Task No: YY86731

Guidance Document for Performance Measurement of Highway Structures

Part A: Framework for Performance Measurement

Report prepared by:

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Report prepared on behalf of:

Highways Agency

CSS Bridges Group

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Acknowledgements

Atkins was commissioned by the Highways Agency to develop a suite of performance measures for highway structures. The commission was subsequently extended with funding from the Department for Transport to ensure the performance measures developed were also appropriate for use by Local Highway Authorities.

Two groups were set up to oversee the development of the performance measures:

Steering Group – to review progress, provide comments and guidance, and accept project deliverables.

Consultation Group – to establish the needs of a diverse range of authorities across the country, to provide feedback on the work performed, and to try and achieve a consensus across the bridge engineering community.

The composition of the two Groups is shown in the table below.

Organisation	Representative
Steering Group	
Highways Agency	Martin Potts (May 2002 to November 2003)
Highways Agency	Awtar Jandu (October 2003 onwards)
CSS	Mike Young (Suffolk)
CSS	Dr Roger Cole (Lancashire)
CSS	Graham Hollett (Derbyshire)
CSS	Peter Brown (Oxfordshire)
Consultation Group	
Highways Agency	Martin Potts (May 2002 to November 2003)
Highways Agency	Awtar Jandu (October 2003 onwards)
CSS	Mike Young (reporting to CSS Bridges Group)
Department for Transport	Ian Holmes & Andrew Oldland
Welsh Assembly Government	John Collins
Scottish Executive	Raymund Johnston
Northern Ireland Office	Ronnie Wilson
Network Rail	Lenny Aristodemou & Alan Dray
Transport for London	Dana Skelly
London Underground	Brian Thorne
LoBEG	Richard McFarlane & David Yeoell

The contribution of all the above organisations and individuals is gratefully acknowledged.

Technical support was provided by Dr Garry Sterritt and Dr Navil Shetty of Atkins.

1. Introduction

1.1 Performance Measures for Highway Structures

This document describes the framework for, and overall context of, performance measurement. The performance measures are contained within one guidance document that contains five stand alone parts:

- Part A: Framework for Performance Measurement
- Part B1: Condition Performance Indicator
- Part B2: Availability Performance Indicator
- Part B3: Reliability Performance Indicator
- Part C: Measuring the Structures Backlog

Part A describes the background and the overall framework for the evaluation, interpretation and use of performance measurement in the management of highway structures.

1.2 Definitions of Performance Measures

The definitions for the four Performance Measures covered by this Guidance Document are as follows:

- **Condition PI** – A measure of the physical condition of the highway structure stock.
- **Availability PI** – A measure of the reduction in the Level of Service provided, on a highway network, due to restrictions placed on highway structures.
- **Reliability PI** – A representation of the ability of the structure stock to support traffic, and other appropriate loading, taking into account the consequence of failure.
- **Structure Backlog** – The monetary value of work required to close the gap between the actual performance provided by an asset and the current required performance.

1.3 Implementation of Highway Structure Performance Measures

Performance Measures have been developed and implemented in many Government sectors (Health, Education, Social Services) and also for roads (through the UKPMS and HAPMS systems). Experience from these sectors has shown that implementation of Performance Measures raises many issues that need to be widely discussed. As such, this set of Performance Indicators has gone through an extensive trialling and consultation period, and amendments have been made based on the feedback received.

It is envisaged that authorities will adopt this set of Performance Indicators, along side their local measures, and embed them within their asset management practices, as set out in the Code of Practice (Ref. 1).

1.4 Performance Measures and Performance Indicators

The terms *Performance Measure* and *Performance Indicator* are used in accordance with the definitions provided in the Government paper *A Framework for Performance Information* (Ref. 2). *Performance Measure* is the generic term used to cover both *Measures* and *Indicators* and these are in turn defined as:

- **Performance Measure** – measuring performance against a robust scale.
- **Performance Indicator** – a proxy used when it is not feasible to develop a clear and simple measure.

1.5 Background

Highway structures represent a significant publicly owned asset that form an integral part of the transport infrastructure and often form prominent features of the community and its heritage. Adopting the principles of Asset Management is fundamental to the effective long-term management and preservation of these assets (Ref. 1). The need to develop tools and procedures to support effective Asset Management of highway structures is widely recognised.

In 2000 the CSS report, Funding for Bridge Maintenance (Ref. 3), identified the need for a Bridge Condition Indicator that could be used to measure and monitor the condition of highway bridges. In April 2002 the CSS published Guidance Documents for Bridge Inspection Reporting (Ref. 4) and Evaluation of the Bridge Condition Indicator (BCI) (Ref. 5). However, it was widely recognised that the Condition Indicator alone would not be sufficient to measure the overall performance, or *fitness for purpose*, of a stock of highway structures and the performance of a highway authority in managing the structures stock.

In May 2002 the Highways Agency (HA) commissioned the development of a balanced set of Performance Measures for trunk road and motorway structures. The commission was subsequently extended to ensure the Performance Measures were also appropriate for use by Local Highway Authorities.

1.6 The Need for Performance Measures

In recent years there has been a growing awareness of the need for highway authorities to adopt a formal asset management approach, see the Code of Practice (Ref. 1) and the *Framework for Highway Asset Management* (Ref. 6). Performance measurement and monitoring are an integral and important component of good Asset Management.

Performance measurement plays a major role in influencing human behaviour, as "*what gets measured, gets done*", and therefore is seen as key to achieving significant improvements in performance. Performance measurement is a mechanism by which audit, review and improvement are achieved. These are fundamental elements of Asset Management and the Government's recent and current initiatives (e.g. Best Value Legislation, Whole of Government Accounts and Gershon Efficiency) which seek to achieve continual improvement in performance through measurement, target setting and benchmarking.

By comparing Performance Measures against identified targets and goals, the strengths and weaknesses in performance can be identified. By monitoring the measures over time warnings of progressive degradation in performance can be identified so that corrective action can be taken at an early stage. Thus Performance Measures provide important inputs to the decision-making processes relating to management of existing assets.

1.7 Objectives of Highway Structure Performance Measures

Performance Measures for a structure stock should measure both the performance of the **structures management function** and the performance of the **structure stock** itself. The following are considered as the main objectives for developing Performance Measures for highway structures:

1. For external reporting (public, customer, Government) to demonstrate how well the organisation/authority is achieving its objectives with regard to structures management.
2. As part of the Modernising Government initiatives which aim to achieve continual improvement in the quality and efficiency of service delivery.
3. To provide feedback for planning and management control by identifying deteriorating trends in time to allow corrective action to be taken.
4. To compare current performance levels against target levels. Where the target levels are defined in accordance with the *Organisational Strategic Plan* and *Asset Management Plan* (see Ref. 1 for definitions of these).
5. To inform business planning and funding allocations to different functions, routes, groups of structures by type and/or geographical area; and
6. To provide a mechanism for reviewing, auditing and identifying areas for improvement at an operational level.

1.8 Interpreting Performance Measures

This Guidance Document describes four Performance Measures (Condition, Availability, Reliability and Backlog). These measures must **<u>not</u>** be used in isolation for decision making and/or external reporting because individually they do not capture the full performance and functionality (or *fitness for purpose*) of a structure stock.

Formal relationships between the different Performance Measures have not been developed. It is the responsibility of the bridge manager to understand, through the guidance provided, the criteria included in each Performance Measure and therefore appreciate how a change in one measure may, or may not, be reflected in the other Performance Measures.

1.9 Scope

The performance measurement Guidance Document, Parts A, B and C, is intended to:

1. Cover the main highway structure types of bridges, larger and small culverts, retaining walls, road tunnels, sign/signal gantries and high masts.

2. Recommend consistent procedures for the evaluation of highway structure Performance Measures (Condition, Availability, Reliability and Structures Backlog).

3. Provide Performance Measures that can be readily adopted and implemented by all authorities with minimal additional data collection.

4. Provide Performance Measures that are meaningful and beneficial to engineers and managers at *Operational*, *Tactical* and *Strategic* management levels.

1.10 Terminology

The following terminology is used in the performance measurement guidance documents:

- **Authority** – refers to any authority or organisation that owns/manages highway structures.

- **Tactical Sets** – groups of structures defined by similar characteristics e.g. structural form, material type, network corridor etc. The Performance Measures for Tactical Sets inform decision making (e.g. funding allocations) at the *Tactical* planning level of Asset Management.

2. Performance Measurement Framework

2.1 General

Experience of using performance measurement in different sectors has shown that, to be successful, the Performance Measures should be clearly linked to the strategic objectives of an organisation. This ensures that the effort is focused on *what really matters* and allows the organisation to demonstrate how well it is meeting its objectives. At the same time it is important to ensure that the chosen Performance Measures form a balanced set covering all the different dimensions of an organisation's function. Otherwise, effort may be focused on those aspects that are being measured and there is a danger that the remaining functions would be overlooked. In this context, the Government paper, *A Framework for Performance Information* (Ref. 2), provides guidance on the criteria and dimensions that should be considered when developing Performance Measures, some of the important considerations are summarised in Table 1.

Table 1 Dimensions for a Performance Measurement Framework

Dimension	Description
Strategic Objectives	Why the service exists and what it seeks to achieve?
Cost/Efficiency	The resources committed to the service and the efficiency with which they are turned into outputs.
Service Delivery Outcomes	How well the service is being operated in order to achieve the strategic objectives?
Quality	The quality of the service delivered, explicitly reflecting users' experience of service.
Fair Access	Ease and equality of access to services.

Apart from this high level government advice (Ref. 2) it has largely been left to the individual sectors (Health, Social Services, Education, Transport etc.) to develop and implement Performance Measures that best reflect the services they provide. It is therefore the responsibility of highway structure engineers to:

1. Identify appropriate Performance Measures for highway structures.

2. Develop the performance measurement procedures and provide guidance on how to evaluate them.

3. Describe a procedure for Performance Measure target setting.

4. Describe the Performance Management System, i.e. the process by which the information on measures should be collated and used for audit, review and continual improvement. The Performance Management System should clearly define the roles, responsibilities and procedures involved.

Important: This commission included consultation and discussions to identify the Performance Measures (point 1 above) and the development of a *Guidance Documents* (point 2 above). This document does not address points 3 and 4 above.

2.2 Performance Measurement Framework for Highway Structures

A questionnaire survey was carried out (in 2002) to determine the most important objectives and strategic functions of a wide range of UK highway authorities with regard to the management of a structures stock. Based on the feedback received and further discussions with the Steering Group and the Consultation Group, a balanced set of six Performance Measures was identified as below:

1. *Condition* as a function of severity and extent of damage. This implicitly measures aesthetics and durability and the potential impact on reliability.

2. *Availability* of the structure for use by traffic.

3. *Reliability* of the structure in supporting the traffic loading taking into account the consequences of failure.

4. *Maintenance Backlog* with a view to providing sustainable programmes of work and minimising whole life costs.

5. *Asset Value* as a function of gross replacement cost, depreciation and impairment to identify if maintenance and renewal are preserving, and if appropriate enhancing, the asset base for future generations.

6. *Cost Efficiency* in delivering maintenance and renewal work.

The framework for the six Performance Measures is shown in Figure 1. The first three (Condition, Availability and Reliability) measure the performance, or health, of the **structures stock** while the latter three (Backlog, Asset Value and Efficiency) measure the stewardship and effectiveness of the highway authority in **managing the structure stock**.

In view of the constraints on this commission and the priorities identified from the Questionnaire Survey; the Steering Group and Consultation Group decided that the following four Performance Measures should be developed as a priority under this commission:

1. Condition Performance Indicator (Ref. 1) - building upon the earlier CSS BCI work (Ref. 4 and 5).

2. Availability Performance Indicator

3. Reliability Performance Indicator

4. Structures Backlog

Guidance on Asset Valuation for highway structures can be found in the Guidance Document for Highway Infrastructure Asset Valuation (Ref. 7). At the time of publication of this document no work has been commissioned on a Cost Efficiency performance measure for highway structures.

It is proposed (in Figure 1) that the Condition and Availability PIs are reported externally because they deal with more readily understood criteria. However, the Reliability PI should not be reported externally because it is an engineering concept and may be misinterpreted by the general public.

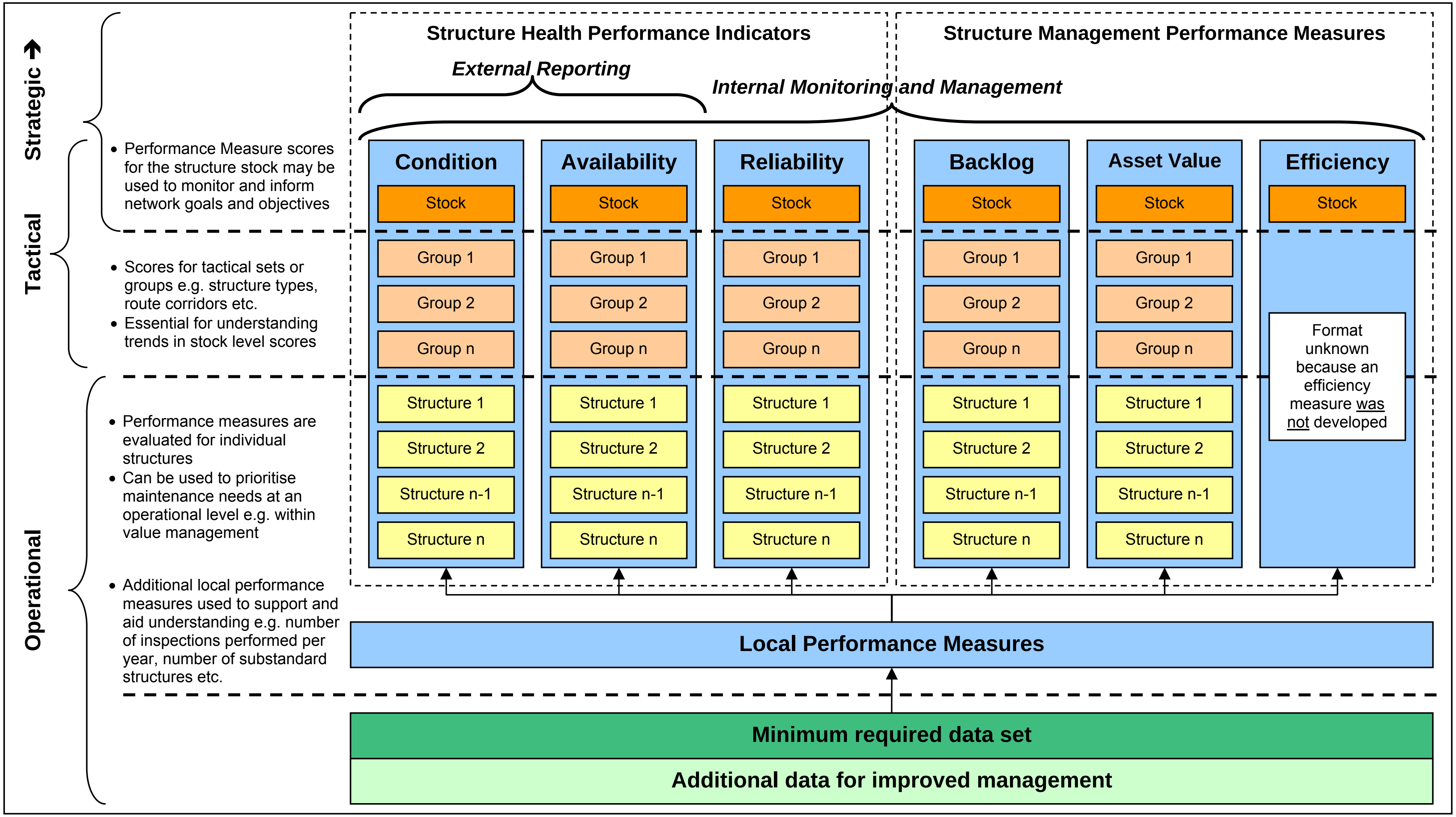

Figure 1 Performance Measurement Framework

3. Performance Measure Information

3.1 General

This section provides an overview of:

1. The boundary/assessment criteria that are used consistently in the performance measurement framework i.e.:

    a. Structure Types (Section 3.2)

    b. Route Types (Section 3.3)

    c. Vehicle Types (Section 3.4)

2. The Performance Indicator scale (Section 3.5).

3.2 Structure Types

The Performance Measures should be applied to all appropriate structure types on an authority's network. Guidance is provided in Parts B1, B2 and B3 on the structures that should be included, however authorities are recommended to check this guidance against the scope of their highway structures stock. As a minimum the structure types covered by the Performance Measures should include.

- Bridges, buried structures, subway underpasses, culverts and any other similar structures
- Sign and/or signal gantries
- High masts
- Tunnels

Suitable definitions for these structures types, and others, are provided in the Code of Practice (Ref. 1), BD62 (Ref. 8) and BD63 (Ref: 9).

3.3 Route Types

The route type hierarchy used by the Performance Measures is shown in Table 2. The Route Types enable a refined, but not overly complex, level of assessment in the performance measurement procedures.

Table 2 Route Types

Route Types
Motorway
Primary A
Other Principal Roads
Classified B and C
Unclassified U
Non-vehicular routes

3.4 Vehicle Types

The vehicle type categories defined in DMRB (Ref. 10) were used to analyse traffic. The characteristics of each vehicle type category were used to establish the economic and social impact of different restrictions types. The six vehicle categories used in the development of the performance measurement procedures were:

1. Cars
2. Light Goods Vehicles (LGV)
3. Other Goods Vehicle 1 (OGV1)
4. Other Good Vehicles 2 (OGV2)
5. Buses and coaches (PSV)
6. Emergency Vehicles (EV).

3.5 Scale for Performance Indicator Reporting

The scale for the Condition, Availability and Reliability Performance Indicators is 0 (worst performance score) to 100 (best performance score), whereas the Structures Backlog is a monetary value of the work identified on the structures stock.

The 0 to 100 scale is subdivided into six bands for ease of understanding. The six bands can be broadly interpreted as shown in Table 3.

Table 3 Performance Categories

PI Score	Generic Category Description
$90 \le x \le 100$	**Very Good** performance
$80 \le x < 90$	**Good** performance
$65 \le x < 80$	**Fair** performance
$40 \le x < 65$	**Poor** performance
$0 \le x < 40$	**Very Poor** performance

More detailed interpretations for each Performance Indicator are provided in the relevant part of the Guidance Document.

4. Using Performance Measures

4.1 General

Performance measures may be used to support bridge managers/engineers in a number of different ways (some of which are discussed below). For all of these the bridge manager should seek to adopt and maintain a standardised format of reporting (i.e. graphs, statistics), thereby enabling easy comparison of values from year to year.

Examples of where the highway structure Performance Measures may be used include:

1. External and internal reporting - an authority should give careful consideration as to whether or not external reporting of Performance Measures for highway structures is required, and if so who should they be reported to, e.g. all stakeholders or only those stakeholders that require or have requested them,

2. Supporting funding bids and forward work planning, i.e. Spending Reviews, Local Transport Plan or Local Implementation Plans, Asset Management Plans etc (see Section 4.2)

3. Supporting management decisions (see Section 4.3).

4.2 Supporting Funding Bids

Many authorities are required to submit bids for funding that cover the next 3 to 5 year period. The bid submission should include up-to-date Performance Measure scores that accurately reflect the current status of the stock.

It is likely that the Authority's Annual Report and/or Business Plans will only include a small number of high level scores for highway structure Performance Measures. This is to be expected given the wide range of assets and services many authorities own and manage. However, in funding/bidding submissions (e.g. Asset management Plans) more effective use should be made of the Performance Measures; in particular the high level scores should be supported by:

1. Scores for tactical sets of structures, e.g. structural type, construction form, material type, location, route etc.
2. Histograms to demonstrate the spread of scores within the stock.
3. Simple statistics to illustrate the percentage of structures in each performance category, i.e. Very Good, Good, Fair, Poor, Very Poor and Severe.
4. Projections/estimates of the impact of reduced funding levels on future Performance Measure scores.

4.3 Supporting Management Decisions

Chapter 3 of the Code of Practice (Ref. 1) sets out an asset management approach for highway structures. This includes a description of the role of Performance Measures, and how they help to link together the *Strategic*, *Tactical* and *Operational* management levels. The Performance Measures can be used to provide vital information for business planning and management control at these three management levels within an organisation. Figure 2 provides an example of how the Performance Measures may be used to support decision making.

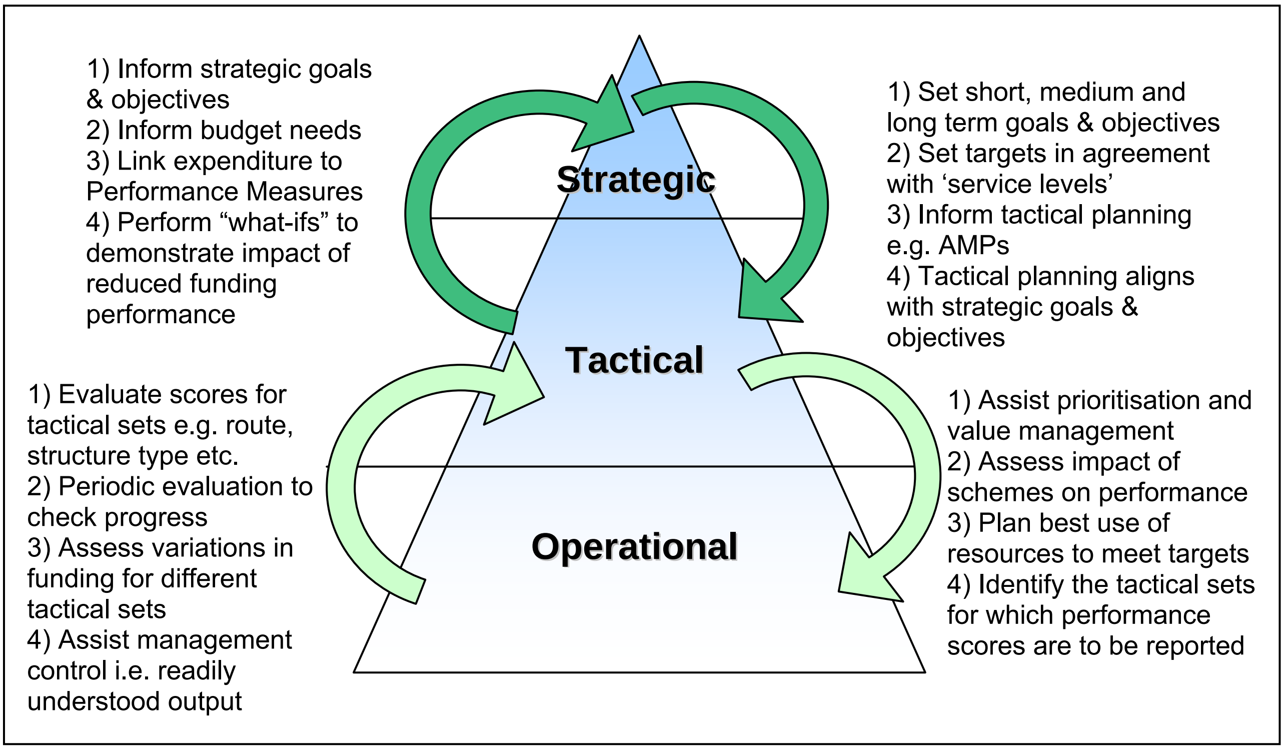

Figure 2 Performance Measurement in Structures Management

5. Implementing Performance Measures

5.1 Resource Requirements

When implementing Performance Measures an authority needs to give full consideration to the resources required. The main areas that require resource input from the authority are:

1. Data collection:

    a. Regular/cyclic data collection, e.g. General and Principal Inspections.

    b. One off data collection exercises, e.g. geometry, obstacle crossed, road carried, assessed capacity/rating etc.

2. Data entry onto a computerised system, e.g. the resources required to enter data onto an appropriate computerised system. This may include the transfer of data from paper records or from another computerised system.

3. Data management - reviewing, auditing and updating when changes to data occur, e.g. maintenance, renewal, new build, change of ownership etc.

4. Software Systems – development or purchase of appropriate software systems that assist the evaluation, analysis and manipulation of the Performance Measures and their associated data.

5. Training – in order to effectively implement and use the Performance Measures an authority's staff may require training to fully understand the measures, manage the data requirements, produce reports and link them into the management process.

It is recommended that an authority gives due consideration to implementing the above, where appropriate, as part of the evolving Asset Management practices. The associated resource requirements should be presented in the structures Asset Management Plan.

5.2 Data Requirements

The essential data required for each Performance Measure are described in Parts B1, B2, B3 and C respectively. A significant proportion of the data requirements overlap with existing data held by authorities, however if an authority identifies that a significant data collection exercise is required then they should consider:

1. A dedicated one off data collection exercise; or

2. Additional data item/s collected during General or Principal Inspections.

Where possible, an authority should give due consideration to other data requirements when compiling Performance Measure data, e.g. Asset Valuation, Risk Assessment and Management and Asset Management Plans (AMPs).

5.3 Software Systems

The ever increasing need to justify and demonstrate the benefit of highway structure expenditure has necessitated the development of a number of management tools and processes, e.g. Performance Measures, Asset Valuation, Risk Assessment, Prioritisation Systems, AMPs etc.

The large number of management tools that will become available over the next 2 to 3 years, and the associated pressures on structure owners and managers to make effective use of them, means it is essential that appropriate support software is developed, implemented and used. It is recommended that an authority considers their current situation and assess where they will need to be in the next 2 to 3 years to meet Government requirements and Asset Management needs. It is the responsibility of all authorities to fully investigate their software support options e.g.:

- Develop a bespoke system or purchase an off-the-shelf commercial package.
- Have a stand alone highway structures package, an integrated highways package or an authority wide package.
- The demands of the stock size, i.e. can expensive software packages be justified for smaller authorities.
- Joining up with other authorities to reduce the individual cost and/or risk of developing or purchasing software systems.

The Code of Practice (Ref. 1) provides further guidance on the requirements of a Bridge Management System.

6. References

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2. Choosing the Right Fabric, A Framework for Performance Measurement, HM Treasury, Cabinet Office, National Audit Office, Audit Commission and Office for National Statistics, March 2001.

3. Funding for Bridge Maintenance, Report by CSS Bridges Group, February 2000.

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5. Bridge Condition Indicator Volume 3, Guidance Note on Evaluation of Bridge Condition Indicators, CSS Bridges Group, April 2002.

6. Framework for Highway Asset Management, CSS, June 2004.

7. Guidance Document for Highway Infrastructure Asset Valuation, CSS/TAG Asset Management Working Group, July 2005, TSO.

8. BD62, As built, operational and maintenance records for highway structures (DMRB 3.2.1).

9. BD63, Inspection of Highway Structures (DMRB 3.1.4).

10. DMRB, Volume 14, Section 1, Part 5: The traffic input to QUADRO.

Task No: YY86731

Guidance Document for Performance Measurement of Highway Structures

Part B1: Condition Performance Indicator

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1. Introduction

This document is based upon and supersedes the *CSS Bridge Condition Indicator: Volume 2: Guidance Note on Evaluation of Bridge Condition Indicators* (Ref. 1).

1.1 Condition Performance Indicator Definition

The Condition PI is defined as:

A measure of the physical condition of the highway structures stock.

1.2 Background, Objectives and Scope

The background, objectives and scope are discussed in *Part A: Framework for Performance Measurement*.

1.3 Terminology

The following terminology is used in the Condition PI procedure:

- **Bridge Condition Indicator (BCI)** – the term used for the Condition PI when it was originally developed by the CSS Bridges Group (Ref. 1).
- **Condition Performance Indicator (Condition PI)** – the generic term used for the Condition PI. For external reporting the Condition PI refers to the highway structure stock, but for internal management/reporting the Condition PI may be used at structure group and individual structure level. The Condition PI is calculated on a scale of 100 (best condition) to 0 (worst condition).
- **Severity and Extent** – approach used in some inspection reporting systems to assess and record the condition of individual structure elements and/or defects. The HA and CSS severity/extent inspection reporting systems can be used directly with the Condition PI.
- **Element Condition Score (ECS)** – the numerical value of the condition of an element evaluated using inspection data (e.g. Severity and Extent) on a scale of 1 (best condition) to 5 (worst condition).
- **Element Importance** – this takes account of the importance of an element to the overall structure in terms of load carrying capacity, durability and public safety, it is designated as Low, Medium, High or Very High. The Element Importance classification is used to identify two factors:
  - **Element Condition Factor (ECF)** – used to weight the ECS to obtain the ECI, this enables direct comparison of element conditions in terms of their contribution to the overall structure condition.
  - **Element Importance Factor (EIF)** – used to weight individual ECI scores (see below) when evaluating the average Structure Condition Score, SCS_{Av} (see below).

- **Element Condition Index (ECI)** – the weighted element condition based on the ECS and ECF.

- **Structure Condition Score (SCS)** – an average and a critical SCS score are evaluated for each structure, where:

    - $\mathbf{SCS_{Av}}$ – the weighted average of all the ECI scores for the structure, the ECI scores are weighted by their respective EIF. The score is on the 1 (best condition) to 5 (worst condition) scale.

    - $\mathbf{SCS_{Crit}}$ – equal to the ECI of the Very High importance element on the structure that is in the worst condition. The score is on the 1 (best condition) to 5 (worst condition) scale.

- **Condition $\mathbf{PI_{Av}}$** – the conversion of the SCS_{Av} score to a more readily understood and presentable 100 (best condition) to 0 (worst condition) scale.

- **Condition $\mathbf{PI_{Crit}}$** – the conversion of the SCS_{Crit} score to a more readily understood and presentable 100 (best condition) to 0 (worst condition) scale.

- **Condition $\mathbf{PI_{i\text{-}Av}}$ and Condition $\mathbf{PI_{i\text{-}Crit}}$** – the *Average* and *Critical* Condition PI scores for structure type group *i*, e.g. bridges, retaining walls etc. The structure group score is the weighted average of the individual Condition PI scores. The weighting is based on the dimensions of the structure, e.g. deck area for bridges, surface are for retaining walls etc. The subscript acronyms used for each structure type are:

    - B = Bridge (also includes culverts)

    - SC = Small Culvert

    - RW = Retaining Wall

    - SG = Sign/Signal Gantry; and

    - HM = High Mast

- **Structure Stock Condition Performance Indicator (SSCPI)** – the Condition PI score for a structure stock is evaluated as the weighted average of the Structure Type Condition PIs, where the Asset Value Factor (AVF) is used to weight the Structure Type score.

- **Asset Value Factor (AVF)** – a weighting factor applied when calculating the Condition PI for a stock of structures, it reflects the importance of one structure type compared to another. An Asset Value Factor (AVF) has been evaluated for each structure type (bridge, retaining wall, sign/signal gantry etc.) based on construction cost data.

2. Overview of Procedure

2.1 General Approach

The Condition PI uses the procedures originally developed for the CSS Bridge Condition Indicator (BCI), Ref. 1 and 2. The Condition PI reiterates the BCI guidance and extends the procedures to cover other structure types (small culverts and high masts) and a more refined level of condition reporting where required.

The Condition PI procedure has been developed for use with the CSS and HA Severity/Extent condition rating systems (see Ref. 3 and 4 respectively). However, condition data collected using other systems can be translated to the aforementioned severity/extent scale if required. The Condition PI is evaluated using condition data collected during General and Principal Inspections.

Inspections should be performed by a suitably qualified inspector or engineer who is capable of applying an appropriate level of engineering understanding and interpretation to the visual information they encounter on-site. Therefore, the Condition PI, in many circumstances, is more than a straightforward reporting of "visual" condition.

2.2 Condition PI Scale

The Condition PI scale is from 0 to 100, where 0 represents the worst possible condition for the structure or stock and 100 represents the best possible condition. Individual structures, structure groups and the structure stock are all reported on the 0 to 100 scale. The scale is divided into five bands (Very Good, Good, Fair, Poor and Very Poor), generic interpretations for these bands are presented in Section 6.

2.3 Condition PI Score

All structures that have regular General and/or Principal Inspections should have a Condition PI score evaluated. The condition score is built up to structure level from the defect and element severity/extent scores. The individual structure scores are used to evaluate the group scores which are weighted by typical dimensions, e.g. deck area for bridges, length for retaining walls etc. The group scores are used to evaluate the stock score which is weighted by the Asset Value Factor (AVF) of each structure type.

2.4 Steps in the Condition PI Procedure

The overall procedure is shown in Figure 1 and summarised below:

Step 1 – Select Structure Type and Structure

The Condition PI procedure uses weightings linked to *Structure Type*, therefore each *Structure Type* needs to be dealt with separately before they are combined to give the Condition PI for the *Structure Stock*. First select the *Structure Type*, i.e. Bridge, Retaining Wall, Sign/Signal Gantry etc., and secondly select an individual structure.

Step 2 – Select Element and Evaluate the Element Condition Score (ECS)

First, select one element from the structure; secondly use the element's condition data to calculate the Element Condition Score (*ECS*). Section 4.1 describes how element condition data are used to evaluate the *ECS*. Section 5 provides guidance on using condition data when a more detailed level of reporting is used, i.e. condition is reported for each longitudinal beam rather than one condition for the whole group.

Step 3 – Element Importance

The Element Importance accounts for the importance of the element to the overall functionality of the structure, e.g. load carrying capacity, durability and public safety. Tables are provided in Section 4.2 for identifying element importance, i.e. *Very High*, *High*, *Medium* or *Low*. The Element Importance and the *ECS* are used to evaluate the Element Condition Factor (*ECF*), Section 4.3.

Step 4 – Element Condition Index (ECI)

The *ECS* (from Step 2) and *ECF* (from Step 3) are combined to produce the Element Condition Index (*ECI*), Section 4.4. The ECI represents the condition of the element on a scale of 1 (Best) to 5 (Worst). Steps 2 to 4 are repeated for all elements on the structure.

Step 5 – Evaluate Structure Condition Score

Two different Structure Condition Scores are evaluated (Section 4.6)

- SCS_{Av} – this is the weighted average of all the *ECI* values for the structure; they are weighted by the Element Importance Factor, *EIF* (Section 4.5).
- SCS_{Crit} – this is the maximum *ECI* value for those elements considered *critical* to the integrity of the structure, i.e. classified as having *Very High Importance*.

The SCS equations are provided in Section 4.6, the output from each is on the same 1 to 5 scale as the *ECI*.

Step 6 – Evaluate Individual Structure Condition PI

The *SCS* values are converted to the corresponding Condition PIs, i.e. Condition PI_{Av} and Condition PI_{Crit}, on the 0 (Worst) to 100 (Best) scale, Section 4.7. Steps 2 to 6 are repeated for all structures in the *Structure Type* group.

Step 7 – Evaluate Structure Type Condition PI

The weighted average of the *Individual Structure* Condition PI scores produces the *Structure Type* Condition PI, Section 4.8. The weighting used is the characteristic dimensions of the structure, e.g. deck area for bridges, wall area for retaining walls, length for sign/signal gantries and area for small culverts.

Step 8 – Evaluate Structure Stock Condition PI

The weighted average of the *Structure Type* Condition PI scores produces the *Structure Stock* Condition PI (average and critical), see Section 4.9. The weighting used is the *Asset Value Factor (AVF)* of each *Structure Type* and the sum of their respective dimensional quantities (which are evaluated as part of Step 7).

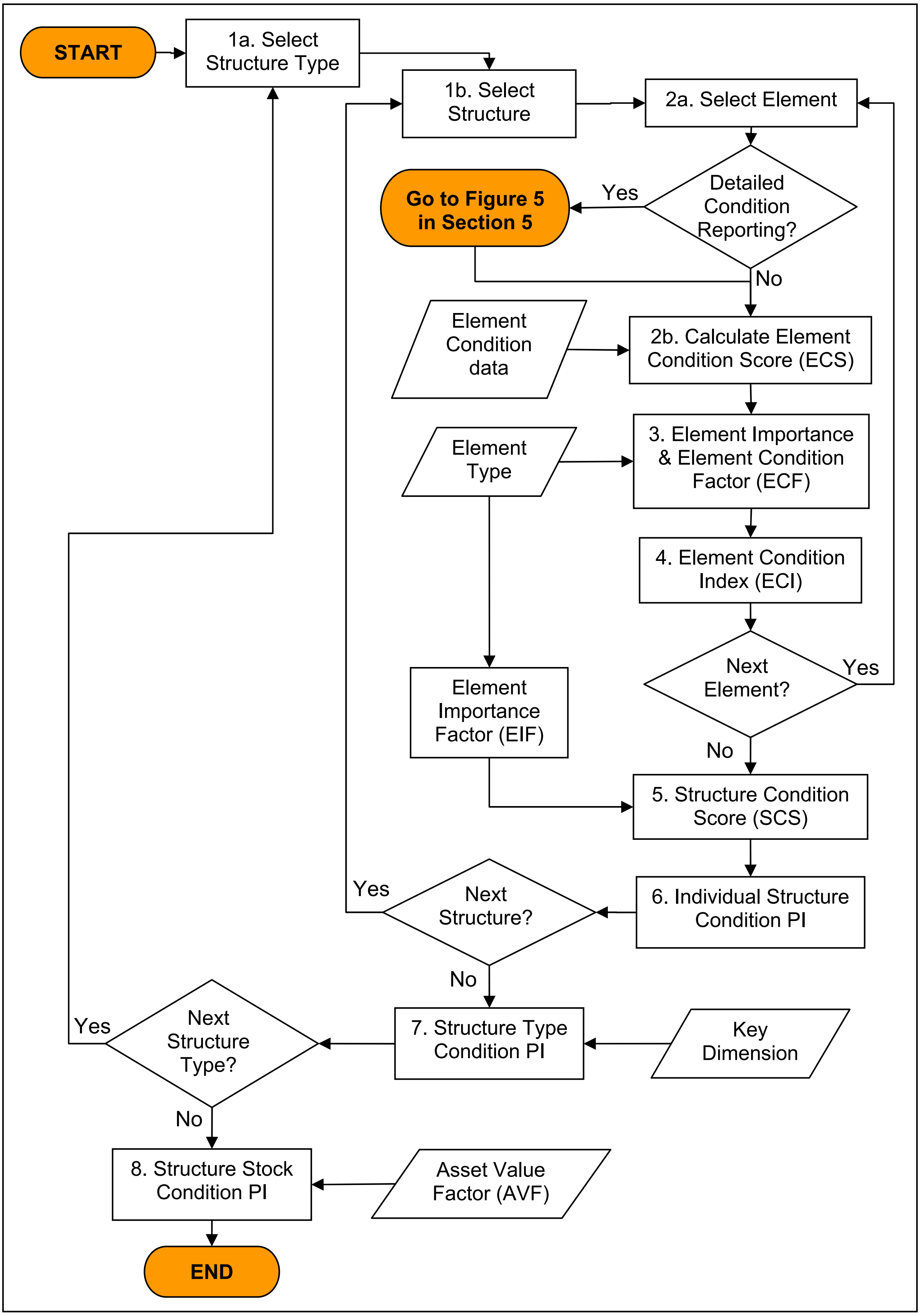

Figure 1 Condition PI Evaluation Procedure

3. Data Requirements

3.1 Relevant structure types

The Condition PI is designed to be applied to all structure types commonly found on the highway network. The typical structure types are shown in Table 1, definitions of the structure types are provided in the Code of Practice, BD62 and BD63 (Refs. 5, 6 and 7).

Table 1 Structure Types

Structure Type	Comment
Bridges and culverts	A standard list of elements and importance classifications are provided in Section 4.2.1
Small culverts (if treated separately from bridges)	Small culverts may be treated separately from bridges, where this is the case a standard list of elements and importance classifications are provided in Section 4.2.2
Retaining Wall	A standard list of elements and importance classifications are provided in Section 4.2.3
Road Tunnel	Road tunnels, as defined in Part A, are not covered by the Condition PI procedure, however, if an authority has a significant number of tunnels they may wish to develop appropriate procedures. To develop a procedure an authority should apply the principles set down in this document and determine a suitable element list with importance classifications
Sign/Signal Gantry	A standard list of elements and importance classifications are provided in Section 4.2.4
High Mast	A standard list of elements and importance classifications are provided in Section 4.2.5
Other structure types	Not covered by the Condition PI. However, if an authority has a significant quantity of other structure types then they may wish to develop an appropriate procedure. To develop a procedure an authority should apply the principles set down in this document and determine a suitable element list with importance classifications

3.2 Essential and Desirable Data

The data required to evaluate the Condition PI is shown in Table 2.

Table 2 Data requirements for Condition PI

Input Data	Type
Condition data	Essential
Element Type	Essential
Structure Type	Essential
Dimensions	Essential
Material type, structural form, year of construction, route etc.	Desirable (for analysis of tactical sets)

4. Evaluating the Condition PI

The following sections describe how the Condition PI is evaluated, building it up from element level to stock level.

4.1 Element Condition Score (ECS)

The first step in evaluating the Condition PI is to determine the Element Condition Score (ECS) for each element based on the condition information obtained from inspections. The CSS BCI Inspection Reporting System (Ref. 3) and HA Inspection System (Ref. 4) use a Severity scale of 1 (Best) to 5 (Worst) and an Extent scale of A (non significant) to E (>50% area affected). The extent and severity values for an element are combined to produce an Element Condition Score (ECS) as specified in:

- Table 3 for the CSS BCI System; and
- Table 4 for the HA Inspection System (see HA SMIS Manuals for explanations of the severity codes, Ref. 4).

The scoring reflects the view that the extent of damage is less critical than the severity of damage.

Table 3 CSS Element Condition Scores (ECS)

<table>
<tr><th rowspan="2">Extent</th><th colspan="5">Severity</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>A</td><td>1.0</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B</td><td></td><td>2.0</td><td>3.0</td><td>4.0</td><td rowspan="4">5.0</td></tr>
<tr><td>C</td><td></td><td>2.1</td><td>3.1</td><td>4.1</td></tr>
<tr><td>D</td><td></td><td>2.3</td><td>3.3</td><td>4.3</td></tr>
<tr><td>E</td><td></td><td>2.7</td><td>3.7</td><td>4.7</td></tr>
</table>

*Shaded boxes represent non-permissible Severity/Extent combinations.

When the condition data is obtained using inspection reporting systems other than the CSS or HA systems, then the harmonisation matrix, Table 5, may be used to translate the condition data to the required scale. The translations in Table 5 may need to be amended to more accurately represent how an individual authority has interpreted/applied a particular inspection system.

Note: If condition data are reported on a more detailed level, e.g. individual beams instead of a group of beams, then the procedure presented in Section 5 should be used to build up the ECS.

Table 4 HA Element Condition Scores (ECS)

		Severity									
CSS Severities		**-**	**1**	**-**	**2**	**3**	**-**	**4**	**-**	**-**	**5**
a) Damage causing defects		-	D1	-	D2	D3	*D3S*	D4	-	*D4S*	D5
b) Paint coatings and protective systems		-	P1	-	P2	P3	-	P4	*P4S*	-	P5
c) Appearance related defects		-	A1	A2	A3	A4	-	-	-	-	-
d) Defects affecting adjacent elements		X1	X2	-	X3	X4	*X4S*	X5	-	-	-
Extent	**A**	1.0	1.0								
	B	1.0	1.0	1.1	2.0	3.0	*3.1*	4.0	*4.1*	*4.2*	5.0
	C	1.0	1.1	1.2	2.1	3.1	*3.2*	4.1	*4.2*	*4.3*	5.0
	D	1.0	1.3	1.4	2.3	3.3	*3.4*	4.3	*4.4*	*4.5*	5.0
	E	1.0	1.7	1.8	2.7	3.7	*3.8*	4.7	*4.8*	*4.9*	5.0

Notes

1. X1 has a score of 1.0 regardless of extent because it does not influence the adjacent element.

2. Appearance related defects (signified by the letter 'A') have lower scores due to their reduced impact on safety, durability and capacity.

3. The *italic* text relates to severity descriptions that refer to public safety. The score is increased by 0.1 when the severity description uses ***may*** or ***likely***; however the score is increased by 0.2 when the severity description uses "***is***", for example, "may be danger to public safety" compared to "is a danger to public safety".

Table 5 Harmonisation Matrix

	Element Condition Score (ECS)																
HA & CSS Scale	**1**	**1.1**	**1.3**	**1.7**	**2**	**2.1**	**2.3**	**2.7**	**3**	**3.1**	**3.3**	**3.7**	**4**	**4.1**	**4.3**	**4.7**	**5**
CSS Inspection System (Ref. 3)	1A, 1B	1C	1D	1E	2B	2C	2D	2E	3B	3C	3D	3E	4B	4C	4D	4E	5
HA BE11 Extent & Severity	1A, 1B	1C	1D	1E	2B	2C	2D		3B	3C	3D		4B	4C	4D		
Lancashire Condition Factor	5					4				3					2		1
PJ Andrews (Ref. 8) Condition Factor						0.9				0.7			0.5		0.3		0.1
Good, Fair, Poor (e.g. Cheshire)	G									F				P			
Condition Factor (e.g. Northumberland)	*					3				2				1			

4.2 Element Importance Classification

The Element Importance Classification reflects the importance of an element to the overall structure in terms of:

- Load carrying capacity.
- Durability, and
- Public safety.

Depending on the function performed by an element and its importance to the overall functioning of the structure, the importance of an element is designated as *Very High*, *High*, *Medium* or *Low*. The element importance classifications for each structure type are shown in:

- Table 6 for Bridges and Culverts.
- Table 9 for Small Culverts (if treated separately to bridges)
- Table 10 for Retaining Walls.
- Table 11 for Sign/Signal Gantries; and
- Table 12 for High Masts.

If the inspection reporting system currently used by an Authority contains elements other than those given in the following tables then their element importance should be assigned based on the equivalent element table shown in Appendix A.

4.2.1 Bridges

Table 6 Element Importance Classifications for Bridges

CSS Element Number	Element Description	Element Importance
1	Primary deck element (see Table 7)	Very High
2	Transverse Beams	Very High
3	Secondary deck element (see Table 8)	Very High
4	Half joints	Very High
5	Tie beam/rod	Very High
6	Parapet beam or cantilever	Very High
7	Deck bracing	High
8	Foundations	High
9	Abutments (incl. arch springing)	High
10	Spandrel wall/head wall	High
11	Pier/column	Very High
12	Cross-head/capping beam	Very High
13	Bearings	High
14	Bearing plinth/shelf	Medium
15	Superstructure drainage	Medium
16	Substructure drainage	Medium
17	Water proofing	Medium
18	Movement/expansion joints	High
19	Finishes: deck elements	Medium
20	Finishes: substructure elements	Medium
21	Finishes: parapets/safety fences	Medium
22	Access/walkways/gantries	Medium
23	Handrail/parapets/safety fences	High
24	Carriageway surfacing	Medium
25	Footway/verge/footbridge surfacing	Low
26	Invert/river bed	Medium
27	Aprons	Medium
28	Fenders/cutwaters/collision protection	Medium
29	River training works	Medium
30	Revetment/batter paving	Low
31	Wing walls	High
32	Retaining walls	Medium
33	Embankments	Low
34	Machinery	Medium
35	Approach rails/barriers/walls	Not included in Condition PI calculation
36	Signs	
37	Lighting	
38	Services	
Additional HA Elements	Diaphragms	High
	Cable Anchor Group	Very High
	Cable System Group	Very High
	Cable Hanger Group	Very High

Lists of typical Primary and Secondary deck element types, which relate to rows 1 and 3 in Table 6, are shown in Table 7 and Table 8 respectively.

Table 7 Primary Deck Elements

Span Structural Form (Primary Deck Element)	
Arch	solid spandrel
	open/braced spandrel
	tied (including hangers)
Beam/Girder	at/below deck surface
	box beams (exterior & interior)
	half through
	filler beam
Truss	at/below deck surface (underslung)
	half through
	full through
Slab	solid
	voided
Culvert/pipe/subway	circular/oval
	box
	portal/U-shape
Troughing	
Cable stayed/suspension	
Tunnel	

Table 8 Secondary Deck Elements

Secondary Deck Element
Buckle Plates
Flat Plate
Jack Arch
Slab
Troughing

4.2.2 Small Culverts

The HA distinguish between small and large culverts, see Part A and also refer to BD62 (Ref. 6), BD63 (Ref. 7) or the SMIS User Manual (Ref. 4) for further information. The Code of Practice (Ref. 5) does not distinguish between small and large culverts and it is recommended that culverts, classified in accordance with the Code of Practice, are dealt within using the bridge guidelines presented in this guidance document.

The list of elements, and their associated importance classifications, that should be used for small culverts, is shown in Table 9.

Table 9 Element Importance Classifications for Small Culverts

CSS Element Number	Element Description	Element Importance
CSS element number not applicable	Culvert	Very High
	Headwall	High
	Parapet/Guardrail/RRS	High
	Wingwall	High
	Revetment	Medium
	Apron	Medium

4.2.3 Retaining Walls

The list of elements, and their associated importance classifications, that should be used for retaining walls is shown in Table 10.

Table 10 Element Importance Classifications for Retaining Walls

CSS Element Number	Element		Element Importance
1	Foundations		High
2	Retaining wall	Primary	Very High
3		Secondary	Very High
4	Parapet beam/plinth		High
5	Drainage		Medium
6	Movement/Expansion joints		Medium
7	Surface finishes: wall		Medium
8	Surfaces finishes: handrail/parapet		Medium
9	Handrail/parapets/safety fences/RRS		High
10	Carriageway	Top of wall	Low
11		Foot of wall	Low
12	Footway/verge	Top of wall	Low
13		Foot of wall	Low
14	Embankment	Top of wall	Low
15		Foot of wall	Low
16	Invert/river bed		Medium
17	Aprons		Medium
18	Signs		Elements not used by Condition Indicator
19	Lighting		
20	Services		
Additional HA Element	Anchoring system		Very High

4.2.4 Sign/Signal Gantries

The list of elements, and their associated importance classifications, that should be used for sign/signal gantries is shown in Table 11.

Table 11 Element Importance Classifications for Sign/Signal Gantries

CSS Element Number	Element	Element Importance
1	Foundations	High
2	Truss/beams/cantilever	Very High
3	Transverse/horiz. bracing elements	Very High
4	Columns/supports/legs	Very High
5	Surface Finishes: truss/beams/cantilever	Medium
6	Surface Finishes: columns/supports/legs	Medium
7	Surface Finishes: other elements	Low
8	Access/walkway/deck	High
9	Access ladder	High
10	Handrails/Guard Rails	High
11	Base connections	Very High
12	Support to longitudinal connection	Very High
13	Sign and signal supports	Medium
14	Signs/Signals	Elements not used by Condition Indicator
15	Lighting	
16	Services	
Additional HA Element	Road Restraint System (RRS)	High

4.2.5 High Masts

The list of elements, and their associated importance classifications, that should be used for high masts is shown in Table 12.

Table 12 Element Importance Classifications for High Masts

CSS Element Number	Element	Element Importance
CSS element number not applicable	Mast	Very High
	Foundation	Very High
	Base Connection	High
	Paint System	Medium
	Lighting	Elements not used by Condition Indicator
	Signs	

4.3 Element Condition Factor, ECF

The Element Condition Factor (ECF) is used to reduce the ECS to reflect the influence the condition of an element has on the condition of the overall structure. It is evaluated using the expressions given in Table 13.

Table 13 Expressions for Element Condition Factor (ECF)

Element Importance	Element Condition Factor (ECF)
Very High	$ECF = 0.0$
High	$ECF = 0.3 - [(ECS - 1) \times 0.3 / 4]$
Medium	$ECF = 0.6 - [(ECS - 1) \times 0.6 / 4]$
Low	$ECF = 1.2 - [(ECS - 1) \times 1.2 / 4]$

4.4 Element Condition Index, ECI

The Element Condition Index (ECI) indicates the contribution the condition of an element makes to the condition of the structure as a whole. The ECI is determined by adjusting the Element Condition Score (ECS) to account for the Element Condition Factor (ECF) as shown below.

$$ECI = ECS - ECF \quad \text{but is always} \geq 1$$

Equation 1

The relationship between the Element Condition Index and the Element Condition Score is shown in Figure 2. This shows that the importance of an element is deemed to influence its impact on the overall condition of the structure, for example:

- A *Very High* importance element with an ECS = 3 has an ECI = 3 whereas a *Medium* importance element with an ECS = 3 has a corresponding ECI = 2.7.

Figure 2 also shows that the impact of the reduction factor decreases as the severity of the defect increases, for example:

- A *Low* importance element with an ECS = 2 has a corresponding ECI = 1.0, however as the condition of the element becomes more severe the reduction decreases, i.e. an ECS = 4 has a corresponding ECI = 3.7.

The ECI for elements of *Very High* importance is the same as the ECS implying that damage on this element is equally critical to the function of the overall structure.

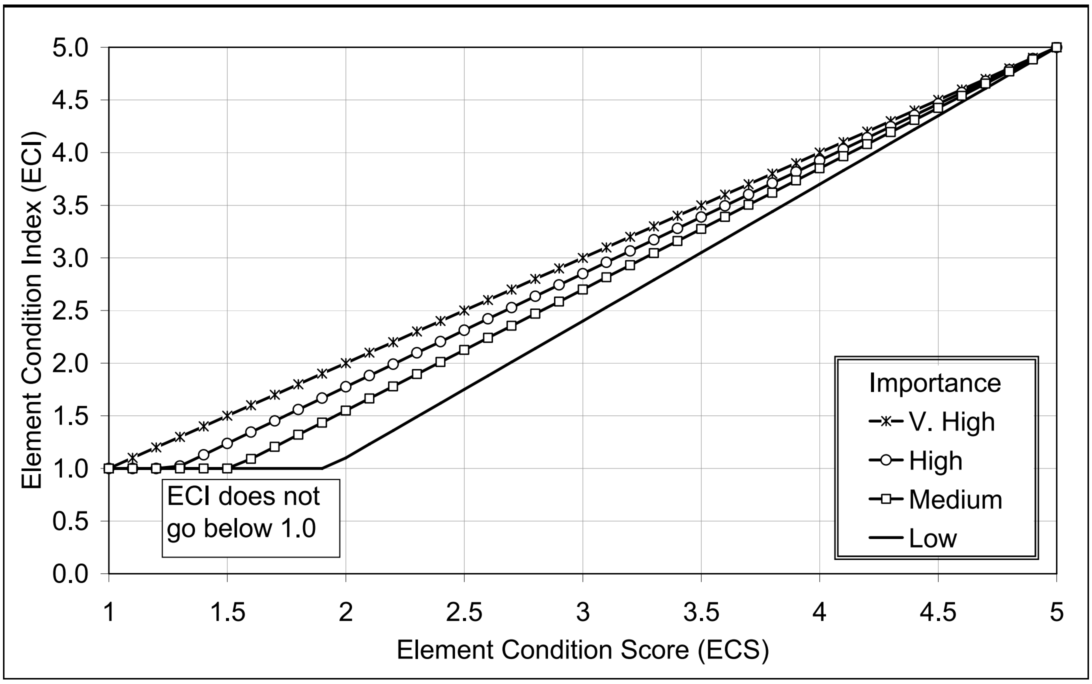

Figure 2 Influence of element importance on the ECI

4.5 Element Importance Factor, EIF

The Element Importance Factor (EIF) is used to weight the ECI values of different elements when evaluating the Structure Condition Score (SCS), see Section 4.6. The EIF represents the importance of the element to the overall functionality of the structure (load carrying capacity, durability and public safety). The EIFs are shown in Table 14.

Table 14 Element Importance Factor (EIF)

Element Importance	EIF
Very High	2.0
High	1.5
Medium	1.2
Low	1.0

4.6 Structure Condition Score, SCS

Two different Structure Condition Scores, SCS_{Av} and SCS_{Crit}, are evaluated using the following expressions. SCS_{Av} considers all the elements in the structure while SCS_{Crit} is based on only those elements which have a *Very High* importance classification. The SCS is on the same scale as the individual elements, that is, 1 indicates best possible condition and 5 the worst possible condition for the structure.

Average Structure Condition Score (SCS_{Av})

$$SCS_{Av} = \frac{\sum_{i=1}^{N}(ECI_i \times EIF_i)}{\sum_{i=1}^{N} EIF_i}$$

Equation 2

where N is the total number of elements on the structure that have an ECI score and:

ECI_i = Element Condition Index for element *i*, from Equation 1 in Section 4.4

EIF_i = Element Importance Factor for element *i*, from Table 14 in Section 4.5

Critical Structure Condition Score (SCS_{Crit})

$$SCS_{Crit} = \max\{\text{ECI for elements with Very High Importance}\}$$

Equation 3

SCS_{Crit} for Bridges

$$SCS_{Crit} = \max\left\{\begin{array}{l}\text{ECI for Primary deck elements}\\ \text{ECI for Transverse beams}\\ \text{ECI for Secondary deck elements}\\ \text{ECI for Half joints}\\ \text{ECI for Tie beam/rod}\\ \text{ECI for Parapet beam/cantilever}\\ \text{ECI for Pier/column}\\ \text{ECI for Cross-head/capping beam}\\ \text{ECI for Cable anchor group *}\\ \text{ECI for Cable system group *}\\ \text{ECI for Cable hanger group *}\end{array}\right\}$$

*signifies additional HA elements

Equation 4a

SCS_{Crit} for Small Culverts

$$SCS_{Crit} = \text{ECI for Culvert}$$

Equation 4b

SCS_{Crit} for Retaining Walls

$$SCS_{Crit} = \max \begin{Bmatrix} \text{ECI for Primary element} \\ \text{ECI for Secondary Element} \\ \text{ECI for Anchoring System} \end{Bmatrix}$$

Equation 4c

SCS_{Crit} for Sign/Signal Gantries

$$SCS_{Crit} = \max \begin{Bmatrix} \text{ECI for Truss/beam/cantilever} \\ \text{ECI for Transverse beams} \\ \text{ECI for Columns/supports/legs} \\ \text{ECI for Base connections} \\ \text{ECI for Support to longitudinal connection} \end{Bmatrix}$$

Equation 4d

SCS_{Crit} for High Masts

$$SCS_{Crit} = \max \begin{Bmatrix} \text{ECI for Mast} \\ \text{ECI for Foundation} \end{Bmatrix}$$

Equation 4e

The SCS_{Av} alone may not give a complete picture of the *health* of a structure. For example, a structure may have a low SCS_{Av} score implying it is in a very good condition, however, the structure may be close to collapse if, for instance, one of the critical elements is in very poor condition, hence the need for the SCS_{Crit}. On the other hand, SCS_{Crit} although giving an indication of the criticality of the structure, does not provide an indication of how widespread the deterioration is over the whole structure. Therefore, both of these indicators should be used to obtain a more complete picture of the health of a structure.

4.6.1 Incomplete Inspections

When the inspector has been unable to inspect an element on site the condition should be recorded as *NI* (Not Inspected). In such cases the condition data recorded at the latest inspection (General or Principal) or, if more recent, the condition recorded after the completion of maintenance work, should be used when evaluating the SCS. If there is no previous data available then this element should not be included when evaluating the *SCS*. “Not Inspected” data should be used to:

- Indicate which structures received an incomplete inspection and identify what action is required to enable a complete inspection; and
- Create an annual measure of the number or percentage of incomplete structure inspections.

4.7 Condition Performance Indicator

The Structure Condition Score (SCS) has the same scale as the Element Condition Score (ECS), i.e. 1 (Best) to 5 (Worst), and can in general be interpreted in an analogous way to the ECS. However, this scale is considered to be somewhat difficult to understand and confusing for those outside highway structure engineering. Therefore, a Condition PI is introduced which is defined on a scale of 100 (best possible condition) to 0 (worst possible condition). Guidance on the interpretation and use of SCS and Condition PI scores is given in Section 6.

The SCS_{Av} and SCS_{Crit} values are converted to the corresponding Condition PI_{Av} and Condition PI_{Crit} values using Equations 5 and 6 and as shown in Figure 3. The non-linear relationship reflects the fact that as the SCS value increases from 1 to 5, the structure condition deteriorates progressively more rapidly.

Average Condition PI for an Individual Structure

$$\text{Condition } PI_{Av} = 100 - 2\left\{(SCS_{Av})^2 + (6.5 \times SCS_{Av}) - 7.5\right\}$$

Equation 5

Critical Condition PI for an Individual Structure

$$\text{Condition } PI_{Crit} = 100 - 2\left\{(SCS_{Crit})^2 + (6.5 \times SCS_{Crit}) - 7.5\right\}$$

Equation 6

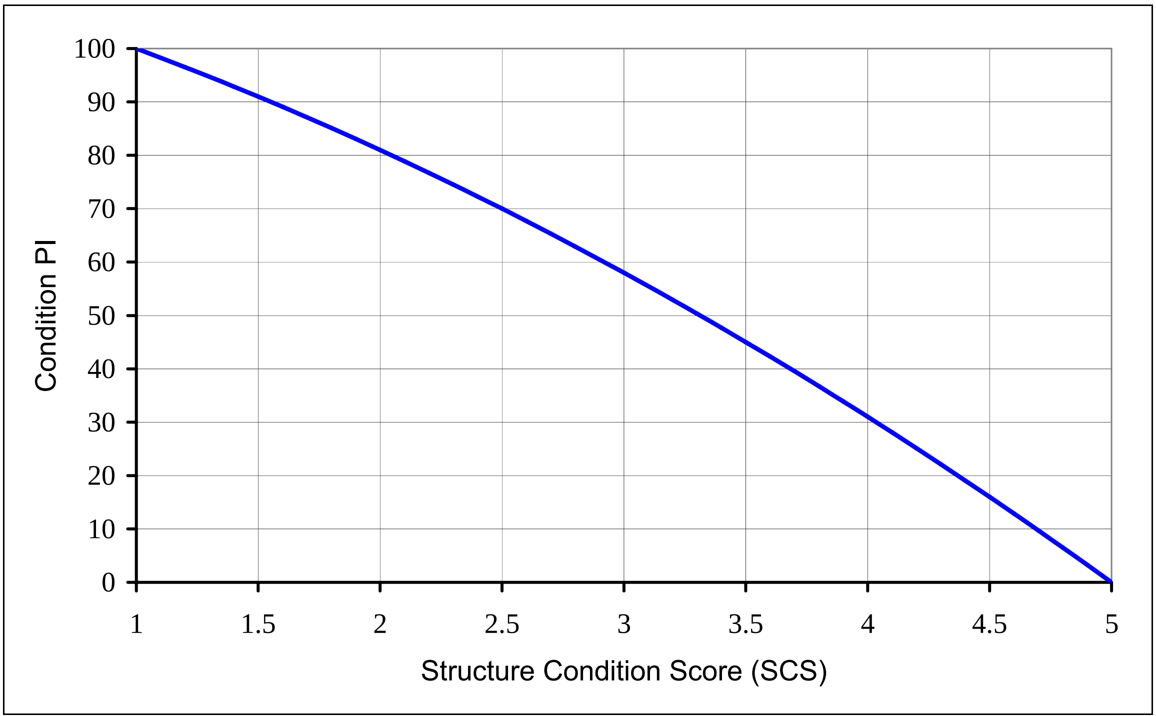

Figure 3 Relationship between SCS and Condition PI

4.8 Structure Type Condition PI

In aggregating the Condition PI values for a *Structure Type* group, the differences in the size and type of structures should be recognised. If size is not considered then, for example, large multi-span bridges carrying four or more traffic lanes which require higher maintenance funding would be unfairly treated compared to small single span bridges carrying one or two lanes of traffic.

4.8.1 Condition PI for Bridges

The Condition PI's for bridges are evaluated using Equations 7a and 7b.

Condition PI for Bridges

$$\text{Condition PI}_{\text{B-Av}} = \frac{\sum_{i=1}^{M}\left(\text{Condition PI}_{\text{Av-i}} \times \text{Deck Area}_i\right)}{\sum_{i=1}^{M}\text{Deck Area}_i}$$

Equation 7a

$$\text{Condition PI}_{\text{B-Crit}} = \frac{\sum_{i=1}^{M}\left(\text{Condition PI}_{\text{Crit-i}} \times \text{Deck Area}_i\right)}{\sum_{i=1}^{M}\text{Deck Area}_i}$$

Equation 7b

Where M = total number of bridges used in the calculation

Condition $\text{PI}_{\text{Av-i}}$ = Condition PI_{Av} score for bridge *i*, from Equation 5

Condition $\text{PI}_{\text{Crit-i}}$ = Condition PI_{Crit} score for bridge *i*, from Equation 6

Deck Area_i = deck area from bridge *i*

The deck area is in m^2 and is the product of width and length, where:

For bridges:

- Width = distance from outside edge to outside edge of deck; and
- Length = distance from support centreline to support centreline.

For culverts

- Width = distance from left bank support centreline to right bank support centreline, i.e. measured perpendicular to the direction of water flow; and
- Length = distance form outside face of headwall to outside face of headwall i.e. distance from entrance to exit.

4.8.2 Condition PI for Small Culverts

The Condition PI's for small culverts are evaluated using Equations 8a and 8b.

Condition PI for Small Culverts

$$\text{Condition PI}_{\text{SC-Av}} = \frac{\sum_{i=1}^{M}\left(\text{Condition PI}_{\text{Av}-i} \times \text{Area}_i\right)}{\sum_{i=1}^{M}\text{Area}_i}$$

Equation 8a

$$\text{Condition PI}_{\text{SC-Crit}} = \frac{\sum_{i=1}^{M}\left(\text{Condition PI}_{\text{Crit}-i} \times \text{Area}_i\right)}{\sum_{i=1}^{M}\text{Area}_i}$$

Equation 8b

Where M = total number of small culverts used in the calculation

Condition $\text{PI}_{\text{Av-i}}$ = Condition PI_{Av} score for small culvert *i*, from Equation 5

Condition $\text{PI}_{\text{Crit-i}}$ = Condition PI_{Crit} score for small culvert *i,* from Equation 6

Area_i = area for small culvert *i*

The area of a small culvert, in m^2, is the product of width and length, where:

- Width = distance from left bank support centreline to right bank support centreline i.e. measured perpendicular to the direction of water flow; and
- Length = distance form outside face of headwall to outside face of headwall i.e. distance from entrance to exit.

4.8.3 Condition PI for Retaining Walls

The Condition PI's for retaining walls are evaluated using Equations 9a and 9b.

Condition PI for Retaining Walls

$$\text{Condition PI}_{\text{RW-Av}} = \frac{\sum_{i=1}^{M}\left(\text{Condition PI}_{\text{Av}-i} \times \text{Wall Area}_i\right)}{\sum_{i=1}^{M}\text{Wall Area}_i}$$

Equation 9a

$$\text{Condition PI}_{\text{RW-Crit}} = \frac{\sum_{i=1}^{M} \left(\text{Condition PI}_{\text{Crit-i}} \times \text{Wall Area}_i \right)}{\sum_{i=1}^{M} \text{Wall Area}_i}$$

Equation 9b

Where M = total number of retaining walls used in the calculation

Condition $PI_{Av\text{-}i}$ = Condition PI_{Av} score for retaining wall *i*, from Equation 5

Condition $PI_{Crit\text{-}i}$ = Condition PI_{Crit} score for retaining wall *i,* from Equation 6

Wall $Area_i$ = wall area for retaining wall *i*

The *Wall Area* is measured in m^2 and is the product of the wall length and the average retained height, where the retained height is the level of fill at the back of the wall above the finished ground level at the front of the structure. If the retaining walls are reported per panel then *Wall Area* should be changed to *Panel Area*.

4.8.4 Condition PI for Sign/Signal Gantries

The Condition PI's for sign/signal gantries are evaluated using Equations 10a and 10b.

Condition PI for Sign/Signal Gantries

$$\text{Condition PI}_{\text{SG-Av}} = \frac{\sum_{i=1}^{M} \left(\text{Condition PI}_{\text{Av-i}} \times \text{Length}_i \right)}{\sum_{i=1}^{M} \text{Length}_i}$$

Equation 10a

$$\text{Condition PI}_{\text{SG-Crit}} = \frac{\sum_{i=1}^{M} \left(\text{Condition PI}_{\text{Crit-i}} \times \text{Length}_i \right)}{\sum_{i=1}^{M} \text{Length}_i}$$

Equation 10b

Where M = total number of sign/signal gantries used in the calculation

Condition $PI_{Av\text{-}i}$ = Condition PI_{Av} score for sign/signal gantry *i*, from Eq. 5

Condition $PI_{Crit\text{-}i}$ = Condition PI_{Crit} score for sign/signal gantry *i,* from Eq. 6

$Length_i$ = length of sign/signal gantry *i*

The length is taken the span length (from support centreline to support centreline) or cantilever length of the sign/signal gantry.

4.8.5 Condition PI for High Masts

The Condition PI's for High Masts are evaluated uisng Equations 11a and 11b.

Condition PI for High Masts

$$\text{Condition PI}_{\text{HM-Av}} = \frac{\sum_{i=1}^{M} (\text{Condition PI}_{\text{Av}-\text{i}} \times \text{Height}_i)}{\sum_{i=1}^{M} Height_i}$$

Equation 11a

$$\text{Condition PI}_{\text{HM-Crit}} = \frac{\sum_{i=1}^{M} (\text{Condition PI}_{\text{Crit}-\text{i}} \times \text{Height}_i)}{\sum_{i=1}^{M} Height_i}$$

Equation 11b

Where M = total number of high masts used in the calculation

Condition $\text{PI}_{\text{Av-i}}$ = Condition PI_{Av} score for high mast *i*, from Equation 5

Condition $\text{PI}_{\text{Crit-i}}$ = Condition PI_{Crit} score for high mast *i,* from Equation 6

Height_{i} = height of high mast *i*

The height is taken as the full height above ground level.

4.9 Structure Stock Condition PI

The *Structure Stock Condition* PI_{Av} is the high level indicator shown in the framework in Part A that should be used for external reporting. The *Condition* PI_{Av} and *Condition* PI_{Crit} for structure types, structure groups and individual structures should be used for internal reporting and to aid decision making.

The Condition Indicators for a stock of structures (bridges, retaining walls, sign/signal gantries etc.) are calculated using Equations 12a and 12b.

Average Structure Stock Condition PI

$$\text{Stock Condition PI}_{\text{Av}} = \frac{\sum((\text{Condition PI}_{\text{i-Av}}) \times (\sum Dim)_i \times (AVF_i))}{\sum((\sum Dim)_i \times (AVF_i))}$$

Equation 12a

Critical Structure Stock Condition PI

$$\text{Stock Condition PI}_{\text{Crit}} = \frac{\sum\left(\left(\text{Condition PI}_{\text{i-Crit}}\right)\times\left(\sum Dim\right)_i \times\left(AVF_i\right)\right)}{\sum\left(\left(\sum Dim\right)_i \times\left(AVF_i\right)\right)}$$

Equation 12b

Where

Stock *Condition* $PI_{i\text{-}Av}$ = Average Condition PI score for structure type *i* *(outcome of Equation 7a, 8a, 9a, 10a or 11a)*

Stock *Condition* $PI_{i\text{-}Crit}$ = Critical Condition PI score for structure type *i* *(outcome of Equations 7b, 8b, 9b, 10b or 11b)*

ΣDim = Sum of dimension quantity for Structure Type *i* *(Denominator from equations 7 to 11)*

AVF_i = Asset Value Factor of structure type *i*, see Table 15

A fully expanded version of Equation 12a is shown in Appendix B. The same expansion is relevant for Equation 12b except the *Average* values are changed to *Critical* values.

Equation 12 uses an Asset Value Factor, *AVF*, to weight one structure type against another. The factors are based on a comparison of the unit replacement cost of the different structure types. The *AVFs* shown in Table 15 were derived using typical construction and replacement cost data from a sample of HA and Local Authority structures. However, if an authority has evaluated the Gross Replacement Cost (as set out in Ref. 9 or equivalent guidance) of the different structure types, then these values should be used in Equation 12 in place of the (*Dim* × *AVF*) component. (**Note**: The Gross Replacement Cost is used in the calculation, not the Depreciated Replacement Cost).

Table 15 Asset Value Factors, *AVF*

Structure Type	Acronym	*AVF*		Units
		Overseeing Authority	*Local Authority*	
Bridge	AVF_B	0.30	0.20	m^2
Retaining Wall	AVF_{RW}	0.25	0.10	m^2
Small Culvert	AVF_{SC}	0.10	-	m^2
Sign/Signal Gantry	AVF_{SG}	1.0	1.0	m
High Mast	AVF_{HM}	0.03	0.03	m
Tunnel	AVF_T	0.5	0.5	m^2

Note: the Sign/Signal Gantry *AVF* is higher because it is per m length; whereas it is per m^2 for Bridges, Retaining Walls, Small Culverts and Tunnels.

The AVFs, or Gross Replacement Cost if used, are applied to the *Structure Type Condition PI* and therefore have the potential to substantially alter the overall *Stock Condition PI* score if they change. However, it is envisaged that the Asset Value Factors will stay the same because, while the real cost of constructing a bridge, retaining wall etc. is likely to change over time, the amount by which they change will be relative, i.e. if the cost of constructing a bridge doubles in 20 years then the cost of constructing a retaining wall is also likely to double, hence the *AVFs* would remain the same. These relative changes would also hold true for the Gross Replacement Cost.

4.10 Multi Span Bridges

The condition inspection of a multi span bridge may report all elements on one standard pro forma, such as the CSS pro forma (Ref. 3), or report each span on a separate pro forma. Either way, the Condition PIs evaluated can be used directly in Equations 7 and 12 provided the respective deck areas are applied correctly. However, if an overall Condition PI is required for a multi span bridge that has been inspected per span then the following equations may be used to combine them:

Average Condition PI for Multi Span Bridge

$$\text{Condition } PI_{Av} = \frac{\sum_{i=1}^{S}\left(\text{Condition } PI_{Av-i} \times \text{Span Deck Area}_i\right)}{\text{Whole Bridge Deck Area}}$$

Equation 13

Critical Condition PI for Multi Span Bridge

$$\text{Condition } PI_{Crit} = \frac{\sum_{i=1}^{S}\left(\text{Condition } PI_{Crit-i} \times \text{Span Deck Area}_{-}\right)}{\text{Whole Bridge Deck Area}}$$

Equation 14

where

S = the total number of spans in the bridge

Condition PI_{Av-i} = Average Condition PI for span i

Condition PI_{Crit-i} = Critical Condition PI for span i

Span Deck $Area_i$ = Deck Area for span i

This approach still applies when the spans are of different construction forms. This approach can also be used when separate Condition PI values have been evaluated for different construction forms within one span.

5. Detailed Condition Reporting

5.1 General

The procedure described in Section 4 assumes that condition (severity/extent) is reported at element level, e.g. columns, parapets, joints etc. This is the standard approach used by the majority of authorities in the UK. However, some authorities report condition at a more detailed level when appropriate in order to provide improved condition data for structures management, i.e. when appropriate the inspector can subdivide elements and report severity/extent at this more detailed level, see Figure 4.

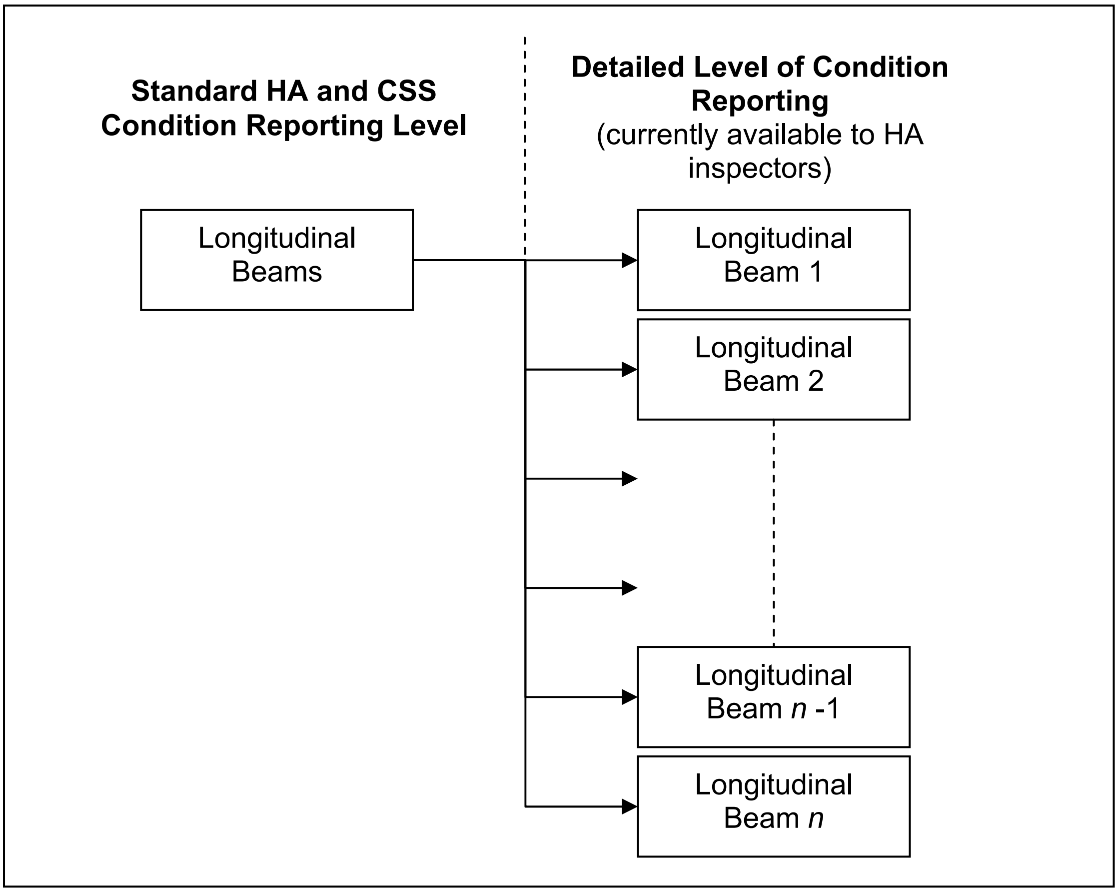

Figure 4 Example of Condition Reporting Levels

The following sections describe how condition data (severity/extent) reported at a more detailed level should be used in the Condition PI procedure. The main focus of the following guidance is to maintain a degree of consistency for Condition PI evaluation regardless of the data reporting procedure used, i.e. *Standard* or *Detailed* level.

5.2 Sub-division of Elements

Element types that inspectors may wish to sub-divide (and can currently do so in the HA SMIS system) are shown in Table 16. The element list shown in Table 16 is not exhaustive and is only for illustration purposes. The principles described in the following sections can be applied to any element sub-division. It is important to remember that the Condition PI does not dictate the level of condition reporting rather the management needs do; the Condition PI is only a procedure that uses the condition data.

Table 16 Element Types that can be Sub-divided

Structure Type	Element Type
Bridge	Transverse Beams
	Longitudinal Beams
	Deck Bracing
	Expansion Joints
	Diaphragms
	Truss Members
	Columns
	Cross-Heads
	Bearings
	Cable Anchors
	Cable System
	Cable Hangars
	Support Bracing
Sign/Signal Gantry	Transverse Beams/Bracing
	Bearings

5.3 Procedure for dealing with Detailed Condition Reporting

The Condition PI procedure described in Section 4 starts at element level, therefore when reporting at a detailed level an additional step is required in the evaluation procedure, i.e. to enable the procedure to progress from *Detailed* sub-element level to *Standard* element level. To do this the procedure shown in Figure 5 and summarised below is used:

1. Select the element type that has been reported at the detailed level, e.g. transverse beams, bearings etc.
2. To ensure consistency this approach requires all the sub-elements, for this particular element, to be identified and their conditions know, even those in 1A condition. If this data is not available then the suitability of the data for evaluating the Condition PI must be challenged.
3. Assign a weighting to each sub-element based on the typical dimensions, e.g. length, deck area served etc., see Section 5.3.1.

4. Select the sub-element/s with the worst **severity** score. The worst sub-element severity is assumed to dictate the element severity (frequently it may only be one sub-element with the worst severity score).

5. Convert the **extent** ratings, for the sub-elements with the worst **severity** score, to numerical extent scores, see Section 5.3.2. Aggregate the **extent** scores of these sub-elements, see Section 5.3.3.

6. Combine the severity and extent scores to give the Element Condition Score (ECS) for the element group, see Section 5.3.4.

7. Proceed with the *Standard* Condition PI procedure described in Section 4.

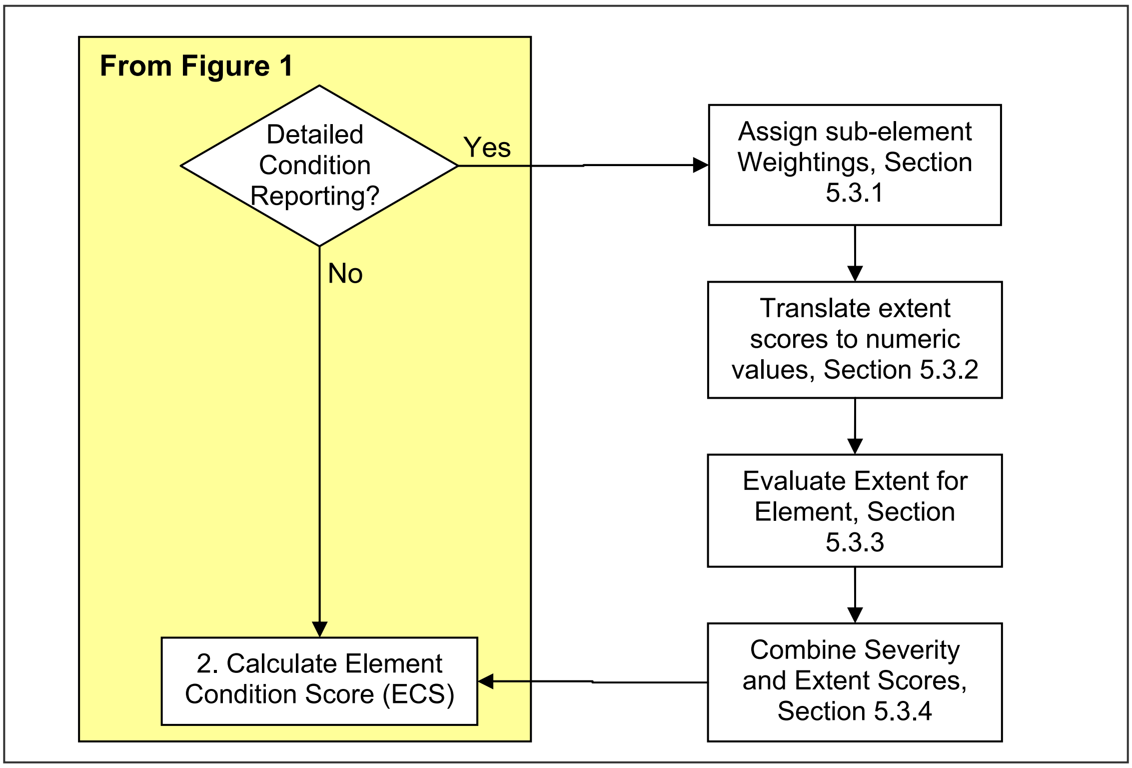

Figure 5 Overview of Detailed Procedure

5.3.1 Sub-Element Weightings, W_{SE}

The sub-elements need to be weighted so that the extent, of the sub-elements in the most severe condition, can be correctly calculated. If all the sub-elements are of the same, or similar, size then the weighting for each can be the same, i.e. W_{SE} = 1.0. However, if the sub-elements are not of equal size then the weightings should reflect this and be based on an appropriate dimension, e.g. length, width, height, deck area served etc. For example, consider expansion joints that have different lengths when sub-divided for inspection, the weightings would be as shown in Table 17.

Table 17 Sub-Element Weighting Examples

Expansion Joint Sub-Element	Length	Sub-Element Weighting, W_{SE}
Sub-Element 1	10m	10/10 = 1.0
Sub-Element 2	8m	8/10 = 0.8
Sub-Element 3	8m	8/10 = 0.8
Sub-Element 4	6m	6/10 = 0.6

Therefore the weighting for each sub-element is simply:

$$W_{SE} = \frac{\text{Dimension of sub-element}}{\text{Maximum Dimension of sub-elements}}$$

Equation 15

5.3.2 Extent Score for Sub-Elements

The extent rating for each sub-element is changed to the numerical score shown in Table 18.

Table 18 Extent Numeric Values

Extent Rating	Numeric Value Range
A	0.0
B	0.0
C	0.1
D	0.3
E	0.7

5.3.3 Extent Score for Element

The overall extent score for the element is evaluated as:

$$Extent = \frac{\sum (Ex_{WS-i} \times W_{SE-i})}{\sum W_{SE}}$$

Equation 16

Where

Ex_{WS-i} = Extent for sub-elements with worst severity in this element group

W_{SE-i} = Weighting for sub-elements with worst severity in this element group

ΣW_{SE} = Sum of all sub-element weightings in this element group

Note: the *Numerator* calculations in Equation 16 are only for the sub-elements with the worst severities, while the *Denominator* summation is for all the sub-elements.

5.3.4 Elements Condition Score, *ECS*

The element condition score is evaluated as:

$$ECS = Severity + Extent$$

Equation 17

Where

ECS = Element Condition Score taken forward to the procedure described in Section 4

Extent = Extent score from Equation 16

Severity = Worst severity rating for sub-elements

6. Interpretation of Condition PI Values

6.1 General

This section provides guidance on the interpretation of the Condition PI. One of the main functions of the Condition PI is to enable an authority to monitor change in the condition of individual structures, structure groups and the structure stock over time to determine if the maintenance programme and funding is:

- Sustaining the current condition.
- Improving condition; or
- Allowing condition to deteriorate.

The *Structure Stock* Condition PI provides an overview of condition change at stock level. Evaluating the Condition PI for *Individual Structures*, *Structure Type* groups and/or *Tactical Sets* can provide beneficial information for analysing trends and aiding decision making (where tactical sets are groups of structures that have similar material, construction type, age, etc). The following sections describe how to interpret the Condition PI and present some techniques that may be used to back-up the Condition PI number.

6.2 Interpretation of Individual Structure Condition PI

The Condition PI scores range from 100 (best possible condition) to 0 (worst possible condition) and can be interpreted broadly as the “percentage service potential” of a structure. Thus, a Condition PI value of 100 implies that the structure has retained 100% of its service potential; a value of 60 implies that the structure has lost 40% of its service potential; while a value of 0 implies that the structure is no longer serviceable.

Figure 3 in Section 4.7 shows that when the Structure Condition Score (SCS) is 2 the corresponding Condition PI is 81 implying that the structure retains 81% of its service potential, while at an SCS value of 4 the structure is considered to retain only 31% of its service potential.

It should be recognised that the effort involved, and hence the maintenance funding required, to improve the SCS value of a structure, for example from 2 → 1 can be significantly different from improving it from 4 → 3. This is reflected in the Condition PI scale, e.g. an improvement in the SCS from 2 → 1 is an improvement of 81 → 100 (19%) on the Condition PI scale, where as a SCS improvement of 4 → 3 is an improvement of 31 → 58 (27%) on the Condition PI scale.

Generic categories for interpreting the Condition PI for an individual structure are shown in Table 19. These categories are based on typical structure types and engineering judgement and therefore may not be suitable in all circumstances. An authority may wish to develop more detailed descriptions that match the characteristics of their structures and material types.

Table 19 Interpretation of Condition PI for individual structures

Range	Condition PI_{Av} (All Structure Elements)	Condition PI_{Crit} (Worst Critical Element)
$90 \leq x \leq 100$	• Likely to be no significant defects in any elements • Structure is in a "Very Good" condition overall	• Insignificant defects/damage • Capacity unaffected
$80 \leq x < 90$	• Mostly minor defects/damage, but may also be some moderate defects • Structure is in a "Good" condition overall	• Minor defects/damage • Capacity unlikely to be unaffected
$65 \leq x < 80$	• Minor-to-Moderate defects/damage • Structure is in a “Fair” condition overall • One or more functions of the structure may be significantly affected	• Minor to moderate defects/damage • Capacity may be slightly affected
$40 \leq x < 65$	• Moderate-to-Severe defects/damage • Structure is in a "Poor" condition overall • One or more functions of the bridge may be severely affected	• Moderate to severe defects/damage • Capacity may be significantly affected
$0 \leq x < 40$	• Severe defects/damage on a number of elements • One or more elements may have failed • Structure is in a "Very Poor" condition overall • Structure may be unserviceable	• Severe defects/damage • Failure or possible failure of critical element • Capacity may be severely affected • Structure may need to be weight restricted or closed to traffic

6.3 Interpretation of Structure Stock Condition PI

The interpretation of the Average and Critical *Structure Stock* Condition PI values in terms of the general condition of the stock is given in Table 20. These interpretations are based on experience to date with the CSS Bridge Condition Indicator and are only provided as broad guidelines. The characteristics of individual stocks mean they may not adhere to the descriptions provided and it is down to the experience and knowledge of the local engineer/s to interpret the Condition PI and the significance of changes and trends.

Table 20 Interpretation of Average and Critical Stock Scores

Score	Average Stock Condition	Critical Stock Condition	Addition Comments
Very Good **90 ≤ x ≤ 100**	The structure stock is in a very good condition. Very few structures may be in a moderate to severe condition.	A few critical load bearing elements may be in a moderate to severe condition. Represents very low risk to public safety.	If it is a relatively new stock of structures then an appropriate maintenance funding level needs to be identified through Asset Management. If it is a mature stock then continuing with the same level of funding is likely to sustain a high condition score and an effective preventative maintenance regime. If not already in place, appropriate asset management practices should be implemented to identify the optimum condition for the stock and the associated level of funding.
Good **80 ≤ x < 90**	Structure stock is in a good condition. Some structures may be in a severe condition.	Some critical load bearing elements may be in a severe condition. Some structures may represent a moderate risk to public safety unless mitigation measures are in place.	As a minimum the current level of funding should be continued, however it may be unclear if this is the appropriate level of funding. If not already in place, appropriate asset management practices should be implemented to identify the optimum condition for the stock and the associated level of funding. There is the potential for rapid decrease in condition if sufficient maintenance funding is not provided. Minor to Moderate backlog of maintenance work.
Fair **65 ≤ x < 80**	Structure stock is in a fair condition. A number of structures may be in a severe condition.	A number of critical load bearing elements may be in a severe condition. Some structures may represent a significant risk to public safety unless mitigation measures are in place.	Historical maintenance work under funded and structures not managed in accordance with Asset Management. It is essential to implement Asset Management practices to ensure work is adequately funded and prioritised and risks assessed and managed. Moderate to large backlog of maintenance work, essential work dominates spending.
Poor **40 ≤ x < 65**	Structure stock is in a poor condition. Many structures may be in a severe condition.	Many critical load bearing elements may be unserviceable or close to it and are in a dangerous condition. Some structures may represent a high risk to public safety unless mitigation measures are in place.	Historical maintenance work significantly under funded and a large to very large maintenance backlog. An Asset Management approach must be implemented. Re-active approach to maintenance that has been unable to contain deterioration. A significant number of structures likely to be closed, have temporary measures in place or other risk mitigation measures. Essential work dominates spending.
Very Poor **0 ≤ x < 40**	Structure stock is in a very poor condition. Many structures may be unserviceable or close to it.	Majority of critical load bearing elements unserviceable or close to it and are in a dangerous condition. Some structures may represent a very high risk to public safety unless mitigation measures are in place.	Historical maintenance work grossly under funded and a very large maintenance backlog. Re-active approach to maintenance that has been unable to prevent deterioration, only essential maintenance work performed. An Asset Management approach must be implemented. Many structures likely to be closed, have temporary measures in place or other risk mitigation measures. All spend likely to be on essential maintenance.

6.4 Reporting and Presentation of Condition Indicator Data

The following sections suggest reporting and presentation techniques for the Condition PI. The techniques discussed are:

1. Time dependent plots (Section 6.4.1)
2. Histograms (Section 6.4.2); and
3. Stacked bar graph (Section 6.4.3).

An authority should consider using these techniques for some or all of the following categories when analysing and presenting results:

1. The whole stock of structures.
2. Comparison of different structure types, e.g. bridges, retaining walls, sign/signal gantries etc.
3. Comparison of different material types, e.g. reinforced concrete, steel, masonry, timber etc.
4. Comparison of different structure ages, e.g. pre 1975 vs. post 1975 etc.
5. Comparison of structures in different areas, districts, parishes, routes etc.

This list is not exhaustive and an authority should consider additional comparators. The Condition PIs are management tools and should be used to best represent the characteristics of a structure stock and any issues that need to be highlighted.

All presentations/reporting should be in a clear and easily understood format. If possible establish a fixed format for annual/periodic reporting so it can be easily compared with historical reports.

6.4.1 Time Dependent Plots

The time dependent plots should including three lines:

1. Average Condition (Condition PI_{Av})
2. Critical Condition (Condition PI_{Crit}) ; and
3. Target Condition PI_{Av} (an additional line can be added if different targets are set for the *Average* and *Critical* Condition PI)

An example plot is shown in Figure 6. The Y-axis is truncated at a Condition PI score of 50 in order to place more emphasis on fluctuations in the group score. It is very <u>unlikely</u> that any group of structures will score less than 50, although individual structures do score less than 50.

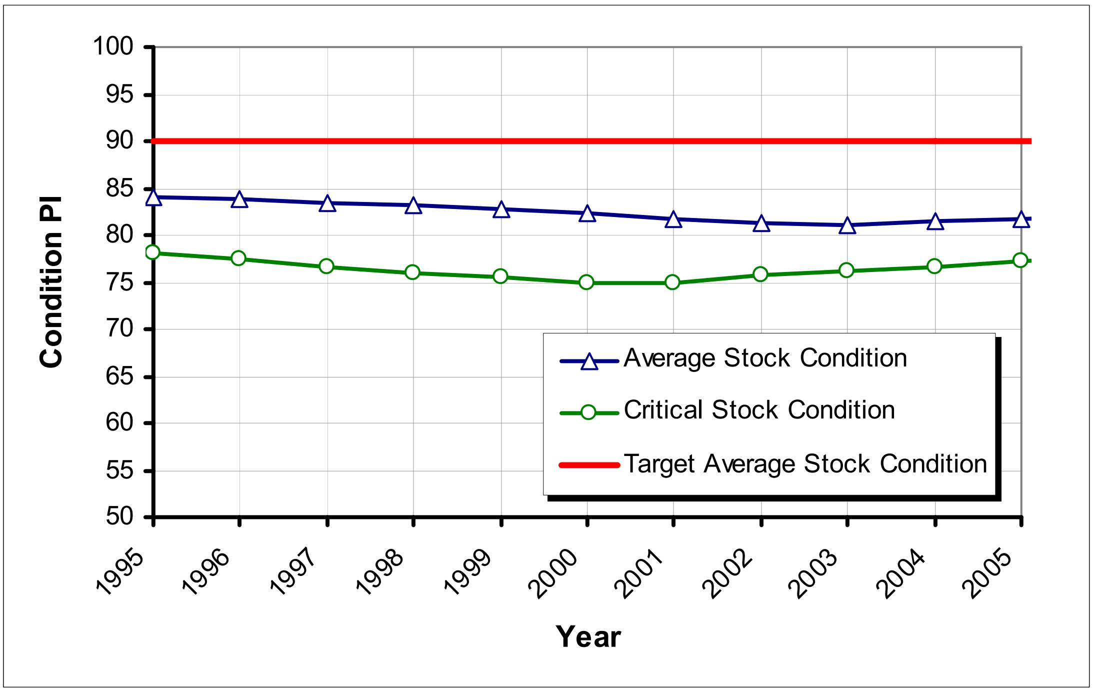

Figure 6 Time Dependent Plot of Condition PI

6.4.2 Histograms

The time dependent plot can be supported by histograms that show the spread of structure conditions, an example is shown in Figure 7.

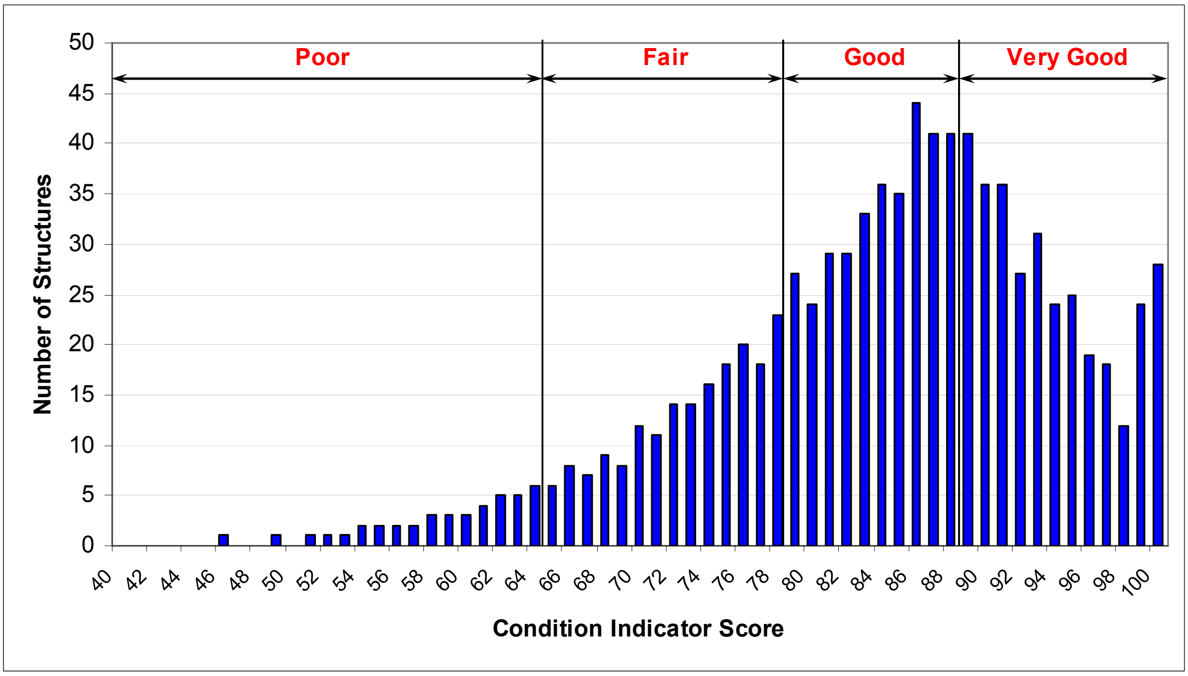

Figure 7 Condition PI Histogram

The y-axis can also be presented as the proportion or % of structures stock, provided different structure types are weighted by the appropriate *Asset Value Factor* (shown in Table 15) and their dimensional quantity.

6.4.3 Stacked Bar Graph

The spread of conditions scores can also be presented in stacked bar graphs as shown in Figure 8.

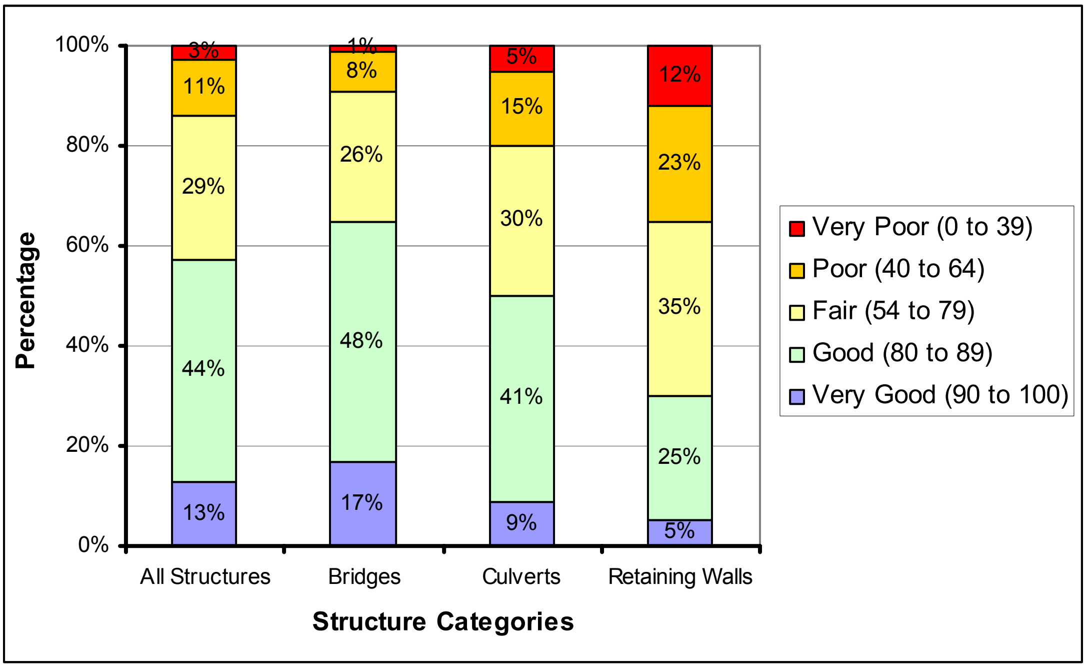

Figure 8 Stacked Bar Graph

7. References

1. Bridge Condition Indicator Volume 3, Guidance Note on Evaluation of Bridge Condition Indicators, CSS Bridges Group, April 2002.

2. Addendum to CSS Guidance Note on Bridge Condition Indicators, August 2004.

3. Bridge Condition Indicator Volume 2, Guidance Note on Bridge Inspection Reporting, CSS Bridges Group, April 2002.

4. HA SMIS Manuals: *A Guide for Structure Inspectors* and *A Guide for Structure Engineers*.

5. Management of Highway Structures: A Code of Practice, UK Bridges Group, September 2005, TSO.

6. BD62 As Built, Operational and Maintenance Records for Highway Structures (DMRB 3.2.1).

7. BD63 Inspection of Highway Structures (DMRB 3.1.4).

8. P.J. Andrews, *Objectivity in Bridge Engineering*, IHT, April 1984.

9. Guidance Document for Highway Infrastructure Asset Valuation, Roads Liaison Group, July 2005, TSO.

APPENDIX A
Equivalent Element Table

No.	ELEMENT DESCRIPTION	EQUIVALENT ELEMENTS
1	Primary deck element	Main Beams
		Truss members
		Culvert
		Arch Arch Ring Vousoirs/Arch Face Arch Barrel/Soffit
		Encased Beams
		Subway
		Box beam interiors
		Armco/Concrete pipe
		Portal/Tunnel portals
		Pre-stressing
		Sleeper bridge
		Tunnel Linings
2	Transverse Beams	
3	Secondary deck element	Concrete deck slab
		Timber deck
		steel deck plates
		Jack Arch
		Troughing
		Stone slab (or primary member)
		Troughing Infill
		Buckle plates
4	Half joints	
5	Tie beam/rod	
6	Parapet beam or cantilever	Edge Beams
7	Deck bracing	Diaphragms
8	Foundations	Piles
9	Abutments (incl. arch springing)	Arch Springing
		Abutment slope
		Bank seat
		Counterfort/Buttresses
10	Spandrel wall/head wall	Stringcourse
		Coping
11	Pier/column	
12	Cross-head/capping beam	
13	Bearings	
14	Bearing plinth/shelf	
15	Superstructure drainage	
16	Substructure drainage	Subway drainage
		Retaining wall drainage
17	Water proofing	
18	Movement/expansion joints	Sealants
19	Painting: deck elements	Sealants
		Decorative Appearance
20	Painting: substructure elements	Sealants
		Decorative Appearance

21	Painting: parapets/safety fences	Sealants
		Decorative Appearance
22	Access/walkways/gantries	Steps
23	Handrail/parapets/safety fences	Balustrade
		Barrier
24	Carriageway surfacing	Ramp Surface
		Approaches
25	Footway/verge/footbridge surfacing	
26	Invert/river bed	Channel bedstones
27	Aprons	
28	Fenders/cutwaters/collision prot.	Flood Barrier
29	River training works	
30	Revetment/batter paving	
31	Wing walls	Newel
32	Retaining walls	Counterfort/Buttresses
		Gabions
		Wall
33	Embankments	Approach Embankments
		Side slopes
34	Machinery	
35	Approach rails/barriers/walls	Posts
		Remote approach walls
36	Signs	
37	Lighting	Subway Lighting
		Primary Lighting
		Secondary Lighting
38	Services	Manholes
		Pipes
		Mast

APPENDIX B
Equation 12 Expanded

Equation 12 is defined as:

Structure Stock Condition PI

$$SSCPI_{\mathrm{Av}} = \frac{\sum\left(\left(\text{Condition PI}_{\text{i-Av}}\right)\times\left(\sum Dim\right)_i \times \left(AVF_i\right)\right)}{\sum\left(\left(\sum Dim\right)_i \times \left(AVF_i\right)\right)}$$

Equation 12a

Expanding Equation 12a gives:

Structure Stock Condition PI

$$SSCPI_{\mathrm{Av}} = \sum\begin{bmatrix}\left(\left(\text{Condition PI}_{\text{B-Av}}\right)\times\left(\sum\text{Bridge Deck Area}\right)\times\left(AVF_B\right)\right)+\\ \left(\left(\text{Condition PI}_{\text{SC-Av}}\right)\times\left(\sum\text{Small Culvert Area}\right)\times\left(AVF_{SC}\right)\right)+\\ \left(\left(\text{Condition PI}_{\text{RW-Av}}\right)\times\left(\sum\text{Retaining Wall Area}\right)\times\left(AVF_{RW}\right)\right)+\\ \left(\left(\text{Condition PI}_{\text{SG-Av}}\right)\times\left(\sum\text{Sign Gantry Length}\right)\times\left(AVF_{SG}\right)\right)+\\ \left(\left(\text{Condition PI}_{\text{HM-Av}}\right)\times\left(\sum\text{High Mast Height}\right)\times\left(AVF_{HM}\right)\right)\end{bmatrix} \Bigg/ \sum\begin{bmatrix}\left(\left(\sum\text{Bridge Deck Area}\right)\times\left(AVF_B\right)\right)+\\ \left(\left(\sum\text{Small Culvert Area}\right)\times\left(AVF_{SC}\right)\right)+\\ \left(\left(\sum\text{Retaining Wall Area}\right)\times\left(AVF_{RW}\right)\right)+\\ \left(\left(\sum\text{Sign Gantry Length}\right)\times\left(AVF_{SG}\right)\right)+\\ \left(\left(\sum\text{High Mast Height}\right)\times\left(AVF_{HM}\right)\right)\end{bmatrix}$$

Task No: YY86731

Guidance Document for Performance Measurement of Highway Structures

Part B2: Availability Performance Indicator

Report prepared by:

ATKINS

Report prepared on behalf of:

Highways Agency

CSS Bridges Group

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Contents

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1. Introduction

1.1 Availability Performance Indicator Definition

The Availability PI is defined as:

> *A measure of the reduction in the Level of Service provided, on a highway network, due to restrictions placed on highway structures.*

This includes any weight, height or width restrictions that were in place during the last 12 month period and had a duration of greater than one month. This excludes restrictions caused during maintenance work because the purpose of maintenance work is to repair the structure and therefore should not be used to penalise the Availability PI. However, if a structure has an interim restriction in place while awaiting work, for example strengthening, then its Availability PI should be penalised for the duration of the waiting period.

1.2 Background, Objectives and Scope

The background, objectives and scope are discussed in *Part A: Framework for Performance Measurement*.

1.3 Terminology

The following terminology is used by the Availability PI procedure:

- **Interaction** – refers to the interaction between a structure and an individual route, e.g. a route crossing a bridge or a route under a bridge.
- **Network** – the complete highway network managed/owned by an authority.

2. Overview of the Availability PI Procedure

2.1 General Approach

The aim of the Availability PI is to provide scores that are meaningful, beneficial and where possible comparable. This cannot be effectively achieved by simply counting the number of structures with restrictions. Instead, a more rigorous approach that takes into account the wider economic, network, traveller and community implications is required in order to provide a suitably robust basis for comparison, decision making and possibly prioritisation. Relevant criteria that an Availability PI procedure should include are:

1. Types of vehicle restricted and their associated economics.
2. Actual number of vehicles restricted.
3. Length and characteristics of the preferred diversion.
4. Queue building and dissipation.
5. Impact on travellers, e.g. delays, driver stress and increased risk of accidents.
6. Impact on communities, e.g. access to community facilities.
7. Impact on businesses, e.g. delays to deliveries/employees; and
8. Impact on the environment.

The Availability PI procedure presented here takes these factors into account, and as such may appear complex. However, it is expected that the procedure will be programmed into Bridge Management Systems, allowing the algorithms to run in the background on readily available information, thereby placing minimal additional burden on bridge managers. The Availability PI is not suitable for hand calculation.

2.2 Availability PI Scale

The Availability PI scale is from 0 to 100, where zero represents a very poor level of availability and 100 is full availability. Individual structures, route types and the structure stock are all scored on the 0 to 100 scale. The Availability PI scale is described in more detail in Section 7.3.

2.3 Availability PI Score

An Availability PI score is evaluated for each time a structure interacts with a section of the highway network, therefore some structures will have more than one Availability PI score. Section 2.3.1 describes the number of Availability PIs evaluated for some common highway structure arrangements.

If a structure interaction <u>does not</u> cause a network restriction then it has a score of 100 for that interaction. When a structure interaction <u>does</u> restrict a network then the

Availability PI score should be penalised accordingly, i.e. the interaction has a score of less than 100.

The Availability PI is a snapshot of the restrictions imposed on the network by structures over the last year (12 month period). Where a restriction was not in place for the full 12 month period the Availability PI procedure allows the actual duration of the restriction (in months) to be taken into account.

2.3.1 Number of Availability PI Scores Evaluated per Structure

The Availability PI measures the impact of structure restrictions on an authority's network caused by structures under the authority's stewardship (see Section 2.4 for dealing with structures that interact with an authority's network but are owned by another authority). A structure receives an Availability PI score for each time it interacts with a part of the authority's network. In the following examples the structures and the networks are assumed to be under the stewardship of the same authority.

1. A bridge that carries one route over another route (see Figure 1a) – an Availability PI score is evaluated for both interactions, i.e. one Availability PI for the route carried and one for the route crossed.

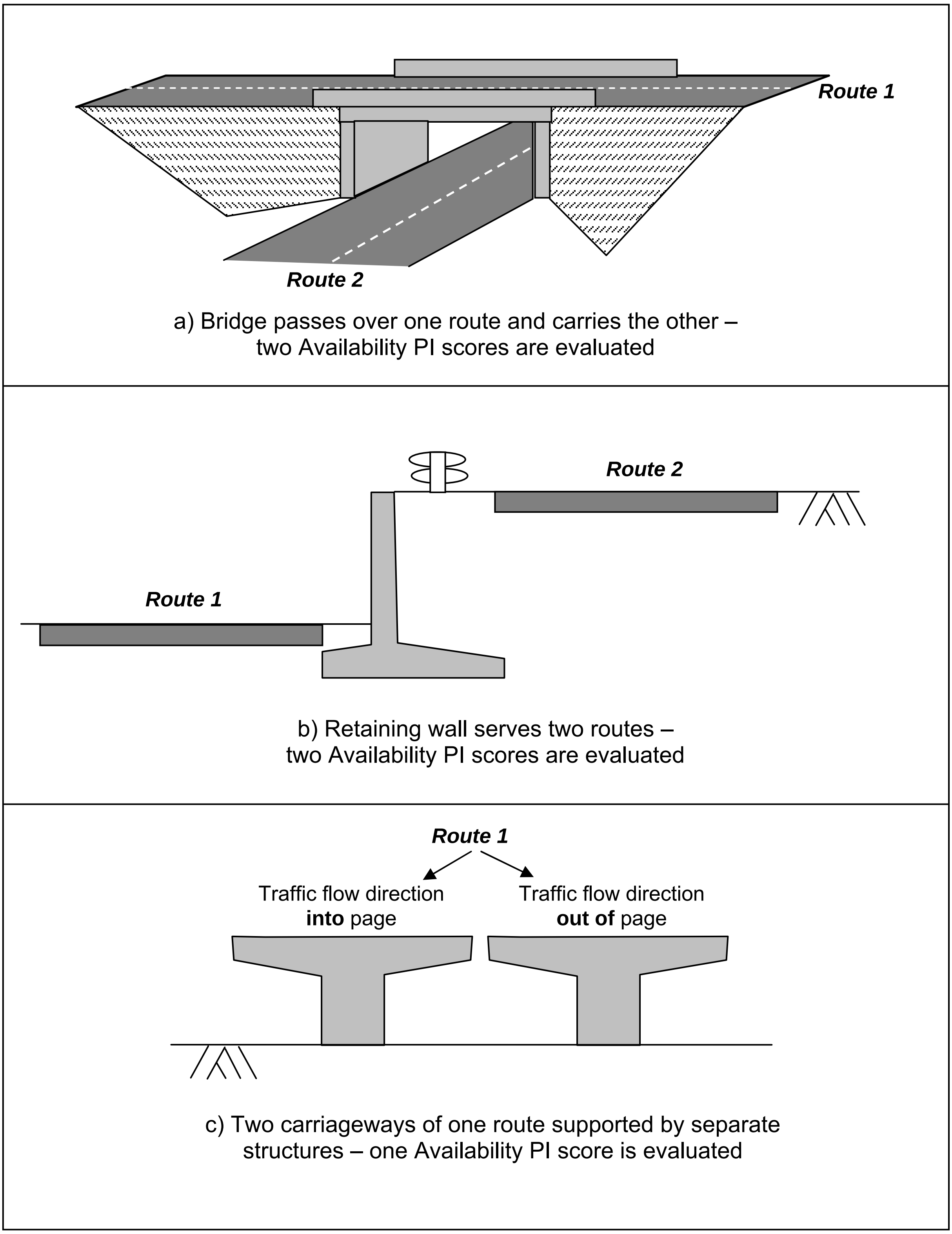
2. A retaining wall *adjacent to* one route and *supporting* a different route (see Figure 1b) - an Availability PI score is evaluated for both interactions, i.e. an Availability PI for the route adjacent to the wall and an Availability PI for the route supported by the wall. However, if the adjacent and supported roads are actually two carriageways of the same route then only one Availability PI score is calculated, i.e. only one Availability PI score is calculated for each interaction with a route not each interaction with a carriageway

3. Two parallel bridges (see Figure 1c):

    a. If the two bridges support two parallel carriageways of the same route then one Availability PI score covers both structures, however this does not include structures on the entrance and exit routes to a site that are sufficient far enough apart to be treated as separate routes.

    b. If the bridges serve two different routes then an Availability PI score should be evaluated for each.

The evaluation of the network Availability PI therefore requires all structure interactions on an authority's network, related to structures under their stewardship, to be identified and an Availability PI score evaluated for each. This should not prove onerous because the majority of structures will receive an automatic Availability PI score of 100 because there was no restriction in place during the last 12 months.



a) Bridge passes over one route and carries the other – two Availability PI scores are evaluated

b) Retaining wall serves two routes – two Availability PI scores are evaluated

c) Two carriageways of one route supported by separate structures – one Availability PI score is evaluated

Figure 1 Highway Structures and their Network Interactions

2.3.2 When to Penalise the Availability PI Score

A highway structure is penalised under the Availability PI procedure, i.e. has a score of less than 100, when the Level of Service provided by the structure is below that of the adjacent/served highway. This should include any restriction in the last 12 month period that had duration of greater than one month, but excluding maintenance work because the purpose of maintenance work is to repair the structure and therefore should not penalise the Availability PI. However, if a structure has an interim restriction in place while awaiting work, for example strengthening, then its Availability PI should be penalised for the duration of the waiting period

The majority of structures/interactions on a network will have an Availability PI score of 100, i.e. no network restrictions were caused by the structure over the last 12 months. Therefore, an authority may find the most suitable starting point is to assign a score of 100 to all structure interactions and only collect data to penalise the Availability PI score when a restriction arises.

Important: Environmental weight restrictions are not used to penalise the Availability Performance Indicator.

2.4 Other Highway Structure Owners

The Availability PI is a measure of the impact of structure restrictions on an authority's network caused by structures under their stewardship. The Availability PI excludes restrictions on the authority's network that are caused by structures under the stewardship of another authority. However, this does not preclude an authority from using this procedure to demonstrate the impact of restrictions, which are outside their direct control, on their network.

Important: In reporting the Availability PI an authority should, first and foremost, report the value for structures under their stewardship. This may be supplemented by further Availability PI scores that illustrate the additional impact of structures owned by other authorities.

2.5 Steps in the Availability PI Procedure

The Availability PI procedure is shown in Figure 2 and summarised in the steps below.

Step 1 – Select Structure

Identify if the structure type is appropriate for inclusion in the Availability PI, see Section 3.1. Identify the number of times the structure interacts with your network, an Availability PI score is evaluated for each interaction.

Step 2 – Is there a restriction?

Detailed data is not required for this step, only knowledge of whether a structure has restricted the network in the last 12 months or not. Structures that did not restrict the network have an Availability PI score of 100 for each interaction and no further calculation is required. Structures with one or more restrictions are passed to Step 3.

Step 3 – Restriction Data Review

Data for restrictions are reviewed and additional data collated where necessary, see Table 2 in Section 3.2. The procedure described in Section 5 is used for restrictions on vehicular routes and the procedure in Section 6 is used for restrictions on non-vehicular routes associated with the highway.

Step 4 – Availability PI for Vehicular Routes

The Availability PI formula and look-up tables are presented in Section 5. The procedure deals with weight, height and width restrictions. The look-up tables allow scores to be selected for:

- Route type and traffic volume.
- Restriction type (weight, height or width).
- Duration of the restriction (particularly relevant for restrictions not in place for the full 12 month calculation period).
- Increased length of journey for diverted traffic; and
- Environmental and Socio-economic impact (on restricted route and diversion route).

Step 5 – Availability PI for Non-Vehicular Routes

The Availability PI formula and look-up tables are presented in Section 6. The look-up tables allow scores to be selected for:

- Volume of users.
- Duration of the restriction (particularly relevant for restrictions not in place for the full 12 month calculation period)
- Increased length of journey for diverted users and any perceived increase in the risk of crime and/or accident; and
- Local importance of the structure/route.

Step 6 – Route Type Availability PI Score

The Availability PI score for each route type (Motorway, Primary A, Other Principal Roads, Classified B & C, Unclassified U and Non-Vehicular) is evaluated separately using Equation 8 (Section 7.1).

Step 7 – Stock Availability PI Score

The Stock Availability PI score is evaluated by combining the route type scores from Step 6 using Equation 9 (Section 7.2).

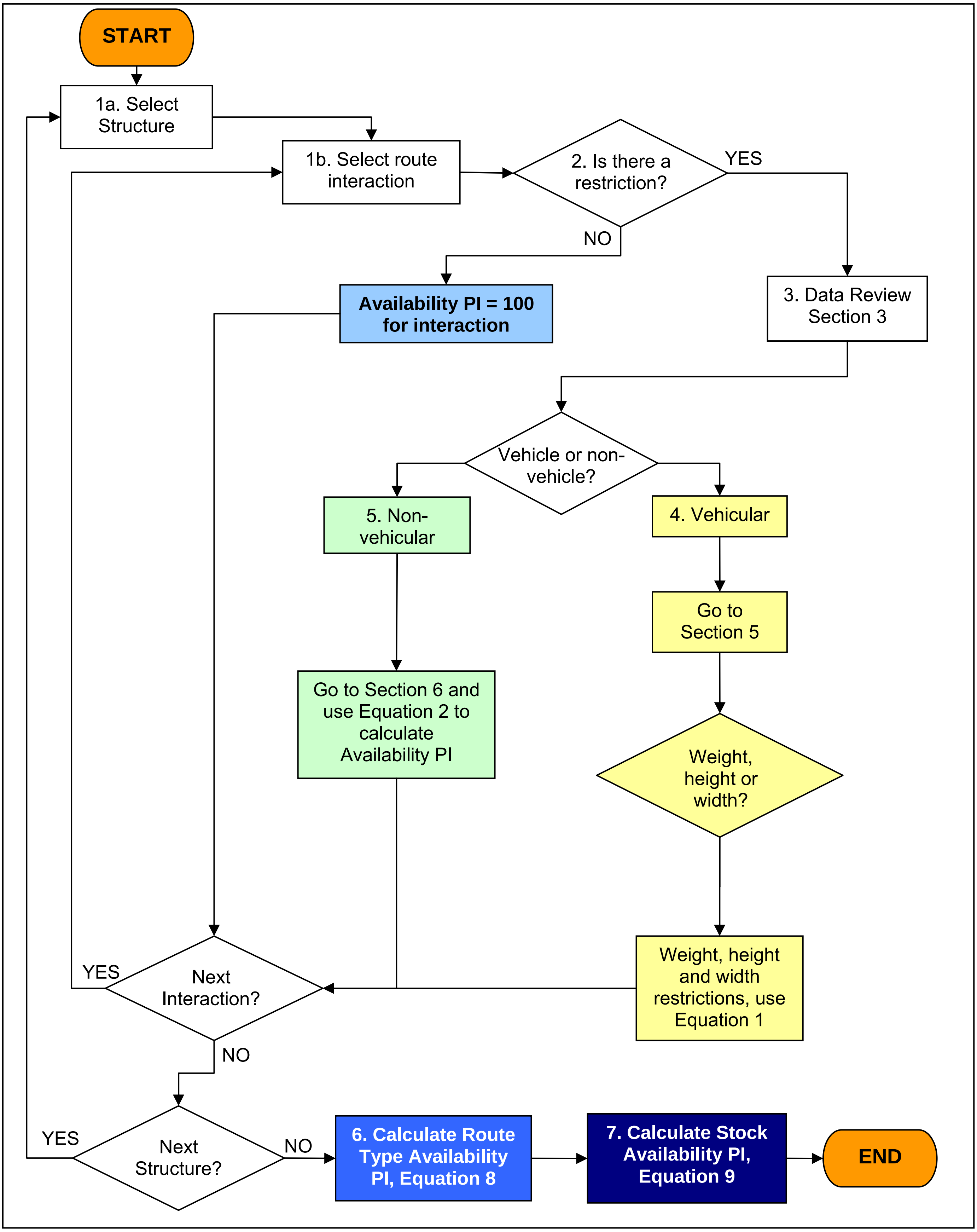


Figure 2 Overview of Availability PI Procedure

3. Data Requirements

3.1 Relevant Structure Types

The relevance of the Availability PI to a structure depends on how the structure interacts with highway traffic (vehicular and pedestrian). Table 1 shows the highway structure types considered under the Performance Measurement Framework and how they typically interact with the highway traffic. Definitions of the structure types are provided in the Code of Practice, BD62 and BD63 (Refs. 1, 2 and 3).

The right hand column of Table 1 shows the restrictions that may be relevant to each structure type.

Table 1 Highway Structure Availability Requirements

Structure Type	Typical interaction with highway traffic (vehicular and pedestrian)	Possible Restriction Types
Bridge and culverts	Allow highway traffic to pass over and/or under	Weight, height and width
Small culverts (if treated separately from bridges)	Allow highway traffic to pass over	Weight and width
Retaining Wall	Allow highway traffic above or below the wall to use the route	Weight* and width
Road Tunnel	Allow highway traffic to pass through and over (tunnel slab)	Weight, height and width
Sign/Signal Gantry	Allow highway traffic to pass under (only gantries that span the route are included, road side cantilever gantries are omitted)	Height and width
High Mast	N/A	N/A
Other structure types	N/A	N/A

* weight restrictions for a retaining wall may be based on a visual inspection when structural load assessment data is not available.

The interactions described in Table 1 are used to identify the total number of interactions on an authority's network. The total number of interactions is required when evaluating the final stock Availability PI. See Section 2.3 for the number of Availability PIs evaluated per structure.

Important: The Availability PI should be based on interactions between vehicular routes and highway structures, where vehicular routes are Motorways, Primary A, Other Principal Roads, Classified B & C and Unclassified routes. However, if an authority wishes to extend the Availability PI to include interactions with non-vehicular routes, including Public Right of Way (PROW) routes (public footpaths, cycle tracks, bridleways and byways), then they can do so.

3.2 Essential and Desirable Data

The data required to evaluate the Availability PI is shown in Table 2.

Table 2 Availability PI Data

No.	Data	Classification
1	Structure owner details (identify the structure owner, i.e. Authority or other, specifying the other owner where possible)	Essential
2	Number of times the structure interacts with the network and details of each interaction	Essential
The following is required for each interaction that has a restriction		
3	Restriction details, e.g. weight limit, height limit and width limit (e.g. road width, number of lanes open/closed)	Essential, where relevant to the restriction type
4	Classification of restricted route, e.g. Motorway, Primary A, other Principal Roads, Classified B & C, Unclassified U, Non-vehicular	
5	Duration of the restriction (in months) if it was not in place for the whole 12 month period. This is best achieved by recording the start and end dates of restrictions.	
6	Road classification of the preferred diversion route*	
7	Increased length of journey for diverted traffic (an estimation e.g. Short, Medium or Long is sufficient)	
8	Environmental and socio-economic impacts (selected from the appropriate tables in this document)	

* the classification of the preferred diversion route should be assessed as follows:

a. If one route type makes up greater than 70% of the preferred diversion length then this classification should be used; otherwise

b. An engineering judgement should be made as to which single route type is equivalent to the mix of route types present on the preferred diversion route.

Important: If a structure interaction has not created an associated network restriction over the previous 12 month period then it has an Availability PI score of 100. Data items 3 to 7 in Table 2 are only required when there is a restriction. An authority may find the most suitable starting point for the Availability PI is to assign a score of 100 to all structure interactions and only collect data items 3 to 7 when a restriction arises.

4. Levels of Service and Restrictions

4.1 Required Level of Service

The Levels of Service for highway structures are defined according to existing design standards and the route type. The weight and height and width requirements for each route type are shown in Table 3.

Table 3 Design Values for Vehicle Weight, Height and Width

<table>
<tr><th>Route Type</th><th>Weight
(BD37 Ref. 4)</th><th>Height
(minimum)</th><th>Width</th></tr>
<tr><td>Motorway</td><td rowspan="2">HA + 45HB</td><td rowspan="6">5.03m (or 6.18m for High Load Route)

In accordance with TD27, Ref. 5</td><td rowspan="6">In accordance with vehicle dimensions, adjacent highway and/or TA46, Ref. 6</td></tr>
<tr><td>Primary A</td></tr>
<tr><td>Other Principal</td><td>HA + 37.5HB</td></tr>
<tr><td>Classified B</td><td rowspan="3">HA + 30HB</td></tr>
<tr><td>Classified C</td></tr>
<tr><td>Unclassified U</td></tr>
</table>

The values shown in Table 3 represent the default Levels of Service used by the Availability PI procedure. These, in particular some of the loading levels, are not statutory requirements for all highway structures. Section 4.3 explains how performance target setting can take account of situations where an authority's policy does not align with these requirements.

4.2 Lower Bound Levels of Service

It is important to recognise that, while the Levels of Service shown in Table 3 are similar for all route types, the lower bound Levels of Service may not be. For example, a restriction that may be tolerated for a period of time on an unclassified road may receive no tolerance on a motorway. The Availability PI scores should reflect this difference in tolerance. Therefore, the tolerable lower bound Level of Service is taken into account when evaluating the Availability PI.

The lower bound Level of Service is defined as:

The average Level of Service at, and below which, the route type is deemed to be critically/severely restricted, by the structure owner/manager and/or public/users, when compared against the required Level of Service.

The lower bound Levels of Service were determined through discussions with the Steering Group and validated using questionnaires that were completed by a sample of bridge managers. Vehicle weight restrictions are used to define the lower bound Levels of Service and are shown in Table 4.

Table 4 Lower Bound Levels of Service

Route Type	Lower Bound Level of Service*
Motorway	26 Tonne GVW
Primary A	26 Tonne GVW
Other Principal Roads	18 Tonne GVW
Classified B and C	7.5 Tonne GVW
Unclassified U	3 Tonne GVW

*Note: the lower bound Levels of Service must not be taken to indicate suitable levels of restriction for these route types. For example, it is unacceptable to have a 3 tonne restriction on an unclassified route if this is the only access point and it prevents emergency vehicles from entering. The lower bound limits are indicative and only used as a basis for comparing the economics and impact of restrictions on different route types.

Example: based on the above lower bound Levels of Service a motorway would receive a very low, possibly 0 score, when a 26 tonne, or worse, weight restriction is in place, while an unclassified route with a 26 tonne restriction is likely to have a relatively high score.

4.3 Acceptable Restrictions

Some highway structure restrictions (apart from environmental restrictions) may be classified as "acceptable" due to policy decisions or local considerations, e.g. certain height and width restrictions. These restrictions are to be included when calculating the Availability PI for the network, however, in reporting the score the bridge manager should indicate the influence of these "acceptable" restrictions relative to "unacceptable" restrictions.

For example, consider a network that has an Availability score of 85 out of 100. However, the "acceptable" restrictions alone give the network a score of 92 out of 100. In this case the score of 92 reflects that the network would not achieve an Availability PI score of 100 because there are a number of "acceptable" restrictions on the network. This would be reported as:

- Availability PI score reported as 85 out of 100.
- Target Availability PI score reported as 92 out of 100.

The acceptability of a restriction must be assessed on a structure by structure basis. It is the bridge engineer's knowledge of local factors and opinions that will enable a restriction to be classified as "acceptable". In addition to standard restriction data (e.g. restriction type, restriction start date etc.), records should indicate why a restriction was classified as "acceptable".

5. Availability PI Score for Vehicular Routes

This section presents the equations and look-up tables used to evaluate the Availability PI for each time a structure restriction interacts with a vehicular route.

Remember: If a structure/network interaction has created no restriction for the previous 12 months then it automatically has a score of 100 and no calculation, or associated data collection, is required.

5.1 Availability PI Formula

The Availability PI is evaluated as a function of the:

1. Traffic volume on the restricted route.
2. Restriction type and the type of traffic it effects.
3. The difference between the classification of the restricted route and the classification of the preferred diversion route.
4. The increased length of journey for road users.
5. Environmental and socio-economic impacts of the restriction; and
6. Duration of the restriction.

Availability PI for each network interaction:

Vehicle Weight, Height and Width Restrictions

$$PI = 100 \times \left\{ \frac{C_{LB} - \left[\frac{T}{12} \left([R \times DR \times OR \times IJL] + \left[\frac{C_{LB} \times (En + SE)}{2 \times (En_{\max} + SE_{\max})} \right] \right) \right]}{C_{LB}} \right\}$$

but not < 0 **Equation 1**

where:

C_{LB} = a constant, specific to the route type served, Section 5.2

T = number of months the restriction was in place for over the previous 12 months, Section 5.3

R = Restriction type score, Section 5.4
- based on the cost of the restriction per vehicle per km

DR = Diversion Route score, Section 0
- based on the difference between route types

OR = Original Route traffic volume score, Section 5.6
- based on the volume of traffic on the restricted route

IJL = Increased Journey Length score, Section 5.7
- based on the increased distance travelled by diverted traffic

En = Environmental score, Section 5.8

En_{max} = maximum value the Environmental score can take, Section 5.8

SE = Socio-Economic score, Section 5.9

SE_{max} = maximum value the Socio-Economic score can take, Section 5.9.

5.2 Lower Bound Constant, C_{LB}

The Lower Bound Constant, C_{LB}, adjusts the Availability PI so it suitably reflects the impact of a restriction on that route type. C_{LB} is calculated using Equation 2 and characteristic data for the route type shown in Table 5.

Lower Bound Constant

$$C_{LB} = (R_{LB} \times DR_{LB} \times OR_{LB} \times ILJ_{LB})$$

Equation 2

Where, the characteristic data for each route type are:

R_{LB} = lower bound weight restriction score
(based on the Levels of Service defined in Table 4, Section 4.2)

OR_{LB} = assumed Original Route type score for the restricted route

DR_{LB} = assumed classification score for the preferred diversion route

IJL_{LB} = assumed Increased Journey Length for diverted traffic

Table 5 Lower Bound Constant, C_{LB}, and Associated Variables

Route Type	R_{LB}	DR_{LB}	OR_{LB}	IJL_{LB}	C_{LB}
Motorway	0.83	1.03	9.0	4	**30.8**
Primary A	0.57	1.06	5.0	4	**12.1**
Other Principal Roads	0.82	1.05	3.0	4	**10.3**
Classified B and C	1.50	1.13	1.0	4	**6.8**
Unclassified U	0.75	1.00	0.3	4	**0.9**
Non-vehicular route	-	-	-	-	**6.8**

C_{LB} enables more meaningful Availability PI scores to be evaluated for individual interactions because they are assessed in terms of the route type they serve rather than their importance to the overall network. However, when the stock Availability PI is calculated the scores are re-adjusted by C_{LB} to ensure the economic consequences of each restriction is treated fairly in the stock evaluation.

5.3 Duration of Restriction, *T*

The Availability PI measures the availability of the network over that last year (12 months). The Availability PI formula (Equation 1) includes a factor to account for the proportion of the year a restriction was in place, i.e. the number of months it was in place. It is likely that:

- For long-term restrictions T = 12 months, i.e. the restriction was in place for the whole 12 month period; and
- For short-term restrictions or restrictions that were removed/installed during the year, T < 12 months, i.e. the restriction was not in place for the whole 12 month period. It is recommended that only restrictions of duration greater than one month are included in the Availability PI.

5.4 Restriction Scores, *R*

The restriction score, *R*, depends on the type of restriction in place, e.g. weight, height or width. The following sections provide look-up tables from which the restriction score, *R*, for each type of restriction is selected.

The Restriction score, *R*, has a 0 to 10 dimensionless scale that is based on:

1. The type of restriction and the hence the type of vehicle diverted.
2. The proportion of the traffic flow affected by the restriction (changes with route classification).
3. Typical vehicle operating costs and highway user time costs.

When a structure creates more than one restriction per interaction at the same time, e.g. a weight and height restriction on a structure apply to one route, then the more severe restriction should be used to calculate the Availability PI. If the restrictions are concurrent over the last 12 month period then a cumulative score should be evaluated for the interaction.

5.4.1 Weight Restriction Score, R_{WT}

The weight restriction score, R_{WT}, is selected from Table 6. The proportion of vehicles restricted by different load ratings is based on the vehicle types described in *Part A: Framework for Performance Measurement*. Examples of the scores selected from Table 6 are:

- A 26 Tonne restriction for a Primary A route has a score of R_{WT} = 0.57.
- A 3 Tonne restriction on an Unclassified route has a score of R_{WT} = 0.75.

When a route is not required to serve HB (or STGO) vehicles then rows 1 and 2 in Table 6 should be set to zero values.

Table 6 Weight Restriction Scores, R_{WT}

		Classification of Restricted Route				
ID	**Weight Restriction**	**Motorway**	**Primary A**	**Other Principal**	**Classified B & C**	**Unclassified U**
1	SV150	0.005	0.005	0.00	0.00	0.00
2	HA 40 tonne (also restricts 25 Units of HB and SV100)	0.02	0.01	0.00	0.00	0.00
3	HA 33 tonne	0.24	0.16	0.14	0.06	0.03
4	HA 26 tonne	0.83	0.57	0.50	0.22	0.12
5	HA 18 tonne	1.30	0.93	0.82	0.39	0.22
6	HA 13 tonne	1.51	1.13	1.07	0.69	0.36
7	HA 10 tonne	1.72	1.33	1.31	0.98	0.49
8	HA 7.5 tonne	2.01	1.62	1.71	1.50	0.70
9	HA 3 tonne	2.13	1.74	1.81	1.57	0.75
10	Closed to vehicular traffic	10.0	10.0	10.0	10.0	10.0

5.4.2 Height Restriction Score, R_H

The proportion of vehicles restricted by different height restrictions are based on:

- The vehicle types, described in *Part A*; and
- Typical dimensions of road traffic vehicles (Ref. 7).

The height restriction score, R_H, is selected from Table 7.

Table 7 Height Restriction Scores, R_H

	Classification of Restricted Route				
Clearance Height	**Motorway**	**Primary A**	**Other Principal**	**Classified B & C**	**Unclassified U**
> 5.03m	0.00	0.00	0.00	0.00	0.00
4.5 to 5.03m	0.20	0.10	0.10	0.00	0.00
4.25 to 4.5m	0.40	0.30	0.30	0.20	0.10
4.0 to 4.25m	0.80	0.60	0.60	0.40	0.20
3.75 to 4.0m	1.00	0.75	0.72	0.47	0.25
3.5 to 3.75m	1.20	0.90	0.85	0.60	0.30
3.25 to 3.5m	1.50	1.15	1.17	0.95	0.45
3.0* to 3.25m	1.70	1.40	1.50	1.35	0.60

*It is assumed that height restrictions below 3m will not be present on the highway.

5.4.3 Width Restriction Score, R_{WD}

Width restrictions are classified as:

1. **Vehicle Width Restrictions** – the structure can accommodate the traffic volume on the route but the actual width of the structure prevents some vehicle types from using the route, i.e. width is less than 2.5m → go to 1 below.

2. **Lane Restrictions** – the width of the carriageway at the structure is less than the route it accommodates, e.g. when four lanes decrease to two, or two lanes decrease to one due to a narrow structure (Note: but not due to maintenance works as these are excluded from the Availability PI). This approach implicitly includes *Vehicle Width Restrictions* when they occur alongside a *Lane Restriction* → go to 2 below.

1. Vehicle Width Restriction

The Width Restriction Score, R_{WD}, caused by a vehicle width restriction is:

$$R_{WD} = 0 \text{ if the lane width is } > 2.5\text{m}$$

$$R_{WD} = 2.5 \text{ if the lane width is } > 2.0\text{m and } \leq 2.5\text{m}$$

$$R_{WD} = 9.0 \text{ if the lane width is } \leq 2.0\text{m}$$

Equation 3

An R_{WD} score of 9.0 means that only bicycles, motorcycles and small cars can gain easy access.

2. Lane Restriction

It is assumed that lane restrictions (i.e. where the structure is narrower than the adjacent route) start to cause traffic delays (e.g. queue building) when the traffic volume on the route exceeds the Congestion Reference Flow (*CRF*), see Ref. 6. When the *CRF* is reached, this indicates that congestion is occurring during the Peak Hour Flow. A rigorous evaluation of the congestion and queue building during Peak Hour Flow is beyond the scope of the Availability PI, therefore the following simplified approach is used (which is based on the *CRF* and Peak Hour Flow described in Ref. 6). The Width Restriction Score, R_{WD}, is:

$$R_{WD} = \left[\frac{(x - CRF_S)}{x} \times y \right] \times 10$$

Given that
- if $CRF_S \geq OR$ *then* $R_{WD} = 0$
- if $CRF_S < OR$
  - *then* if $CRF_R < OR$ *then* $x = CRF_R$
  - if $CRF_R \geq OR$ *then* $x = OR$

but not < 0 **Equation 4**

Where:

OR = Original Route score (see Section 5.6)

CRF_S = Congestion Reference Flow score of the structure (Table 8)

CRF_R = Congestion Reference Flow score of the adjacent route (Table 8)

x = takes account of whether or not the route is already congested

y = relates to the proportion of the traffic delayed (see Table 9)

10 = 0 to 10 scale that restriction scores are evaluated on

If the *CRF* score is greater than or equal to *OR* this indicates the narrow structure has not created any traffic delays and hence R_{WD} is equal to zero (see Equation 4).

Table 8 CRF score for different lane types

Lane Type	*Estimated vehicle flow capacity*	*CRF score*
Dual Lane	32,500 ×*NL*	3.25 ×*NL*
Wide Single	32,500	3.25
Single 7.3	22,500	2.25
Narrow Lane (but at least one lane in each direction (*LW* > 2.5m but < 3.65m)	$22{,}500 \times \frac{LW}{3.65} \times NL$	$2.25 \times \frac{LW}{3.65} \times NL$
Total road width > 2.5m and < 5m	5000	0.5

Where:

NL = the number of lanes in each direction at the structure or (total number of lanes)/2 if there is an odd number of lanes

LW = Lane Width

Table 9 Proportion of Traffic Delayed (y)

$\frac{x}{CRF_S}$	y
≤ 1.0	0
> 1.0 and ≤ 1.25	0.05
> 1.25 and ≤ 1.5	0.15
> 1.5 and ≤ 1.75	0.30
> 1.75 and ≤ 2.0	0.60
> 2.0	1.0

5.5 Diversion Route Score, *DR*

The Diversion Route Score, *DR*, accounts for the economic consequences of diverting traffic to a different route classification. The criteria considered in developing the relationship were:

1. Frequency of traffic accidents on different route classifications.
2. Average vehicle speed on different route classifications.
3. Vehicle operating and user costs for different route types.

The economic consequences of a route type change were evaluated as:

Economic consequences per vehicle per km =
cost per vehicle per km on diversion route
- cost per vehicle per km on original route

The factors shown in Table 10 are applied to the Restriction score, *R*, in Equation 1 as a direct multiplication factor. If the diversion route has a higher classification than the original route then the reduced consequences are also reflected.

Table 10 Diversion Route Score, *DR*

		Original Route Type				
		Motorway	**Primary A**	**Other Principal**	**Classified B & C**	**Unclassified U**
Diversion Route Type	**Motorway**	1.00	0.99	0.98	0.93	0.80
	Primary A	1.01	1.00	0.99	0.94	0.81
	Other Principal	1.03	1.01	1.00	0.95	0.83
	Classified B & C	1.08	1.06	1.05	1.00	0.88
	Unclassified U	1.20	1.19	1.18	1.13	1.00

If there are road works on the preferred diversion route there is a higher likelihood of road accidents and a slower average speed. When road works are present on the diversion route, *DR* is amended as follows (Ref. 8):

$$DR_{RW} = DR \times 1.5$$

Equation 5

where DR_{RW} = score for Diversion Route with Road Works

If the road works are only on the diversion route for part of the diversion period then the *DR* used in Equation 1 should be a weighted average of *DR* and DR_{RW}, where the weighting used is the number of months applicable to each.

5.6 Original Route Type Score, *OR*

The Original Route Type score, *OR*, is based on the traffic volume (AADT) the route accommodates when there is no restriction. *OR* is evaluated as:

$$OR = \frac{AADT}{10{,}000}$$

Equation 6

AADT is the Average Annual Daily Traffic flow which is the average 24 hour two-way flow on the route. The *OR* factor is applied to the product of *R* and *DR* in Equation 1 to take account of the total volume of traffic on the route. The Original Route Type score, *OR*, is selected from Table 11.

Table 11 Original Route Type Score, *OR*

Original Route Type	Traffic Flow		*OR*
	Description	AADT	
Motorway	Heavy	> 90,000	9.0
	Moderate	30,000 to 90,000	6.0
	Light	< 30,000	3.0
Primary A	Heavy	> 50,000	5.0
	Moderate	20,000 to 50,000	3.5
	Light	< 20,000	2.0
Other Principal Roads	Heavy	> 30,000	3.0
	Moderate	10,000 to 30,000	2.0
	Light	< 10,000	1.0
Classified B & C	Heavy	> 10,000	1.0
	Moderate	3000 to 10000	0.65
	Light	< 3000	0.30
Unclassified U	Heavy	> 3000	0.30
	Moderate	1000 to 3000	0.20
	Light	< 1000	0.10

5.7 Increased Journey Length Score, *IJL*

Restrictions normally cause some road users to make longer journeys. The length of the increased journey created by a restriction is assumed to be relative to the route type restricted, i.e. higher route classifications are primarily used for longer journeys while lower route classifications are primarily used for shorter local journeys, therefore the nature of the assumed diversion should reflect this. The increased journey length is therefore defined as:

Motorway, Primary A and Other Principal Routes (also see Figure 3)

Increased Journey Length = (Length of diversion route, *DR*, from junction A to B)

– (Length of original route, *OR*, from junction A to B)

Classified B & C and Unclassified U Routes (also see Figure 4)

Increased Journey Length =

Distance from one side of the restricted structure to the other via a diversion

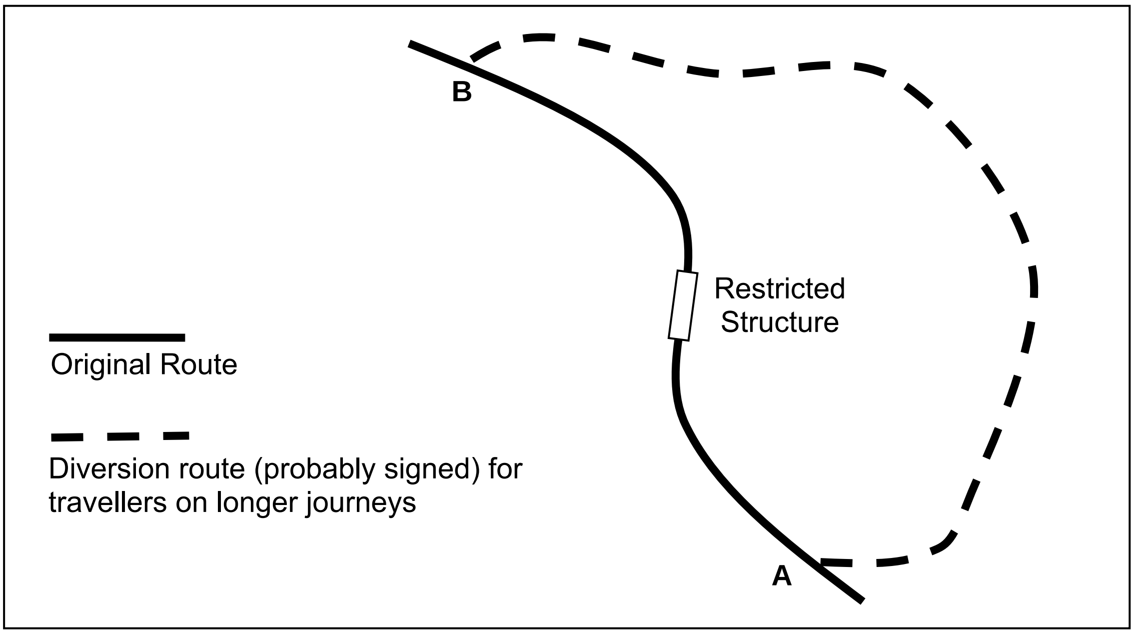


Figure 3 IJL for Motorway, Primary A and Other Principal Routes

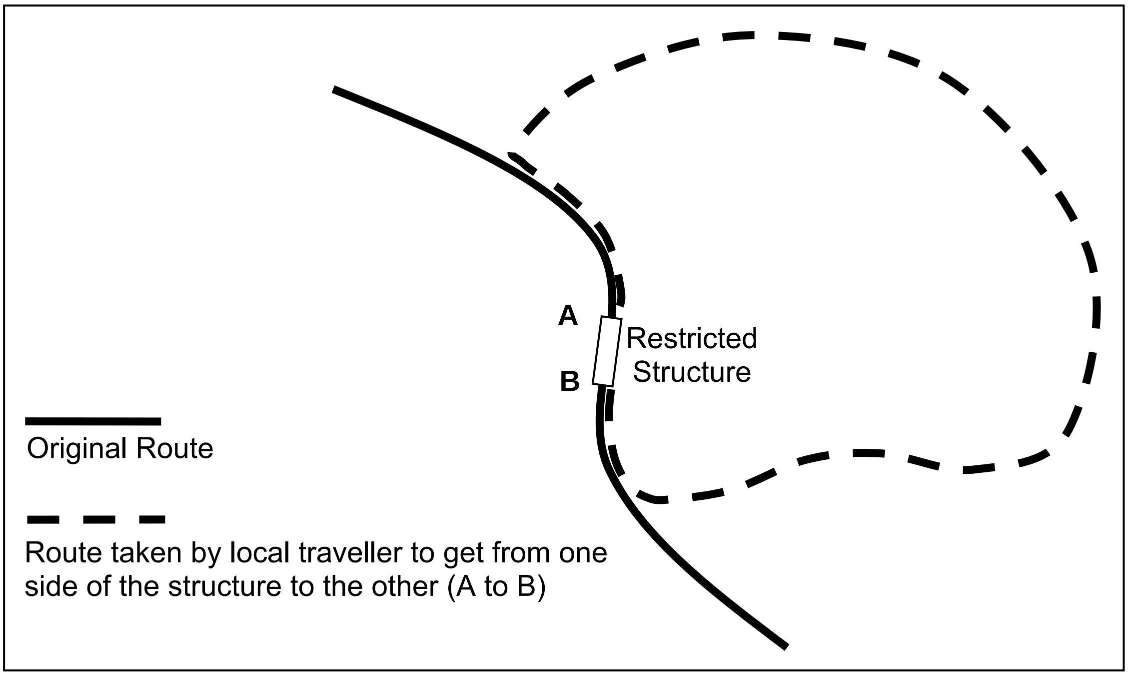


Figure 4 IJL for Classified B & C and Unclassified U Routes

IJL is applied to the product of *R*, *DR* and *OR* in Equation 1 to account for the extra distance actually travelled. The *IJL* score is selected from Table 12 and should be based on the preferred diversion route.

The *IJL* score is not based on a one-to-one mapping of the actual increased diversion length. Instead, the real journey lengths were translated to an *IJL* score that reflects engineering opinion. The engineering opinion was provided via a questionnaire survey which indicated that the absolute length of the diversion should not be used in the Availability PI calculation.

Table 12 Increased Journey Length Score, *IJL*

Preferred Diversion Route	Increased Journey Length, km	*IJL*
Negligible	Zero/minimal	0
Very Short	< 2km	1
Short	2 to 5km	2
Medium	5 to 10km	3
Long	10 to 20km	4
Very Long	> 20km	5
No alternative	-	10

5.8 Environmental Score, *En*

The environmental score is based on:

1. The environmental sensitivity of the diversion route, Table 13; and
2. The magnitude of the impact on the diversion route, Table 14.

The environmental sensitivity, Table 13, takes into account the type of area the diversion route passes through and the other users on this route, i.e. non vehicular traffic.

Table 13 Environmental Sensitivity

		Dominant use of area surrounding diversion route		
		Industrial or unused	**Rural or urban commercial**	**Residential or Environmental Class 2, 3 or 4 from App. B**
Number of non vehicular users, e.g. pedestrian, cyclist and equestrian	**Low**	Low	Low	High
	Medium	Low	Medium	High
	High	Medium	High	High

The magnitude of the environmental impact, Table 14, is based on the difference between the original and diversion route classifications. The greater the difference between the classifications the greater the environmental impact, that is:

- A small volume of traffic diverted from a higher route classification is likely to represent a significant traffic volume increase for a lower route classification.
- On average driver stress levels will increase as route class decreases, e.g. poorer road signs & lighting, reduced sight distances, poorer road surface quality, narrower lanes etc.

Table 14 Magnitude of Environmental Impact

		Original Route Classification				
		Motorway	**Primary A**	**Other Principal**	**Classified B & C**	**Unclassified U**
Diversion Route Classification	**Motorway**	Medium	Low	Low	Low	Low
	Primary A	Medium	Medium	Low	Low	Low
	Other Principal	High	Medium	Medium	Low	Low
	Classified B & C	High	High	Medium	Medium	Low
	Unclassified U	High	High	High	Medium	Medium

The ratings from Table 13 and Table 14 are used to select the Environmental Score, *En*, from Table 15.

Table 15 Environmental Score

		Environmental Impact		
		Low	**Medium**	**High**
Environmental Sensitivity	**Low**	0	5	10
	Medium	5	10	15
	High	10	15	20

Important: The environmental score should be taken as 20 if there is no alternative diversion route because it is assumed that the queuing traffic will have a detrimental impact on the environment. The environmental score is zero if there is no restriction.

5.9 Socio-Economic Score, *SE*

The Socio-Economic impact is evaluated as a function of:

- The impact on the area/community served by the restricted route, Table 16; and
- The impact on the area/community served by the preferred diversion route, Table 17.

Table 16 Impact on Restricted Route

Rating	Description
Low	No/negligible impact on business and communities; or No restrictions on emergency vehicles
Medium	Some loss of business; or Some loss of access to community facilities; or Access for emergency vehicle restricted to < 7.5 tonne
High	Significant loss of business; or Loss of access to important community facilities e.g. hospital, schools; or Loss of access to many community facilities; or No access for emergency vehicles; or No diversion route available

Table 17 Impact on Diversion Route

Rating	Description
Low	No/negligible impact on diversion routes
Medium	Some impact on diversion routes e.g. noticeable increase in traffic volume
High	Alternate routes nearing saturation level or gridlocked; or Traffic/HGVs diverted past schools, nurseries, sensitive areas etc.; or No diversion route available

The ratings from Table 16 and Table 17 are used to select the Socio-Economic score, *SE*, from Table 18.

Table 18 Socio-Economic Score, *SE*

		Impact on Restricted Route		
		Low	**Medium**	**High**
Impact on Diversion Route	**Low**	0	10	20
	Medium	10	20	30
	High	20	30	40

Important: The socio-economic score is zero if there is no restriction.

6. Availability PI Score for Non-Vehicular Routes

If an authority wishes to extend the Availability PI for interactions with non-vehicular routes, including Public Right of Way (PROW) routes (public footpaths, cycle tracks, bridleways and byways), then they can do so using the equations and look up tables presented below.

Remember: If a structure/network interaction has created no restriction for the previous 12 months then it automatically has a score of 100 and no calculation, or associated data collection, is required.

6.1 Non-Vehicular Availability PI Formula

The economic costs to non-vehicular traffic are difficult to quantify and therefore the procedure is more subjective than that presented in Section 5 for vehicular routes. The Availability PI for non-vehicular routes is based on:

1. The restriction.
2. The quantity of non-vehicular users on the restricted route.
3. The characteristics of the preferred diversion route.
4. Local importance of the restricted route.
5. Duration of restriction.

The Availability PI is evaluated as show in Equation 7:

Availability PI for each Network Interaction

$$PI = 100 - \frac{T}{12}\left(R_{NV} \times \left\{\left(OR_{NV} \times Div\right) + L_{imp}\right\}\right)$$

but not < 0 **Equation 7**

where R_{NV} = restriction score for the non-vehicular route, Section 6.2

OR_{NV} = volume of users on the restricted route, Section 6.3

Div = diversion characteristics, Section 6.4

L_{imp} = local importance of the restricted route, Section 6.4

T = duration of restriction in months, see Section 5.3

6.2 Restriction Score, R_{NV}

Restrictions on non-vehicular routes are classified into two categories:

1. The route is not restricted or not fully closed by the structure restriction.
2. The route is fully closed by the structure restriction.

The restriction score is selected from Table 19.

Table 19 Restriction Score for Non-Vehicular Routes

	Restricted and fully closed	No restriction or not fully closed by restriction
R_{NV}	1.0	0.0

6.3 Volume of Users, OR_{NV}

This score accounts for the volume of non-vehicular traffic that uses the route. The score is selected from Table 20.

Table 20 Score for Volume of Users, OR_{NV}

	Volume	OR_{NV}
Low	< 100 users per day	1.0
Medium	100 to 1000 users per day	5.0
High	> 1000 users per day	10.0

6.4 Diversion Score, *Div*

This score accounts for the diversion characteristics and takes into account the increased length of journey the diverted users need to make, the increased risk of crime to the user and the increased risk of accident to the user, see Table 21.

Table 21 Score for Diversion Characteristics, *Div*

	Increased Journey Length		
	< 100m	100 to 500m	> 500m
Crime and accident risk is less than or similar to restricted route	1.0	2.0	3.0
Increased risk of crime and/or accident compared to restricted route	3.0	4.0	5.0

6.5 Local Importance Score, L_{imp}

This score accounts for the importance of the structure to the local community and is selected from Table 22. The local importance of a non-vehicular route is a subjective issue, but the criteria considered should include:

- Access to important community facilities, e.g. hospitals, schools, council offices etc.
- Access to residential areas.
- Number of alternative routes.
- Is the structure, or route, a locally important feature, e.g. tourist attraction?

Table 22 Local Importance of Route, L_{imp}

Importance	L_{imp}
Low	0
Medium	20
High	50

7. Structure Stock Availability PI

The Availability PI score for each Route Type within the stock *must* be evaluated prior to the Structure Stock Availability PI, see Figure 2 in Section 2.5. The Route Type Availability PIs are evaluated separately because the scales differ due to the lower bound constant, C_{LB}, as described in Section 5.2. The Route Type Availability PIs are combining to produce the Structure Stock Availability PI.

Important: The Availability PI should be based on interactions between vehicular routes and highway structures, where vehicular routes are Motorways, Primary A, Other Principal Roads, Classified B & C and Unclassified routes. However, if an authority wishes to extend the Availability PI to include interactions with non-vehicular routes, including Public Right of Way (PROW) routes (public footpaths, cycle tracks, bridleways and byways), then they can do so.

7.1 Availability PI by Route Type

The Availability PI score for each route type is evaluated using Equation 8.

Route Type Availability PI score

$$\text{Route Type PI Score } (PI_R) = 100 - \frac{\sum\left[(100 - API)\times\left(F_R - API\left[\frac{F_R}{100}\right]\right)\right]}{N_R}$$

but not < 0 **Equation 8**

Important

$$\left[(100 - API)\times\left(F_R - API\left[\frac{F_R}{100}\right]\right)\right] = 0$$

$$\text{when API} = 100$$

Therefore, the numerator is simply a summation for those structures/interactions that have had a restriction over the previous 12 months.

where:

API = Individual Availability PI score for an interaction on this route type, this is the output from Equation 1 in Section 5.1

N_R = the number of times structures on this route type interact with the network

F_R = route type factor, see below

The objective of the route type factor, F_R, is to produce scores for each route type that are:

- More sensitive to change; and

- More reflective of the percentage of restrictions that are likely to cause severe/critical disruption for the route type on a network wide scale.

The proposed Route Type Factors, F_R, and the percentage of lower bound restrictions they are based on, are shown in Table 23.

Table 23 Route Type factors, F_R

Route Type	% of lower bound restrictions deemed to make the route type severely restricted	F_R
Motorway	5%	20
Primary A	10%	10
Other Principal	10%	10
Classified B & C	15%	6.67
Unclassified U	20%	5
Non-vehicle routes	15%	6.67

The format of Equation 8 is such that as the severity of an individual restriction increases its influence on the group, or overall stock, Availability PI score increases disproportionately.

7.2 Availability PI Score for Stock

The Availability PI score for the structure stock is evaluated using Equation 9.

$$\text{Stock Availability PI Score} = \frac{\sum (PI_i \times N_i \times C_{LB-i})}{\sum (N_i \times C_{LB-i})}$$

Equation 9

Where:

PI_i = Availability PI score for route type *i*, from Equation 8

N_i = the number of structure/network interactions on route type *i*

$C_{LB\text{-}i}$ = Lower Bound constant for route type *i*, from Table 5

The weighting, C_{LB}, is used in Equation 9 to remove the economic imbalance it imposed in Equation 1. C_{LB} was originally used to give a more meaningful score, on the 0 to 100 scale, for each route type relative to their respective lower bound restrictions and route economics, i.e. number of vehicles, user costs etc. In the stock evaluation the economics should be comparable across all route types therefore C_{LB} is used again to counter its initial influence.

7.3 Interpretation of Availability PI Score

Availability PI interpretations are provided in Table 24 for individual structures and Table 25 for structures on a route type and the structure stock. All the Availability PI scores are on the 0 to 100 scale and take into account the required Levels of Service, shown in Table 3 in Section 4.1, and the lower bound restrictions, shown in Table 4 in Section 4.2 and Table 5 in Section 5.2. Therefore, a score of zero does not mean that the network is completely unavailable; instead it means that the structure stock has fallen below the lower bound availability levels defined.

Note: The Availability PI scores for individual structures should be with caution as they could be easily misinterpreted by those not familiar with the procedure. It is recommended that only the structure stock Availability PI score is used for reporting performance.

Table 24 Individual Structure Availability PI Interpretations

Score	Interpretation of Score
90 ≤ x ≤ 100	**Very Good Availability** – structure is causing negligible/no loss of availability on the route
80 ≤ x < 90	**Good Availability** - structure is causing a minor loss of availability on the route
65 ≤ x < 80	**Fair Availability** - structure is causing a moderate loss of availability on the route
40 ≤ x < 65	**Poor Availability** - structure is causing a considerable loss of availability on the route
0 ≤ x < 40	**Very Poor Availability** - structure is causing a major/severe loss of availability on the route

Table 25 Route and Stock Availability PI Interpretations

Score	Interpretation of Score
90 ≤ x ≤ 100	**Very Good Availability** - Negligible loss of availability on the route type or whole network
80 ≤ x < 90	**Good Availability** - Minor loss of availability on the route type or whole network
65 ≤ x < 80	**Fair Availability** - Moderate loss of availability on the route type or whole network
40 ≤ x < 65	**Poor Availability** - Considerable loss of availability on the route type or whole network
0 ≤ x < 40	**Very Poor Availability** – Major/severe loss of availability on the route type or whole network

8. References

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5. TD 27: Cross-sections and Headrooms (DMRB 6.1.2).

6. TA46: Traffic Flow Ranges for use in the assessment of new rural roads (DMRB 5.1.3).

7. New Metric Handbook, P. Tutt and D. Adler.

8. DMRB, Volume 14, Section 1: The QUADRO Manual, Part 5: The traffic input to QUADRO.

9. DMRB: Volume 11 – Environmental Assessment: Section 3 – Environmental Assessment Techniques: Part 4 – Ecology and Nature Conservation, June 1993.

APPENDIX A
Environmental Classifications

Environmental Classifications

The list of *Designated Sites* is taken from the DMRB (Ref. 9). More detailed descriptions of each site type are provided in Ref. 9, along with guidance on assessing and classifying a non-designated site that may be of potential nature conservation interest.

Category	Site Importance	Classifications (Designated Sites)
Class 1	Non-Designated Sites (Default Value)	Site not classified as one of the following (if it is believed the site may be of potential nature conservation interest then refer to Ref. 9 Annex V for guidance).
Class 2	Sites of Regional and Local Importance	• Local Nature Reserves (LNRs) • Regional Parks • Non-Statutory Sites of Importance for Nature Conservation • Non-Statutory Nature Reserves • Forest Nature Reserves
Class 3	Sites of National Importance	• National Nature Reserves (NNRs) • Marine Nature Reserves (MNRs) • Sites of Special Scientific Interest (SSSIs) • Areas of Special Scientific Interest • Areas of Special Protection for Birds • Ancient Woodlands • Natural Heritage Areas
Class 4	Sites of International Importance	• World Heritage Sites • Biosphere Reserves • Biogenetic Reserves • Ramsar Sites (Wetlands of International Importance) • Special Protection Areas (SPAs) • Special Areas of Conservation (SACs) • The Berne Convention • The Bonn Convention

Task No: YY86731

Guidance Document for Performance Measurement of Highway Structures

Part B3: Reliability Performance Indicator

Report prepared by:

ATKINS

Report prepared on behalf of:

Highways Agency

CSS Bridges Group

2007

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1. Introduction

1.1 Reliability Performance Indicator Definition

The Reliability PI is defined as:

A representation of the ability of the structure stock to support traffic, and other appropriate loading, taking into account the consequence of failure.

1.2 Background, Objectives and Scope

The background, objectives and scope are discussed in *Part A: Framework for Performance Measurement*.

1.3 Terminology

The following terminology is used by the Reliability PI procedure:

- **Live Load Rating** – the terminology used for the live load capacity (in tonnes) assigned to the structure at design or assessment.

2. Overview of Reliability PI Procedure

2.1 General Approach

The aim of the Reliability Performance Indicator (PI) is to represent the ability of a structure to support traffic, and other appropriate, loads and take into account the consequence of failure to road users, businesses and communities. The Reliability PI is defined as:

$$\text{Reliability PI} = f(\text{Probability of Failure, Consequence of Failure})$$

Where the probability and consequence of failure are defined as:

Probability of Failure - given the current condition, assessed capacity, loading, safeguards/restrictions etc., what is the likelihood that an element or part of the structure will fail?

Consequence of Failure - given that a failure occurs what are the likely consequences in terms of casualties, traffic delay costs, reconstruction costs and socio-economic impact?

The quantification of failure probabilities and consequences has the potential of creating a highly involved and complex procedure requiring significant quantities of data. This approach is not practical for the Reliability PI because:

- All relevant structures are included in the Reliability PI calculation therefore it must be relatively straightforward and require minimal effort and data.

- The procedure must align, where possible, with readily available data and/or data that are required for good Asset Management. A large number of data fields must not be created solely for the purpose of PI reporting.

A procedure has been developed that utilises the principles of the probability and consequence of failure. The procedure can be readily programmed and has been designed to operate on minimal/coarse data, but can also make full use of more detailed data when available.

It is important to note that the Reliability PI does not cover scour, vehicle impact (pier, deck or parapet) or other similar risks, for this reason the term <u>Reliability</u> has been used instead of <u>Risk</u> or <u>Safety</u>.

2.2 Reliability PI Scale

The Reliability PI scale is from 0 to 100, where 0 represents an unacceptable level of reliability and 100 represents a high level of reliability. Individual structures, tactical sets and the structure stock are all scored on the 0 to 100 scale. The scale is divided into five bands (Very Good, Good, Fair, Poor and Very Poor) with generic reliability descriptions for each, these are presented in Section 7.3.

2.3 Reliability PI Score

All structures, under stewardship of the authority, that support traffic and other appropriate loading are included in the Reliability PI. One Reliability PI score is evaluated per structure.

The Reliability PI for structure groups and the stock is simply the average of the individual structures that make up the group/stock, see Section 7. It is not a weighted average, like the Condition PI, because the importance of a structure is implicit in the Reliability PI calculation.

2.4 Other Highway Structure Owners

The Reliability PI excludes structures that are within the footprint of an authority's highway but under the stewardship of another authority. However, this does not preclude an authority from using this procedure to assess the reliability of these structures, although it is unlikely that the authority would hold the necessary information for structures not under their stewardship.

Important: In reporting the Reliability PI an authority should, first and foremost, report the value for structures under their stewardship. This may be supplemented by further Reliability PI scores that illustrate the reliability of structures owned by other authorities.

2.5 Steps in the Reliability PI Procedure

An overview of the Reliability PI procedure is shown in Figure 1, the steps involved are summarised below.

Step 1 – Select Structure Group

It is recommended that the Reliability PI is evaluated for groups of structures (Tactical Sets) as well as the stock as a whole. The structure stock may be subdivided into separate groups in order to analyse the Reliability PI in more detail, for example, bridges, retaining walls, route corridor, material type etc.

Step 2 – Select Individual Structure

The Reliability PI is evaluated at individual structure level for all appropriate structures, therefore each structure is selected in turn, see Section 3.1

Step 3 – Compile Data

The data required to evaluate the Reliability PI are defined in Section 3.2, e.g. Live Load Rating, change in critical element condition, route type served, span length etc.

Step 4 – Identify Critical Load Bearing Element

For structures that have been assessed, the Reliability PI is based on the critical load bearing element on the structure, which is selected based on assessment data and/or condition data, see Section 4.

Step 5 - Evaluate the Probability of Failure

The *simplified notional probability of failure* is based on the Live Load Rating of the structure. The Live Load Rating is compiled from design or assessment records if available otherwise a procedure is provided for deriving a probability of failure when assessment data is not available. The probability of failure is modified, where appropriate, to account for change in condition of the critical load bearing element, interim measures, monitoring activity and inspection accessibility, see Section 5.

Step 6 – Evaluate the Consequence of Failure

The consequence of failure of a structure is based on casualties, reconstruction costs, user disruption, Socio-Economic impact, reconstruction duration and the extent of failure, see Section 6.

Step 7 – Evaluate Reliability PI

Risk is the product of the Probability and Consequence of Failure. The risk score is converted to a Reliability PI, see Section 7.1.

Step 8 – Next Structure

Select the next structure within this structure group.

Step 9 – Evaluate Structure Group Reliability PI

The structure group Reliability PI is the average of all the individual structure scores in the group, see Section 7.2.

Step 10 – Next Structure Group

Select the next structure group for which the Reliability PI calculation will be performed.

Step 11 – Evaluate Structure Stock Reliability PI

The structure stock Reliability PI is the average of all the individual structure scores, see Section 7.2.

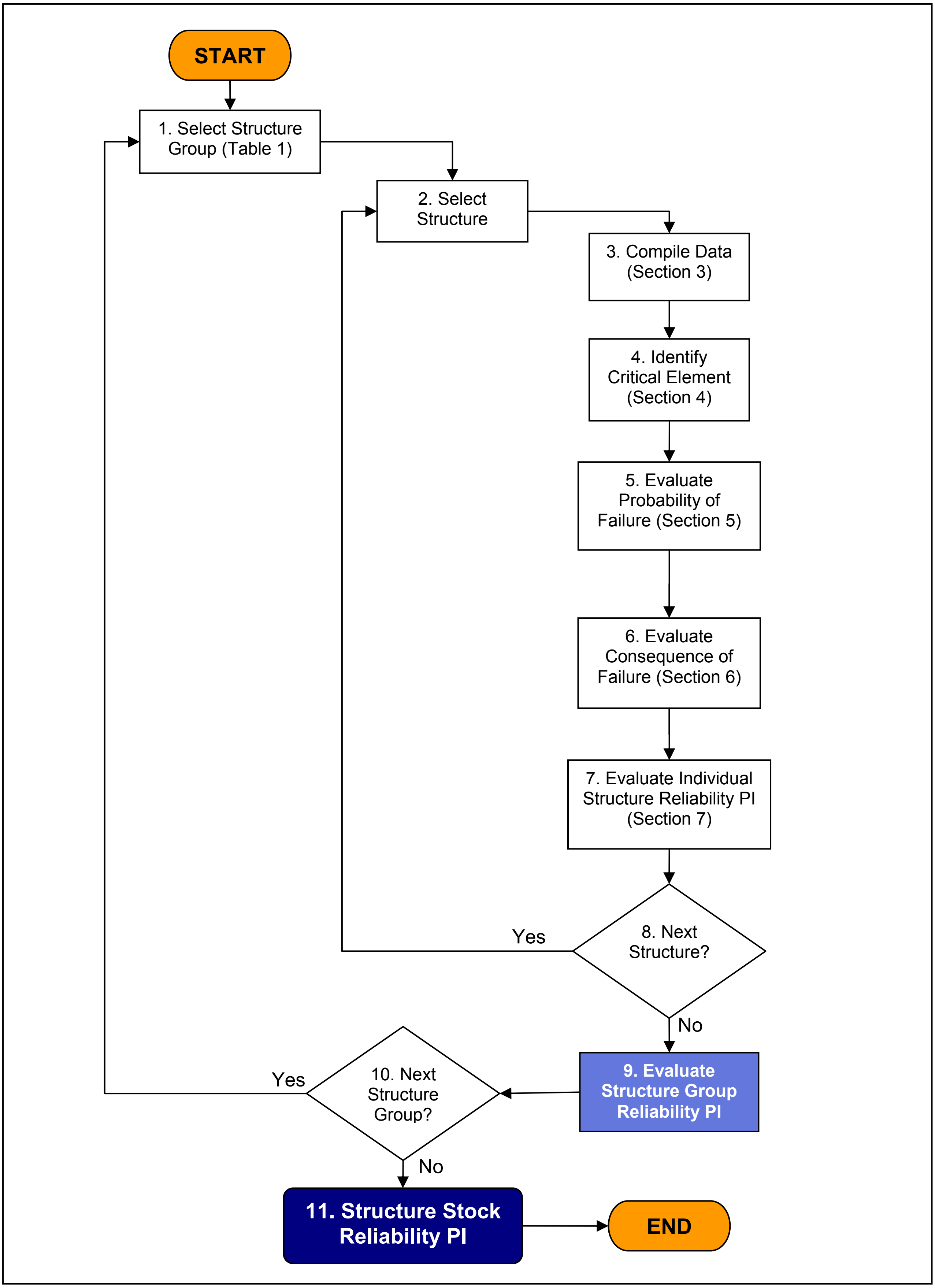

Figure 1 Flowchart of Reliability PI Procedure

3. Data Requirements

3.1 Relevant Structure Types

The Reliability PI assesses the ability of a structure to support traffic and other appropriate loading; therefore not all structure types are relevant. The exclusion of some structure types does not mean their reliability is of no relevance to the highway manager/engineer, only that they were deemed inappropriate for inclusion in the Reliability PI due to data requirements and their minimal influence on the overall Reliability PI score. The structures included and excluded from the Reliability PI are shown in Table 1, definitions of the structure types are provided in the Code of Practice, BD62 and BD63 (Refs. 1, 2 and 3).

Table 1 Structure Types Included and Excluded from Reliability PI

Structure Type	Reliability Requirement	Reliability PI
Bridge and culverts	To support appropriate loading (e.g. vehicular, pedestrian or other)	Included
Small culverts (if treated separately from bridges)	To support appropriate loading (e.g. vehicular, pedestrian or other)	Included
Retaining Wall	To support the highway, cutting or other loading, see Figure 2.	Included
Road Tunnel	When a tunnel slab supports the highway	Included
Sign/Signal Gantry	-	Excluded
High Mast	-	Excluded
Services and other crossings	-	Excluded

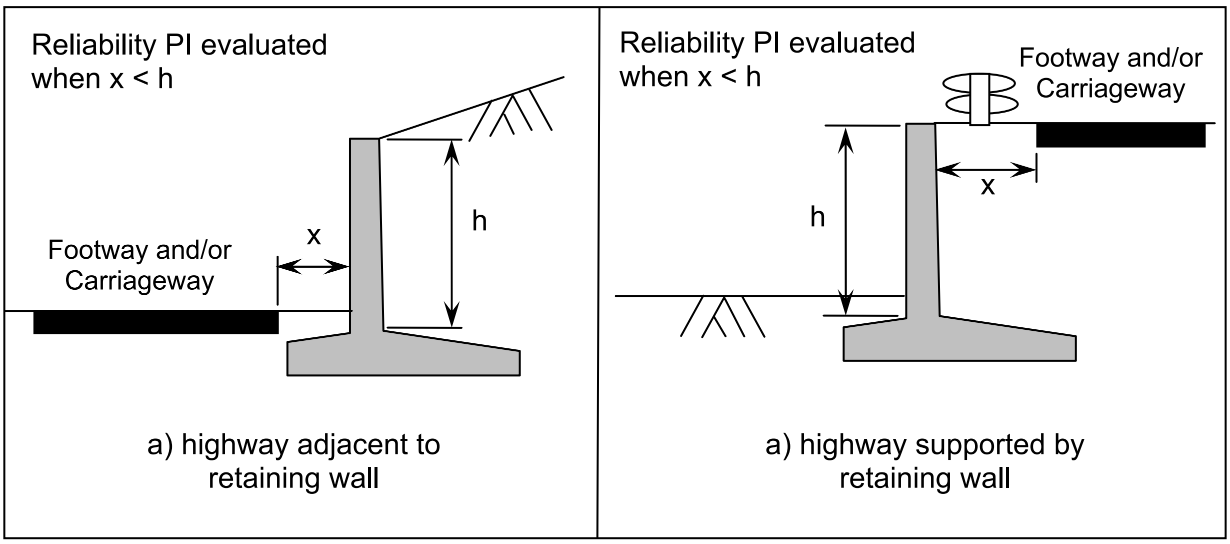

Figure 2 Retaining Wall Reliability Requirements

3.2 Essential and Desirable Data

Table 2 shows data that are essential and desirable for calculating the Reliability PI:

- **Essential Data** – must be known when calculating the Reliability PI. If this data is not known then the uncertainty in the Reliability PI for an individual structure is judged to be unacceptable. However, it is acceptable to base this data on engineering judgement provided the engineer has a good working knowledge of the structure.

- **Desirable Data** – the Reliability PI may be calculated without this data but its inclusion may improve accuracy.

Table 2 Essential and Desirable Data

No.	Data	Classification
1	Assessment information: • Live Load Rating • Structure still to be assessed. • Structure excluded from assessment programme.	Essential
2	Traffic, or other users, carried by bridge/culvert or supported by a retaining wall, e.g. route classification, footbridge, business/residential property supported etc.	Essential
3	Obstacle crossed by bridge/culvert or adjacent to retaining wall	Essential
4	Structure dimensions, e.g. • Bridge/culvert length and width • Retaining wall height and length	Essential
5	Element types on structure (from condition inspection)	Essential
6	Safeguards and restrictions	Essential
7	Condition Data: a. Element Condition Data; and/or b. Change in condition since last load assessment	 Essential Desirable
8	Reduction Factor, K	Desirable
9	Inspection Accessibility	Desirable
10	Increased Journey Length for diverted traffic	Desirable

4. Structure Reliability Evaluation

4.1 Reliability

The reliability of a highway structure can be evaluated as a function of all the individual element reliabilities on the structure as shown in Equation 1a.

$$\textit{Structure Reliability} = f(RE_1, RE_2, RE_3 \ldots RE_n)$$

Equation 1a

Where n = the number of elements on the structure

RE_i = Reliability score for *Element i*

Equation 1a is the ideal approach however this is not wholly necessary because the reliability score of a structure is normally dominated by the element with the lowest capacity and/or in the worst condition. The individual structure reliability can therefore be more simply defined as:

$$\textit{Structure Reliability} = (\textit{Reliability of Critical Element})$$

Equation 1b

The Reliability PI adopts the approach shown in Equation 1b. Therefore the Probability of Failure and Consequence of Failure are evaluated relevant to the *Critical Element*.

4.2 Critical Element

The Reliability PI is concerned with the primary load carrying/supporting function of the structure. Therefore *Critical Elements* are limited to those that govern structural capacity, see Table 3. The categories in Table 3 align with the Importance Classifications used in *Part B1: Condition Performance Indicator*. Table 3 does not show any elements in the Medium and Low Importance categories because these elements they do not govern structural capacity.

The *Critical Element* is selected from Table 3 based on the following rules:

1. ***Known Critical Element*** – the assessment records identify the critical load bearing element, e.g. main beams, transverse beams, foundations. This element is used in the Reliability PI procedure.

2. ***Unknown Critical Element*** – assessment records do not identify the critical load bearing element or the structure has not been assessed. Therefore, the element from Table 3 that has the worst **Severity** condition rating is used as the *Critical Element* in the Reliability PI. If two elements have the same **Severity** condition rating then the element in the higher consequence category in Table 3 is taken as the *Critical Element*, if they are in the same consequence category then the element with the higher **Extent** rating is used as the *Critical Element*.

The consequence category (left hand column of Table 3) is used in the Consequence of Failure calculation in Section 6. Higher importance elements are assumed to cause more extensive failures and thereby have greater Consequence of Failure.

Table 3 Critical Elements

Consequence (Importance) Category	Superstructure Elements	Substructure and Retaining Wall Elements
Very High	**<u>Bridges</u>** • Primary deck element • Transverse Beams • Secondary deck element • Half joints • Tie beam/rod • Parapet beam or cantilever	**<u>Bridges</u>** • Pier/column • Cross-head/capping beam • Foundations **<u>Retaining Walls</u>** • Primary Element • Secondary element **<u>Small Culvert</u>** • Culvert
High	**<u>Bridges</u>** • Deck Bracing • Bearings	**<u>Bridges</u>** • Foundations • Abutments • Spandrel Wall **<u>Retaining Walls</u>** • N/A **<u>Small Culvert</u>** • Headwall
Medium	N/A	N/A
Low	N/A	N/A

A distinction is made in Table 3 between superstructure and substructure elements; this distinction is used by the Probability of Failure procedure, in Section 5.2.3.

5. Probability of Failure

5.1 Overview of the Probability of Failure Procedure

The probability of failure is based on the Live Load Rating of the structure. A simple qualitative assessment procedure is provided for structures where the Live Load Rating is unknown. The Probability of Failure derived from the Live Load Rating is then adjusted to account for the following factors when appropriate:

- Assessment Category, i.e. assessed, not included in assessment programmed and still to be assessed, with the latter including those structures designed to the latest standards (Section 5.2).
- When the *Critical Element* supports a footway beside a carriageway rather than the carriageway (Section 5.3).
- Any interim measures, e.g. restrictions/safeguards or temporary supports in place (Section 5.4).
- Change in condition of the *Critical Element* since the last load assessment (Section 5.5).
- Inspection Accessibility, i.e. ability to adequately inspect the *Critical Element* on the structure (Section 5.6).
- Structure monitoring in accordance with BD79 (Section 5.7).

An overview of the procedure for evaluating the Probability of Failure is shown in Figure 3, the associated equation is:

$$P_f = P_{f\text{-}LLR} \times AD_F = P_{f\text{-}LLR} \times (F_{FbC} \times F_{IM} \times F_{CON} \times F_{IA} \times F_{MON})$$

Equation 2

where P_f = Probability of failure of the critical element

$P_{f\text{-}LLR}$ = Probability of Failure for given Live Load Rating (Section 5.2)

AD_F = Adjustment factor

F_{FbC} = Footways beside Carriageways factor (Section 5.3)

F_{IM} = Interim Measures adjustment factor (Section 5.4)

F_{CON} = Element Condition adjustment factor (Section 5.5)

F_{IA} = Inspection Accessibility adjustment factor (Section 5.6)

F_{MON} = Monitoring adjustment factor (Section 5.7)

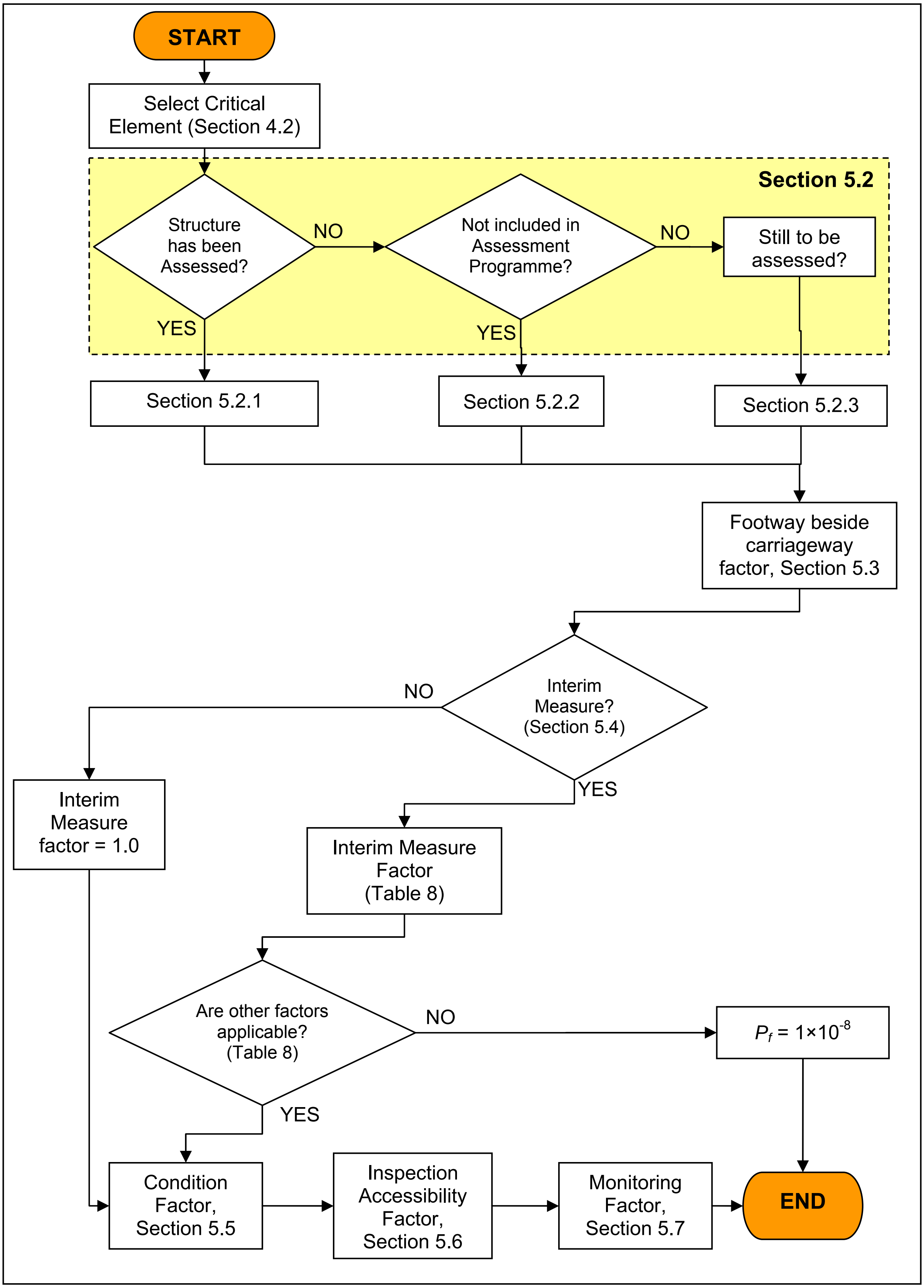

Figure 3 Overview of Probability of Failure Procedure

5.2 Live Load Rating, *LLR*

Structures are divided into three categories based on assessment, or where relevant design, information. The categories are shown in Table 4. The methodology for evaluating the Live Load Rating Probability of Failure, $P_{f\text{-}LLR}$, differs for each category.

Table 4 Assessment Categories

Cat.	Assessment Details	Live Load Rating Probability of Failure, $P_{f\text{-}LLR}$	Probability of Failure, P_f
1	Assessed (qualitative and/or quantitative)	$P_{f\text{-}LLR}$ = *f*(Assessment Live Loading and Assessment Level) Go to Section 5.2.1	$P_f = P_{f\text{-}LLR} \times AD_F$
2	Not included in Assessment Programme (i.e. not required by BD34, BD46 or BD50, Refs. 4, 5 and 6)	$P_{f\text{-}LLR}$ = *f*(structure characteristics and local knowledge) Go to Section 5.2.2	$P_f = P_{f\text{-}LLR} \times AD_F$
3	Still to be assessed (including structures designed to latest standards)	$P_{f\text{-}LLR}$ = *f*(design code and local knowledge) Go to Section 5.2.3	$P_f = P_{f\text{-}LLR} \times AD_F$

Where AD_F = Adjustment factor (see Section 5.1).

The Live Load Rating is used to evaluate the initial probability of failure of a structure relative to the current loading requirements. Current loading requirements are taken to be Type HA loading that allows for the effects of 40 tonne vehicles. Under this approach, a structure assessed to have a 3 tonne rating has a different $P_{f\text{-}LLR}$ than a structure assessed to have a 40 tonne rating because the procedure assumes they are both taking full HA loading. Adjustment factors are then applied to the $P_{f\text{-}LLR}$, as shown in the right hand column of Table 4, to account for any mitigation measures currently in place, e.g. a structure with a 3 tonne rating may have vehicle barriers.

It is beyond the scope of, and also unnecessary for, the Reliability PI to request structural reliability assessments. The probability of failure utilised by the Reliability PI is the *simplified notional probability of failure*, where this is described as:

- **Total Probability of Failure** – evaluated using probabilistic procedures that take into account normal factors, e.g. loading, material strength, engineering model uncertainty etc. and abnormal factors e.g. gross errors, misuse (overload) etc.

- **Notional Probability of Failure** - evaluated using probabilistic procedures that take into account all normal factors, e.g. loading, material strength, engineering model uncertainty etc. Abnormal factors are not included in the analysis.

- **Simplified Notional Probability of Failure** – average/typical values obtained from *Notional Probability of Failure* analyses are used to define a simplified relationship between assessed capacity and probability of failure. This approach only differentiates between structures based on the assessment rating and may not provide accurate values for all individual structures.

5.2.1 Category 1 – Assessed Structures

The Probability of Failure for a given Live Load Rating, $P_{f\text{-}LLR}$, for a Category 1 structure subject to full loading[1] is evaluated using Equation 3 or 4. These equations were derived from the curve and assumptions presented in Appendix A.

The Live Load Rating should be taken as the Assessment Live Loading (calculated from BD21, Ref. 7). The Live Load Rating may therefore relate to the calculated loading capacity (e.g. 46.5 tonne, 35.4 tonne, or any value), or the assigned loading category, (e.g. 40 tonne, 18 tonne, 7.5 tonne or 3 tonne). Either can be used in Equation 3, although the former would provide a more representative result. Where only the latter is available, but details of the BD21 Reduction Factor K are also available, then Equation 4 may provide a more representative result.

$$P_{f-LLR} = e^{\{(-0.282 \times LLR \times F_{AL}) - 5.974\}}$$

Equation 3

where LLR = Live Load Rating (Tonnes) of *Critical Element*

F_{AL} = Factor to account for Assessment Level

Where Assessment Level 3, F_{AL} = 1.00

Assessment Level 2, F_{AL} = 1.05

Assessment Level 1, F_{AL} = 1.10

Qualitative Assessment, F_{AL} = 1.00 (default value)

$$P_{f-LLR} = e^{\left\{\left(-0.282 \times \left(LLR \times \frac{K}{K_R}\right) \times F_{AL}\right) - 5.974\right\}}$$

Equation 4

where K = the reduction factor evaluated according to BD21

K_R = the reduction factor relating to the Live Load Rating plot line in BD21[2]

The Assessment Level factors, F_{AL}, are generalisations that represent the typical reserve capacity remaining in a structure when a particular assessment level is applied. These factors should not be used outside the remit of the Reliability PI.

[1] **Important**: Equations 3 and 4 implicitly assume a structure is currently catering for 40 tonne vehicles. As such, a structure assessed to have 3 tonne capacity has a higher probability of failure than a structure assessed to have 40 tonne capacity. Any mitigation or interim measures currently on the 3 tonne structure are taken into account as described in Section 5.4.

[2] **Important**: K and K_R are not necessarily the same, because K is normally between two plot lines on the Assessment Live Loading graphs in BD21, which requires the lower plot line to be selected for rating the structure. Therefore, the ratio between K and K_R indicates the possible reserve capacity of the structure above its Assessment Live Loading.

A change in condition of the *Critical Element* after an assessment is accounted for by the Condition Adjustment Factor, F_{CON}, as described in Section 5.5.1. This factor is applied directly to $P_{f\text{-}LLR}$. Alternatively, the Reduction Factor (K) can be adjusted in accordance with BD21 if appropriate, see Section 5.5.2.

The probability of failures, calculated using Equation 3, for the assessment categories defined in BD21 are shown in Table 5.

Table 5 $P_{f\text{-}LLR}$ given assessed capacity and current 40 tonne loading

Live Load Rating (Tonnes)	Dead Load Only	3	7.5	10*	13*	18	26	33*	≥ 40 **Default**
$P_{f\text{-}LLR}$	2.5×10^{-3}	1.0×10^{-3}	2.5×10^{-4}	1.1×10^{-4}	4.5×10^{-5}	9.6×10^{-6}	8.0×10^{-7}	9.1×10^{-8}	1.0×10^{-8}

*These assessment Live Loadings are recommended in BD21 for masonry arches.

5.2.2 Category 2 – Structures not included in the Assessment Programme

The $P_{f\text{-}LLR}$ for structures not included in the assessment programme is selected from Table 6. Structures not included in the assessment programme typically include footbridges, buried structures and some forms of retaining walls, see BD34, BD46 or BD50 (Refs. 4, 5 and 6) for further guidance. Table 6 can be used as a qualitative assessment if no quantitative data are available. The *design* of the structure refers to its most recent design specification, therefore, if any design alterations have accounted for load increases since the original design they would no longer constitute load increases as defined in Table 6.

Table 6 $P_{f\text{-}LLR}$ for Structures Not Included in the Assessment Programme

No.	Loading Description	$P_{f\text{-}LLR}$
1	Live and dead loads are similar to, or the same as, those the structure was designed for. Total increase in load is less than 10% of the design Live Load.	1.0×10^{-8}
2	There has been a moderate increase in the combined live and dead loads above the design capacity. Total increase in load 10% to 50% of the design Live Load.	1.0×10^{-7}
3	There has been a major increase in the combined live and dead loads above the design capacity. Total increase in load greater than 50% of the design Live Load.	1.0×10^{-6}
4	Unknown	1.0×10^{-5}

It is assumed that structures excluded from the assessment programme typically have a low live load to dead load ratio (see BD34, Ref. 4). Therefore Table 6 only shows a small change in $P_{f\text{-}LLR}$ for significant changes in live load.

5.2.3 Category 3 – Structures still to be Assessed

Structures still to be assessed, or designed to the latest standards, are divided into two groups, those where the *Critical Element* is on the *substructure* and those where the critical element is on the *superstructure*, *Critical Elements* are defined in Table 3 in Section 4.2. The probability of failure is selected as follows:

1. The *Critical Element* is on the *bridge superstructure*; therefore $P_{f\text{-}LLR}$ is selected from Table 7.
2. The *Critical Element* is on the *bridge substructure*, a retaining wall or dry stone wall; therefore $P_{f\text{-}LLR}$ is selected from Table 6 in Section 5.2.2

Table 7 $P_{f\text{-}LLR}$ for Superstructure Elements Still to be Assessed

Design Code (and likely construction date)	Live Load Probability of Failure, $P_{f\text{-}LLR}$
Pre BS153 Part 3A (pre 1950)	1×10^{-5}
BS 153 Part 3A (1950 to 1975)	1×10^{-6}
BS 5400 (1975 to 1990)	1×10^{-7}
BD 37 (post 1990) (Ref. 8)	1×10^{-8}
Unknown	1×10^{-5}

5.3 Footways beside Carriageways Factor, F_{FbC}

If the primary function of the *Critical Element* is to support a footway beside a carriageway then $P_{f\text{-}LLR}$ is modified to account for the reduced vehicle loading frequency and severity of loading combinations. F_{FbC} is equal to 0.1 when the Critical Element and structure comply with one of the scenarios shown in Figure 4, otherwise F_{FbC} is equal to 1.0.

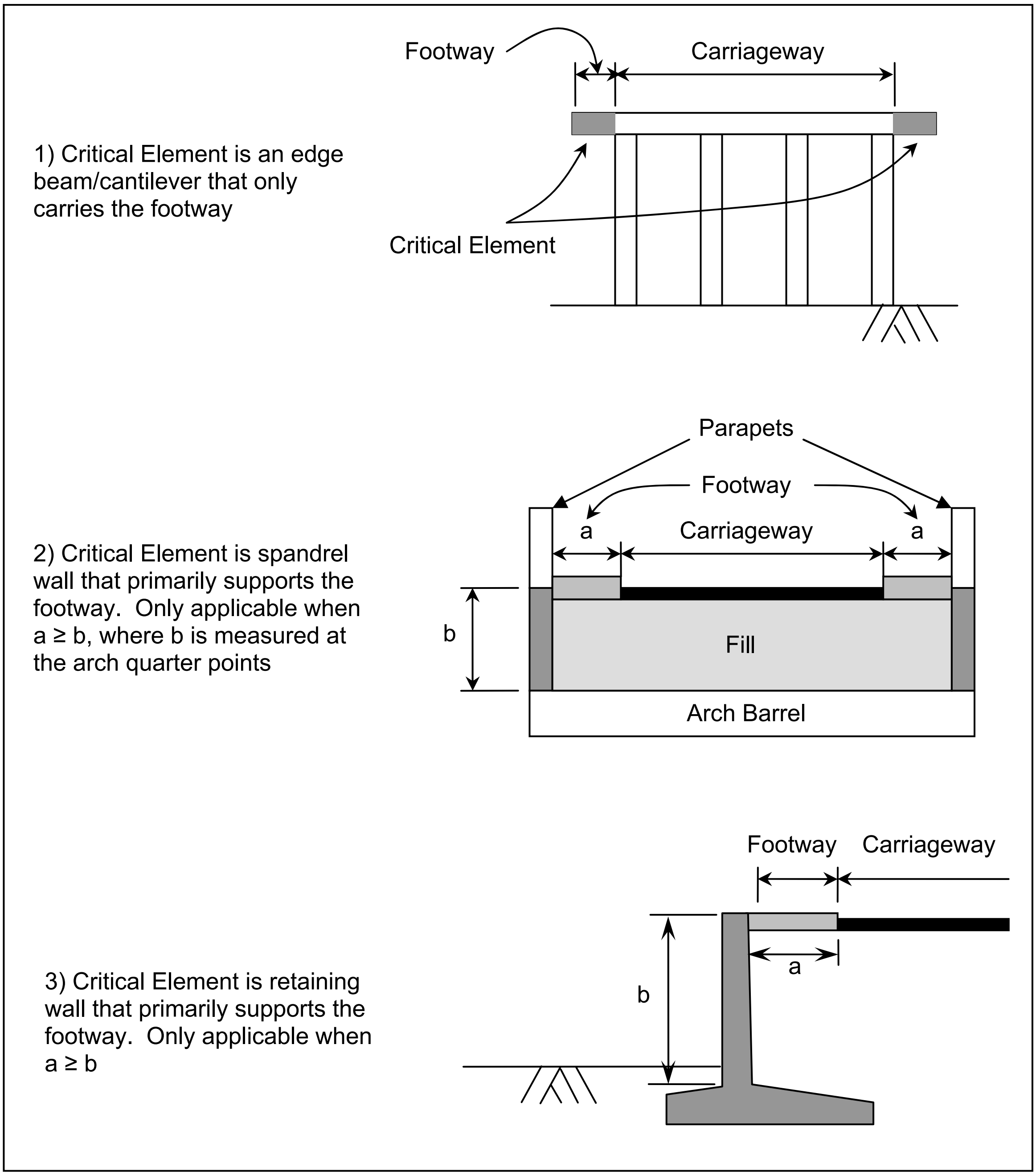

Figure 4 Footways besides Carriageways

5.4 Interim Measures Adjustment Factor, F_{IM}

Interim measures, in the context of the Reliability PI, are those that:

- Protect substandard structures, or a substandard area of a structure, from traffic loading; or
- Assist the structure in supporting the loading.

The interim measures considered, and their associated impact on the $P_{f\text{-}LLR}$, are shown in Table 8. The interim measure factor, F_{IM}, selected form Table 8 must relate to the *Critical Element* under consideration, see Section 4.2. Number 6 in Table 8 is applied when *No Interim Measures* are used.

Table 8 Interim Measures

No.	Interim Measure	Impact on $P_{f\text{-}LLR}$	Interim Measures Factor (F_{IM})	Other Factors
1	Structure closed to vehicular traffic	No traffic live loading on structure	Set $P_f = 1\times10^{-8}$	Other adjustment factors are not applied
2	Sub-standard area protected from vehicular traffic, e.g. bollards or guard rail for weak footway	No live loading on sub-standard area	Set $P_f = 1\times10^{-8}$	
3	Temporary support, e.g. propping*	$P_{f\text{-}LLR}$ based on design capacity of temporary support	$P_{f\text{-}LLR}$ from Equation 3 or 4 based on temporary support capacity F_{IM} = 1.0 unless 4 or 5 below apply	Other adjustment factors are applied
4	Physical barriers to enforce a 3 tonne weight restriction	Assumed to effectively restrict traffic above the restriction limit	$P_{f\text{-}LLR}$ from Equation 3 and F_{IM} Table 9	
5	Weak structure weight restriction signs/notices	Only assumed to make the majority of the "restricted" traffic divert	$P_{f\text{-}LLR}$ from Equation 3 and F_{IM} Table 9	
6	No interim measures	None	$P_{f\text{-}LLR}$ from Equation 3 and F_{IM} = 1.0	

* Temporary supports are used to provide the desired capacity for the structure, therefore structures with temporary supports will, in general, have good Reliability PI scores and in many cases propping or the inclusion of additional supports will become permanent features. An authority should check that temporary supports/propping are adequately accounted for in the Condition and Availability PI.

Table 9 F_{IM} for Restricted Structures

Live Load Restriction (Tonnes)	3	7.5	10*	13*	18	26	33*	40 (No Restriction)
F_{IM} for Physical Restriction/Barrier	0.0001	N/A	N/A	N/A	N/A	N/A	N/A	1.0
F_{IM} for Signs/Notices	0.05	0.1	0.2	0.3	0.5	0.75	1.0	1.0

*These Live Load Ratings are recommended in BD21 for masonry arches.

5.5 Condition Assessment

This section describes how the Probability of Failure is amended to account for the latest reported condition of the *Critical Element*. An authority may adopt either of the following approaches to carry out the condition assessment:

1. **Condition Adjustment Factor, F_{CON}** (Section 5.5.1) – a simplified assessment procedure developed specifically for use with the Reliability PI. The latest condition data is used to directly amend the Probability of Failure evaluated in Section 5.2.

2. **Condition Factor, F_C** (Section 5.5.2) – the latest condition data is used to re-assess the structure as described in BD21 (Ref. 7).

The former should be used for the Reliability PI. The BD21 approach has only been included for completeness and to indicate that it should be used (and not the Reliability PI procedure) if there are genuine concerns about the safety or load carrying capacity of the structure. The BD21 assessment should **not** be performed solely for the purpose of the Reliability PI evaluation.

5.5.1 Condition Adjustment Factor, F_{CON}

F_{CON} assumes that condition deterioration is directly proportional to decreasing load carrying capacity. This assumption may not hold true in all cases but it is deemed adequate for the Reliability PI evaluation. The severity/extent ratings used by F_{CON} are shown in Table 10 and Table 11, see HA (Ref. 9) and CSS BCI (Ref. 10) guidance for additional details. If the condition data has not been reported on this scale then it should be translated to the Severity/Extent scale as described in *Part B1*.

Table 10 Generic Severity Descriptions

Code	Description
1	As new condition or defect has no significant effect on the element (visually or functionally).
2	Early signs of deterioration, minor defect/damage, no reduction in functionality of element.
3	Moderate defect/damage, some loss of functionality could be expected
4	Severe defect/damage, significant loss of functionality and/or element is close to failure/collapse
5	The element is non-functional/failed

Table 11 Extent Codes

Code	Description
A	No significant defect
B	Slight, not more than 5% of surface area/length/number
C	Moderate, 5% - 20% of surface area/length/number
D	Wide: 20% - 50% of surface area/length/number
E	Extensive, more than 50% of surface area/length/number

The condition data, along with the assessment information described in Table 4 of Section 5.2, is used to identify the appropriate F_{CON} from either Table 12 or Table 13. A flowchart of the process, which indicates which table to use, is shown in Figure 5.

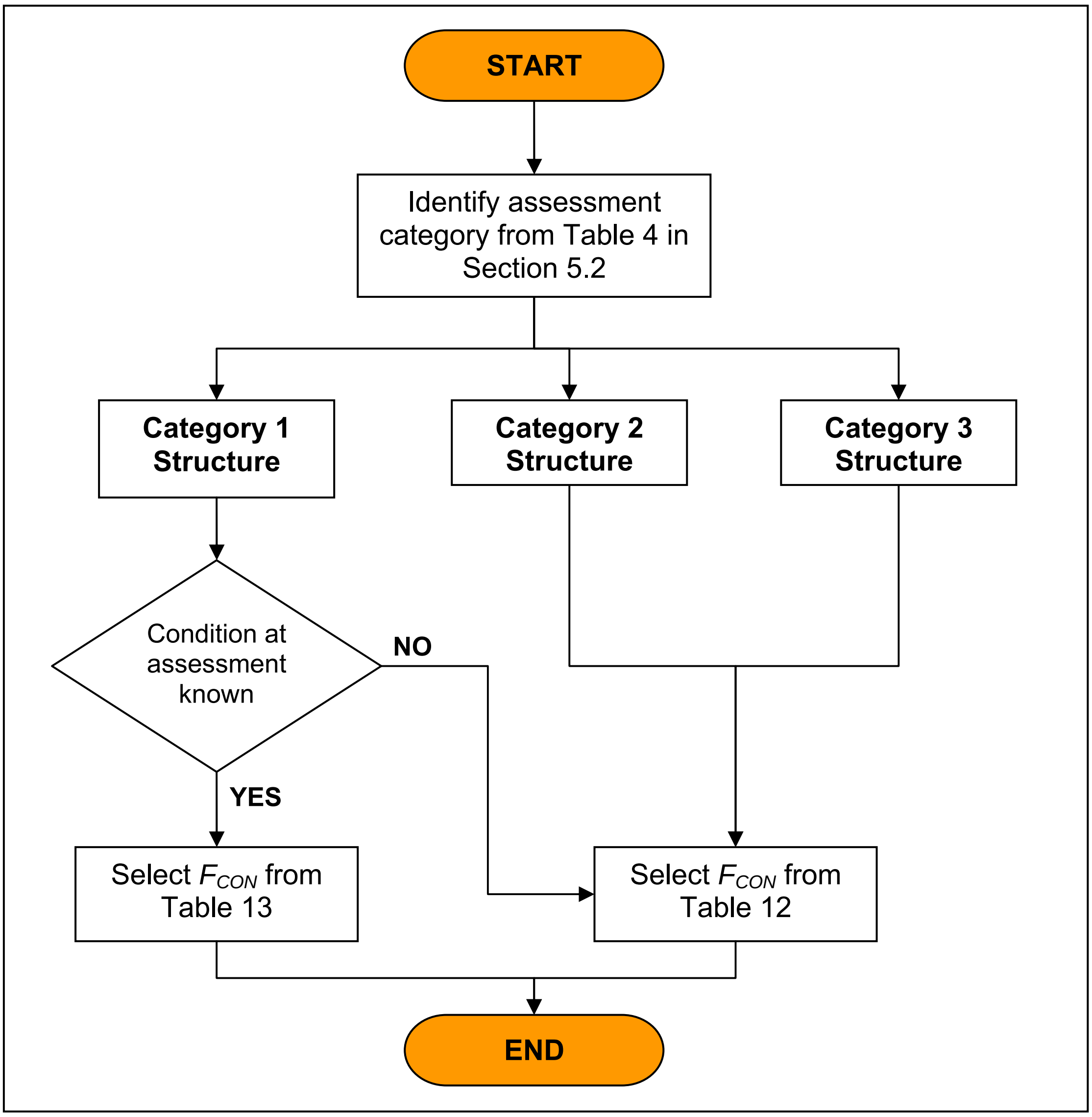

Figure 5 Applying F_{CON}

Table 12 Condition Adjustment Factor, F_{CON}

Condition	1A to 2E	3B	3C	3D	3E	4B	4C	4D	4E	5
Factor	1	100	200	400	800	10000	20000	40000	80000	**Failed**

A severity rating of 5 represents a failed element, therefore in these cases the P_f of Equation 2 should be set to one (1.0), i.e. failure has already occurred.

The factors in Table 13 assume that the condition of the critical element was adequately analysed at the time of assessment. Therefore the condition at the time of assessment is implicit in the Live Load Rating, Section 5.2.1. Condition improvements in Table 13 are assigned an F_{CON} of **one** regardless of the maintenance carried out. Some maintenance actions do increase the capacity of the element however this rule is not applied, instead any increase in capacity must be validated by re-assessing the repaired element, i.e. a fresh assessment establishes a new baseline Live Load Rating, *LLR*, and condition for the element, see Section 5.5.2 below.

5.5.2 Condition Factor, F_C (BD21)

The reader is referred to the procedure in BD21 (Ref. 7) which describes how to use condition data when assessing the capacity of a structure/element. In particular, a change in element condition may influence:

1. Live Load rating, *LLR*, in Equation 3 in Section 5.2.1; or

2. Reduction Factor, *K*, in Equation 4 in Section 5.2.1.

If the BD21 approach is used to re-assess *LLR* or *K* then the Condition Adjustment Factor, F_{CON}, is 1.0 because the *Condition at Time of Assessment* and *Condition at Latest Inspection* will be the same, i.e. a new baseline Live Load Rating, *LLR*, has been established.

Table 13 Modification factors for change in Condition since last assessment, F_{CON}

	Condition at Time of Assessment													
Condition at Latest Inspection after Assessment	**1A**	**2B**	**2C**	**2D**	**2E**	**3B**	**3C**	**3D**	**3E**	**4B**	**4C**	**4D**	**4E**	**5**
1A	1	1	1	1	1	1	1	1	1	1	1	1	1	**Failed**
2B	1	1	1	1	1	1	1	1	1	1	1	1	1	**Failed**
2C	1	1	1	1	1	1	1	1	1	1	1	1	1	**Failed**
2D	1	1	1	1	1	1	1	1	1	1	1	1	1	**Failed**
2E	1	1	1	1	1	1	1	1	1	1	1	1	1	**Failed**
3B	100	100	100	100	100	1	1	1	1	1	1	1	1	**Failed**
3C	200	200	200	200	200	2	1	1	1	1	1	1	1	**Failed**
3D	400	400	400	400	400	4	2	1	1	1	1	1	1	**Failed**
3E	800	800	800	800	800	8	4	2	1	1	1	1	1	**Failed**
4B	10000	10000	10000	10000	10000	100	100	100	100	1	1	1	1	**Failed**
4C	20000	20000	20000	20000	20000	200	200	200	200	2	1	1	1	**Failed**
4D	40000	40000	40000	40000	40000	400	400	400	400	4	2	1	1	**Failed**
4E	80000	80000	80000	80000	80000	800	800	800	800	8	4	2	1	**Failed**
5	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**

where **Failed** = a failed element when in the severity rating is 5, a P_f of one (1.0) is assigned to Equation 2.

5.6 Inspection Accessibility, F_{IA}

The Inspection Accessibility adjustment factor, F_{IA}, modifies the probability of failure to account for the ability of the inspector to adequately inspect the *Critical Element* during a General Inspection. The factor in Table 14 simply distinguishes between structures where the *Critical Element* can be adequately inspected and those where it can not be adequately inspected.

Table 14 Inspection Accessibility Factor, F_{IA}

Factor, F_{IA}	1	10
Description	The *Critical Element* (see Table 3) is not hidden and can be adequately inspected during a General Inspection.	The *Critical Element* (see Table 3) is hidden and/or cannot be adequately inspected during a General Inspection.

Important: An Inspection Accessibility score of 1.0 should be set as the default.

5.7 Monitoring Factor, F_{MON}

When the *Critical Element* is identified as appropriate for monitoring, and the monitoring is in place and performed in accordance with BD79 (Ref. 11), then $P_{f\text{-}LLR}$ is adjusted accordingly. The monitoring categories in BD79 account for the different classes of monitoring, where a higher class normally indicates:

- A higher immediate or sudden risk of collapse.
- A more rapid mode of failure and/or speed of progression towards collapse once visual signs appear.
- Visual signs only appearing as the structure progresses towards collapse.
- Higher likelihood of advanced defects and/or signs of degradation.

Table 15 assumes that the level of monitoring applied is commensurate with the level of risk posed by the *Critical Element*. As such, each monitoring category has the same degree of improvement on the probability of failure. The monitoring factor implicitly covers the mode of failure, i.e. ductile or brittle because structures and/or elements with brittle failure modes are **not** appropriate for monitoring, see BD79

Table 15 Monitoring Adjustment Factors, F_{MON}

Description	**Description of Monitoring Classes from BD79**	**Monitoring Factor, F_{MON}**
Monitoring appropriate and in place	Class 1 – Basic Monitoring	0.1
	Class 2 – Detailed Monitoring	
	Class 3 – Global Monitoring	

Important: A Monitoring Adjustment score of 1.0 should be set as the default.

6. Consequence of Failure

6.1 Overview of Consequence of Failure Procedure

The consequence of failure procedure was originally developed to include:

1. **Traffic disruption** = f(traffic volume, duration of reconstruction, extent of failure, diversion routes)
2. **Obstacle crossed** = f(obstacle crossed, duration of reconstruction, extent of failure, diversion routes)
3. **Reconstruction cost** = f(structure dimensions, extent of failure, unit reconstruction costs)
4. **Casualties** = f(traffic volume, obstacle crossed, structure dimensions, extent of failure)
5. **Socio-Economic Impact** = f(impact on community/area, duration of reconstruction, extent of failure)

All of the above factors were included and evaluated explicitly in the initial consequence model. Although the model produced reasonable and meaningful scores it also created an overly complex and data intensive procedure. This was not desirable because the Reliability PI needs to be evaluated for the majority of the structures in the stock and as such should be relatively straightforward with minimal data requirements

A sensitivity study demonstrated that the complexity of the procedure could be significantly reduced by making a number of generic simplifications. The simplifications retained the fundamental meaning and sensitivity of the complex model but enabled the procedure to be streamlined. The Consequence of Failure is thus described by Equation 5.

C_f = (4 × Casualty Score + Reconstruction Score +

0.5 × Disruption Score + Socio-Economic Impact Score) × *Ext*

$$C_f = [(4 \times Cas_S) + RC_S + (0.5 \times Dis_S) + SE_S] \times Ext$$

but C_f not > 100,000,000

Equation 5

Where Cas_S = *Casualty Score*, see Section 6.2

RC_S = *Reconstruction Score*, see Section 6.3

Dis_S = *Disruption Score*, see Section 6.4

SE_S = *Socio-Economic Impact Score*, see Section 6.5

Ext = Extent of failure score, see Section 6.6

4 = adjustment factor to represent the higher importance of casualties

0.5 = adjustment factor to represents the lower importance of disruption

Equation 5 produces a score where each point is the equivalent of one pound (£1). Therefore, when the Consequence of Failure is combined with the Probability of Failure the risk score is in monetary terms.

6.2 Casualty Score, Cas_S

The Casualty Score, Cas_S, accounts for the fatalities and injuries that would arise from a structure failure, both on the route supported and the obstacle crossed. The Casualty Score varies with failure length (bridge span or retaining wall panel), route type, traffic volume and the type of obstacle crossed, e.g. river, railway road etc. The data required to evaluate the casualty score is not readily available therefore a number of simplifying assumptions are used, see Appendix B. Based on these assumptions the casualty score is evaluated as the **sum** for the routes/obstacles affected:

$$Cas_S \text{ per route/obstacle effected} = (Dimension + 70) \times R_S \times 4500$$

Equation 6a

$$Cas_S = \sum (Cas_S \text{ for all routes/obstacles effected by the failure})$$

Equation 6b

Where R_S = Route/obstacle score from Table 16 and/or Table 17

Dimension = assessed relative to interaction with route i.e.:

- span when the route passes over a bridge or small culvert
- width when the route passes under a bridge
- length when the route passes below or above a retaining wall.

The scores shown in Table 16 are for structures that support or cross vehicular highway routes. The scores were derived using the procedure developed for the Availability PI. The scores shown in Table 17 are for structures that support or cross over non-vehicular highway routes, other transport networks (e.g. rail, canal), properties and land. Disruption data for these were not readily available therefore scores were derived by aligning them with equivalent vehicular highway routes from Table 16.

Table 16 Route Scores for highways, R_S

Route Type	Traffic Flow		R_S
	Description	AADT	
Motorway	Heavy	> 90,000	9.0
	Moderate	30,000 to 90,000	6.0
	Light	< 30,000	3.0
Primary A	Heavy	> 50,000	5.0
	Moderate	20,000 to 50,000	3.5
	Light	< 20,000	2.0
Other Principal Roads	Heavy	> 30,000	3.0
	Moderate	10000 to 30,000	2.0
	Light	< 10000	1.0
Classified B & C	Heavy	> 10,000	1.0
	Moderate	3000 to 10000	0.65
	Light	< 3000	0.30
Unclassified U	Heavy	> 3000	0.30
	Moderate	1000 to 3000	0.20
	Light	< 1000	0.10

Table 17 Routes score for other obstacles/route types, R_S

Obstacle crossed	R_S
Rail	
Inter City Line	9.0
Suburban, Tram, Underground	5.0
Freight	1.0
Other	
Business and Community Premises	5.0
Residential Premises	2.5
Pedestrian subway	1.0
Footpath or navigable watercourse/canal including a footway beside a carriageway	0.5
Bridle path	0.1
Farmland/Disused/non-navigable watercourse/canal	0.0

6.3 Reconstruction Score, RC_S

The Reconstruction Score, RC_S, is equal to the monetary value of reconstruction.

Important: If an authority holds reconstruction cost information for their structures, for example, Gross Replacement Costs for asset valuation, they should use this information for RC_S. Otherwise, they may use the following generic equations which are based on a sample of recent construction projects.

Reconstruction score for bridges

$$RC_S = [((9.6 \times span_{max}) + 242) \times (L \times W)] + (5124 \times W) + (1742 \times L) + 50000$$

Equation 7a

Reconstruction score for small culverts

$$RC_S = 282 \times L \times W$$

Equation 7b

Reconstruction score for retaining walls

$$RC_S = [(264 \times H) + 881] \times (H \times L)$$

Equation 7c

Where $span_{max}$ = maximum span length for the bridge (m)

L = overall length of bridge, culvert or wall (m)

W = width of bridge or culvert (m)

H = retained height of retaining wall (m)

Where retained height is the level of fill at the back of the wall above the finished ground level at the front of the structure.

Important: For bridges with more than three spans it is highly unlikely that a failure would require more than three spans to be reconstructed; as such it is unrealistic for RC_S to be based on the replacement cost of the whole structure. Instead, RC_S should be based on the reconstruction cost of three spans.

6.4 Disruption Score, Dis_S

The disruption score, Dis_S, reflects the extra cost to road users caused by a failure. The extra cost is taken to be the extra user and vehicle costs incurred due to a longer journey length. A simplified relationship has been developed, based on the principles established by the Availability PI, that takes into account the traffic volume, the increased journey length, vehicle/user costs and the duration of the disruption.

Important: The disruption score should be the summation of each route (highway and other) effected by the failure of a structure.

Disruption score for highways and other route types

Dis_S = f(traffic volume, increased journey length,

vehicle/user costs, duration of disruption)

Dis_S per route effected by the failure = $(R_S \times 1500) \times IJL_{km} \times Dur$

Equation 8a

$Dis_S = \sum Dis_S$ per route effected by the failure

Equation 8b

Where

R_S = Route/obstacle score from Table 16 and/or Table 17

IJL_{km} = Increased Journey Length in km, see Section 6.4.1

1500 = factor relating to costs per user/vehicle per km travelled

Dur_S = duration score based on span/panel length, see Section 6.4.2

Equation 8a was evaluated using highway traffic information. Data on other route types (railways, footways, waterways etc.) was not readily available therefore the same equation is used for other route types by selecting the equivalent R_S value from Table 17.

6.4.1 Increased Journey Length, IJL_{km}

The diversion route scores are based on the Increased Journey Length, *IJL*, procedure used by the Availability PI. The increased journey length is defined as:

Motorway, Primary A and Other Principal Routes

Increased Journey Length = (Length of diversion route from junction A to B)

– (Length of original route from junction A to B)

Classified B & C and Unclassified U Routes

Increased Journey Length =

Distance from one side of the restricted structure to the other via a diversion

More prescriptive guidance, including diagrams, is provided in Section 5.7 of *Part B2: Availability PI*. The IJL_{km} is selected from Table 18 below.

Important: It is recommended that an IJL_{km} of *No Alternative* is used for railways and navigable waterways. An increased journey length of Very Short should be used as the default setting.

Table 18 Increased Journey Length Score, IJL_{km}

Preferred Diversion Route	Increased Journey Length, km	IJL_{km}
Very Short	< 2km	1
Short	2 to 5km	3.5
Medium	5 to 10km	7.5
Long	10 to 20km	15
Very Long	> 20km	25
No alternative	-	50

6.4.2 Duration of Reconstruction, Dur_S

The duration of reconstruction is based on the size of the structure, i.e. bridge span or length and retaining wall height. The duration of the reconstruction, Dur_S, implicitly covers:

1. Duration of the failure investigation.
2. Duration of design and checking.
3. Duration of site preparation and preliminaries.
4. Duration of reconstruction.

The duration is based on the total reconstruction period and this is factored by *Ext* (see Equation 5 in Section 6.1) to take into the account the actual extent of the failure, see Section 6.6 below. The reconstruction duration for retaining walls is based on the height because a finite length of the wall is assumed to fail. The duration, Dur_S, in days, is selected from Table 19.

Table 19 Duration of Reconstruction Factor, Dur_S

Bridge/Span Length		< 5m	5 to 10m	10 to 25m	25 to 50m	> 50m
Small Culverts		All sizes	-	-	-	-
Retaining Wall Height		< 2m	2 to 4m	> 4m	-	-
Dur_S (days)	**Motorway, Primary and Other Principal**	**30**	**30**	**45**	**60**	**90**
	Other Roads	**30**	**60**	**90**	**120**	**180**

6.5 Socio-Economic Score, SE_S

The Socio-Economic impact of a failure is difficult to quantify because it is the cost to a community and/or businesses. Therefore, a subjective assessment of the importance of a structure should be made, taking into account:

1. The impact on emergency vehicle access.

2. The impact on the community and business, such as.

    a. Access to community facilities, e.g. hospital, library, council offices etc.

    b. Business deliveries.

    c. Vehicles diverted past sensitive areas, e.g. schools, parks etc.

3. The size of the community, business or industry served by the route.

Based on this subjective assessment of importance, a Socio-Economic score, SE_S, should be selected for each structure based on the categories shown in Table 20.

Table 20 Socio-Economic Score, SE_S

Importance	Motorway, Primary and Other Principal	Other Roads
High	10,000,000	1,000,000
Medium	1,000,000	100,000
Low	100,000	0

Important: Low importance should be set as the default.

This approach is more straightforward than that used in the Availability PI because the Reliability PI requires a value for all structures whereas the Availability PI only requires a socio-economic score for those structures with restrictions.

6.6 Extent of Failure, *Ext*

The extent of failure factor, *Ext*, is used to estimate the magnitude of the failure. *Ext* is based on the classification of the *Critical Element* (as defined in Table 3 in Section 4.2) because the structural form of the *Critical Element* is assumed to influence the extent of the failure. The *Critical Element* classification is therefore used to select the appropriate *Ext* factor from Table 21. However, if the engineer believes the *Ext* score defined by the *Critical Element* classification is inappropriate they may select a more appropriate (higher or lower) *Ext* score from Table 21.

Table 21 Extent of Failure Factor, *Ext*

Consequence Category (defined in Table 3)	Ext
Very High	1.0
High	0.5
Medium	0.25
Low	0.1

7. Reliability PI Score

7.1 Individual Structure Risk and Reliability PI

The risk posed by an individual structure is calculated using Equation 9.

$$\textit{Individual Structural Risk} = \textit{Probability of Failure} \times \textit{Consequences of Failure}$$

Equation 9

The risk scores are categorised as:

- **Risk score ≤ 1.0** – structural capacity is adequate and/or consequence of failure is low; and
- **Risk score ≥ 10,000** – structural capacity may represent an unacceptable risk to road users and/or the consequence of failure is high.
- **Risk score > 1.0 and < 10,000** – structural capacity and consequence of failure are gradually changing between the aforementioned bounds.

The relationship between the risk score and the Reliability PI is shown in Figure 6.

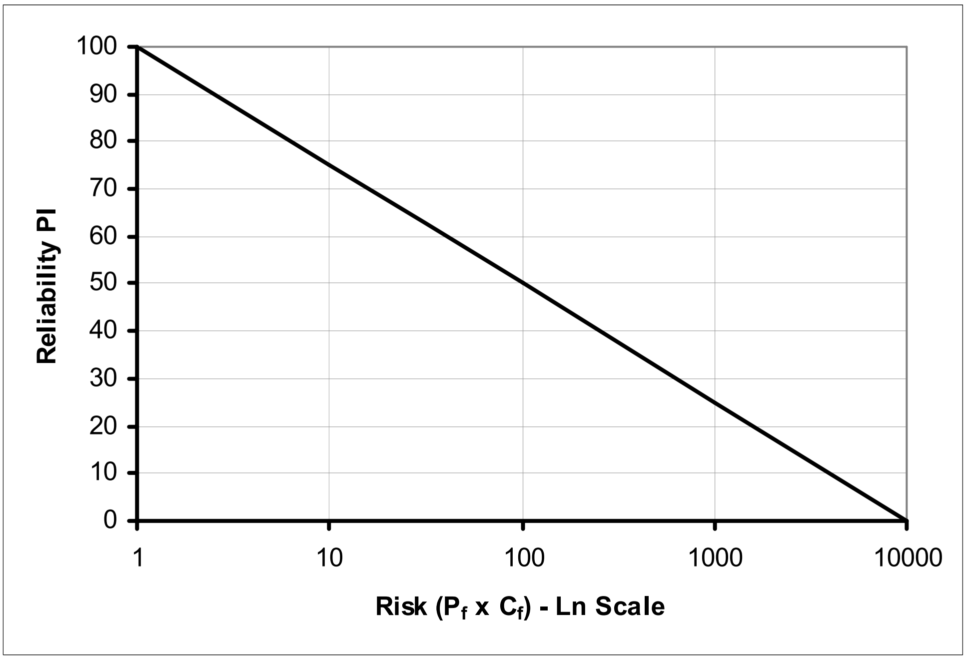

Figure 6 Risk and Reliability PI relationship

Figure 6 shows the Reliability PI scale aligned with upper (10,000) and lower (1.0) risk bounds. The Reliability PI score, and the above graph, are calculated using the following equations.

Individual Structure Reliability PI

If Risk ≤ 1 then

Reliability PI = 100

If Risk > 1 and ≤ 10,000 then

$$\text{Reliability PI} = 100 - [10.857 \times \ln(Risk)]$$

If Risk > 10,000 then

Reliability PI = 0

Equation 10

7.2 Structure Group and Stock Reliability PI

The structure group and stock Reliability PI are the average of the individual Reliability PI scores. Therefore the structure group or stock score are calculated using Equation 11.

$$\text{Group or Stock Reliability PI} = \frac{\sum(\text{Individual Reliability PI score})}{\text{N}}$$

Equation 11

Where N = total number of structures in the structure group or stock for which Reliability PI scores have been evaluated.

7.3 Reliability PI Scale

The Reliability PI is evaluated on a scale of 0 to 100 where:

- 0 represents very poor/unaceptable structural reliability; and
- 100 represents very good structural reliability.

Descriptions of the Reliability PI categories, applicable to individual structures, are shown in Table 22. The Reliability PI categories align with the Condition PI and Availability PI categories.

Table 22 Individual Structure Reliability PI Categories

PI Range	Reliability PI Category Descriptions
90 ≤ x ≤ 100	Structure has **very high** reliability. Represents a **negligible risk** to public safety.
80 ≤ x < 90	Structure has **high** reliability. Represents a **low risk** to public safety.
65 ≤ x < 80	Structure has **fair** reliability. Represents a **slight risk** to public safety in its current state.
40 ≤ x < 65	Structure has **poor** reliability. Represents a **significant risk** to public safety in its current state.
0 ≤ x < 40	Structure has **very poor** reliability. Represents a **high risk** to public safety in its current state.

The Reliability PI interpretations for a Structure Stock are shown in Table 23. The stock value is best used to monitor trends over time because it is difficult to assign concise interpretations at stock level. Authorities are recommended to produce histograms and simple statistics (as discussed in *Part A: Framework for Performance Measurement*) to assist the interpretation of the stock Reliability PI score.

Table 23 Structure Stock Reliability PI Categories

PI Range	Reliability PI Category Descriptions
90 ≤ x ≤ 100 Very Good	On average the structure stock has **Very High** reliability and represents a **Negligible Risk** to public safety. A small number of structures may represent a higher risk to public safety.
80 ≤ x < 90 Good	On average the structure stock has **High** reliability and represents a **Low Risk** to public safety. A small number of structures may represent a higher risk to public safety.
65 ≤ x < 80 Fair	On average the structure stock has **Fair** reliability and represents a **Slight Risk** to public safety. A significant number of structures may represent a higher risk to public safety.
40 ≤ x < 65 Poor	On average the structure stock has **Poor** reliability and represents a **Significant Risk** to public safety. A larger number of structures may represent a higher risk to public safety.
0 ≤ x < 40 Very Poor	On average the structure stock has **Very Poor** reliability and represents a **High Risk** to public safety. Many structures may represent a higher risk to public safety.

8. References

1. Management of Highway Structures: A Code of Practice, UK Bridges Group, September 2005, TSO.

2. BD62 As Built, Operational and Maintenance Records for Highway Structures (DMRB 3.2.1).

3. BD63 Inspection of Highway Structures (DMRB 3.1.4).

4. BD34: Technical Requirements for the Assessment and Strengthening Programme for Highway Structures: Stage 1 – Older Short Span Bridges and Retaining Structures (DMRB 3.4).

5. BD46: Technical Requirements for the Assessment and Strengthening Programme for Highway Structures: Stage 2 – Modern Short Span Bridges (DMRB 3.4.1).

6. BD50: Technical Requirements for the Assessment and Strengthening Programme for Highway Structures: Stage 3 – Long Span Bridges (DMRB 3.4.2).

7. BD21: The assessment of highway bridges and structures (DMRB 3.4.3).

8. BD37: Loads for Highway Bridges (DMRB 1.3.14).

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11. BD79: The management of sub-standard highway structures (DMRB 3.4.18).

12. Road Accidents Great Britain 1998, DETR.

13. Reducing Risks, Protecting People; HSE's Decision Making Process, HSE, 2001.

14. Economic Assessment of Road Maintenance: The QUADRO Manual: Part 2 – the valuation of costs in QUADRO, Highways Agency, May 2002.

APPENDIX A
Live Load Rating and Probability of Failure

Live Load Rating and Probability of Failure

Section 5.2.1 presents two equations (Equations 3 and 4) that describe the relationship between the Live Load Rating and the Probability of Failure. These equations were derived by fitting curves to the plot shown in Figure 7.

Figure 7 Probability of failure as a function of Live Load Rating

The probability of failure values shown in Figure 7 are based on the following work:

- Development and calibration work on probabilistic assessment techniques for highway structures; and
- Probabilistic calibration of *National Annex for EN 1990: Annex A2 – Basis of Structural Design: Application for Bridges*.

The aforementioned work used a sample of real and hypothetical highway bridges, which were first assessed using Level 1 and 2 techniques, to calculate the probability of failure. The work identified that, on average, the sample bridges assessed to have 40 tonne ratings using the Eurocode and BD21 procedures have a probability of failure of 1×10^{-8}, whereas the sample bridges assessed to have a 3 tonne rating (but not load restricted) have an average probability of failure of 1×10^{-3}. Additional analysis identified that the relationship between assessed capacity and probability of failure is broadly as shown in Figure 7. However, it is recognised that the relationship is generic and only differentiates between structures based on the assessment rating and as such may not provide accurate values for individual structures and their specific circumstances.

APPENDIX B
Casualty Assumptions

Casualty Assumptions

The simplifying assumptions used to derive the Casualty Score equation are:

1. The casualty costs are the same for a given road type whether it is crossing over or passing under a bridge.
2. Fatalities and injuries are as defined in Ref. 12 (Road Accidents Great Britain 1998, DETR), and:
    - o one fatality is equivalent to £1,000,000 (HSE value of preventing a fatality, VPF, Ref. 13),
    - o one serious injury is equivalent to £250,000.
    - o one slight injury is equivalent to £10,000.
3. Given a failure occurs it is assumed that for vehicles directly involved:
    - o ¼ of vehicle occupants are fatalities
    - o ½ of vehicle occupants are serious injuries; and
    - o ¼ of vehicle occupants are slight injuries.
4. Stopping distances are taken from the Highway Code, average speed of 80km/hr assumed.
5. Vehicle occupancy taken from QUADRO, Ref. 14.
6. Vehicle proportions taken from QUADRO, Ref. 14.
7. Road occupancy taken as 16 hours per day.

Task No: YY86731

Guidance Document for Performance Measurement of Highway Structures

Part C: Measuring the Structures Backlog

Report prepared by:

ATKINS

Report prepared on behalf of:

Highways Agency

CSS Bridges Group

2007

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1. Introduction

1.1 Structures Backlog Definition

The Structures Backlog is defined as (Ref. 1):

> *The monetary value of work required to close the gap between the actual performance provided by an asset and the current required performance.*

1.2 Background, Objectives and Scope

The background, objectives and scope are discussed in *Part A: Framework for Performance Measurement*.

2. Proposed Approach

2.1 General

The following is a proposed approach for calculating the monetary value of the Structures Backlog. It is recommended that a computerised Bridge Management System (BMS) is used to calculate the backlog as it is not efficient to perform the calculation manually. This approach aligns with the Asset Management Planning process described in the Code of Practice (Ref. 1)

2.2 Performance Measures and Targets

In accordance with the Code of Practice (Ref. 1), backlog is defined as *The monetary value of work required to close the gap between the actual performance provided by an asset and the current required performance*. As such, an appropriate suite of Performance Measures are required to:

- Describe the current performance of the structure stock; and
- Describe the Performance Targets for the structure stock.

It is recommended that the Condition, Availability, Reliability Performance Indicator and suitable local indicators, are used to define the current performance and the Performance Targets.

2.3 Structures Backlog Scale

The Structures Backlog is expressed in pounds. Thus a set scale, such as that used for the Condition, Availability and Reliability PIs, is not appropriate. However, time vs. backlog profiles can be used to indicate if funded is set at an appropriate level, i.e. is the backlog increasing, decreasing or steady state over a period of time.

2.4 Structures Backlog Score

The Structures Backlog is the cumulative cost, in pounds, of the work required on the structure stock to close the gap between the current performance and the Performance Targets. If there is no gap between the current performance and the Performance Targets then the Structures Backlog is zero.

In order to compare the backlog evaluated in different years it is important to index historical backlog values. Section 4.2 provides details of how indexation should be applied to the Structures Backlog.

2.5 Steps for evaluating the Structures Backlog

An overview of the proposed approach for calculating the Structures Backlog is shown in Figure 1; the following summarise each step. It should be noted that the majority of the boxes in Figure 1 align with the Asset Management Planning process from the Code of Practice (Ref. 1).

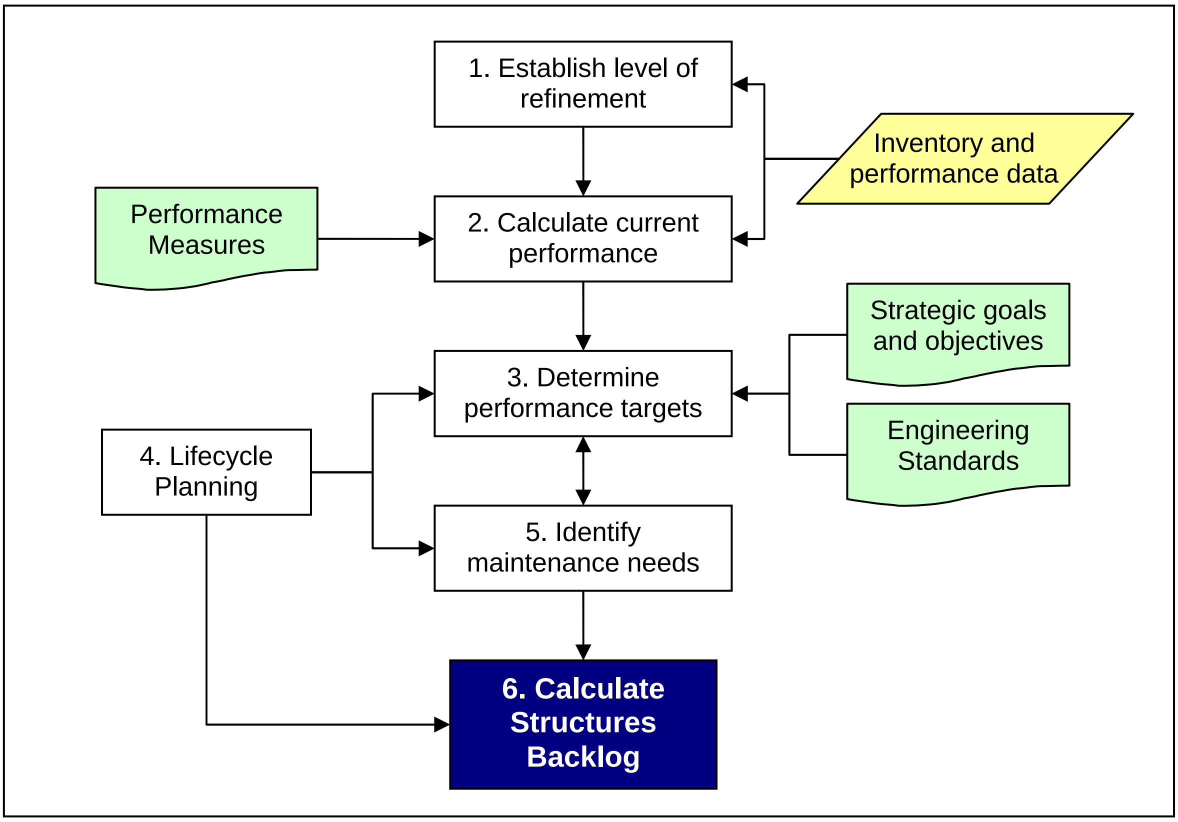

Figure 1 Flowchart of Structures Backlog evaluation procedure

Step 1 – Establish level of refinement

The approach for calculating the Structures Backlog is relatively straightforward; however the effort involved in performing the calculation depends on the level of refinement adopted. For example, Table 1 shows how the level of refinement may differ between a *Basic* and an *Advanced* approach.

Table 1 Level of Refinement

Criteria	Basic	Advanced
Calculations	Are based on generic groups of structures, e.g. concrete, masonry and metal bridges	Are based on specific elements, e.g. parapets on bridge x, abutments on bridge y
Performance Measures	Use the Condition Performance Indicator	Use the Condition, Availability and Reliability PIs, plus local PIs
Performance Targets	Targets based on engineering judgement	Targets derived from strategic goals, lifecycle plans and "what-if" analysis
Unit Rates	Are based on inspector and/or engineering experience and judgement	Are based on contract rates and final scheme outturn costs and take account of influencing criteria, e.g. access and traffic management.

An authority should identify the level of refinement that best suits their asset information, BMS functionality and resource availability. The level of refinement adopted should be fully documented in order to ensure repeatability of the exercise and continuity between consecutive calculations. It may be prudent to first adopt the *Basic* approach and then progress towards an *Advanced* approach in parallel with the development of improved asset management practices.

Step 2 – Calculate current performance

The Performance Measures selected in Step 1 should be used to calculate the current performance of the structures stock.

Step 3 – Determine performance targets

The Performance Targets should take account of the authority's strategic goals and objectives (see Section 3 of the Code of Practice, Ref. 1) and any relevant engineering standards, for example:

- *Strategic Goals and Objectives* – if a strategic objective is to maintain the highway network in a "Good State of Repair", then the bridge manager may interpret this as maintaining a Condition PI score for the structure stock of 85 or greater.

- *Engineering Standards* – the requirement to cater for 40 tonne vehicles may be interpreted by setting an Availability PI target of 100.

The Performance Targets should also be informed by the management policies and strategies, particularly the Lifecycle Plans (see Step 4).

Step 4 – Lifecycle Planning

Sections 3 and 5 of the Code of Practice (Ref. 1) provide guidance on developing Lifecycle Plans. A Lifecycle Plan is defined as is *a long-term strategy for managing an asset, or group of similar assets, with the aim of providing the required levels of performance while minimising whole life costs* (Ref. 1).

The Lifecycle Plan determines the maintenance intervention thresholds thereby influencing the overall Performance Targets (see Step 3). For example, consider the Condition PI scores that would be produced by the following Lifecycle Plans:

- Lifecycle Plan 1 – identifies that a preventative maintenance strategy is more economic for a particular group of reinforced concrete bridges, e.g. cathodic protection and silane impregnation.

- Lifecycle Plan 2 – identifies that a reactive maintenance strategy is more economic for a particular group of masonry arch bridges, e.g. undertake moderate masonry repairs when they are identified.

Lifecycle Plan 1 would in general produce a higher Condition PI score for the group of structures than Lifecycle Plan 2 because maintenance mitigation and/or intervention occur at an earlier stage of the deterioration process. As such, this should be reflected in the PI target.

The key information provided by a Lifecycle Plan is:

- The frequency of a maintenance activity and/or the condition/performance threshold that triggers the maintenance activity.
- The type of maintenance activities used on the structure/component.
- The units cost of the maintenance activity.
- Factors that account for influences on the unit cost, e.g. traffic management, access etc.
- Algorithms that calculate the overall cost of an item of maintenance work, taking account of the unit rate, any influencing factors and the characteristics (dimensions) of the component, structure or group of structures.

A database of maintenance unit rates and influencing factors should be compiled and continually updated. Section 4.3 provides further guidance on unit rates and maintenance cost algorithms.

Step 5 – Identify maintenance needs

The maintenance needs that contribute to the Structures Backlog are all those works that have passed the intervention threshold. Examples would include (also see Section 4.4):

- Overdue inspections.
- Overdue routine maintenance
- Life expired components, e.g. bearings and expansion joints.
- Components that have passed the condition intervention threshold specified in their lifecycle plan, e.g. a lifecycle plan may require moderate concrete repairs to intervene before or at condition 3B, therefore, if the condition of the element passes condition 3B the work is classified as a backlog.
- Structures/components that have substandard performance, e.g. load carrying capacity less than 40 tonne.

It is important that asset information is kept up-to-date; otherwise the identified maintenance needs may include previously completed work. The details of how an authority identifies completed work and removes it from their database will depend on systems/procedures they have in place. This is best achieved through computerised systems where work actions can be readily tracked, via unique identifiers, and *closed out* or *signed-off* when the work is completed.

Step 6 – Calculate structures backlog

The costs of the maintenance identified in Step 5 are calculated using the unit costs, influencing factors and algorithms developed under Step 4. The cumulative cost of these maintenance needs is the Structures Backlog.

3. Data Requirements

The data requirements for the Structures Backlog are shown in Table 2.

Table 2 Data Requirements

Data	Classification
Asset inventory, condition and performance information commensurate with the refinement of the approach adopted (the condition and performance information should be dated*)	Essential
Details of completed work including the date they were completed (so they are excluded form the backlog calculation)	Essential
Maintenance unit rates	Essential

* the dates relating to the condition/performance information are essential if an authority wishes to produce profiles of how the backlog is changing over time.

4. Calculating the Structures Backlog

4.1 General

Further guidance on certain aspects of the backlog calculation are provided in the following, including:

- Indexation of costs, Section 4.2
- Maintenance Costs, Section 4.3
- Work type definitions, Section 4.4

4.2 Indexation of Costs

Performance Measures are beneficial when used to monitor trends over time. However, the monetary value of maintenance work changes over time due to inflation and other influencing factors, therefore to enable meaningful comparisons over time it is important to account for these influences in the Structures Backlog. An index is used to account for these factors as shown in Equation 4. An authority should consistently apply the index that is most suitable for their construction projects, e.g. Baxter Index, Road Construction Price Index or Road Construction Tender Price Index.

$$C_{Y1} = \frac{C_{Y0} \times Index_{Y1}}{Index_{Y0}}$$

Equation 1

Where C_{Y1} = value of backlog adjusted to current year

C_{Y0} = value of backlog from original estimation year

$Index_{Y0}$ = Index for original year

$Index_{Y1}$ = Index for current year

The monetary value of previous calculated backlogs can then be adjusted for direct comparison with the current backlog, thus allowing meaningful time profiles to be developed.

4.3 Maintenance Costs

To provide consistency in backlog calculations (i.e. year on year comparability and comparability between authorities), the maintenance costs should include:

1. Direct Costs (labour, plant and materials).
2. Preliminaries, e.g. site prep, access etc.

3. Traffic management.

4. STATS, e.g. gas, electric, telephone etc.

5. Other – included to cover other criteria that the inspector/engineer may feel is particularly relevant to this work activity.

The format of the algorithm used to calculate the maintenance cost will depend on the structure/component type, type of maintenance and the site characteristics, e.g. access requirements. However, the maintenance cost for an identified need would normally take the following form:

$$C = f(UR, Dim, Def, AD)$$

Equation 2

Where

C - maintenance cost

UR - unit rate

Dim - dimensions of structure/component, used to scale the base unit rate

Def - defect rating, used to scale the base unit rate, i.e. extent of damage

AD - factor/s to take account of additional costs, e.g. access

It is recommended that neighbouring authorities work together to establish a set of generic unit costs and algorithms in order to share the workload and provide comparability. It should be noted that the same maintenance unit rates and algorithms are required for long-term asset management planning (Ref. 1) and asset valuation (Ref. 2).

The cost of work required to improve the condition/performance of a structure will depend on the condition/performance that the engineer wishes to achieve after the work is complete. The condition/performance sought after work may not always be the as-built condition or full performance. If the most appropriate action for the structure is not to regain as-built condition or full performance then this should be reflected in the cost included in the backlog.

4.4 Maintenance Types

The Structures Backlog should include all overdue maintenance. Table 3 provides guidance on when a certain maintenance type may be included in the backlog. The maintenance types presented in Table 3 align with the categories and types provided in Section 5 of the Code of Practice (Ref. 1).

Table 3 Work Types

Maintenance Category	Maintenance Type	What to include in the backlog?
Regular Maintenance	Inspections	Any inspection (General, Principal or Special) that has passed its scheduled year
	Structural Reviews and Assessments	Any structural review or assessment that has passed its scheduled date or has not been carried out after the need was identified
	Routine Maintenance	Any routine maintenance scheduled for the past 12 months that has not been carried out
	Management of Substandard Structures	The cost of appropriate interim measures for any structure that is classified as substandard but currently has no interim measures in place
Programmed Maintenance	Preventative Maintenance	Any preventative maintenance that has passed the time/condition of application, e.g. painting, cathodic protection, minor repairs
	Component Renewal	Any renewable component (e.g. bearings and expansion joints) that has passed the time/condition of renewal
	Upgrading	Any work required to bring a structure up to the authority's required standard, e.g. strengthening, waterproofing, parapet upgrade
	Widening and Headroom Improvements	Any work required to bring a structure up to the route requirements (provided it is deemed as being below the performance required by the authority)
Reactive Maintenance	Emergency	Not applicable - any work deemed as emergency should be dealt with immediately
	Essential Maintenance	Should already be covered by the regular and programmed maintenance categories, i.e. a defect or damage needs to pass the regular or programmed maintenance thresholds before it can be classified as essential

5. References

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2. Guidance Document for Highway Infrastructure Asset Valuation, Roads Liaison Group, TSO, July 2005.