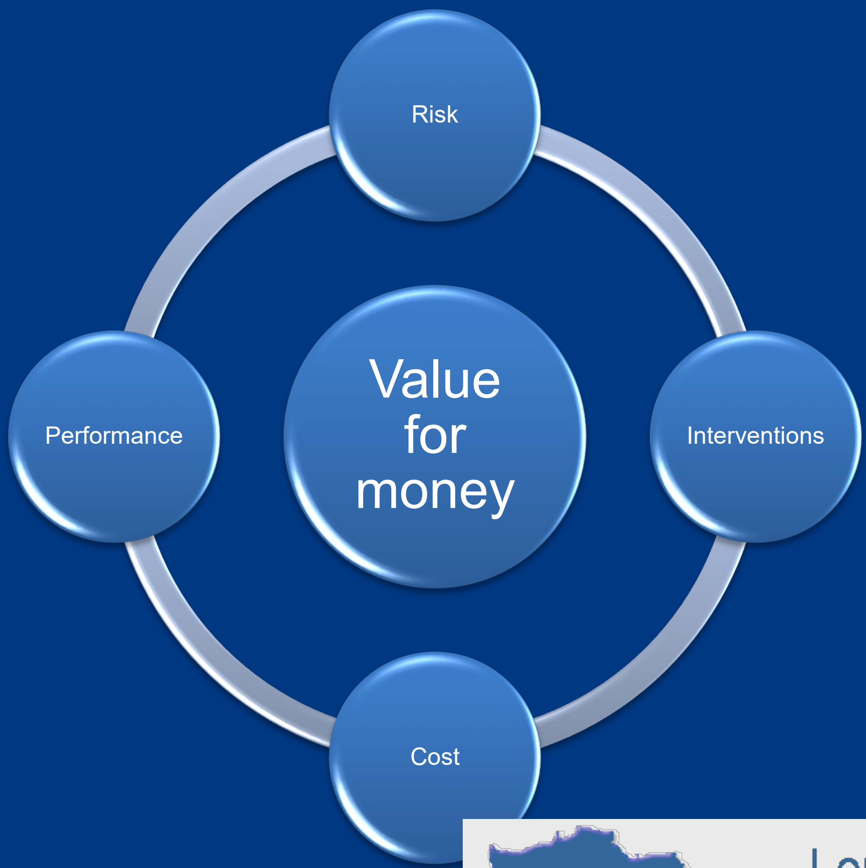
LoBEG Good Practice Guide

Risk-based Prioritisation & Value for Money

Objective Risk-Based Prioritisation of Planned Maintenance Work for the achievement of Value for Money.

Version 1.0

November 2018



London Bridges Engineering Group

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Glossary

Asset[1]	Physical highway infrastructure and other items that have a distinct value to a highway authority, e.g. carriageway, footway, structures, tunnels, lighting, etc.
Asset Lifecycle[2]	Time interval that commences with the identification of the need for the creation of an asset and terminates with the decommissioning of the asset or any associated liabilities.
Control Factor	The effect a maintenance or work activity is having on mitigating or eliminating the risk posed by the event hazard.
Do Minimum[3]	This option will address the safety risks only and will not consider any preventative maintenance.
Do Something[3]	The Do Something options typically focus on mitigating some or all of the risks identified for the scheme whilst, at the same time, minimising Whole Life Costs (WLCs). The resultant action will extend the serviceable life of the asset by (i) slowing down the rate of deterioration, or (ii) satisfying safety/performance targets, or (iii) minimising network disruption.
Essential Works [3]	Work required to maintain safety standards to ensure the asset does not become unsafe.
Financial Indicator[3]	A ratio that is a function of Whole Life Costs and scheme costs of competing options; it provides a basis for comparing the financial benefits offered by alternative schemes and their options.
Fit for Purpose[2]	When an asset is managed in such a way that it remains available to the traffic permitted for a route.
Floodplain[4]	An area that would naturally be affected by flooding if a river rises above its banks, or by high tides and stormy seas flooding in coastal areas.
Lifecycle Plan[2]	A considered strategy for managing an asset, or group of similar assets, from construction to disposal. A lifecycle plan should give due consideration to minimising costs and providing the required performance.
Maintenance[2]	Activities and operations undertaken to manage and maintain an asset, e.g. inspection, assessment, renewal, upgrade, etc.
Performance Measure[2]	A measure or indicator that reflects the condition and/or performance of an asset.
Planned/Programmed Maintenance[2]	Scheduled essential, preventative or upgrading works.

Preferred Option[3]	The option selected for implementation.
Preventative Works[3]	Maintenance activities that are not safety related but are justified on financial grounds, as they provide the best whole life value solution. Timely and appropriately targeted preventative works should reduce the potential of more costly works in the future.
Prioritisation	See 'Value Management'.
Prioritisation Criteria[2]	The criteria considered during the Value Management process to prioritise needs, also see 'Value Criterion'.
Regular Maintenance[2]	Covers inspections, structural assessments, routine maintenance and management of substandard structures.
Residual Risk[3]	The value of the Risk Rating Benchmark once the risk has been mitigated for each element.
Risk Mitigation[3]	The level of risk reduction against the Total Risk Rating Benchmark for a proposed scheme.
Risk Rating Benchmark[3]	The sum of the weighted Value Criteria Risk Scores, calculated for each element.
Risk Score[3]	The score or rating assigned to a specific Value Criterion based on an assessment of the likelihood and consequence of the event hazard.
Risk[3]	An event or hazard that has the potential to hinder the achievement of business objectives.
Safe for Use[2]	When an asset is managed in such a way that it does not pose a risk to public safety.
Scheme	An elaborate and systematic plan of action undertaken to maintain/enhance an asset at safe and/or serviceable condition.
Structural Assessment[2]	A process of confirming the adequacy of a structure to support specified loads and determining appropriate remedial actions if necessary. Assessment is carried out in accordance with national standards and generally involves detailed numerical calculations.
Upgrading[3]	Work resulting from changes in and/or non-compliance with requirements (e.g. changes in design/assessment standards, etc.).
Value Criterion[3]	A measure or principle that is relevant to the delivery of business objectives, for example, safety, functionality, environment and financial. An agreed set of Value Criteria is used in Value Management to rate competing projects.
Value Engineering[2]	Development of optimal solutions for prioritised maintenance using option appraisal, whole life costing, scheme development, and synergies with other schemes.
Value for Money[1]	The optimum combination of whole-life cost and quality of an asset to meet the users' requirements.

Value Management[3]	A systematic approach for identifying, assessing, prioritising and optimising a portfolio of projects, based on an agreed set of Value Criteria, which maximises contribution to the business objectives for a defined budget.
Value[1]	Value is the benefit to the principal stakeholder, that is, the project is worth doing and can be quantified in business terms ensuring that the right choices are made about obtaining the optimum combination of benefit, cost and risk.
Whole Life Cost[1]	The cost of all items/activities that need to be considered in a whole life costing analysis, such as the costs of acquiring (includes design and construction costs), operating and maintaining an asset over its whole life through to its eventual disposal.
Whole Life Costing[1]	An economic assessment considering all projected significant and relevant cost flows over a period of analysis expressed in monetary value. The projected costs are those needed to achieve defined levels of performance, including reliability, safety and availability.
Whole Life Value[1]	The benefits risks and costs associated with an infrastructure asset over its whole-life taking account of the interests of all stakeholders affected by its construction and existence and its wider economic, social and environmental impact. There will be trade-offs between the various short-term project constraints (such as time, costs and quality) and the conflicts in stakeholders' longer-term interests and objectives.

Abbreviations

AADT	Annual Average Daily Traffic
ACC	Assessed Containment Capacity
ADEPT	Association of Directors of Environment, Economy, Planning & Transport
ALL	Assessment Live Load
BCI	Bridge Condition Index
BPRN	Borough Principal Road Network
CF	Control Factor
CSS	County Surveyors Society (currently known as **ADEPT**)
EA	Enviroment Agency
ECS	Element Condition Score
EC_S	Environment Consequence Score
$EC_{S\text{-}CON}$	Environment Consequence Score for Condition Related Defects
$EC_{S\text{-}OTHER}$	Environment Consequence Score for Defects other than Condition
ER_S	Environment Risk Score
FC_S	Functionality Consequence Score
FR_S	Functionality Risk Score
GPG	Good Practice Guide
HA	Highways Agency (currently known as Highways England)
LIP	Local Improvement Plan
LoBEG	London Bridges Engineering Group
$L_{S\text{-}BCI\text{-}Av}$	BCI Average Likelihood Score
$L_{S\text{-}BCI\text{-}Crit}$	BCI Critical Likelihood Score
$L_{S\text{-}FLOOD}$	Flooding Likelihood Score
$L_{S\text{-}SC}$	Structure Condition Likelihood Score
$L_{S\text{-}SCOUR}$	Scour Likelihood Score
$L_{S\text{-}SUBPAR}$	Substandard Parapets Likelihood Score

$L_{S\text{-}SUBSTR}$	Substandard Structures Likelihood Score
$L_{S\text{-}SUPPORTS}$	'At Risk' Supports Likelihood Score
LTP	Local Transport Plan
PMT_{MF}	Primary Material Type Modification Factor
Ps	Priority Score
Ps-cap	Capacity Priority Score
Ps-con	Condition Priority Score
RRB	Risk Rating Benchmark
SC_S	Safety Consequence Score
SR_S	Safety Risk Score
RR	Residual Risk
TAMP	Transport Asset Management Plan
TfL	Transport for London
TLRN	Transport for London Road Network
TRRB	Total Risk Rating Benchmark
TRR	Total Residual Risk
TS	Transport Scotland
VE	Value Engineering
VfM	Value for Money
VM	Value Management
VRS	Vehicle Restraint System
WCC	Westminster City Council
WLC	Whole Life Cost

1 Executive Summary

Highway structures form essential links in any highway network. A potential failure of any of these links could result in delays to the travelling public, deterioration of the environment and even injuries depending on the severity of the failure event.

The London Bridges Engineering Group (LoBEG) and Transport for London (TfL) have developed a risk-based approach to the prioritisation of planned maintenance projects. This method is appropriate for bridges and other structures and is used to implement a consistent, objective and transparent prioritisation approach.

It was developed in order to enable authorities to:

- Identify needs and provide justification for maintenance activities by formalising the assessment of benefits and risks.
- Allocate limited resources to schemes that are most in need.
- Enable consistent comparison of different needs between different assets.
- Maximise the benefits from appropriate utilisation of available funds.

The risk-based prioritisation methodology uses data, such as condition, primary materials, structure dimensions, annual average daily traffic, average speed of vehicles and diversion lengths with the aim of:

- Assessing the current Equivalent Annual Risk (EAR) of the structure.
- Formulating the scope of proposed works.
- Evaluating its EAR following the proposed maintenance works.
- Calculating the Value for Money (VfM) ratio of the proposed maintenance works.

This guide is split into the following sections:

- Maintenance Planning Process
- Risk Based Approach
- Value Criteria
- Identification of Needs
- Prioritisation and Value for Money

2 Introduction

2.1 General

This Good Practice Guide describes the methodology jointly developed by the London Bridges Engineering Group (LoBEG) and Transport for London (TfL) for the prioritisation of planned maintenance work.

This can be used to implement a consistent, objective and transparent prioritisation approach for all highway structures.

2.2 Purpose

The purpose of this guide is to provide a step-by-step guide to risk-based prioritisation of planned maintenance works for highway structures explaining how and when the methodology should be used.

This document supersedes LoBEG's Good Practice Guide: Phase 1 Maintenance Prioritisation[5].

2.3 The Need for and Benefits of Maintenance Prioritisation

Highway authorities have a duty to maintain the public highway[6]. The Code of Practice[2] interprets this as a duty to maintain the two essential functions of *safe for use* and *fit for purpose*. This duty is performed within an overall management context of limited maintenance budgets, increasing financial scrutiny and a need to demonstrate that maintenance requirements have been identified and prioritised in an objective manner that aligns with good practice and satisfies relevant safety and performance policies.

It is no longer acceptable to plan maintenance on an ad-hoc and subjective basis and it is clearly not possible to implement all maintenance projects simultaneously due to budgetary and other constraints. Maintenance prioritisation is increasingly used to support structures engineers and managers to:

- Produce a prioritised (ranked) list of maintenance schemes that provides a fair basis for decision making and allocation of funds;
- Enables consistent comparison of differing needs, e.g. preventative vs. essential vs. upgrades, etc.;
- Provides justification for maintenance activities by formally assessing benefits and risks;
- Maximises benefits from appropriate utilisation of available funding.

2.4 Value for Money

Value for Money (VfM) is about achieving the maximum benefits possible with the available resources. It is about achieving the right local balance between economy, efficiency and effectiveness – the three pillars of VfM, also referred to as the 3Es – spending less, spending well and spending wisely:

- **Economy** – minimising the cost of resources ('doing things at a low price')
- **Efficiency** – performing tasks with reasonable effort ('doing things the right way')
- **Effectiveness** – the extent to which objectives are met ('doing the right things at the right time').

This means that VfM not only measures the cost of goods and services but also takes account of the mix of cost with quality, resource use, fitness for purpose and timeliness to judge whether or not, together, they constitute good value.

Local authorities are under constant pressure to maximise annual service returns, by making best use of available resources. Value management provides a structured platform to demonstrate the achievement of long-term strategic goals. Assets are evaluated against agreed needs and objectives, and are assessed on their relative importance and value.

2.5 Layout of the Good Practice Guide

The layout of the Good Practice Guide is summarised in Table 1.

Table 1: Layout of the Good Practice Guide

Section	Description
1. Executive Summary	A brief but comprehensive synopsis of this document.
2. Introduction	The current section that serves as a general overview of this document.
3. Maintenance Planning Process	Describes the role of prioritisation in the overall context of the maintenance planning process.
4. Risk Based Approach	Describes how a risk based methodology is utilised in maintenance prioritisation to support the objective and systematic prioritisation of works.
5. Value Criteria	Explains why value criteria are required and lists the agreed criteria that are used for scheme prioritisation.
6. Identification of Needs	A description of the tools available and the method used for identifying structures and elements of these structures that may be candidates for prioritisation.
7. Risk-based Prioritisation & Value for Money	Presents the risk-based prioritisation process. This includes a description of the data and information required to support the prioritisation process. Explains how the Value for Money ratio is calculated and how it is used in the wider context of Value Management.
8. References	Relevant documents referred to for the purpose of this study.

3 Maintenance Planning Process

3.1 Overview

Maintenance planning is a logical process by which:

- Information is systematically interrogated and maintenance needs identified;
- Needs are analysed in a formalised, repeatable and auditable manner; and
- Robust and defendable work plans are prepared.

As indicated in Figure 1 a fundamental component of a robust and defendable maintenance planning process is the identification and prioritisation of needs. This is also known as 'Value Management' (VM) and enables the available/expected funding to be appropriately targeted to areas which contribute to effective management of maintenance needs.

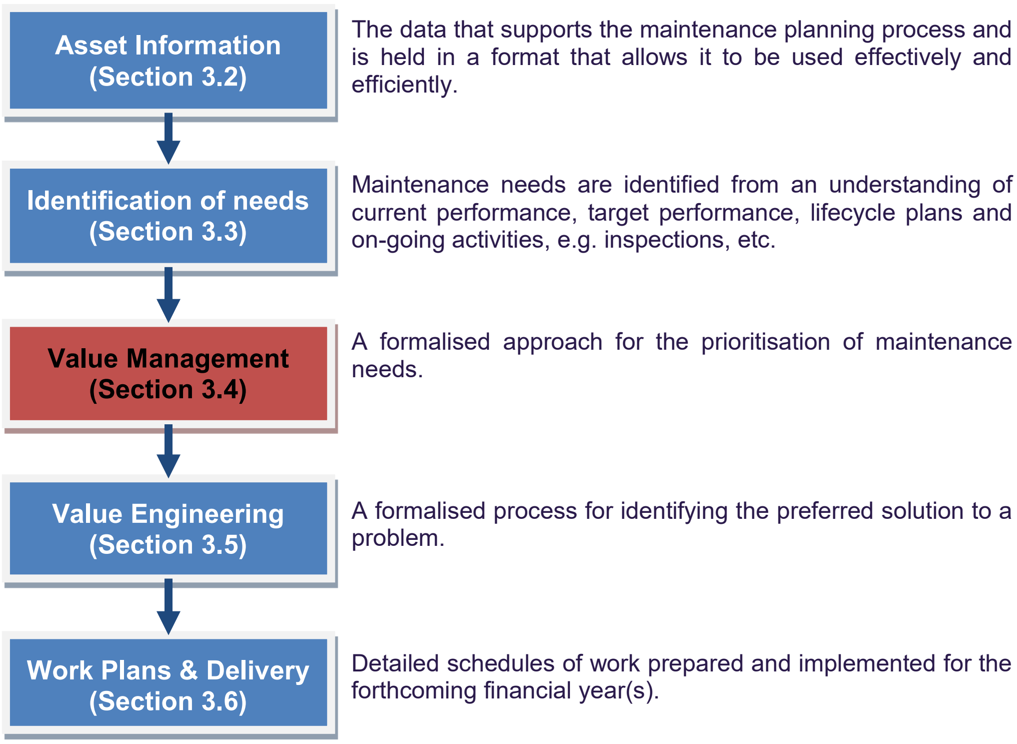


Figure 1: Maintenance Planning Process

The following sections provide a brief description of each key component of the Maintenance Planning Process (Figure 1) and describe the significance of Value Management in the overall process.

3.2 Asset Information

A key input to the Maintenance Planning Process is up-to-date and relevant information, including:

- Structure Identification Data (e.g. Structure name/reference, owner, managing agent, etc.)
- Inventory Data

- Inspection, Condition and Performance Data
- Structural Assessment and Restrictions Data
- Maintenance Data
- Cost Data
- Other Management Data

This enables the structures engineer/manager to determine the current performance of highway structures in a way that supports the identification of needs. The data should be recorded and stored in a format that is cost effective and reliable and that enables it to be readily captured, transferred, accessed and used.

3.3 Identification of Needs

All maintenance needs on highway structures and associated cost estimates should be identified and documented. These are then referred to as the Structures Workbank. This forms the foundation of the subsequent Value Management (VM) and Value Engineering (VE) component of the Maintenance Planning Process. Some of the key considerations for identifying maintenance needs include:

- Condition and Performance Data
- Lifecycle Plans
- Transport Asset Management Plan (TAMP)

Taking into account the above considerations, the Structures Workbank is formed which comprises all the maintenance work that is currently outstanding on the network, including the estimated costs for doing the work. This is then taken forward to the Value Management process where maintenance needs are appropriately prioritised.

The identification of needs is not a formal process. Proposed works schemes can be added to the workbank in a variety of ways. For example:

- By utilising the standard reports on Bridgestation.
- By building specific reports incorporating certain conditions that are relevant to the authority
- By customer surveys or complaints
- For authorities with a small number of structures, this could even be based on local knowledge or expertise.

LoBEG, aiming to assist authorities with the task of identifying needs, has developed the Structure Level Analysis (Tier 1) and Element Level Analysis (Tier 2) tools. These tools help to quickly create an initial list of structures (Tier 1) and elements of these structures (Tier 2) that may be added to the workbank as candidates for Prioritisation and Value for Money analysis (Tier 3).

3.4 Value Management

Value Management (VM) is a structured process that:

- Provides a means to clearly define objectives and scope in terms of the organisation’s and end user’s needs
- Supports decision-making based upon maximising value for money
- Enables more efficient delivery by employing fewer resources and using these resources to better effect
- Encourages innovation that is well-aligned to the organisation’s goals
- Facilitates optimal balance between short-term investment and long-term operating expenditure
- Provides a means of measuring and auditing value

VM is essential as it provides a formalised approach which allows comparison of risks and benefits associated with different scheme options. This includes quantifying the risks of not undertaking (or deferring) works as well as quantifying the benefits of undertaking a scheme. 'Hard' issues such as condition and capacity are considered along with 'soft' issues such as social impact. The process should be relatively simple and transparent to allow engineers to quickly calculate and compare priorities of schemes.

A VM regime should set out:

- ***When Value Management is required?*** – different activities will require different frequencies, e.g. automatic prioritisation based on condition can be done on a continuous basis, whereas more subjective criteria e.g. local importance may require regular workshops to facilitate their assessment.
- ***What should be assessed?*** – the value criteria required and what constitutes them.
- ***Who should be involved in reviews/workshops?***

Management of Highway Structures: A Code of Practice[2] recommends a risk-based approach to Value Management which uses at least the following prioritisation criteria:

- ***Safety and functionality*** – using the asset inventory, the maintenance needs should be prioritised in terms of both the condition (likelihood of element failure) and the routes supported/crossed, location, traffic flows (consequence of failure) to determine which needs represent the highest risk to public safety.
- ***Benefits and dis-benefits*** – This criterion should attempt to quantify the associated benefits and dis-benefits associated with undertaking maintenance and not undertaking maintenance.
- ***Socio-economic and environmental*** – this covers the 'soft' issues which cannot be easily determined and automated, such as impact on local communities and environment, sustainability, alignment with policies.

3.5 Value Engineering

The purpose of Value Engineering is to develop and optimise maintenance solutions by reducing waste and unnecessary aspects of a treatment in design and construction, or minimise the need for further maintenance. Value Engineering can be broken into two components – Option Appraisal and Scheme Development.

Option Appraisal involves choosing the most suitable treatment(s) for a need from a range of potential treatments. From the Value Management phase, a list of needs which require attention should have been identified. *Management of Highway Structures: A Code of Practice*[2] provides a summary of common maintenance techniques. Value Engineering should be done as early as possible so it can have the most possible influence and deliver better long-term savings. Value Engineering relies heavily on whole life costing to determine the best whole-life solution and to make trade-offs between initial cost and whole-life cost.

Scheme Development looks at the possibility, advantages and disadvantages of combining options into a scheme to minimise network disruption, contractor mobilisation costs and improve continuity of work. Options can be combined in three generic ways:

- ***Combine work items on the same structure*** – the objective here is to reduce the overall delay for maintenance by putting one larger user delay in place rather than several smaller user delays. This may have a large scheme cost as the contractor has to address several issues and more than one contractor may be required.
- ***Combine similar work types*** – the objective of this is to reduce costs by mobilising a single contractor to carry out a series of similar repairs on a network,

thereby reducing mobilisation costs and providing a steady work stream. This method may lead to more disruptions if a number of these schemes are carried out on a structure.

- ***Combine schemes across an area*** – this combines the first two methods to provide lower mobilisation costs, steady work streams and reduced overall user delays. However it can lead to programme extensions, site conflicts and a large network disruption during a shorter period when work is carried out.

3.6 Work Plans and Delivery

A Work Plan is drawn up to give a detailed programme of work. This should draw together the work proposed following the Value Management and Value Engineering stages as well as the work which does not require Value Management, i.e. routine maintenance, inspections, assessments.

Work scheduling is used to develop the programme and detail the year's maintenance work, including start/finish/milestone dates. It should aim to give a balanced programme of works, minimised disruption and give detailed costs.

Delivery includes the aspects of work remaining after Work Plans and schedules are completed: this includes H&S plans, environmental management plans, undertaking the work and on-site plans. Annual work plans should be reviewed to monitor delivery of work i.e. planned costs against actual costs and changes required to the planned works.

4 Risk Based Approach

4.1 General

Asset Management was first defined in the Framework for Highway Asset Management [9] as:

> ***A strategic approach that identifies the optimal allocation of resources for the management, operation, preservation and enhancement of the highway infrastructure to meet the needs of current and future customers.***

There is a growing movement to develop methodologies that support formal/advanced asset management techniques for highway structures. The publication of the Code of Practice[2] and of ISO 55000[10] has given further impetus to this.

An important component of Risk-Based Asset Management is categorisation of assets by level of risk which enables asset owners to objectively assess asset condition, evaluate maintenance and inspection programs, study operating protocols, and estimate the remaining life of assets – in relation to considering the likelihood and consequences of structural and/or other failure. This information is then used to modify and optimise inspection and maintenance programmes, audit procedures, operating limits, and safety information.

4.2 Why Use a Risk-Based Approach?

Until recently, the structural safety of most highway structures has been assured by two factors:

- Design, assessment and maintenance in accordance with codes or rules incorporating empirical safety factors; and
- Regular inspections to provide assurance that no accidental damage or unanticipated deterioration has occurred.

Both inspection and maintenance strategies should take account of the risk of structural failure, i.e. both the probability of failure and its consequences have to be considered. Using traditional approaches to inspection and maintenance planning, risk tends only to be considered implicitly and is not assessed in an auditable manner.

The concept of risk takes into account, not only the probability of failure and/or deterioration, but also the consequences of failure and/or deterioration. These may encompass consequences in terms of lost profits, repair and re-justification costs, human casualties and environmental costs. A risk-based approach supports the objective identification and prioritisation of work by systematically assessing network issues, e.g. deteriorated condition, with respect to the risk they pose to the service. It also provides a basis for assessing the level of risk mitigation provided by proposed intervention options, and therefore, when assessed alongside costs, enables optimisation across a portfolio of candidate schemes. Optimisation therefore identifies the schemes that maximise risk reduction/mitigation for the given budget.

4.3 Risk Definition

Risk is defined, as the occurrence of a failure event or a hazard, which potentially could have a negative impact on the availability and operation of a structure.

The risk thresholds that are generally applied for assessing maintenance priorities have been derived from the HSE risk assessment methodology. Figure 2 illustrates the principles applied for risk categorisation.

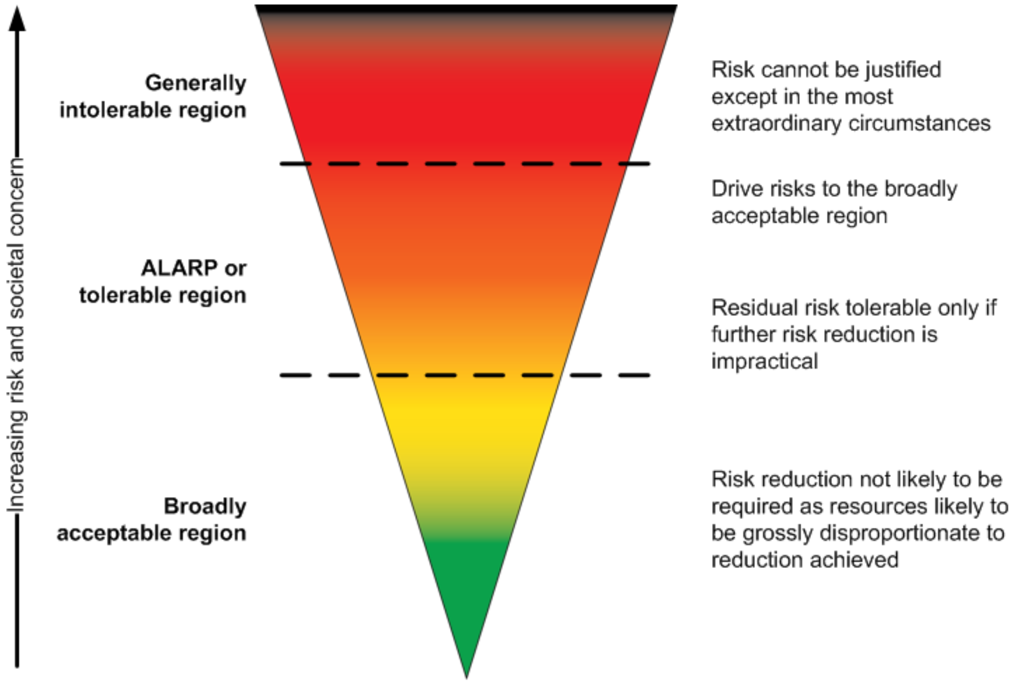


Figure 2: Categorisation of risk

Risk is expressed as a function of likelihood and consequence given the event/hazard has occurred:

Risk = f(likelihood of event/hazard, consequence of event/hazard)

A failure event is any incident where a structure will become unavailable or unsafe, and therefore prohibited to use. The most severe failure event is an unexpected collapse. Therefore, in order to quantify the current risk of the structure, the risk-based analysis assumes this worst-case scenario as the failure event and then proceeds to quantify the probability (Likelihood) and severity (Consequences) of that event.

5 Value Criteria

5.1 What are Value Criteria?

Value criteria are the criteria that will be used throughout the prioritisation process to measure the suitability and performance of the 'solutions' being considered and delivered. These criteria aid in appraising the level of achievement of each authority's business drivers, principles and objectives as set in their asset strategies.

There are a number of different criteria that are selected in this prioritisation process to represent the aforementioned values.

5.2 Deriving the Value Criteria

Identifying Value Criteria is fundamental to establishing an objective, transparent and efficient prioritisation process.

A literature review of the VM processes used by a number of organisations/local authorities identified some of the Value Criteria that are commonly used for appraising maintenance schemes.

Table 2 provides a list of the typical Value Criteria used, indicating the authority using each criterion together with corresponding definitions.

It is noted that this list should not be regarded as a comprehensive list.

Table 2: List of Value Criteria Typically Used by Authorities

		Authority			
Value Criteria	**Definitions**	**HA**[11]	**TS**[12]	**TfL**[3]	**WCC**[13]
Safety	The overall effects on the end user, including fatalities and injuries that would be caused by a failure. [2]	✓	✓	✓	✓
Functionality	The impact of a loss or reduction in service. This may be considered at route, structure or component level. [2]	✓	✓	✓	✓
Sustainability	Whether the work meets the needs of the present without compromising the ability of future generations to meet their own needs. [2]	✓	✓		
Environment	Environmental impacts, such as pollution caused through traffic delay, the sensitivity of the route/area, etc. [2]	✓	✓	✓	✓
Financial	Increased/decreased cost due to bringing forward or delaying work. [2]	✓	✓	✓	✓
Customer Perception	Customer satisfaction relating to the level and quality of the services provided.			✓*	✓

*Customer perception is included in TfL's 'functionality' Criteria, even though it is shown separately in Table 2 above.

These criteria were considered by LoBEG and TfL to inform the development of the risk-based prioritisation process presented in Section 7. The agreed Value Criteria are presented in Table 3 below. LoBEG considers ‘Safety’, ‘Functionality’, ‘Environment’ and ‘Financial’ to be the most relevant criteria when developing a Planned Maintenance programme.

The ‘Sustainability’ Value Criterion as it is currently defined and used by other organisations’ prioritisation systems appears to cover the principle of WLC and as such it was decided to capture this aspect as part of the ‘Financial’ considerations.

The ‘Customer Perception’ Value Criterion is not systematically captured by all authorities. Should it exist, it is considered that this should be factored into the prioritisation process using engineering judgement.

5.3 Agreed Value Criteria

Table 3 presents the list of agreed Value Criteria to be used when developing the Planned Maintenance Programme for highway structures along with their definitions and aspects they cover.

Table 3: List of Agreed Value Criteria

Value Criteria	Definitions	Aspects Covered
Safety	To ensure that structures are maintained in a safe condition without compromising public safety and perception.	***Substandard in service:*** • Deterioration • Load carrying capacity • Flood/impact/scour damage ***Substandard due to new requirements***: • New standards
Functionality	To ensure that the structures are fit for purpose and provide the necessary agreed operational capacities and smoothing traffic flows.	***Restricted Usage:*** • Lane, Weight and/or Traffic Speed Restrictions, M&E failure • Drainage system failure • Bus route availability • Non-motorised users route availability
Environment	To minimise environmental impact and to protect the aesthetics of the structures as necessary.	***Positive/negative impact:*** • Pollution due to traffic • CO_2 emissions • Watercourse pollution • Levels of noise/ dust/waste • Sustainable materials • Habitats • Heritage e.g. listed structures • Appearance of Structures
Financial	To ensure that Value for Money is delivered in terms of the overall risk mitigation, WLC and any financial constraints.	
Others	To ensure that aspects not referred to in other criteria are taken into consideration.	Others as appropriate, e.g. Political aspects, organisational objectives.

5.4 Using the Value Criteria

As mentioned in Section 4, the risk of a failure event is the metric that the prioritisation is based on. To ensure that the measure of risk is quantified on a common scale it has been agreed that currency will be the unit of risk that influences scheme priorities. This is referred to as the Annual Economic Risk (AER).

One or more intervention options are proposed through the prioritisation process and their impact on risk is evaluated for every one of the Value Criteria. The results of this evaluation are summed to give the total AER for a proposed scheme before and after of its implementation.

This is the Annual Economic Benefit of the proposed scheme:

$$AEB = AER_{Pre\ Implementation} - AER_{Post\ Implementation} \tag{1}$$

A description of the data and information required to support the VM process is presented in Section 6.

6 Identification of Needs

6.1 Overview

Like all methods and processes developed by LoBEG, this one is also based on the assumption that the asset data required will exist and it will be adequately accurate. Evaluating risk always has an element of subjectivity, but the more accurate the data, the more reasonable the results. The **Data Gap Report** tool in Bridgestation can be used to quickly identify missing data. All data is shown in a familiar spreadsheet format so it can be reviewed and modified with ease.

As this is primarily a prioritisation tool, it is reasonable to assume that an authority has clearly identified its maintenance needs. Understanding the importance of the identification of needs in Value Management, LoBEG has developed a set of tools to assist with this task. **Structure Level Analysis – Tier 1** identifies structures that may be good candidates for maintenance. **Element Level Analysis – Tier 2** identifies elements that may be considered in scope for a maintenance scheme. Figure 3 presents an overview of the tools used for identification of needs.

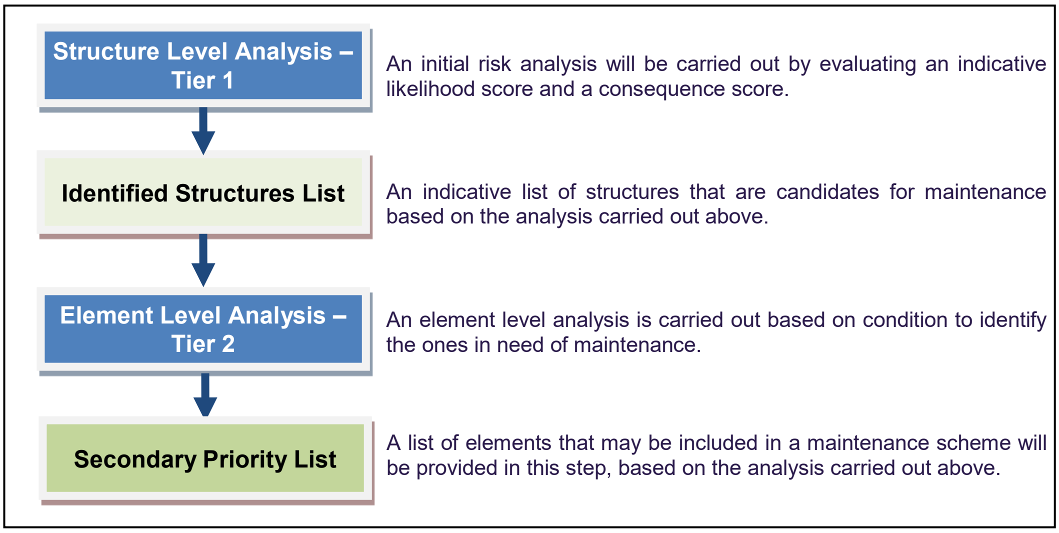


Figure 3: Identification of needs

The two Tiers cannot be used independently as Tier 2 relies on data generated using the Tier 1 analysis.

It is important to note that, if an authority has an alternative and well-established method for identification of needs, or even a good understanding of its assets, it is not necessary to use the tools described above. Once a workbank of structures for prioritisation is established the Prioritisation & Value for Money tool can be used to carry out the analysis.

6.2 Data Gap Report

The purpose of the Data Gap Report is to provide a quick and easy way to review all the necessary data for the different modules in Bridgestation and fill in any gaps that might exist. The report is set up in a familiar spreadsheet format where data for every structure is presented in a single line and can be filtered as required. A percentage of completeness of the data is shown for specific structures and when a structure with less than 100% is found, a quick examination of its line will reveal all the empty cells (data gaps).

The missing data can be added in the report and the structure record will be automatically updated. Structures with incomplete data (less than 100%) on the Basic Data, Identification of Needs tabs will not be considered in the relevant modules. In the Prioritisation and Value for Money module the user can add any structure and has the chance to fill in the missing data, without altering the permanent record of the structure.

6.3 Structure Level Analysis

6.3.1 Overview

The purpose of the Structure Level Analysis tool is to identify structures that may be considered for further analysis. This is achieved by assigning scores and factors based on a number of criteria that are relevant for each structure. These are presented in more detailed in Figure 3 below.

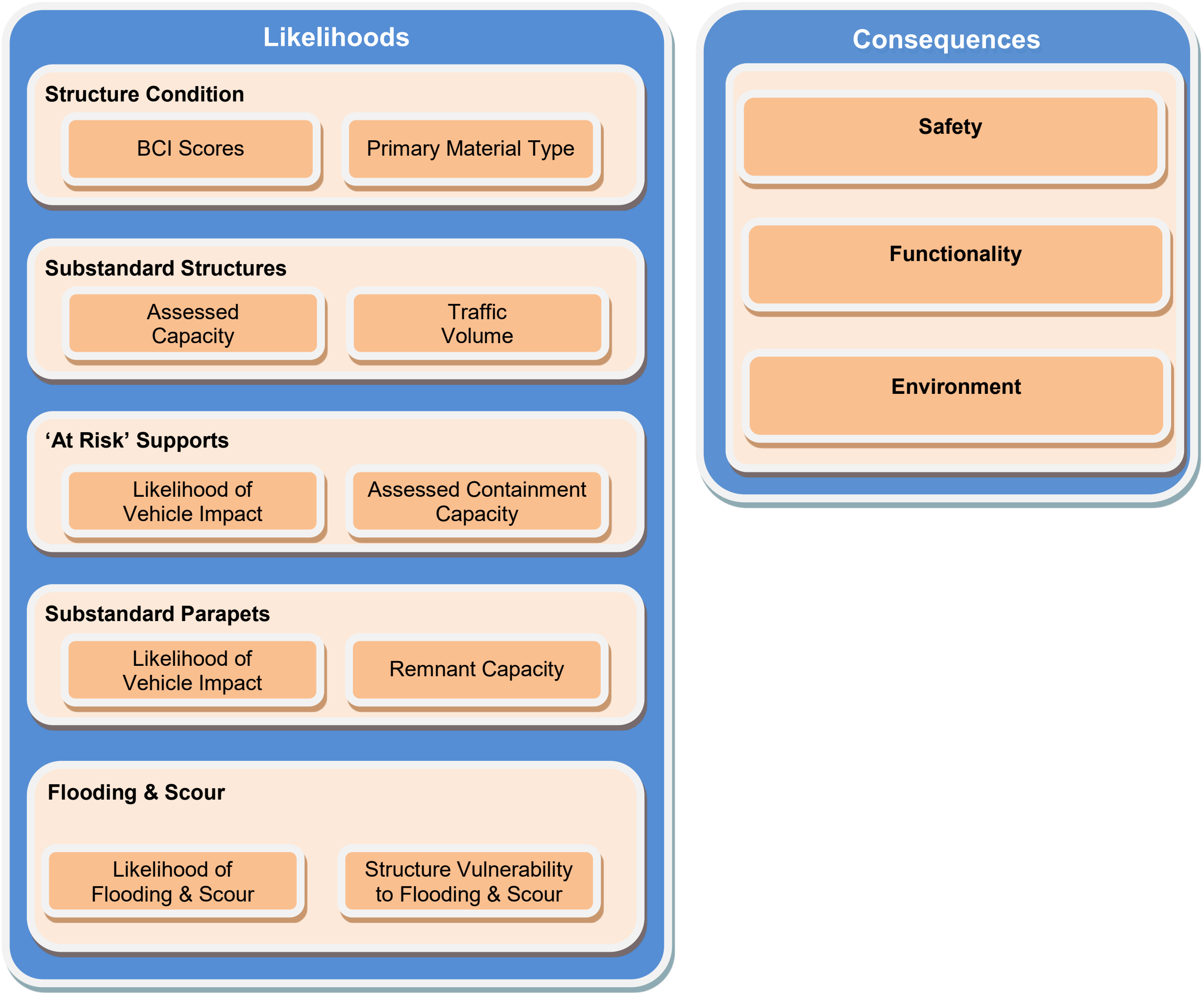


Figure 4: Criteria Used to Assess Risk in Tier 1

6.4 Element Level Analysis

6.4.1 Overview

Structures filtered through the Tier 1 analysis will be taken forward to the Tier 2 analysis, where element level analysis is undertaken and a secondary priority list of structures/elements is produced.

In the Tier 2 analysis the following criteria are considered:

- Element condition (severity and extent)
- Structure capacity
- Safety and functionality consequences (quantified in monetary terms), if a structure fails

Whilst Tier 2 provides analysis at element level, it does not take account of the residual effect failure of one element has on another. It is clear that the failure of waterproofing will have an adverse effect on the primary deck element, or a failed expansion joint could have residual effects on the deck or the bearings. Where it is thought there is a high risk of residual effect on other structural elements, this should be taken into account in Tier 3. Provision should be made in scheme options that generate the VfM score.

Note that the monetary values of consequences derived in the Tier 2 analysis are notional only for objective prioritisation – they are not intended to reflect real monetary consequences that an Authority may incur.

7 Risk-based prioritisation and Value for Money (VfM)

7.1 Overview

This section provides guidance on the prioritisation of an established workbank of proposed structures schemes. As mentioned in Section 4, the annual risk of a structure is evaluated based on the consequences of a failure event and the likelihood of this event occurring. For all structures the failure event is assumed to be the same: the unexpected collapse of the structure. The likelihood is estimated based on the condition, and the consequences are based on the nature of the structure, its' location, the traffic above and/or below it among other things.

The risk analysis and prioritisation of a structure, and the calculation of the VfM score are carried out using the Prioritisation & Value for Money method. This is an iterative, user-driven process that assists in quantifying the risk for each structure. Therefore, structures with the highest risk are the ones with the highest priority, and consequently a prioritised list of schemes is created based on available funds this gives the authority a clear view of its' short-term investment requirements.

The VfM score is obtained by looking at the relationship between the risk mitigated by each scheme (or the Risk Reduction of a scheme) and its cost. The risk mitigated by each scheme is weighted against the scheme cost and a VfM score is obtained, which is used as the final indicator for selecting the most appropriate scheme.

When calculating the VfM score, Risk Reduction is the difference between the current Discounted Risk of a structure and the Discounted Risk of that structure after performing an intervention option. Discounted Risk incorporates the use of Total Annual Risk in its calculation. Total Annual Risk is a function of likelihood multiplied by consequence in addition to identified risks.

The following sections describe the process of evaluating the Likelihood of Failure, as well as the Safety Consequences, Functionality Consequences, Environmental Consequences, and Financial/Other Consequences.

Bridge managers should note that the LoBEG Package Leader and TfL may require additional information on schemes to be submitted before the final allocation of funding on a particular scheme is approved. This information will typically comprise of those reports, test results, investigations, load assessments, surveys, presentations, etc. used to justify a particular scheme and the options considered when developing a particular scheme. This information may be required for audit purposes to evidence appropriate ‘checks and balances’ are in place to provide comfort that a particular scheme can be approved and taken forward to implementation.

7.2 Likelihood of Failure

7.2.1 State of Good Repair

Based on the Bridge Condition Indicators guidance document[1], the ***Bridge Condition Index (BCI)*** is the numerical value of a bridge condition on a scale of 100 (best condition) to 0 (worst condition). The ***average Bridge Condition Index (BCIav)*** is evaluated taking into account the condition of all structural elements in a bridge; whereas the ***critical Bridge Condition Index (BCIcr)*** is evaluated taking into account the condition of those elements deemed to be of very high importance to the bridge. Both the average and the critical Bridge Condition Indicators must be used in order to provide an accurate description of the condition of a structure as well as an authority's stock of structures.

LoBEG and TfL have sought to simplify the way the condition of individual and stocks of structures are indicated and reported in all their relevant performance reports, without moving away from the principles of the established Bridge Condition Indicators methodology. It was agreed that a single number, as a measure of condition, would achieve this. The following figure for the Stage of Good Repair (SoGR) has been defined:

$$SOGR = 0.6 \times BCI_{av} + 0.4 \times BCI_{cr} \quad (2)$$

7.2.2 Likelihood of failure due to condition (LF_{con})

Current British Standard *BS EN 1990:2002 +A1:2005 Eurocode – Basis of structural design* defines the failure probability (P_f) of a newly built structure that has a high consequence class (CC3) as:

$$\boldsymbol{P_f = 10^{-7}\ or\ 1\ in\ 10,000,000\ or\ \frac{1}{10,000,000}} \quad (3)$$

LoBEG and TfL are utilising the Bridge Condition Indicators method in order to assess the condition of a structure. The rate of deterioration will be different for every structure and it is a function of its' components, materials, usage, general environment and maintenance history among other factors. The condition scores (BCI_{av} and BCI_{cr}) represent a description of the condition of every structure irrespective of the time it took to get to that condition. For this reason, they have been used in the evaluation of the likelihood of the failure event for all types of structure.

Therefore, equation (2) above is redefined as:

$$\begin{gathered} For\ every\ structure\ where\ SOGR = 100, then \\ LF_{con} = 10^{-7}\ or\ 1\ in\ 10{,}000{,}000\ or\ \frac{1}{10{,}000{,}000} \end{gathered} \quad (4)$$

[1] Bridge Condition Indicators. Volume 3. Guidance Note on Evaluation of Bridge Condition Indicators. CSS. July 2002

Where LF_{con} : Likelihood of failure due to condition.

Based on DfT's Structures Asset Management Toolkit (Department for Transport, 2015), the deterioration of a structure can be generally depicted in the following graph:

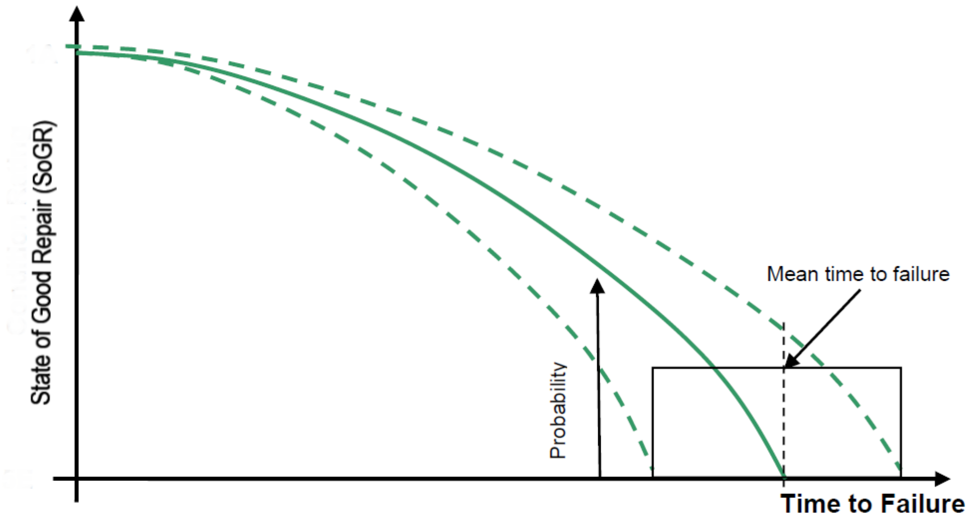


Figure 5: Deterioration Profile

Using the assumptions made in the aforementioned document for a typical structure, and starting from a SoGR of 100, the following table was created in order to assign values for the Likelihood of failure due to condition LF_{con} for this structure as it is deteriorating over time.

Table 4: Likelihood of failure due to condition (LF_{con})

Condition			BCIcr												
			Very Good		Good		Fair			Poor					Very Poor
			95-100	90-94.99	85-89.99	80-84.99	75-79.99	70-74.99	65-69.99	60-64.99	55-59.99	50-54.99	45-49.99	40-44.99	0-39.99
BCIav	Very Good	95-100	10,000,000	2,000,000	1,000,000	200,000	100,000	20,000	10,000	6,000	3,500	2,000	800	400	200
		90-94.99	5,000,000	1,000,000	500,000	100,000	50,000	10,000	5,000	3,000	1,750	1,000	400	200	100
	Good	85-89.99	3,750,000	750,000	375,000	75,000	37,500	7,500	3,750	2,250	1,300	750	300	150	75
		80-84.99	2,500,000	500,000	250,000	50,000	25,000	5,000	2,500	1,500	875	500	200	100	50
	Fair	75-79.99	1,875,000	375,000	187,500	37,500	18,750	3,750	1,875	1,125	655	375	150	75	40
		70-74.99	1,250,000	250,000	125,000	25,000	12,500	2,500	1,250	750	440	250	100	50	25
		65-69.99	1,000,000	200,000	100,000	20,000	10,000	2,000	1,000	600	350	200	80	40	20
	Poor	60-64.99	750,000	150,000	75,000	15,000	7,500	1,500	750	450	250	150	60	30	15
		55-59.99	625,000	125,000	62,500	12,500	6,250	1,250	625	375	220	125	50	25	12
		50-54.99	500,000	100,000	50,000	10,000	5,000	1,000	500	300	175	100	40	20	10
		45-49.99	375,000	75,000	37,500	7,500	3,750	750	375	225	130	75	35	17	8
		40-44.99	300,000	60,000	30,000	6,000	3,000	600	300	180	105	60	30	15	7
	Very Poor	0-39.99	250,000	50,000	25,000	5,000	2,500	500	250	150	90	50	20	10	5

7.2.3 Primary material adjustment factor (AF_{PMT})

The type of material used in a structure has a direct influence on how that structure behaves, and on its condition. Similarly, failure associated with structures can be linked with the primary material used in the construction of that structure. It is important to take this into account when accessing the likelihood of a failure event for each structure. Depending on the material type, the collapse mechanism of a structure can range from unexpected and sudden to gradual and more or less likely to occur.

For this reason, a Likelihood adjustment factor due to the primary material (AF_{PMT}) of the structure has been introduced. Table 7 shows that materials that are more prone to sudden failure are given a lower adjustment factor (and therefore a higher likelihood) than those materials that demonstrate a progressive collapse. Note that where primary material is not known, the modification factor reflects the higher likelihood for a failure event.

Table 5: Adjustment factor due to primary material type (AF_{PMT})

Material Type				AF_{PMT}
Bridges		Retaining Wall	Sign/signal Gantries	
Concrete	reinforced	Reinforced concrete	Reinforced concrete	1.00
	plain / mass	Mass concrete	-	1.10
	post-tensioned	-	Pre-stressed concrete	0.80
	pre-tensioned	-		0.80
Metal	steel	Steel	Steel	1.00
	cast iron	-	-	0.80
	wrought iron	-	-	0.80
	aluminium		Aluminium	1.00
	corrugated steel	-	-	1.00
	corrugated aluminium	-	-	1.00
Masonry	brick	Masonry	-	1.10
	stone		-	1.10
FRP/GRP/ Composite		FRP/Plastic	FRP/Plastic	1.00
Timber		Timber	-	0.80
Other / Unknown		Other / Unknown	Other / Unknown	0.80

7.2.4 Likelihood of failure (L_f)

Therefore, the Likelihood of failure (L_f) of a structure is defined as the product of the Likelihood of failure due to its condition (LF_{con}), adjusted for the relevant primary material of this structure (AF_{PMT}):

$$\boldsymbol{L_f = 1\ in\ (LF_{con} \times AF_{PMT}) years} \quad (5)$$

Or:

$$\boldsymbol{L_f = \frac{1}{(LF_{con} \times AF_{PMT})}\ years} \quad (6)$$

7.3 Consequence

7.3.1 Safety Consequence

Safety consequence (C_{sft}) is defined in notional monetary terms using the expected number of casualties when the failure event occurs.

The expected number of casualties incorporates an estimate of the number of vehicles over the structure at the moment of failure. Depending on the obstacle crossed, an estimate of the number of casualties under the structure at the moment of failure is also incorporated. An estimate of the number of vehicles within stopping distance of the structure is also calculated and included in the consequences if it is relevant.

In calculating the safety consequences, the average value of prevention of accidents and figures for vehicle occupancy are used, both of which come from published government data.

The expected number of casualties under/over the structure and within stopping distance of the structure are based on the Annual Average Daily Traffic of the road, as well as vehicle occupancy. Dimensional data such as the span length, width and height are included in the calculations. Stopping distances over/under the structure are calculated based on the Highway Code, and depend on the average speed of vehicles on the roads over/under the structure[2].

It can, therefore, be expressed as:

$$C_{sft} = \left(SP_f + ST_f\right) \times F_v \tag{7}$$

Where:

SP_f: Persons over and under the area of the structure affected by the failure event.

ST_f: Persons at the stopping distance around the area of the structure affected by the failure event.

F_v: Value of prevention of a fatality (at the time of writing: $F_v = £1{,}635{,}937$)

7.3.2 Functionality Consequence (C_f)

The functionality consequence is defined as the sum of the User Delay Costs (UDC) that may be incurred by the traffic using the roads over or under the structure, following a failure event. The values used should be taken from the affected route, whether it is over or under the structure.

User Delay Costs are estimated using data relating to the length and duration of the diversion that will be required following a failure event, as well as an estimate of the average speed of the vehicles on this diversion. The number of vehicles on diversion is assumed to be equal to the number of vehicles that were using the structure prior to the failure event.

The Value of Time per Vehicle is used to generate the notional value in monetary terms, which is taken from published government data (at the time of writing: £13.91/hour[3]).

[2] The Highway Code. General rules, techniques and advice for all drivers and riders (103 to 158). Rule 126

[3] http://webarchive.nationalarchives.gov.uk/20130414170953/http:/www.dft.gov.uk/webtag/documents/expert/pdf/U3_5_

In addition to the User Delay Costs that are related to a failure event, existing restrictions such as loading restrictions, speed restrictions, lane restrictions and diversions that cause delays to some or all vehicles are also taken into account when estimating the Functionality Consequence.

The Functionality Consequence can, therefore, be expressed as:

$$C_{Fnc} = UDC_{Under} + UDC_{Over} + UDC_{Ex} \tag{8}$$

Where:

UDC_{Under}: User delay costs for vehicles under (or at the foot of) the structure

UDC_{Over}: User delay costs for vehicles over (or at the top of) the structure

UDC_{Ex}: User delay costs from existing restrictions related to the structure

7.3.3 Environment Consequence

As with Functionality described above, changes to the function of a structure following a failure event or any existing restrictions in place result in additional journey time for all road users. This has environmental consequences in the form of extra CO_2 released from these vehicles.

The Climate Change Act 2008 creates a new approach to managing and responding to climate change in the UK. At the heart of the Act is a legally binding target to reduce the UK's greenhouse gas emissions, to be achieved through action at home and abroad. It is, therefore, important that the impacts of schemes on greenhouse gas emissions are identified and incorporated within the Value Management methodology in a consistent way.

According to the DfT's TAG unit A3 environmental impact appraisal, the following are required:

- Estimation of changes in emissions of greenhouse gases
- Monetary valuation of these changes

The environment consequences can, therefore be expressed as:

$$C_{Env} = CO_2 \times P_{CO_2} \tag{9}$$

Where:

C_{Env}: Environment consequence (£)

CO_2: CO_2 equivalent emissions (t)

P_{CO_2}: Non traded value of CO_2 (£/t)

7.3.4 Total consequence

The overall consequence (C_f) is the sum of the Safety, Functionality and Environment consequences.

So:

6-vot-op-cost-120723.pdf

$$C_f = C_{Sft} + C_{Fnc} + C_{Env} \tag{10}$$

Where:

C_{Sft}: Safety consequence

C_{Fnc}: Functionality consequence

C_{Env}: Environment consequence

7.4 Failure Event Risk

The risk of a failure event (R_f) is defined as a function of Likelihood and Consequence. More specifically:

$$R_f = C_f \times L_f \tag{11}$$

Where:

R_f: Risk of the failure event (£/year)

C_f: Consequence of the failure event (£)

L_f: Likelihood of the failure event (1/years)

7.5 Specific Element Risk

The failure event risk represents an estimate of the risk due to the overall condition of the structure. There are, however, components of a structure whose failure introduces additional risk. This can either be a risk that is associated to the function of the structure, or to the Whole Life Cost of the structure. For example, a failed parapet will have safety, functionality and environment consequences that are not necessarily captured in the failure event risk. The reason for this is that the condition of the parapet does not have a very big impact on BCI_{av} and it has no impact at all on the BCI_{cr}. An example of an element that impacts the Whole Life Cost of the structure is waterproofing. Failure of the waterproofing will consequently accelerate the deterioration of the primary deck element and therefore affects the future maintenance costs of the structure. This represents an additional risk that must be captured.

An estimate of the additional risk is carried out for the following components:

- Expansion Joints (failure event)
- Parapets (failure event)
- Waterproofing (Whole life cost)
- Bearings (Whole life cost)
- Painting/Surfacing (for steel structures) (Whole life cost)

The overall additional risk for all the elements above can, therefore be represented as:

$$R_{el} = R_{EJ} + R_{PR} + R_W + R_B + R_P \tag{12}$$

Where:

R_{el}: Total risk from specific elements (£/year)

R_{EJ}: Risk from expansion joints failure (£/year)

R_{PR}: Risk from parapet failure (£/year)

R_W: Risk from waterproofing failure (£/year)

R_B: Risk from bearings failure (£/year)

R_P: Risk from painting system failure (£/year)

The risk for all the elements mentioned above is estimated:

- For elements that affect the function of the structure, by modelling a failure event and estimating their discreet Likelihood, Safety/Functionality/Environment Consequences in a similar manner to that described above.
- For elements that affect the maintenance cost of the structure, a whole life cost analysis is carried out based on the Structures Asset Management Planning Toolkit guidance documents as published by CIPFA.

7.6 Prioritisation

Every structure on the list of candidate maintenance schemes that is identified in Section 6 should go through the process described in Section 7. Subsequently, the list is prioritised based on the estimated Annual Economic Risk of each structure. Higher AER means higher priority.

7.6.1 Annual Economic Risk

The Annual Economic Risk is the sum of the Failure Event Risk and the Specific Elements Risk:

$$AER = R_f + R_{el} \tag{13}$$

Where:

AER: Annual Economic Risk

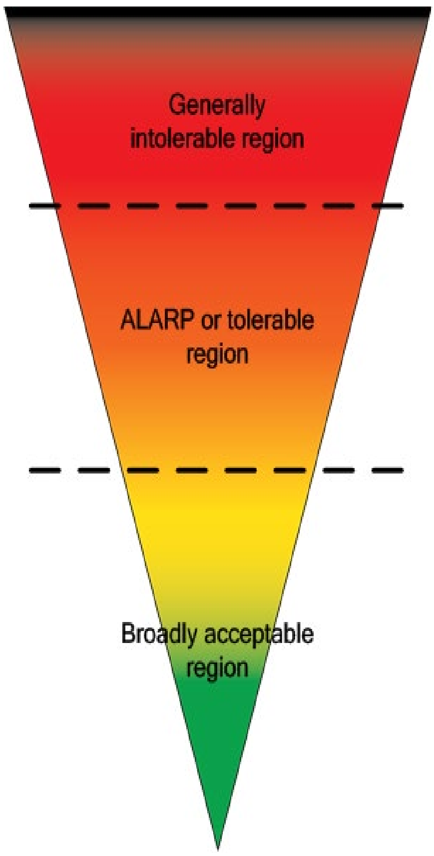
R_f: Risk from failure event

R_{el}: Specific Elements Risk

7.6.2 Risk Categories

The estimated AER falls into the following 5 categories:

Table 6: Risk Categories and Descriptions based on AER

Risk Category (£k)	Description	Risk Acceptable
≥ 5,000	**Critical** – the asset represents an unacceptable risk to network safety and/or reliability and TfL's reputation, action must be taken to reduce the level of risk	
≥ 1,000 & < 5,000	**Very High** – network safety and/or reliability are at or below broadly acceptable levels, and action must be taken to improve safety and reliability	
≥ 50 & < 1,000	**High** – action must be taken to maintain network safety, reliability and/or State of Good Repair at or above acceptable levels, interventions may be further justified on the basis of reduced whole life costs	
≥ 5 & < 50	**Medium** – action should be taken to deliver preferred levels of network safety, reliability and State of Good Repair, to fully achieve Surface Transport and TfL outcomes, and to reduce whole life costs	
< 5	**Low** – action may be appropriate on the basis of whole life cost savings and reducing future disruption.	

7.7 Value for Money

7.7.1 Scheme formulation

Following the risk-based prioritisation of the identified structures list, an initial proposal for the scope of the maintenance scheme can be formulated. This proposal should be based on the condition information available and any other relevant information collected during the Identifications of Needs step (Section 6). In its simplest form, the scheme proposal can be a list of all the elements that are deemed to require repair. The elements can be identified either using a Life Cycle Planning tool or using simple rules (for example: all elements with a condition 3C or worse will be repaired) as long as they are clearly defined.

7.7.2 Annual Economic Risk Post Implementation

It is assumed that upon completion of the proposed works, the condition of all the elements that were repaired will be as new or in very good condition (1A). The condition of the structure (BCI_{av}, BCI_{cr}) will be estimated based on this assumption.

The process described in Sections 7.2 to 7.6 will then be followed for the assumed state of the structure after the proposed works. This will provide an estimate of the Annual Economic Risk post implementation ($AER_{Post\ Implementation}$).

7.7.3 Annual Economic Benefit

The reduction of risk that will be realised by carrying out the proposed works is the Annual Economic Benefit.

$$AEB = AER_{Pre\ Implementation} - AER_{Post\ Implementation} \qquad (14)$$

7.7.4 Risk Mitigation Life

The Risk Mitigation Life (RML) represents an estimate of the number of years that the risks of a structure will be mitigated to a satisfactory level. This number can be estimated using a Life Cycle Planning tool. It can also be estimated based on the nature of the proposed works and the life span of the elements that are proposed to be repaired/replaced as part of these works.

7.7.5 Discounted Economic Benefit

The Discounted Economic Benefit (DEB) of the candidate scheme is then calculated:

$$DEB = \sum_{i=1}^{RML} \frac{AER}{(1+DR)^i} \qquad (15)$$

Where:

DEB: Discounted Economic Benefit

RML: Risk Mitigation Life

MY: Mitigation Year

AER: Annual Economic Risk

DR: Discount Rate

7.7.6 Value for Money

Value for Money (VfM) is the ratio of the Discounted Economic Benefit (DEB) over the cost of the scheme. The VfM ratio is used to optimise different scheme maintenance proposals by selecting one that maximises it.

$$VfM = \frac{DEB}{SC} \qquad (16)$$

Where:

VfM: Value for Money ratio

DEB: Discounted Economic Benefit

SC: Scheme Cost

7.7.7 Programme Optimisation

The optimisation of programme needs to happen at several levels, and there is an important sequence to build a transparently justified total programme that deliver desired outputs within the programme constrains. Firstly, individual projects should be optimised for cost, benefit, risk and timing - this will include decision-making, for example, about the VfM and optimal timing for specific investment, interim measure or major strengthening work or renewal/replacement of a particular structure.

With such understanding (of different tasks that are individually worth doing, and when), the next level of optimisation should consider the best mix of different activities on the same structure over its whole life cycle. This may involve a number of “what if?” scenarios, to explore different mixes of capital investment and operating strategies. The asset ‘whole life cycle’ optimisation represents the best value mix of activities required to ensure effective, efficient and sustainable asset performance.

Finally comes the optimization of delivery activities - the best work programming, task bundling, resourcing and efficient delivery of multiple tasks across multiple assets. Such refinements of asset management plan implementation should consider the cost/risk impact of, for example, doing some tasks prematurely or beyond their optimal timing in order to gain greater, shared benefits of the programme investment, planning and other resourcing efficiencies.

8 Conclusion

The process described in the previous sections depends greatly on the accuracy of the data used at each step. It is recommended to review all the data thoroughly in order to avoid false indications as much as reasonably practical. A review of the AER and VfM ratios should be carried out at the end of each stage in the planning and execution process of the maintenance scheme. As the relevant data is reviewed and updated at each stage’s gate review, it will provide the assurance to all the stakeholders that their investment is still optimised or that changes to the scope of works are required.

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