Beyond Data Collection – Bridge Inspections in the Digital Age

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Abstract: Collecting, processing, and administering data from bridge inspections underpins bridge lifecycle management. Although, the inspection process and identification of material defects is well defined and documented, little guidance is given on systems for data collection and management.

Erasito Beca Consultants Ltd was commissioned by the Fiji Roads Authority in late 2015 to undertake a rapid inspection of more than 1,200 bridges in Fiji's road network. A flexible and easy to use system for rapid collection of well-structured and high quality data was needed. Moreover, we required a system that would aid management and review of the collected data. No legacy system was in place, so this made possible the consideration of options to use a state of the art system which is now available.

We adopted a modern hosted system using smartphones for input to a cloud based data management platform. It has capabilities greatly exceeding those typically used for bridge inspections in New Zealand and Australia. Data collection systems need to be flexible, intuitive, integratable and tailored to the inspection environment, and client requirements. Close collaboration between all parties is desirable to maximize benefits and avoid issues. Technologies are constantly developing, therefore organisations and processes need to be adaptable. The process of transitioning to new systems must be well managed to get buy in from all involved parties. We also found that engineers who collect and work with inspection data are more engaged and satisfied when equipped with modern and state of art systems.

This paper describes how a modern data collection system was implemented for bridge inspections in Fiji. It describes the implementation process and its challenges, and discusses possible future developments.

Keywords: *Bridge, Inspection, Data Collection, Disaster, Change Management*

1. Introduction

Data collection and management is an often undervalued part of bridge inspections and life cycle management. The inspection process itself, such as identification of material defects, prioritisation of repairs, H&S requirements, etc., are well defined and documented. Major highway agencies such as in New Zealand, United Kingdom and Australia publish detailed guides on this topic, e.g. New Zealand Transport Agency (1), UK Highways Agency (2) and Austroads (3).

However, there is currently no or little guidance on technologies and systems to be used for collection and management of inspection data. Systems and tools vary widely between individual consultants, agencies and asset owners. Moreover, these systems are undergoing significant changes facilitated by recent advances in technology.

Despite the technological advancements some engineers continue to use pen and paper, while others are slowly adopting modern systems. Inevitably, many practitioners have misgivings about using and transitioning to more sophisticated systems. These include concerns about:

- Compatibility of existing data and processes with new systems.
- Perceived inefficiencies and rework involved in handling and transferring data.
- The security of data from accidental loss or unauthorised access.

Asset managers and bridge engineers have a wealth of knowledge and experience in bridge engineering and life cycle management. They may however lack an understanding of modern technologies available for collection and management of inspection data. Their operations are often highly shaped by, and adapted to existing systems. Therefore, the perceived need for change to adopt modern tools is typically minimal.

Organisations are often understandably hesitant to undertake transformational changes (Kotter, 5). A lack of understanding, and fear of the unknown may mean that adoption of new tools is perceived as risky. Many questions arise including: What the cost and personnel effort will be? Can we rely on externally developed systems? How will the new systems fit around the existing ones? Where to start?

1.1. Inspection Programme in Fiji

Fiji is an island nation with a geographical area equivalent to 20 times the landmass of urban Auckland. Its geography as well as climate and infrastructure are truly diverse and unique. There is a great variety of bridge structures, from the recently built major crossings such as 425m long Rewa River Bridge designed by Beca Ltd in 2005 to steel I-Beam and timber deck bridges from the time of Fiji being a British colony.

As is the case in many developing nations, maintenance of bridge assets over recent decades was hampered by the lack of capital, skilled on the ground resources and political instability (IPENZ)(4). Moreover, a large percentage of the bridge stock is located near the coast. This harsh environment, combined with the widespread maintenance deficit means that many bridges are in poor condition.

Until recently information held by the Fiji Roads Authority (FRA), previously the Department of National Roads, about the country's bridges was high level, and focused on locating bridges and assessing primary qualitative risk levels. This data captured the majority of bridges but was understandably incomplete and did not allow for prioritisation and planning of maintenance.

To start to address the issue, the FRA commissioned Erasito Beca Consultants Ltd (a partnership between Erasito Consultants Ltd and Beca Ltd), in late 2015, to undertake a structured inspection of all bridges in Fiji. This comprises over 1,200 bridges, crossings, and major culverts. Examples are shown in Figure 1 below. The objective of the project was to identify defects in order to enable prioritisation, planning and funding of repairs. All of 1,200 structures were inspected at least once in 2016, followed by more detailed and focused inspections during 2017. Erasito Beca engaged Fulcrum Mobile Solutions LLC to provide a data collection and management system. A series of images displaying the variety of structures in Fiji is shown in Figure 1.

Figure 1. Examples of Bridge Structures in Fiji.

A data collection tool was required to enable rapid inspections, reviews and management of data. Key requirements included:

- The ability to have multiple and geographically spread inspection teams active at the same time to rapidly inspect the asset base.
- A simple interface to enable effective collection and review of inspection data.
- A single tool to manage all data and processes including collection and storage of photos, reviews, and reporting.
- Being able to function in remote environments such as the interior, and outer islands which have limited connectivity.
- Flexibility to adapt and extend the system as new requirements emerged and the ability to communicate with other data management software.

This paper describes how a modern data collection system was implemented for bridge inspections in Fiji. It compares options for systems, describes implementation process and its challenges, and discusses possible future developments.

2. Comparison of Data Collection and Management Systems

Advances in technology have led to the evolution of data collection systems. This has resulted in wildly ranging degrees of functionality and complexity between systems. Key stages of this evolution are described below.

2.1. Manual - Pen and Paper

Manual, pen and paper systems can range from filling in pre-prepared forms to simply jotting down notes while on site. Pen and paper is still widely used due to its simplicity and flexibility. It has advantages for small-scale and one-off inspections, or inspections of specific elements, where the data to be collected may not be known beforehand and has little repetition. Little or no specific training or system development is required.

The same simplicity and flexibility that make pen and paper so versatile can also cause issues when it is applied to larger inspection projects. It is more difficult to maintain consistency between inspections and inspectors when data collection is not well structured. Transcription errors may also be caused by smudging, paper deterioration, and difficult to read handwriting. Back office transcription of data into a computerised form (typically either Microsoft Word or Excel) is often required. Data stored on paper is difficult to retrieve, and only available in one place.

2.2. Early Computerised Systems

Computerised systems were developed to address some of the shortcomings of pen and paper based methodologies. These can vary greatly in their sophistication and utility.

At one end of the spectrum are computerised systems that are merely an extension of paper based workflows - notes taken on site are entered into the system back in the office. This gives rise to the same potential errors as described in the section above. Some systems widely adopted by bridge inspectors include Microsoft Excel spreadsheets, Microsoft Access databases and custom in-house applications.

Storing data in a structured system makes it easier to query and gain insights into the underlying asset base. This can help to answer questions such as “how many bridges have defective paint systems?”, “what is the cost to repair all high priority elements?”, “which elements have the most costly defects?”, “how effectively are minor issues being addressed by the maintenance programme?” With a paper based system, individual reports have to be searched through to find information about a bridge or group of bridges.

Many of these systems have been in use for a long time and have been developed by practitioners themselves. While they fitted the needs at the time they were developed, they may not have kept up with technological developments. Additionally, computer data systems that rely on outdated, or proprietary software and data formats can be difficult to extend, maintain or update. An example of this inflexibility is seen in systems where photos and data are stored separately. For example, inspection data contained in a Microsoft Access database with photos stored separately in a folder structure on a networked drive. This increases the likelihood of data going missing, or getting out of sync, and imposes a greater maintenance burden.

Most computerised data management solutions used by bridge inspectors run on individual computers or corporate networks. This means that data is not easily accessed outside the office.

2.3. Modern Hosted Systems

Computerised systems have come a long way from the simple database systems originally used. Key features of modern systems include: ease of use, availability and portability of data, and the flexibility to accommodate changes.

The requirements of a data collection system are often not fully known before an inspection programme begins. Modern systems should have the flexibility to adapt to newly discovered, or changing requirements.

Inspectors should not require extensive training in the use of data collection systems. This allows for more training time to be devoted to understanding inspections, rather than data entry. The use of technology already familiar to inspectors including mobile apps and online maps helps achieve this. A bridge inspector using a modern hosted system in field is shown in Figure 2. Pen-and-paper and an external camera were fully and successfully replaced by smartphones and tablets connected with cloud interfaces accessible instantaneously anywhere from the world.

Figure 2. A bridge inspector using a modern hosted system in field.

Modern systems are typically hosted on remote servers, rather than in the practitioner's office. This means that secure access to data is available anywhere with an internet connection. Hosted systems keep all data in one place, meaning that issues with photos getting lost or out of sync are reduced or avoided.

The utility of the collected data is greatly enhanced if it is simple, quick and easy to work with in external software and systems. Remote access to data in open, industry standard data formats means that data collected can be mapped and analysed. This is an evolution in the ability to query data as described above, meaning that more complex questions can be asked and answered. These could include, for example:

- Exporting data to a Geographical Information System (GIS) programme to ask “how does the damage to bridges change with distance from the coast?”
- Creating automatically updating charts and graphics to outline the breakdown of repair costs by element.
- Linking the data to online services such as Google Sheets to create an automatically updating dashboard.

The increased ability to leverage data collected and gain insights into the underlying assets can help practitioners more effectively communicate the state of assets and underlying risks to asset owners.

2.3.1. Comparison of Modern Hosted Systems

There are many platforms available to support data collection for asset inspections. These products include Fulcrum (system we use), ESRI Collector, ESRI Survey 123, Bentley AssetWise, and Agile Assets Bridge Inspector.

When selecting a system, practitioners should arm themselves with the skills necessary to make informed decisions around what features they require. Consideration should be given to:

- Ease of use.
- Available features.
- Interoperability with other systems.

One system does not fit all, therefore practitioners and asset owners should evaluate suitable available products based on their own needs.

2.3.2. Ease of Use

When considering mobile systems, it is important to consider both the field collector and administrator. Data entry during the inspection should be simple and straightforward to increase efficiency and reduce the likelihood of errors. Reviewers should be able to easily check the results of inspections and make changes, or give comments to the inspector if required. Data administrators should have the ability to easily import, export, and manipulate the data to facilitate merges, backups, and batch updates.

2.3.3. Features

Practitioners must evaluate the features they require when selecting an inspection and data management system. Some features that may be required include: offline capability, multiple simultaneous inspectors, web based reviews, exporting reports with attached photographs and other media, and the ability to modify the inspection system without compromising existing data.

2.3.4. Licensing and Support

Licencing options, restrictions and costs are an important factor when evaluating an inspection system. Some options are licenced on a flexible, per user basis, while others may be available as part of enterprise licencing agreements. The cost-effectiveness of each option will depend on project scale, flexibility required, and existing enterprise software usage.

Availability of support should be considered when selecting an option. The level of customer support available varies and may be included in the licencing fee or incur extra costs.

2.3.5. Interoperability

Bridge inspection data will typically need to be used in many software packages for review, analysis, and presentation. Practitioners should consider options to transfer and share from the inspection system. This should be based on other systems currently in use and potential new systems to be developed.

3. Managing Change - Transition to Modern Data Collection Systems

As Kotter (5) points out in his classic article on change, adoption of new technologies is not an event but rather a lengthy process. There are numerous obstacles and risks to be overcome and potentially many mistakes to be made.

It is therefore worthwhile to discuss the transformation process as related to adoption of new technologies used for data collection and management together with our own experience and the pitfalls we encountered.

The process of change can be summarised into a number of distinct steps as described below (Kotter describes 8 steps, the authors reduced it to 5 steps for simplicity).

There are many more aspects of adoption of new technologies as related to change that could be discussed and presented here. For bridge engineers and asset managers it may be a new discipline to tackle. Similar to learning from textbooks and colleagues how to design a bridge or its component, we would suggest that it will pay off to learn about the process of change to increase one’s awareness prior or while managing it.

3.1. Step 1 – Establish Urgency

Establishing a sense of urgency is a starting point for change. In our case, where over 1,200 bridges needed to be inspected in less than one year it was relatively easy to establish. While the existing data collection systems such as pen and paper and simple incomplete data collection systems were used across the organization and could have been adopted, we realized that the recent technological advancements in data collection need to be implemented for efficiency.

Our on the ground team in Fiji was small and geographically scattered, we needed the most efficient system that would allow collaboration to accomplish the goals of the project while also ensuring profitability. We also wanted to champion new systems beyond these typically adopted in New Zealand and Australia, despite operating from a basic office with limited infrastructure in a developing country.

Lack of urgency is recognised by Knight (6) as the primary reason for delayed adoption of technological advancements. We continue to see this within our organizations and also externally. Transitioning to modern systems of data collection and management requires skill sets beyond the typical expertise of bridge engineers and asset managers. Development and maintenance of web/mobile applications, databases, and visualisation systems requires collaboration between practitioners and software developers which is often not easy to establish. Change may stagnate without forces such as competition, client pressure or internal champions. For these reasons, many projects continue to operate with less than ideal efficiency, despite enormous scope for improvements.

3.2. Step 2 – Form a Guiding Coalition

Forming a guiding coalition is the next step. No one can make change on their own. Large organisations typically have many interconnected systems which are standardised across the business to achieve economies of scale. This can create a great deal of resistance to change which requires a strong group of individuals to overcome it.

At the start of the Fiji bridge inspection project our organization had in place partially in-house developed data collection tools that undergone a major upgrade in around 2013-2014. Technological advances between development of this system, and the beginning of our project in 2015 included: increased performance of phones, decreased cost of mobile data, and supplier development of cloud based systems. We proposed implementing a new system based on these developments rather than updating the existing system. Unsurprisingly, this was initially met with negative feedback and resistance. Many good and reasonable questions were raised:

- Will the effort already put into developing the in-house system be in vain?
- How much are the ongoing costs and will it be more cost effective than the in-house system?
- How will data transfers be handled and will our data stored with a third party be safe?
- Who will manage the new systems on ongoing basis?

To start with we had few answers. We had only just embarked on the process of change and were still exploring options. However, having a strong project team and realistic and clear vision as discussed below, enabled us to establish support from senior management and in turn get approval for the project.

3.3. Step 3 – Creating a Vision

Vision is typically unclear at the beginning of a change process. Having a sense of urgency on its own is not enough to produce a result. A clear and easy to communicate vision is required to clarify the change required. It helps to clarify objectives and keep team members working towards the same goals. The guiding coalition must work cooperatively to develop a picture of the future that is easy to communicate and visualise.

Our vision was to have a simple modern system taking advantage of current technologies. Beyond the hard numbers of personnel effort, efficiency and profitability, our vision also included championing new systems within the wider company. We translated our vision into a simple illustrative picture that was easy to communicate to others.

Simplicity is a key part of vision. From our observations, one common pitfall is attempting to answer all questions and develop the entire system at the outset, before forming a vision. This would be a mistake as we would have buried ourselves in details which we would be unable to communicate to others effectively. A clear vision enables building a business case for senior management while seeking approval for the project.

3.4. Step 4 – Creating Short-Term Wins

Planning for and creating short-term wins translates the vision into quantifiable changes. Based on our experience, we would recommend to proceed in small steps which can be completed successfully. To start with, we developed and tested a cloud and smartphone based application for collection of data only. When this was working well, additional incremental improvements were made. This staged development process was somewhat risky and inevitably resulted in rework. However, it enabled us to progress and celebrate accomplished goals. Attempting to develop all features of the systems at once, would likely have resulted in an overly complex and poorly functioning system. It is likely that none of its parts would have produced a good result.

Some key improvements are described below.

3.4.1. Reports

The default reports created by our system were initially generic and did not match the format required by the client. Once the data collection system was working, we added the ability to generate professionally formatted inspection reports in the New Zealand Transport Agency's format required by the FRA. Once this process was automated it required no additional time or effort to produce printable inspection reports for the client. PDF copies of these reports are available directly in the app and can be accessed from any authorised device. First two pages of a sample are shown in Figure 3. This functionality means that the latest data is always available, and can be shared, for example in meetings with clients.

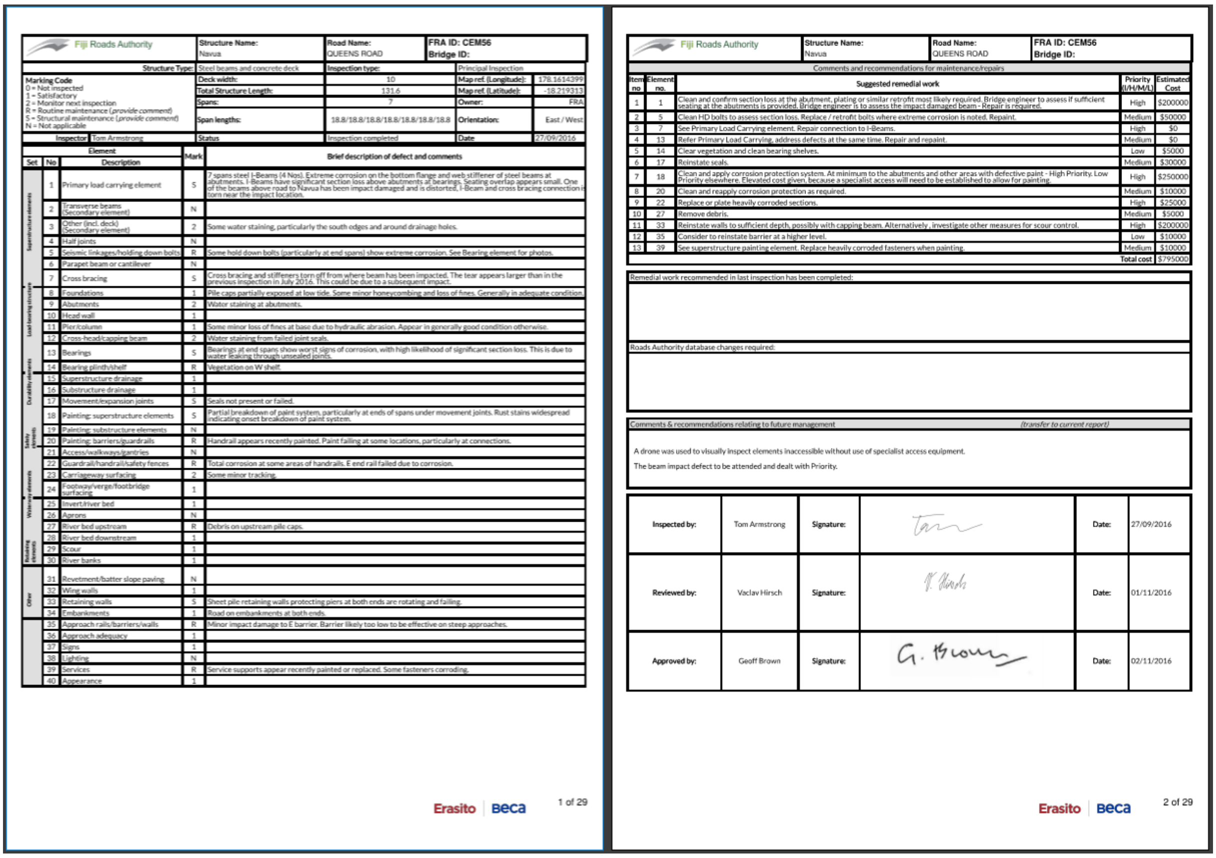

Figure 3. Custom report exported directly from data collection system, photographs with description are provided on following pages.

3.4.2. Dashboard

We initially developed Excel spreadsheets to assist with planning and reviews of inspections. These were useful tools and worked well but had drawbacks including: having to manually update data, difficulty visualising location data, and complex formulas.

In order to overcome some of the difficulties the authors developed a 'proof of concept' web interface. This had both map and table views and allowed filtering by inspection status, location, date, and other fields. Although simple, and unpolished, this interface proved immediately useful for:

- Enabling inspectors to plan upcoming trips.
- Reviewers and approvers to manage their workloads.
- Errors in the data to be spotted and corrected.

The proof of concept dashboard, was later replicated and further developed using the data visualization software Tableau. Some effort was duplicated, however, development of the initial system helped to clarify requirements and resolve technical issues. This reduced development time and effort for the final dashboard. The initial dashboard was used internally. Later iterations using Tableau were used externally via a cloud based interface and facilitated numerous visual presentations to the client's senior management which was met with positive feedback. Refer Figure 3 below for a screenshot of one of the dashboards that gives management overview of the asset base and some key indicators.

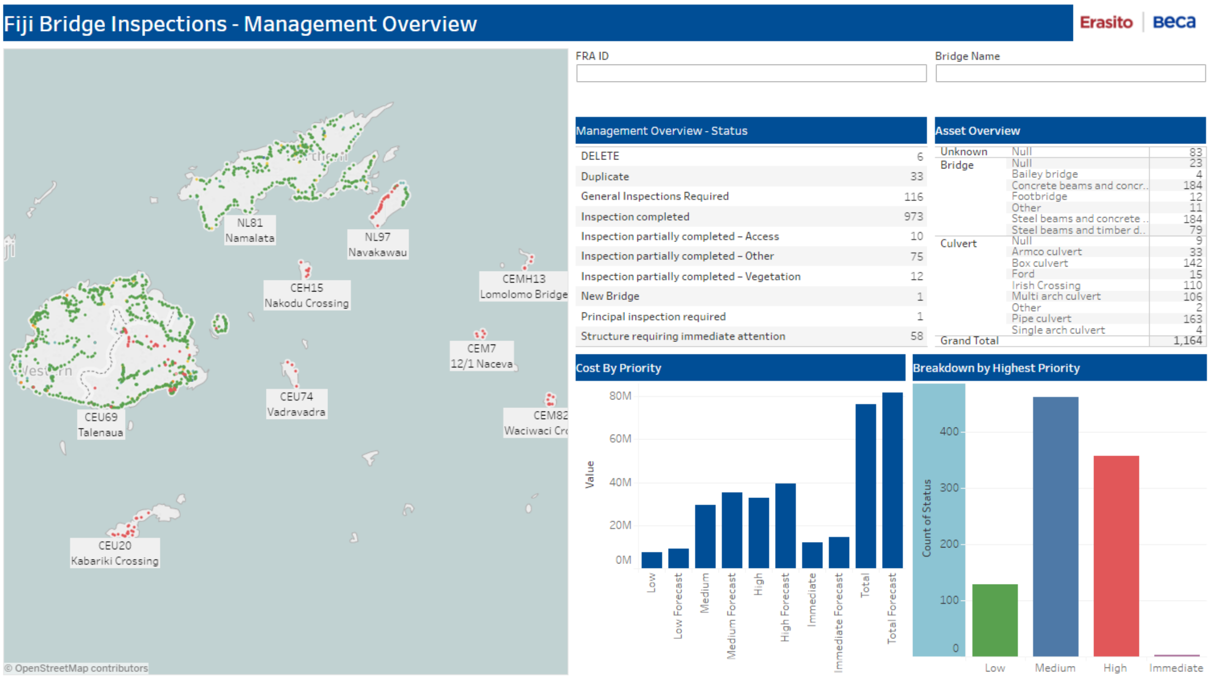

Figure 3. Management overview dashboard

3.5. Step 5 – Consolidating improvements and producing still more change

A common error seen in organisations attempting large changes is stopping when changes are only partially complete (Kotter, 5, Kegan and Lahey, 7). Once our new data collection and management system was put in full scale use, it appeared to be a success. It was functioning well and offered numerous advantages over the older systems. However, minor problems and weaknesses started to be identified.

For example, management of inspection data become more complex with subsequent inspections of the same asset; hard to discover errors were made in the database by inspectors. Based on our experience, we would recommend that issues discovered are tackled in a timely manner before they accumulate. If they, are forgotten about they will appear on outputs such as final inspection reports or inspection data summaries.

Moreover, full scale use enabled us to seek feedback from the key users. We held regular feedback sessions with all bridge inspection staff. This enabled key learnings from reviewers, inspectors, and assistants to be shared. One of the most valuable parts of these sessions was discussion around changes to the data collection system. The flexibility of the system we adopted allowed us to make changes to improve efficiency. These included:

- Changing the order of inspection items to better match inspection workflow.
- Implementing a mechanism for reviewer feedback directly in the web application.
- Modifications to the application structure to facilitate multiple inspections per bridge.

Learnings from the data collection and management system adopted in Fiji were shared within the company. The idea was to continue the transformation begun in Fiji by communicating successes, setbacks, and solutions to obstacles encountered.

4. Future Developments

Technologies are constantly evolving, and today's modern system can easily become outdated. As described in this paper, modern technologies can bring many advancements that streamline and more importantly enrich work outputs and interaction between parties. Therefore, consideration should be given to promoting emerging technologies, and their applicability to the bridge / asset inspection programmes.

The current trend is to unite asset management systems used by a consultant and an asset owner. We understand, that for example Auckland Transport Agency is developing a data collection tool which will be given to bridge inspectors to streamline process of data collection.

Recent advances in augmented reality technology present exciting opportunities for bridge inspections. Platforms such as OpenAR, Google Glass, and Microsoft's Hololens allow users to overlay additional data onto the surrounding world on location, and in real time. Augmented reality could allow 'hands free' inspections, where inspectors tag specific elements, while recording narrated, location aware images and videos.

For example, our inspection programme uses drones for inspections of multi-span bridges limiting the need for expensive, complex and potentially unsafe access solution. Currently, drones are capable of taking high resolution video and images. Technology currently available is being actively developed to allow these photos to be combined to create full 3D models. Will bridge engineers of the future wear a Hololens and use a speech-to-text to describe defects? Will it be possible to compare the current bridge condition to a previous photorealistic and 3D model from an earlier inspection? How would this affect the current approach to data collection which is still largely based on written descriptions?

5. Disaster Recovery

Earthquakes, cyclones, floods, and other natural disasters can have a devastating effects on bridges and other infrastructure. Decision makers need good data for effective response and recovery. In order to be useful, data must be:

- Gathered at the required level of detail in a timely manner.
- Available to decision makers, even where other infrastructure may be unavailable.
- Easily transferred to other parties, and incorporated into their systems.
- High quality and consistent to enable the data to be trusted - bad information can be worse than no information.

The modern hosted technological solution we have adopted for the bridge inspections fulfils many of these requirements. First, data can be rapidly gathered and reviewed by multiple teams simultaneously. Data is entered and reviewed in a structured and consistent way. This increases the quality, and ability to trust the data. Second, decision makers can be granted access directly to the platform, or given limited access to only reviewed reports. Using a data visualisation tool with a GIS interface such as Tableau, significantly aids collaborative review of data and subsequently decision making. Finally, data gathered and stored in a structured and consistent way may be reviewed and analysed retrospectively. Moreover, modern hosted solutions offer instant access to incredibly rich data, all stored and access from any location.

Network disruption to hosted systems may limit their usefulness in disaster recovery. This is a very significant risk, however recent experience has shown cellular data networks to be highly resilient. Networks remained operational throughout recent disasters including major disasters such as the 2011 Christchurch Earthquake and 2016 Category 5 Cyclone Winston. Additional resiliency can be achieved with alternate network connections such as satellite phones.

6. Conclusions

Data collection and management has advanced considerably beyond the pen and paper systems used originally. Modern hosted systems with cloud based interfaces increase collaboration and productivity and reduce the likelihood of errors and lost data.

Several options exist for data collection systems. Practitioners should arm themselves with the skills necessary to make informed decisions around what features are required when considering adopting such a system. Collaboration between supplier of data collection systems, bridge engineers as well as IT support teams is essential to select and develop a suitable system.

Transitioning from an old system to a more modern one requires overcoming obstacles and being aware of common pitfalls including resistance, poor and poorly communicated vision, inability to translate vision into small wins, keeping momentum, etc. Success is more likely if well-established change management principles are followed.

The recent technological improvements which we exploited such as widespread use of cellular data transfers, quality of smartphone cameras and cloud based collaborative approach enabled a small team of practitioners to collect rich and extensive data in a short time frame. Moreover, thanks to the technologies adopted, i.e. cloud based interfaces, geographically dispersed team members were instantaneously able to work with and share the collected data.

The previous major upgrade of bridge inspection technologies adopted by Beca Ltd of New Zealand occurred in 2013-14. At that time, the upgrade undertaken was considered a state of art approach. Despite this being only 2 years ago, we were able to significantly advance the data collection system well beyond what was possible with incremental and minor improvements. This clearly demonstrates the speed of technological improvements with which practitioners and asset owners need to cope with. Despite this apparent burden, we found that engineers who collect, process and work with inspection data are more engaged and satisfied when equipped with modern and state of art systems and have opportunity to contribute to its development.

Future developments including drones and augmented reality offer exciting prospects for the future of bridge inspections. The evolution of these technologies should be explored and closely followed by bridge engineers and bridge asset managers. How will recent advances in augmented reality such as Microsoft's Hololens affect the current approach to data collection that is still largely based on a written descriptive approach developed years ago?

References

Austroads, "Guide to Bridge Technology, Part 7: Maintenance and Management of Existing Bridges", 2009, Sydney, Australia.

NZTA, New Zealand Transport Agency, "Bridge Inspections and Maintenance Manual", 2001, New Zealand.

Highways Agency, The Stationery Office, "Inspection Manual for Highway Structures, Volume 2: Inspector's Handbook", 2007, London, United Kingdom.

IPENZ, Institution of Professional Engineers New Zealand, "The Roads to Reform", Engineering Insight, November/December 2013, Volume 14/6, pp 9 - 14.

Kotter, J., "Leading Change, Why Transformation Efforts Fail", Harvard Business Review, March - April 1995.

Knight, R, "Convincing Sceptical Employees to Adopt New Technology", Harvard Business Review, March 2015

Kegan, R and Lahey, L, "The Real Reason People Won't Change", Harvard Business Review, November 2001.