Defect identification and maintenance management of bridges and concrete structures using Artificial Intelligence

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Abstract:

In terms of asset management and maintenance, bridges are 'time bombs' – time bombs that require regular condition assessment in order to make optimised decisions about maintenance and renewal. In Australia, the majority of asset managers assess bridges and other concrete structures using visual inspection, with most local councils and state road authorities having these inspections carried out on a four-year cycle.

Unfortunately, the manual nature of the inspection process makes it highly subjective, and as such, results can be inconsistent among inspectors. Whether these inconsistencies result from the inspector being time-poor and overlooking key issues in a rush to produce reports, their inability to effectively collaborate with stakeholders, or simply a result of human error, is effectively a moot point. When a defect or damage is missed, it not only becomes difficult to confidently assess the condition of the bridge or structure, it also becomes all but impossible to assess how a particular defect's severity is progressing with time.

Too often, these 'subjective' inspections serve as little more than a process to meet audit requirements, rather than providing an effective condition assessment reporting tool to guide asset management objectives.

Horsham Rural City Council is the first council in Australia to emerge from this 'subjective' inspection scenario through the use of an innovative new system of bridge health monitoring incorporating the latest in cutting-edge AI-enabled technology. In 2021, Council started using Dynamic Infrastructure's cloud-based asset condition assessment and reporting solution - a proven, Artificial Intelligence (AI) technology that has been tested by certified bridge and structural engineers - to find, categorise and assess critical faults in bridges and tunnels.

The application utilises a series of photos of the bridge(s) which are scanned using AI-enabled algorithms to identify defects and assess risk against the appropriate risk profile for the asset. The data is presented in an interactive 3-D model, accessed via an interactive easy-to-use 'dashboard' user interface.

As images from subsequent inspections are uploaded to the system, the system locates the images on the 3D model, allowing the propagation of individual defects to be assessed across each cycle of photo updates. Data and images for

each fault can be viewed in a ‘timeline’ format, which enables users to see how a particular defect is propagating over multiple photo inspections. As defects are repaired or rectified through maintenance, they are automatically cleared from the maintenance schedule.

The data are stored in a centralised repository on a cloud platform, enabling collaboration between teams, including contractors, engineers and field crews. Council has adopted this technology as the way forward, where AI, drone photography and cloud computing are collectively used to solve the condition assessment problem in civil infrastructures.

KEYWORDS:
bridges, culverts, concrete structures, asset management, asset maintenance, asset reporting, condition assessment, artificial intelligence, 3-D model

Introduction

In Australia, around 800 organisations are responsible for approximately 53,000 public road bridges. Some 23,000 of these bridges are managed by state road authorities, with the remainder managed and maintained by local councils. This equates to approximately one bridge per 490 people, which is one of the highest bridge per-capita densities in the world. Thus, there is a clear economic and social imperative to maintain, renew and upgrade this crucial infrastructure.

The majority of Australia's road bridges were constructed between the 1940s and 1960s. As such, most were designed with significantly smaller vehicle loads in mind – both in terms of vehicle sizes and numbers. Vehicles such as B-Doubles, A-Triples and Road Trains were not conceived or foreseen, let alone accounted for in the bridge design and engineering calculations. Add to this the sheer increase in vehicle numbers and it's easy to see why much of Australia's ageing bridge infrastructure is struggling to keep up with the demands being placed on it.

The Australian economy is largely reliant on the mining and agricultural sectors – both of which are widely dispersed across rural, regional and even remote areas of our continent. As such, much of the output from these sectors is transported to the nearest port, grain silo or intermodal hub via road. While these rural and regional roads may not carry a particularly high number of vehicles per day when compared to major metropolitan arterials, the large percentage of heavy vehicle traffic places an extraordinary strain on bridges along these roads.

Unfortunately, despite the effort being put in by state and federal governments and local councils, it takes decades to renew these structures. In short, budgetary limitations, together with the sheer size of the task, make it impractical to consider replacing or even upgrading the load capacity of every bridge on the road network in the short-term.

One alternative would be to utilise smaller trucks, however, this requires additional trips to achieve the same outcome. This approach is not only inefficient it also results in increased vehicle emissions, higher traffic volumes, increased risk of accidents and/or incidents, and increased transport costs. Hence, local produce becomes costlier and less competitive in global markets.

To improve bridge load capacity, asset managers need to first improve their bridge condition assessment strategies. This, in turn, will allow them to optimise and prioritise their bridge maintenance, renewal and upgrade programs.

Horsham Rural City Council is achieving this, thanks to some innovative thinking, and through the adoption of some world-leading technological advancements.

Problem definition

There are a number of significant issues related to traditional bridge health monitoring.

Currently, the most commonly used process involves an inspector visually inspecting a bridge, and then manually producing a condition assessment report. The report data generally covers the bridge and its components, recording the current condition, together with any defects that the inspector believes require urgent attention. This 'subjective' data then forms the basis of the asset owner's maintenance and renewal planning.

While this methodology has many shortcomings – particularly in terms of its largely subjective nature – it has generally been the only option available. Importantly, however, in the modern era of IT, many of these shortcomings are now able to be overcome through the use of mobile data capabilities, cloud computing and Artificial Intelligence (AI).

Issue 1:

Most current asset management software only has limited capacity for storing detailed analysis of all minor defects. The data often sits in a PDF document with no traceable history of previous condition and/or maintenance efforts. Furthermore, there is often no mechanism for the system to alert the asset owner of the need to rectify poor condition. Without an effective condition alert mechanism, there is a risk of missing critical maintenance.

Issue 2:

There is currently no convenient way to monitor the propagation of defects across multiple inspections. For example, if a small hairline crack or similar defect is detected on a particular element, but remains unchanged over a few years, then the risk is low. However, if the crack is expanding, it would require urgent attention.

Issue 3:

For larger structures, with many components, it is all but impossible to accurately define the exact location of all defects on the structure. If there is an issue, for example, with the third and sixth headstock, inspectors have to not only detail the fault, they also have to describe the exact location of the fault in relation to both the component and in the context of the overall structure. This can be extremely difficult to achieve in text format, even for a relatively small bridge. Not surprisingly, the bigger the bridge or more complex the structure, the more difficult this becomes.

Issue 4:

Communication and collaboration between stakeholders such as inspectors, design engineers, suppliers and contractors can represent a major challenge. To accurately describe an issue, the asset engineer usually has to provide many photos, together with specific descriptions and other detailed documents. This can be a complex and onerous task, generally involving numerous calls, meetings and/or site inspections in order to clearly define the issue and plan a suitable solution or course of action.

Issue 5:

There is no central repository for condition data that can be easily communicated or shared between councils and government. Data is usually isolated within each council's server with knowledge relating to its location generally held by very few people.

Issue 6:

Once a defect has been rectified, the information is usually manually recorded in the asset register. These data are often difficult to recover for future condition assessments.

Solution

In recent years, technological advancements including increases in computing capabilities and data handling, as well as continuing developments in the Artificial Intelligence (AI) space have provided programmers with the tools to overcome many of these issues.

A leading company leading the way in this space globally is the New York-based international technology specialist Dynamic Infrastructure. Using the power of AI-enabled algorithms and high-performance cloud-based computing, the Dynamic Infrastructure package can identify, assess and locate faults and damage on a detailed 3-D digital twin of critical assets to record condition assessments and display defects across multiple inspections. This system allows asset owners to claim control over future risks and avoid unexpected maintenance events.

The system's high-performance algorithmic model scans digital images to automatically detect defects in critical transport infrastructure and generate actionable alerts. It uses deep learning detection and segmentation technology (similar to facial recognition) to analyse photographic records, cross-referencing the data against an extensive global database of bridge structures.

Once detected, the defects are geolocated on the 3D digital twin and prioritised within the critical assets. Subsequent photographic inspections will identify the same defects and report on any change in condition.

The Dynamic Infrastructure software provides a professional context for all identified faults, together with real-time alerts for maintenance planning.

Pilot program for Australia

Horsham Rural City Council is the first council in Australia to adopt this cutting-edge AI-enabled technology for bridge health monitoring within the municipality. With all of Council's bridge asset data centralised within the cloud-based Dynamic Infrastructure package, Council's asset management team now has immediate access to a full and highly accurate 'health record' for every bridge asset. This not only allows for accurate and informed condition assessments of all bridge assets across the municipality, it has also plays a major role in helping to prioritise works and optimise budgeting.

One of the assets now held within the database is *Gross' Bridge*, located on the Drung-Jung Road some 12.5 km east of the Horsham CBD.

A series of photos of Gross Bridge were imported into the Dynamic Infrastructure program to create the bridge record within the system. The software then scanned the photos for faults, automatically computing and outputting the following information.

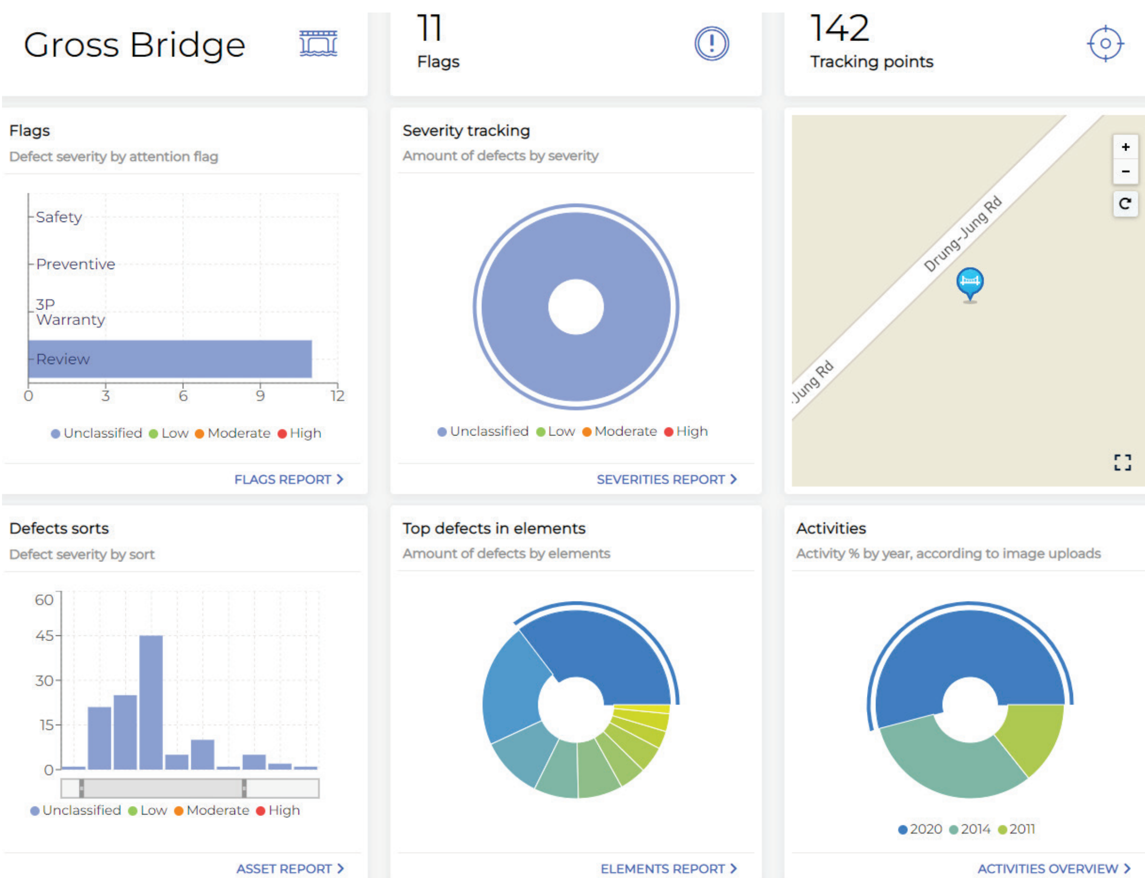

Figure 1: Dashboard showing automatically detected defects

Analysis of automatic detections

1. Locating defects on a 3D model (digital twin)

Figure 2: Defects are highlighted on a 3D Model (digital twin) of the asset

Figure 2 (above) shows a 3D model (digital twin) of Gross' Bridge that was created as part of the Dynamic Infrastructure process. The system presents the exact location of each defect automatically detected from the photographs supplied.

Photos of the defect are shown on the right of the screen next to the digital twin for quick reference.

2. Monitoring the propagation of defects

Photos of the same location taken over a number of years will demonstrate how the defect is propagating over time. The user can access this informaiton immediately by clicking on the right top corner of Figure 2 screen (shown above).

This will open a separate 'timeline' screen (Figure 3 below) which shows any changes or escalation of the defect over time. This feature provides a critical insight into the severity of the defect (i.e. a rapidly propagating defect is more critical than a defect that remains unchanged over years).

Figure 3: The 'timeline' screen provides details of defect propagation between inspections

3. Sharing data on selected defects with stakeholders

The system allows for data on a particular defect, or group of defects, to be easily shared with other stakeholders including engineers, maintenance crews, contractors and/or material suppliers (Figure 4 below).

This easy-to-use method of data sharing plays a major role in streamlining collaboration between stakeholders which, in turn, helps to expedite repair and maintenance works. Furthermore, the highly accurate and visual nature of the data also helps to clarify the required works by visually pinpointing the location of the fault on the structure.

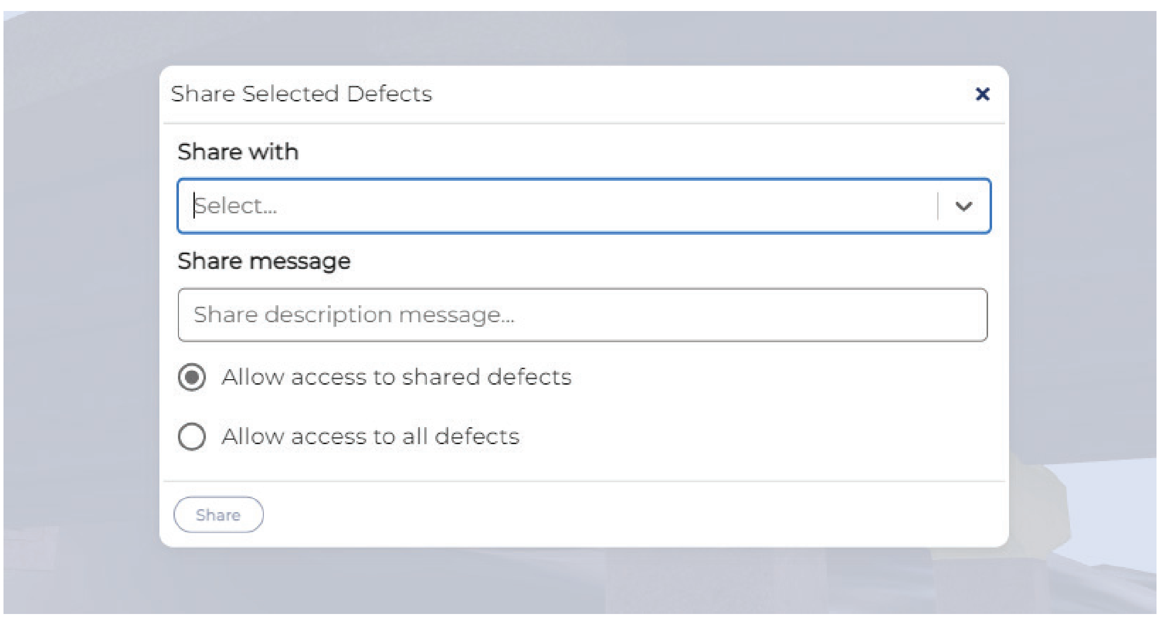

Figure 4: The ability to easily share details of defects between stakeholders helps to streamline collaboration and expedite works

4. Identifying defect type, severity and component

For each defect, the model automatically identifies its location on the asset and the component(s) affected, as well as the type of defect and its severity.

Depending on the severity of the defect, the system is able to generate specific automated notifications. The system also allows defects to be sorted and grouped based on type. This enables 'like' defects across the entire bridge asset base (e.g. crack defects, concrete spalling, etc.) to be grouped and assigned to a maintenance team/contractor as a 'works package', to improve economies of scale.

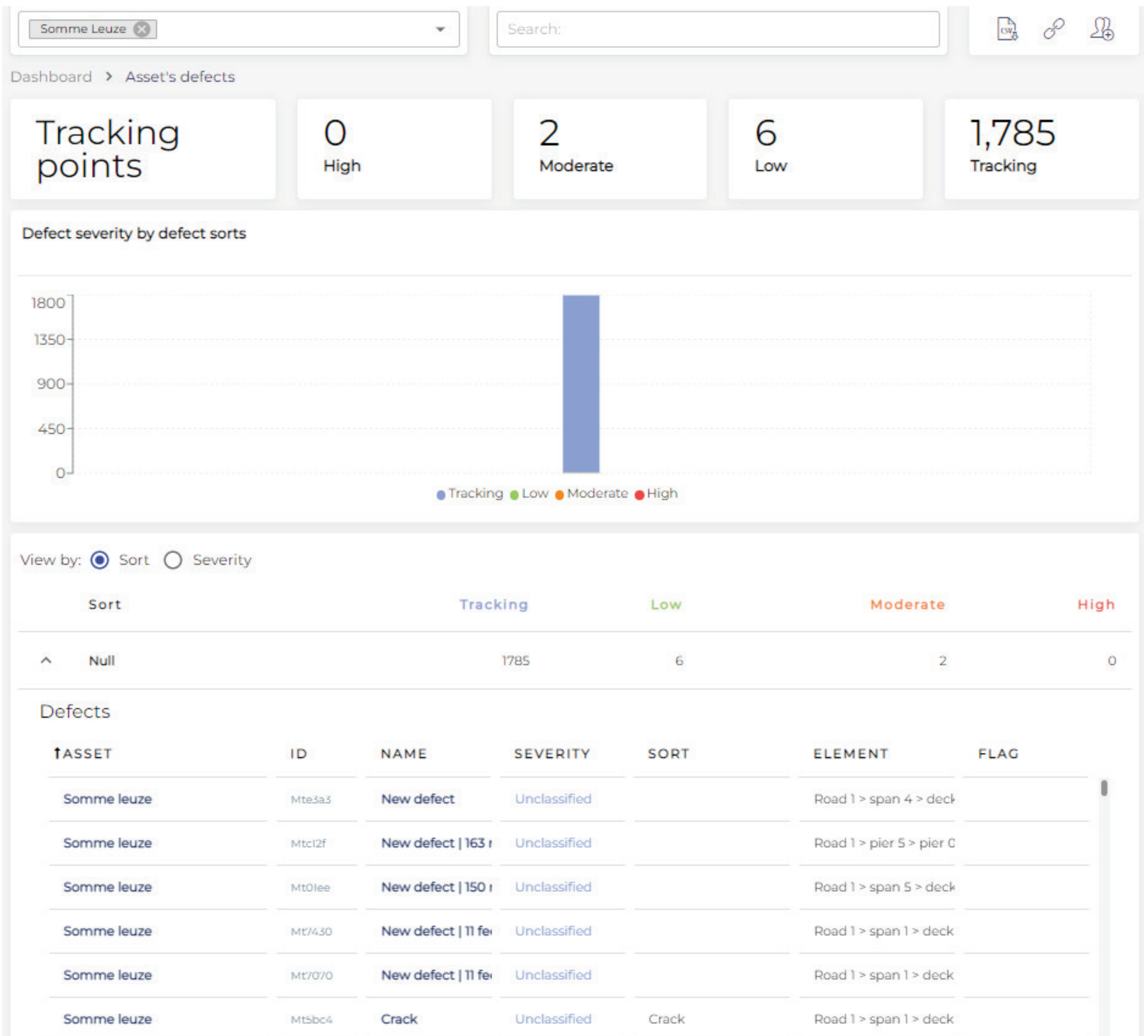

Figure 5: Defect categorization based on severity and type

5. Defect visualisation on photographs

The Dynamic Infrastructure application marks out detected defects on each of the images loaded up into the system as shown in Figure 6a.

For each marked item, a corresponding defect type is generated and, upon clicking on the defect area, its exact location is shown on the corresponding 3-D digitial twin model of the bridge (Figure 2).

Users can also access a separate dashboard (Figure 6b) showing all images containing defects that have been identified for a specific bridge. The pane on the right side of the dashboard (Figure 6b) lists each of the defects, together with information relating to defect type and severity, and hyperlinks to the 3-D digital twin model.

Figure 6a: Defects detected by the system's AI algorithm are marked out on the uploaded images

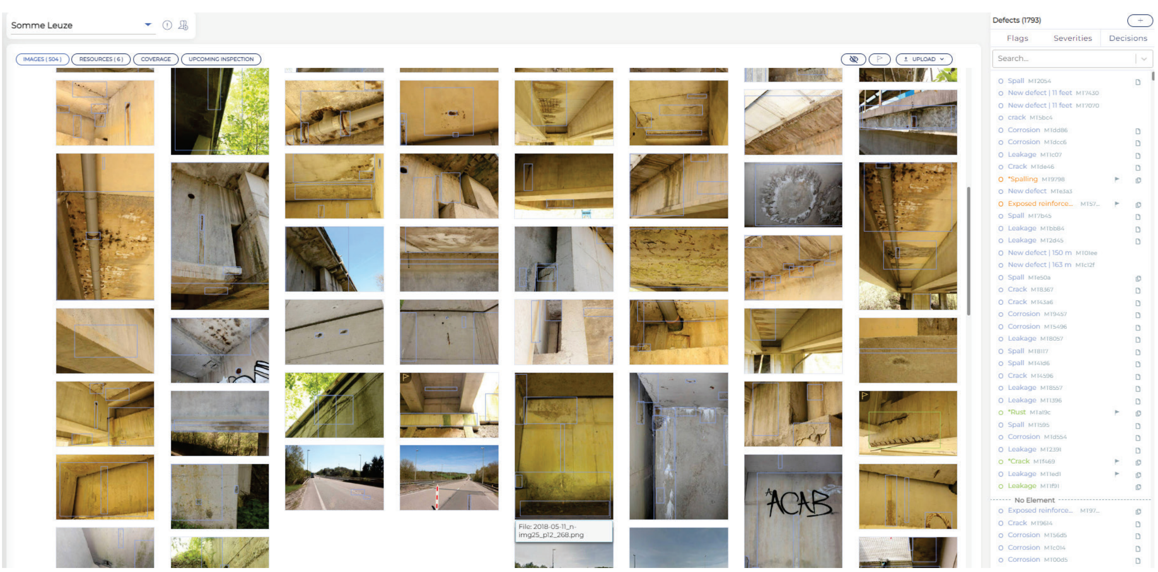

Figure 6b: A separate dashboard shows all images containing defects identified for the bridge. The pane on the right details each defect and provides hyperlinks to the 3-D digital twin model.

Conclusion

If a section of road fails due to inadequate maintenance or renewal, people can still commute during dry weather. If a bridge is not serviceable, it completely blocks the movement of people, freight, and equipment - resulting in significant impacts on both the community and economy.

Given that the greater majority of Australia's road bridges are regularly subjected to heavier loads and greater vehicle numbers than they were designed for, it is clear that we need to monitor these key assets more closely than ever before to detect defects before they progress to a critical failure.

With that in mind, it is also clear that this type of increased scrutiny of bridge assets requires a sophisticated 'objective' bridge health monitoring system to enable timely, accurate detection of even minor defects, as well as a level of operability that allows for effective data sharing and collaboration, better planning and optimised risk reduction.

A system that enables timely, efficient and cost-effective maintenance of infrastructure not only helps to optimise asset maintenance planning and budgeting, it will also improve the longevity of our structures. Whilst the conventional approach has led to successful management of structures over many years, it is time to adopt new technologies such as AI-enabled algorithms to assist in protecting aging structures against increasing load profiles. The system provided by Dynamic Infrastructure or equivalent is such a technology.

Recommendation

It is recommended that the current approach to bridge health monitoring be replaced with a centralised cloud-based system that provides the ability to:

1. facilitate effective communication between asset owners, design engineers, maintenance teams, contractors and suppliers
2. improve collaboration between local councils and state agencies
3. efficiently and 'objectively' identify defects and monitor their propagation over time
4. automatically detect issues and faults, thereby avoiding errors resulting from manual 'subjective' assessment
5. automatically assess the condition of the structure and its components through analysis of defects
6. develop a comprehensive 'condition history' for each bridge asset, which accurately records and categorises all defects and treatments.

Horsham Rural City Council has used the Dynamic Infrastructure product with success; thus, it is recommended that other councils consider adopting a similar, modern AI-enabled approach to managing their critical infrastructure.