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Bridge data – what do we collect and how do we use it?

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ABSTRACT The organisations responsible for managing bridge assets in the United Kingdom collect large quantities of data on their bridges. A primary aspiration in the collection of asset data is that it can be processed into useful information that can inform decisions about future management of structures and enhance industry best practice. To enable this, bridge managers must take care to specify appropriate parameters to be recorded, in conjunction with a practical recording interval. In addition, the design of data collection and recording processes is key to ensuring that the data obtained can be transformed into useable information. This study draws on perspectives from a series of interviews with key agents involved in the management of bridges in the United Kingdom. The paper explores the nature of the data that is collected, and how this data is currently used.

1 BACKGROUND

With one of the oldest infrastructure networks in the world, the United Kingdom faces the large and growing challenge of maintaining and renewing its critical assets to allow them to continue delivering the social and economic benefits for which they were built (see also Thurlby 2013). Considering the scale of the investment that will be required in bridge assets in the coming years, it is important that we are able to understand their current and future condition and make informed decisions on what work to do, and when.

Understanding the current condition of bridge assets represents a significant challenge, with established practice being for periodic visual inspection of the structure by an experienced person. A balance has to be struck between the desire to have regular monitoring of the assets' condition and the cost and disruption to the network involved in carrying out an inspection; consequently thorough, touching distance, Principal Inspections (PI) are typically carried out at 6yr intervals (Highways Agency 2007). The recording of extant condition defects at a bridge is subject to the interpretation of the individual bridge inspector and their consideration of the defect type, extent and severity. Furthermore, visual inspections are often undertaken in non-ideal environmental and lighting conditions. Consequently, it is unsurprising that several studies have shown that there is considerable variation in the recoding of defects between inspectors and between individual inspections (Moore *et al.* 2001; Lea & Middleton 2002). Various technological solutions, and particularly Structural Health Monitoring (SHM) systems, have been proposed to supplement or replace visual inspections as a source of bridge condition data (McRobbie *et al.* 2015). These systems can offer dramatically improved data collection intervals, more objective and repeatable data, reduced network disruption, and measurement of variables that is not possible with visual inspection (e.g., Hoult *et al.* 2009).

Several approaches have been proposed to optimise spending on the management of infrastructure assets and to address the inherent uncertainties in the decision making process. Many authors have proposed systems for predicting the future condition of bridges based on imperfect current data (e.g., Enright & Frangopol 1999), and such processes are reported to be in use by bridge owners internationally (Mirzaei *et al.* 2012). Others propose decision support tools which consider evidence for current performance, such as inspection data and historic failures, and explicitly present the uncertainties to give an overview of current performance which could be used to inform future management (Hall *et al.* 2004).

The ownership of bridge assets in the UK is split based on: transport mode, strategic importance, and location. The management of these assets is often then further delegated to contractors, with specialist sub-contractors and consultants frequently picking up more complex work, load-rating assessments and renewal designs. The consequence of this is that asset data collection and decision making processes across the bridge stock are highly heterogeneous, with no clear view of current practice available in standards or the literature.

This paper presents a narrative around the management of the UK's bridge structures, focused on the collection and use of bridge condition data. The work has been built from a series of semi-structured interviews with key individuals in bridge management organisations around the UK.

2 RESEARCH METHODOLOGY

The research was designed as a cross-sectional series of semi-structured interviews with individuals in UK bridge management. In selecting the participants for such a study, it is important that the respondents are representative of the main population (e.g., Oppenheim 1992). Therefore, the participants interviewed were selected to be representative of the range of agents in UK bridge management, including individuals responsible for setting policy in major organisations, as well as those inspecting and making decisions on individual structures. Particular care was taken in ensuring that the all transport modes, levels of authority (i.e. strategic, city region and local authority) and elements of the supply chain were included.

In total, 9 interviews were conducted, with 11 participants who collectively have nearly 300 years' experience in the sector. Table 1 shows the details of the interviewees' organisational roles and the sectors in which they work. Throughout this paper, quotations from those interviewed are presented and are referenced using the notation shown in Table 1 (e.g., *C1*) printed in brackets following the quotation.

The interview approach was standardised using the same interview protocol for each interview. It explored key research questions and areas for enquiry. The interviews were recorded and transcribed and then analysed by coding against research questions and emerging themes in the transcripts (e.g., Saunders *et al.* 2009). Computer aided qualitative data analysis software (CAQDAS) was used to facilitate a thorough and auditable approach.

Table 1. Details of the interviewees' roles and sectors.

Ref.	Role	Sector	Scope
C1	Senior Policy Advisor	Highways	Strategic
C2	Structures Manager	Highways	Metropolitan Transport Authority
C3	Structures Manager	Highways	Local
C4	Structures Engineer	Highways	Local
C5	Structures Asset Manager	Rail	Strategic
C6	Structures Manager	Rapid transit	Metropolitan Transport Authority
C7	Regional Structures Specialist	Highways	Strategic
C8	Head of Engineering	Highways	Strategic, Concessionaire
C9	Assistant Head of Engineering	Highways	Strategic, Concessionaire
C10	Researcher	Highways	Local, Heritage
C11	Structures Watchman	Highways	Strategic, Service provider

3 DATA COLLECTED

The following sections set out the nature of bridge condition data which is collected in the UK.

3.1 Visual Inspection

Without exception, all of the organisations use visual inspection as their primary source of condition data, and many see it as driving the management of their structures. One participant said: *"inspections are, really, the foundation for everything we do" (C3)*. The majority of inspections record condition data as the nature, severity and extent of the defects, mostly using, or similar to, the County Surveyors' Society system (Sterritt 2002). The rail sector uses a similar process, but records defect risk in terms of consequence and likelihood. Inspections are typically also used to record maintenance actions, which may be tagged to specific defects and allocated indicative costs: *"we record suggested remedial works, indicative prices, that sort of thing" (C4).*

Recently, many organisations have begun to extend the inspection intervals for some structure beyond 6 years on a risk basis: *"the cycle is dependent on risk, so if you've got a brand new concrete or weathering steel structure you might want to look at it less frequently" (C5).*

An interesting feature of one inspection programme is that it has been aligned with the inspections for assessment required for an 18 year cycle of steady-state load-rating assessments such that *"Every 18 years you will get an engineer, doing an examination [whereas otherwise] ... our examiners are generally ex-trades[people]" (C5).*

Several participants noted the importance of ensuring the reliability of inspection data for example: *"... subsequently we obviously make the decisions on it, and if you're making it on the basis of unreliable data then that's clearly poor practice." (C1).*

Evidence for the variability of inspection data was noted, including an unpublished study where inspectors from 5 local authorities were each asked to inspect the same bridge, with marked variations between inspectors. Several respondents reported a lack of confidence in the quality of inspections delivered by their supply chain *"we are finding the quality of those inspections that we're getting done externally is ... inadequate" (C2),* consequently, some respondents reported that they are looking at changing the delivery of their inspection programmes: *"it may be that inspections are handled in-house or maybe with a contract that's separate from our service providers" (C1).*

3.2 Monitoring Inspections

If an element of a structure is deemed to require a higher level of data collection than the routine visual inspection process most of the organisations interviewed would implement a programme of monitoring inspections. The inspection periods are reviewed depending on the severity of the defect, on-going deterioration and the importance of the element *"it's a balance between keeping everything safe, and keeping an eye on everything and working within the resources we're given." (C3).*

3.3 Structural Health Monitoring

The deployment of structural health monitoring systems was generally limited to specific structures with particularly serious defects which are critical to the network: *"we have specific monitoring, so if we've got a specific problem we're concerned about and we want to gain information about it then we will ... have targeted monitoring, [that] definitely will help with what we need to do ... we're talking about a handful of cases" (C2).* Another interviewee similarly reported that: "*we have, probably a dozen sites where we have real-time monitoring. They're the stuff we're really worried about ... it's not very often, but we do do-it" (C5).* While another said that if they were to deploy SHM: *"it would be, very much, targeted" (C1).* Some interviewees responded that in terms of monitoring systems they have: "*none at the moment ... not any remote monitoring*" *(C11).*

The exception to this is for asset managers responsible for large and strategically important structures: *"Where do we start? We're monitoring wire breaks ... there's wind speed for bridge closure ... there's the weigh-in-motion system ..." (C8, C9).*

Some of the interviewees indicated their interest in potentially deploying structural health monitoring in the future: *"I am aware of ... remote monitoring as well" (C3*), while another interviewee stated that: *"we probably don't do as much as we should" (C2).* Others – when asked if there is monitoring they would like to do, but currently do not – noted that the condition of their structures does not currently warrant the use of monitoring systems: *"we've not really got anything that is of a serious concern, to say I really want that minute-by-minute" (C6).* Others noted the cost of monitoring systems as a deterrent: *"part of it would be cost, so, can we justify putting it in?" (C2)* it was also noted that managers need to ask themselves *"what is this monitoring really going to tell you?"(C5).*

3.4 Recording of data

The majority of the interviewees reported that bridge condition data is held in dedicated databases which typically hold inventory, inspection and maintenance data. These databases often also hold the results of load-rating assessments and risk assessments such as for scour or safety. The maturity of these tools varies, with a few organisations relying on spreadsheets for some aspects of their data management, while others have complex integrated IT solutions. Many participants mentioned either newly implemented or imminent IT solutions: *"we're in the process of rolling it [the new system] out ... it pulls all those databases together, so we've got one version of truth" (C5).* Another interviewee reported on developing a new system: *"well it's still in its infancy, I mean we've probably been running it for 3 or 4 years now and it's evolved slightly as well ... we've now got a refined approach ... we'll refine the process as well and keep reviewing it, and it'll become better and better and also we'll have more historical data to be able to verify against as well" (C2).*

4 USE OF DATA

Several participants linked the data that is collected and recorded and its use to inform management decisions: "*[the database] is just a repository for data, and perhaps some information, the knowledge is how you use it, and the wisdom is implementing that" (C1).* The use of the data varies across the organisations interviewed, however, generally it was possible to categorise it into: identification of need; informing assessment; analysis of trends; provision of an audit trail or use as a contractual tool.

4.1 Identifying and Prioritising Need

Identifying the need for maintenance interventions is the most common use for bridge condition data. *"So we get a great big long list [element by element, across all structures], so we can look at that and say those are the sorts of things we need to be looking at, and that's a first pass" (C2).* One interviewee reported that they rely on contractors to identify renewals: *"A lot of it relies on our service providers ... to identify need" (C1).*

Monitoring data too is used to identify needs and target interventions to resolve them: "*Take the example of acoustic emissions – we collate the data so we know where the highest instances of wire breaks is ... if we did get a cluster of wire breaks, then obviously when we went in to do our next intrusive inspection, then that [data] would feed into the selection of the panels for the intrusive inspection" (C9).*

4.2 Informing Assessments

Several candidates recognised the link between understanding the condition of their structures and assessing their capacity: *"There's interaction between the two sides, so it may be that an assessment triggers an additional inspection. Examination may trigger assessment [which is] more likely than assessment triggering an examination" (C5)* and one suggested change in condition can trigger a reassessment of load-rating: "*so it's as things change, or we're aware of some deterioration that effects the assessment, then we look at reassessing" (C3).* Monitoring data may also be used to verify structural analysis: *"as part of the assessment process, we do use strain gauges or whatever, so we can back analyse" (C5).*

4.3 Analysing Trends

All of the owners had some overview of the trends in their stock's condition with time and there was recognition that analysing trends is an opportunity for future development *"so we look at trends in condition ... but it's mainly used at a strategic level and obviously what we want to do is to be able to look at trends at an operational level as well ... looking to the future, there's a lot more opportunity to use the data in much smarter ways ... we're not probably very good at looking at trends, so it relies on individual's judgement to say whether we've got problems with particular types of structures" (C1).*

4.4 Maintaining an Audit Trail

One important use of data is to provide an evidence base to justify decisions to do work and what work to do: *"we have a finite resource; it's about justifying where's the best place to spend it" (C2).* Another organisation noted that it can be just as important to justify when work is not done: *"that priority score* *also helps us defend not doing something to politicians or the public" (C3)*.

4.5 As a Contractual Tool

The management decisions for some structures are delegated from the asset owner to contractors who are given responsibility for maintaining the asset for a number of years. It is in the asset owners' interests to put measures in place to ensure that good decisions are made for the long-term performance of the structures, rather than short-term profit of the contractor. Two of the organisations interviewed noted contractual terms related to the condition of the assets: *"we have to hand it back in a condition which allows it to be operated for the remainder of its design life" (C9)* and one interviewee noted contractual terms that specifically use condition data *"on a fixed date at the end of the contract they have to hand back all structures with a BCI score of 90 or above" (C6).* A third organisation noted interest in using condition scores as a contractual tool for measuring service provider performance in the future.

5 DECISION MAKING

While the systems and processes by which management decisions are taken were found to vary considerably across the organisations, it was possible to identify some common themes.

5.1 Prioritisation Processes

All of the participants stated that they undertake some sort of prioritisation process to decide what work to do and when. For some organisations, this is quite a simple process: *"the priority is often very simple ... we've a high, medium or low priority" (C5)* other organisations have more quantitative approaches: *"we've got our own priority scoring system ... Which relates to the importance of the element, the severity of the defect, the size of the structure in terms of deck area, and cost" (C4).* One interviewee set out their prioritisation process as follows: "*we have an inspection programme, which highlights defects in structures, which generates what we call a risk score ... those highest risk scores go forward to a renewals programme and what we then try and do is, through Value Management, prioritise those renewals" (C7).*

It is worth noting that, while at least two organisations referred to a *"Value Management"* process, the mechanics of these processes had some significant differences, particularly in whether they are used to prioritise need, appraise solution options, or prioritise schemes put forward as the best solution to a need. The incorporation of costs into the processes also had significant differences, with some calculating a ratio of risk reduction per pound: *"effectively, we start off with the three risk categories and then we prioritise on that, and then we ... put the costs against each of those items there, and then we get a value ratio" (C2).* Others calculate the ratio of future anticipated savings in whole life cost over immediate cost and then combine that with risk scores. Some individuals reported processes that did not appear to consider cost.

5.2 Lifecycle Planning

Many of the interviewees consider the overall lifecycle of their assets. This may include deterioration modelling and whole life costing to inform planned preventative maintenance *" [the system] tries to predict the condition of different elements over the next 30/40 years, which gives us an indication of ... we don't have to do that now, we can do that in 5 years' time etcetera"(C4).* One of the organisations had the capability to review the costs and effects of different maintenance strategies for their whole asset stock *"the whole life costing's based on our lifecycle plans ... in terms of putting the programme together as a whole ... we will also do an absolute minimum scenario, see what does that look like, we'll run an optimised programme, what does that look like" (C2).*

Other interviewees noted frustrations in attempts to adopt whole life costing approaches *"We've tried in the past ... we used to have a system [which] I never got on with because it always came up with the same answer in my mind which was, 'the cheapest option today is the best'" (C5).*

5.3 Standard Asset Operating Policies

One approach to managing structures is to set out standard operating policies for different kinds of assets and components. For example prescribing that bearings are to be greased every *x* years, and then eventually replaced after *y* years. Alternatively, policy could set out standard interventions for common defects, and specify condition trigger levels for different intervention types. The benefits of this are a unified approach across an asset stock, and a move to planed preventative maintenance, with low downtime, rather than reactive maintenance. These approaches were noted to be taken by some organisations: *"so those maintenance manuals will have 'this area once every x years' so there's a rolling programme you take out every year" (C8)*. In the rail sector, it was reported that standard interventions are used as *"a starter for ten" (C5)*.

However, while noting an intention to develop policy in this area, some participants were more cautious about such approaches: *"you can make some broad assumptions about deteriorations but you've always got to look at the particular condition of those assets" (C1)*.

5.4 Engineering Judgment

All eleven individuals interviewed stressed the continued importance of engineering judgement in making bridge management decisions: "*Engineering judgement still rules the day" (C5)*. The two larger, strategic, organisations interviewed both mentioned peer review panels as key to their decision making processes: *"We have a peer review process to evaluate decisions ... where I have to pitch to my peers" (C5)*. A contracting reported discussing the work to be done with the client: *"the list I produce gets discussed at the monthly meetings, so it's pretty much pencilled in at that point which [schemes] are going to be focused on" (C11)*.

6 CONCLUDING REMARKS

The majority of organisations represented in this survey currently use a programme of visual inspections as their primary source of bridge condition data. The deployment of SHM systems is limited, except in targeted cases where there is a clearly articulated use for the data. Collected bridge condition data is used to inform decisions and, although this paper draws on a limited sample of stakeholder and practitioner views, the study does tend to confirm the perceived heterogeneity of approaches to the management of bridges, particularly in the decision making process.

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