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A strategy for integration of NDT/SHM into bridge asset management – a New Zealand perspective

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ABSTRACT: Bridges are expensive and critical components of transportation systems and need to be managed in a cost effective way to ensure network reliability and integrity. In New Zealand (NZ), bridge asset management (BAM) is carried out by either the state highway operator or local authorities but little systematic knowledge is available on the levels of development in BAM across those entities. This paper reports on the results of a survey conducted in order to understand BAM practices in NZ. Advanced asset management requires quality data about asset performance and condition and the focus of a study that followed up on the survey findings was the development of a strategic framework for bridge data collection. The proposed framework calls for a close alignment of the breadth and depth of the data collected with criticality and risk of bridges within their transportation networks. Advanced data collection will increasingly be relying on non-destructive testing and structural health monitoring and their role in the proposed data collection strategy and issues related to their integration into BAM are discussed.

1 INTRODUCTION

The importance of modern, efficient and safe road networks to the economy of any country is paramount but in New Zealand (NZ) there are even higher road lengths and freight (tone-km) per person or per $GDP than in most other developed countries. Two components of road systems, namely pavements and structures (including bridges), are typically the most expensive to build and maintain and therefore require special attention in any road asset management program. NZ legislative documents such as Local Government Act 2002 (NZ Government 2010a) and the Land Transport Management Act 2003 (NZ Government 2010b) have placed focus on the development of proper asset management processes for all assets. However, while the NZ maintenance planning practices for road pavements are well developed, in bridge asset management (BAM) there is real need for improvement. This gap places a high priority on the development of a standardized BAM system.

There are some 18,000 bridges and large culverts on state highways and local authority roads in NZ, 70% of them are more than 35 years old (NZ Transport Agency 2010). Despite ongoing maintenance, this large stock of bridge structures ages and deteriorates. Harsh environmental and operating conditions, e.g. corrosive environment or overloading, only exacerbate problems.

In addition to slow deterioration processes, bridge structures are subjected to sudden hazardous events, such as earthquakes, floods or vehicle impacts. On top of the concerns about bridge load bearing capacity and structural strength, of importance are also functional aspects, such as adequate clearance under the bridge and/or deck geometry (width and number of lanes), which may render structures functionally deficient (US Government Accountability Office 2008). At the same time, bridges are expected to support ever increasing demands, with forecasts predicting steady increase in traffic volumes and loads.

It is of critical importance that transportation networks provide the required levels of service to the communities and economy now as well as in the future. Despite all these realities and pressures, NZ does not have a clear and coherent strategy for improving BAM or developing standardized management and decision making methodologies and tools to that end. It is obvious that at the foundation of any asset management process lies a practical, robust and pragmatic regime for collection of data on asset inventory, performance and condition. Without high quality and reliable data even the most sophisticated BAM systems will not perform their function. This paper reports on findings from a research project aiming at developing a comprehensive strategy for data collection and monitoring of bridges in NZ.

The outline of the paper is as follows. Firstly, a brief overview of general asset management best practices is provided with a discussion on how those high level recommendations apply to the specific context of BAM. These considerations are used to demonstrate the role and place of bridge data collection in the broader context of decision making. Following this, the results of a survey conducted by the authors and aiming at understanding the NZ bridge data collection and BAM practice are reported and discussed. Based on the review of international best practice and identified gaps in the local practices, a criticality and risk based strategy for data collection and monitoring is outlined. Finally, the role of non-destructive testing/structural health monitoring (NDT/SHM) in the proposed data collection strategy is discussed.

2 OVERALL CONTEXT OF BRIDGE ASSET MANAGEMENT

A well recognized standard that covers general asset management is PAS 55-1:2008: Specification for the Optimized Management of Physical Assets (British Standards Institution 2008). The document defines asset management as "*systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan*". The document identifies a number of practices that good asset management should follow: i) consideration for the life cycle management of assets, ii) taking into account risks and criticalities of asset and asset systems, iii) identifying function, performance and condition of existing assets and asset systems, and iv) stating the desired future function(s), performance and condition of existing and new assets and asset systems. The recognized good practice document used in NZ is International Infrastructure Management Manual (IIMM) (NAMS Group 2006). IIMM links levels of service, performance measures, data collection, decision making, and implementation to create a formalized asset management process. IIMM also introduces a stepped approach with core asset management providing a basic understanding of the asset and its needs, and advanced asset management developing a deeper understanding of the asset through the appreciation of the relationship between levels of service, performance, and funding needs. One of the few standards that address the specific asset management needs of highway structures is Management of Highway Structures – A Code of Practice (MHSCoP) (Road Liaison Group 2005). This document sets out a bridge specific asset management framework and includes best practice recommendations on inspections, condition and inventory data collection, data management, and financial management practices. The document strongly promotes the use of condition rating for structures. MHSCoP introduces a comprehensive bridge management framework, however, the data collection systems and the decision making process have not been adequately integrated. In line with IIMM, the document recognizes the benefits of a stepped approach to asset management.

A model for asset management cycle that takes into account best practice is shown in Figure 1. At the top of the hierarchy, asset management is driven by high level policies and legislation that formulate goals, objectives and responsibilities overarching management of various groups of assets. In the NZ context, the aforementioned Local Government Act 2002 and the Land Transport Management Act 2003 are examples of such legislation. The general expectations articulated in these documents serve as a departing point for defining a vision and strategic targets for each broad asset group. In NZ, for transportation networks these are formulated in the NZ Transport Strategy (NZ Ministry of Transport 2008) and NZ Transport Agency (NZTA) Statement of Intent (NZ Transport Agency 2009), while the Government Policy Statement on Land Transport Funding (NZ Ministry of Transport 2009) details budgetary allocations, thus setting up the financial constrains. The NZTA defined vision is that "*People and freight in New Zealand have access to an affordable, integrated, safe, responsive and sustainable transport system.*" Affordability requires effective management of transportation infrastructure assets, safety demands highly reliable structures, responsiveness assumes networks are able to recover quickly from disasters such as floods and earthquakes, and sustainability requires transportation systems to contribute to economic, social, environmental and cultural goals of NZ. The most efficient use of existing infrastructure, rather than investment in new one, is also emphasized. These requirements drive the local BAM practices.

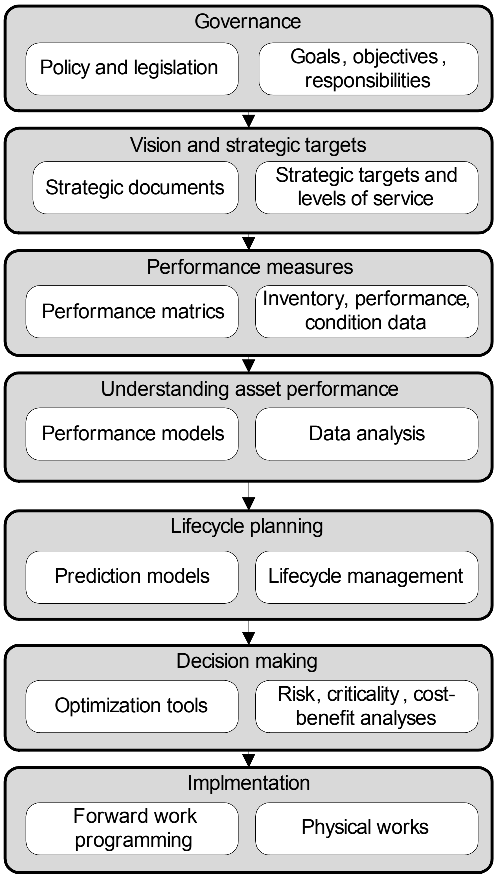

Figure 1. Integrated advanced asset management.

There is an obvious need to make the high level targets more specific by assigning performance measures so that the degree of their attainment can be objectively judged. There is a wide range of performance measures including customer focus and technical measures, the former having stronger relation to operations and efficiency of the entire network rather than being bridge specific. For this reason, technical, bridge specific measures are relevant for this research. It is recognized (Ghasemi et al. 2009) that there is currently no commonly recognized performance metrics for bridges. Technical performance measures for bridges are derived from specifications included in documents such as Transit NZ Bridge Manual (Transit NZ 2003) and design codes for different materials (Standards NZ 1993, 1995, 1997). Inherent in performance measure application to BAM is the collection of relevant bridge data that can be used in BAM process.

The decision making process in asset management cycle comprises (NAMS Group 2006): i) collection, storage and maintenance of data on asset inventory, performance and condition, ii) analysis of stored data and model development to understand current, and predict future, performance and condition, iii) lifecycle planning to achieve optimal allocation of resources, and iv) decisions related to the implementation of required actions. The asset management process concludes with forward work planning and physical realization of plans. As can be seen, data collection plays a critical role linking the expectations of transport networks users with planning and practical actions to deliver these expectations in an optimal and cost effective way.

3 SURVEY OF NEW ZEALAND BRIDGE ASSET MANAGEMENT PRACTICE

Little systematic information about the state of practice in BAM in NZ is available. Anecdotal evidence suggests that the state of practice and development levels will vary considerably across the many road controlling authorities. Before a unified and enhanced BAM strategy could be proposed it was therefore necessary to obtain an insight into the current NZ BAM practice. This was achieved by conducting a survey of NZTA and local authority bridge managers. The objective of the survey was twofold: i) assess how local NZ practice compares to internationally recognized best practice, and ii) assess how the practices adopted by individual authorities are aligned with the specific needs of their networks. This section briefly describes the survey methodology and questionnaire, analysis of returns and major conclusions; a detailed account will be included in the forthcoming project report (Bush et al. 2011).

The survey targeted a representative sample of NZ's roading authorities. These were selected based on the size of their network and the overall level of development of asset management processes. In total, responses were received from 67% of NZTA regions and 10.5% of local authorities; by bridge population these corresponded to 11% of the NZ's stock.

The survey questionnaire was divided into seven broad areas as follows:

1. Data collection on overall network inventory (length of road network, urban/rural mix, number of bridges and other structures, number of bridges by types and material, number of significant/strategic bridges),
2. Data collection on general bridge inventory (bridge location; route importance; traffic volumes; risk/criticality; bridge type; overall geometry; posting; number, material and age of individual components; drawings; photos; assessment/special inspection reports),
3. Data collection on bridge condition (types/frequency/triggers of inspections; standards/best practice documents followed; types of data collected: defects, defect severity, condition; content of reports produced: defect/condition lists, cost estimations, recommended actions; ways of ensuring consistency between individual inspections/inspectors; validation standards),
4. Use of NDT/SHM (problems that required undertaking specialist testing, triggers for these and what was done, use of NDT/SHM data in BAM process),
5. Performance and risks (risk identification, levels of service understanding, use of defect/condition data, use of deterioration/performance models, use of cost data, triggers for action),
6. Optimization/prioritization (budget management; risk management: prioritization of forward works plan, tools for optimizing risks/levels of service/costs; breakdown of funding allocation between roads/structures/bridges and maintenance/upgrading/replacement, asset value of bridges, optimal maintenance budget required, data needed to implement improvements), and
7. Systems tools and quality assurance (data storage and management systems used, data validation/verification standards and processes, use of data systems in BAM decision process).

In order to benchmark the local NZ practice internationally (the first survey objective), the answers received to individual questions were ranked between 1 and 3, where the ranking of 3 corresponded to full or nearly full compliance with the identified best practice, while the ranking of 1 indicated only minimum compliance. The second survey objective, understanding whether the adopted practices are suitable for the needs of individual networks, is important as more complex networks were considered in need of more advanced, higher quality and stringent approaches to data collection, while it was agreed that for less complex networks these requirements can be reasonably relaxed. Network complexity is, however, difficult to judge, let alone quantify. In this study, the following factors were taken to determine a score between 3 (high) and 1 (low) for network complexity: i) total length of network, ii) urban/rural mix, iii) number of specific issues facing BAM, iv) number of bridges, and v) number of strategic bridges. To compare how condition data collection levels of development are aligned with the perceived network complexity, the assumed scores for complexity were subtracted from the overall scores for best practice compliance levels. The difference indicated the degree of misalignment (not necessary showing deficiencies, as in some cases local practices appeared to be at a level higher compared to network needs).

An analysis of the returns for all seven survey areas suggests that current NZ practice on average lags slightly behind what is considered to be the optimal levels of development. The following gaps in NZ BAM processes require attention:

- Adaption of full life cycles management for BAM and closer integration between BAM steps,
- Required levels of service need to be better articulated and understood,
- Inventory data needs clear and commonly followed definitions of asset classes,
- Condition, performance and other data such as drawings need to be collected,
- Quality assurance processes for data collection, such as via visual inspections, need to be introduced,
- Formalized condition rating standards need to be introduced,
- Awareness of NDT/SHM needs to be raised,
- Data collection needs to be tied to the needs of particular networks and their risk profiles, and
- Decision making process should include clear links with the data collected and prioritization of tasks based on risk and criticality.

4 DATA COLLECTION FRAMEWORK BASED ON CRITICALITY AND RISK

BAM faces increasing pressures due to the high expectations of the performance and reliability of transportation networks on the one hand, and limited funding for maintenance and upgrade of bridges on the other. Infrastructure ageing, deterioration and occurrence of defects are a fact of life and it is impossible to maintain all bridges and at all times to a nearly perfect condition. Realistic and pragmatic asset management is rather about identifying, assessing and managing risks through cost effective approaches and interventions. It is increasingly accepted that criticality, i.e. consequences of the bridge underperforming (including a spectrum of issues from say mild vehicle load restrictions up to a bridge collapse), and risk (probability of underperforming multiplied by consequences) are key factors to guide prioritization of decisions in BAM. The criticality factor will mostly govern approaches to just a few bridges that need to be kept operational and protected at even a very high cost, e.g. because they are a part of lifelines supposed to stand up to even a large natural disaster. In such cases, managing the consequences of underperformance is the focus. Risk based approaches, on the other hand, will suit the majority of bridges as they are not critical and their probabilities and consequences of underperformance vary. One of the challenges to be acknowledged is that BAM has tended to consider bridges in isolation and only recently their interactions with, and risks and criticalities within, transportation networks have started to be taken into account more widely in the BAM process.

As discussed earlier, advanced BAM depends on the availability of quality inventory, performance and condition data. However, data collection faces the same challenges of limited resource that can be committed to the task. It is argued here that efficient data collection needs to be aligned with strategic, i.e. criticality and risk based, drivers of the whole asset management cycle. To that end, a stepped approach to data collection, following general asset management developments promoted by IIMM, is proposed as outlined in Table 1. This framework proposes core, intermediate and advanced development levels adopted after Paterson & Scullion (1990). As the criticality and/or risk of a bridge increase, its data collection regime will move from core towards advanced. Guidelines about the details of data that each level of data collection entails are provided in Bush et al. (2011). As can be seen in Table 1, with increased criticality and/or risk the requirements of reporting level become more detailed, e.g. at the core level aggregated data for major bridge components will suffice, while at the advanced level component and element level data will need to be obtained. Not only the more detailed data will be required for critical and at-risk structures but the data collected need to be less subjective. This could be achieved with a wider use of NDT/SHM.

Table 1. Criticality and risk based data collection framework.

Data collection regime	Bridge criticality and/or risk	Reporting level	Data collection tools
Core	Low	Major component	Visual inspections, limited NDT/SHM
Intermediate	Intermediate	Component	Visual inspections, some NDT/SHM
Advanced	High	Component and/or element	Visual inspections, advanced NDT/SHM

5 NDT/SHM IN BRIDGE ASSET MANAGEMENT

The above data collection framework envisages the use of NDT/SHM at all levels of data collection with increasing reliance on these techniques at the higher levels. NDT/SHM techniques have recently been developing at a rapid pace across a number of relevant domains including progress in sensors and system integration on the one hand, and data processing and interpretation on the other. However, wider and systematic integration and adoption of NDT/SHM in BAM has not yet occurred. In several papers (e.g. Brownjohn et al. 2004, Chen 2010), the authors argue the main reason for the delay is due to a misalignment between the traditional SHM approaches and the real needs of bridge asset managers and engineers. That has led to a perception of limited usefulness and even mistrust in NDT/SHM amongst civil engineers. The traditional approaches originated in machine and/or aerospace engineering and mostly target measurement of vibration signals for damage detection. On the other hand, civil infrastructure possesses a number of distinctive characteristic that require different methods:

- Large inventories comprising many unique, non-typical structures,
- Structures existing in complex, spatially vast networks,
- Uncertain loads, environmental and operating conditions,
- Uncertain material characteristics and boundary conditions,
- Multiple hazard environment and deterioration processes, and
- Long service life and often poorly documented history and current condition.

There are specific issues which are critical and/or widespread in BAM (Ansari 2009, Chen 2010) where NDT/SHM should be more widely adopted and will be an efficient way of addressing data collection and management:

- Scour rate,
- Reinforcement steel corrosion,
- Delaminations in concrete decks,
- Crack width in concrete structures,
- Fatigue in steel structures, and
- Large and/or yielding strains in steel.

NDT/SHM can be understood as a tool for collecting more reliable and objective performance data and from that point of view can be understood as a tool for reducing uncertainties in data and managing risk. In order to "quantify" the impact of more reliable data collection tools, Moon et al. (2009) proposed a formula for calculating risk that includes an uncertainty premium coefficient. This multiplicator ranges between the minimum value for best practice data collection inclusive of NDT/SHM, and the maximum value for data collection based on minimum acceptable standards of visual inspections.

NDT/SHM can make a difference in at least two broadly defined situations. The fist one is when a structure presents a large risk of, and from, developing defects that cannot easily or early be discovered by visual inspections. An example can be corrosion of prestressing strands. The second situation is risk management of structures with known problems, e.g. bridges with known fatigue crack issues (Beamish et al. 2006). In both cases, NDT/SHM can provide early warning and/or ongoing data for efficient risk management. However, the decision to use NDT/SHM needs to be preceded by wider considerations and a cost/benefit analysis. This is because visual inspections, if not too frequent and capable of assessing the problem adequately, can still be the most cost effective risk management approach.

The results of our survey indicate that the majority of NZ bridge asset managers have carried additional, albeit usually limited, testing and monitoring. This, however, was typically as a reaction to identified problems and was poorly integrated with other data collection practices and the BAM process. Proactive use of NDT/SHM has not been widely reported. A few exceptions include bridge inspections triggered by larger earthquakes recorded by the national seismic monitoring array, scour monitoring of bridge foundations and periodic chloride testing of bridges near the costal line. Given that many authorities nominated strategic bridges in hard to reach locations the awareness and use of NDT/SHM in NZ BAM needs to be further advocated and developed.

6 CONCLUSIONS

The paper presents the results of a survey conducted in order to understand the BAM practices in NZ. Several pivotal BAM areas were investigated including inventory, performance and condition data collection, the use of data in BAM process, approaches to decision making, planning and prioritization of maintenance and interventions, and the use of NDT/SHM. Several gaps in NZ practice have been identified, the most important amongst them being the lack of condition data collection and standards for condition rating, poor understanding of bridge levels of service, underutilization of maintenance prioritization tools, and poor links between collected data, network risk and criticality profiles and data use in overall BAM decision making process. A criticality and risk based framework for bridge data collection has been proposed that consists of core, intermediate and advanced collection regimes. With increased criticality and/or risk of a structure the required data will become more detailed, complete, objective, quantifiable and certain. To gather such data, BAM will increasingly be relying on NDT/SHM but these technologies need be tailored to specific needs of bridges, well integrated into the BAM process and used in a cost effective way.

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