the project, with the first stage (delivered in October 2009) dealing with 'cradle to installation'. Use of the road was considered out of scope since it cannot be significantly influenced by the road construction industry. It was decided to follow *PAS 2050:2008: The Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services* [10]. At the time the project was initiated, PAS 2050 was the only carbon footprinting specification available. The WRI/WBCSD GHG protocol [11] has only became available from September 2011, and the development process for ISO 14067 [12] and the harmonisation efforts of the European Commission [13] will be ongoing throughout 2012. PAS 2050 recommends an approach to 'carbon footprint' any given product or service, by taking a life cycle approach and by providing a list of inclusions, methodological guidelines and standard factors to use. Until the introduction of the PAS, the process of carbon footprinting was far less defined and therefore, in some cases, somewhat haphazard with respect to what was included within assessments, for example, with regards to how supply chain emissions should be included within assessments. From the perspective of asPECT it was important to follow the specification to add legitimacy and clarity to the process.

Life-cycle stage		**Description**
1	**Raw Material Acquisition**	Winning of raw materials from the natural environment with the input of energy
2	**Raw Material Transport**	Linking the winning of raw materials to processing of raw materials
3	**Raw Material Processing**	Crude oil refining, rock crushing and grading, recycled and secondary material reprocessing
4	**Processed Material Transport**	Linking the processing of raw materials to the manufacture of bitumen bound highway components
5	**Road Component Production**	Production of bitumen bound mixtures
6	**Material Transport to Site**	Delivery of bound materials to site
7	**Site Preparation, Laying and Compacting**	Included for new road construction: capping, sub-base, base, binder course, surface course
8	**Scheme Specific Works**	Installation of geosystems, traffic management etc.
9	**Maintenance**	Interventions to maintain the road. Re-surfacing, surface dressing works, patching, haunching etc.
10	**End of Life**	Deconstruction and material management

Use

Figure 2 : Generic life cycle for road construction

2.3 The component parts

asPECT has three components:

- a protocol;
- further guidance document; and
- software.

Whilst PAS 2050 proved very useful to establish what should be included in an assessment of asphalt and aggregate products it did not define *how* to collect the data, which of course is sector specific; neither did it define which sources of default data to use when required. It is expected that greenhouse gas assessment will eventually feature tender assessment processes, so it was important to remove any sources of potential ambiguity within the measurement process. The protocol therefore took the requirements of the PAS and added further elements to tighten the process, thereby making it specific to asphalt products. Since the full release of asPECT, PAS 2050 has gone through one revision [14]. Of particular note in the revision was the addition of a section of "supplementary requirements", recognising the fact that their use could enhance application of PAS 2050 in particular product sectors or categories. asPECT essentially provides the set of "supplementary requirements" for the asphalt sector.

The further guidance document was used to justify the inclusions and approaches in the protocol and also to demonstrate how the requirements of the PAS were met. The software provides a series of forms which are designed to capture the data required by the protocol in a straightforward way. Despite the inclusion of the software, perhaps the most important component was in fact the protocol, since the accounting required to fulfil the requirements of the protocol might adequately be fulfilled by internal business management systems (e.g. ("Systems, Applications and Products in Data Processing" software: SAP™).

2.4 Stakeholder engagement and peer review

A collaborative effort was essential in the development of asPECT. The TRL project team needed the assistance of industry to provide insights on a number of levels. Much of the exercise of carbon footprinting involves converting energy use data into GHG emissions; hence the insights of industry into plant and processes were required to understand how and where fuels and electricity are consumed, and how energy consumption is recorded. The protocol clauses and calculations were built on the insights provided, and a balance had to be struck between laboriousness and the level of data required to calculate product-specific footprints. Furthermore, industry involvement was necessary to obtain and agree default GHG contributions for minor asphalt constituents and less significant life cycle processes. Agreeing default values reduced the potential for ambiguities (or unsubstantiated claims) and also streamlined the overall process, ensuring that the more significant raw materials and processes were focussed on. Above all, the industry representatives on the steering group helped to inform the sector as a whole of asPECT's development, thus achieving the wider buy-in necessary for asPECT's ultimate adoption.

To ensure the requirements of PAS 2050:2008 were met, three independent peer reviewers were asked to review asPECT's documentation against the requirements of the PAS before release.

3. KEY FEATURES OF THE METHODOLOGY

This section provides some insights into the asPECT methodology and the approaches adopted to ensure that practices specific to the asphalt industry are accurately accounted for in carbon footprint calculations. Carbon dioxide-equivalent (CO_2e) is referred to throughout this section. This reflects the fact that, wherever possible, the contribution of CH_4 and N_2O emissions are analysed alongside CO_2 emissions in the asPECT framework.

3.1 Aggregates

Aggregates contribute over 90% by mass to asphalt products. The asPECT methodology only permits the use of primary data for aggregates and filler. Energy consumption is based on the last full year's energy consumption and also takes account of explosive and water use. All sources of aggregates are covered including land won crushed rock and sand and gravel, dredged sand and gravel, offshore island sources, manufactured sources (such as glass, slag and ash), recycled sources and filler (both virgin and reclaimed). In terms of allocation, in the case of manufactured ("secondary") aggregates such as slag or pulverised fuel ash, or recycled aggregates such as glass, the methodology assumes that these materials have zero CO_2e at the steel works pit, power station precipitator or recycling site stockpile. Any CO_2e generated in processing or transporting the material after this point, to prepare it for incorporation into asphalt, is attributed to the asphalt life cycle.

3.2 Recycled content & recyclability

It is widely accepted that asphalt is 100% recyclable and that very little milled material ends up in landfill at end of life [15]. However, a relatively low proportion of reclaimed asphalt planings (RAP) actually follows a closed-loop recycling route back to bound courses, with the vast majority being utilised in unbound applications [16]. It was decided to devise an approach in asPECT to distribute the benefits of recycling between the users of recycled asphalt and the producers of recyclable asphalt. This approach would reward both the users of RAP and the producers who preserve recyclable asphalt and therefore contribute to conserving the potential for asphalt to be recycled back into asphalt.

A 60% reduction in embodied CO_2e is applied to actual use of RAP in mixtures and a 40% reduction potential is applied to recognise the future recyclability of RAP. This ratio is chosen in recognition of the fact that closed-loop recycling of RAP to bound courses is currently relatively low, although levels are gradually increasing in relation to open-loop recycling to unbound courses. Therefore, at present, more reward is given to the actual practice of recycling than the future recycling potential. Materials with higher levels of recycling achieved as the norm would tend towards 50:50 ratios or even higher recyclability 'potentials'.

In life cycle assessment, allocation of the 'environmental credits' (benefits) derived from recycling depends on the aim and scope of the assessment. There is not a single universal approach, but a number of different methodologies. Two of the many were specifically taken into account.

The PAS 2050:2008 uses a 'recycled content' approach that allocates all the environmental credits to the users of the recycled material, on the basis that the benefits of recycling can only be realised when the recycled material is used. A second approach, called the 'substitution method', allocates all the benefits to the producers of the material that can be recycled, on the basis that recyclable material would not exist without the system producing it in the first place. This method features alongside the recycled content approach in the draft WRI/WBCSD Product Accounting & Reporting Standard [11]. Both approaches have merits and drawbacks and are applicable to asphalt as recyclable material which provides the highest benefits when recycled back into asphalt. It was felt that an approach combining the two methodologies would provide the best solution to quantify the environmental credits, shared between the users of recycled asphalt and the producers of recyclable asphalt. A combined approach is also postulated as an alternative in the draft WRI/WBCSD Product Accounting & Reporting Standard [11]. A good discussion of recycled content and recyclability approaches and the intermediate solution is provided in Jones [17].

3.3 Heating & drying energies

There was a need to develop a method in asPECT to accurately and fairly distribute plant energy consumption to the different mixtures that are manufactured. The energy involved in heating and drying will be different for different mix types. Low fines content mixtures with low moisture content and low temperature mixes will consume less energy per tonne and generate less GHGs per tonne than high fines, high moisture and high temperature mixes. The energy consumption data advocated for use is based on annual audited energy consumption data. The approach devised calculates the CO_2e per tonne for each of a number of defined sub-groups of mixture types with similar heating/drying characteristics. The methods are also specific to the plant type, whether continuous or batch. "Special" processes are used to cover other types of plant including those utilising recycling (with cold batch or continuous addition), parallel drum recycling pre-heaters and non-standard mixtures including those which utilise warm temperature mixing (with additives or foam).

3.3.1 Continuous single dryer methodology

The asPECT protocol enables the CO_2e for a plant (continuous single dryer) to be allocated to different mix types based on knowledge of the plant operating characteristics. It requires knowledge of the following:

- Total production in the previous year.
- Total heating fuel consumption, per type of fuel, in the previous year.
- Tonnage produced of each of *n* mix types, grouped by fuel consumption.
- Production rate in tonnes per hour (tph) of each mix type at full burner setting.

The formula below works on the basis that the fuel consumption per tonne of the mix groups will be in inverse proportion to their (maximum) production rates with the burner operating at maximum.

The following parameters define mix production with a given F_{tot} (annual energy consumption), per type of fuel (burner only):

Mix type	Yearly production, t	Production rate, tph
Mix 1	T1	k1
Mix 2	T2	k2
Mix 3	T3	k3
Mix 4	T4	k4
Mix 5	T5	k5
…	…	…
Mix X	TX	KX

The mix with the highest production rate K shall be identified and the energy F, per type of fuel, used for the production of one tonne of it is calculated using Equation 1:

$$\mathbf{F} = \frac{\mathbf{F_{tot}}}{\sum_{n=1}^{N} \frac{\mathbf{T_n k}}{\mathbf{k_n}}} \qquad \textbf{Equation 1}$$

Where N is the number of mix types.

The energy (Fn) per tonne, per type of fuel, used for each of the mixes is inversely proportional to the rate of production and is calculated using Equation 2:

$$\mathbf{F_n = F \times \frac{K}{Kn}} \qquad \textbf{Equation 2}$$

For special processes, a notional production rate in tph of each mix type is calculated. Operating variants are considered by trial comparison with normal production. Continuous runs of both the non standard process and one of the main standard production groups shall be monitored by measuring each type of fuel required to produce a minimum of 100 tonnes of each. The notional production rate k is calculated from the standard process rate as follows:

$$\textbf{Notional k} = \textbf{standard process rate} \times \left(\frac{\textbf{standard product energy}\ (^{L}/_{t})}{\textbf{non-standard product energy}\ (^{L}/_{t})}\right) \qquad \textbf{Equation 3}$$

The notional rate can then be inserted directly into Equation 1.

3.3.2 Batch heater plant

For batch heater plants, the energy use is directly proportional to the dwelling time. The following parameters define mix production for a given F_{tot} (annual energy consumption), per type of fuel (batch heater only):

Mix type	Yearly production, t	Heating time, s
Mix 1	T1	t1
Mix 2	T2	t2
Mix 3	T3	t3
Mix 4	T4	t4
Mix 5	T5	t5
…	…	…
Mix X	TX	tX

The mix with the longest heating time t is identified and the energy F, per type of fuel, used for the production of a tonne of can be calculated using Equation 4:

$$\mathbf{F = \frac{F_{tot}}{\sum_{n=1}^{N} \frac{T_n t_n}{t}}} \qquad \textbf{Equation 4}$$

Where N is the number of mix types.

The energy (F_n) used for a tonne of each of the mixes, per type of fuel, is proportional to the heating time and is calculated using Equation 5:

$$\mathbf{F_n = F \frac{t_n}{t}} \qquad \textbf{Equation 5}$$

3.4 Transport

The transport equation provides a method to realise the benefits of improved utilisation (or the drawbacks of under utilisation) in the emissions calculation for a single journey. It works on the principle that improved utilisation will avoid the requirement for another vehicle to undertake the same journey with part of the load. Similarly, for under utilisation, it takes account of the fact that another vehicle will have to undertake the same journey with part of the load. The actual utilisation is reflected in the calculation using the factor f (as a percentage). Equation 6 is used to work out the balance of emissions which should be added or subtracted from the emissions of a single return journey with 50% utilisation, if the utilisation is changed. In an improved utilisation scenario, the 'balance' of emissions that is applied results from increasing the load factor but more so by avoiding some of the emissions from another vehicle's journey. The equation uses vehicle emissions factors from the UK's Department of Environment, Food and Rural Affairs (Defra) for different vehicle loadings (0% and 50%).

$$\textbf{kg CO}_2\textbf{e per journey} = \textbf{Distance travelled (vkm)} \times \left(\textbf{Defra 50\% load factor [Total GHG } \frac{[\text{kgCO}_{2e}]}{[\text{vkm}]}]\right) - \left((\mathbf{f - 50\%}) \times \textbf{ Defra 0\% load factor [Total GHG } \frac{[\text{kgCO}_{2e}]}{[\text{vkm}]}]\right) \qquad \textbf{Equation 6}$$

3.5 Product lifetimes

In the process of whole-life carbon assessment, it was important to include the service lifetime of the asphalt product in the assessment. The service lifetime was defined as the period from the point of installation through to where the material is first milled or bulk excavated. This allowed a reflection of the durability of different materials to be incorporated into the assessment. "Aspirational design lifetimes" were used for the purpose, and these were based on an evaluation of a survey of local government highway engineers, the findings of TRL report 674 [18] and the expert opinion of the project's steering group. As part of the ongoing development of asPECT, submission of evidence relating to the design lifetimes of asphalt products is positively encouraged so that an even greater consensus over the figures will be arrived at in the future. The aspirational design lifetimes in asPECT are displayed in Table 1.

Table 1 : Aspirational design lives for the principal asphalt types

		Design Lifetime	
Course	**Asphalt Material**	**Designed Road**	**Evolved Road**
Surface	Thin Surface Course Systems	15	10
	Paver Laid Surface Dressing	10	10
	Micro-surfacing	6	6
	Hot Rolled Asphalt (high stability)	20	20
	Hot Rolled Asphalt (low stability)	-	25
	Close Graded Macadam	8	6
	Surface Dressing (racked in)	10	12
	Surface Dressing (single)	6	10
Binder	Hot Rolled Asphalt	30	20
	Stone Mastic Asphalt	30	20
	Dense Bituminous Macadam / Heavy Duty Macadam	30	20
	Enrobés à Module Élevé (EME)	50†	20
Base	Dense Bituminous Macadam / Heavy Duty Macadam	40	-
	Enrobés à Module Élevé (EME)	50†	-

†The figure associated with EME is based on an estimate of future performance.

Capability is built into the asPECT framework for the lifetimes in Table 1 to be enhanced via in-situ maintenance of the pavement, with use of treatments such as overlay, surface dressing, slurry/micro surfacing, patching, crack sealing or retexturing. For each treatment an additional CO_2e per tonne of the original asphalt laid is specified along with an additional predicted lifetime resulting from use of the treatment.

Overall, in whole life carbon assessments, the total CO_2e accumulated over the lifetime of the asphalt product from raw material acquisition through to end-of-life is normalised across the years of service of the material, as indicated by Equation 7. This provides a basis for comparison between asphalt products.

$$\textbf{Whole life carbon impact} = \frac{\mathrm{CO_2e\ impacts\ Steps\ 1{-}10\ (^{kgCO_2e}/_{t})}}{\mathrm{product\ lifetime\ (years)}} \qquad \textbf{Equation 7}$$

4. CONCLUSIONS

This paper has described the development process and some of the key features of a carbon footprinting tool designed specifically for asphalt products. The development process required a high level of stakeholder development throughout to ensure the applicability of finished product. It was also necessary to follow the PAS 2050 standard to introduce further credibility into the process.

It will be necessary for asPECT to evolve in the future; it will need to be a "living" system. Emissions intensities of energy sources, vehicles and materials will inevitably change over time and these new values will need to be incorporated into the framework. Other data, such as lifetime data arising primarily from the industry itself, will also improve over time and this too can be used to improve the accuracy of the framework. Furthermore, it is expected that carbon footprinting standards will advance rapidly and asPECT will need to be adapted to keep astride of the developments.

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REFERENCES

[1] Specter, M. (2008). Big foot. *The New Yorker* February 25, 2008, 44. London: Condé Nast.

[2] The Climate Change Act 2008. (c.27), London: HMSO.

[3] TRL Limited (2011). Asphalt Pavement Embodied Carbon Tool [online]. http://www.sustainabilityofhighways.org.uk/

[4] Jordan, R.W., Coley, C., Harding, H.M., Carswell, I. & Hassan, K.E. (2008). Best practice guide for overlaying concrete. *TRL Road Note 41*. Crowthorne: TRL Limited.

[5] Nicholls, J.C., McHale, M.J. & Griffiths, R.D. (2008). Best practice guide durability of asphalt pavements. *TRL Road Note 42*. Crowthorne: TRL Limited.

[6] International Road Federation (2011). *CHANGER: IRF Greenhouse Calculator*. International Road Federation [online]. http://www.irfnet.org/index.php

[7] AASHTO (2010). *GreenDOT*. American Association of State Highway and Transportation Officials [online] http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2621

[8] Highways Agency (2009). Integrated whole life cost model for maintenance [online]. http://www.highways.gov.uk/knowledge_compendium/21E78A8765C04E5DA76A1C7AF096B552.aspx

[9] BSi (2009). BS 8902:2009: Responsible sourcing sector certification schemes for construction products. Specification [online]. http://shop.bsigroup.com/ProductDetail/?pid=000000000030191223

[10] BSi, Carbon Trust & Defra (2008). Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050) [online] http://www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050

[11] World Resources Institute (WRI)/ World Business Council for Sustainable Development (WBSCD) (2010). Greenhouse gas protocol initiative [online]. http://www.ghgprotocol.org/standards/product-and-supply-chain-standard

[12] International Organization for Standardization (2012). Carbon footprint of products -- Requirements and guidelines for quantification and communication (under development).

[13] European Commission (2012). Environmental footprint of products [online]. http://ec.europa.eu/environment/eussd/product_footprint.htm

[14] BSi, Carbon Trust & Defra (2011). Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050) [online] http://www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050

[15] EAPA (2008). Arguments to stimulate the government to promote asphalt reuse and recycling [online]. http://www.eapa.org/usr_img/position_paper/arguments_stimulate_asphalt_May2008.pdf

[16] Direct-MAT project (2011). Best practices for asphalt materials [online]. http://direct-mat.fehrl.org/index.php?m=49&id_directory=1438.

[17] Jones (2009). Embodied Impact Assessment: the methodological challenge of recycling at the end of building lifetime, Construction Paper 248. Construction Industry Quarterly 11(3), pp 140-146.

[18] Nicholls J, Carswell I, Thomas, C & Sexton, B (2010) TRL 674: Durability of thin asphalt surfacing systems. Part 4: Final report after 9 years' monitoring. Wokingham: TRL Limited.