LoBEG Good Practice Guide

Phase I – Maintenance Prioritisation for Highway Structures

Version 4.0

August 2011

London Bridges Engineering Group

Notice

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The photograph on the front cover is Albert Bridge constructed between 1870 and 1872; the photograph was kindly provided by Kevin Andrews of WestOne.

Table of Contents

1 Introduction

1.1 General

This Good Practice Guide describes the prioritisation methodology, developed by the London Bridges Engineering Group (LoBEG). The Group consider this methodology to be appropriate for bridges and other highway structures.

This can be used to streamline and support the objective identification and prioritisation of maintenance on highway structures.

1.2 Purpose

The purpose of this guide is to provide a step-by-step guide to maintenance prioritisation for highway structures, explaining how and when the methodology should be used. This guide is intended to ensure a degree of consistency and comparability between prioritisation activities.

1.3 The Need for Maintenance Prioritisation

Highway authorities have a duty to maintain the public highway[1]. 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 needs have been identified and prioritised in an objective manner that aligns with good practice and satisfies relevant safety and performance requirements.

It is no longer acceptable to plan maintenance on an ad-hoc and subjective basis. The maintenance planning process must provide the bridge manager/engineer with a robust mechanism of identifying and prioritising needs.

1.4 Benefits of Maintenance Prioritisation

Maintenance prioritisation is being increasingly used to support bridge engineers and managers to:

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

1.5 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
2. Maintenance Planning and Prioritisation	Describes the role of prioritisation in the process of maintenance planning.
3. Assumptions and Rules	States the assumptions and rules that apply to the prioritisation process described in Section 4.
4. The Prioritisation Process	Presents an overview of the prioritisation process and provides a detailed description of each stage in the process.
5. References	Relevant documents referred to for the purpose of this study.
Appendices	Provide supporting information including the default scores that can be used for calculating the element priorities.

2 Overview of Maintenance Planning

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' and enables the available/expected funding to be appropriately targeted to areas which contribute to effective management of maintenance needs.

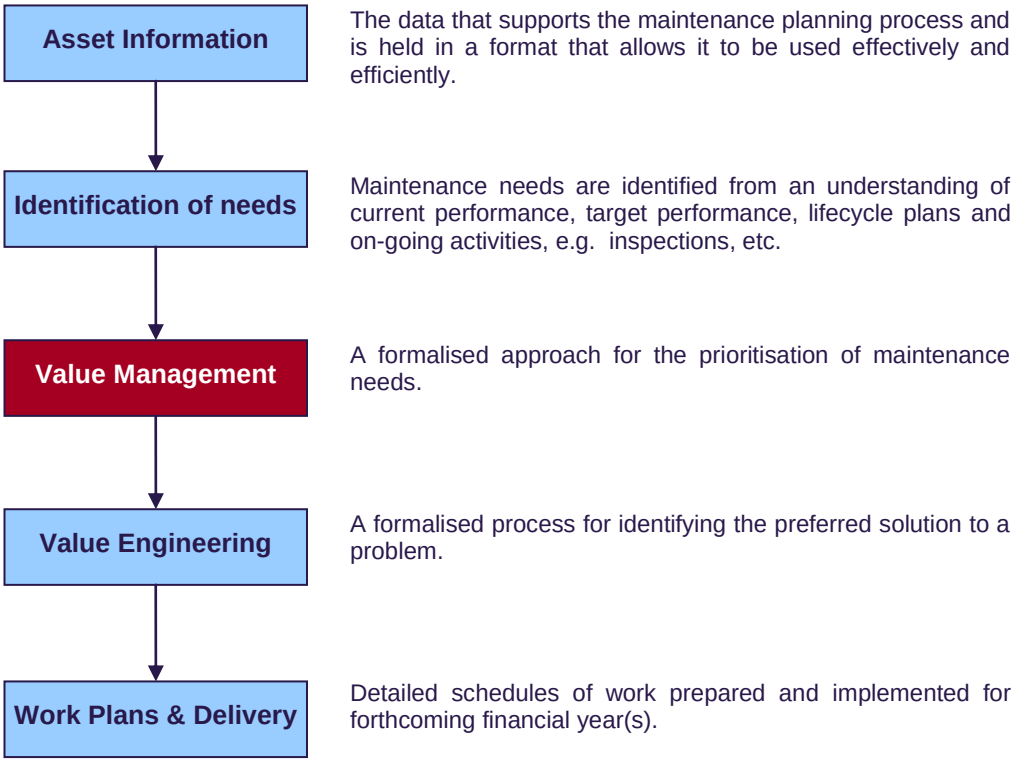


Figure 1: Maintenance Planning Process

Management of Highway Structures: A Code of Practice[2] provides further details on the maintenance planning and management process and its key components.

3 Assumptions and Rules

The following Assumptions and Rules apply to the Prioritisation process described in Section 4.

1. LoBEG is developing a two phase process for prioritisation of maintenance for highway structures, as described in section 4.1. This Good Practice Guide covers only the Phase 1 Prioritisation process (initial identification and prioritisation of needs), i.e. stages 1 to 5 (see Figure 2). Phase 2 will be presented in a separate document.
2. Stage 2 (Element Priority Scoring, see Figure 2) of the Phase 1 process distinguishes between the elements in condition 1A to 2E and the elements in condition 3B to 5E, with the former receiving a priority score of zero, thus requiring no further analysis unless overwritten by the bridge manager/engineer.
3. The Prioritisation process described in this Good Practice Guide provides a practical means of readily and objectively prioritising needs. However, it is the responsibility of the bridge manager/engineer to:
    - Ensure that the data held by the authority are suitably robust to support this process
    - Incorporate known local factors into the prioritisation process to ensure that these are taken into account.

4 The Prioritisation Process

4.1 Overview

LoBEG have identified the need for a two-phase prioritisation process to support the robust and objective identification and prioritisation of maintenance on highway structures. Figure 2 presents the two-phase prioritisation process which is described in detail in the following section.

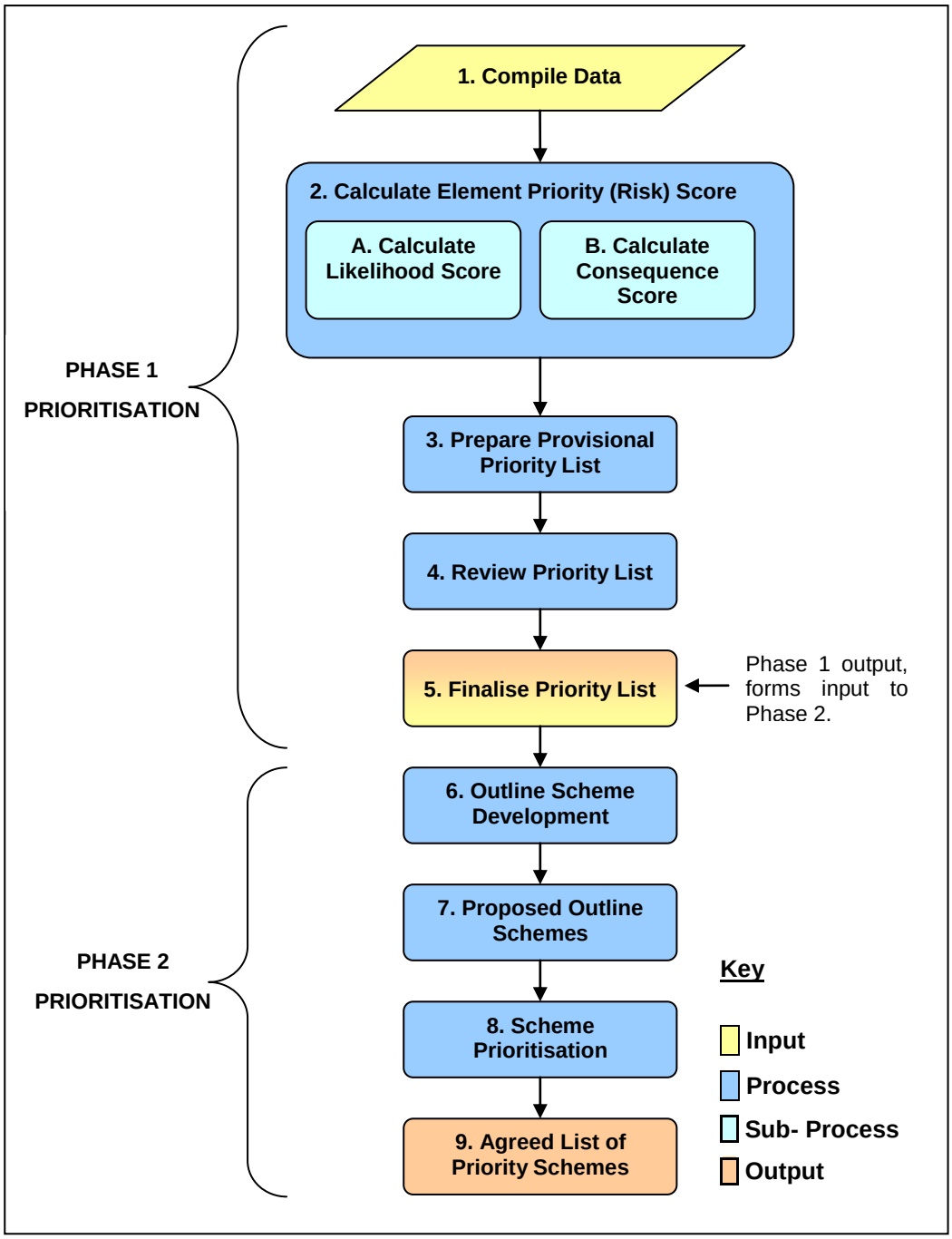


Figure 2: Flowchart of Prioritisation Process

4.1.1 Phase 1 Prioritisation

1. ***Compile Data*** – Assemble the data and information that will support the prioritisation process. This includes:
   - detailed inventory for each structure under consideration; and
   - inspection data provided by the two and six yearly General and Principal Inspections undertaken in accordance with the CSS Inspection Procedure [3-5].
2. ***Calculate Element Priority (Risk) Score*** – The inventory and condition data are used to score all elements in terms of their maintenance priority; the scoring is based on element condition, element importance, structure type and usage and structure dimensions.
3. ***Prepare Provisional Priority List*** – The priority scores are used to produce a provisional priority list which contains all elements, ranked from highest to lowest priority; this can be presented either by element or by structure.
4. ***Review of the Priority List*** – The bridge manager/engineer should review the Priority List and, where appropriate, manipulate the list (i.e. promote and demote needs) based on additional information (e.g. local factors and preventative/cyclic treatments). The supporting rationale for any promotion/demotion should be captured. This review should provide agreement on structures that need to be taken forward to outline scheme development, at this point, taking account of rough scheme cost estimates to ensure full use would be made of likely funding allocations. Where practical, the review should be undertaken in a workshop environment.
5. ***Finalise Priority List*** – The outcome of the review is a final and agreed Priority List of structures that need to be taken forward to outline scheme development.

4.1.2 Phase 2 Prioritisation

The prioritised needs from Phase 1 are used to inform the development of schemes of work.

6. ***Outline Scheme Development*** – The bridge manager/engineer should develop outline schemes for the agreed structures and compile the information required for scheme prioritisation.
7. ***Proposed Outline Schemes*** – A list of proposed outline schemes should be prepared along with the associated information required by the prioritisation process.
8. ***Scheme Prioritisation*** – Schemes are prioritised using the *LoBEG Strengthening and Capital Maintenance Prioritisation System*[6].
9. ***Agreed List of Priority Schemes*** – An agreed list of priority schemes is put forward to obtain appropriate funding.

4.2 Stage 1: Compile Data

A detailed description of the data and information required to support the prioritisation process is presented in the following sections.

4.2.1 Structure Details

The Prioritisation process requires the following information for each structure included in the analysis:

- ***Structure Details*** – which includes:
  - Structure Type:
    - Bridge
    - Culvert/Subway
    - Tunnel
    - Earthworks
    - Retaining Wall or River Wall
    - Reinforced/strengthened soil/fill structure with hard facings
    - Sign/Signal Gantry
  - Route Supported by the structure, e.g. A class or a distributor road, etc.;
  - Obstacle Crossed by the structure, e.g. A class road, watercourse, etc.;
  - Structure Dimensions:
    - Bridges: Span Length (m);
    - Culverts/Subways: Width (m);
    - Tunnels: none required;
    - Earthworks: none required;
    - Retaining Walls or River Walls: Height (m);
    - Reinforced/strengthened soil/fill structure with hard facings: Height (m);
    - Sign/Signal Gantries: none required
- ***Inventory*** – All elements present on the structure, classified according to the CSS inspection procedure [3-5].

4.2.2 Inspection data

Inspection data are normally collected during the two and six yearly General and Principal Inspections and/or other appropriate inspection regimes and are usually undertaken in accordance with the CSS inspection procedure [3-5] e.g. the severity/extent of defects relating to the condition of each structural element and component. The information used in the prioritisation process includes:

- Element importance and/or [potential] failure severity;
- Condition data for each element (Severity and Extent) to the latest inspection.

4.3 Stage 2: Calculate Element Priority Score

The Priority Score of an element is evaluated using a classical risk approach of Likelihood and Consequence where these are defined as:

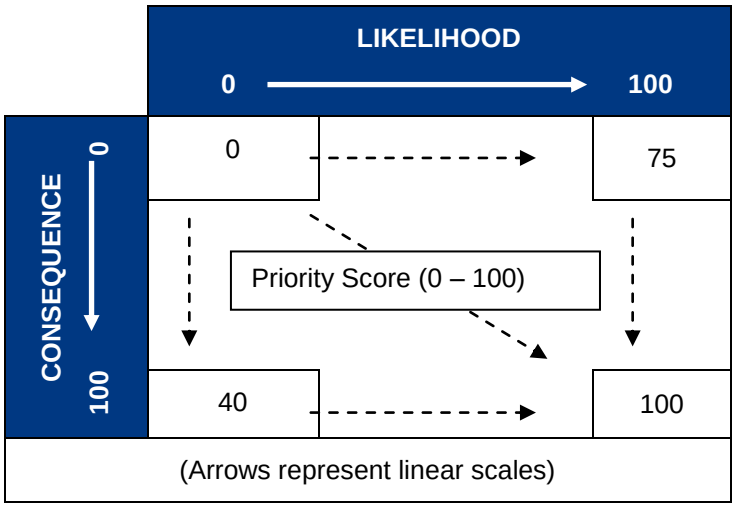
- *Likelihood* – The probability of a defect/damage causing a safety, functionality or durability problem.
- *Consequence* – What is the impact on the structure (safety, service, etc.) due to the defect or damage?

The Likelihood and Consequence are evaluated on a scale of 0 to 100 and the overall Priority Score is evaluated as shown in Table 2 and Equation 1, i.e. Likelihood is taken to be more significant than Consequence. This aligns with the approach used in other prioritisation systems [6].

- If the Likelihood Score (L_S) > Consequence Score (C_S) then $P_S = 0.75L_S + 0.25C_S$
- If the Likelihood Score (L_S) = Consequence Score (C_S) then $P_S = 0.50L_S + 0.50C_S$
- If the Likelihood Score (L_S) < Consequence Score (C_S) then $P_S = 0.60L_S + 0.40C_S$

Equation 1

Table 2: Risk Matrix for Maintenance Prioritisation



Note: All elements in condition 1A to 2E should be assumed to have a Priority Score of 0 and thus require no further analysis under Phase 1; **however** they can be included via Stage 4 using the Local Factor and/or Lifecycle Plan criteria. The Lifecycle Plan may identify preventative needs for elements that have not yet reached condition 3B. All elements in condition 3B or worse should be scored.

Table A.1 in Appendix A presents a detailed priority matrix based on different likelihood and consequence scores, calculated using Equation 1.

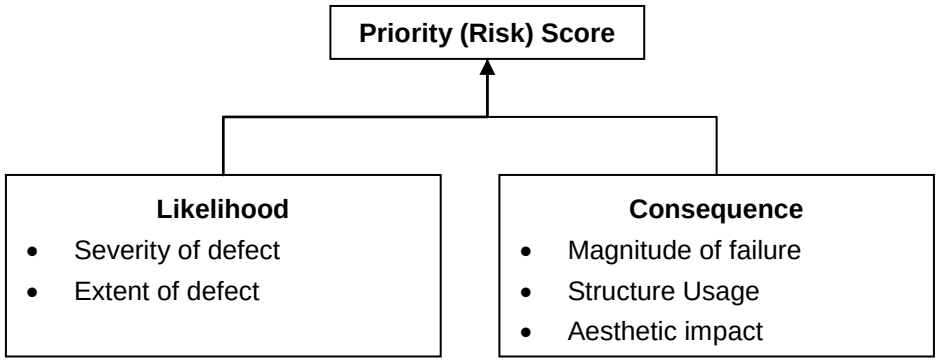


Figure 3: Criteria that contribute to the Phase 1 Priority score

The criteria that inform the likelihood and consequence are shown in Figure 3 above. The following sections describe the process of evaluating the likelihood and consequence scores using the defined criteria.

4.3.1 Likelihood Score, L_S

The Likelihood Score is evaluated based on the element condition, i.e.

- Severity of defects (rated on a 1 to 5 scale); and
- Extent of defects (rated on a 1 to 5 scale).

This provides an alphanumeric rating for each element, e.g. 1A, 2B, 3C, etc. The alphanumeric ratings are converted to a numeric Element Condition Score (ECS)[3-5] using the relationship shown in Table 3.

Table 3: Numerical Element Condition Score (ECS)

		Severity				
		1	**2**	**3**	**4**	**5**
Extent	**A**	1.0	-	-	-	-
	B	-	2.0	3.0	4.0	5.0
	C	-	2.1	3.1	4.1	5.0
	D	-	2.3	3.3	4.3	5.0
	E	-	2.7	3.7	4.7	5.0

The ECS is converted to a 0 to 100 likelihood scale using Equation 2. This equation establishes a non linear relationship between severity 1 and 5, with deterioration considered to pose a progressively higher risk as the severity increases. This conforms with the approach published in the *Inspection Manual* for *Highway Structures* and other relevant guidance [3-5].

$$\text{Likelihood Score } (L_S) = 100 - [115 - 2 \times ECS \times (ECS + 6.5)]$$

Equation 2

4.3.2 Consequence Score, C_S

The Consequence Score is evaluated as a combination of:

- Magnitude of Failure;
- Structure Usage, i.e. importance of route carried/obstacle crossed; and
- Aesthetic impact of not undertaking maintenance works.

The consequence score is calculated by combining each of the aforementioned criteria using Equation 3:

$$\text{Consequence } (C_S) = 0.55 \times \text{Failure Score} + 0.35 \times \text{Structure Usage Score} + 0.10 \times \text{Aesthetic Score}$$

Equation 3

Each of the above mentioned scores are described in detail in the following sections.

Note: The weightings in Equation 3 are those that have been identified and considered to be suitable by LoBEG. If necessary these can be amended to suit local circumstances.

4.3.2.1. Failure Score

The Failure Score of an element can be obtained based on the:

- Structure Type
- Element type, element importance and/or [potential] failure severity; and
- Structure Dimensions.

The failure scores of elements associated with different structure types and dimensions can be obtained from:

- Table A.2 or Table A.3 for Bridges, Culverts, Subways, Tunnels and/or Earthworks;
- Table A.4 or Table A.5 for Retaining Walls, River Walls and /or Reinforced/strengthened soil/fill structure with hard facings; and
- Table A.6 or Table A.7 for Sign/Signal Gantries.

Note: Failure may not necessarily be the collapse of element(s)/structure(s), but may be failure of drainage element(s) or expansion joint(s) which may affect the function and durability of the structure.

4.3.2.2. Structure Usage Score

If the appropriate maintenance activities are not identified and undertaken, it has potential to impact the local and wider community, e.g. accessibility to community services, business deliveries, access to leisure facilities, etc. These are important considerations and can lead to adverse public opinion and “bad press” if not managed accordingly.

The Structure Usage Score is used to evaluate consequence in terms of:

- Inconvenience to the community due to diversions, delays and restrictions.
- Inconvenience to businesses due to diversions, delays and restrictions.

These effects can be difficult to quantify but it is considered that there is a close relationship between these and the route supported or obstacle crossed by the structure.

The Structure Usage Score can therefore be selected from Table A.8 in Appendix A based on the route supported and the obstacle crossed by the structure.

4.3.2.3. Aesthetic Score

The appearance of a structure may be seriously affected if appropriate works are not carried out in a timely manner. The impact of this for some heritage structures could be significant. The 'aesthetic score' of an element should be based on the:

- Aesthetic impact of the element on the whole structure, which can be obtained from:
  - Table A.9 or Table A.10 for Bridges, Culverts, Subways, Tunnels and/or Earthworks;
  - Table A.11 or Table A.12 for Retaining Walls, River Walls and/or Reinforced/strengthened soil/fill structure with hard facings; and
  - Table A.13 or Table A.14 for Sign/Signal Gantries.
- Aesthetic impact of the structure on the local environment and community, e.g. High impact (listed structure), Medium impact (having high visual importance due to being situated at a prominent location), or Low impact (other structures).

The aesthetic score for an element can be obtained from the matrix presented in Table A.15 in Appendix A.

4.3.3 Priority Score Classification

The priority scores obtained from the aforementioned process can be classified into critical, high, medium and low categories, as shown in Table 4.

Table 4: Priority Score Categories

Priority Category	Priority Score	Description
Critical	**80 to 100**	Represents a high risk to service, safety and/or durability and must be rectified as a matter of urgency.
High	**60 to < 80**	Should be investigated further as it is likely that work is required on safety and/or durability grounds.
Medium	**40 to < 60**	Should be investigated further to identify if proactive and/or preventative works would reduce whole life costs and to assess if the defect can be packaged with higher priority needs.
Low	**< 40**	Likely that no action is required.

Note: The above categories and their descriptions are intended to act as a guideline during the identification and prioritisation of maintenance needs; this must be supplemented and challenged by local knowledge and site visits as appropriate.

4.4 Stage 3: Prepare Provisional Priority List

The provisional priority list can be generated based on the priority scores/categories calculated in stage 2, Section 4.3 and can be presented:

- By element; and/or
- By structure.

It is envisaged that the latter will be the primary mechanism for identifying structures to take forward to outline scheme development.

4.4.1 Presentation by Element

A simple way to use the Priority Score (P_S) is to create one Priority List of maintenance needs by element, with the greatest need at the top and the lowest at the bottom, as shown in Table 5.

Table 5: Ranked List of Priority Scores

Rank	Structure Name	Element	Work Type	Priority Score	Local Factor	Lifecycle Plan
1	Bridge A	Longitudinal Beams	U1: Strengthening	93		
2	Bridge A	Bearing Plinth/Shelf	M3: Essential Maintenance	85		
3	Bridge B	Parapets	U2: Component Upgrade	84		
4	Bridge C	Abutments	M3: Essential Maintenance	76		
5	Bridge D	Expansion joints	M1: Component Renewal	59		
	↓			↓		
100	Bridge E	Footway surfacing	M4: No Action Required	38		
101	Bridge F	Secondary beams	M4: No Action Required	0		
102	Bridge G	Foundations	M4: No Action Required	0		

The arrangement shown in Table 5 can be readily understood and enables the most critical defects to be easily identified. Section 4.5 describes how the Local Factor and Lifecycle Plan columns could be used. The 'Work Type" column can be used to categorise defects by the type of work required to rectify them, for example:

- ***Upgrades:***

- *U1: Strengthening* – May relate only to load strengthening of a structure where the original design has failed the assessment criteria.
- *U2: Component Upgrade* – May relate to all work (except load strengthening) required to bring existing components up to the required standard, e.g. parapet upgrade.
- *U3: Widening* – Increasing the width of an existing structure.
- *U4: Headroom* – Increasing the headroom of an existing structure.

- ***Maintenance:***
  - *M1: Component Renewal* – Renewal works relate to components that have a finite life, e.g. bearings, expansion joints and waterproofing.
  - *M2: Preventative Maintenance* – Timely intervention to maintain the condition of the structure by protecting it from deterioration or slowing down the rate of deterioration, e.g. re-pointing, re-painting, minor/moderate defect repairs, silane impregnation, etc.
  - *M3: Essential Maintenance* – Major structural repair work undertaken when part or all of the structure is considered to be or about to become inadequate or unsafe.
  - *M4: No Action Required* – May be used when no action is assigned.

4.4.2 Presentation by Structure

Table 5 does not necessarily make it easy to identify which structures are most suitable for outline scheme development (i.e. packaging a number of needs together), especially when considering needs below the 'Critical' and 'High' levels. To support outline scheme development it may be more beneficial to view the ranked Priority List by structure and further support the Priority Score (P_S) by other readily available or easily evaluated values such as:

- The number of critical Priority Scores on a structure.
- The number of high Priority Scores on a structure.
- The Average Bridge Condition Index (BCI_{Av}) of a structure.
- The Critical Bridge Condition Index (BCI_{Crit}) of a structure.

These are shown in Table 6, along with Local Factor and Lifecycle Plan columns which are explained in Section 4.5.

The element that the Max P_S corresponds to is identified. Table 6 also includes a 'Work Type' column as per Table 5. In Table 6 the 'Work Type' relates to the work required on the element with the maximum Priority score (Max P_S).

Table 6 provides more information about the structure when compared to Table 5 but still retains the ability to rank solely using the Priority Score (P_S). However, a "Selection Filter" can be used to rank the structures using any one of the above criteria, thereby providing a means of comparing how the rank of a structure changes when alternative filters are used.

Table 6: Ranking Needs to Support Scheme Development

Selection Filter →				☒	☐	☐	☐	☐	-		-	
Rank	**Structure Name**	**Max P_S Element**	**Work Type**	**Max P_S**	**No. of Critical P_S**	**No. of High P_S**	**BCI_{Av}**	**BCI_{Crit}**	**Local Factor**		**Lifecycle Plan**	
									Old	New	Old	New
1	Bridge A	Longitudinal Beams	U1: Strengthening	84	2	3	67	42				
2	Bridge B	Parapets	U2: Component Upgrade	91	1	1	75	38				
3	Bridge C	Abutments	M3: Essential Maintenance	79	0	2	88	65	12	3		
4	Bridge D	Expansion joints	M1: Component Renewal	64	0	3	87	59				
5	Bridge E	Longitudinal Beams	U1: Strengthening	53	0	1	89	70			23	5
etc.												

4.5 Stage 4: Review of Priority List

The Priority List prepared in stage 3 (Section 4.4) should be reviewed by the bridge manager/engineer and, where appropriate, manipulated (i.e. promote and demote needs) based on additional information (e.g. local factors and preventative/cyclic treatments). Based on the review, the bridge manager/engineer should identify structures to be taken forward to outline scheme development.

The following sections explain how the priority list should be manipulated to take account of local factors and lifecycle plans.

4.5.1 Manipulating Priorities

When identifying structures to be taken forward to outline scheme development it is important to consider other criteria that could have an influence, e.g. local considerations/factors and the approach recommended in a structure specific lifecycle plan. These criteria cannot be readily scored; instead they rely heavily upon engineering judgement and local knowledge.

It is recommended that these criteria are taken into account by promoting (or demoting) structures on the ranked list. The amount by which a structure is promoted or demoted is based on the engineering judgement of the bridge manager/engineer, but in all instances of promotion and demotion it is essential that:

- The supporting rationale is fully captured and recorded; and
- The magnitude of promotion/demotion is consistently applied, i.e. if one structure is moved to the top of the list for 'Reason X', then other structures where this applies should be treated in a similar manner.

The position of the structure on the list is amended by entering the preferred 'Rank' of the structure in the 'New' column under the appropriate criteria (i.e. Local Factor or Lifecycle Plan), see Table 6 in Section 4.4.

4.5.2 Local Factor, LF

It is recommended that a Local Factor is used to promote/demote a structure in circumstances such as:

- Major/prestigious event is scheduled and it is essential that the structure is maintained to a 'good state of repair'.
- An improvement scheme is planned for the route/area and it is an opportune time to combine some bridge works with this scheme, e.g. to make good use of access and traffic management arrangements and efficient use of public money.
- Complaints from local residents and/or businesses have been received regarding features on the structure.
- There are known engineering issues/problems on the structure that should be rectified as a matter of priority.
- It is possible to combine bridge works with planned highway resurfacing work.

4.5.3 Lifecycle Plan, LP

A lifecycle plan sets out the preferred long-term strategy for managing a structure, i.e. best time and type of interventions to minimise whole life costs and traffic disruptions. Whilst it is good practice to minimise whole life costs these works should not take

precedence over structures that are categorised as having a Priority Score of ‘Critical’ or ‘High’. Therefore, lifecycle plan information should be used, at this stage, to supplement ‘Critical ‘ and ‘High’ priority scores and to help inform decisions on best use of available funds after the ‘Critical’ and ‘High’ priority problems have been selected.

4.6 Stage 5: Finalise Priority List

The outcome of Phase 1 Prioritisation is a final and agreed Priority list of structures to be taken forward to outline scheme development.

4.6.1 How many structures to take forward?

As a minimum, the Priority list should include all structures with elements in condition 3B and worse. The bridge manager/engineer should then decide upon how many/which structures to take forward to outline scheme development. In deciding upon this the following should be taken into consideration:

- Have all those structures with elements classified as 'Critical' and 'High' been taken forward to outline scheme development and if not is there sound justification for not doing so?
- Have all those schemes with important local considerations been taken forward and if not is there a strong justification for not doing so?
- Will the quantity of schemes taken forward make full use of the predicted local and centrally provided maintenance allocations? A rough engineering estimate should be made of scheme values at this stage to assess if the demand will meet the predicted allocation.
- In addition to the above, it is recommended that an additional one to three schemes are taken forward to act as reserve schemes for situations where:
  - Additional funding becomes available.
  - Original schemes have been delayed for unforeseen reasons.
  - Funding required for original schemes is less than the available budget.

5 References

1. Highways Act, 1980, HMSO.
2. Management of Highway Structures: A Code of Practice, TSO, 2005.
3. Inspection Manual for Highway Structures, Volume 1: Reference Manual, TSO, 2007.
4. Bridge Condition Indictors Volume 2: Guidance Note on Bridge Inspection Reporting, County Surveyors' Society, 2002.
5. Addendum to CSS Guidance Note on Bridge Condition Indictors Volume 2, County Surveyors' Society, 2004.
6. Prioritisation System for the Strengthening and Maintenance of Bridges in London Area, Annex D – Data Input and Scoring Explanatory Notes, LoBEG, 2000/2001.

Appendix A: Element Priority – Default Scores

Table A.1: Priority Score Matrix

Consequence \ Likelihood	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	0	4	8	11	15	19	23	26	30	34	38	41	45	49	53	56	60	64	68	71	75
5	2	5	9	13	16	20	24	28	31	35	39	43	46	50	54	58	61	65	69	73	76
10	4	7	10	14	18	21	25	29	33	36	40	44	48	51	55	59	63	66	70	74	78
15	6	9	12	15	19	23	26	30	34	38	41	45	49	53	56	60	64	68	71	75	79
20	8	11	14	17	20	24	28	31	35	39	43	46	50	54	58	61	65	69	73	76	80
25	10	13	16	19	22	25	29	33	36	40	44	48	51	55	59	63	66	70	74	78	81
30	12	15	18	21	24	27	30	34	38	41	45	49	53	56	60	64	68	71	75	79	83
35	14	17	20	23	26	29	32	35	39	43	46	50	54	58	61	65	69	73	76	80	84
40	16	19	22	25	28	31	34	37	40	44	48	51	55	59	63	66	70	74	78	81	85
45	18	21	24	27	30	33	36	39	42	45	49	53	56	60	64	68	71	75	79	83	86
50	20	23	26	29	32	35	38	41	44	47	50	54	58	61	65	69	73	76	80	84	88
55	22	25	28	31	34	37	40	43	46	49	52	55	59	63	66	70	74	78	81	85	89
60	24	27	30	33	36	39	42	45	48	51	54	57	60	64	68	71	75	79	83	86	90
65	26	29	32	35	38	41	44	47	50	53	56	59	62	65	69	73	76	80	84	88	91
70	28	31	34	37	40	43	46	49	52	55	58	61	64	67	70	74	78	81	85	89	93
75	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	79	83	86	90	94
80	32	35	38	41	44	47	50	53	56	59	62	65	68	71	74	77	80	84	88	91	95
85	34	37	40	43	46	49	52	55	58	61	64	67	70	73	76	79	82	85	89	93	96
90	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81	84	87	90	94	98
95	38	41	44	47	50	53	56	59	62	65	68	71	74	77	80	83	86	89	92	95	99
100	40	43	46	49	52	55	58	61	64	67	70	73	76	79	82	85	88	91	94	97	100

Likelihood > Consequence [$P_S = 0.75L_S + 0.25C_S$]
Likelihood = Consequence [$P_S = 0.50L_S + 0.50C_S$]
Likelihood = Consequence [$P_S = 0.60L_S + 0.40C_S$]

Table A.2: Element Failure Score for Bridges, Culverts, Subways, Tunnels and Earthworks

		Failure (Consequence) Categories			
Bridge (Span Length)		**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
Culvert / Subway (Width)		**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
Tunnel		**N/A**	**N/A**	**N/A**	**All**
Earthworks		**All**	**N/A**	**N/A**	**N/A**
Element Type	**Element Importance / Failure Severity**	**Failure Score**			
1. Primary Deck Element	Very High	70	80	90	100
2. Transverse Beams	Very High	70	80	90	100
3. Secondary Deck Element	Very High	70	80	90	100
4. Half Joints	Very High	70	80	90	100
5. Tie beam/rod	Very High	70	80	90	100
6. Parapet beam or cantilever	Very High	70	80	90	100
7. Deck Bracing	Very High	70	80	90	100
8. Foundations	High	30	40	50	60
9. Abutments (incl. arch springing)	High	30	40	50	60
10. Spandrel wall/head wall	High	30	40	50	60
11. Pier/Column	Very High	70	80	90	100
12. Cross-head/capping beam	Very High	70	80	90	100
13. Bearings	High	30	40	50	60
14. Bearing plinth/shelf	Medium	5	10	20	30
15. Superstructure Drainage	High	30	40	50	60
16. Substructure Drainage	Medium	5	10	20	30
17. Water Proofing	Medium	5	10	20	30
18. Movement/Expansion Joints	High	30	40	50	60
19. Finishes: Deck elements	Medium	5	10	20	30
20. Finishes: Substructure elements	Medium	5	10	20	30
21. Finishes: Parapets/safety fences	Low	0	5	10	15
22. Access/walkways/gantries	Medium	5	10	20	30
23. Handrail/parapets/safety	High	30	40	50	60

		Failure (Consequence) Categories			
Bridge (Span Length)		**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
Culvert / Subway (Width)		**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
Tunnel		**N/A**	**N/A**	**N/A**	**All**
Earthworks		**All**	**N/A**	**N/A**	**N/A**
Element Type	**Element Importance / Failure Severity**	**Failure Score**			
fences					
24. Carriageway surfacing	High	30	40	50	60
25. Footway/verge/footbridge surfacing	Low	0	5	10	15
26. Invert/river bed	Medium	5	10	20	30
27. Aprons	Medium	5	10	20	30
28. Fenders/cutwaters/collision protection	Medium	5	10	20	30
29. River training works	Medium	5	10	20	30
30. Revetment/batter paving	Low	0	5	10	15
31. Wing Walls	High	30	40	50	60
32. Retaining Walls	High	30	40	50	60
33. Embankments	Medium	5	10	20	30
34. Machinery	Medium	5	10	20	30

Table A.3: Element Failure Score for Bridges, Culverts, Subways, Tunnels and Earthworks (Elements grouped by Importance)

		Failure (Consequence) Categories			
Bridge (Span Length)		**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
Culvert / Subway (Width)		**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
Tunnel		**N/A**	**N/A**	**N/A**	**All**
Earthworks		**All**	**N/A**	**N/A**	**N/A**
Element Importance /Failure severity	**Element Type**	**Failure Score**			
Low	25. Footway/ verge/ footbridge surfacing 30. Revetment/ batter paving 21. Finishes: Parapets/ safety fences	0	5	10	15
Medium	14. Bearing plinth/shelf 16. Substructure Drainage 17. Waterproofing 19. Painting: Deck elements 20. Painting: Substructure elements 22. Access/walkways/ gantries 26. Invert/ river bed 27. Aprons 28. Fenders/cutwaters/ collision protection 29. River training works 32. Retaining walls 33. Embankments 34. Machinery	5	10	20	30
High	8. Foundations 9. Abutments 10. Spandrel wall/ head wall 13. Bearings 15. Superstructure drainage 18. Expansion joints 23. Handrail/parapets/safety fences 31. Wing walls 32. Retaining walls 24. Carriageway surfacing	30	40	50	60
Very High	1. Primary deck Elements	70	80	90	100

		Failure (Consequence) Categories			
	Bridge (Span Length)	**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
	Culvert / Subway (Width)	**<3m**	**3 to 10m**	**10 to 25m**	**>25m**
	Tunnel	**N/A**	**N/A**	**N/A**	**All**
	Earthworks	**All**	**N/A**	**N/A**	**N/A**
Element Importance /Failure severity	**Element Type**	**Failure Score**			
	2.Transverse beams 3. Secondary deck element 4. Half Joints 5. Tie rods 6. Parapet beam 7. Deck bracing 11. Pier/ column 12. Cross-head/capping beam				

Table A.4: Element Failure Score for Retaining Walls, River Walls and Reinforced/strengthened soil/fill structure with hard facings

		Failure (Consequence) Categories			
Retaining Wall / River Wall (Height)		<1.5m	1.5 to 3m	3 to 5m	>5m
Reinforced/strengthened soil/fill structure with hard facings (Height)		<1.5m	1.5 to 3m	3 to 5m	>5m
Element Type	Element Importance / Failure Severity	Failure Score			
1. Foundations	High	30	40	50	60
2. Primary Element	Very High	70	80	90	100
3. Secondary Element	High	30	40	50	60
4. Parapet beam/plinth	Very High	70	80	90	100
5. Drainage	Medium	5	10	20	30
6. Movement/Expansion Joints	High	30	40	50	60
7. Finishes: Wall	Medium	5	10	20	30
8. Finishes: Handrail/Parapet	Low	0	5	10	15
9. Handrail/Parapets/Safety Fences	High	30	40	50	60
10. Carriageway: Top of Wall	High	30	40	50	60
11. Carriageway: Foot of Wall	High	30	40	50	60
12. Footway/verge: Top of Wall	Low	0	5	10	15
13. Footway/verge: Foot of Wall	Low	0	5	10	15
14. Embankment: Top of Wall	Low	0	5	10	15
15. Embankment: Foot of Wall	Low	0	5	10	15
16. Invert/river bed	Medium	5	10	20	30
17. Aprons	Medium	5	10	20	30

Table A.5: Element Failure Score for Retaining Walls, River Walls and Reinforced/strengthened soil/fill structure with hard facings (Elements Grouped by Importance)

		Failure (Consequence) Categories			
Retaining Wall / River Wall (Height)		**<1.5m**	**1.5 to 3m**	**3 to 5m**	**>5m**
Reinforced/strengthened soil/fill structure with hard facings (Height)		**<1.5m**	**1.5 to 3m**	**3 to 5m**	**>5m**
Element Importance /Failure Severity	**Element Type**	**Failure Score**			
Low	8. Finishes: Handrail/Parapet 12. Footway/verge: Top of Wall 13. Footway/verge: Foot of Wall 14. Embankment: Top of Wall 15. Embankment: Foot of Wall	0	5	10	15
Medium	5. Drainage 7. Finishes: Wall 16. Invert/river bed 17. Aprons	5	10	20	30
High	1. Foundations 3. Secondary Element 6. Movement/Expansion Joints 9. Handrail/Parapets/Safety Fences 10. Carriageway: Top of Wall 11. Carriageway: Foot of Wall	30	40	50	60
Very High	2. Primary Element 4. Parapet beam/plinth	70	80	90	100

Table A.6: Element Failure Score for Sign/Signal Gantries

Sign / Signal Gantry Element Type	Element Importance / Failure Severity	Failure Score
1. Foundations	High	40
2. Truss/Beams/Cantilevers	Very High	80
3. Transverse Members	Very High	80
4. Columns/Supports/Legs	Very High	80
5. Finishes: truss/beam/cant.	Medium	10
6. Finishes: columns/supports	Medium	10
7. Finishes: other elements	Low	5
8. Access walkway/deck	Medium	10
9. Access Ladder	Medium	10
10. Handrails	High	40
11. Base Connections	Very High	80
12. Support to longitudinal connection	Very High	80
13. Sign and signal supports	High	10

Table A.7: Element Failure Score for Sign/Signal Gantries (Elements grouped by Importance)

Element Importance / Failure Severity	Sign / Signal Gantry Element Type	Failure Score
Low	7. Finishes: other elements	5
Medium	5. Finishes: truss/beam/cant. 6. Finishes: columns/supports 8. Access walkway/deck 9. Access Ladder	10
High	1. Foundations 10. Handrails 13. Sign and signal supports	40
Very High	2. Truss/Beams/Cantilevers 3. Transverse Members 4. Columns/Supports/Legs 11. Base Connections 12. Support to longitudinal connection	80

Table A.8: Structure Usage Score

		Route supported by the structure		
		Unclassified, Cyclist and Pedestrian	B and C Class (local access / distributor) Road	A Class / Principal Road
Obstacle Crossed by the structure	Waste Ground/disused/non-navigable watercourse	0	30	70
	Unclassified, Cyclist and Pedestrian	30	60	80
	B and C Class (local access / distributor) Road and Business Premises	60	80	90
	Navigable watercourse and A Class / Principal Road	80	90	95
	Railway	90	95	100

Table A.9: Element Aesthetic Impact for Bridges, Culverts, Subways, Tunnels and Earthworks

Element Type	Aesthetic Impact
1. Primary Deck Element	High
2. Transverse Beams	Medium
3. Secondary Deck Element	Medium
4. Half Joints	Medium
5. Tie beam/rod	Medium
6. Parapet beam or cantilever	High
7. Deck Bracing	Medium
8. Foundations	Low
9. Abutments (incl. arch springing)	High
10. Spandrel wall/head wall	High
11. Pier/Column	High
12. Cross-head/capping beam	High
13. Bearings	Low
14. Bearing plinth/shelf	Low
15. Superstructure Drainage	High
16. Substructure Drainage	Medium
17. Water Proofing	Very High
18. Movement/Expansion Joints	High
19. Finishes: Deck elements	Very High
20. Finishes: Substructure elements	Very High
21. Finishes: Parapets/safety fences	Very High
22. Access/walkways/gantries	High
23. Handrail/parapets/safety fences	High
24. Carriageway surfacing	Very High
25. Footway/verge/footbridge surfacing	Very High
26. Invert/river bed	Low
27. Aprons	Low
28. Fenders/cutwaters/collision protection	Low
29. River training works	Low
30. Revetment/batter paving	Medium
31. Wing Walls	High
32. Retaining Walls	High
33. Embankments	Medium
34. Machinery	Low

Table A.10: Categorisation of element aesthetic impact for Bridges, Culverts, Subways, Tunnels and Earthworks

	Aesthetic Impact			
	Low	**Medium**	**High**	**Very High**
Bridge, Culvert, Subway, Tunnel, Earthwork Element types	8. Foundations 13. Bearings 14. Bearing plinth/shelf 26. Invert/river bed 27. Aprons 28. Fenders/cutwaters/collision protection 29. River Training Works 34. Machinery	2.Transverse beams 3. Secondary deck element 4. Half Joints 5. Tie rods 7. Deck bracing 16. Substructure Drainage 30. Revetment/batter paving 33. Embankments	1. Primary Deck Elements 6. Parapet beam 9. Abutments 10. Spandrel wall/head wall 11. Pier/column 12. Cross-head/capping beam 15. Superstructure Drainage 18. Expansion joints 22. Access/walkways/gantries 23. Handrail/parapets/safety fences 31. Wing walls 32. Retaining walls	17. Waterproofing 19. Finishes: Deck elements 20. Finishes: Substructure elements 21. Finishes: Parapets/safety fences 24. Carriageway surfacing 25. Footway/verge/Footbridge surfacing

Table A.11: Element Aesthetic Impact for Retaining Walls, River Walls and Reinforced/strengthened soil/fill structures with hard facings

Element Type	Aesthetic Impact
1. Foundations	Low
2. Primary Element	High
3. Secondary Element	High
4. Parapet beam/plinth	High
5. Drainage	Medium
6. Movement/Expansion Joints	High
7. Finishes: Wall	Very High
8. Finishes: Handrail/Parapet	Very High
9. Handrail/Parapets/Safety Fences	High
10. Carriageway: Top of Wall	Very High
11. Carriageway: Foot of Wall	Very High
12. Footway/verge: Top of Wall	Very High
13. Footway/verge: Foot of Wall	Very High
14. Embankment: Top of Wall	Medium
15. Embankment: Foot of Wall	Medium
16. Invert/river bed	Low
17. Aprons	Low

Table A.12: Categorisation of element aesthetic impact for Retaining Walls, River Walls and Reinforced/strengthened soil/fill structures with hard facings

	Aesthetic Impact			
	Low	**Medium**	**High**	**Very High**
Retaining Wall, River Wall, Reinforced/strengthened soil/fill/structure with hard facings Element types	1.Foundations 16. Invert/river bed 17. Aprons	5. Drainage 14. Embankment: Top of Wall 15. Embankment: Foot of Wall	2. Primary Element 3.Secondary Element 4. Parapet beam/plinth 6. Movement/Expansion Joints 9. Handrail/Parapets/Safety Fences	7. Finishes: Wall 8. Finishes: Handrail/Parapet 10.Carriageway: Top of Wall 11.Carriageway: Foot of Wall 12. Footway/verge: Top of Wall 13. Footway/verge: Foot of Wall

Table A.13: Element Aesthetic Impact for Sign/Signal Gantries

Element Type	Aesthetic Impact
1. Foundations	Low
2. Truss/Beams/Cantilevers	High
3. Transverse Members	High
4. Columns/Supports/Legs	High
5. Finishes: truss/beam/cant.	Very High
6. Finishes: columns/supports	Very High
7. Finishes: other elements	Very High
8. Access walkway/deck	High
9. Access Ladder	High
10. Handrails	High
11. Base Connections	Low
12. Support to longitudinal connection	Low
13. Sign and signal supports	Medium

Table A.14: Categorisation of element aesthetic impact for Sign/Signal Gantries

	Aesthetic Impact			
	Low	**Medium**	**High**	**Very High**
Sign/Signal Gantry Element types	1. Foundations 11. Base Connections 12. Support to longitudinal connection	13. Sign and signal supports	2. Truss/Beams/Cantilevers 3. Transverse Members 4. Columns/Supports/Legs 8. Access walkway/deck 9. Access Ladder 10. Handrails	5. Finishes: truss/beam/cant. 6. Finishes: columns/supports 7. Finishes: other elements

Table A.15: Aesthetic Score for an Element

		Aesthetic impact of whole structure		
		Low – all other structures	Medium – structures at prominent location	High – listed structures
Aesthetic impact of element (from Table A.9 – Table A.14)	Low	0	20	40
	Medium	20	40	60
	High	40	60	80
	Very High	60	80	100

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