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BRIDGE OWNERS FORUM TECHNICAL DISCUSSION SESSION

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Risk-Based Inspection Planning for Bridge Networks

By

Saenthan Sathananthan

Dr. Imran Rafiq

Brian Bell

www.surrey.ac.uk

Acknowledgements

- University of Surrey
- Network Rail
- Project Steering Committee
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  - RSSB
  - Mouchel

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Research Objectives

Current Inspection Practice

- Fixed Time Based Detailed Inspections
- Not Consider Differences Among Bridges

→

- Ineffective Use of Resources?
- Increased Risk?

→

- To Develop A Methodology to optimize the Inspection interval
- To Maintain Constant level of risk across the network

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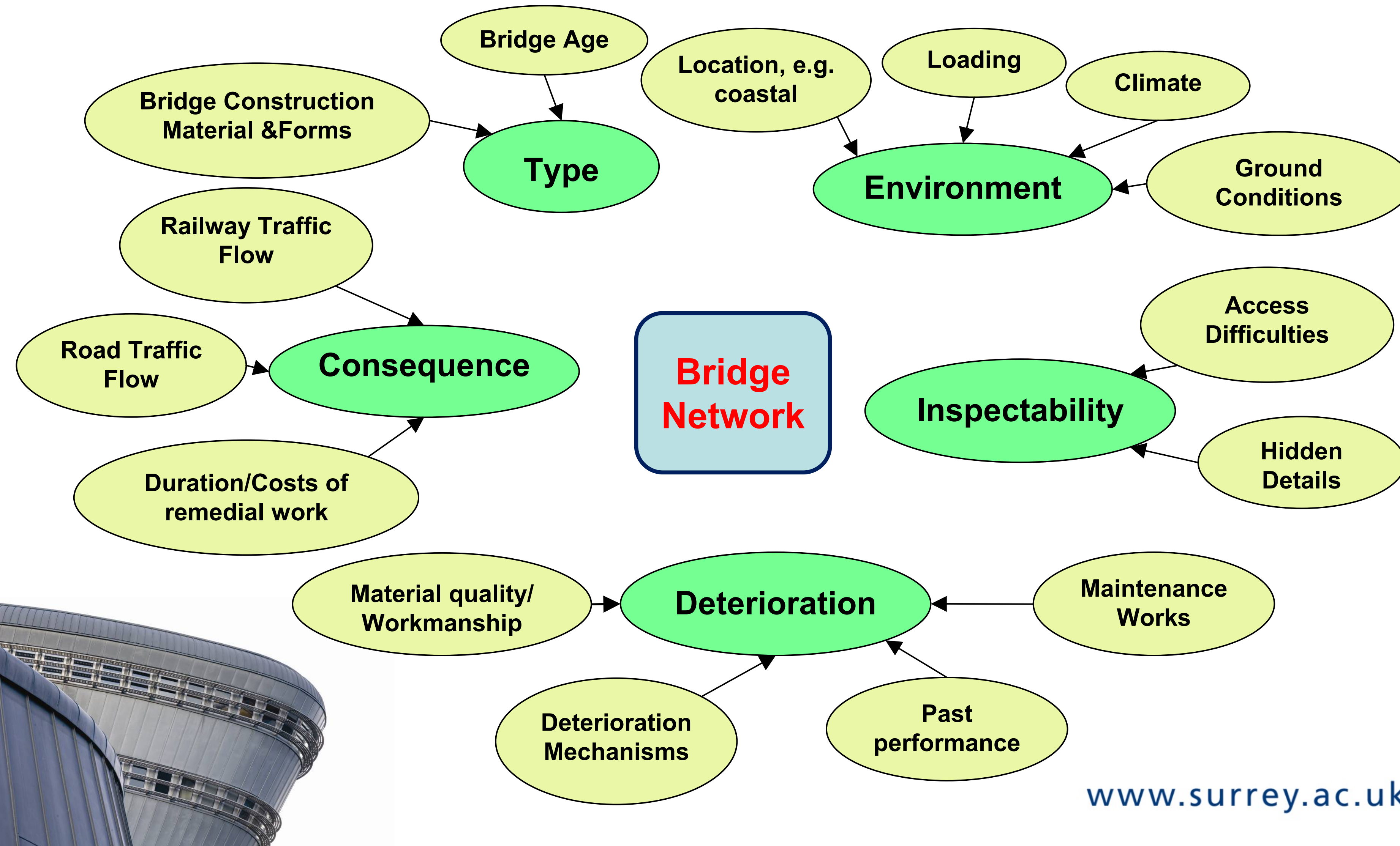
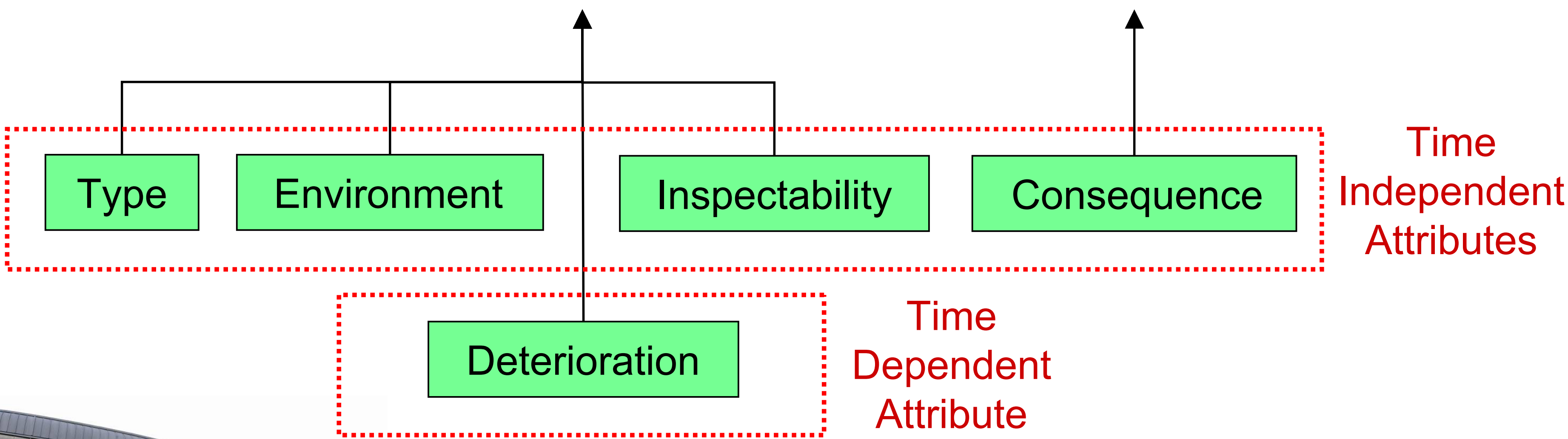
Bridge Attributes Considered



Risk

Risk = Probability of Failure X Consequence of Failure



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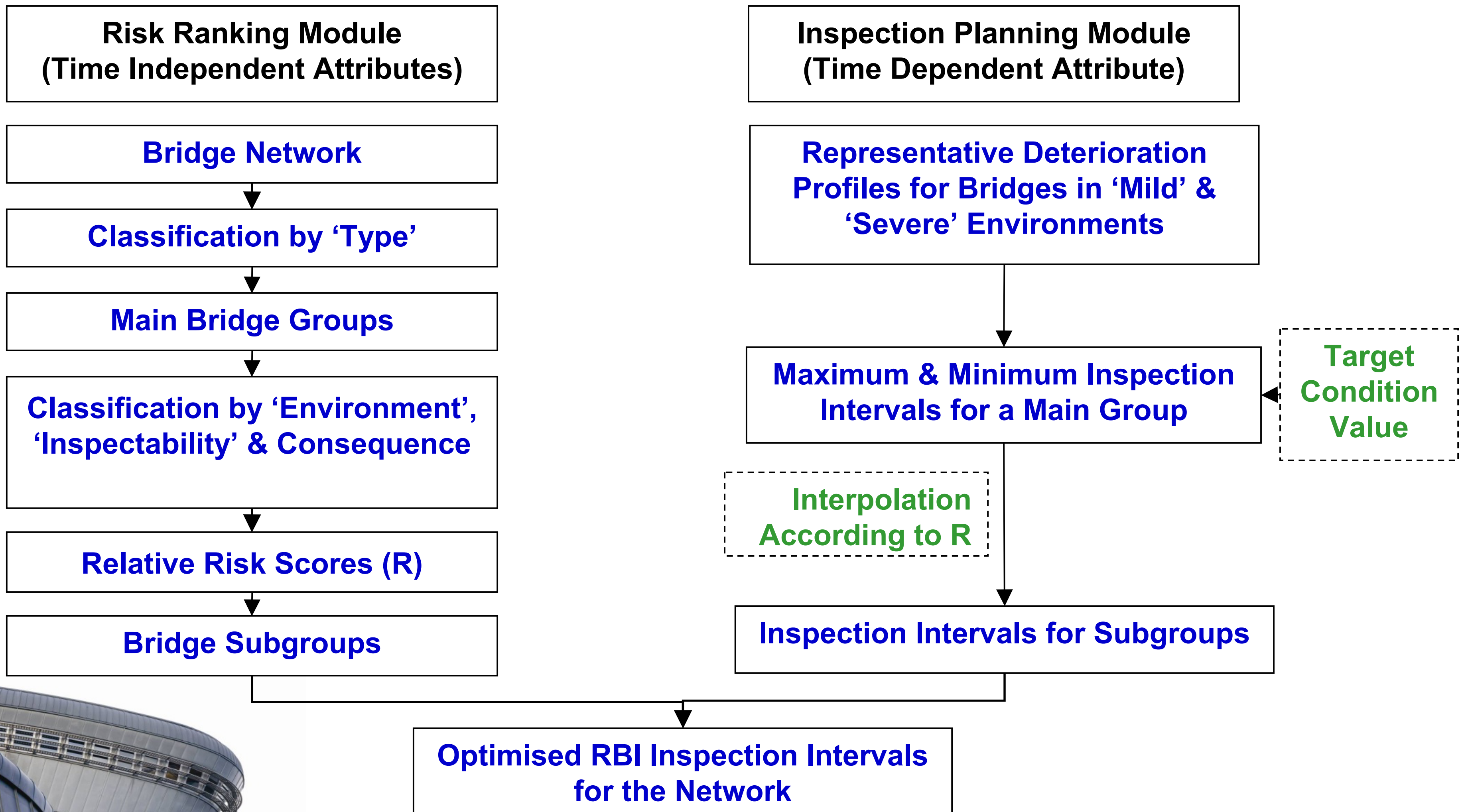
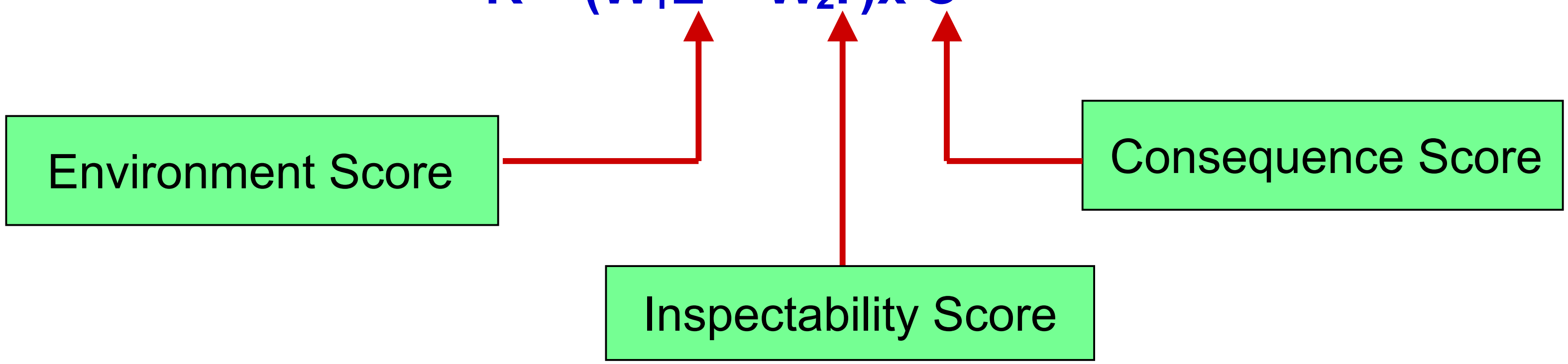
Framework for Proposed RBI



Risk Ranking Scoring System

$$R = (W_1E + W_2I)\times C$$



W_1 , W_2 – Weight Factors

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Risk Score

Sensitivity studies on weight factors

↓

Effect is small

Scores are qualitative measure of the relative risk only

↓

Weight factors ignored

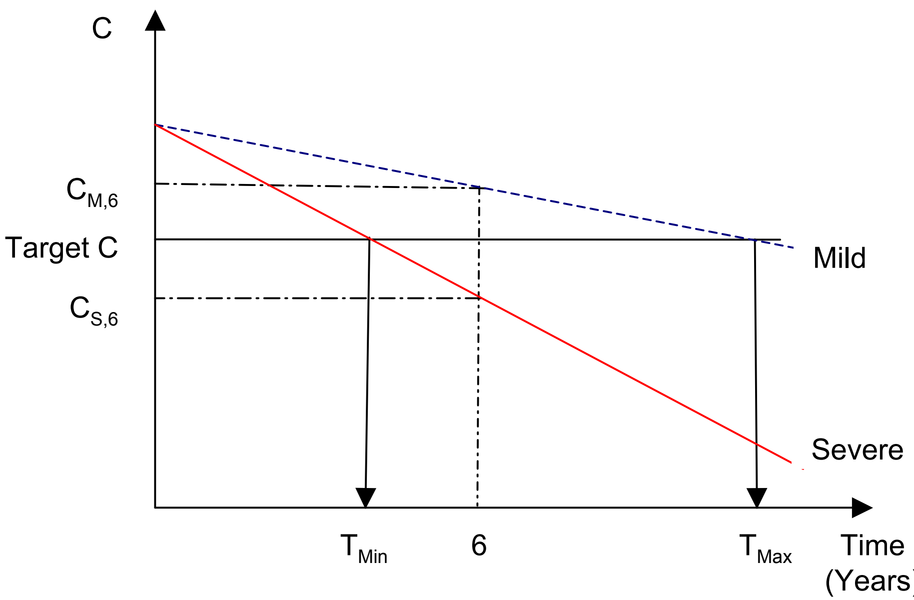
↓

R = (E + I) x C

Scores made to vary between 1 and 2 by linear interpolation

A Conceptual RBI Planning Model

- Deterioration curves for mild & severe environments
- Expected Conditions ($C_{M,6}$ & $C_{S,6}$) at year 6 from the curves
- Weighted average C
- Target C = Weighted Average C
- Inspection when C curve reaches target
- T_{Max}, T_{Min}
- Inspection intervals of subgroups according to the risk scores



Deterioration Modelling

- A Bridge is a system made up of elements
- Elements can be further divided into minor elements
- Minor elements fail due to deterioration
- Element failure propagates through the system
- This may lead to progressive failure of the bridge
- Fault Tree Models (FTM) have been used in these situations
- Bayesian Belief Networks (BBN) can also be used

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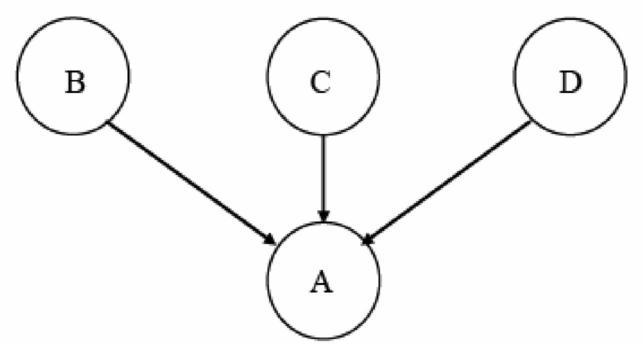
Bayesian Belief Networks (BBN)

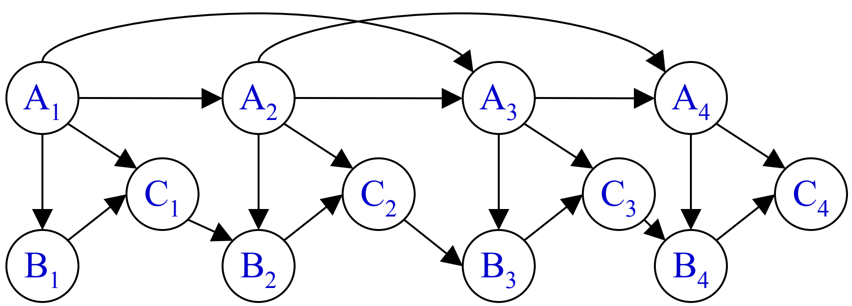
- A structured way to show Relationships between variables in network
- Relationships estimated by conditional probabilities
- Effective when data is uncertain or incomplete
- Widely used in various industries e.g. Medical industry, water management, weather forecasting, etc.



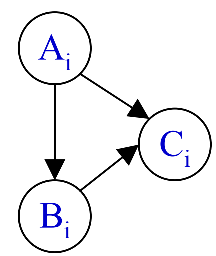
$$P(A,B,C) = P(A/B,C)P(B)P(C)$$

Dynamic Bayesian Network (DBN)

- Special type of BBN
- Deals with domains which evolve over time



Repetitive structures



Time Slice

- Three time frames have to be considered
  - initial time, t_0
  - transition interval, Δt
  - time horizon, $T = t_{final} - t_0$

Benefits of BBN

- Previous knowledge can be utilized
- Updating with new information is possible
- Can be used to model problems with variable quality/quantity data
- Graphical representation helps understanding
- Expert knowledge can be utilized in the absence of physical data

Shortcomings of BBN

- Fully specified Conditional Probability Tables (CPT) are required
- CPTs may become very large when parent nodes are multi-state

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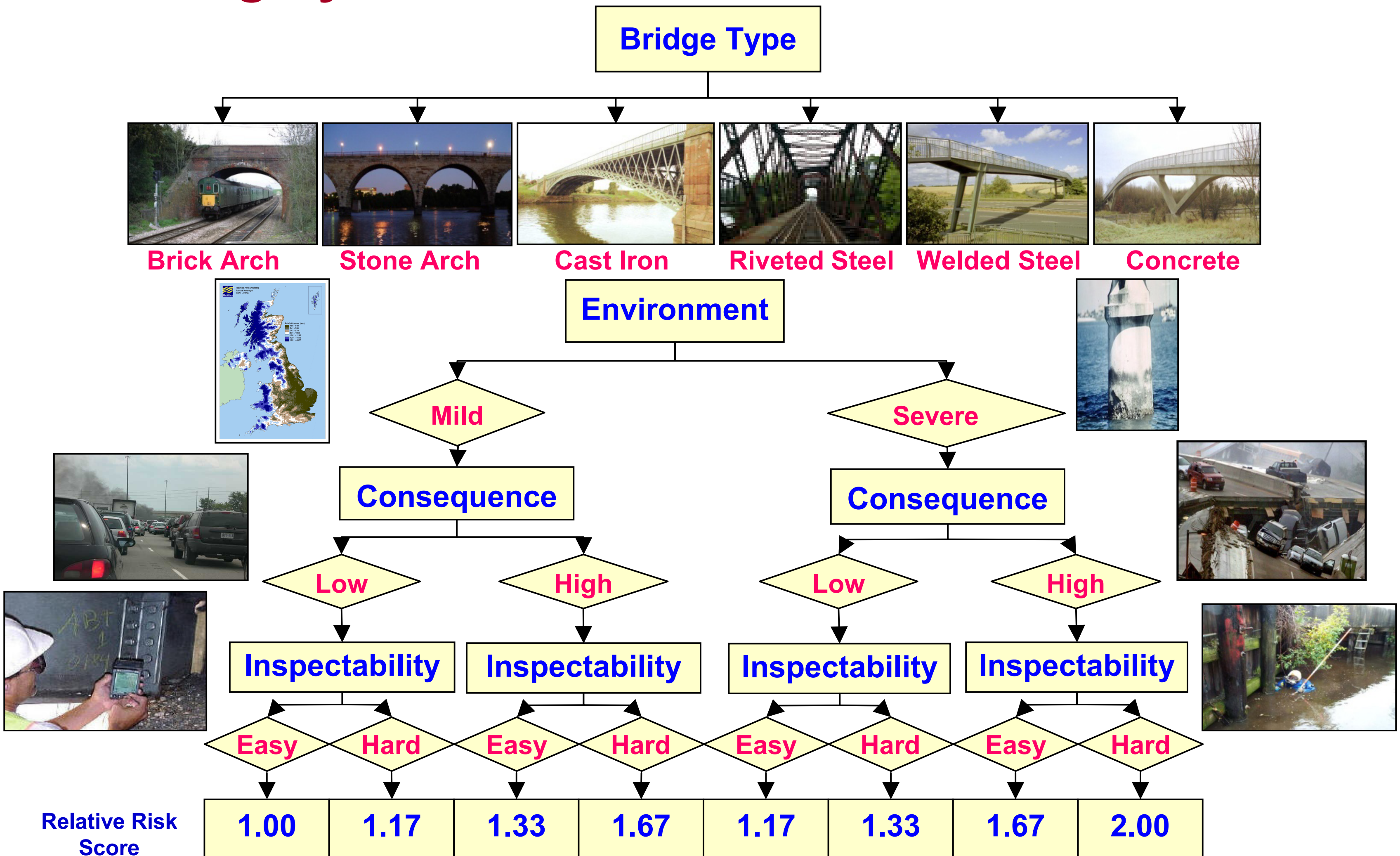
Risk Ranking System



Criteria for Identification of ‘Environment’

- Masonry arch bridges considered, since they are about half of the NR bridge stock
- The environment of a bridge considered as severe, if two or more of the following factors are severe/heavy:

  - Loading
  - Climate
  - Location of the bridge
  - Ground Conditions

Classification of Loading

A qualitative classification of loads based on the type of traffic :

- Under line bridges (Bridges carrying railway lines):
  - Primary
  - LSE
  - Freight routes

  → Severe

- Over line bridges (Bridges carrying roads over railway lines):
  - Motorway
  - Trunk road

  → Severe

Criteria for Identification of ‘Consequence’

If two or more of the factors are classified as high, then the ‘consequence’ is considered high:

- Railway traffic flow:
  - Primary and LSE lines
  - or bridges maintained under policy A
- Road traffic flow:
  - Motorways and trunk roads
  - or Traffic sensitive roads
- Cost and/or duration of remedial actions
  - bridges with multi or long spans

Criteria for Identification of 'Inspectability'

Bridges with hidden details

Access difficulties for inspection

Inspectability – Hard

These details are normally available in inspection reports

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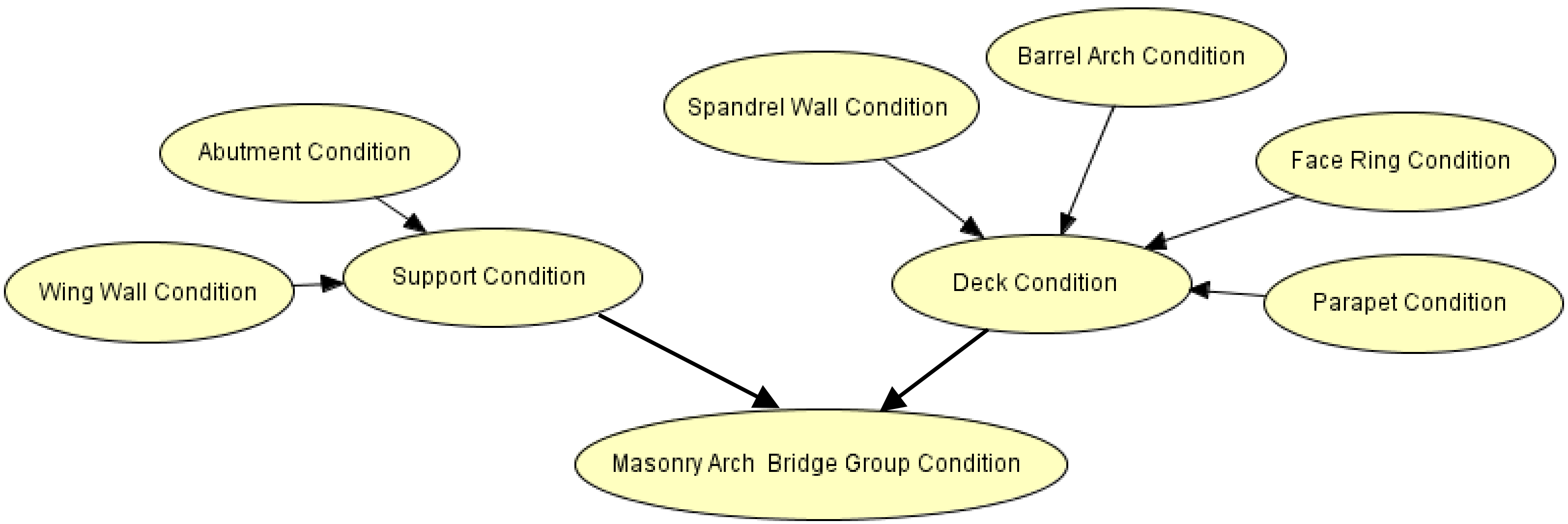
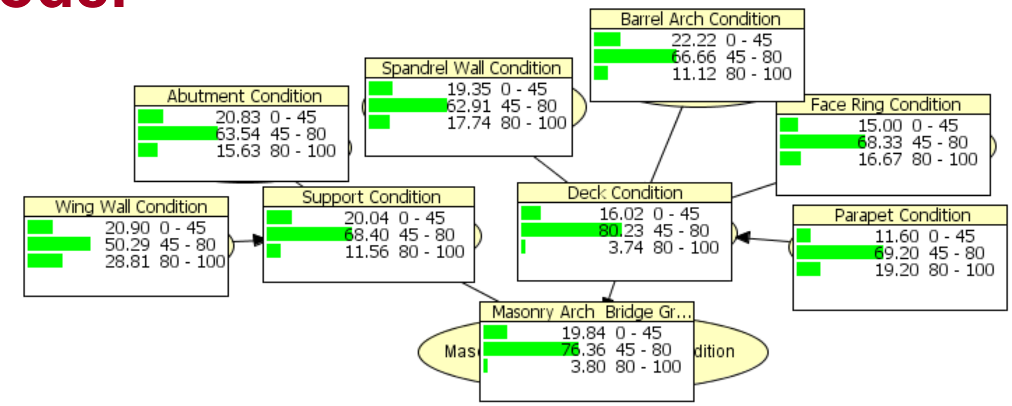
A BBN Model for Masonry Arch Bridge Group Condition



- Numerical variables with 3 intervals; (0-45), (45-80) & (80-100)
- Conditional probabilities from relative weightings of elements
- Initial element level condition from sample structures

Output from the BBN Model

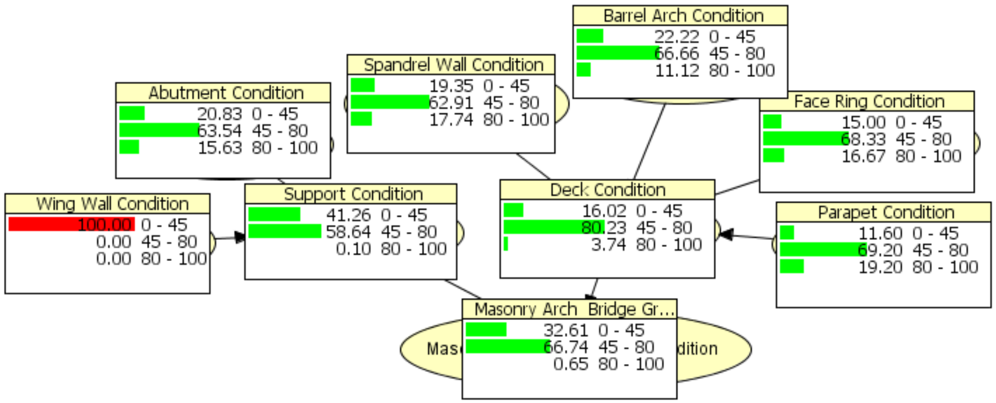
Main group level condition for Masonry Arch Bridges



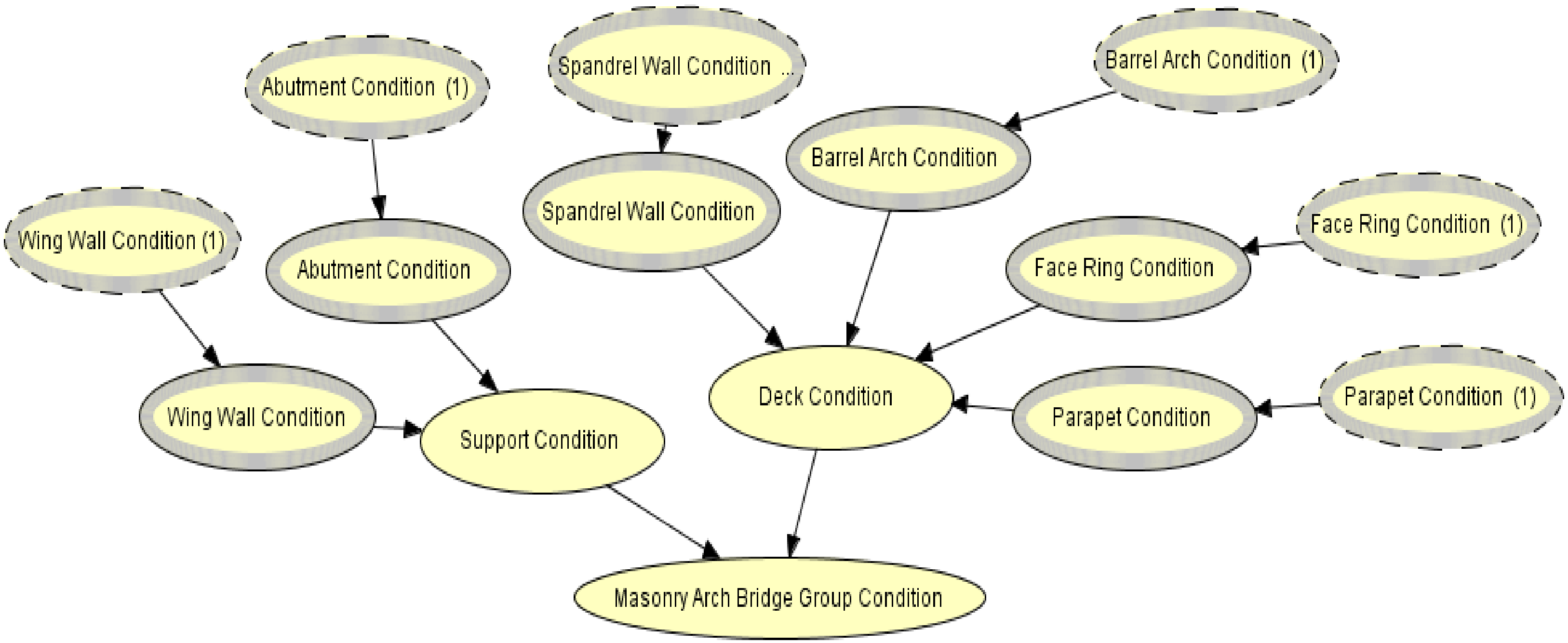
'What-If' Scenarios

In BBN evidences about variables can be easily updated

– e.g. If wing walls are known to be in poor condition



Inclusion of Time Variability: DBN



- Element condition at any time t depends on the element condition at time t-Δt

Conditional Probabilities between Time Steps

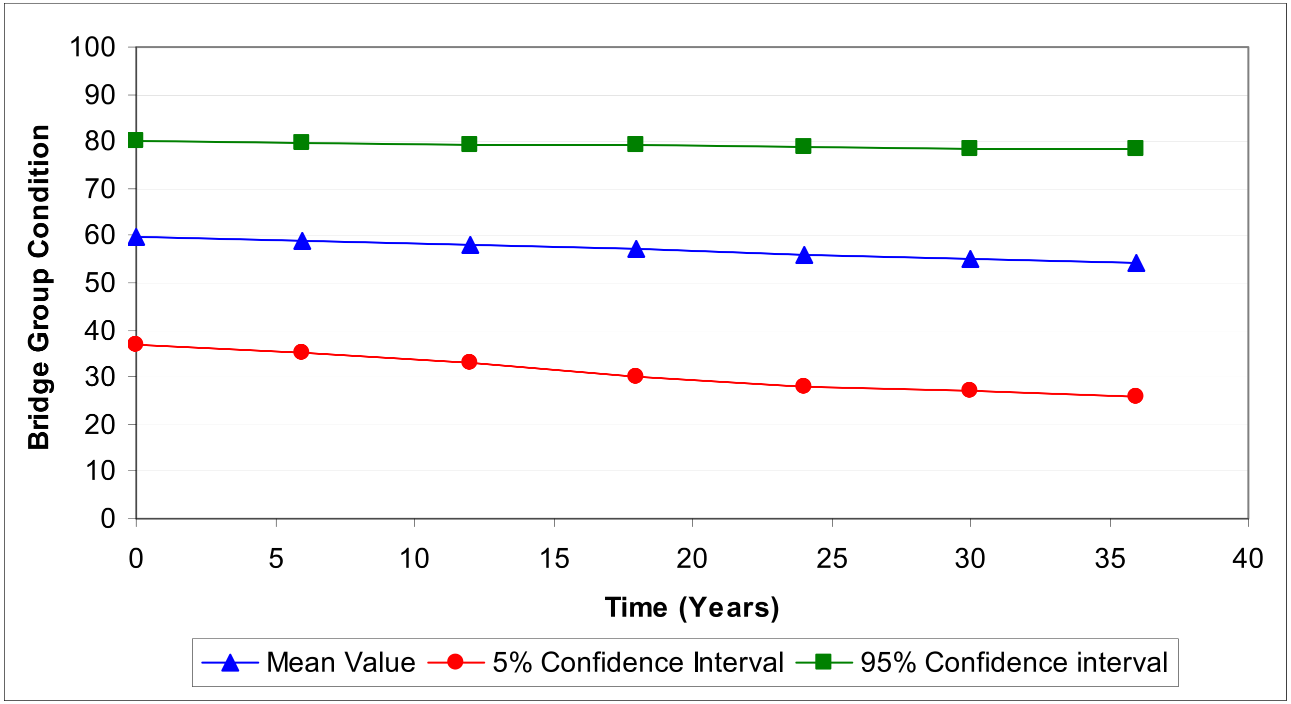
Conditional probabilities between time steps to follow Markov principal

e.g. By assuming 5% deterioration to the next state between two time steps:

Probability of wing wall SCMI at next time step [$Sw(t_{i+1})$]	**Current wing wall SCMI [$Sw(t_i)$]**				
	0-20	**20-40**	**40-60**	**60-80**	**80-100**
$P(Sw(t_{i+1})\leq 20)$	1	0.05	0	0	0
$P(20< Sw(t_{i+1})\leq 40))$	0	0.95	0.05	0	0
$P(40< Sw(t_{i+1})\leq 60))$	0	0	0.95	0.05	0
$P(60< Sw(t_{i+1})\leq 80))$	0	0	0	0.95	0.05
$P(Sw_{i+1})>80))$	0	0	0	0	0.95

Deterioration of Bridge Group Condition from DBN

From DBN, the deterioration of bridge group mean SCMI and the 5%, 95% confidence interval values with time can be obtained



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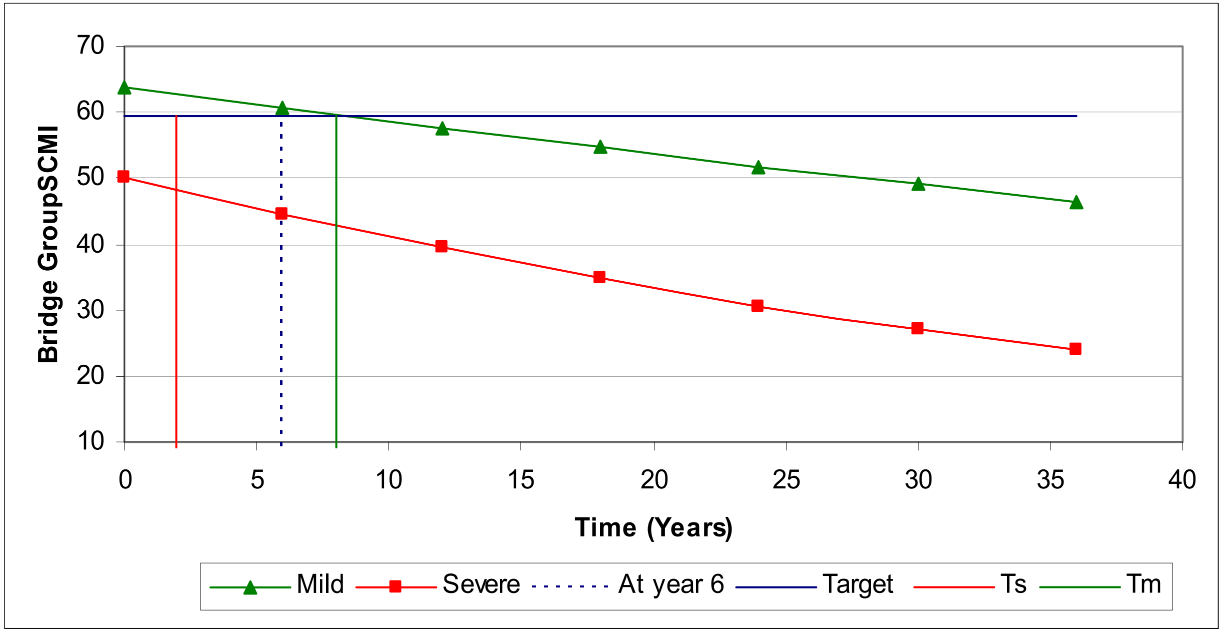
Case Study of RBI planning using DBN

- A random sample of bridges from Network Rail's bridge stock is ranked according to the risk ranking strategy
- Deterioration curves for bridges in mild and severe environment obtained from DBN



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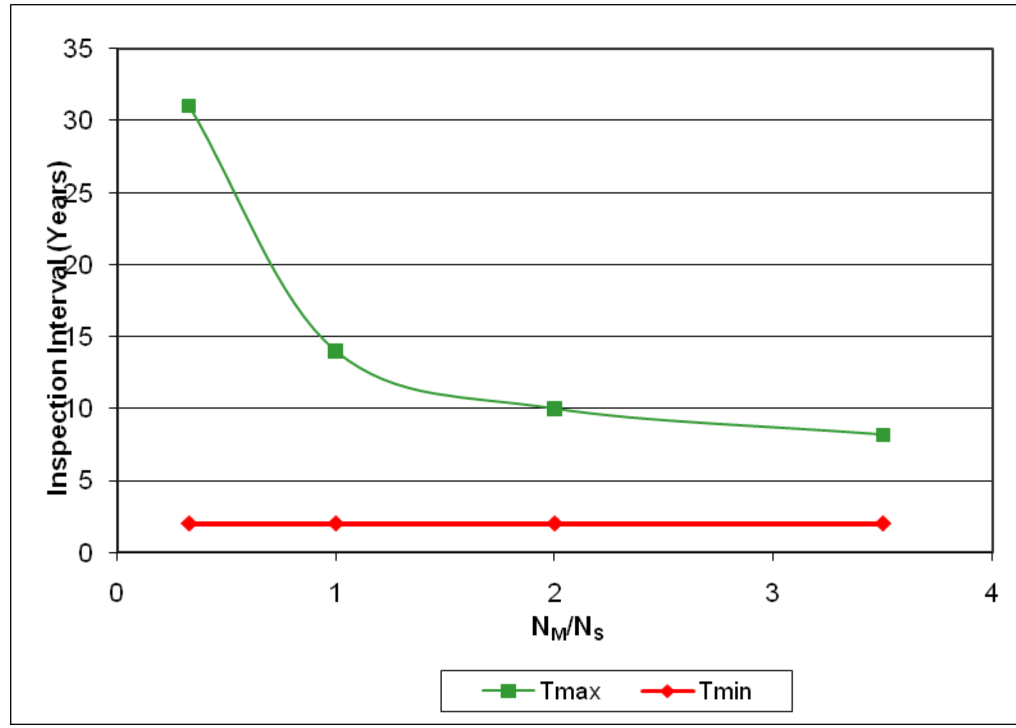
Inspection Intervals for the Subgroups of the Sample Structures

Subgroup	Relative Risk Score, R	Inspection Interval (Years)	
		From Analysis	Recommended
SG1	1.00	8.2	8
SG2	1.17	7.2	7
SG3	1.33	6.2	6
SG4	1.67	4.1	4
SG5	2.00	2.0	2

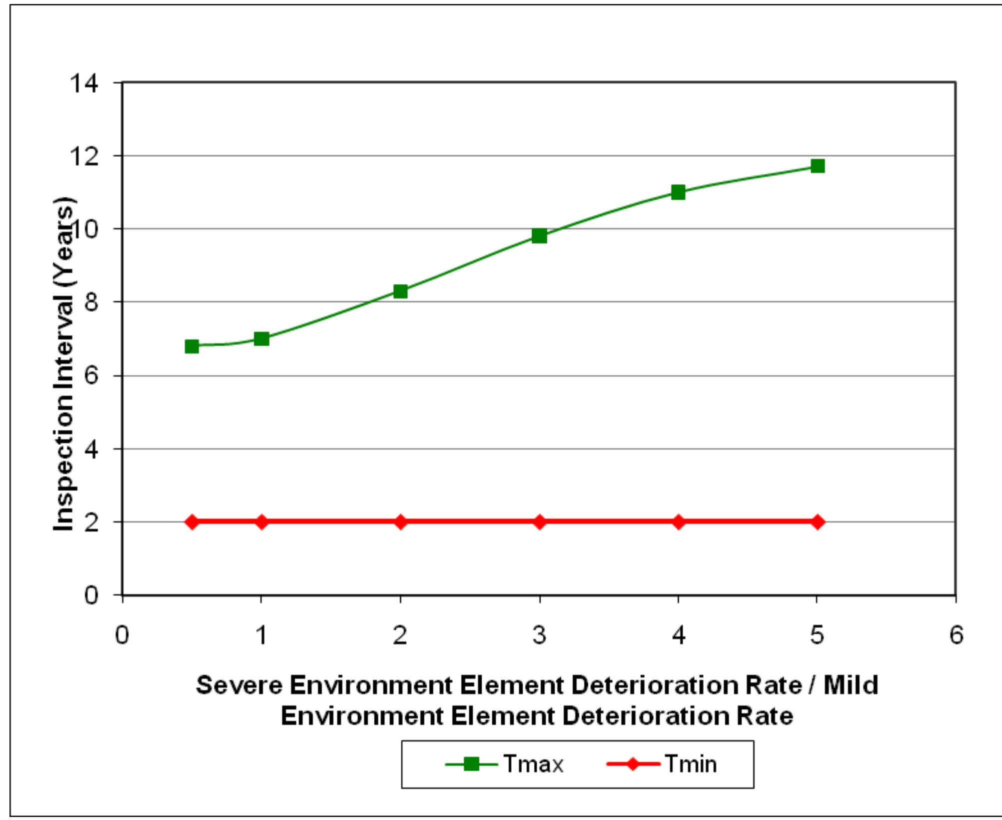
Change in the Inspection Intervals - I

- When there are more bridges in severe environment, T_{max} can be extended up to 30 years
- This is the result of target value chosen on the basis of main group level average
- Industry Good Practice of Maximum of 18 Years can be used as the upper limit



Change in the Inspection Intervals - II

- TMax can be extended up to 12 years depending on the relative rate of deterioration
- This is also related to the target value selection



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Concluding Remarks

- Risk ranking strategy:
  - Helps to identify critical structures in a network
  - Systematic approach and practical to apply
  - Case study on some sample structures
- DBN deterioration model for masonry arch bridge group:
  - Need for a deterioration model at a main group level identified
  - Real data or engineering judgments can be utilised
  - Can be extended to any type of bridges
- Risk-Based Inspection Model:
  - A conceptual model for bridge networks
  - Case study to illustrate the use of the model on RBI planning
  - Inspection intervals for sample bridges

Recommendations for Future Work

- Refinement of risk ranking attribute categorisation (e.g. mild, moderate & severe ‘environment’)
- Development of deterioration models for each main group of bridges
- Alternative criteria for target risk level
  - Collapse
  - Functional
  - Serviceability
- Possibility of updating the inspection intervals based on inspection findings
- Use of other inspection methods / Effectiveness of inspection in reducing risk levels

References

- Rafiq, M.I., Sathananthan, S. & Chryssanthopoulos, M.K., 2010. Network level deterioration modeling: A case study on Masonry Arch Bridges, IABAMS
- Sathananthan S., Rafiq M.I. & Onoufriou T., 2008. A Risk Ranking Strategy for Network Level Bridge Management, Structure &Infrastructure Engineering (available online: http://www.informaworld.com)
- Sathananthan S., Rafiq M.I. & Onoufriou T., 2008. A Risk Ranking Strategy for Network Level Bridge Management, IALCCE'08: Italy.

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Thank you

Criteria	RBI System				
	University of Surrey		Network Rail	Welsh Assembly Government	TfL
Definition of Risk	Probability of Failure x Consequence of Failure		Not Explicitly Defined, but mainly likelihood of event is considered	Not Explicitly Defined, but a Combination of Likelihood and Consequence	f(Probability of Rapid Deterioration, Damage or Failure, Consequences of Failure)
Level of Analysis	Network Level		Individual Structures	Group of Structures/Individual Structures	Group of Structures/Individual Structures
Attributes Considered	Attribute Group	Attributes			
	Type	Bridge Construction Form and Material Type	Structural Form and Material	Structure Type, Material Type, Structural Form	Structure Type, Material Type, Structural Form
		Age		Age	
	Environment	Location		Level of Contamination	Exposure Seviarity
		Loading		Loading	
		Climate		Exposure Severity	
		Ground Conditions			
	Inspectability	Access Difficulties			Inspectability, Principal Inspection Interval
		Hidden Details			
	Deterioration	Material Quality/Workman ship			
		Potential Deterioration Mechanisms		Potential Modes of Failure	Potential Failure Mode,
		Current Condition	Condition	Current Condition	Current Condition
		Past Performance	Capacity	Historical Rate of Deterioration	Rate of Deterioration
		Maintenance Works			
	Consequence	Railway Traffic Flow		Wider, global consequences	Route Supported
		Road Traffic Flow			Obstacles Crossed
		Duration/cost of remedial Works (number of spans/span length)		Localised Consequence	Span Length/Height, Extent of Failure
				Severity and extent of damage due to incidents	
Risk Categorisation	In a scale of 1.00-2.00		Lower, Medium or Higher	0%-100%	In a Scale of 0-100
Maximum Inspection Intervals	Various		Various	12 Years	18 Years