Robert Street Bridge Rehabilitation – Digital Twin and AI

Genevieve Taurand, M.Sc., Ing.
Product Manager
Bentley Systems
Quebec City, Qc, Canada
genevieve.taurand@bentley.com

Barritt LoveLace, P.E.
Vice President of UAS, Artificial Intelligence and Reality Modeling
Collins Engineers, Inc.
St. Paul, Mn, US
blovelace@collinsengr.com

Scott Becher
Senior Solutions Specialist
Bentley Systems
Neptune Beach, FL, US
scott.becher@bentley.com

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Abstract

Owners and operators who are responsible for managing, inspecting, and repairing bridge infrastructure are currently faced with an increasingly difficult task. Bridge inspection can be a tedious, often dangerous, and time-consuming effort. Inspectors need to meticulously survey every inch of the asset, often in high-traffic areas or in hard-to-reach environments. Regardless of these challenges, bridge inspection is a central part of public safety and resilient infrastructure. In some cases, such as the Robert Street Bridge located in St-Paul Minnesota, it even plays a crucial role in maintaining the city's historical value by preserving its architectural heritage.

The rapid increase of structures that are due for repairs or replacement combined with an expanding network and labor force challenges requires an innovative solution from the industry. It is imperative that the owner/operators and the consultants they rely on leverage the latest technology to provide more accurate and consistent data in less time.

As we increase our ability to collect and analyze large amounts of data using unmanned aerial systems (UAS), reality models, artificial intelligence (AI), and Internet of Things (IoT) sensing to create digital twins, we are revolutionizing the way bridges are inspected and managed. Building reality models in a

collaborative cloud-based platform introduces the new workflow of pre-inspection, on-site inspection and report delivery which allows:

- Better asset assessment even before starting the inspection job
- Better planning of resources and equipment for the inspection job
- Increased worker efficiency
- Reduced on-site time Increased safety for all workers and travelling public
- Data-rich delivery enhanced with insights to stakeholders
- Better decision-making based on more data than previously available.
- Opportunity for quality control review of the field inspection.

This presentation covers how Bentley Systems and Collins Engineers collaborated on the Robert Street Bridge Rehabilitation project using UAS, reality data models, AI, and IoT. These technologies enabled a new and improved inspection workflow, to preserve the century-old architectural marvel that is this bridge. We will cover how leveraging the digital twin, we were able to attain:

- 30% reduction in inspection hours which is over $90,000 USD in savings.
- 20% estimated future construction savings which could translate to up to $15M in savings.
- 20% fuel reduction.
- 10% reduction in material production during future construction.
- 1000x increase in the amount of quantifiable data available to decision-makers.

Introduction

Many organizations who are responsible for inspecting, monitoring, and maintaining bridge infrastructure are faced with the challenges of workforce shortages and an increasing backlog of aging bridges. Addressing these challenges requires a multi-faceted solution from the owner/operators, the engineering consultants they rely on as well as the entire infrastructure industry. Leveraging the latest technology to improve the current workflows should be a significant component of the comprehensive solution. The collection of reality data with a UAS and creation of a digital twin has proven to be a valuable tool in augmenting traditional inspections by utilizing remote visualization. As technology matures, there continues to be advances in the tools that can be used along with the digital twin to assist inspectors. These tools include georeferenced annotations of a 3D reality model, AI/ML assisted defect detection, AR/VR visualization, and IoT assisted structural health monitoring.

An effective way to demonstrate the benefits of the technology is to highlight a project where the tools were used to augment existing workflows. Collins Engineers worked closely with Bentley Systems to implement the software to provide a completed inspection to Minnesota Department of Transportation on the Robert Street Bridge project.

Figure 1. Robert Street Bridge

Project Overview

The Robert Street Bridge is an eight-span reinforced concrete arch bridge with the main span consisting of massive rainbow arch ribs that define its modern architectural style. The bridge is located and was constructed in 1926. The Robert Street Bridge is on the National Register of Historic Places and is an important vehicular and pedestrian connection crossing the Mississippi River. The bridge is owned by the Minnesota Department of Transportation and in addition to crossing the river it also crossed two railways and a local roadway for a total length of 1429 feet (436 meters).
The bridge was rehabilitated in 1989 but significant deterioration has occurred since then and the project includes a detailed inspection to support a bridge management plan to facilitate another rehabilitation project in the future.

We teamed with Michael Baker on this important project and our role included creating a digital twin of the structure, performing the detailed inspection and documenting and communicating the condition of the bridge.

A key objective of this project includes collecting detailed information on the condition of the bridge through inspection and testing. Another objective is to calculate a load rating of the bridge based on the condition information to determine the current load carrying capacity of the bridge. The last objectives are a bridge management plan and service life analysis that will inform the rehabilitation efforts.
The main challenge of this project is the difficulty in efficiently and accurately collecting detailed inspection information for such a large structure with so many defects and deficiencies. Using traditional

inspection data collection methods would be very tedious and expensive so the team had to find innovative ways to not only be more efficient but also to provide a higher quality deliverable for the Minnesota Department of Transportation.
Workforce shortages are another challenge we needed to address. With traditional inspection methods highly trained and educated engineers spent much of their time doing mundane tasks such as measuring and sketching defects. We proposed using these new technologies and workflows to make data collection easier and ensure engineers were spending their time making decisions versus collecting data.

Figure 2. Field Inspection

Project Plan

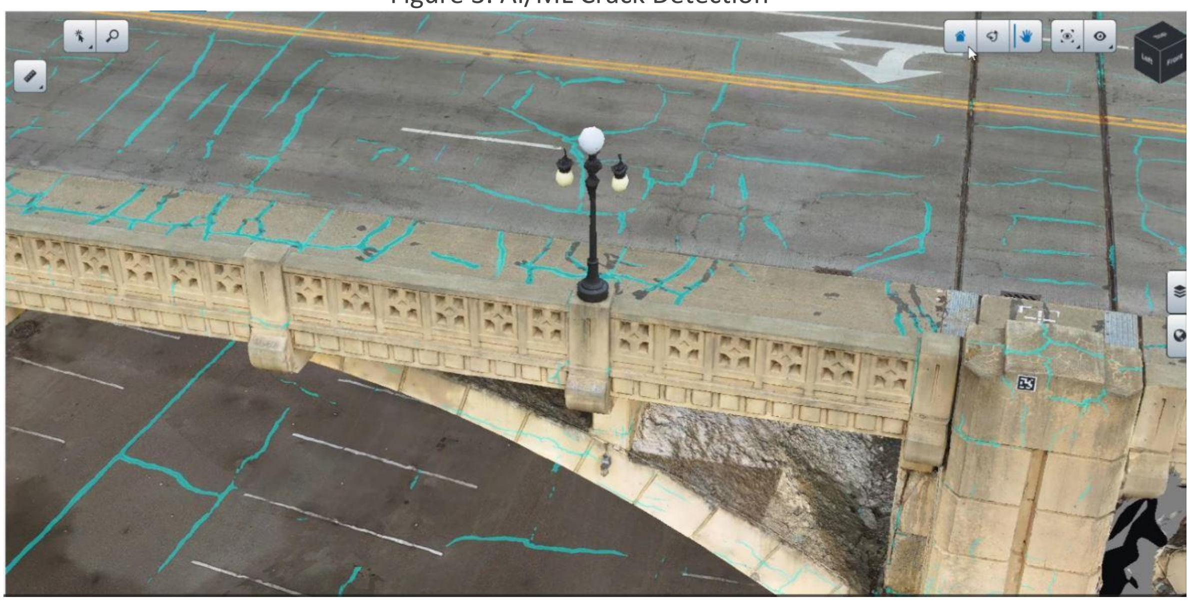
In order to meet the challenges of this project, the team proposed using UAS to collect data in order to create a detailed digital twin of the bridge. Using the digital twin as part of the online remote inspection platform we could share the model across the team, and it would become the central repository for the inspection, inventory, and testing information. The team proposed collecting all the inspection information in the field using internet-connected tablet computers using custom forms built for this project in the Forms Designer. Using this form would ensure consistent data and the ability to quickly input inspection information. The scope of work for the project included the following:

- Collect data using Skydio drones with artificial intelligence to autonomously collect all of the images. By using their3D scan application the data was collected efficiently and consistently.
- Post process the images and ground control collecting into digital twins of each span using iTwin Capture, a photogrammetry 3D reconstruction software. Both automatic ground control points

and semi-permanent QR codes were used to aid in the processing. The software tool produces high quality models that can be used to pre-inspect the bridge in the office.

- The models were uploaded into the iTwin Experience online digital twin sharing service and since ground control was used, the entire bridge could be viewed at one time or by individual span.
- The engineers on the team performed a pre-inspection in the office using the online digital twin platform and the custom forms that were developed in the Form Designer. Additionally, the team used artificial intelligence defect detection to automatically find and document concrete cracks and spalls.
- The fieldwork was performed and all previously input inspection results were verified and additional inspection information was input it the field using internet-connected tablet computers.
- The digital twin with annotated inspection information was shared with the entire team and all team members have the ability to review and add information to the models.

Figure 3. AI/ML Crack Detection



One of the largest breakthroughs of our team approach included the ability to pre-inspect the bridge by using the digital twin in the office prior to starting field work. While traditional inspection requires workers to close down lanes or traffic on the bridge and start looking for defects, this method allows engineers to validate defects instead of recording detailed information in the field. Time spent on the bridge becomes much more efficient and closure times are drastically reduced.

Another significant breakthrough is the ability to use artificial intelligence to automatically find, quantify and communicate concrete crack information. This workflow using cloud-based software products is revolutionary and is a large leap forward in the bridge inspection industry. Traditional methods of reporting the cracks manually are very tedious as it is very hard to find every single instance and measure them with high accuracy. Drawing or taking pictures often lack the 3D perspective of the cracks' position and severity. The total number of cracks and severity are often roughly estimated by inspectors making an imprecise assessment of the bridge. With our workforce shortages applying these technologies will provide the industry a way to deliver improved inspection results.

Another significant breakthrough is the ability to perform quality control based around the digital twin and photo navigation feature in the online-platform. Previously, if an inspector missed a defect the only way to verify was by performing an independent inspection. Using the digital twin, another inspector can check the field inspectors work for accuracy.

Figure 3. AI/ML Crack Detection

Results

By using digital twins for the inspection our team saved over 30% on inspection hours and fees with a very significant improvement in the quantity and quality of the deliverables. As our team works through bridge rehabilitation process, we expect to see a minimum of 20% construction savings stemming from the improvements in the quality of inspection data since better decisions can be made with more complete information.

Our innovative workflow is impacting the local community by reducing the amount of time our teams need to spend in the field which in turn reduced traffic control and lane closures. This not only reduces traffic impacts that the public is affected by but also reduces safety risks associated with lane closures and traffic control.

Implementing these tools into the workflows not only reduces safety risks for the public and inspectors, but it also reduces risk for the project team and MnDOT. Better data leads to better decisions, thereby reducing the risk of design errors or applying the wrong repair and rehabilitation solutions. Because the team used a single online platform to share the digital twins, inspection data and testing data, everyone on the project team had easy access to all the relevant information regarding the bridge. Team members also had the ability to contribute data to the model to further enhance collaboration from all stakeholders and used across disciplines. Due to the technology implemented, The Robert Street Bridge Rehabilitation Project has more quality data accessible to all team members than any other similar project.

Quantitative Summary of Results:

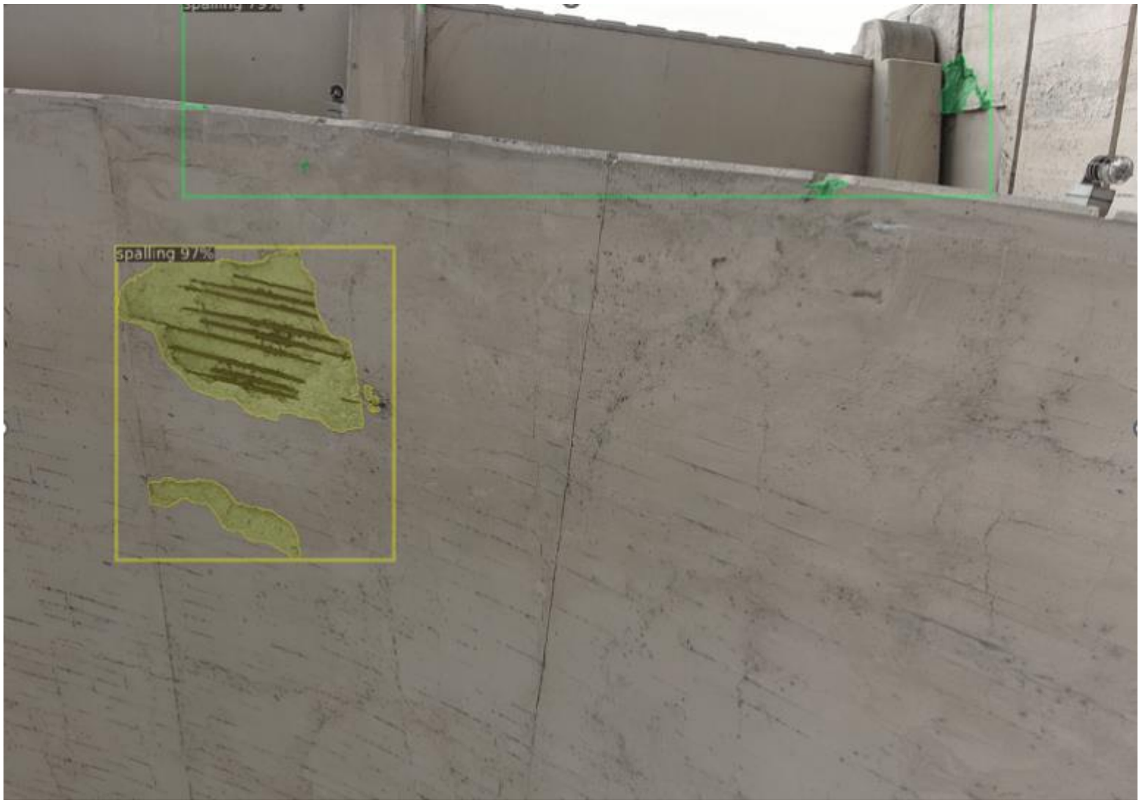
- 30% Reduction in inspection hours which is over $90,000 USD in savings.
- 20% Estimated future construction savings which could translate to up to $15M in savings.
- 20% fuel reduction.
- 10% reduction in material production during future construction.
- 1000x increase in the amount of quantifiable data available to decision makers.

Future Outlook

The Robert Street Bridge Project utilized tools to augment a workflow that generated significant benefits, despite being one of the first projects where the team had used these tools. Future projects will undoubtedly use these tools faster and more easily to further improve the benefits. Additionally, the reliability and power of the tools will continue to be enhanced.

The team effectively used the AI/ML concrete crack detector to streamline a tedious task of identifying a specific defect, however bridge inspections required identification of other defects such as spalling, corrosion, and delamination. AI/ML defect detection is still in early stages and the quality and types of the detectors will continuously be improved as the amount of data is inputted into the models.

Figure 5. AI/ML Spalling Detection



The visualization of 3D models also presents an opportunity for further enhancement of bridge inspection workflows. Extended reality (XR) offers many potential benefits including remote worker collaboration and bridge inspector training programs. The ability to easily navigate an accurate reality model at 1:1 scale, make annotations and have access to all relevant information at the touch of a hand, will further transform bridge inspection workflows. Essentially, workers will have the benefits of being onsite, with the convenience of a computer for documentation and reduce many of the inherent risk factors associated with bridge inspection.

Although IoT sensors were not used in the Robert Street Bridge, the integration of sensors into a monitoring program has the potential to further supplement the technology discussed earlier. While IoT sensors are not necessarily new, the data feeds they provide can be visualized in the same model created for remote inspections, giving owner/operators a more complete picture of the health and performance of the bridge in one environment.

The digital twins created, and the inspection data collected were targeted for our specific rehabilitation project, however it is expected that it will be used to manage this important bridge for many years to come. While the Robert Street Bridge is a large, multi-faceted project, this workflow can be adapted and streamlined for almost any kind of structure including smaller bridges, retaining walls and sign structures, among others. This type of technology will only continue to grow within the inspection and construction field. We anticipate this new workflow will be adopted for many projects of this type in the next few years since the benefits are so compelling.

Conclusion

The Robert Street Bridge project serves as a compelling case study, showcasing the effectiveness of digital twins in augmenting traditional inspections through remote visualization. The challenges posed by workforce shortages and the complexity of inspecting aging structures were met with an innovative approach, resulting in substantial benefits, and paving the way for future advancements in the industry. The collaboration between Collins Engineers and Bentley Systems has demonstrated the transformative impact of leveraging the latest technology to streamline workflows and enhance the quality of inspection data. The project's success is evident in the significant reduction in inspection hours. The innovative workflow not only improved efficiency, but also had a positive impact on the local community by reducing the time spent in the field, minimizing traffic disruptions, and enhancing safety for both the public and inspectors. The outlook is promising, with continuous enhancements anticipated in AI/ML defect detection, extended reality (XR) applications, and the integration of IoT sensors.

While the digital twins and inspection data collected were tailored for the specific rehabilitation project of the Robert Street Bridge, the adaptability of this workflow for various structures, from smaller bridges to retaining walls, signifies a broader industry transformation. In essence, the Robert Street Bridge project marks a significant leap forward in the bridge inspection and maintenance field, setting a precedent for the industry to embrace and integrate advanced technologies that not only address current challenges but also pave the way for a more efficient, data-driven, and future-ready approach to infrastructure management.