Towards Utilization of Digital Technology for Railway Infrastructure

Sizarta Sarshar[a] and Isabelle C.R. Tardy[b]
[a] Institutt for energiteknikk (IFE), Halden, Norway, sizarta.sarshar@ife.no
[b] Bane NOR, Oslo, Norway, Isabelle.c.r.tardy@banenor.no

Abstract: The Norwegian railway is being modernized and emerging technologies allow for a digital transformation to improve efficiency and safety. New digital enablers include among others fast and high bandwidth communication systems, new sensors, and internet of things (IoT) solutions, use of artificial intelligence (AI) and digital twins to support e.g., automated train operations and smart asset management. To better understand some of the needs and challenges with introducing the digital enabler digital twins in the railway domain in Norway, a pre-project was established by the Norwegian Railway Directorate and carried out by the research institute IFE and infrastructure owner Bane NOR. The intention was to identify gaps where research is needed. Two use cases were studied to explore a holistic approach for utilizing digital twins where relevant end users were interviewed to identify needs and gaps: (1) Maintenance and inspection of a bridge which relates to asset management, and (2) Train operations which relates to planning and dispatching train movements. This paper discusses the findings considering “challenges and opportunities” for utilizing the technologies in operation.

1. INTRODUCTION

The pre-project [5] identified some gaps in Norwegian railway with respect to developing and using digital models. Two use cases were explored, and their gaps include:

- Asset management exemplified through maintenance and inspection of bridges: Increase the quantity and quality of measurement data of bridges to simulate and predict functionality, behaviors and remaining life associated with risk evaluation.
- Train operations: Automate insight gathering from infrastructure and current operations reporting status which in turn allow for further scenario simulations and event handling. Further work should explore what the gaps between existing systems (such as TMS[*]/RBC[†] /ETCS[‡]) and the real needs are, and which digital twins can fill.

In Norway, the railway ecosystem is fragmented, and interoperability is a challenge which needs to be addressed when progressing with the digitalization. For example, the train operators and infrastructure managers currently do only to some extent automatically exchange data between each other. Many European railway actors face similar challenges and wish to jointly develop solutions. This is also reflected by Europe’s largest research and innovation program (Europe’s Rail), which has a principle thematic focus on digital enablers and digital twins.

Section 2 describes digital enablers for asset management within our context of bridge as case. Section 3 discuss utilization of digital models of infrastructure. Section 4 concludes the work and describes the next steps.

[*] Traffic Management System
[†] The Radio Block Centre (RBC) receives positioning of each train continuously and calculates smallest possible train distances at any time.
[‡] ETCS is the core signalling and train control component of ERTMS. ETCS continuously calculates a safe maximum speed for each train, with cab signalling for the driver and on-board systems that take control if the permissible speed is exceeded.

2. DIGITAL ENABLERS FOR ASSET MANAGEMENT

In Norway there are over 3000 railway bridges. Bane NOR is responsible for monitoring, maintenance, and control of these. These are all inspected every 6th year.

The Hølendalen bridge is one of these being inspected manually. The purpose of the inspection is to monitor the health of the construction. The bridge is tension reinforced concrete construction and weakness in tension will cause deformation by design. During inspection one monitor vibration and deformation to be within regulatory requirements. The inspection requires scaffolding and reduction and stopping of train operations on track due to safety. The inspection is time consuming and costly.

The inspection is documented in reports with measurements and pictures taken with handheld cameras of potential weaknesses. For analysis purpose historical pictures are to be found in archives and compared to new pictures to evaluate e.g., crack development. Measurements and pictures being updated on a 6-year basis provides little data for continuous monitoring and operational decision support.

In 2020, Bane NOR and Nordic Unmanned performed an inspection as part of the project Drone4Rail [4] (lead by International Union of Railways, UIC) to explore the use of drones for railway constructions. By using drones[§], both time and money can be saved because, among other things, one does not need to put up scaffolding to do the inspection. One also avoids stopping train traffic, and travelers can use the train as normal while the bridge is inspected.

Using drones as sensor platform to support visual inspection using cameras and lidars allows for documenting the inspection by building 3D models of the entire construction with high resolution pictures and point clouds. This allows for more detailed analysis of the construction compared to the manual pictures taken in traditional inspections. In addition, one can cover the entire construction and not parts that were selected for manual inspection. The goal is to map all railway bridges in Norway with the use of drones in the future. There is a need for more systematic work for technical health control of infrastructure. The aim of the project is to create a guide for inspecting railway bridges with the use of drones.

Example images from the Hølendal bridges using infrared camera are provided in Figure 1. In addition to infrared camera, the drone is equipped with normal camera and lidar. Digital models of the bridge are made based on the gathered data from the drone [4].

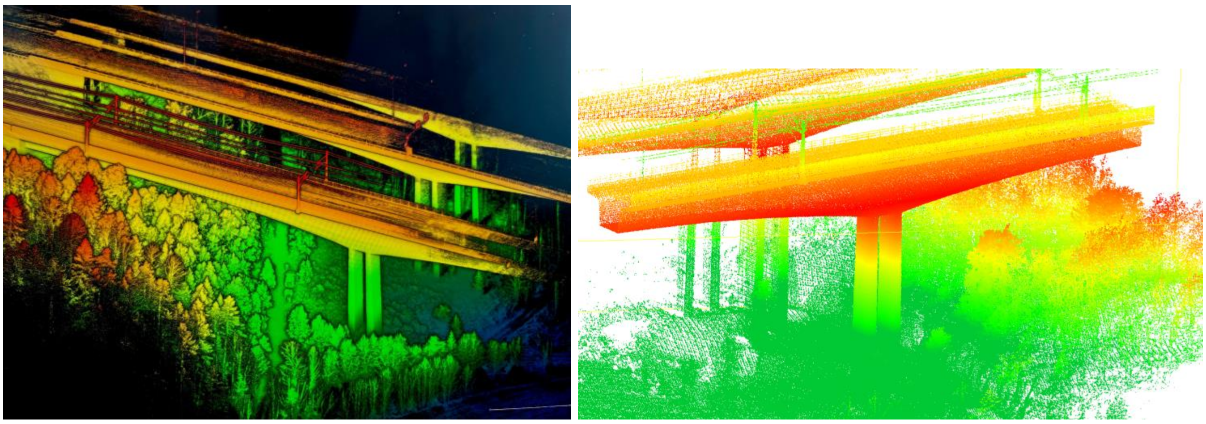

Figure 1: Images from the Drone4Rail project of Hølendalen bridges using infrared camera [4].

[§] https://www.banenor.no/Nyheter/Nyhetsarkiv/2021/inspiserte-jernbanebru-med-drone-fra-hjemmekontoret

Use of drones as sensor platform can ease the inspection, provide more detailed measures, and cover the entire construction. One can quickly access structures which are usually difficult to reach and would otherwise require to stop the traffic, perform a geometrical and structural survey, obtain 3D measurable models in high resolution, record the extent and the position of the defects of the structure and decrease the time for compiling analysis. Data update is however still dependent on inspection frequency. The inspection frequency is decided based on the organizations (infrastructure owner) capabilities and cost-value estimates. With the use of drones for inspection the frequency could increase allowing for more up to date monitoring.

With today's solutions one operates in different phases. First, one inspects manually in the field and gather data. The data is then analyzed in the next phase and used for planning e.g., maintenance. In a digital solution the planning and decision will be closer to the field as sensors will update the model close to real-time/on the fly.

Table 1 provides a simple overview of data acquisition, assessment, and decision support for various measurements on bridge health including manual inspection, drone inspection, sensors on bridge, measurement trolley, sensors on trains and simulation.

Manual inspection, drone inspection and sensors on the bridge gather data about the bridge construction while measurements from trolley and trains must be done in parallel. It will be an additional point of information that can indicate differences that may trigger the need for a more accurate measurement from e.g., a drone. When measuring on the train, there are many more things that come into play – the condition of the rails, the ballast or whether there is something wrong with the train.

3. UTILIZING DIGITAL MODELS OF INFRASTRUCTURE

Making use of emerging technology for monitoring, updating 3D models, and analyzing the health of the infrastructure requires user involvement. The solutions should be developed with a user-centered approach to assure that the end user can understand and make sense of the gathered information and analysis to support his/her decisions and tasks at hand. Relevant methods may be user involvement [7] to satisfy end users in a development process, where an iterative improvement of the work process based on Human Factors Engineering is facilitated, this is often called user-centered design. Relevant topics that graphics must consider are issues related to e.g., situational awareness [1], risk visualization [6], and human-machine interaction [8]. Further the organization might need to adjust processes and other services to allow for improving work. Work processes can also be changed by increased situational awareness, and methods such as the MTO method [3] can be used for assessment and further development of work processes.

Merging information into models also requires experts from different disciplines to communicate with each other. Experts on rails and tracks need to e.g., understand image processing and information presented to assure it has a value and adds to knowledge building.

Figure 2 illustrates a simple overview of various inputs to build a digital model. First there will be an engineering model of the bridge itself, where the structural components are modelled to a desired degree of fidelity. This would for a modern bridge most likely exist already as part of the construction project. It can also be created based on structural drawings and information about the materials used and the construction process, which would be needed to model older bridges built before modern computer tools were used in construction. The information provided by a basic structural model of the bridge will be the global behavior, e.g., expected overall motions and vibration frequencies, as well as the load bearing capacity of both the bridge as a whole and each component.

Table 1: Simple overview of data acquisition, assessment, and decision support for various measurements on bridge health

Monitoring	*Data acquisition*	*Data assessment*	*Decision support*	*Comments*
Manual inspection	Take pictures of defects and document	Analyze photos and data and how standards are met. Compare with archive photos when existing. Pictures can exist of specific locations and defects, but seldom from the same location.	Updated every 6-year, used for planning maintenance. Data gathered and analyzed depends on expert judgement. Very much based on empirical data (inconsistent).	Requires sometimes scaffolding, is time consuming, lot of manual labor, risk of missing information from archive, train traffic reduced or stopped during inspection.
Drone inspection	Build 3D model based on lidar scan, high resolution pictures and thermal camera for fault and crack detection.	All data is stored and can be assessed with image processing. The entire construction is scanned, not just visually easy to see defects.	Provide a lot more data and model scans can be compared with upcoming scans.	Requires drone with cameras and operator, can to some extent be operated without interfering with train operations.
Attached sensors on bridge	Vibration and deformation sensors can be connected to the bridge construction.	Allows for measurements with and without trains passing. Allow for capturing the effect of load dynamically.		Installation of such sensors can weaken the construction; data transfer requires infrastructure on site.
Measuring trolley	Roger 1000 is a measuring trolley used which makes use of optical system (laser), gyroscopes and inclinometers, and mechanical systems as accelerometers. Cameras take pictures of the overhead line and ahead of the train seen from the train drivers view.	Track conditions are measured, e.g.: track width between the rails, side and height geometry, curves, and dosage in turns. Data are assessed while the train moves and stored for post analysis.	This information further helps to plan maintenance, control maintenance, and need for additional inspections.	Measurements are normally run in the autumn and in the spring (no snow).

Monitoring	*Data acquisition*	*Data assessment*	*Decision support*	*Comments*
Sensors on train	Accelerometers, sonar, lidar etc. mounted on a passenger/freight train.	Data from the train can be combined with the sensor measurements from the bridge to build calibrated bridge models.	Would allow for updating the model every time a train pass the bridge and allow for continuous input to maintenance planning and status of the bridge.	The new sensors provide better coverage compared to the Roger 1000 and can in time be mounted on several trains allowing for continuous data gathering.
Simulation	Element models are built and updated with online sensor and train information.	Allows for simulation of future train movements on the bridge and their consequence on the structure health: how defects and cracks can develop.	Would support preventive maintenance planning and planning for larger upgrades. Would increase knowledge on how fast the defect/danger is developing (how long will a defect be categorized as a deviation before it becomes a danger).	This is the aim for establishing digital models, shadows, and twins of bridges.

Current capabilities allow for detailed structural and environmental modelling, as well as the output of relevant sensor data. Such models can, depending on the chosen level of fidelity, provide real-time or faster than real-time modelling of structural behavior (if required for quick decision-making) or slower, but indeed much more accurate assessment of long-term projected behavior. Switching between levels of fidelity is a simple task. Modelling the loads experienced during the crossing of trains is also possible, but the capabilities are more limited and a future project exploring digital twins for rail bridges would develop this further. Providing output data in a format that is informative and useful for a range of different personnel is also a challenge, as is the exchange/communication of data between different databases. Making sure that the digital models fit well into the natural workflow of those working with both operation and maintenance will be perhaps the most challenging aspect of such a project [5]. In addition, the data can be correlated with data on other elements of the network like ballast and track, or vegetation, that could prompt maintenance decisions on a particular stretch.

Existing models of bridges are provided in the system MAXIMO (asset management system) and are very simplified representations. They represent meta-schematic models of the infrastructure. The granularity of these meta-schematics is very coarse, and the bridges are not divided in sub-components.

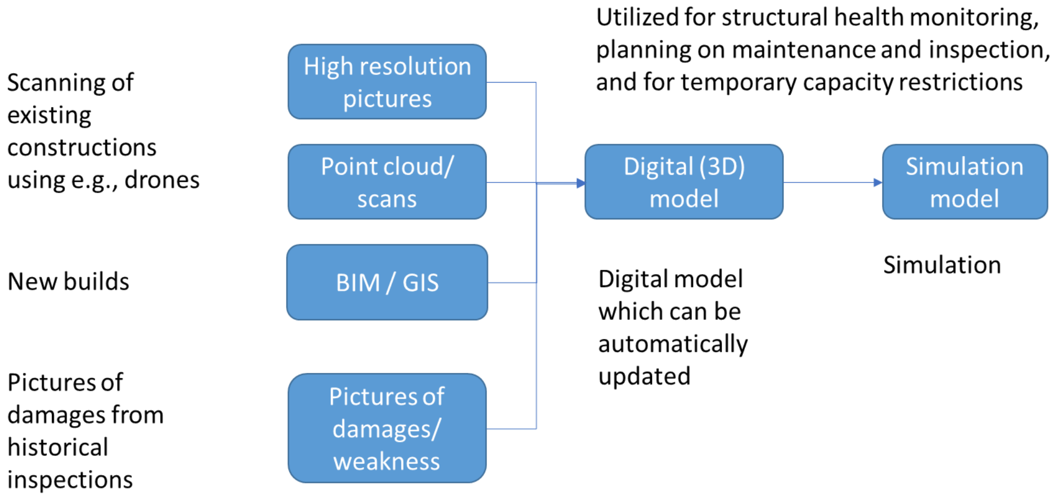

Figure 1: Simple overview of input to building a digital model of e.g., a bridge

Lifetime of bridges is essentially known through empirical data today. How could historical data be utilized with a digital model of the construction? Using lidar and scanning of bridges to establish 3D models is valuable from now on into the future. However, the constructions have a history which is not part of these models. How has the construction aged over the last decades? There exist a lot of documentation and pictures of damages and weaknesses from earlier inspections. If these can be mapped to the model one could illustrate and analyze development of the damage or weakness over time. This knowledge is very valuable for decision support as the remaining life of the bridges could be assessed more precisely.

RSSB[**] (Table 2) propose layers of digital twins which can be applied to modeling the bridge. The system is today built upon BIM (Building Information Modelling); however, many constructions do not have a BIM and one needs to reconstruct the structure based on a set of images or other measurement data. Once a model is established one might add measurements, data, and status information. A bridge has a function that needs to be checked regularly through measurements. Nowadays these measurements are done through manual inspection routines while a small portion of reporting is done through

[**] https://www.rssb.co.uk/what-we-do/insights-and-news/blogs/digital-twins-and-the-railway-one-framework-many-implementations

automatic measurements. It is widely envisaged that inspection becomes more digital, automatic, and continuous using e.g., drones and other sensor platforms. This type of reporting can be done in non-real time for maintenance purposes or in real-time enquiries following an event. Based on a digital model and updated status, simulations can be run offline to predict future behavior, for example after renewal of a portion of the bridge.

Table 2: Proposed digital twin layers by RSSB

Digital Twin Layer	Existence *What is there?*	Status *What is it doing?*	Operational *What is it doing NOW?*	Simulation *What might it do IF ____ changes?*	Cognitive *What is it going to do?*
Data required	real, static	real, dynamic – direct status	real, dynamic – event-based	simulation-generated	any, augmented by analytics
Systems it is built upon	BIM, organisational charts, schematics	sensors, periodic surveys, IT system reporting, comms, existence twin	sensors, reporting, comms, existence twin	digital (physics) models, with / without info from other twin levels	actuators, rules; info from other twin levels
What it shows	as-designed	as-is(-currently)	as-behaving	as-capable	as-predicted
Enables	structured single source of truth	analytics, prediction, real-time status information		capability assessments, optioneering, prediction	automated making and implementation of decisions

The function for train operations requires a model of the tracks and trains with their attributes, the trains´ position, and a plan for train movements. The status of these is updated based on movements and TCR (temporary capacity restrictions). If a measurement from a bridge requires an action for inspection or repair, this will add a TCR for that bridge with e.g., limited speed or even full traffic stop. This illustrates the need for a federated data space where (although at different levels) the status information of a bridge should be available for both maintenance and train operation.

The case explored are at the "status layer" for asset management and the ambition is to develop techniques and methods towards the cognitive level. A digital model would help in automatically transmitting data between different process flows, thereby ensuring that up-to-date information is considered in otherwise independent processes. It is foreseen that this will allow more efficient management and operation of the railway assets.

Introducing digital twins is not a step change – one does not go from nothing to everything – one needs to implement it stepwise with an implementation plan, considering granularity and topology aspects (i.e., relationships) and consider cost-benefit of the stepwise improvements. Safety assessment of the bridge remaining lifetime is an essential goal towards a good cost/benefit balance. In the process of introducing digital twins, one also ensures that possible new risks are not added, or at least that they are mitigated. Detailed domain knowledge should be represented in a standardized and relevant manner in the digital twin and control points with a relevant visualization tool allow for a good management of the digital twin. The result of this stepwise approach is an expected confidence in the tools developed. With a reduced number of physical inspections and more videos from drones, the risk assessment will be more back a screen, and more automatized. Organizational processes will be impacted, and competences needed be adapted.

4. CONCLUSIONS AND NEXT STEPS

New digital enablers are introduced to increase safety and railway infrastructure capacity for freight and passengers transport, increased productivity, and reduction of cost.

Research gaps need to address the interconnection between humans, technology and organization aspects when preparing for utilizing digital enablers. A user-centered approach could for the case on maintenance and inspection of a bridge address what strategic goal one should leverage data to reach when collecting data. What one would do differently to reach the goal if one had increased relevant insight. Which insight is needed to enable the desired way of working? What analytical approach can provide the desired insight and enable the desired action? What data is needed to conduct the specified analysis and is the data available? There is a need to:

- Apply user-centered product development transforming the digital enablers together with the end-users, e.g., robotics for inspection and maintenance.
- Apply user-centered design of human machine interface and operator screens and interfaces.
- Organizational adjustments to allow for efficient use of the new technology (updating procedures and processes, knowledge and competence building, training).
- Digital enablers and model interactions must allow for cross disciplinary collaboration.
- Digital models should visualize both the current situation and simulate different future scenarios.

Our next step is to establish a pilot case to gain experience with setting up the required data transfer infrastructure to allow for online monitoring and updating of models.

Acknowledgements

The authors wish to thank Ian Willoughby and Aziz Kameran from Bane NOR for their expertise in maintenance and inspection of bridges, and the PSAM reviewers for their valuable comments for improving this paper.

The pre-project this paper builds on consisted of a cross-disciplinary project team including experts from IFE and Bane NOR: Dr. Sizarta Sarshar (IFE, digital twins and digital enablers), Dr. Alf Ove Braseth (IFE, interaction designer and gathering of user's perspectives), Dr. Lars Einar Stieng (IFE, digital modelling and simulation of bridges), Dr. Harald P-J. Thunem (IFE, digital twins and applied data sciences), Tomislav Arsenovic (Bane NOR, digital enablers), Dr. Isabelle C.R. Tardy (Bane NOR, digital twins and digital enablers), Ian Willoughby (Bane NOR, maintenance and inspections), and Aziz Kameran (Bane NOR, maintenance and inspections).

References

[1] Endsley M. R. (2013). Situation Awareness, In Lee J.D. and Kirlik A. (Eds.), The Oxford Handbook of Cognitive Engineering, pp. 89, 99, Oxford University Press.
[2] Erduran E. (2020). NEAR Project description: Next Generation Finite Element Calibration Methods for Railway Bridges, Oslo Metropolitan University.
[3] IO MTO Handbook (2012). Version 4.0. Center for integrated operations in the petroleum industry.
[4] Nordic Unmanned (2020). Hølen bridge inspection 2020 – data acquisition status report.
[5] Sarshar S., Braseth A.O., Stieng L.E., Thunem H. P-J., Arsenovic T., Tardy I.C.R., Willoughby I., and Kameran A. (2022). Pre-project on Digital Twins for the Norwegian Railway Infrastructure, IFE/F-22/004, Institute for Energy Technology (IFE) and Bane NOR, Norway.
[6] Sarshar S. and Haugen S. (2017). Visualizing risk related information through the planning process of maintenance activities, Safety Science, vol. 101, 144-154.
[7] Yin, R. K. (2008). Case Study Research: Design and Methods. SAGE Publications, 4th edition
[8] Ware C. (2013). Information Visualization, Perception for Design, Third Edition, Elsevier, Morgan Kaufmann Publishers, USA.