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**WARRANTY STATEMENT**

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**Abstract**

Climate change is arguably the greatest challenge facing the developed world today. Bridge maintenance decisions can have a significant impact on the whole life cost and carbon footprint of bridges. At present bridge maintenance decisions in the UK are entirely cost driven due to budget constraints within local authorities. The UK has set a target to become carbon neutral by 2050 therefore bridge engineers need to consider the affect that maintenance decisions will have on the carbon footprint of bridges.

This study appraises a local authority bridge to determine the optimal maintenance strategy considering whole life costs, traffic delays and CO2 emissions; and identifies the subsequent funding requirements. This was accomplished by conducting a parametric study using an excel model developed by Arup to compare maintenance costs and traffic delays for different maintenance strategies. Carbon emissions for each maintenance strategy were estimated using a carbon calculator bridge design tool developed by Atkins. Carbon emissions were monetised using UK carbon valuations used in policy appraisal so that CO2 emissions could be incorporated into the whole life costing analysis. The results of this study found that a planned preventive maintenance strategy was the most cost effective and sustainable strategy with 7.7% lower discounted maintenance costs and 7% less CO2 compared to an unplanned reactive strategy,

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# **Chapter 1: Introduction**

## **Overview**

The UK local highway network includes over 70,000 bridges, with an estimated maintenance backlog of £6.7bn identified in the 2017-18 financial year. Over 3,000 bridges are considered to be sub-standard and unable to carry 44 tonne highway loading, indicating a funding shortfall (RAC Foundation, 2019). Budget constraints and maintenance decisions throughout the life cycle of bridges can have a significant impact on their whole life cost and sustainability (Teslim et al., 2019). There has been a 25% reduction in local government funding since 2010 (Transportation Committee, 2019).

The short fall in funding and subsequent budget constraints have increased the requirement to optimise maintenance and minimise whole life costs. Adopting a life cycle management strategy for bridges will extend their service life and subsequently alleviate financial burdens associated with bridge replacements and refurbishments. (Kevin et al, 2012)

## **Background**

Life cycle analysis has been recognised as an important tool in the management of bridges to determine the optimal resource allocation (funding) to maintain bridges in a serviceable and safe condition. It is also a useful tool to quantify the benefits and drawbacks of a proposed maintenance programme and to aid in putting a case forward for future funding allocations. (Frangopol & Kim, 2014)

The main outputs from life cycle planning include, expected total expenditure required for bridge maintenance and repairs for the remaining life of the asset; identification of the most cost-effective type of maintenance, and period to undertake maintenance; and remaining service life of the structure. (Frangopol & Kim, 2014)

Maintenance can be categorised as either preventative or essential. Essential maintenance is the minimum maintenance required to ensure the bridge remains safe and serviceable for the life of the asset. Preventative maintenance is intended to delay on-set deterioration for example through the application of silanes or sealers on the surface of reinforced concrete structures, or the installation of cathodic protection systems. (Tantele et al., 2005)

# **Chapter 2: Research Overview**



## **Aim**

The aim of this study is to propose a new methodology to inform maintenance decisions and budget requirements for bridges considering whole life costs and carbon emissions.

## **Purpose**

There is a common theme within the literature that urgent action is required to tackle climate change. It is also evident that there is also a lack of guidance and good practise guides for delivering sustainable bridge management and a subsequent lack of consensus within the industry. A paper undertaken by Zhang (2010) concluded that ‘’application-oriented research is required to develop best practise guides’’. This study will aim to utilise current tools (applications) available and develop a new methodology to support bridge management and maintenance decisions and inform budget requirements.

## **Objectives**

The objective of this study is to appraise a local authority managed bridge and identify and evaluate the following:

* Determine the optimal maintenance strategy considering whole life costs, traffic delays and the carbon footprint of the bridge;
* Determine the budget requirements for the bridge;
* Evaluate the consequences of underfunding, by examining the impact on whole life costs and carbon emissions.

The approach used in this study could be used as the basis to develop best practice guides and inform improvements to existing software applications (tools) used by bridge engineers.

# **Chapter 3: Critical Literature Review**



## **Whole Life Costing**

Whole life costing for bridges is the process of calculating the total expected expenditure throughout their entire life cycle including construction, maintenance and demolition. Whole life costing can be used to evaluate options for remedial works and establish the most cost-effective treatments and maintenance strategy for a structure. (Atkins, 2011)

When undertaking whole life costing, all costs are generally discounted to the year when the investment decisions are being considered. Discounting replicates the ‘time value of money’ and allows options undertaken at different stages throughout the analysis period (known as the ‘time horizon’) to be accessed on an equivalent basis (present value). If discounting was not applied, the whole life costs would not be quantifiable, and it would not be possible to establish the most cost-effective option. (Atkins, 2011)

The recommended Green Book discount rates are shown in Figure 1.

|  |  |  |  |
| --- | --- | --- | --- |
| **Declining Long-Term Discount Rates (HM Treasury, 2018, p.122)** | | | |
| **Year** | **0-30** | **31-75** | **76-125** |
| STPR (standard) | 3.50% | 3.00% | 2.50% |
| STPR (reduced rate where pure STP = 0) | 3.00% | 2.57% | 2.14% |
| Health | 1.50% | 1.29% | 1.07% |
| Health (reduced rate where pure STP = 0) | 1.00% | 0.86% | 0.71% |

Figure 1 - Declining Long-Term Discount Rates

Whole life costing can either be undertaken using the net present cost (‘NPC’) or net present value (‘NPV’) (LoBEG, 2011). The net present cost (‘NPC’) is the discounted ‘present cost’ (actual costs incurred) which is calculated using the formula in Equation 1 (LoBEG, 2011).

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

Where;

T = Time horizon in years (analysis period)

t = Current year (t = 0 in base year)

Ct = Costs incurred in year

Rt = The discount rate for year t (expressed as a fraction)

The net present value (NPV) is the discounted ‘present value’ of all costs, plus monetised values for any benefits and disbenefits (e.g. driver delays costs) . The net present value (NPV) can be calculated using the formula in Equation 2 (LoBEG, 2011).

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

Where;

T = Time horizon in years (analysis period)

t = Current year (t = 0 in base year)

Mt = Monetised benefits and disbenefits

Rt = The discount rate for year t, expressed as a fraction

To determine the optimal funding for bridge maintenance, a NPV whole life costing approach would be appropriate, to firstly determine the most advantageous maintenance strategy considering both cost and social economic impacts. However, the actual costs for the preferred option will be needed to inform budget requirements. Generally, inflation is not considered where inflation rates for all costs are approximately equal (LoBEG, 2011). However, where the analysis is being used to inform budget requirements, inflation will need to be applied to the outputs using the appropriate index (LoBEG, 2011). In order to produce different maintenance strategies for comparison using WLC, the timings and types of maintenance must be established based on predicted deterioration profiles for the structure.

## **Deterioration Rates / Profiles**

To establish the deterioration profile for a structure it is important to understand the deterioration mechanisms and develop a deterioration model.

### Reinforced Concrete Bridges

Deterioration of reinforced concrete bridges occurs mainly due to corrosion of embedded steel reinforcement as result of carbonation and chlorides. The rate of deterioration is influenced by several factors including the quality of the concrete, cover to reinforcement and environmental exposure (e.g. traffic loading & exposure to chlorides). (Highways Agency, 2007)

Carbonation is a result of atmospheric CO2 reducing the alkalinity of the concrete. Carbonation starts at the surface of the concrete and progresses toward the steel reinforcement over time (generally slow). Chloride ingress is primarily a result of de-icing salts. Chloride ions breakdown the protective oxide layer on the embedded steel reinforcement causing anodic and cathodic conditions. (Highways Agency, 2007)

There is a high degree of uncertainty when predicting deterioration rates of bridges, as the influencing factors are variable and may change throughout the service life of a structure (for example increased loading / traffic) (Frangopol & Kim, 2014).

Chloride induced corrosion prediction can be estimated using Fick’s second law using the formula in Equation 3 (Rafiq et al., 2005).

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

Where;

= Time to corrosion initiation at depth X

= Modelling uncertainty

D = Effects diffusions coefficient

= Chloride concentration threshold to corrosion initiation

= Surface chloride concentration

However, in practice the chloride concentration threshold varies and its corresponding value can lead to wide differences in times to corrosion initiation. This uncertainty can result in discrepancies between the predicted and actual rates of deterioration. (Vassie & Arya, 2008)

### Steel Bridges

The service life of steel bridges is predominantly affected by corrosion and fatigue related damage with influencing factors including fatigue-sensitive details, a lack of proper maintenance (painting), environmental exposure conditions and increases in loading and corresponding stresses. If the steelwork on bridges is left unprotected, the section loss will eventually lead to structural inadequacies which could result in structural failure or increased maintenance costs as result of strengthening. (Kevin et al., 2012)

Models have been developed to predict corrosion deterioration and fatigue damage to steel girders. The reduction in section to the web and flange of a steel beam over time can be calculated using the formula in Equation 4 (Kevin et al., 2012).

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

Where;

= Initial flange thickness

= Initial web thickness

= Average corrosion penetration (mm) at time

The rate of corrosion and loss of section is influenced by the environmental exposure condition (e.g. exposure to chloride contaminated water) (Kevin et al., 2012). Corrosion time versus penetration rate can be estimated by the exponential function in Equation 5 (Kevin et al, 2012).

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

Where,

= Average corrosion penetration in micrometres (*µ*m)

= Time (years) of exposure

= Corrosion loss parameter after one year of exposure

= Parameter determined from regressive analysis of experimental data

Kevin et al. (2012) carried out a study on life-cycle management strategy on steel girders in bridges and argued that “researchers have pursued extensive studies to predict time-variant corrosion propagation to capture the actual corrosion’’ therefore adopted Lee’s corrosion model to predict the service life of steel girders shown in Equation 6 (Kevin et al., 2012).

|  |  |  |
| --- | --- | --- |
|  |  | (6) |

Where,

= Corrosion propagation depth in micrometer (*µ*m) and time in years during th repainting period

= Random corrosion rate parameter

= Random time-order parameter

= Random corrosion initiation

= Periodic repainting period (years)

### Markov Chains

Markov Chains are widely used to predict the rate of deterioration of bridges and deemed to be more appropriate. Markov Chains are probabilistic models used to determine the possibility of typical bridge element deteriorating from one condition state to another (based on element condition ratings). Markov Chains are generally reliant on condition data from a portfolio of comparable bridges and elements in order to determine deterioration profiles. However, there are bridge management systems that have been developed where transition probabilities (deterioration profiles) are based on the judgements of industry experts. This is suitable if there is a lack of historic records and condition data. (Mckibbins et al, 2019)

Recently, stand-alone life cycle planning tools have been developed to help bridge engineers with maintenance decisions and determine budget requirements. An example of one such tool is the Structures Asset Valuation and Investment Tool (‘SAVI’) which was developed for the UK Bridges Board and released on the 11th March 2020. The software can be can used to compare asset management plans, by defining different intervention thresholds for remedial works (user defined treatments). This tool can be used to undertake a parametric study to identify the most cost-effective maintenance strategy for a structure. Different levels of funding can also be defined to determine the effects of different budgets on performance – this feature enables sensitivity analysis to be undertaken. Default data (based on expert opinion) is used in the analysis, including deterioration profiles and unit costs, making this extremely well suited where there is a lack of available or reliable data. Deterioration profiles are determined based on defined influencing factors including traffic volumes and exposure conditions. This tool is great leap forward to assist bridge engineers determine the optimal levels of expenditure for bridge maintenance. However, the decision support tool does not yet consider greenhouse gases (e.g. carbon emissions). (CIHT, 2020)

## **Sustainability**

In order to determine the optimal maintenance strategy and funding requirements, it is important to consider both cost and sustainability. Du, Pettersson and Karoumi (2018) state:

*‘’Life Cycle Assessment (LCA) is a comprehensive, standardized and internationally recognized approach for quantifying all emissions, resource consumptions and the related environmental and health impacts linked to a service, asset or product’’*

Although CO2 emissions are considered during design, research undertaken by Balogun et al. (2020) found that maintenance decisions generally do not consider CO2 emissions. Climate change is one the greatest challenges facing the civil engineering industry. Atmospheric carbon dioxide levels are currently at the highest levels in the last 3 million years. The construction industry was responsible for 12.7 million metric tons of CO2 emissions in 2018, which equated to approximately 3% of the UK’s total CO2 emissions. (Tiseo, 2020)

The Department for Transport (‘DfT’) and local Government need to provide adequate levels of funding to minimise whole life costs and reduce carbon emissions. Failure to consider carbon emissions during maintenance planning could undermine the UK’s target to reduce CO2 emissions by 2050 (Baloggun et al., 2020). To support the industry and adopt a more sustainable approach, good practice guides must be developed, as there is little guidance in the current literature (Zhang, 2010).

## **Life Cycle Analysis**

A study undertaken by Itoh & Kitagawa (2003) aimed to develop a life cycle analysis (‘LCA’) methodology to assess the environmental impact of bridges, considering energy consumption and CO2 emissions. The environmental impact during maintenance was determined using the formula in Equation 7 (Itoh & Kitagawa, 2003).

|  |  |  |
| --- | --- | --- |
|  |  | (7) |

Where;

= Environmental impact from maintenance activities

= Environmental impact during maintenance from material and components for bridge component

= Environmental impact during maintenance from construction machinery for bridge component

Analysis period

= Service life of bridge component

Unfortunately, this calculation excludes CO2 arising from traffic diversions and congestion caused as a result of maintenance activities. Transportation of materials and plant to site for maintenance activities is also not considered during this study.

Zhang (2010) argues that the main sources of CO2 emissions include embodied CO2 in construction materials, CO2 arising from traffic disruption and diversions, and construction site activities. Although further sources of CO2 emissions arise from waste disposal and project-related personal travel, they are considered negligible (Zhang, 2010).

Uncertainties such as distances travelled during transportation of goods and future volumes of traffic highlight the importance of sourcing materials locally and using a local work force. The UK government has also recently announced a ban on all petrol and diesel cars sales from 2030 which adds further uncertainty to any life cycle analysis (Harrabin, 2020).

Due to the complexities associated with LCA, software tools have been developed to simplify the process. An example of such software is the carbon calculator design tool for bridges developed by Atkins for BCSA and Tata Steel. A study undertaken by Smith et al. (2014) adopted this tool to undertake a comparison of two different bridges: a steel composite bridge and a pre-tensioned precast concrete beam bridge. In this study the carbon calculator was used to determine the CO2 emissions during construction, operation, and demolition. Default data is provided, although many of the parameters can be overridden and manually defined making this an enormously useful tool to quantify embodied and operational CO2. However, the software does not enable the number of vehicles affected by maintenance activities to be defined based on available traffic count data. The software also does not consider traffic growth, or changes in vehicle emissions over time. Additionally, the maintenance activities are limited so the resultant CO2 is not fully representative of the required maintenance. (Smith et al., 2014)

## **Monetisation of Carbon**

In order to provide a consistent approach to assess both costs and carbon emissions, a form of weighting is necessary to enable the quantitative assessment. A study was undertaken by Mott Macdonald (2012) on the monetisation of carbon in WLC in construction. The study concluded that monetisation of carbon is unlikely to be included in WLC, as carbon emissions during ‘service life’ represents a smaller portion of overall emissions; it is difficult to quantify and there is minimal regulation and taxes in place (Mott Macdonald, 2012).

Du & Karoumi (2012) carried out a research on the life cycle assessment framework for railway bridges and argues that the environmental burdens during the service life of bridges represent a larger portion of the overall environmental impact due to the subsequent traffic disturbances. However, Du & Karoumi (2012) also states;

‘’*Weighting relies on political, monetary, ethical and cultural viewpoints. Since there is no societal consensus on these fundamental values, there is no reason to expect consensus either on weighting factors or on the weighting method, or even on the choice of using a weighting method at all.’’*

Recently, a study has been undertaken by Du et al. (2018) to determine an alternative design solution for short spans considering LCA. In the study the environmental impacts were monetised using two different weighting approaches, Ecovalue 08 (with updated value of Ecovalue 12) & Ecotax02 to determine the environmental cost of each design. Ecovalue and Ecotax02 are shown Table 1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Characterized environmental impact categories and monetary weighting factors (Du et al., 2018)** | | | | |
| **Environmental impact category** | **Acronym** | **Unit** | **Ecovalue (SEK)** | **Ecotax02 (SEK)** |
| Global warming | GWP | Kg CO2 eq. | 2,85 | 0,63 |
| Ozone depletion | ODP | Kg CFC-11 eq. | - | 1200 |
| Human toxicity | HTP | Kg 1,4-DB eq. | 2,81 | 1,5 |
| Photochemical oxidant formation | POFP | Kg NMVOC | 16 | 156 |
| Particulate matter formation | PMFP | Kg PM10 eq. | 273 | - |
| Ionizing radiation | IRP | Kg U235 eq. | - | - |
| Terrestrial acidification | TAP | Kg SO2 eq. | 30 | 15 |
| Freshwater eutrophication | FEP | Kg P eq. | 670 | - |
| Marine eutrophication | MEP | Kg N eq. | 90 | 12 |
| Terrestrial ecotoxicity | TETP | Kg 1,4-DB eq | - | 176 |
| Freshwater ecotoxicity | FETP | Kg 1,4-DB eq | - | 92 |
| Marine ecotoxicity | METP | Kg 1,4-DB eq | 12 | 0,3 |
| The P in each acronym refers to potential. | | | | |

Table 1- Characterised environmental impact categories and monetary weighting factors

Ecovalue 08 is derived from market valuations of resource depletion and estimates on willingness to pay for environmental quality. Ecotax 2002 is derived from Swedish eco-taxes on emissions and fees on resource use. The application of monetised environmental impacts allows both cost and carbon emissions to be considered in a consistent manor. (Durão et al., 2019)

The UK has an agreed set of carbon valuations for policy appraisal as shown in Table 2. UK guidance on carbon valuation for sectors not covered under the EU emissions trading scheme (ETS) provide central estimates for 2020 of 60 GBP/t CO2e, rising to 308 GBP/t CO2e in 2075 before declining (Department of Energy & Climate Change, 2011). The carbon valuations are based on the marginal abatement cost which reflects the cost to reduce emissions, to levels consistent with the UK’s greenhouse emission targets. This approach was adopted in 2009 with prior valuations based on the damages associated with climate change. (Department of Energy & Climate Change, 2013)

| **UK social values of carbon (£/tCO2e at 2009 prices) (Valatin, 2011)** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Sectors covered by EU ETS** | | | **Sectors not covered by EU ETS** | | |
| **Central price of carbon** | **Discounted price of carbon** | **Index (2010 discounted price = 100)** | **Central price of carbon** | **Discounted price of carbon** | **Index (2010 discounted price = 100)** |
| 2010 | 14 | 14 | 100 | 52 | 52 | 100 |
| 2020 | 16 | 12 | 82 | 60 | 43 | 82 |
| 2030 | 70 | 35 | 250 | 70 | 35 | 68 |
| 2040 | 135 | 48 | 341 | 135 | 48 | 93 |
| 2050 | 200 | 53 | 376 | 200 | 53 | 103 |
| 2060 | 266 | 52 | 372 | 266 | 52 | 102 |
| 2070 | 301 | 44 | 313 | 301 | 44 | 85 |
| 2080 | 306 | 33 | 237 | 306 | 33 | 65 |
| 2090 | 292 | 24 | 173 | 292 | 24 | 47 |
| 1100 | 268 | 17 | 124 | 268 | 17 | 34 |

Table 2 - UK social values of carbon (£/tCO2e at 2009 prices)

## **Conclusion**

To determine the optimal maintenance strategy and calculate the budget requirements for a bridge, it is essential to take a life cycle planning approach, taking both cost and sustainability into consideration. Although life cycle planning tools have been developed for bridges, the current driver for bridge maintenance decisions remains to be cost. The industry will need to adopt a more sustainable approach to bridge maintenance planning, so not to undermine the governments targets for reducing CO2 emissions by 2050. Monetisation of carbon emissions arising from maintenance activities provides a credible method for considering the effects of carbon emissions in addition to other factors such as cost and driver delays. Monetised values for carbon emissions can be incorporated into whole life costing analysis to determine the optimal maintenance strategy.

# **Chapter 4: Methodology and Limitations**



## **General**

To determine the optimal maintenance strategy for a local authority managed bridge, considering whole life costs and carbon emissions; and to determine the subsequent budget requirements, an application oriented parametric study was carried out varying input parameters to compare different maintenance strategies.

The following maintenance strategies were considered as part of this study:

* Planned Preventative – undertake preventative maintenance to prevent deterioration and extend the life of the structure.
* Unplanned Reactive – maintenance only carried out if there is a significant loss of functionality to bridge elements.

(LoBEG, 2011)

The Structures Asset Valuation and Investment Tool (SAVI) was initially used to produce life cycle plans for both strategies and determine the maintenance requirements, individual scheme costs and traffic delays costs. SAVI is a Microsoft Excel model that was developed Arup and is owned by the UK Bridges Board. SAVI was designed to assist local authorities manage their bridges so was regarded as the ideal application for this study.

To calculate the carbon emissions arising from the individual maintenance schemes, a carbon calculator design tool for bridges was used. The carbon calculator tool was developed to estimate the carbon footprint of steel-concrete composite bridges and was developed by Atkins. The carbon calculator was designed to enable a quick comparison between different design options. The carbon calculator was selected for this study as it is able to provide reasonable estimates for various maintenance activities including emissions from road and lane closures.

Carbon emissions were then monetised using UK social values of carbon so that carbon emissions could be incorporated into the whole life cost analysis. UK social values for carbon were used to provide a value of CO2 which was consistent with the UK’s target of reducing CO2 emissions.

## **Structure Description**

The bridge used in this study is a single span highway bridge carrying an A road over a railway line. The bridge is semi-integral and consists of 8 no. weathering steel girders acting compositely with a reinforced concrete deck slab. The bridge is simply supported and set at a skew angle of 9° to the supports. The bridge deck bears onto reinforced concrete cellular abutments founded on to piled foundations and was constructed in 2000.

Each steel girder is supported on a pot bearing at each end, with each bearing being mounted on an individual reinforced concrete bearing plinth on the top face of the abutment walls. The expansion joints are asphaltic plug type joints.

## **Key Geometric Data**

The following measurements were obtained from the available structure records.

|  |  |
| --- | --- |
| No of Spans: | 1 |
| Span length: (Between abutments) | 22.65m |
| Skew Angle: | 9⁰ |
| Width of deck: (Between parapets) | 14.58m |

## **Expected Outcomes**

It was envisaged that a preventative maintenance strategy would provide the most cost-effective and sustainable strategy. Adopting a preventative maintenance strategy would enable defects to be repaired before they develop into more costly issues, for example strengthening or replacement of elements.

## **Key Assumptions**

The key assumptions used in this study are outlined in Table 3.

| **Key Assumptions** | |
| --- | --- |
| **ID** | **Assumptions** |
| 01 | All deterioration rates assume that routine maintenance is undertaken. If routine maintenance is not undertaken, the deterioration rates would be accelerated. (CIHT, 2020) |
| 02 | Elements are treated once they reach their predefined condition trigger as shown in Appendix D. (CIHT, 2020) |
| 03 | Condition after treatment is 2B unless element replacement takes place, in which case the condition is set at 1A. (CIHT, 2020) |
| 04 | The cost of surfacing, services and lighting working due to waterproofing maintenance / renewal are included in the unit rates for waterproofing works. (CIHT, 2020) |
| 05 | Metalwork repairs to the weathering steel beams, and concrete repairs to reinforced concrete deck slab are completed as a package due to SAVI’s predefined assumptions that the condition of these elements will be similar. (CIHT, 2020) |
| 06 | Due to SAVI’s predefined assumptions, only one work pattern is utilised – Daytime Working. (CIHT, 2020) |
| 07 | The base year in the life cycle analysis is 2020 and unit rates for maintenance activities were indexed to this year automatically using the ROADCON Tender Price Index of Road Construction. |
| 08 | Carbon values beyond year 2100 were excluded as UK social values of carbon do not exist further than 2100. |
| 09 | Regional traffic forecasts used to estimate emissions arising from road and lane closures assume a shift towards electric vehicles. |
| 10 | Vehicle emissions beyond 2050 were excluded, as it is assumed the UK will be shifting towards electric vehicles. |
| 11 | CO2 from the transportation of materials was estimated based on a distance travelled of 50km local, 250km national. |
| 12 | Routine bridge inspections (General and Principal inspections) were excluded from this analysis as it was anticipated that the inspection regime for the structure would not differ from one strategy to another, therefore have no influence on the result. |
| 13 | The analysis period is 100 years which will represents the remaining service life of the structure assuming a design life of 120 years. |

Table 3 - Key Assumptions

## **Data Input**

To develop life cycle plans for the two maintenance strategies, SAVI required some initial input to define the general information about the structure and details of all structural elements. All this information was obtained from the structure records which included the most recent inspection reports and as-built information.

To determine both, the rate of deterioration to structural elements and the subsequent years in which maintenance should be carried out, the environmental exposure conditions for the bridge and intervention thresholds were also defined as outlined in this section.

### Exposure Environment

The obstacle supported by the structure and obstacles crossed were firstly defined, including whether the routes supported or crossed were salted (located on a gritted route). Winter maintenance (salting) routes for the local authority were reviewed and confirmed the road supported by the structure is subjected to de-icing salts.

### Bridge Elements and Proximity to Traffic Spray

Each element of the bridge was defined in SAVI indicating the component / material type, condition and proximity to traffic spay as indicated in Table 4. The condition of bridge elements in the UK are defined using CSS condition scores using severity and extent codes. Extent and severity codes along with the corresponding descriptions are provided in Tables 5 & 6.

| **Element Condition and Proximity to Traffic Spray** | | | |
| --- | --- | --- | --- |
| **Full Name of Element** | **Component/Material Type** | **Condition at last inspection** | **Proximity to Traffic Spray Zone** |
| Br01. Primary Deck Element | Weathering Steel | 1A | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br03. Secondary Deck Element | In-situ Reinforced Concrete | 1A | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br07. Deck Bracing | Other/Unknown Material | 2B | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br08. Foundations | Foundation material | 1A | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br09. Abutments (incl. Arch Springing) | Precast Reinforced Concrete | 3D | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br13. Bearings | Pot | 2D | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br14. Bearing Plinth/Shelf | Precast Reinforced Concrete | 3C | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br15. Superstructure Drainage | Other/Unknown Drainage System | 1A | Within 3 metres’ proximity to spray zone |
| Br16. Substructure Drainage | Concrete Pipe | 4B | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br17. Waterproofing | Other/Unknown Waterproofing | 1A | Within 3 metres’ proximity to spray zone |
| Br18. Expansion Joints | Asphaltic Plug Joint | 3E | Within 3 metres’ proximity to spray zone |
| Br22. Access/Walkways/Gantries | Fabricated Steel, Rolled Steel, Steel, or Steel Plate | 1A | Not within 3 metres’ proximity to spray zone / Not applicable |
| Br23. Handrail/Parapets/Safety Fences | Concrete | 2B | Within 3 metres’ proximity to spray zone |
| Br24. Carriageway surfacing | Carriageway surfacing | 1A | Within 3 metres’ proximity to spray zone |
| Br25. Footway/verge/footbridge surfacing | Footway surfacing | 2C | Within 3 metres’ proximity to spray zone |
| Br32. Retaining Walls | In-situ Reinforced Concrete | 2B | Not within 3 metres’ proximity to spray zone / Not applicable |

(Note: The condition scores data obtained in this section has been taken from the last Principal Inspection)

Table 4 – Element Condition and Proximity to Traffic Spray Zone

|  |  |
| --- | --- |
| **Extent Codes (Highways Agency, 2007)** | |
| **Code** | **Description** |
| A | No significant defect |
| B | Slight, not more than 5% of surface area/length/number |
| C | Moderate, 5% - 20% of surface area/length/number |
| D | Wide: 20% - 50% of surface area/length/number |
| E | Extensive, more than 50% of surface area/length/number |

Table 5 – Extent Codes

|  |  |
| --- | --- |
| **Severity Descriptions (Highways Agency, 2007)** | |
| **Code** | **Description** |
| 1 | As new condition or defect has no significant effect on the element (visually or functionality) |
| 2 | Early signs of deterioration, minor defect/damage, no reduction in functionality of element |
| 3 | Moderate defect/damage, some loss of functionality could be expected |
| 4 | Severe defect/damage, significant loss of functionality and/or element is close to failure/collapse |
| 5 | Extensive, more than 50% of surface area/length surface |

Table 6 – Severity Descriptions

### Traffic Category

The traffic category for the structure was then defined using the exposure descriptions in Table 7 and the available Annual Average Daily Traffic Counts (AADT) from the Department for Transport (DfT) in Table 8. Using this information, the traffic category for the structure was classified as ‘Medium’.

| **Traffic Category (CIHT, 2020)** | |
| --- | --- |
| **Category** | **Exposure Description** |
| **High** | * Structure or Route located at or is adjacent to features (e.g. junctions, interchange, etc.) that frequently impose obstructions to traffic flow (i.e. resulting in queuing/slow moving traffic). * Speed limit >40mph, with poor horizontal and vertical alignment (e.g. uneven carriageway, located on/near a bend or gradient, etc.) * High Annual Average Daily Traffic (e.g. AADT >25,000 vehicles) * High volume of Commercial Vehicles (e.g. CV >2,500 vehicles) * High volume of Heavy Goods Vehicles |
| **Moderate** | * Structure or route is located at or is or adjacent to features (e.g. junctions, interchanges, etc.) that occasionally impose obstructions to traffic flow (i.e. resulting in queuing/slow moving traffic). * Speed limit >20mph to ≤40mph, with poor horizontal and vertical alignment (e.g. uneven carriageway, located on/near a bend or gradient, etc.) * Medium Annual Average Daily Traffic (e.g. AADT >10,000 to ≤ 25,000 vehicles) * Medium volume of Commercial Vehicles (e.g. CV >1,000 to ≤ 2,500 vehicles) * Medium volume of Heavy Goods Vehicles |
| **Low** | Structure or route or is adjacent to features do not impose obstructions to traffic flow   * Speed limit ≤ 20mph, with good horizontal and vertical alignment (e.g. even carriageway, level and straight stretch route). * Low Annual Average Daily Traffic (e.g. AADT ≤ 10,000 vehicles) * Low volume of Commercial Vehicles (e.g. CV ≤ 1,000 vehicles) * Low volume of Heavy Goods Vehicles |
| **Note:** it is considered that the traffic category would be influenced by the frequency , speed and concentration of traffic flows (especially HGV’s) and would be dependent on the location, e.g. rural, urban, etc. | |

Table 7 - Traffic Category

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **AADT** | | | | | | |
| **Pedal Cycles** | **Two Wheeled Motor Vehicles** | **Cars and Taxis** | **Buses and Coaches** | **LGVs** | **HGVs** | **All Motor Vehicles** |
| 132 | 155 | 21548 | 52 | 1512 | 411 | 23810 |

Table 8 – Traffic Data (Year 2020)

After the environmental exposure conditions were defined the intervention thresholds (e.g. the condition state at which maintenance is carried out) was selected. For the planned preventive strategy, early intervention was selected, where maintenance was carried out once the elements had reached a condition score between (2C-3C). For the unplanned reactive strategy, late intervention was selected where maintenance is only undertaken when an element had reached a condition score of 5B.

Once the environmental exposure conditions and intervention thresholds for each element was defined, SAVI was able to determine the deterioration profile for each element, identify when maintenance was required and calculate the individual scheme costs and driver delay costs as indicated in Section 4.7 & 4.8.

## **Scheme Costs**

Scheme costs were calculated in SAVI using the following formula:

|  |  |  |
| --- | --- | --- |
|  |  | (8) |

= Scheme Cost

= Total works cost (The sum of all individual maintenance activities works costs calculated in SAVI using base rates in Appendix E)

= Traffic Management Cost (Refer to Appendix E)

= Preliminaries Cost (Refer to Appendix E)

= Design Cost (Refer to Appendix E)

= Other Cost (Refer to Appendix E)

Unit rates per m2 were multiplied by the size of the component if replacement was necessary, or by a percentage of the component size if repairs were required. Percentage of component size was based on the total extent of defects in Table 9. Element size formulas used are available in Appendix F.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Total Extent of Defects (%) (CIHT, 2020)** | | | | | | | | |
| **Primary Condition** | | **Lesser Condition Also Present** | | | | | | **Total Extent of Defects (TEoD)** |
| **1A** | 0.00% | - |  | - |  |  | - | 0.00% |
| **2B** | 2.50% | - |  | - |  |  | - | 2.50% |
| **2C** | 7.50% | - |  | - |  |  | - | 7.50% |
| **2D** | 12.50% | - |  | - |  |  | - | 12.50% |
| **2E** | 15.00% | - |  | - |  |  | - | 15.00% |
| **3B** | 0.00% | 2D | 12.50% | - |  |  | - | 15.00% |
| **3C** | 2.50% | 2D | 12.50% | - |  |  | - | 20.00% |
| **3D** | 7.50% | 2E | 10.00% | - |  |  | - | 22.50% |
| **3E** | 12.50% | 2E | 10.00% | - |  |  | - | 25.00% |
| **4B** | 0.00% | 3D | 12.50% | 2E | 10.00% |  | - | 25.00% |
| **4C** | 2.50% | 3D | 12.50% | 2E | 10.00% |  | - | 30.00% |
| **4D** | 7.50% | 3D | 12.50% | 2E | 10.00% |  | - | 35.00% |
| **4E** | 12.50% | 3D | 12.50% | 2E | 10.00% |  | - | 37.50% |
| **5B** | 2.50% | 4D | 12.50% | 3D | 12.50% | 2E | 10.00% | 37.50% |
| **5C** | 7.50% | 4D | 12.50% | 3D | 12.50% | 2E | 10.00% | 42.50% |
| **5D** | 20.00% | 4D | 12.50% | 3D | 12.50% | 2E | 12.50% | 57.50% |
| 5E | 50.00% | 4D | 20.00% | - |  |  |  | 70% |

Table 9 - Total Extent of Defects (%)

## **Traffic Delay Costs**

Traffic delay costs were calculated using the criteria in Table 10 and daily traffic rates in Table 11. Daily traffic delay rates (£/day) were automatically indexed to the base year using ROADCON Tender Price Index of Road Construction.

|  |  |  |  |
| --- | --- | --- | --- |
| **Traffic Restrictions (CIHT, 2020)** | | | |
| **ECS [At least one Element of ‘Very High’’ Importance]** | **Traffic Restriction** | **Structure Length (l)** | **Time over which the Traffic Restriction Applies [Days]** |
| 4.0 ≤ ECS < 5.0 | One lane closed in each direction | L ≤ 10m | 5 |
| 10m < l ≤ 20m | 10 |
| L > 20m | 15 |
| ECS ≥ 5.0 | Entire bridge closed | N/A | 30 |

Table 10 - Traffic Restrictions

|  |  |
| --- | --- |
| **Traffic Delay Costs (2014/2015 prices) (CIHT, 2020)** | |
| **Category of Traffic Volume** | **Daily Traffic Delay Rates (£/Day)** |
| High | £996 |
| Medium | £695 |
|
| Low | £301 |
|

Table 11 - Traffic Delay Costs (2014/2015 prices)

## **Carbon Emissions**

After the maintenance requirements, scheme costs and traffic delay costs were identified for each strategy, the carbon emissions arising from the individual maintenance schemes were estimated using the carbon calculator design tool for bridges developed by Atkins. Initial input was carried out to define the following information:

* Type of bridge (highway bridge)
* The obstacle crossed (railway)
* Key geometric data (as per Section 4.3)
* The construction duration in weeks obtained from available records (78 weeks).
* Diversion route (type of road, speed limit and length of diversion - identified using Google Maps)
* Volumes of materials as per Table 12 (calculated from as-built records)

|  |  |  |
| --- | --- | --- |
| **Volumes of Materials** | | |
| **Bridge Element Type** | **Material** | **Volume (m3) / Tonnage (t) / Quantity (No.)** |
|  | | Volume (m3) |
| Foundations | Reinforced Concrete | 200.2 |
| Structural Steel | 0 |
|  | | Volume (m3) |
| Substructure | Reinforced Concrete | 184.37 |
|  |  | Quantity (No.) |
| Articulation | Bearings | 16 |
|  | | Tonnage (t) |
| Deck | Painted Structural Steel | 0 |
| Weathering Structural Steel | 52.38 |

Table 12 - Volumes of Materials

Although the carbon calculator was able to provide CO2 estimates with very little input, the emissions resulting from certain maintenance activities were not provided, for example carriageway resurfacing & repairs and re-waterproofing. The emissions for maintenance activities that were not provided, were estimated using a percentage of the estimated emissions arising from the construction of those particular components. If element replacement was required, then 100% of the estimated construction emissions for that particular component was applied. If repairs were required rather than replacement, the emissions were calculated using a percentage of the estimated construction emissions, using on the total extent of defects (%) in Table 9. The emissions for maintenance activities included embodied CO2,emissions arising from the transportation of materials and emissions emitted from construction plant.

Although the carbon calculator also estimated the CO2 emissions arising from lane and road closures during maintenance activities, the estimates did not consider traffic growth, or changes in vehicle emissions over time. To enable more accurate estimations of CO2 throughout the analysis period,regional road traffic forecasts in Section 4.10 were applied independently.

It is also worth noting that the available traffic count data was not sufficient to determine the number of vehicles that would be affected during maintenance as this would require traffic count data at specific times (e.g. 22:00-06:00) to reflect actual traffic management periods. Therefore, default emissions arising from lane and road closures were initially taken from the carbon calculator design tool prior to the application forecast traffic growth (%) and reductions in tailpipe emissions (%).

## **Traffic Forecasts**

The following regional traffic forecasts in Table 13 were used in this study. The traffic forecasts assume a shift towards electric vehicles.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Road Traffic Forecasts: Scenario 7 Shift to EVs - Traffic in England and Wales (DfT, 2018)** | | | | | | | | | | |
| **Traffic growth rate from 2015 (%)** | | | | | | | | | | |
| **Vehicle Type** | **Road Type** | **Country** | **Region** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| Car | Principal A | England | Eastern England | 5.4% | 10.4% | 15.8% | 21.9% | 27.4% | 31.8% | 35.4% |
| LGV | Principal A | England | Eastern England | 9.4% | 14.7% | 23.8% | 40.5% | 63.0% | 85.7% | 101.9% |
| HGV | Principal A | England | Eastern England | -0.7% | 0.2% | 2.1% | 3.8% | 5.7% | 7.5% | 9.3% |
| PSV | Principal A | England | Eastern England | -10.0% | -10.0% | -10.0% | -10.0% | -10.0% | -10.0% | -10.0% |
| Total | Principal A | England | Eastern England | 5.6% | 10.4% | 16.2% | 23.7% | 31.5% | 38.6% | 43.9% |
| **Road Traffic Forecasts: Scenario 7 Shift to EVs - CO2 Traffic Tailpipe Emissions in England and Wales (DfT, 2018)** | | | | | | | | | | |
| **CO2 Traffic Tailpipe Emissions growth rate from 2015 (%)** | | | | | | | | | | |
| **Vehicle Type** | **Road Type** | **Country** | **Region** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| Car | Principal A | England | Eastern England | -8.6% | -20.0% | -36.4% | -59.7% | -80.6% | -92.8% | -96.8% |
| LGV | Principal A | England | Eastern England | 0.4% | -10.3% | -26.2% | -49.5% | -73.1% | -89.0% | -94.8% |
| HGV | Principal A | England | Eastern England | -11.6% | -13.7% | -13.3% | -13.5% | -13.6% | -13.1% | -11.7% |
| PSV | Principal A | England | Eastern England | -19.3% | -29.2% | -41.5% | -48.1% | -51.7% | -52.7% | -53.4% |
| Total | Principal A | England | Eastern England | -7.8% | -17.6% | -31.1% | -50.3% | -67.9% | -78.4% | -81.8% |

Table 13 - Road Traffic Forecast

Note: Regional traffic growth rates and reductions in tailpipe emissions were available between 2015 and 2050 at 5-year intervals. The carbon calculator design tool was developed in 2013, therefore emissions from lane and road closures would have been based on traffic volumes and tail pipe emissions from 2013. The traffic growth rate and percentage reduction in vehicle emissions between 2013 and 2015 was not available and subsequently not applied.

## **Carbon Values**

The total carbon emissions arising from maintenance activities in each year of the analysis period for both strategies was then monetised using the UK social values of carbon for sectors not covered by EU ETS (central price of carbon). The values were inflated to the base year (2020) using the Bank of England’s inflation calculator. However, the inflation calculator only went as far as 2019, so 0% inflation was assumed between 2019-2020. Discounted carbon values used in this study are shown in Table 14. As carbon prices were only provided at 10-year intervals, interpolation was used to determine the price of carbon for each year in the analysis period.

|  |  |  |  |
| --- | --- | --- | --- |
| **UK social values of carbon (£/tCO2e at 2009 prices + 35% inflation)** | | | |
| **Year** | **(Sectors not covered by EU ETS – Central Price (£/tCO2e at 2009 prices)** | **(£/tCO2e at 2009 prices + 35% inflation** | **Discounted Price** |
| 2020 | £60.00 | £81.00 | £81.00 |
| 2030 | £70.00 | £94.50 | £66.99 |
| 2040 | £135.00 | £182.25 | £91.59 |
| 2050 | £200.00 | £270.00 | £96.20 |
| 2060 | £266.00 | £359.10 | £110.08 |
| 2070 | £301.00 | £406.35 | £92.69 |
| 2080 | £306.00 | £413.10 | £70.12 |
| 2090 | £292.00 | £394.20 | £49.79 |
| 2100 | £268.00 | £361.80 | £50.18 |

Table 14 - UK Carbon Values (£)

## **Discount Rates**

The scheme costs, traffic delay costs and CO2 costs for both maintenance strategies were then discounted to determine the net present value using the discount rates indicated in Table 15.

|  |  |  |  |
| --- | --- | --- | --- |
| **Discount Rates** | | | |
| **Year** | **0-30** | **31-75** | **76-125** |
| Discount Rate | 3.50% | 3.00% | 2.50% |

Table 15 - Discount Rates

The strategy with the lowest NPV was considered to be the preferred maintenance strategy.

# **Chapter 5: Results**



## **Overview**

The planned preventative maintenance strategy has 7.7% lower discounted maintenance costs, 83% lower traffic delay costs, 5% lower discounted CO2 costs, and overall, 30% lower NPV. Additionally, the planned preventive strategy had 7% less CO2 emissions,  and the discounted workbank at the end of the analysis period is 98% lower. The workbank represents the back log of maintenance work. A summary of the results is shown in Table 17.

|  |  |  |
| --- | --- | --- |
| **Results** | | |
|  | **Unplanned re-active** | **Planned Preventive** |
| **Discounted Maintenance Costs** | £876,040.97 | £808,495.16 |
| **Discounted Traffic Delay Cost** | £389,293.88 | £65,231.67 |
| **Discounted Price of Carbon** | £24,122.72 | £22,954.76 |
| **Net Present Value** | £1,289,457.5 | £896,495.16 |
| **Discounted workbank after year 100** | £7,379.73 | £163.20 |
| **Total tCO2** | 394 | 366 |

Table 17 - Results Summary

Details of the individual maintenance schemes are tabulated in Appendix H. Discounted scheme costs, traffic delay costs and CO2costs throughout the analysis period are illustrated in Figures 2 to 7. CO2 emissions throughout the analysis period are shown in Figures 8 & 9.

## **Discounted Scheme Costs**

Figure 2 – Discounted Scheme Costs for the Planned Preventive Maintenance Strategy

*Figure 3 – Discounted Scheme Costs for the Unplanned Re-active Maintenance Strategy*

## **Discounted Traffic Delay Costs**

## 

Figure 4 – Discounted Traffic Delay Costs for the Planned Preventive Maintenance Strategy

Figure 5 - Discounted Traffic Delay Costs for the Unplanned Re-active Maintenance Strategy

## **Discounted CO2 Costs**

Figure 6 – Discounted CO2 Costs for the Planned Preventive Maintenance Strategy

Figure 7 - Discounted CO2 Costs for the Unplanned Re-active Maintenance Strategy

## **CO2 Emissions**

Figure 8 - tCO2 Emissions for the Planned Preventive Maintenance Strategy

Figure 9 - tCO2 Emissions for the Unplanned Re-active Maintenance Strategy

The discounted CO2 costs from traffic restrictions during maintenance were calculated using the discounted unit costs in Table 16 multiplied by the default emissions for lane and road closures from the carbon calculator which were modified using regional traffic forecasts (refer to Section 4.10).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Carbon Value per tCO2** | £81 | £87.75 | £94.5 | £138.375 | £182.25 | £226.125 | £270 |
| **Discounted Carbon Value per tCO2** | £81.00 | £73.88 | £66.99 | £82.59 | £91.59 | £95.68 | £96.20 |
| **Discounted cost per Night Closure 22:00-06:00** | **£134.50** | **£114.72** | **£91.50** | **£86.63** | **£65.87** | **£48.77** | **£43.05** |
| **Discounted cost per Lane Closure - Weekend** | **£3,025.45** | **£2,580.55** | **£2,058.30** | **£1,948.70** | **£1,481.83** | **£1,097.00** | **£968.49** |
| **Discounted cost per Lane Closure 24hrs** | **£2,095.33** | **£1,787.21** | **£1,425.51** | **£1,349.61** | **£1,026.27** | **£759.74** | **£670.74** |
| **Discounted cost per Road Closure – Night Closure**  **22:00-06:00** | **£256.69** | **£218.95** | **£174.64** | **£165.34** | **£125.73** | **£93.07** | **£82.17** |
| **Discounted cost per Road Closure - Weekend** | **£5,825.51** | **£4,968.85** | **£3,963.25** | **£3,752.22** | **£2,853.26** | **£2,112.27** | **£1,864.82** |
| **Discounted cost per Road Closure - 24hrs** | **£3,962.59** | **£3,379.88** | **£2,695.86** | **£2,552.31** | **£1,940.83** | **£1,436.79** | **£1,268.48** |

(Note: Interpolation was used to determine the emissions from traffic management in each year of the analysis period)

Table 16 - CO2 Costs from Traffic Management

# **Chapter 6: Analysis**



## **Maintenance Costs**

Figures 10 & 11 illustrate the non-discounted maintenance scheme costs throughout the analysis period.

Figure 10 - Expenditure for the Planned Preventive Maintenance Strategy

Figure 11 - Expenditure for the Unplanned Re-active Maintenance Strategy

The general trend of expenditure for the planned preventive strategy is neither increasing nor decreasing throughout the analysis period. However, the trend of expenditure using the unplanned-preventive strategy indicates that maintenance costs are increasing throughout the analysis period. Although maintenance is undertaken less frequently using the unplanned re-active maintenance strategy, the scheme costs are much higher.

## **Carbon Emissions**

The planned preventive maintenance strategy resulted in 28 tonnes less CO2 emissions overall. CO2 emissions from traffic restrictions during maintenance represented 6.9% of maintenance emissions using the planned preventive strategy and 5.26% of maintenance emissions using the unplanned reactive strategy as shown in Figure 12. This indicates that the main contributors of CO2 emissions during maintenance were the embodied CO2 from construction materials and CO2 from construction plant.

Figure 12 - CO2 Emissions

The estimated emissions from construction using the carbon calculator design tool equated to approximately 558 tCO2. Emissions from maintenance activities for the 100-year analysis period represent 39.6% of total carbon footprint of the bridge considering a planned preventive strategy and 41.4% for the unplanned reactive strategy (excluding decommissioning). This indicates that CO2 emissions from construction represents a higher proportion of the carbon footprint of the structure.

## **Condition**

The overall condition of the structure (BCIav) at the end of the analysis period using an unplanned re-active maintenance strategy is ‘Poor; and the condition of critical elements (BCIcrit) is ‘Very Poor’. Conversely, the overall condition of the structure (BCIav) at the end of the analysis period using a planned preventive maintenance strategy is ‘Good’; and the condition of critical elements (BCIcrit) is ‘Poor’. Table 18 provides general descriptions of the condition based on the Bridge Condition Indicator (BCI).

|  |  |  |
| --- | --- | --- |
| **Bridge Condition Indicators (BCI) (Atkins, 2007)** | | |
| **BCI Score** | **Overall Condition of the Structure** | **Condition of Critical Elements** |
| 90 ≤ x ≤ 100 Very Good | No significant defects in any elements;  Structure is in a “Very Good” condition overall | Insignificant defects/damage;  Capacity unaffected |
| 80 ≤ x < 90 Good | Mostly minor defects/damage, but may also be some moderate defects;  Structure in “Good” condition overall | Minor defects/damage;  Capacity unlikely to be affected |
| 65 ≤ x < 80 Fair | Minor-to-moderate defects/damage;  Structure is in a fair condition overall;  One or more functions of the bridge may be significantly affected | Superficial defects/damage;  Capacity may be slightly affected |
| 40 ≤ x < 65 Poor | Moderate-to-severe defects/damage;  Structure is in poor condition overall;  One or more of functions of the structure may be severely affected | Moderate defects/damage;  Capacity may be significantly affected |
| 0 ≤ x < 40 Very Poor | Severe defects/damage on a number of elements;  One or more elements have failed;  Structure is in very poor condition;  Structure is unserviceable | Possible failure or actual failure of critical element;  Severe defects/damage;  Capacity may be severely affected;  Structure may need to be weight restricted or closed to traffic |

Table 18 – Bridge Condition Indicators

Figure 13 & 14 illustrate the condition of the bridge throughout the analysis period using the planned preventive strategy and unplanned re-active strategy.

*Figure 13 - Bridge Condition (Planned Preventive)*

In the planned preventive maintenance strategy, the overall condition (BCIav) varies from a good to fair condition with a low score of 74.52%; and the condition of critical elements (BCI crit) varies from very good to a poor condition with a low score of 55.48%.

Figure 14 - Bridge Condition (Unplanned Re-active)

In the unplanned reactive maintenance strategy, the overall condition (BCIav) varies from a good to poor condition throughout the analysis period with a low score of 58.31%; and the condition of critical elements (BCI crit) varies from a very good condition to a very poor condition with a low score of 9.72%.

# **Chapter 7: Discussion**



## **General**

The net present value (‘NPV’) which represents all the monetised benefits and disbenefits was significantly lower using a planned preventative strategy, therefore this would be the preferred strategy for the bridge. The scheme costs are the direct costs incurred by the local authority. Therefore, budget requirements can be determined by taking the non-discounted scheme costs occurring in each year and inflating the costs using the appropriate index.

## **Maintenance Costs**

From the analysis it is evident that the maintenance costs were lower for the planned preventive maintenance strategy as defects were rectified earlier before they required more costly repairs.

Several elements on the bridge have a finite life which is less than the design life of the structure (e.g. expansion joints, bearings, etc.) and require replacement during the service life of the bridge. There are also a number of defects that if not rectified will affect the long-term durability of the structure. For example, leaking expansion joints, blocked drainage, or impairment of the waterproofing membrane. If these defects are not rectified, chloride-ion contaminated water will accelerate deterioration to the bridge deck and substructure elements and result in more costly repairs. This is evidenced by the poorer condition thresholds prior to conducting maintenance using an unplanned reactive maintenance strategy and the higher overall expenditure.

## **Traffic Delays**

Traffic delays for the planned preventive maintenance strategy were considerably lower, as maintenance was undertaken to prevent severe deterioration to elements of very high importance (key structural elements). Deterioration to key structural elements would eventually impact the load carrying capacity of the bridge and subsequently result in traffic restrictions being implemented on the structure to safeguard road users. In the unplanned re-active maintenance strategy, the condition of at least one element of very high importance was frequently in a very poor condition, which meant traffic restrictions were imposed on a regular basis.

## **CO2 Emissions**

This study did not include CO2 emissions due to non-maintenance related restrictions or closures. For example, emergency closures due the structure becoming unsafe or restrictions due the structure no longer being able to support full highway loading due to deterioration of elements of very high importance. If CO2 emissions arising from these closures or restrictions were incorporated into the analysis it would have demonstrated further CO2 reductions using the planned preventive strategy.

Emissions emitted from construction represented a higher proportion of the carbon footprint of the structure in comparison to emissions from maintenance during the analysis period. However, the emissions emitted from maintenance are significant considering that the 100-year analysis period represents the remaining service life of the structure and not the initial 20 years which has already lapsed. This demonstrates that reducing emissions during the operational life of the structure is just as important as reducing emissions during construction.

The analysis has also found that the main contributors of CO2 emissions include the embodied CO2 from construction materials and CO2 from construction plant. Although this contradicts previous research, which indicates that traffic delays would result in a significant contribution to the overall emissions, this presents a more accurate depiction and reflects the shift towards electric vehicles.

## **Condition**

The condition of critical load bearing elements of the bridge using an unplanned re-active maintenance strategy becomes in a very poor condition at several points throughout the analysis period. This means that there would be a high risk to public safety. Furthermore, at the end of the analysis the bridge would likely be unserviceable and require replacement. The bridge may even need to be decommissioned before the structure has reached it’s intended design life. Dissimilarly, the overall condition of the structure (BCIav) at the end of the analysis period using a planned preventive maintenance strategy is ‘Good’, which means that there is potential to extend the life of the structure beyond the intended design life of 120 years. The estimated emissions from construction using the carbon calculator design tool equated to approximately 558 tCO2. Therefore, extending the life span of the bridge by a further 15 years would save approximately 70 tCO2, excluding the difference in CO2 arising from maintenance for that period and assuming a like-for-like replacement.

## **Accuracy of Results**

### General

Although the planned preventive strategy was found to be the preferred option for the bridge, this study only considered two different strategies. Further analysis should be undertaken to consider alternative strategies.

### Maintenance Costs

The Structures Asset Valuation and Investment Tool (‘SAVI’) used in this study assumes that routine maintenance is undertaken. If routine maintenance is not undertaken, the deterioration rates would be accelerated, so it is important that local authorities have a sufficient routine maintenance regime in place. Additionally, costs for routine maintenance activities (e.g. rodding or jetting drainage or vegetation clearance) are not included, so budget requirements for this would need to be determined separately. Additionally, due to SAVI’s predefined assumptions, only one work pattern (daytime working) is utilised when determining the scheme costs. In practice, this will not always be the case, as there are often limitations on the availability of traffic management and railway possessions, which subsequently means that night-time working is more common. Therefore, actual costs may be slightly higher than estimates generated using this tool due to uplifts.

The Structures Asset Valuation and Investment Tool (SAVI) also excludes some maintenance activities including the application of anti-carbonation coatings and cathodic protection so the effects of these could not be considered in the analysis.

Routine bridge inspections were also excluded from this analysis as it was anticipated that the inspection regime for the structure would not differ from one strategy to another, therefore have no influence on the result. However, it is probable that as the condition of the bridge becomes very poor using an unplanned re-active strategy, more frequent inspection, testing or possibly monitoring may be required which would increase cost and emissions. However, consideration into the cost and emissions as a result of inspections is likely to be more relevant during design. Bridges that incorporate features such as viewing galleries or access walkways could eliminate the need for road or lane closures, which would have a greater impact on the result of reducing CO2 emissions.

### Carbon Emissions

The carbon calculator tool developed by Atkins did not include traffic growth or changes in vehicle emissions over time which is expected as the UK moves towards electric vehicles. Therefore, emissions from vehicles were estimated independently using regional traffic forecasts. Zero vehicle emissions were assumed beyond 2050 as it is envisaged that all vehicles will be fully electric, and the UK’s electricity will be produced from renewable energy sources (e.g. wind turbines).

Carbon values beyond year 2100 were excluded as UK social values of carbon do not exist further than 2100. This meant that carbon emissions for the last 20 years of the analysis period were not given any cost. However, the UK carbon values are reflective of the UK’s current targets which will evolve over time. The maintenance strategy will need to be reviewed if there are any changes in UK carbon values or policies relating to carbon emissions.

# **Chapter 8: Conclusion**

At present, maintenance decisions for bridges are entirely cost driven with CO2 emissions completely excluded from the decision-making process. Furthermore, inadequate funding and budget constraints are inhibiting the delivery of sustainable infrastructure in the UK. This is evidenced by the vast backlog of maintenance resulting from extensive and prolonged underfunding. The method in this study presents a new methodology for evaluating and identifying maintenance and funding requirements that is consistent with the UK’s targets on carbon emissions.

This study has demonstrated that adopting an appropriate maintenance strategy can reduce the whole life cost and carbon footprint of a bridge. There are thousands of local authority managed bridges in the UK, therefore if this approach was implemented and sufficient funding was provided to local authorities, there would be a significant reduction in carbon emissions. Conversely, if the industry continues to follow the same process and inadequate funding is provided, the UK’s target to become carbon neutral by 2050 could be in undermined.

This study has also found that the existing tools to assist bridge managers are inadequate. Analysing one bridge is a significantly time-consuming exercise and this level of analysis would not be practical for a local authority with a bridge stock consisting or hundreds or thousands of structures. There is an urgent need to refine existing tools or develop new tools to assist bridge managers with maintenance decisions that consider the carbon footprint of bridges. This is essential to ensure the industry is consistent with the UK’s targets to become carbon neutral by 2050. Monetisation of CO2 using UK carbon valuations in whole life costing analysis would provide a sensible method for considering the carbon footprint of bridges.

Further research is required to evaluate the potential CO2 emissions resulting from traffic restrictions due the structure no longer being able to support full highway loading. This will enable a more accurate reflection of the carbon savings using an appropriate maintenance strategy. Additionally, sensitivity analysis should be carried out to identify the impacts of any reductions in funding.

# **Appendix A – Default Exposure Classification**

# **Appendix B – Default Deterioration Profiles**

# **Appendix C – Element or Structure Size Formula**

# **Appendix D – Default Intervention Levels and Effects**

# **Appendix E – Base Unit Rates and Add-on Costs**

Note: All costs were indexed to the base year in the analysis using ROADCON Tender Price Index of Road Construction.

# **Appendix F – Element or Structure Size Formula**

# **Appendix G – Vehicle Emissions**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **tCO2 emitted per Lane Closure - Night** | | | | | | | |
|  | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Car** | 1.23 | 1.19 | 1.09 | 0.91 | 0.61 | 0.30 | 0.12 | 0.05 |
| **LGV** | 0.15 | 0.17 | 0.16 | 0.14 | 0.11 | 0.07 | 0.03 | 0.02 |
| **HGV** | 0.21 | 0.19 | 0.18 | 0.19 | 0.19 | 0.19 | 0.20 | 0.20 |
| **PSV** | 0.11 | 0.08 | 0.07 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 |
| **Total** | 1.71 | 1.66 | 1.55 | 1.37 | 1.05 | 0.72 | 0.51 | 0.45 |
|  |  |  |  |  |  |  |  |  |
|  | **tCO2 emitted per Lane Closure - Weekend** | | | | | | | |
|  | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Car** | 29.68 | 28.58 | 26.20 | 21.86 | 14.58 | 7.32 | 2.82 | 1.30 |
| **LGV** | 3.50 | 3.84 | 3.60 | 3.19 | 2.48 | 1.53 | 0.71 | 0.37 |
| **HGV** | 2.75 | 2.42 | 2.38 | 2.43 | 2.47 | 2.51 | 2.57 | 2.66 |
| **PSV** | 2.45 | 1.78 | 1.56 | 1.29 | 1.14 | 1.06 | 1.04 | 1.03 |
| **Total** | 38.38 | 37.35 | 34.93 | 30.72 | 23.59 | 16.18 | 11.46 | 10.07 |
|  |  |  |  |  |  |  |  |  |
|  | **tCO2 emitted per Lane Closure 24 hrs** | | | | | | | |
|  | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Car** | 16.82 | 16.20 | 14.85 | 12.39 | 8.27 | 4.15 | 1.60 | 0.74 |
| **LGV** | 3.17 | 3.48 | 3.26 | 2.89 | 2.25 | 1.39 | 0.64 | 0.33 |
| **HGV** | 4.43 | 3.89 | 3.83 | 3.92 | 3.98 | 4.05 | 4.14 | 4.28 |
| **PSV** | 2.16 | 1.57 | 1.37 | 1.14 | 1.01 | 0.94 | 0.92 | 0.90 |
| **Total** | 26.58 | 25.87 | 24.19 | 21.28 | 16.34 | 11.20 | 7.94 | 6.97 |
|  |  |  |  |  |  |  |  |  |
|  | **tCO2 emitted per Road Closure - Night** | | | | | | | |
|  | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Car** | 2.42 | 2.33 | 2.14 | 1.78 | 1.19 | 0.60 | 0.23 | 0.11 |
| **LGV** | 0.35 | 0.38 | 0.36 | 0.32 | 0.25 | 0.15 | 0.07 | 0.04 |
| **HGV** | 0.35 | 0.30 | 0.30 | 0.31 | 0.31 | 0.32 | 0.32 | 0.34 |
| **PSV** | 0.14 | 0.10 | 0.09 | 0.07 | 0.06 | 0.06 | 0.06 | 0.06 |
| **Total** | 3.26 | 3.17 | 2.96 | 2.61 | 2.00 | 1.37 | 0.97 | 0.85 |
|  |  |  |  |  |  |  |  |  |
|  | **tCO2 emitted per Road Closure - Weekend** | | | | | | | |
|  | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Car** | 58.31 | 56.14 | 51.48 | 42.94 | 28.65 | 14.37 | 5.55 | 2.55 |
| **LGV** | 7.98 | 8.77 | 8.21 | 7.29 | 5.67 | 3.50 | 1.63 | 0.84 |
| **HGV** | 4.50 | 3.95 | 3.89 | 3.98 | 4.04 | 4.11 | 4.20 | 4.35 |
| **PSV** | 3.10 | 2.25 | 1.98 | 1.63 | 1.45 | 1.35 | 1.32 | 1.30 |
| **Total** | 73.89 | 71.92 | 67.25 | 59.16 | 45.43 | 31.15 | 22.08 | 19.39 |
|  |  |  |  |  |  |  |  |  |
|  | **tCO2 emitted per Road Closure – 24 hrs** | | | | | | | |
|  | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Car** | 33.05 | 31.82 | 29.18 | 24.34 | 16.24 | 8.15 | 3.14 | 1.45 |
| **LGV** | 7.23 | 7.94 | 7.43 | 6.60 | 5.13 | 3.17 | 1.47 | 0.76 |
| **HGV** | 7.26 | 6.37 | 6.27 | 6.42 | 6.52 | 6.63 | 6.78 | 7.01 |
| **PSV** | 2.73 | 1.98 | 1.74 | 1.44 | 1.27 | 1.19 | 1.16 | 1.14 |
| **Total** | 50.26 | 48.92 | 45.75 | 40.24 | 30.90 | 21.19 | 15.02 | 13.19 |

# **Appendix H – Life Cycle Plans**

| **Unplanned Re-active** | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Repair / Maintenance** | **Traffic Management** | **Quantity** | **Total tCO2 from traffic management** | **Total discounted cost of CO2 emissions from TM** | **tCO2 emitted from maintenance** | **Discounted cost of CO2 emitted during maintenance** | **TOTAL Discounted Price of Carbon** | **Traffic Delay Costs** | **Discounted Traffic Delay Cost** | **Scheme Costs** | **Discounted Scheme Cost** |
| 0 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 1 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 27,158.31 | £0 | £ - |
| 2 | Replace Expansion Joints | Road Closure - Night | 3 | 9.35 | £724.77 | 7.29 | £569.60 | £1,294.37 | £ - | £ - | £20,097 | £ 18,760.52 |
| 3 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 4 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 5 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 11,833.45 | £0 | £ - |
| 6 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 22,866.57 | £0 | £ - |
| 7 | Replace Bearings | Railway Possession | 0 |  | £0.00 | 22.825 | £1,622.70 | £1,622.70 | £ - | £ - | £137,423 | £ 108,013.16 |
| 8 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 9 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 10 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 9,963.45 | £0 | £ - |
| 11 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 19,253.04 | £0 | £ - |
| 12 | Replace Expansion Joints | Road Closure - Night | 3 | 7.09 | £512.76 | 7.29 | £540.57 | £1,053.33 | £ - | £ - | £20,097 | £ 13,299.69 |
| 13 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 14 |  |  | 0 |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 8,682.57 | £0 | £ - |
| 15 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 3.5625 | £294.24 | £294.24 | £ 14,054.42 | £ 8,388.95 | £34,640 | £ 20,676.47 |
| 16 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 8,105.27 | £0 | £ - |
| 17 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 7,831.18 | £0 | £ - |
| 18 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 7,566.36 | £0 | £ - |
| 19 | Replace Substructure Drainage | Railway Possession | 0 |  | £0.00 | 0.85 | £76.70 | £76.70 | £ 14,054.42 | £ 7,310.49 | £3,597 | £ 1,870.74 |
| 20 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 7,063.27 | £0 | £ - |
| 21 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 13,648.84 | £0 | £ - |
| 22 | Replace Expansion Joints | Road Closure - Night | 3 | 3.64 | £337.98 | 7.29 | £683.34 | £1,021.32 | £ 14,054.42 | £ 6,593.64 | £76,496 | £ 35,888.36 |
| 22 | Replace Handrail/ Parapets/ Safety Fences | Lane Closure - Night | 1 | 0.64 | £59.03 | 14.15 | £1,326.37 | £1,385.40 |
| 23 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 6,370.67 | £0 | £ - |
| 24 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 6,155.24 | £0 | £ - |
| 25 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 5,947.09 | £0 | £ - |
| 26 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 5,745.98 | £0 | £ - |
| 27 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 5,551.67 | £0 | £ - |
| 28 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 5,363.93 | £0 | £ - |
| 29 | Access/ Walkways/ Gantries | Railway Possession | 0 |  | £0.00 | 3 | £288.98 | £288.98 | £ 14,054.42 | £ 5,182.54 | £102,268 | £ 37,711.11 |
| 29 | Footway surfacing | Footway Closure | 0 |  | £0.00 | 0.58835 | £56.67 | £56.67 |
| 30 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 5,007.288 | £0 | £ - |
| 31 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 11,243.179 | £0 | £ - |
| 32 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £814.81 | £814.81 | £ 28,108.85 | £ 10,915.707 | £313,155 | £ 121,609.747 |
| 32 | Renew waterproofing | Contraflow |  |  | £0.00 | 6.2 | £692.98 | £692.98 |
| 32 | Replace superstructure Drainage | Lane Closures | 10 |  | £0.00 | 0.85 | £95.01 | £95.01 |
| 33 | Concrete repairs to abutments | Railway Possession |  |  | £0.00 | 23.2875 | £2,605.29 | £2,605.29 | £ 14,054.42 | £ 5,298.887 | £269,524 | £ 101,617.483 |
| 33 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £2,553.55 | £2,553.55 |
| 34 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 5,144.55 | £0 | £ - |
| 35 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 9,989.42 | £0 | £ - |
| 36 | Carriageway Surfacing | Lane Closures | 10 |  | £0.00 | 3.51165 | £391.91 | £391.91 | £ 14,054.42 | £ 4,849.23 | £100,681 | £ 34,738.11 |
| 37 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 4,707.99 | £0 | £ - |
| 38 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 4,570.87 | £0 | £ - |
| 39 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 4,437.73 | £0 | £ - |
| 40 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 4,308.48 | £0 | £ - |
| 41 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 8,365.98 | £0 | £ - |
| 42 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £776.36 | £776.36 | £ 14,054.42 | £ 4,061.16 | £21,663 | £ 6,259.70 |
| 43 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 7,885.74 | £0 | £ - |
| 44 | Metalwork repairs to deck bracing | Railway Possession |  |  | £0.00 | 1.3875 | £142.85 | £142.85 | £ - | £ - | £130,346 | £ 35,502.55 |
| 45 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 46 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 47 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 3.5625 | £348.25 | £348.25 | £ - | £ - | £37,340 | £ 9,307.29 |
| 48 |  |  |  |  | £0.00 | 2.1 | £201.70 | £201.70 | £ - | £ - | £0 | £ - |
| 49 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 50 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 3,205.91 | £0 | £ - |
| 51 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 6,225.08 | £0 | £ - |
| 52 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £639.05 | £639.05 | £ - | £ - | £21,663 | £ 4,657.80 |
| 53 | Access/ Walkways/ Gantries | Railway Possession |  |  | £0.00 | 3 | £255.75 | £255.75 | £ - | £ - | £87,182 | £ 18,199.18 |
| 54 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 55 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 56 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 2,684.90 | £0 | £ - |
| 57 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 2,606.70 | £0 | £ - |
| 58 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 5,061.56 | £0 | £ - |
| 59 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £1,645.73 | £1,645.73 | £ 14,054.42 | £ 2,457.07 | £148,132 | £ 25,897.27 |
| 60 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 2,385.50 | £0 | £ - |
| 61 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 4,632.04 | £0 | £ - |
| 62 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £477.40 | £477.40 | £ - | £ - | £725,564 | £ 116,082.821 |
| 62 | Metal work repair to weathering steel beams | Railway Possession |  |  | £0.00 | 25.0875 | £1,642.90 | £1,642.90 |
| 62 | Concrete Repairs to reinforced concrete slab | Railway Possession |  |  | £0.00 | 28.125 | £1,841.82 | £1,841.82 |
| 63 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 64 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 65 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 66 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 67 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,939.631 | £0 | £ - |
| 68 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,883.136 | £0 | £ - |
| 69 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,828.288 | £0 | £ - |
| 70 | Footway surfacing | Footway Closure | 10 |  | £0.00 | 0.58835 | £29.29 | £29.29 | £ 28,108.85 | £ 3,550.074 | £17,601 | £ 2,222.928 |
| 71 | Replace Handrail/ Parapets/ Safety Fences | Lane Closure - Night | 1 |  | £0.00 | 14.15 | £678.34 | £678.34 | £ 28,108.85 | £ 3,446.673 | £60,536 | £ 7,422.824 |
| 72 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £336.48 | £336.48 | £ 14,054.42 | £ 1,673.142 | £21,663 | £ 2,578.913 |
| 73 | Renew waterproofing | Contraflow |  |  | £0.00 | 6.2 | £275.52 | £275.52 | £ 14,054.42 | £ 1,624.410 | £300,980 | £ 34,787.256 |
| 73 | Replace superstructure Drainage | Lane Closures | 10 |  | £0.00 | 0.85 | £37.77 | £37.77 |
| 74 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,271.71 | £0 | £ - |
| 75 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,231.09 | £0 | £ - |
| 76 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 4,303.57 | £0 | £ - |
| 77 | Access/ Walkways/ Gantries | Railway Possession |  |  | £0.00 | 3 | £166.48 | £166.48 | £ 14,054.42 | £ 2,099.30 | £183,806 | £ 27,455.00 |
| 77 | Carriageway Surfacing | Lane Closures |  |  | £0.00 | 3.51165 | £194.87 | £194.87 |
| 78 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 2,048.10 | £0 | £ - |
| 79 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 3.5625 | £184.89 | £184.89 | £ 14,054.42 | £ 1,998.15 | £37,340 | £ 5,441.41 |
| 80 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,949.41 | £0 | £ - |
| 81 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 3,803.73 | £0 | £ - |
| 82 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £0.00 | £0.00 | £ 14,054.42 | £ 1,855.48 | £21,663 | £ 2,931.46 |
| 83 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,810.22 | £0 | £ - |
| 84 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 3,532.14 | £0 | £ - |
| 85 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £0.00 | £0.00 | £ 14,054.42 | £ 1,723.00 | £148,132 | £ 18,614.25 |
| 86 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,680.97 | £0 | £ - |
| 87 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,639.97 | £0 | £ - |
| 88 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,599.97 | £0 | £ - |
| 89 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 3,121.90 | £0 | £ - |
| 90 | Metalwork repairs to deck bracing | Railway Possession |  |  | £0.00 | 1.3875 | £0.00 | £0.00 | £ 14,054.42 | £ 1,522.88 | £130,346 | £ 14,476.83 |
| 91 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 28,108.85 | £ 2,971.47 | £0 | £ - |
| 92 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £0.00 | £0.00 | £ 28,108.85 | £ 2,898.99 | £21,663 | £ 2,290.05 |
| 93 | Metal work repair to weathering steel beams | Railway Possession |  |  | £0.00 | 25.0875 | £0.00 | £0.00 | £ - | £ - | £474,344 | £ 47,728.05 |
| 93 | Concrete Repairs to reinforced concrete slab | Railway Possession |  |  | £0.00 | 28.125 | £0.00 | £0.00 |
| 94 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 95 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 96 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 97 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ - | £ - | £0 | £ - |
| 98 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,249.90 | £0 | £ - |
| 99 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,219.41 | £0 | £ - |
| 100 |  |  |  |  | £0.00 |  | £0.00 | £0.00 | £ 14,054.42 | £ 1,189.67 | £0 | £ - |

| **Planned Preventive** | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Repair / Maintenance** | **Traffic Management** | **Quantity** | **Total tCO2 from traffic management** | **Total discounted cost of CO2 emissions from TM** | **tCO2 emitted from maintenance** | **Discounted cost of CO2 emitted during maintenance** | **TOTAL Discounted Price of Carbon** | **Traffic Delay Costs** | **Discounted Traffic Delay Cost** | **Scheme Costs** | **Discounted Scheme Cost** |
| 0 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - |  | £0.00 |
| 1 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ 28,108.85 | £ 27,158.31 | £0 | £0.00 |
| 2 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ 28,108.85 | £ 26,239.91 | £0 | £0.00 |
| 3 | Replace Expansion Joints | Road Closure - Night | 3 | 9.14 | £702.14 | 7.29 | £559.22 | £ 1,261.35 | £ - | £ - | £130,196 | £117,429.18 |
| 3 | Replace Substructure Drainage | Railway Possession |  |  | £0.00 | 0.85 | £65.20 | £ 65.20 |
| 3 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 1.9 | £145.75 | £ 145.75 |
| 3 | Concrete repairs to abutments | Railway Possession |  |  | £0.00 | 12.42 | £952.74 | £ 952.74 |
| 3 | Substructure drainage maintenance | Railway Possession |  |  | £0.00 | 0.17 | £13.04 | £ 13.04 |
| 3 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £13.04 | £ 13.04 |
| 4 |  |  |  |  | £0.00 |  | £0.00 | £ - |  |  | £0 | £0.00 |
| 5 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ 14,054.42 | £ 11,833.45 | £0 | £0.00 |
| 6 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £1,654.42 | £ 1,654.42 | £ - | £ - | £148,524 | £120,824.45 |
| 6 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £12.32 | £ 12.32 |
| 7 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 8 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 9 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £11.62 | £ 11.62 | £ - | £ - | £457 | £335.22 |
| 10 | Footway surfacing | Footway Closure |  |  | £0.00 | 0.11767 | £7.88 | £ 7.88 | £ - | £ - | £1,700 | £1,205.44 |
| 11 | Replace Expansion Joints | Road Closure - Night | 3 | 7.46 | £518.34 | 7.29 | £515.68 | £ 1,034.02 | £ - | £ - | £21,663 | £14,837.92 |
| 12 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £12.61 | £ 12.61 | £ - | £ - | £457 | £302.35 |
| 13 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 14 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 15 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £14.04 | £ 14.04 | £ - | £ - | £25,456 | £15,194.71 |
| 15 | Repair Parapet Handrail/ Parapets/ Safety Fences | Footway Closure |  |  | £0.00 | 3.74 | £308.90 | £ 308.90 |
| 16 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 17 | Carriageway repairs | Lane Closures | 1 | 0.92 | £78.33 | 0.70233 | £61.02 | £ 139.35 | £ - | £ - | £11,282 | £6,286.37 |
| 18 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £15.07 | £ 15.07 | £ - | £ - | £457 | £245.96 |
| 19 | Replace Expansion Joints | Road Closure - Night | 3 | 4.50 | £400.95 | 7.29 | £657.81 | £ 1,058.76 | £ - | £ - | £62,764 | £32,646.94 |
| 19 | Access/ Walkways/ Gantries | Railway Possession |  |  | £0.00 | 0.6 | £54.14 | £ 54.14 |
| 20 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 1.9 | £174.03 | £ 174.03 | £ - | £ - | £13,964 | £7,017.79 |
| 21 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £15.77 | £ 15.77 | £ - | £ - | £457 | £221.84 |
| 22 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 23 | Footway surfacing | Footway Closure |  |  | £0.00 | 0.11767 | £11.12 | £ 11.12 | £ - | £ - | £1,700 | £770.76 |
| 24 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £16.18 | £ 16.18 | £ - | £ - | £457 | £200.09 |
| 25 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 26 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 27 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £16.36 | £ 16.36 | £ - | £ - | £21,854 | £8,632.78 |
| 27 | Replace Expansion Joints | Road Closure - Night | 3 | 2.78 | £266.13 | 7.29 | £701.70 | £ 967.83 |
| 28 | Renew waterproofing | Contraflow |  |  | £0.00 | 6.2 | £597.36 | £ 597.36 | £ - | £ - | £455,972 | £174,023.52 |
| 28 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £2,199.16 | £ 2,199.16 |
| 28 | Metalwork repairs to deck bracing | Railway Possession |  |  | £0.00 | 0.74 | £71.30 | £ 71.30 |
| 29 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 30 | Carriageway repairs | Lane Closures | 1 | 0.45 | £43.05 | 0.70233 | £67.56 | £ 110.61 | £ - | £ - | £11,474 | £4,087.78 |
| 30 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £16.35 | £ 16.35 |
| 31 | Repair Parapet Handrail/ Parapets/ Safety Fences | Footway Closure |  |  | £0.00 | 3.74 | £417.24 | £ 417.24 | £ - | £ - | £25,141 | £10,056.13 |
| 32 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 33 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £19.02 | £ 19.02 | £ - |  | £457 | £172.25 |
| 34 | Access/ Walkways/ Gantries | Railway Possession |  |  | £0.00 | 0.6 | £67.13 | £ 67.13 | £ - | £ - | £41,101 | £15,044.76 |
| 35 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £814.92 | £ 814.92 | £ - | £ - | £21,663 | £7,698.64 |
| 36 | Footway surfacing | Footway Closure |  |  | £0.00 | 0.11767 | £13.13 | £ 13.13 | £ - | £ - | £2,016 | £695.47 |
| 36 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £18.97 | £ 18.97 |
| 37 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 1.9 | £211.54 | £ 211.54 | £ - | £ - | £13,964 | £4,677.67 |
| 38 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 39 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £18.80 | £ 18.80 | £ - | £ - | £457 | £144.26 |
| 40 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 41 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 42 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £18.10 | £ 18.10 | £ - | £ - | £457 | £132.02 |
| 43 | Carriageway repairs | Lane Closures | 1 |  | £0.00 | 0.70233 | £73.55 | £ 73.55 | £ - | £ - | £31,740 | £8,904.37 |
| 43 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £763.41 | £ 763.41 |
| 44 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 45 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £457 | £120.82 |
| 46 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £16.91 | £ 16.91 | £ - | £ - | £0 | £0.00 |
| 47 | Repair Parapet Handrail/ Parapets/ Safety Fences | Footway Closure |  |  | £0.00 | 3.74 | £365.60 | £ 365.60 | £ - | £ - | £25,141 | £6,266.65 |
| 48 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £16.33 | £ 16.33 | £ - | £ - | £457 | £110.56 |
| 49 | Footway surfacing | Footway Closure |  |  | £0.00 | 0.11767 | £11.10 | £ 11.10 | £ - | £ - | £42,801 | £10,056.17 |
| 49 | Access/ Walkways/ Gantries | Railway Possession |  |  | £0.00 | 0.6 | £56.62 | £ 56.62 |
| 50 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £2,115.68 | £ 2,115.68 | £ - | £ - | £148,132 | £33,790.07 |
| 51 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £657.13 | £ 657.13 | £ - | £ - | £22,082 | £4,890.34 |
| 51 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £15.32 | £ 15.32 |
| 51 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £15.32 | £ 15.32 |
| 52 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 53 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 54 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £14.09 | £ 14.09 | £ - | £ - | £14,421 | £2,922.66 |
| 54 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 1.9 | £157.51 | £ 157.51 |
| 55 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 56 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £13.33 | £ 13.33 | £ - | £ - | £11,509 | £2,198.73 |
| 56 | Carriageway repairs | Lane Closures | 1 |  | £0.00 | 0.70233 | £55.06 | £ 55.06 |
| 57 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £12.96 | £ 12.96 | £ - | £ - | £457 | £84.74 |
| 58 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 59 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £525.63 | £ 525.63 | £ - | £ - | £69,132 | £12,085.93 |
| 59 | Metalwork repairs to deck bracing | Railway Possession |  |  | £0.00 | 0.74 | £53.36 | £ 53.36 |
| 60 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £11.92 | £ 11.92 | £ - | £ - | £457 | £77.55 |
| 61 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £11.52 | £ 11.52 | £ - | £ - | £227 | £37.49 |
| 62 | Footway surfacing | Footway Closure |  |  | £0.00 | 0.11767 | £7.71 | £ 7.71 | £ - | £ - | £1,700 | £272.04 |
| 63 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £461.36 | £ 461.36 | £ - | £ - | £25,456 | £3,954.14 |
| 63 | Repair Parapet Handrail/ Parapets/ Safety Fences | Footway Closure |  |  | £0.00 | 3.74 | £236.69 | £ 236.69 |
| 63 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £10.76 | £ 10.76 |
| 64 | Access/ Walkways/ Gantries | Railway Possession |  |  | £0.00 | 0.6 | £36.69 | £ 36.69 | £ - | £ - | £41,101 | £6,198.24 |
| 65 | Renew waterproofing | Contraflow | 10 |  | £0.00 | 6.2 | £366.42 | £ 366.42 | £ - | £ - | £295,983 | £43,335.78 |
| 66 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £9.71 | £ 9.71 | £ - | £ - | £684 | £97.28 |
| 66 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £9.71 | £ 9.71 |
| 67 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £402.30 | £ 402.30 | £ - | £ - | £313,050 | £43,203.55 |
| 67 | Metalwork repairs to weathering steel beams | Railway Possession |  |  | £0.00 | 13.38 | £738.38 | £ 738.38 |
| 68 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 69 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £8.76 | £ 8.76 | £ - | £ - | £11,474 | £1,492.55 |
| 69 | Carriageway repairs | Lane Closures | 1 |  | £0.00 | 0.70233 | £36.19 | £ 36.19 |
| 70 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £8.46 | £ 8.46 | £ - | £ - | £39,186 | £4,949.14 |
| 70 | Retaining wall repairs |  |  |  | £0.00 | 13.74 | £684.07 | £ 684.07 |
| 71 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £8.15 | £ 8.15 | £ - | £ - | £14,004 | £1,717.20 |
| 71 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 1.9 | £91.08 | £ 91.08 |
| 72 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £7.85 | £ 7.85 | £ - | £ - | £148,524 | £17,681.40 |
| 72 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £1,053.53 | £ 1,053.53 |
| 73 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 74 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 75 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £7.00 | £ 7.00 | £ - | £ - | £23,366 | £2,545.62 |
| 75 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £300.21 | £ 300.21 |
| 75 | Footway surfacing | Footway Closure |  |  | £0.00 | 0.11767 | £4.85 | £ 4.85 |
| 76 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £9.75 | £ 9.75 | £ - | £ - | £227 | £34.83 |
| 77 | Concrete repairs to abutments | Railway Possession |  |  | £0.00 | 12.42 | £689.23 | £ 689.23 | £ - | £ - | £81,732 | £12,208.23 |
| 78 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £9.12 | £ 9.12 | £ - | £ - | £457 | £66.58 |
| 79 | Repair Parapet Handrail/ Parapets/ Safety Fences | Footway Closure |  |  | £0.00 | 3.74 | £194.10 | £ 194.10 | £ - | £ - | £66,242 | £9,417.77 |
| 79 | Access/ Walkways/ Gantries | Railway Possession |  |  | £0.00 | 0.6 | £31.14 | £ 31.14 |
| 80 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 81 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - | £ - | £ - | £684 | £92.61 |
| 81 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - |
| 82 | Carriageway repairs | Lane Closures | 1 |  | £0.00 | 0.70233 | £0.00 | £ - | £ - | £ - | £11,282 | £1,489.46 |
| 83 | Replace Expansion Joints | Road Closure - Night |  |  | £0.00 | 7.29 | £0.00 | £ - | £ - | £ - | £21,663 | £2,790.20 |
| 84 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - | £ - | £ - | £457 | £57.41 |
| 85 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 86 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - | £ - | £ - | £227 | £27.21 |
| 87 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - | £ - | £ - | £457 | £53.31 |
| 88 | Footway surfacing | Footway Closure |  |  | £0.00 | 0.11767 | £0.00 | £ - | £ - | £ - | £15,664 | £1,783.24 |
| 88 | Concrete repairs to bearing plinth / shelf | Railway Possession |  |  | £0.00 | 1.9 | £0.00 | £ - |
| 89 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 90 | Metalwork repairs to deck bracing | Railway Possession |  |  | £0.00 | 0.74 | £0.00 | £ - | £ - | £ - | £59,447 | £6,441.48 |
| 90 | Renew waterproofing | Contraflow |  |  | £0.00 | 6.2 | £0.00 | £ - |
| 90 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - |
| 91 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - | £ - | £ - | £21,890 | £2,314.10 |
| 91 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £0.00 | £ - |
| 92 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 93 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - | £ - | £ - | £457 | £45.97 |
| 94 | Access/ Walkways/ Gantries |  |  |  | £0.00 | 0.6 | £0.00 | £ - | £ - | £ - | £167,154 | £16,408.64 |
| 94 | Replace Bearings | Railway Possession |  |  | £0.00 | 22.825 | £0.00 | £ - |
| 95 | Repair Parapet Handrail/ Parapets/ Safety Fences | Footway Closure |  |  | £0.00 | 3.74 | £0.00 | £ - | £ - | £ - | £35,780 | £3,426.68 |
| 95 | Carriageway repairs | Lane Closures | 1 |  | £0.00 | 0.70233 | £0.00 | £ - |
| 96 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - |  |  | £684 | £63.94 |
| 96 | Substructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - |
| 97 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 98 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |
| 99 | Superstructure drainage maintenance |  |  |  | £0.00 | 0.17 | £0.00 | £ - | £ - | £ - | £21,854 | £1,896.17 |
| 99 | Replace Expansion Joints | Road Closure - Night | 3 |  | £0.00 | 7.29 | £0.00 | £ - |
| 100 |  |  |  |  | £0.00 |  | £0.00 | £ - | £ - | £ - | £0 | £0.00 |

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