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Road and Rail Infrastructure IV

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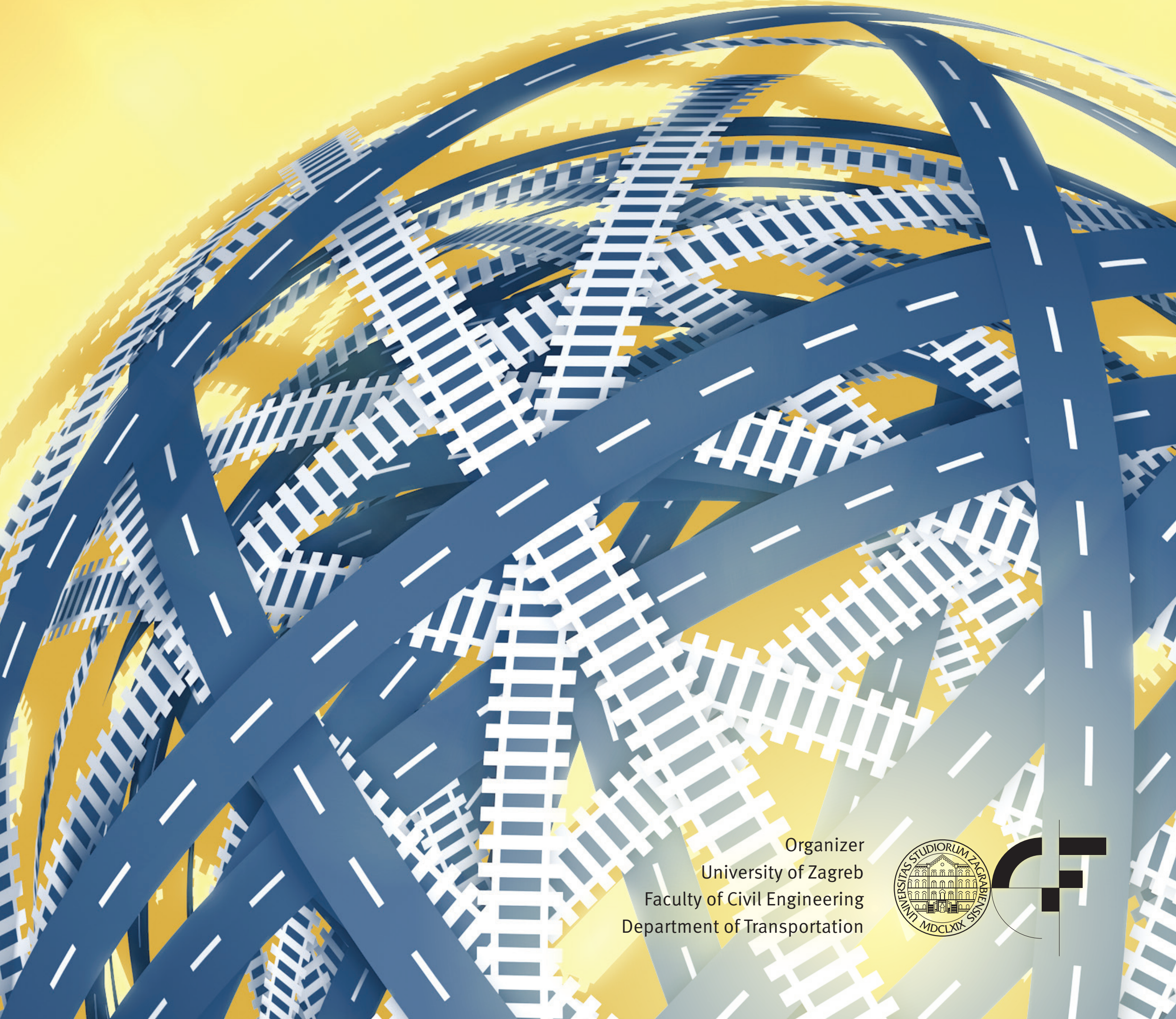

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Road and Rail Infrastructure IV

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A LOCAL AUTHORITY'S RISK-BASED APPROACH TO PRINCIPAL INSPECTION FREQUENCY OF STRUCTURES

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Abstract

Scotland's bridges are an integral part of its infrastructure, therefore it is imperative that they are inspected and maintained correctly. Current standards state that general inspections (GI's) are carried out every 2 years and principal inspections (PI's) every 6 years. This study examines a risk-based approach to principal inspection frequency and development of a tool for relevant structures. The current inspection practices were investigated with regards to the research behind the existing inspection intervals. A full literature review was carried out on a number of case studies and documents to ascertain all options that could be utilised for a risk-based approach of this type. The major factors that could affect the structural stability of highway structures were explored and a shortlist of factors was finalised. These factors were weighted against each other, e.g. Bridge Condition Index (BCIcrit) weighted higher than span length of the structure. Individual variables were researched for each factor and rated in accordance to perceived risks. All factors are used and an inspection frequency score is output from the assessment as well as a risk score for the structure. The results presented will assist the Bridge Manager of a Local Authority (LA) to organise PI's on each structure within their stock based on its risk profile. Engineering judgement and knowledge of the structures will require to be used to complete the assessment tool for risk-based approach to PI frequency of structures. The main benefits of establishing a risk-based principal inspection frequency are reduced cost, higher level of safety and best value optimisation of resources.

Keywords: Risk, inspection, frequency, reliability, local authority, structures

1 Introduction

In Scotland there are thirty two Local Authorities (LAs) all of which have the responsibility of managing their assets. For the purpose of this study, highway structures, such as bridges, are defined as 'assets' (The Highways Agency, 2007). The nation's road and railway bridges are an integral and critical part of its infrastructure; therefore it is important that they are inspected and maintained correctly. The current economic downturn has promoted ways of thinking to manage assets in a more economical way. With relative budget and resource cuts within the local authorities (Local Government Association, 2014), the need for innovation and a new approach is necessary.
The LAs in Scotland currently carry out General Inspections (GI's) of their structures every two years, with Principal Inspections (PI's) scheduled every six years (The Highways Agency, 2007). The purpose of inspections is to provide suitable information for the asset manager to plan future maintenance, intervention, funding and to ensure the structures are fit for purpose and safe for use (UK Roads Liaison Group, 2013).

Inspections are perceived in the civil engineering industry as the best way to evaluate structures, along with assessments (Wang & Foliente, 2008). An inspection requires a competent inspector or engineer to score each element of a structure to obtain its condition rating. An assessment of a structure uses numerical data to analyse its load carrying capacity and its condition (Design Manual for Road and Bridges, 2001).
In Scotland, structures such as the Forth Road Bridge or Clackmannanshire Bridge are nationally important local bridges which form an integral and critical part of the highway infrastructure and therefore require suitable inspection and maintenance. Many bridges carry a vast amount of traffic each day, carrying vehicles across rail, road and water. The highway trunk roads in Scotland are currently maintained by Scotland Transerv, Amey and Bear on behalf of Transport Scotland. Bridge asset owners such as Network Rail, Scottish Canals, BP, etc all maintain structures which can be on the list of public roads but are their asset. Local Authorities within Scotland maintain all other adopted public roads.
The purpose of this paper is to determine the Principal Inspection frequency according to the risk profile of an individual structure in an attempt to help the asset managers in the LAs with scheduling and prioritising the PIs. To achieve this, we review current standards for inspection along with existing literature, consult Scottish LA bridge managers, and create a risk assessment tool which is easy to use and fulfils its purpose.

2 Background

All Local Authorities in Scotland have the statutory duty (BD63/07) to undertake a Principal Inspection of every structure within six years of its last PI (The Highways Agency, 2007). Principal inspection intervals can be decreased if agreed by the Overseeing Organisation with full documentation for the reason (The Highways Agency, 2007). The intervals can also be increased through a risk assessment, but cannot exceed twelve years (The Highways Agency, 2007). Falkirk Council, one of the 32 LAs in Scotland, is liable to inspect 356 structures in total with approximately 45 PI's every financial year on the structures that are owned by the LA. Three engineers are tasked with this, which equates to approximately 15 structures for each member of staff. A small number of structures are owned by Falkirk Council that cross the railway network which require closures to that network during inspection. This means additional costs for temporary works as well as a fee payable to the Railway Asset Manager for each railway possession. In the past, this fee has been above £6,000 for the possession, excluding labour, plant and access costs, which prove to be a heavy burden on the decreasing budget of the LA. Falkirk Council is responsible for 40 structures which are deemed to be confined spaces. These are structures that are partially enclosed or cannot be entered and exited safely by any person. These structures require the term consultant to inspect these to the same intervals as the remainder of the LA's structure stock and charge £900-£1,300 per structure, depending on the method of inspection, ranging from CCTV camera inspection to mobilisation of a full confined space inspection team. The above shows that public spending cuts are increasing and local authority budgets as well as staffing levels are decreasing. These factors are some of the major driving forces for change to provide a more economical approach to bridge inspection. On the other hand, the current standards and guidelines (UK – BD63/07 (2007), Management of Highway Structures: ACoP (2013), Inspection Manual for Highway Structures (2007)) all prescribe GIs in 2 year intervals and PIs in a 6 year intervals without detailing the background research and rationale for the interval length. The above current UK standards and guidelines do not include for the history of the structure, i.e. previous defects and repairs.
The Interim Advice Note IAN 171/12 (Highways Agency, 2012) aimed at risk-based inspection intervals in England, was accompanied by a questionnaire for stakeholders to use when establishing their Principal Inspections. However, the IAN lacked suitability in analysing the likelihood of a potential risk.

Many other industries began using a Risk-Based Inspection (RBI) framework (Yang & Trapp, 1974) and (Faber et al, 1996) for inspection a long time ago, and it seems we may be behind the times in this respect. TWI and Royal & SunAlliance Engineering (1999) analysed the RBI framework for plant such as pressure systems and storage tanks which are also structural assets. This trend towards risk-based analysis is becoming common practice in many disciplines and it is now necessary to establish a standard for RBI frequency for our structures.

3 Methodology

A mixed method approach was used to achieve the aims and objectives of this paper. With this methodology, use was made of contributions from both quantitative and qualitative research (Halcomb and Hickman, 2015). The primary qualitative data that was obtained was the individual factors that were to be used for highway structures on their risk profile. These were taken from various pieces of literature that have been written on the topic. A request to bridge managers of Scottish LAs to rank each factor from most to least influential on the risk profile of a structure was then carried out. The bridge managers were also asked to rank the variables within construction form and construction material in terms of reliability from their experience within the field. Fifteen responses were forward in the specified timescale from thirty four requested. Quantitative data was taken from Falkirk Council's WDM Bridges Database on all repairs carried out to a specific group of fifty structures. The research of existing literature assisted in sourcing individual factors that could be used to determine a structures risk profile with requested information very useful in weighting each factor. From this information a risk-based tool was created for use on all highway structures to identify an optimum inspection frequency. With both research methods showing limitations, it is thought that a mixed method approach is better rounded research and can give more accurate results by triangulating the research i.e. the weaknesses of each method will be counter balanced by the strengths of the others (Yin, 2004). Producing "a final product which can highlight the significant contributions of both" (Naoum, 1995).
When creating the risk assessment tool, failure was defined as "any situation when a bridge does not fulfil its performance expectations" (Bush et al 2011). Therefore, any bridge with a weight restriction placed upon it, should be prohibited from a risk-based inspection regime. Every structure with a weight restriction was assessed as not to be able to carry full HA/HB loading and was therefore unable to go through the framework.
To follow the current guidelines (County Surveyors Society, 2002), factors affecting the structures have been chosen based on research and each were weighted on their importance to the structures risk to determine inspection intervals for Principal Inspection. All input from the factors above will require to accurate and recent. To prioritise the factors and weight them will require engineering judgement and expertise, especially of the structures. That is why all relevant departments of all LAs in Scotland were consulted and their input included in the creation of the new tool.

4 Results and discussion

Thirteen of the thirty two local authorities returned the Research Requested information in the specified timescale. Two additional returns were completed by Chartered Engineers who are colleagues at Falkirk Council. One local authority currently does not have a bridges department. At the moment their inspections, assessments and maintenance is carried out by Falkirk Council who are under a term consultancy contract. One other local authority did not wish to participate as they felt it would not benefit their Council from utilising a risk-based principal inspection frequency.

Local Authorities	20 No Individual Factors																			
	Construction Form	Construction Material	Material Quality/Workmanship	Span Length	Access for Inspections	Age of Structure	Scour Susceptibility	Flood Susceptibility	Salt Corrosion Vulnerability	Accident Damage Vulnerability	Environment	History of Defects / Past Performance	BClav	BCIcrit	Loading	Route Supported by or Adjacent to Structure	Obstacle Crossed by the Structure	Probable Magnitude of Failure	Heritage Value of Structure	Cost to Replace (including damage to adjacent)
	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5
1	14	11	15	13	10	17	18	19	20	4	7	16	5	9	8	6	3	12	1	2
2	7	8	5	6	4	11	16	10	9	15	2	17	19	20	12	13	14	18	1	3
3	11	12	13	10	1	2	15	14	3	4	5	16	20	19	6	17	9	18	7	8
4	18	18	18	10	1	11	1	4	11	11	6	1	6	11	4	6	6	17	11	11
5	13	12	8	15	1	7	10	9	5	4	3	14	19	20	18	16	17	6	2	11
6	16	15	9	14	13	7	11	10	17	2	1	20	6	18	5	3	12	19	8	4
7	13	12	9	19	10	11	7	6	5	3	1	18	16	17	14	15	8	20	2	4
8	20	17	9	12	11	2	17	12	2	2	2	9	15	16	2	12	2	19	1	2
9	11	10	8	5	4	9	20	19	12	6	7	18	16	17	13	15	3	14	2	1
10	11	10	9	1	6	5	17	16	8	7	4	14	19	20	15	12	13	18	3	2
11	7	9	19	2	3	5	15	16	10	17	14	20	12	13	18	11	1	8	6	4
12	14	14	6	14	6	6	14	6	1	1	1	6	1	14	14	6	6	14	6	1
13	15	15	15	5	5	5	15	15	5	5	5	5	5	5	5	1	1	15	1	1
14	19	19	3	13	1	10	16	3	3	3	3	16	3	3	13	13	12	16	2	10
15	13	5	5	5	5	5	13	13	5	1	1	13	5	13	5	13	13	13	1	1
Total Score	202	187	151	144	81	113	205	172	116	85	62	203	167	215	152	159	120	227	54	65
Average Score	13.5	12.5	10.1	9.6	5.4	7.5	13.7	11.5	7.7	5.7	4.1	13.5	11.1	14.3	10.1	10.6	8.0	15.1	3.6	4.3
	5	6	11	12	17	15	3	7	14	16	19	4	8	2	10	9	13	1	20	18
Total 2880	7.0	6.5	5.2	5.0	2.8	3.9	7.1	6.0	4.0	3.0	2.2	7.0	5.8	7.5	5.3	5.5	4.2	7.9	1.9	2.3

Figure 1 Importance ranking of bridge inspection factors in the opinion of 15 LAs

		% Weighting
Construction Form	1.1	7.0
Construction Material	1.2	6.5
Material Quality / Workmanship	1.3	5.2
Span Length	1.4	5.0
Access for Inspections	1.5	2.8
Age of Structure	1.6	3.9
Scour Susceptibility	2.1	7.1
Flood Susceptibility	2.2	6.0
Salt Corrosion Vulnerability	2.3	4.0
Accident Damage Vulnerability	2.4	3.0
Environment	2.5	2.2
History of Defects / Past Performance	2.6	7.0
BClav	3.1	5.8
BCIcrit	3.2	7.5
Loading	3.3	5.3
Route Supported by or Adjacent to Structure	4.1	5.5
Obstacle Crossed by the Structure	4.2	4.2
Probable Magnitude of Failure	4.3	7.9
Heritage Value of Structure	4.4	1.9
Cost to Replace (including damage to adjacent	4.5	2.3

Figure 2 Weighting table of individual factors for the risk pro forma

The response from each LA was tabulated and the results (values) were inverted to allow proper weighting of each factor (Figure 1). The initial format of the requested research was that the most influential factor on risk score of a structure was to be ranked as number one with the least influential ranked number twenty. All factors would then receive a number between one and twenty, depending on how the research participant (bridge manager) felt they ranked in terms of importance on the risk score of a structure. The research participants were asked to rank the factors from their experience in the industry and knowledge of their own structures. With all rankings being inverted, number one became twenty, number two became nineteen and so on until twenty become one. The rankings were inverted to give correct allocation of weighting for each factor. The percentage of weighting of each individual factor would affect the risk score of a structure. My opinion felt that each factor influences the risk profile of a structure to varying degrees and this was why the weighting exercise was carried out. After ranking from each Scottish LA bridge manager, the factors used were weighted by totalling all fifteen responses for LAs. These were then portioned into weightings as a percentage of the total number of returns.

The results from the respondents show that the most influential factor is The Probable Magnitude of Failure and the least influential factor Heritage Value of the Structure (Figure 1). The probable magnitude of failure has the highest weighting of all the factors. The research participants as a whole have felt that this must be the most influential factor. This is more than likely due to the fact that different failure types and magnitudes can result in very different situations. If complete failure were to occur in a structure it is more than likely that loss of life may follow. The BCIcrit of any given structure is also high in the rankings probably due to its obvious nature. The BCIcrit of a structure states its condition out of one hundred which is easily understood. The current condition of a structure clearly has to be play a major part in its risk scoring, which has been confirmed through the research participants. The scour susceptibility has the third highest weighting with bridge managers in Scotland who are very knowledgeable about scour problems to their structures. The history of defects / past performance of the structure are factors that has been omitted from many risk-based analysis. These results have defined this as a major factor with the fourth highest weighting. This individual factor gives a clear indication of how the structure has coped since its construction. The fifth highest weighting is the construction form of the structure, which with individual knowledge and research on failures of certain forms can assist in analysing structures in terms of risk.

The research participants were asked to rank the nineteen types of construction form in terms of reliability from their knowledge and experience of their bridge stock. The most reliable construction form from the research participants is solid spandrel arch, with cable stayed / suspension and other the least reliable (Fig. 3).

	19 No Construction Forms																		
Local Authorities	Solid Spandrel Arch	Open Spandrel Arch	Tied Arch (Bowstring)	Beam & Slab	Box Beam	Half Through Girder	Filter Beam	Underslung Truss	Half Through Truss	Through Truss	Slab Solid	Slab Voided	Culvert/pipe/subwaycircular/oval	Culvert/pipe/subway box	Portal/u-shape	Troughing	Cable Stayed/Suspension	Tunnel	Other
1	1	2	12	3	4	13	14	15	16	17	7	8	5	6	9	10	18	11	19
2	1	11	17	8	10	12	6	16	15	14	5	7	2	3	4	13	18	9	19
3	8	9	13	7	10	14	15	16	17	11	1	2	3	5	4	12	18	6	19
4	1	5	5	5	1	5	5	14	14	14	5	5	5	1	1	10	5	5	10
5	3	10	16	4	11	12	7	13	14	9	8	15	1	2	5	17	6	18	19
6	1	2	8	6	7	13	9	13	13	13	5	17	12	3	4	18	10	11	19
7	1	14	12	4	9	8	7	17	15	16	5	6	3	2	10	11	18	13	19
8	16			10	8	7	15		8	12	8		18	17		7			
9	1	2	11	8	9	10	18	14	13	12	5	6	4	3	7	16	15	17	19
10	5	4	17	8	9	11	10	15	13	12	7	14	1	2	6	16	18	3	19
11	3	18	13	8	6	10	9	12	11	16	4	5	2	14	15	7	17	1	19
12	1	1	16	1	16	11	1	11	11	11	1	1	11	1	1	1	16	1	16
13	1			3	3		13	3	3	3	1	11	3	3	3	14	11	3	
14	4	7	10	5	8	13	15	14	12	11	6	9	1	2	3	16	18	17	19
15	1	7	15	1	7	7	7	15	15	7	1	7	1	1	1	7	15	7	15
Total Score	48	92	165	81	118	146	151	188	190	178	69	113	72	65	73	175	203	122	231
Average Score	3.2	7.1	12.7	5.4	7.9	10.4	10.1	13.4	12.7	11.9	4.6	8.1	4.8	4.3	5.2	11.7	14.5	8.7	17.8
	1	7	15	6	8	12	11	17	16	14	3	9	4	2	5	13	18	10	19

Figure 3 Risk ranking of bridge construction forms in the opinion of 15 LAs

As for Construction Form, the research participants were asked to rank the construction material. There were fourteen construction material variables. As shown in the table below, the most reliable construction material is masonry stone with the least reliable other and metal – cast iron.

Local Authorities	Concrete Reinforced	Concrete Mass	Concrete Post-Tensioned	Concrete Pre-Tensioned	Metal Steel	Metal Cast-Iron	Metal Wrought Iron	Metal Aluminium	Metal Corrugated Steel	Metal Corrugated Aluminium	Masonry Brick/Stone	FRP/GRP/Composite	Timber	Other
	14 No Construction Materials													
1	3	2	10	5	6	13	8	9	12	11	1	7	4	14
2	3	2	6	4	5	9	8	10	7	11	1	13	12	14
3	7	2	8	9	10	5	4	3	11	12	1	13	6	14
4	8	7	1	1	1	10	8	10	4	10	4	14	4	10
5	2	1	4	5	3	12	13	10	8	9	6	11	7	14
6	5	2	7	6	4	3	12	10	11	13	1	8	9	14
7	4	3	12	5	9	10	11	7	6	8	1	13	2	14
8	9	19	15	17	7	8	8		15		13		5	
9	4	2	7	6	5	10	9	11	3	12	1	13	8	14
10	3	1	6	5	4	7	8	10	9	11	2	12	13	14
11	4	7	8	2	3	12	9	11	5	10	1	6	13	14
12	6	1	1	1	1	9	9	6	9	9	1	6	9	9
13	8	3	3	3	8	8	8	3	3		1	1	8	
14	2	1	14	3	8	11	9	4	10	5	6	7	12	14
15	4	1	12	12	4	4	4	4	4	4	1	1	4	4
Total Score	72	54	114	84	78	131	128	108	117	125	41	125	116	163
Average Score	4.8	3.6	7.6	5.6	5.2	8.7	8.5	7.7	7.8	9.6	2.7	8.9	7.7	12.5
	3	2	6	5	4	11	10	7	9	13	1	12	8	14

Figure 4 Risk ranking of construction materials in the opinion of 15 LAs

5 Conclusions

The aim of this research was to improve safety and optimise management of resources by determining the principal inspection frequency according to the risk profile of individual highway structures. To current practice, principal inspections are carried out on every highway structure on a six year regime.
The risk profile of highway structures has been identified to a certain degree of accuracy with the individual factors and weightings used. This could be enhanced by further research into the ratings of each individual factor and variable used. The risk-based tool, complete with user guide includes a complete flow chart for ease of use. Bridge managers in Scotland can input all twenty factors regarding each specific highway structure with the output an inspection frequency score. The score then gives an indication of inspection regime, in terms of frequency, that structure could be incorporated into.
The inspection frequency score of each highway structure is only an indication of inspection frequency, engineering judgement, along with a high level of experience of the structure should be used. Each bridge manager can adjust inspection frequency groupings to suit owned bridge stock.

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