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Performance Measures for Highway Structures

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Overview of Presentation

- Introduction to Performance Measures including:
  - The need for Performance Measures
  - Developing Performance Measures
  - Highway structure performance measurement framework
- Condition Performance Indicator
- Availability Performance Indicator
- Reliability Performance Indicator
- Structures Workbank Performance Measure

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Performance Measures for Highway Structures

An Introduction to Performance Measures

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The need for Performance Measures

- Performance measures are a fundamental component of the Government's drive to **improve and modernise** the management of public sector resources
- Performance Measures are also a key component of **Asset Management** because they:
  - Enable performance to be **measured and monitored** over time
  - Enable medium to long term **performance targets** to be defined
  - Link strategic, tactical and operational activities and objectives
  - Ensure effort is focused on **what really matters** and allow the organisation to **demonstrate how well** it is meeting its objectives
  - Give a **balanced view of the key services and functions** the organisation is providing

Highway Structure Performance Measurement Framework

- Consultations with Overseeing Organisations and Local Authority representatives identified four measures to be developed for highway structures under this commission:

- **Condition PI** – a measure of the physical condition of a highway structure stock
- **Availability PI** - a measure of the reduction in the service level provided, on a highway network, due to restrictions on highway structures. This includes long term and temporary works restrictions
- **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
- **Structures Workbank** - The cumulative cost of all work identified for and arising from inspections, assessments and other needs

Framework Documents

- The performance measures identified have been organised into a suite of documents:
  - Part A: Framework for Performance Measurement
  - Part B: Performance Indicators for Highway Structures:
    - Part B1: Condition Performance Indicator
    - Part B2: Availability Performance Indicator
    - Part B3: Reliability Performance Indicator
  - Part C: Measuring the Structures Workbank

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Performance Indicator Scale

- The Condition, Availability and Reliability PIs are all measured on a 0 to 100 scale, where this is broadly interpreted as:

PI Score	Generic Category Description
95 to 100	**Very Good** performance
90 to 94	**Good** performance
80 to 89	**Fair** performance
65 to 79	**Poor** performance
40 to 64	**Very Poor** performance
0 to 39	**Severe/critical** performance

- The Structure Workbank is a monetary value

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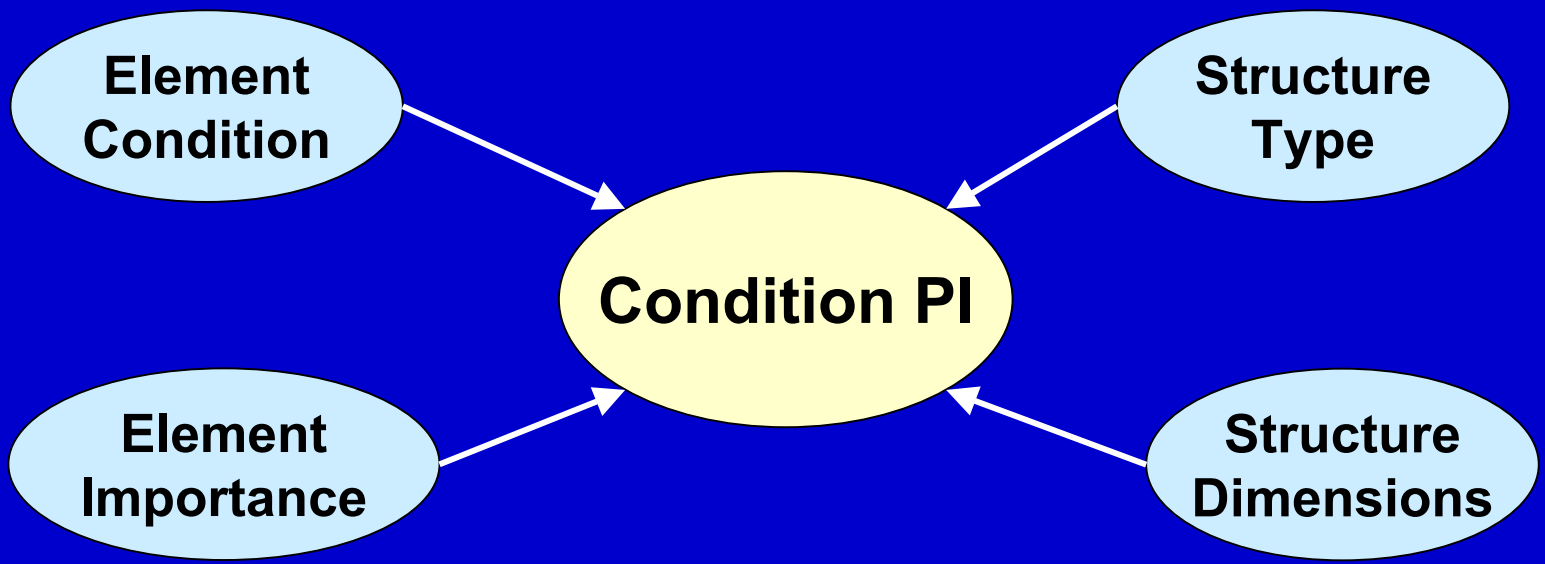
Part B1: Condition Performance Indicator

Condition PI Overview

- The Condition PI is a measure of the physical condition of a highway structure stock



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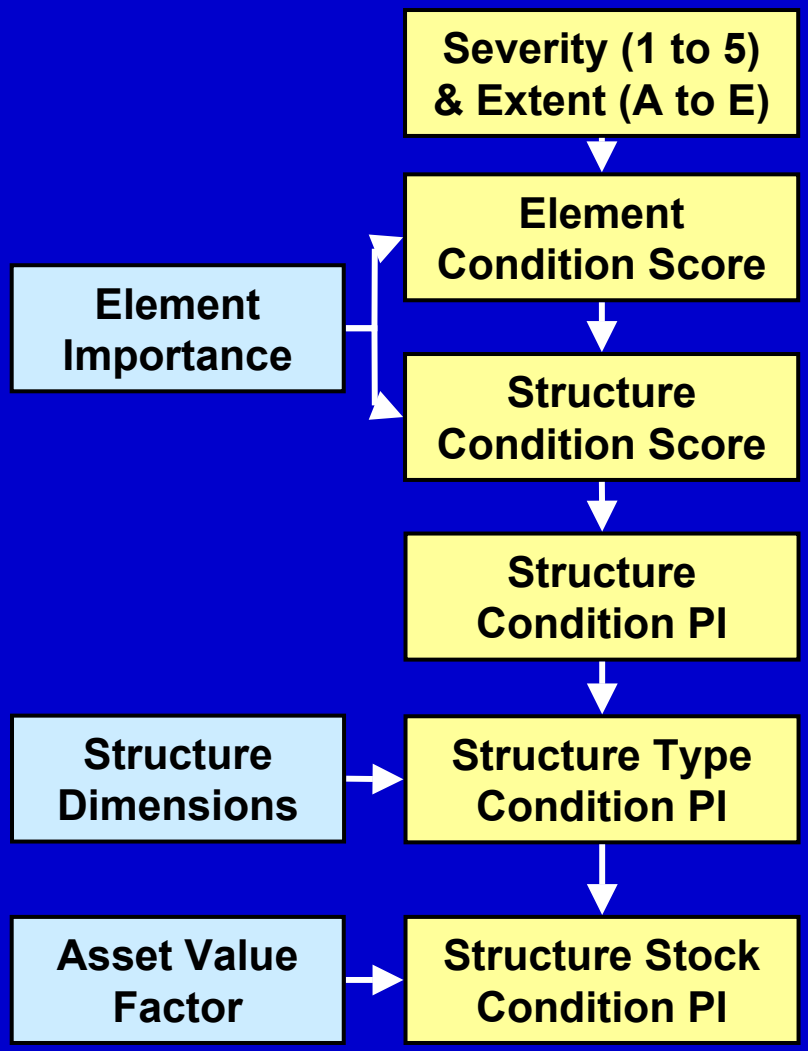
Condition PI Procedure



- Condition is reported for highway structures on a Severity (1 to 5) and Extent scale (A to E)
- The Severity and Extent is converted into a numerical score for each element, the Element Condition Score
- The Element Condition Scores are adjusted by their element importance & averaged to give the Structure Condition Score
  - The 1 (best) to 5 (worst) scale is used
- The Structure Condition Score is converted to an individual Structure Condition PI score
  - The 100 (best) to 0 (worst) scale is used
- The Structure Condition PIs are weighted by an appropriate dimension and averaged to give the Structure Type Condition PI score
  - The 100 (best) to 0 (worst) scale is used
- The Structure Type Condition PIs are weighted by the Asset Value Factor and averaged to give the Structure Stock Condition PI score
  - The 100 (best) to 0 (worst) scale is used

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Condition PI Weightings

- Three weightings are used in the Condition PI:
  - **Element Importance** – used to reflect the importance of individual element to the overall load carrying capacity, durability and safety of the structure
  - **Structure Dimensions** – uses structure size to identify the magnitude of condition deterioration e.g. deck area for bridges and surface area for retaining walls
  - **Asset Value Factor** – uses the average cost of construction to distinguish between different structure types e.g. cost per m^2 for bridges is different that the cost per m^2 for retaining walls
- **Important**: the Condition PI does not distinguish between structures based on network importance

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Area Number	No. Structures	PI Ave	PI Crit
Area 1	409	88.5	79.0
Area 2	767	82.1	73.9
Area 3	845	85.6	74.0
Area 4	619	79.3	67.5
Area 5	1459	83.6	72.6
Area 6	618	83.1	71.9
Area 7	494	83.0	70.7
Area 8	684	84.6	71.2
Area 9	1079	81.6	68.5
Area 10	1596	76.8	63.0
Area 11	777	83.3	67.6
Area 12	1087	83.8	68.1
Area 13	638	80.4	63.5
Area 14	380	82.3	69.4

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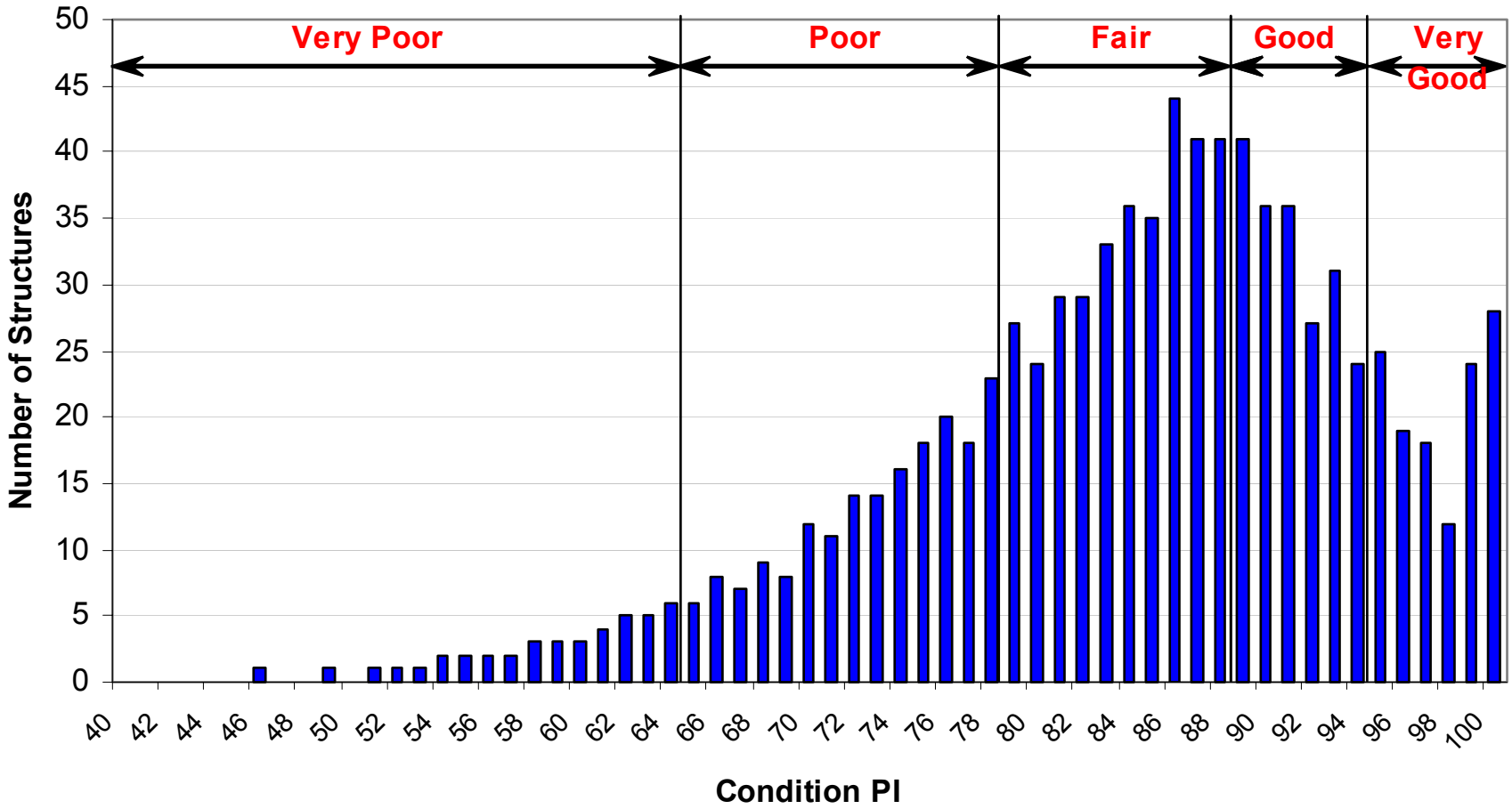
Condition PI Histogram



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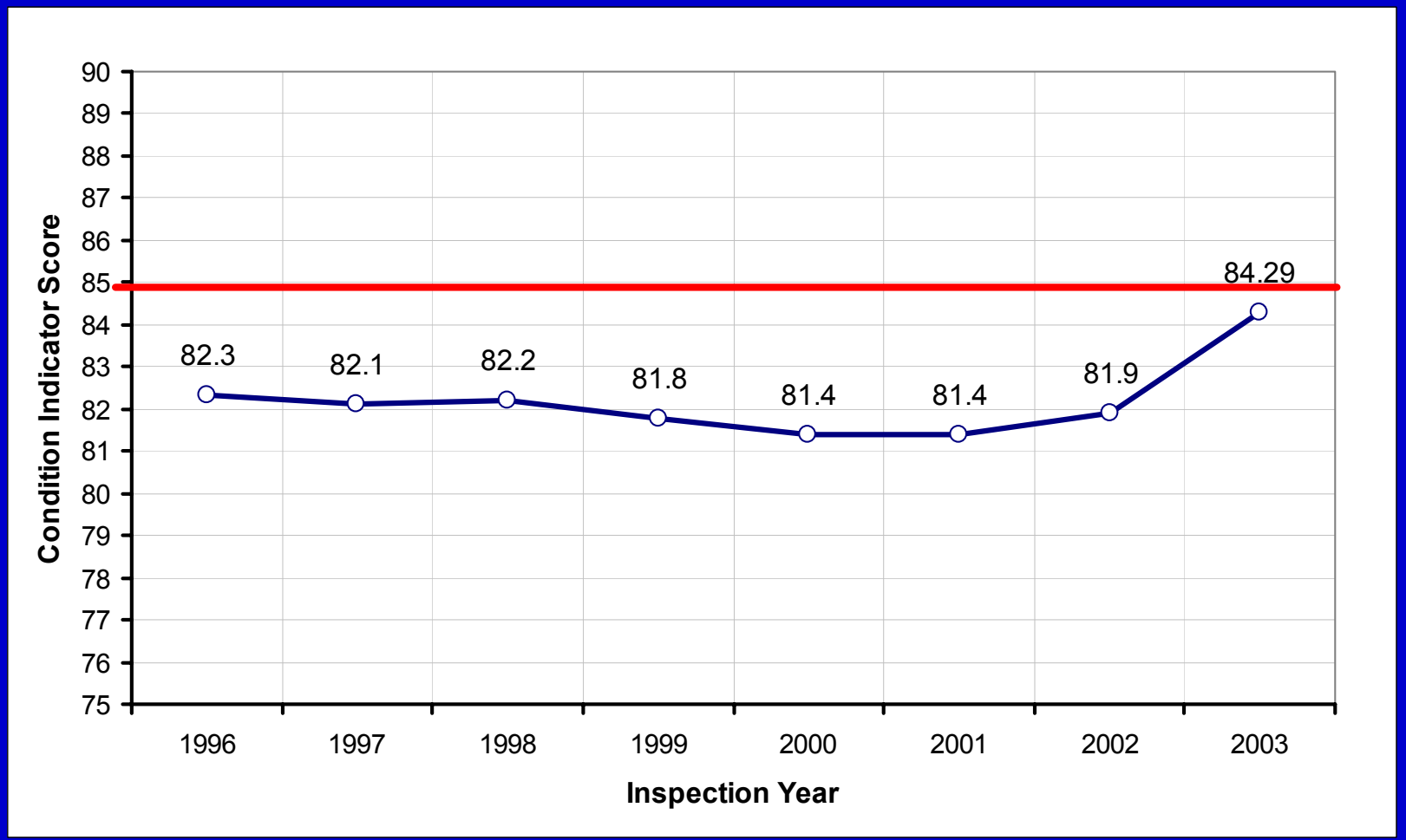
Sample Historical Condition PI Profiles



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Condition PI Summary

- The Condition PI is well establish and has been in use since April 2002 when originally published by the CSS as the Bridge Condition Indicator (BCI)
- The Condition PI uses relatively straightforward algorithms and weightings
- A Condition PI is readily understood within and outside the bridge engineering community
- This document has extended the Condition PI to cover other structure types and more refined levels of condition reporting

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Part B2: Availability Performance Indicator

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Availability PI Overview

- The Availability PI is a measure of the reduction in the service level provided, on a highway network, due to restrictions on highway structures. This includes long term and temporary works restrictions
- It was agreed that a simple “counting” of the number of restrictions was not sufficient to measure and monitor the real impact of restrictions on highway users and communities
- The methodology developed seeks to provide a more robust measure of restriction impacts using readily available data

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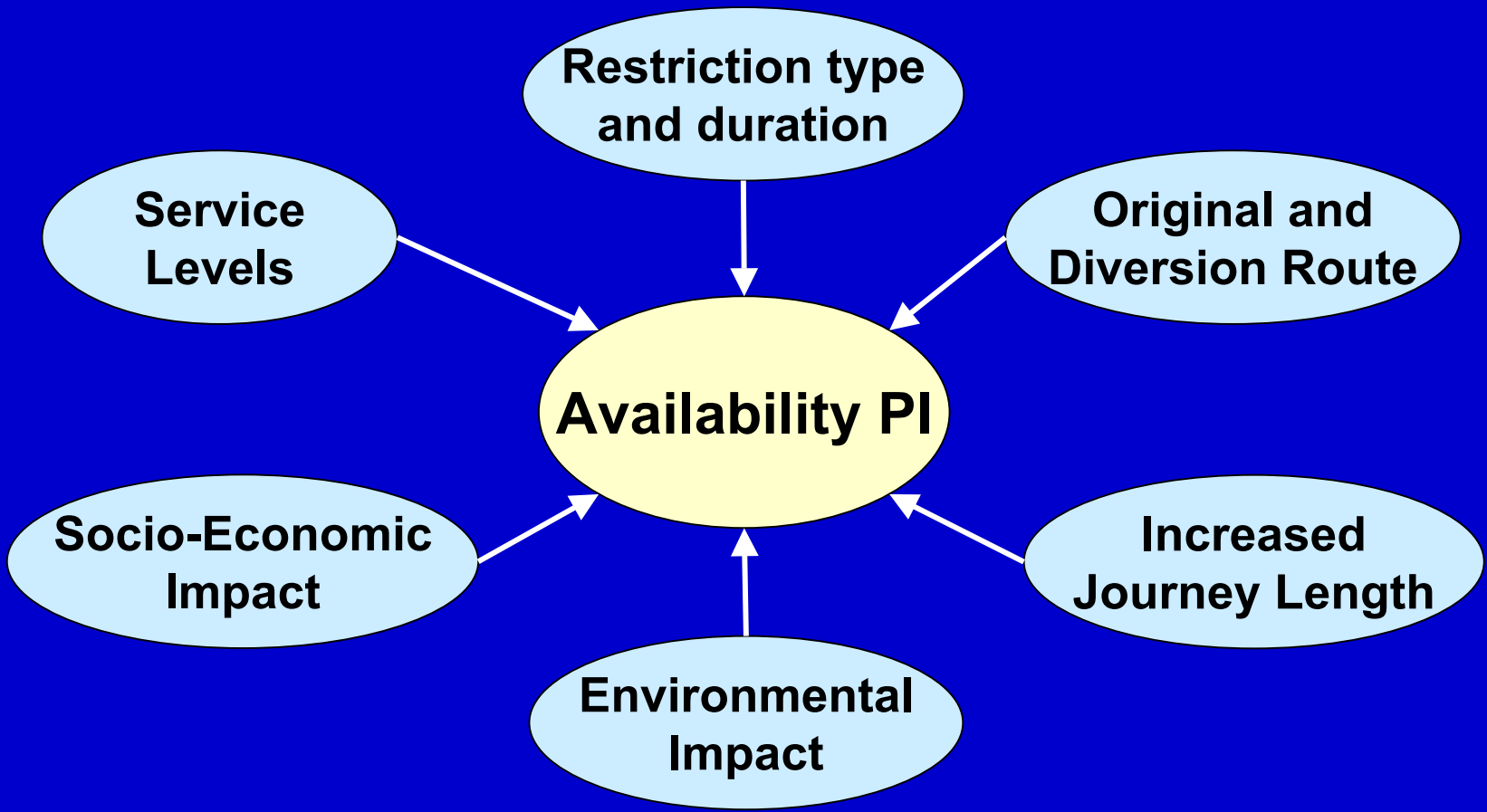
Availability PI



Availability PI Characteristics

- The Availability PI is calculated for all structure/road interactions on an organisation's network
  - Therefore if the organisation manages/owns the roads over and under a bridge they should calculate an Availability PI for both interactions
- If a route is fully available at a structure, i.e. there is no restriction, then the interaction has a score of 100 (Very Good Availability) and no further calculation is required
- An organisation may also classify a restriction as acceptable, in these cases a score of 100 is also assigned
- Therefore, only structures with restrictions, that are unacceptable to the organisation, need to pass through the full Availability PI calculation

Availability PI Formula

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

- C_{LB} = a constant, specific to the route type served
- T = duration of the restriction in months
- R = Restriction type score
- DR = Diversion Route score
- OR = Original Route traffic volume score
- IJL = Increased Journey Length score
- En = Environmental score, Section
- En_{max} = maximum value the Environmental score can take
- SE = Socio-Economic score, Section
- SE_{max} = maximum value the Socio-Economic score can take

Default Service Levels

- The assumed default service levels that highway structures should provide are shown below:
  - The service levels below, especially some of the weights, are not statutory for all highway structures, therefore the procedure allows an organisation to override the default values when they deem a restriction to be acceptable

<table>
<tr><th>Route Type</th><th>Weight (BD37/01)</th><th>Height (minimum)</th><th>Traffic Flow</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 TD27/96</td><td rowspan="6">In Accordance with adjacent Highway and/or TA46/97</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>

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Lower Bound Service Levels (C_{LB})

- Are used to define the 100 to 0 scale and are described as:
  - The average service level 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 service level
- They have been defined using weight restrictions

Route Type	Lower Bound Service Level
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

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Restriction Score (R)

- The restriction types considered by the Availability PI are:
  - Vehicle weight restrictions
  - Vehicle height restrictions
  - Vehicle width and traffic flow restrictions
- Look up tables provide the scores for each restriction types
- The restrictions may be created by:
  - Long term restrictions e.g. low bridge, week bridge restriction, narrow bridge etc.
  - Short term restrictions i.e. restrictions at structures due to maintenance/renewal on the structure that lasts longer than one month
- The duration of all restrictions (up to a maximum of 12 months) is used in the calculation
  - 12 months is the maximum because the Availability PI only takes into account the availability over the last 12 months

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Original and Diversion Route

- The Original Route Score (OR) is based on the route classification and the volume of traffic on the route (defined as Heavy, Moderate or Light if more detailed data is not available)
- The Diversion Route Score (DR) is based on the difference between the original route classification and the diversion route classification and takes into account
  - Accident frequency on a route type
  - Average vehicle speed on a route type; and
  - Vehicle operating and user costs for different route types.

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Increased Journey Length (IJL)

- For Motorways, Primary A Roads and Other Principal Routes it is calculated as:

  Increased Journey Length =

  (Length of diversion route from junction A to B)

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

- For Classified B & C and Unclassified U Routes it is calculated as

  Increased Journey Length =

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

- The two equations are assumed to reflect the difference between traffic movement on trunk roads and local roads

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Environmental and Socio-Economic Impact

- The Environmental Impact score takes into account
  - The environmental sensitivity of the diversion route e.g. rural, urban, Environmental Classification etc.
  - The magnitude of the impact based on the difference between the original and diversion route classifications
- The Socio-Economic Impact score takes into account
  - The impact on the community/areas served by the restricted route e.g. loss of business, loss of access to community facilities, reduced access for emergency vehicles etc.
  - The impact on the community/areas served by the diversion route e.g. increased traffic volumes, traffic diverted past schools etc.
- Look up tables with High/Medium/Low bandings and descriptions are provided for the above

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Availability PI Summary

- The Availability PI covers all structure/route interactions but the full procedure only needs to be applied to restrictions deemed unacceptable by the organisation
- It is envisaged that the full calculation will only be required for a small number of structures each year
- Look up tables are provided for all the variables used in the procedure e.g. restrictions, route scores, diversion impacts etc.

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Part B3: Reliability Performance Indicator

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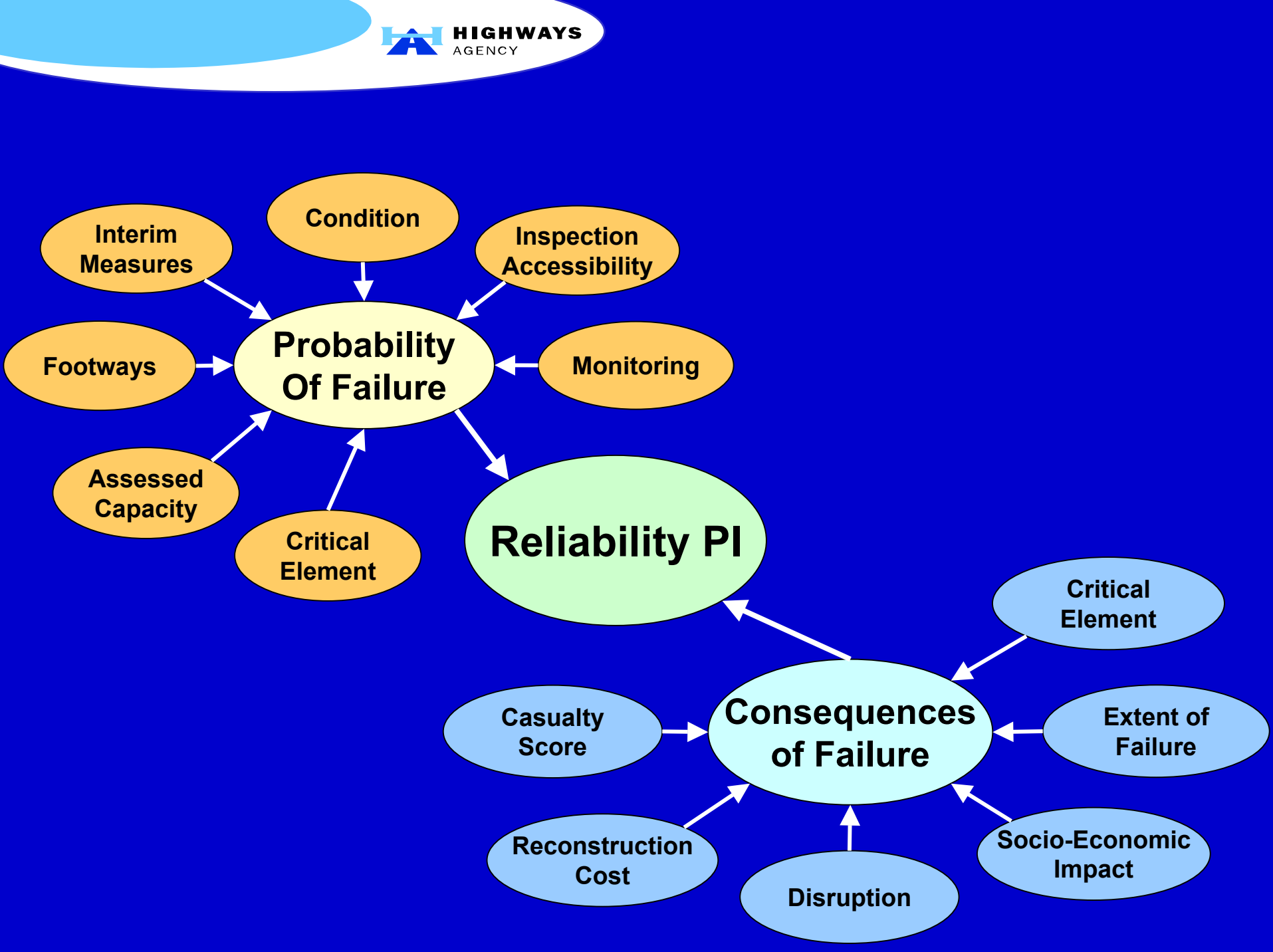
Reliability PI Overview

- The Reliability PI is a representation of the ability of the structure stock to support traffic, and other appropriate loading, taking into account the consequence of failure
- The Reliability PI is calculated as:

Reliability PI = f(Probability of Failure, Consequences of Failure)

- Where:
  - 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.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Interim Measures
Condition
Inspection Accessibility
Footways
Probability Of Failure
Monitoring
Assessed Capacity
Critical Element
Reliability PI
Critical Element
Casualty Score
Consequences of Failure
Extent of Failure
Reconstruction Cost
Disruption
Socio-Economic Impact

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Critical Element

- The reliability of a highway structure can be defined as:

  Structure Reliability = f(RE_1, RE_2, RE_3…RE_n)

- Where

  n = the number of elements on the structure

  RE_i = Reliability score for Element i

- This is the ideal approach however the reliability of a structure is normally dominated by the element with the lowest capacity and/or in the worst condition, hence reliability can be more simply defined as:

  Structure Reliability = (Reliability of Critical Element)

- The latter approach is used for the Reliability PI

Probability of Failure

- The Probability of Failure is defined as:

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

- where
  - P_f = Probability of failure of the critical element
  - $P_{f\text{-}LLC}$ = Probability of Failure for Live Load Capacity
  - AD_F = Adjustment factor
  - F_{FbC} = Footways beside Carriageways factor
  - F_{IM} = Interim Measures adjustment factor
  - F_{CON} = Element Condition adjustment factor
  - F_{IA} = Inspection Accessibility adjustment factor
  - F_{MON} = Monitoring adjustment factor

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Live Load Capacity

- The probability of failure derived from the Live Load Capacity depends on the assessment category

Cat.	Assessment Details	Live Load Capacity Probability of Failure, $P_{f\text{-}LLC}$	Probability of Failure, P_f
1	Assessed (qualitative and/or quantitative)	$P_{f\text{-}LLC} = f$(Assessed Live Load, Reserve Factor and Assessment Level)	$P_f = P_{f\text{-}LLC} \times AD_F$
2	Not included in Assessment Programme (i.e. not required by BD34, BD46 or BD50)	$P_{f\text{-}LLC} = f$(structure characteristics and local knowledge)	$P_f = P_{f\text{-}LLC} \times AD_F$
3	Still to be assessed	$P_{f\text{-}LLC} = f$(design code and local knowledge)	$P_f = P_{f\text{-}LLC} \times AD_F$

Live Load Capacity

- An equation is provided for Category 1 structures that links the assessed capacity to a probability of failure (see below)
- Look up tables are provided for Category 2 and 3 structures

Adjustment Factors

- Five adjustment factors are applied to the Probability of Failure:
  - Footways besides Carriageways – used to improve the probability of failure if the critical element is below a footway i.e. reduced loading frequency
  - Interim Measures – used to improve the probability of failure if any interim measures are in place to mitigate the risk e.g. propping, restrictions etc.
  - Condition Factor – accounts for the condition of the critical element compared to the time of original assessment
  - Inspection Accessibility – used to increase the probability of failure if the critical element cannot be adequately inspected
  - Monitoring – used to decrease the probability of failure if appropriate monitoring is in place
- Look up tables are provided for all four adjustments factors

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Consequence of Failure

- The Consequence of Failure is evaluated as:

  C_f = (4 × **Casualty Score + Re-Construction Score +**
  0.5 × Disruption Score + Socio-Economic Impact Score) × ***Ext***
- Where:
- Casualty Score = approximates the number of fatalities and causalities if the structure fails
- Re-construction Score = the cost to reconstruct the structure
- Disruption Score = the cost of disruption to road users (uses a simplification of the QUADRO procedure)
- Socio-Economic Impact Score = the estimated cost to businesses and communities served by the structure if it fails
- *Ext* = Extent of failure Score
- 4 = adjustment factor to represent the importance of casualties
- 0.5 = adjustment factor to represents the importance of disruption

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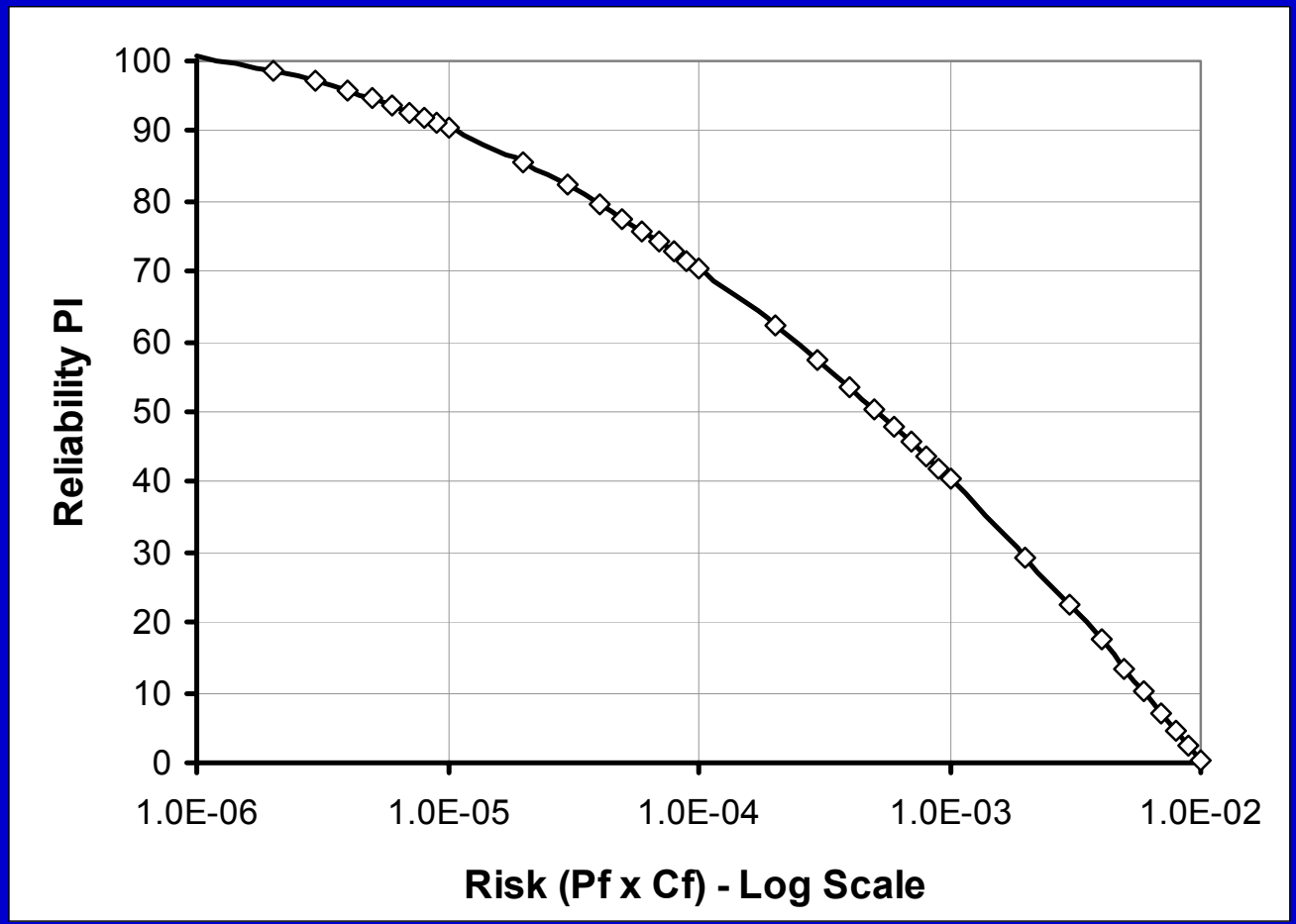
Consequence of Failure

- Look up tables and equations are provided for all the previous scores
- Each score is translated to a common scale
- The Consequence of Failure procedure is not a precise calculation, it is only used to establish the general magnitude of failure consequences

Reliability PI

- Risk is the product of the Probability and Consequence of Failure scores
- The Risk scale has upper and lower bounds defined in accordance with standard practice
- The Risk score is converted to the Reliability PI scale (100 best to 0 worst)



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Reliability PI Summary

- The Reliability PI needs to be calculated for all structures
- The data required for the Reliability PI should be readily available
- The procedure does appear complex but has been designed to be programmed into Bridge Management Systems so engineers only need to select values from the look up tables
- The Reliability PI is based only on load carrying capacity, it does not assess for scour susceptibility, vehicle impacts etc.

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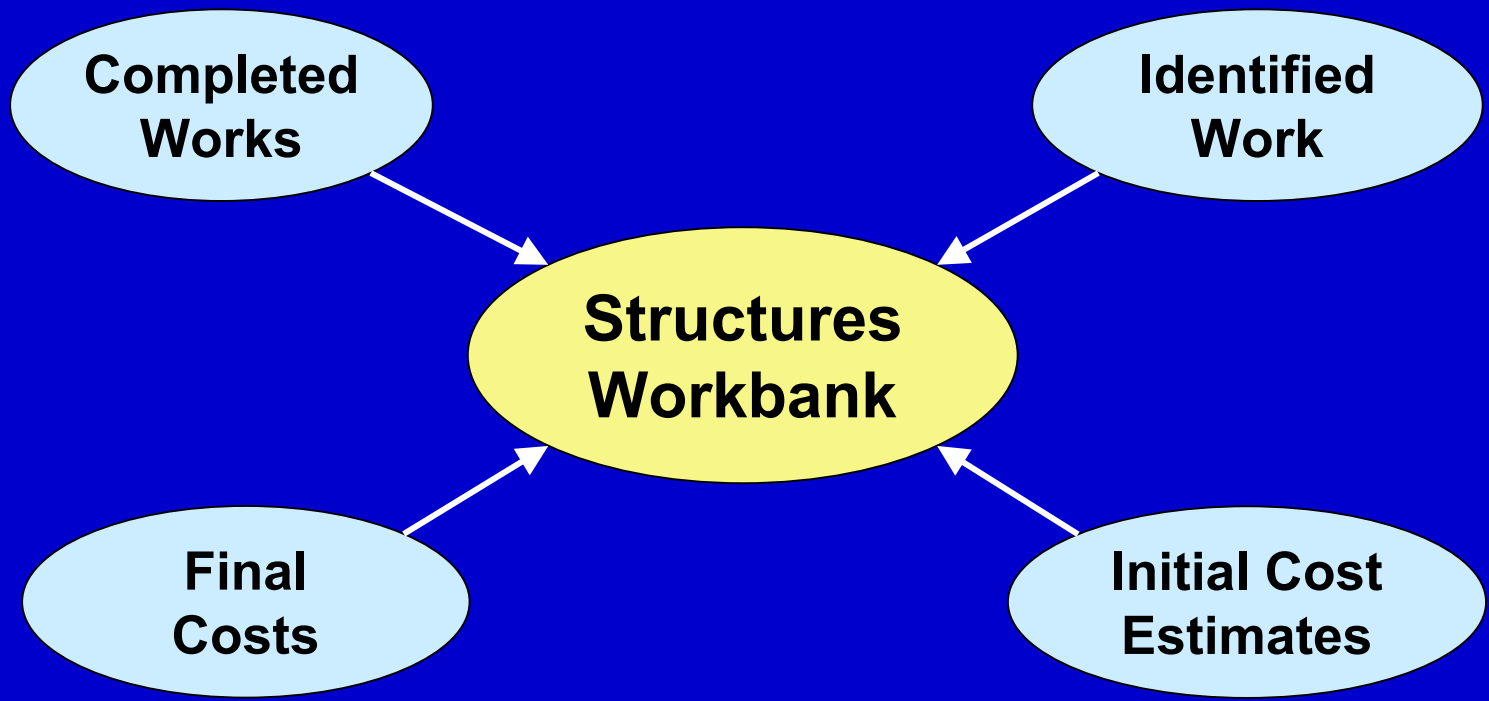
Part C: Measuring the Structures Workbank

Structures Workbank Overview

- The Structures Workbank is a measure of the cumulative cost of all work identified for and arising from inspections, assessments and other needs



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Work Types Included

- The work types included in he Structures Workbank are:
  - Inspections
  - Structural Assessments
  - Emergency
  - Routine Maintenance
  - Preventative Maintenance
  - Re-active/Essential Maintenance
  - Component Renewal
  - Upgrading
  - Widening and Headroom Improvements
  - Replacements
  - Management of substandard structures
- A definition for each work type is provided in Part C of the Guidance Document

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Characteristics

- The Structures Workbank is based on the work identified, not only the work planned
- The Structures Workbank does not consider resource constraints, therefore such issues should not be considered when identifying defects/works
- Guidance is provided on the timeframe that should be considered for including different work types e.g.
  - Current plus two years - activities that have, in general, low individual costs and are carried out regularly e.g. routine maintenance and inspections
  - Current plus five years - activities that may have high individual costs and may not occur on a regular basis e.g. essential maintenance and component renewals

Structures Workbank Summary

- The Structures Workbank compiles the base information that is required to calculate a Structures Backlog
- A Structures Backlog procedure was not developed because it was decided that Asset Management practice is not sufficient advanced to support its calculation
- The workbank is an important measure because it demonstrates if maintenance costs are increasing, decreasing or remaining constant

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Performance Measures Summary

- A set of performance measures for highway structure has been developed in consultation with the wider engineering community
- The four performance measures provide a balance view of the “health” of a structure stock
- It is essential to monitor how the performance measures change over time, this will indicate if maintenance funding levels are adequate
- Organisations must maintain the performance measurement base data other wise the measures will quickly become out-of-date and inaccurate

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Way Forward

- The Performance Measurement document suit will be launched as a working version in January 2005
- A working period of 12 to 18 months is envisaged before feedback is requested and discussions held
  - If required the documents will be amended after this period (as has occurred with other Performance Measures e.g. UKPMS)
- It is now important to:
  - Link the Performance Measures into the highway structure Asset Management process; and
  - Develop models that can predict the medium to long term impact on Performance Measures for different levels of funding

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Thank you