An Application to Measure the Whole Life Cost and Whole Life Carbon Footprint of Pavement Maintenance

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ABSTRACT

Road authorities are currently faced with the challenge of reducing their carbon footprint in response to Climate Change at a time when many also have to cope with reduced capital and maintenance budgets due to the economic climate. When considering alternative maintenance options, those strategies with the lowest capital or whole life cost are not always those with the lowest carbon footprint. This gives the road authorities a dilemma when it comes to selecting the optimum maintenance option to meet their business objectives. Understanding the relative cost and carbon impact of alternative design options is, therefore, critical to managing these competing demands.

URS Scott Wilson has developed an application (app), branded WLCO2T, which measures the whole life cost and whole life carbon footprint of alternative maintenance strategies for pavement assets over a 60-year analysis period. WLCO2T includes a database of maintenance activities for flexible, composite and rigid pavements that contains cost data and greenhouse gas emissions factors. The User builds a maintenance strategy by allocating maintenance activities to a specific year. WLCO2T then calculates the: capital cost, operational cost, whole life cost, capital carbon footprint, operational carbon footprint and whole life carbon footprint.

The outputs of the app provides road authorities with high-level decision making information which is intended to be used at preliminary design stage to select the preferred option or several options for further design development. The app can also be used to determine the optimum year in which to carry out the maintenance.

Keywords : Carbon, Climate change, Whole life costing, Maintenance, Life cycle assessment

1. INTRODUCTION

Road authorities are currently faced with two, sometimes conflicting, demands: manage their pavement assets with reduced budgets and, minimise carbon consumption in response to Climate Change. Understanding the relative impacts of cost and carbon of pavement maintenance is essential to aligning maintenance strategies with an organisation's goals and objectives. This paper explains this challenge in more detail and describes the development of an application (app), branded WLCO2T, which calculates the Whole Life Cost and Whole Life Carbon Footprint of road pavement maintenance strategies. The context of the need for the WLCO2T app can be understood by the following quotations.

In his Presidential Address [1], Peter Hansford (Chairman of the Institute of Civil Engineers) said:
"*Less carbon does not mean less construction. It means constructing different forms of infrastructure, by different methods, using different materials. And to do that we need to develop new skills and new tools. We need new tools for project appraisal. Today this is about whole-life costs and net present value in monetary terms. We refer to 'Capex' and 'Opex'. We now need to add the carbon factor. We need to know how much carbon will be embodied in the proposed infrastructure, and how much will be used during construction and operation.*
We need to know the 'CapCarb' and 'OpCarb' - new terms for most of us. And importantly we need to understand the relationship and trade-off between these two measures."

Guidance from the Met Office [2] regarding Climate Change is:
"While there are noticeable highs and lows in year to year data, over longer periods of time there is a discernable warming trend across the globe. Natural causes can explain only a small part of this warming. The overwhelming majority of scientists agree that this is due to rising concentrations of heat-trapping greenhouse gases in the atmosphere caused by human activities.
To avoid these problems, we will have to significantly reduce our energy needs and generate more power from non-carbon sources. The transition to a low carbon economy presents major global opportunities for business. The demand for low carbon and environmental goods and services is already worth £3.2 trillion per year, and is predicted to increase as the move to a low carbon economy occurs."

A conclusion from the Stern report [3]:
"Global warming could shrink the global economy by 20% while taking action now would cost just 1% of global gross domestic product."

The drivers behind developing the WLCO2T app align with the philosophy behind Peter Hansford's address. Our industry's awareness of the impact of Climate Change and the response measures required is advancing at pace and this comes at a time when our Clients' budgets are under unprecedented pressure. Consequently our Clients are currently facing two significant challenges:

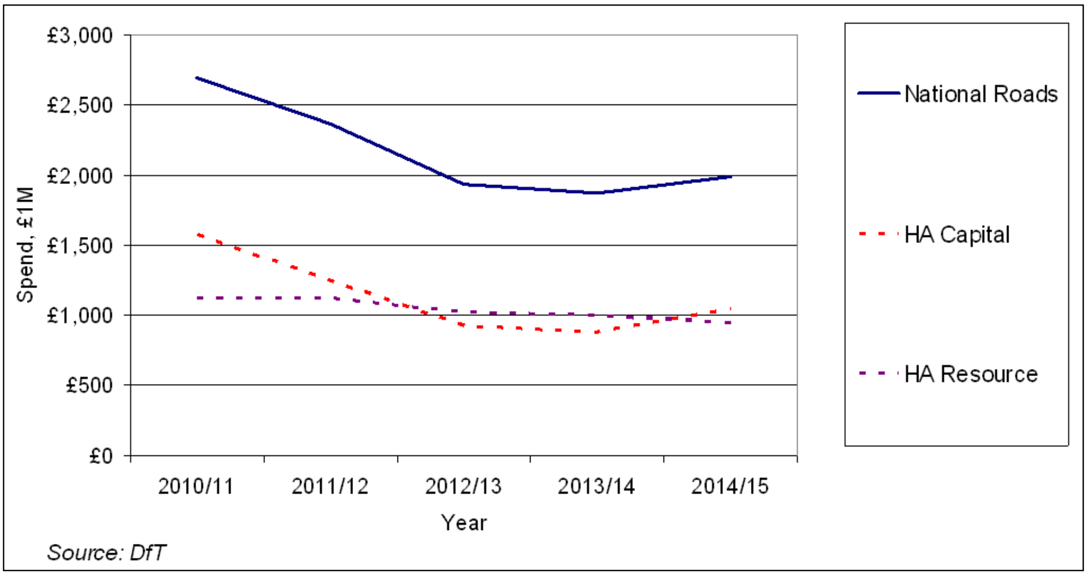
- The economic climate dictates that construction of new infrastructure will be greatly reduced and that smarter use will need to be made of budgets for maintenance and renewal of existing assets
- Legislative and corporate pressure to implement low-carbon designs, in response to Climate Change, are driving new material technologies and methods of working

1.1 Economic Climate

The Financial Crisis of the late 2000's, triggered by the collapse of the US Housing Market, caused economies around the world to slow down as access to credit became more difficult and international trade declined. As the subsequent recession hit in 2008, Governments are the world introduced a range of measures to reduce their economies' reliance on borrowing. These measures included significant spending cuts and consequently budgets for construction and maintenance of highways have been cut accordingly.

In the United Kingdom road operators have had to adapt to a specific set of circumstances; not all of which were caused by the financial crisis:

- A Government imposed reduction in the highways budget of 28% between the current financial year and the year 2012/13 (Figure 1)
- The continued development of Eastern economies fuelling increases in commodity prices, which have not typically been observed in previous economic cycles; for instance, the cost of bitumen has risen 60% since 2007 with further similar increases forecast
- The bulk of specialist highway maintenance vehicles had their fuel tax concession removed (red diesel exception) in 2008
- Changes in the aggregate levy have increased the costs of primary aggregate used in road construction and maintenance by 22%
- A reduced internal resistance to change within Government and their Service Providers, as it is accepted than changes are necessary



Source: DfT

Figure 1 : Highways Agency forecast spend

The factors listed above have inevitably impacted on expenditure for constructing new roads and maintaining existing networks at a time where traffic growth shows no signs of slowing. Efficient, well-maintained highway networks are a vital element of having a healthy economy so, any reduction in budget needs to be managed carefully with systems to target expenditure where it is most needed. At a time where affordability is such an issue, it is understandable that clients may take a more short-term view of managing expenditure instead of considering the longer-term Whole Life Cost; this contradicts what has, for sometime, been considered good practice.

1.2 Drivers for Reducing Carbon Footprints

Corporate Social Responsibility

Sustainability, particularly in terms of reducing carbon footprints and waste, is an important part of Corporate Social Responsibility (CSR). Companies have recognised the associated benefits, such as reduced overhead costs and improved brand image that can be gleaned from implementing an effective sustainability policy. CSR policies and strategies typically include initiatives to reduce the organisations carbon footprint. Over the past decade, emerging legislation and market forces have generated further drivers which have pushed companies to embed carbon reduction practices within their day-to-day business activities.

Current Legislation

The Carbon Reduction Commitment Energy Efficiency Scheme (previously renamed the Carbon Reduction Commitment) is the first mandatory carbon trading scheme in the United Kingdom and aims to reduce carbon emissions by larger low energy-intensive organisations by 1.2million tonnes of CO2 by 2020. The initial phase is compulsory for organisations that consumed over 6,000 MWh of half-hourly metered electricity during the period from January 2008 to December 2008. At today's prices, this is roughly equivalent to total half-hourly metered electricity bills of approximately £500,000 per year. Companies are ranked in a league table using three metrics:

- Absolute emissions – the percentage reduction in carbon emissions compared with the previous year
- Growth – the percentage reduction on carbon emissions per unit of turnover, to take account of growth
- Early – early action initiatives made by the organisation to reduce their carbon emissions by April 2011

The UK's Carbon Reduction Commitment Energy Efficiency Scheme works hand-in-hand with the European Union Emissions Trading Scheme (EU ETS) which now extends to 11,000 power stations in 30 countries (the 27 member states plus Iceland, Lichtenstein and Norway). The EU ETS works on the *cap and trade* principle, which requires energy intensive businesses to purchase carbon credits on the total amount of greenhouse gases they emit, and there are plans for airlines to join in 2012 and petrochemicals, ammonia and aluminium industries to join in 2013. The EU hopes to link their scheme with other around the world to from a global carbon trading market.

In 2008 the UK became the first country in the world to set legally binding targets to reduce carbon emissions with the passing of the Climate Change Act. The Act set a target for at least an 80% cut in the UK's Greenhouse Gas emissions by 2050 against a 1990 baseline, within an interim target of 34% by 2020.

Climate Change Levy (CCL) a charge placed on most businesses directly linked to their gas and electricity consumption. Sector related Climate Change Agreements (CCA) set carbon reduction targets. Intensive energy using businesses can sign up to a CCA in return for a reduced payment under the CCL.

Future Legislation

In May 2011, the Secretary of State for Energy and Climate Change, Chris Huhne, set out an ambitious target for the UK to reduce greenhouse gas emissions by 50% by 2027 from 1990 levels. Now set in law, this target for the fourth carbon budget period provides a stepping stone to ensure the UK stays on course to meet the 80% reduction in greenhouse gas emissions set out in The Climate Change Act 2008. In delivering his speech Chris Huhne stated:

"The Fourth Carbon Budget places the UK at the leading edge of the global low-carbon industrial transformation. It will set Britain on the path to green growth. It will establish our competitive advantage in the most rapidly growing sectors of the world economy, generate jobs and export opportunities in these sectors, maintain energy security and protect our economy from oil price volatility. It is a framework not just for action on climate but for growth and prosperity."

In 2011, the UK Government also published the draft 'Government Carbon Plan ', outlining their commitment to reducing the carbon impacts from Government, the public sector and the nation as a whole. Significantly for much of the work URS Scott Wilson undertake in the UK, the plan includes a commitment to introduce ambitious energy efficiency standards for new homes and buildings, including delivery of zero carbon homes from 2016 and non-domestic buildings from 2019.

1.3 Balancing Conflicting Demands

The two challenges of managing restricted budgets and reducing carbon footprints can be conflicting; low-carbon designs are not always those with the lowest initial capital cost or whole life cost. This provides the client with a dilemma in terms of managing these competing demands, to meet business objectives and targets.

As engineers, it is our responsibility to provide clients with the necessary decision making tools so they can make informed decisions. For pavement maintenance, currently there is no tool available that will quickly and easily quantify the relative trade-off between cost and sustainability when it comes to implementing maintenance strategies.

Procedures for calculating the Whole Life Cost of alternative maintenance strategies are well established. Mapping out the planned maintenance activities associated with an asset allows the long-term expenditure to be understood; discounting future costs to those of the base year allows the Net Present Value (NPV) of costs to be calculated. The strategy with the lowest NPV provides the best value for money.

Procedures for calculating the Whole Life Carbon Footprint are less well documented but our understanding is improving. Figure 1 outlines the lifecycle of a project/asset and defines various stages through its life where interventions can be made to reduce carbon. Taking this approach, carbon emissions should be considered from cradle to grave of the asset, i.e. from the extraction of the raw materials required, through to its construction and operation and then on to decommissioning; in the same way that cost is considered for Whole Life Cost analyses. Only by adopting this approach will engineers have the best opportunity to *design-out* carbon.

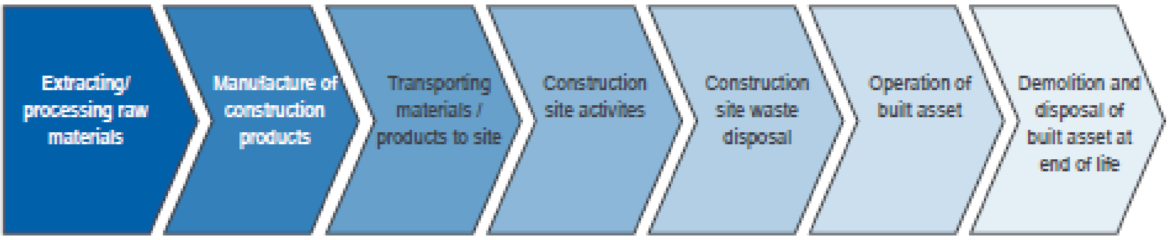


Figure 1 : Stages for reducing carbon during a project lifecycle

Mapping out the Whole Life Carbon Footprint of an asset is a systematic process for identifying the life cycle carbon emissions associated with a project and thereby provides a road map for identifying the greatest opportunities for reducing emissions associated with the project. To obtain maximum benefit from this approach, the Whole Life Carbon Footprint needs to be considered as early as possible in the asset's lifecycle and the carbon reduction strategy should be re-visited at each stage.

2. DESCRIPTION OF THE TOOL

Tools currently exist to measure WLC and carbon on a separate basis (indeed Scott Wilson has been involved in the development of some of the carbon measurement tools such as the IRF's CHANGER software) and much of the architecture of these tools is similar:

- Timeline: WLC and carbon measurement tools both use a timeline datum for specifying construction/maintenance activities
- Resources: WLC and carbon measurement tools both use similar resource databases (materials, plant, transportation) for calculating cost or carbon respectively

It was therefore considered feasible to develop an integrated tool that would calculate both the Whole Life Cost and Whole Life Carbon Footprint, based on quantities of resources required to maintain an asset throughout its lifetime, and thereby give clients decision making information they need without the need to make use of multiple tools. The development required definition of relevant maintenance activities, integration of the cost and carbon measurement methodologies into a single system architecture, creation of a user front-end and link to a maintenance activities database.

The app's architecture was built on an Excel/Visual Basic platform as shown in Figure 2. The calculation methodology makes use of established approaches to calculating whole life cost [4] (in terms of applying discount factors and residual value) and publicly available emissions factors [5]. The maintenance activities database includes a wide range of treatments, for flexible, composite and rigid pavements, from retexturing through to reconstruction.

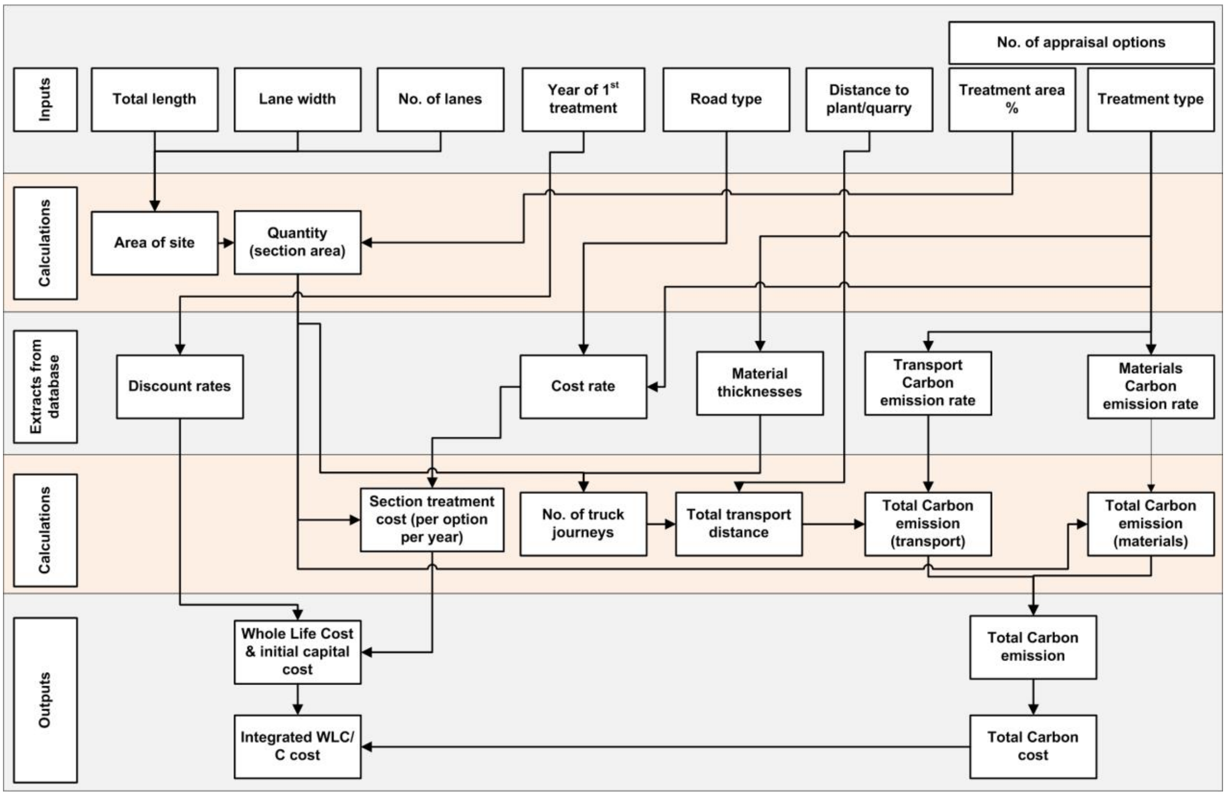
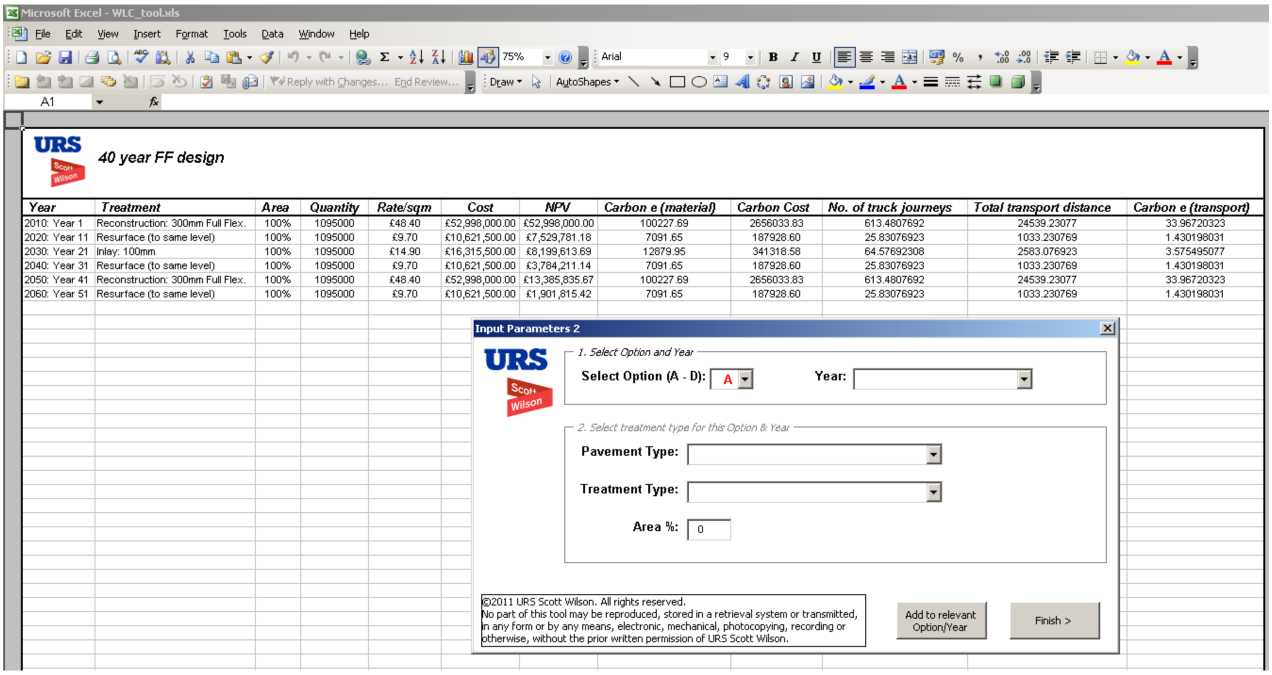


Figure 2 : WLCO2T system architecture

Initially the User defines the type of road (i.e. single carriageway, dual carriageway or motorway), the length of the scheme and the number of lanes to be treated. The User also enters the distance to the asphalt plant, concrete plant and aggregates quarry to enable calculation of carbon emissions associated with the transport of materials.

WLCO2T allows comparison of four alternative maintenance strategies. The User defines each strategy by selecting the maintenance activities required from the app's database and allocating them to specific years within the 60-year analysis period as shown in Figure 3. The year and maintenance activity are selected from drop-down menus and the User manually defines the percentage of the area of the scheme to be treated.

The maintenance activities database is populated with unit cost rates and emissions factors for each activity and these can be amended by the User if project-specific data are available. Additional maintenance activities can also be added to the database if required. The default cost database includes the unit rate for the plant, labour and materials associated with each maintenance activity. The unit rate does not include the cost of preliminaries or traffic management. The app also does not consider user delay costs or optimism bias.



40 year FF design

Year	Treatment	Area	Quantity	Rate/sqm	Cost	NPV	Carbon e (material)	Carbon Cost	No. of truck journeys	Total transport distance	Carbon e (transport)
2010: Year 1	Reconstruction: 300mm Full Flex.	100%	1095000	£48.40	£52,998,000.00	£52,998,000.00	100227.69	2656033.83	613.4807692	24539.23077	33.96720323
2020: Year 11	Resurface (to same level)	100%	1095000	£9.70	£10,621,500.00	£7,529,781.18	7091.65	187928.60	25.83076923	1033.230769	1.430198031
2030: Year 21	Inlay: 100mm	100%	1095000	£14.90	£16,315,500.00	£8,199,613.69	12879.95	341318.58	64.57692308	2583.076923	3.575495077
2040: Year 31	Resurface (to same level)	100%	1095000	£9.70	£10,621,500.00	£3,784,211.14	7091.65	187928.60	25.83076923	1033.230769	1.430198031
2050: Year 41	Reconstruction: 300mm Full Flex.	100%	1095000	£48.40	£52,998,000.00	£13,385,835.67	100227.69	2656033.83	613.4807692	24539.23077	33.96720323
2060: Year 51	Resurface (to same level)	100%	1095000	£9.70	£10,621,500.00	£1,901,815.42	7091.65	187928.60	25.83076923	1033.230769	1.430198031

1. Select Option and Year

Select Option (A - D): A

Year:

2. Select treatment type for this Option & Year

Pavement Type:

Treatment Type:

Area %: 0

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Figure 3 : Defining a maintenance strategy

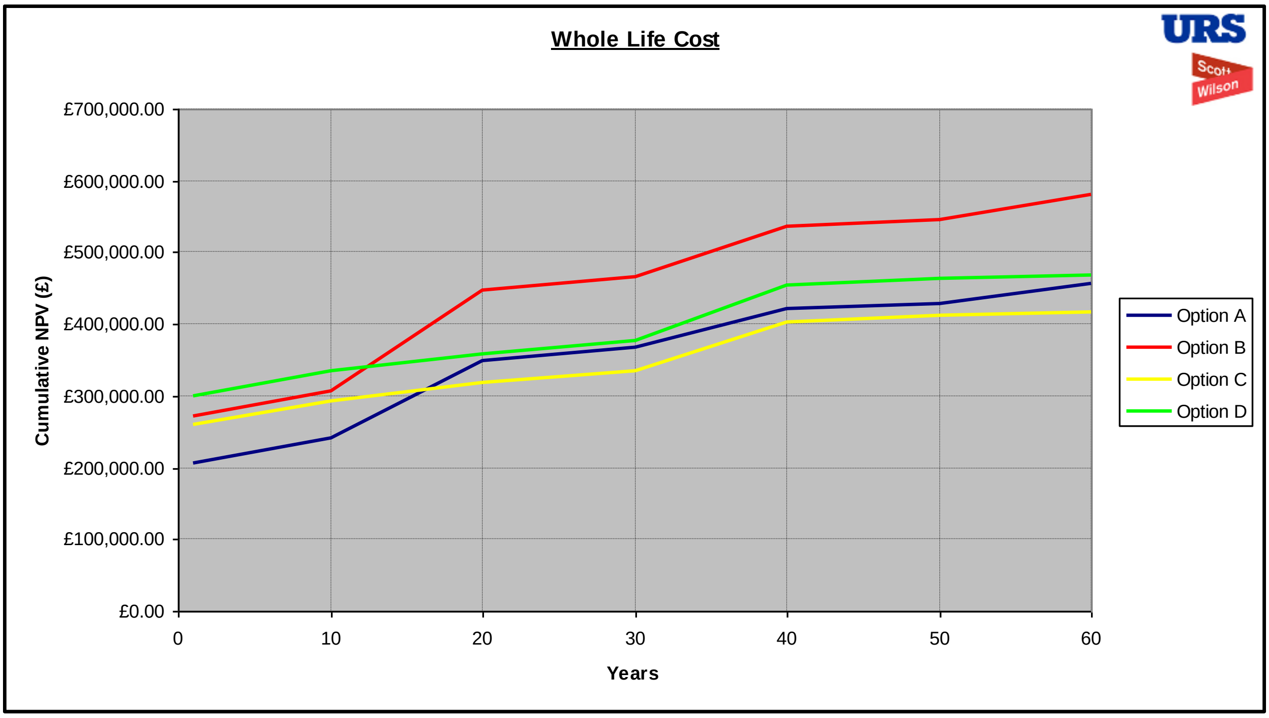
Once the maintenance strategies are entered, the app calculates the following:

- Capital expenditure (Capex): initial investment during Year 1 – Year 5
- Operational expenditure (Opex): cost of planned maintenance/strengthening, during Year 6 – Year 60
- Whole life cost (WLC): the discounted cost of all works during the 60-year analysis period
- Capital carbon (CapCarb): carbon footprint of the initial investment during Year 1 – Year 5
- Operational carbon (OpCarb): carbon footprint of planned maintenance/strengthening during Year 6 – Year 60
- Whole Life Carbon Footprint (WLCF): the carbon footprint of all works during the 60-year analysis period

Results are displayed in tabular and graphical format as shown in Table 1 and Figure 4.

Table 1 : Example Results from WLCO2T

Option	*Description*	*Capital Cost (£)*	*Operational Cost (£)*	*Whole Life Cost (£)*	*CapCarb (tCO2)*	*OpCarb (tCO2)*	*Whole Life Carbon Footprint (tCO2)*
A	*20 year fully flexible design*	**£207,174.00**	**£249,323.30**	**£456,497.30**	**172.18**	**618.66**	**790.84**
B	*40 year fully flexible design*	**£259,208.40**	**£158,394.23**	**£417,602.63**	**464.81**	**620.83**	**1,085.65**
C	*40 year rigid design*	**£324,733.20**	**£175,523.23**	**£500,256.43**	**0.00**	**156.02**	**156.02**
D	*do minimum*	**£11,087.39**	**£355,117.83**	**£366,205.23**	**5.76**	**501.66**	**507.43**



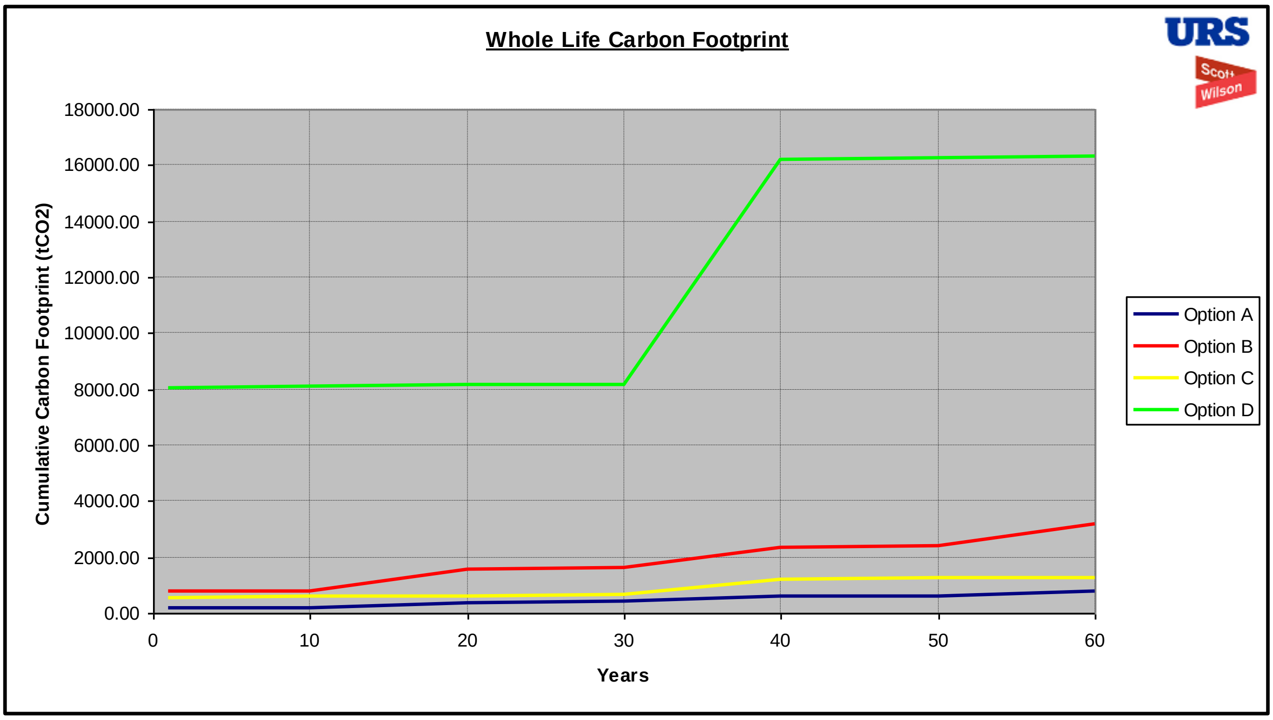


Figure 4 : Graphical display of results

3. CASE STUDY

It is intended that the app will be used at preliminary design stage to provide outputs that will allow clients to understand the cost/carbon proportionality associated with alternative design options. This will facilitate strategic selection of the preferred design option or identify alternative options for further development. The app can also be used to determine the optimum year in which to carry out the maintenance.

3.1 Selecting the Preferred Design Option

This case study is from a pavement evaluation project that URS Scott Wilson carried out in north London. The existing flexible composite pavement was substantially deteriorated and required strengthening. Four maintenance options were selected for analysis:

A. Replace the existing pavement with a flexible pavement designed for 20 years
B. Replace the existing pavement with a flexible composite pavement designed for 20 years
C. Replace the existing pavement with a flexible pavement design for 40 years
D. Replace the existing pavement with a rigid pavement designed for 40 years

The strategies were input to the WLCO2T app as shown in Table 2 and the results are shown in Table 3.

Table 2 : Alternative Maintenance Strategies

Year	Option A	Option B	Option C	Option D
	20 year flexible design	20 year flexible composite design	40 year flexible design	40 year rigid design
2011: Year 01	Reconstruction: 250mm Full Flex.	Reconstruction: 250mm Flex Comp.	Reconstruction: 350mm Full Flex.	Reconstruction: 200mm CRCP
-	-	-	-	-
2020: Year 10	Resurface (to same level)	Resurface (to same level)	Resurface (to same level)	Resurface (to same level)
-	-	-	-	-
2030: Year 20	Reconstruction: 250mm Full Flex.	Reconstruction: 250mm Flex Comp.	Resurface (to same level)	Resurface (to same level)
-	-	-	-	-
2040: Year 30	Resurface (to same level)	Resurface (to same level)	Resurface (to same level)	Resurface (to same level)
-	-	-	-	-
2050: Year 40	Reconstruction: 250mm Full Flex.	Reconstruction: 250mm Flex Comp.	Reconstruction: 350mm Full Flex.	Reconstruction: 200mm CRCP
-	-	-	-	-
2060: Year 50	Resurface (to same level)	Resurface (to same level)	Resurface (to same level)	Resurface (to same level)
-	-	-	-	-
2070: Year 60	Reconstruction: 250mm Full Flex.	Reconstruction: 250mm Flex Comp.	Resurface (to same level)	Resurface (to same level)

Table 3 : Results of Analysis of Alternative Maintenance Strategies

Option	*Description*	*Capital Cost (£)*	*Operational Cost (£)*	*Whole Life Cost (£)*	*CapCarb (tCO2)*	*OpCarb (tCO2)*	*Whole Life Carbon Footprint (tCO2)*
A	*20 year flexible design*	**£207,174**	**£249,323**	**£456,497**	**172**	**619**	**791**
B	*20 year composite design*	**£272,217**	**£308,704**	**£580,921**	**766**	**2,401**	**3,168**
C	*40 year flexible design*	**£259,208**	**£158,394**	**£417,603**	**559**	**729**	**1,287**
D	*40 year rigid design*	**£300,161**	**£169,100**	**£469,261**	**8,064**	**8,234**	**16,298**

The results show that the Client has a choice of maintenance options depending on his priorities. Options B and D prove themselves to be undesirable due to the higher construction cost and higher emissions factors associated with production of cement and steel. Option A has the lowest capital cost and lowest capital carbon, operational carbon and whole life carbon footprints so would appear to be the preferred option; especially if there short-term budget constraints, as there are with many road authorities in the UK at present, and whole life cost is therefore less important. Option C has the lowest whole life cost, primarily due to the significantly lower operational cost, so may be selected by the Client if long-term expenditure is more of a priority than the carbon footprint. Option C has a higher carbon footprint than Option A due to the thicker construction, and hence more required materials, than Option A.

3.2 Selecting the Optimum Year for Maintenance

The preferred option can be tested to determine the optimum year for maintenance by analysing the impact of continuing with routine maintenance to delay the capital expenditure. Option A was selected from 3.1 and can be further tested as follows:

- Construct option A in Year 1
- Routine maintenance in Year 1, construct option A in Year 2
- Routine maintenance in Years 1 and 2, construct option A in Year 3
- Routine maintenance in Years 1, 2 and 3, construct option A in Year 4

Table 4 shows how the strategies above are input to WLCO2T to identify the optimum year for maintenance by understanding how long the capital expenditure can be deferred for by continuing with patching. For this analysis it was necessary to have knowledge of the current level of routine maintenance, in terms of the area of patching required in previous years and the associated cost, to enable a prediction of the likely future routine maintenance requirements; typically this information can be found in Routine Maintenance Management Systems.

Table 4 : Analysis Strategies to Determine Optimum Year for Intervention

Year	Option A	Option B	Option C	Option D
	20 year flexible design	20 year flexible design	20 year flexible design	20 year flexible design
		deferred by 1 year	deferred by 2 years	deferred by 3 years
2011: Year 01	Reconstruction: 250mm Full Flex.	Structural Patch: 50mm depth	Structural Patch: 50mm depth	Structural Patch: 50mm depth
2012: Year 02	-	Reconstruction: 250mm Full Flex.	Structural Patch: 50mm depth	Structural Patch: 50mm depth
2013: Year 03	-	-	Reconstruction: 250mm Full Flex	Structural Patch: 50mm depth
2014: Year 04	-	-	-	Reconstruction: 250mm Full Flex.
-	-	-	-	-
2020: Year 10	Resurface (to same level)	-	-	-
2021: Year 11	-	Resurface (to same level)	-	-
2022: Year 12	-	-	Resurface (to same level)	-
2023: Year 13	-	-	-	Resurface (to same level)
-	-	-	-	-
2030: Year 20	Reconstruction: 250mm Full Flex.	-	-	-
2031: Year 21	-	Reconstruction: 250mm Full Flex.	-	-
2032: Year 22	-	-	Reconstruction: 250mm Full Flex	-
2033: Year 23	-	-	-	Reconstruction: 250mm Full Flex.
-	-	-	-	-
2040: Year 30	Resurface (to same level)	-	-	-
2041: Year 31	-	Resurface (to same level)	-	-
2042: Year 32	-	-	Resurface (to same level)	-
2043: Year 33	-	-	-	Resurface (to same level)
-	-	-	-	-
2050: Year 40	Reconstruction: 250mm Full Flex.	-	-	-
2051: Year 41	-	Reconstruction: 250mm Full Flex.	-	-
2052: Year 42	-	-	Reconstruction: 250mm Full Flex	-
2053: Year 43	-	-	-	Reconstruction: 250mm Full Flex.
-	-	-	-	-
2060: Year 50	Resurface (to same level)	-	-	-
2061: Year 51	-	Resurface (to same level)	-	-
2062: Year 52	-	-	Resurface (to same level)	-
2063: Year 53	-	-	-	Resurface (to same level)
-	-	-	-	-
2070: Year 60	Reconstruction: 250mm Full Flex.	-	-	-

The results from this analysis are shown in Table 5.

Table 5 : Results of Optimum Year Analysis

Option	*Description*	*Capital Cost (£)*	*Operational Cost (£)*	*Whole Life Cost (£)*	*CapCarb (tCO2)*	*OpCarb (tCO2)*	*Whole Life Carbon Footprint (tCO2)*
A	*20 year flexible design (year 1)*	£207,174.00	£249,323.30	£456,497.30	172.18	618.66	790.84
B	*20 year flexible design (year 2)*	£204,215.24	£214,594.59	£418,809.82	137.94	365.64	503.58
C	*20 year flexible design (year 3)*	£201,356.53	£207,337.77	£408,694.29	139.86	365.64	505.50
D	*20 year flexible design (year4)*	£198,594.49	£200,326.34	£398,920.83	141.78	365.64	507.43

These results show that minimum Capital Cost and Whole Life Cost are achieved by delaying the main expenditure until Year 4; this strategy achieves gains the maximum benefit from discounting of the main capital expenditure and does not require the reconstruction intervention in Year 60 as in option A. The lowest carbon footprints occur when the main expenditure is delayed until Year 2 because this strategy removes the need for reconstruction in Year 60 and uses less material for routine maintenance compared with Options C and D.

4. CONCLUSION

To enable road authorities to achieve their business objectives and targets, it is imperative that they understand the cost and carbon impact of design decisions. URS Scott Wilson has developed an app (WLCO2T) that can analyse up to four alternative maintenance strategies. The app calculates a range of cost and carbon parameters to facilitate selection of the preferred maintenance strategy and identification of the optimum year in which to implement the strategy:

- Capital expenditure
- Operational expenditure
- Whole Life Cost
- Capital carbon footprint
- Operational carbon footprint
- Whole Life Carbon Footprint

The app includes a database of costs and emission factors for a wide range of maintenance activities. The database can be edited by the user to reflect project-specific cost and carbon data. The cost and carbon data are mutually exclusive in the database so, the app can be used to study either both parameters together or one parameter individually.

The app provides road authorities with a relatively quick but, robust method for high-level appraisal of alternative maintenance strategies.

5. ACKNOWLEDGEMENT

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