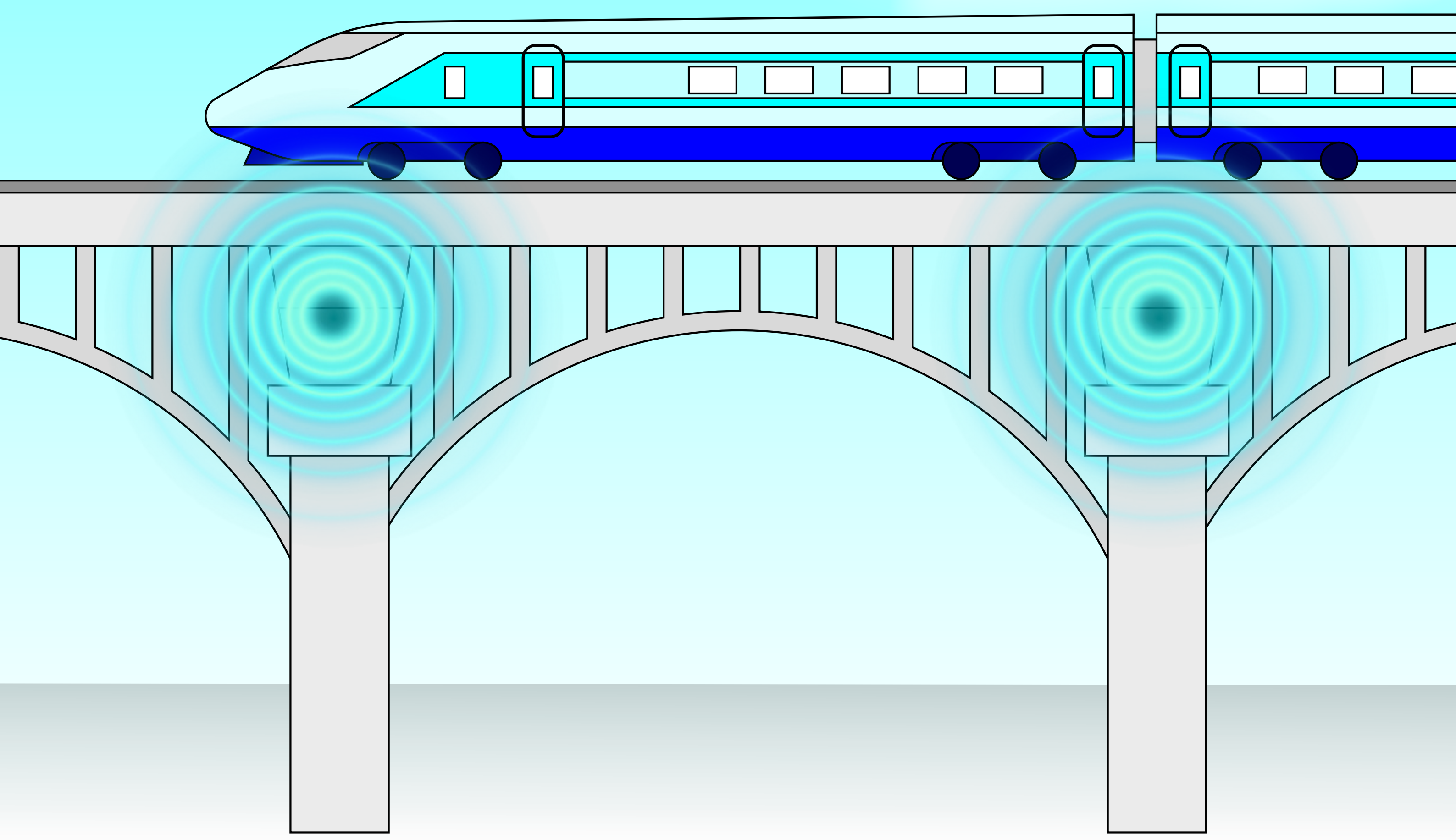
INNOVATION-SANDBOX for Artificial Intelligence



Sensor-based bridge monitoring

Data collection and forecasting for infrastructure maintenance

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Rising traffic volumes and ageing infrastructure are increasing the resources needed to monitor and maintain bridges. In the Innovation Sandbox for AI, Schweizerische Südostbahn AG (SOB) and irmos technologies tested how data-driven monitoring can provide a better basis for decision-making. At the Reidholz railway bridge in Wädenswil (ZH), sensors recorded train traffic and provided a more precise picture of loads and structural condition. The data was used to develop different scenarios for the remaining service life of the bridge. The project showed that data-driven methods can support maintenance and investment decisions. At the same time, the Sandbox team clarified legal issues relating to liability, data protection and operation. The pilot project illustrates how data-driven approaches can make infrastructure maintenance in the Zurich metropolitan area safer, more efficient and more sustainable.

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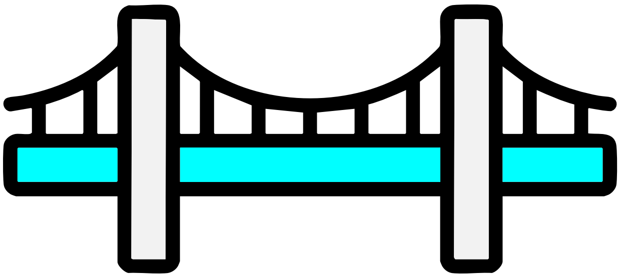
01. Background: *infrastructure in transition*



Switzerland is a country of bridges. Around 40,000 of them connect transport routes for cars, trains and pedestrians and ensure that this infrastructure can function day to day.[1] However, many of these bridges are showing signs of ageing. Maintaining them is becoming more expensive and complex, while the demands placed on the structures are also increasing.

Increasing strain on bridges
Bridge loads have been steadily increasing for decades and will continue to do so as traffic and transport volumes rise. Rail traffic today operates with more trains, higher loads and denser timetables than originally envisaged when many older structures were designed.[2] Driven by freight, delivery and logistics activity, heavy goods traffic on the roads has also risen continuously since the 1980s and is set to increase further. For supporting structures, this accelerates material ***fatigue**** and damage processes, which in turn increases the need for monitoring, ***structural reassessment***, reinforcement and renewal.[3]

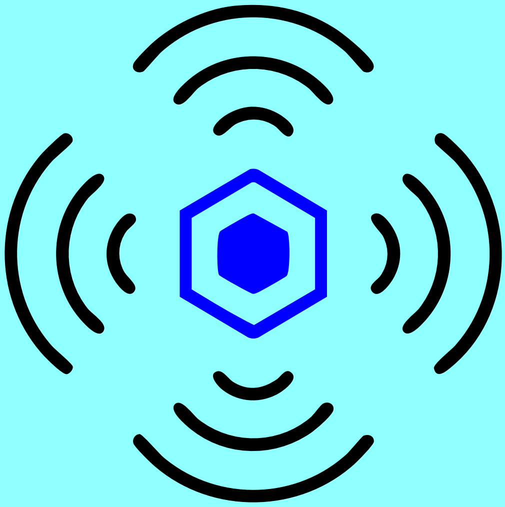
Ageing bridges
This increasing load is compounded by an ageing asset base. Many bridges date from the 1950s to the 1980s and are nearing the end of their calculated service life. If damage is not detected in time, this can have serious consequences. Collapses endanger human lives, cause enormous property damage and disrupt key transport routes. This was demonstrated in dramatic fashion with the collapse of the Morandi Bridge in Genoa in 2018, which killed 43 people and affected a major transport route for years.[4] Another example is the Carolabrücke bridge in Dresden, which had to be temporarily closed to traffic in 2024 following a partial collapse.[5] These two incidents in neighbouring countries showed just how quickly safety-related deficiencies can emerge.

These challenges are being further exacerbated by climate change. Extreme weather events such as heavy rain, flooding, heatwaves and frost-thaw are occurring more frequently and putting more pressure on bridges.[6]

The situation is clear: there is a growing need for precise monitoring methods to detect risks at an early stage and to manage infrastructure safely, efficiently and sustainably.

* Highlighted words are explained in more detail in the glossary.
[1] ETH Zurich: Across rivers and gorges: Switzerland and its bridge-builders
[2] SBB: Expansion step 2035 (STEP AS 2035)
[3] FEDRO: Examination of existing road bridges with an updated traffic load model (Documentation)
[4] Ministerio delle Infrastruktur e die transporti (Rapport della Commissione Ispettiva With)
[5] Dresden: Collapse and cause of collapse
[6] National Centre for Climate Services (CH2018 Climate Scenarios for Switzerland)

02.
Monitoring: *from estimation to measurement*



Today, infrastructure operators monitor bridges primarily through visual inspections and standards-based structural reassessments to provide the required evidence of compliance.[7] Experts assess damage using defined condition classes, regular inspection cycles and selective measurements. This practice is well established but is increasingly reaching its limits: it does not provide real-time data, it is partly subjective and it is based on conservative safety assumptions. This often results in high costs because bridges are reinforced or replaced as a precaution, even though their actual *remaining service life* might have been longer. Infrequent inspection intervals, heterogeneous designs and limited capacities further exacerbate these challenges.

Potential of data-driven bridge monitoring
Against this backdrop, data-driven monitoring is becoming increasingly important. Bridge maintenance is set to become more expensive in the coming years. To make efficient use of their scarce resources, operators need an accurate picture of the condition of their structures. Data-driven monitoring and forecasting provide the basis for this and deliver key added value:

- **Safety:** data-driven monitoring makes it possible to detect damage and hazards at an early stage and thus significantly increase safety.
- **Service life:** continuous measurement data shows how long a bridge can actually be operated safely, which avoids unnecessary interventions and reduces construction emissions.
- **Cost-effectiveness:** precise condition data helps to channel investments more effectively and reduce costs by avoiding overly cautious reinforcement or premature replacement.
- **Portfolio management:** operators can compare bridges objectively, set priorities better and manage the entire asset base more efficiently and strategically.

New technological developments are making it possible to systematically leverage these benefits. Modern sensors measure vibrations, deformations, strains and the resulting stresses during operation and simultaneously record relevant traffic data such as the number, weight, speed and type of trains. This enables realistic load profiles and fatigue processes of a bridge to be continuously determined. AI-assisted methods enhance pattern recognition,

[7] SIA: Eurocode 1: Actions on supporting structures – Part 2: Traffic loads on bridges (SIA 261.008)

identify anomalies and adapt engineering models to reflect real-world data.

Requirements for data-driven monitoring systems

At the same time, data-driven monitoring methods present operators with new technical and organisational requirements that must be taken into account to ensure successful implementation:

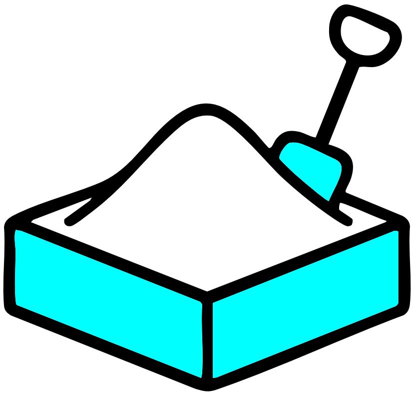
- **Data management:** infrastructure operators must reliably collect, store and process large amounts of data to avoid information gaps or misinterpretations.
- **Data quality and calibration:** sensors must be calibrated regularly and environmental influences correctly taken into account so that the measurement data that has been acquired remains meaningful and reliable.
- **Skills development:** infrastructure operators and engineering firms need new skills for working with data- and AI-based models in order to correctly interpret measurement results and translate them into decisions.
- **System operation:** sensor technology, power supply and data transmission must be stable and reliable, as malfunctions or failures can significantly limit the benefits of monitoring.

These points show that data-driven monitoring offers great potential – but this potential can only be realised if infrastructure managers have the necessary technical systems, processes and skills. Permanent monitoring thus enables a paradigm shift: away from conservative assumptions and towards precise, continuously collected condition data. For infrastructure managers, this means not only greater safety and better planning, but also a reliable basis for strategic decisions about the maintenance, reinforcement or replacement of individual bridges, resulting in a more robust, cost-effective and sustainable portfolio in the long term.

«Data-driven monitoring does not replace existing evidence, but complements it with measurement data from live operations»

Raphael von Thiessen, AI Sandbox Programme Manager, Canton of Zurich

03. Sandbox project: *Südostbahn and irmos technologies*



To test the potential of data-driven monitoring in practice, Schweizerische Südostbahn AG (SOB) and irmos technologies conducted a pilot project on a bridge in the canton of Zurich as part of the Innovation Sandbox for AI. The five-metre-long Reidholz bridge on SOB's Wädenswil–Einsiedeln line dates back to 1910 and was converted from a steel to a concrete slab in 1953, with the original abutments retained. According to the available documentation, both the abutments and the concrete slab were reinforced with shotcrete in 1990.

Figure 1: Reidholz bridge on SOB's Wädenswil–Einsiedeln line (built in 1910, rebuilt in 1953).

SOB operates regional trains on this section of the route and manages a large number of bridges within its overarching network. The Reidholz bridge is showing the first signs of fatigue. At the same time, it is unclear what traffic loads it is actually exposed to. Earlier evidence is based on conservative assumptions about load models and ***dynamic amplification factors***, which is why structural safety could only be demonstrated in calculations by means of redistribution measures. For the project, SOB collaborated with irmos technologies, a company specialising in data-driven infrastructure monitoring and AI-assisted data interpretation. The combination of age, uncertainties and conservative assumptions made the bridge a suitable pilot object for the sandbox project being carried out by irmos and Südostbahn.

«With the data obtained and historical load data, it should be possible to calibrate the calculation model and estimate the remaining service life more accurately.»
Stephan Zürcher,
Technology Manager Infrastructure SOB

03. Sandbox project: Südostbahn and irmos technologies

Determining remaining service life using data
At the heart of the project was the question of whether the actual remaining service life of the bridge could be determined more accurately than with standards-based methods, which use extremely conservative assumptions. SOB, which regularly tests new technical approaches and is committed to the ongoing development of its maintenance processes, wanted to assess whether it would be technically feasible and economically justifiable to extend the service life from ten years to twenty. At the same time, SOB examined whether the methodology could also be applied to comparable bridges in the portfolio.

Figure 2: Camera recording of a train to capture train type, speed and composition.

Measurement strategy with a lean sensor network
In addition to algorithms, irmos technologies develops easy-to-install sensors that are specifically tailored to the requirements of bridge monitoring. To collect the data, irmos installed a lean sensor network: accelerometers for recording the dynamic response, strain gauges to measure stress variations, and a temperature sensor to account for seasonal influences. A data acquisition unit recorded the measured values. In addition, cameras were used to document train types, speeds and compositions and to validate the traffic loads that had been modelled. The test phase, which lasted several months, provided real-world operational data to enable meaningful analyses.

03. Sandbox project: Südostbahn and irmos technologies

Digital analysis with cloud-based platform
SOB and the Sandbox team were able to track all metrics in real time on a cloud-based dashboard. Among other pieces of information, the platform showed the number of trains by type, along with their speed and passage frequency. The measurements also made it possible to derive the train weight and the axle loads per bogie – a key factor in assessing fatigue. In addition, the dashboard showed the daily maximum ***deflection*** and current stiffness of the bridge, as well as the development of these values over the entire measurement period. The strains recorded made it possible to identify outliers and calculate the stresses caused by individual train passes. Together, this resulted in a transparent, data-driven picture of the structural behaviour of the bridge.

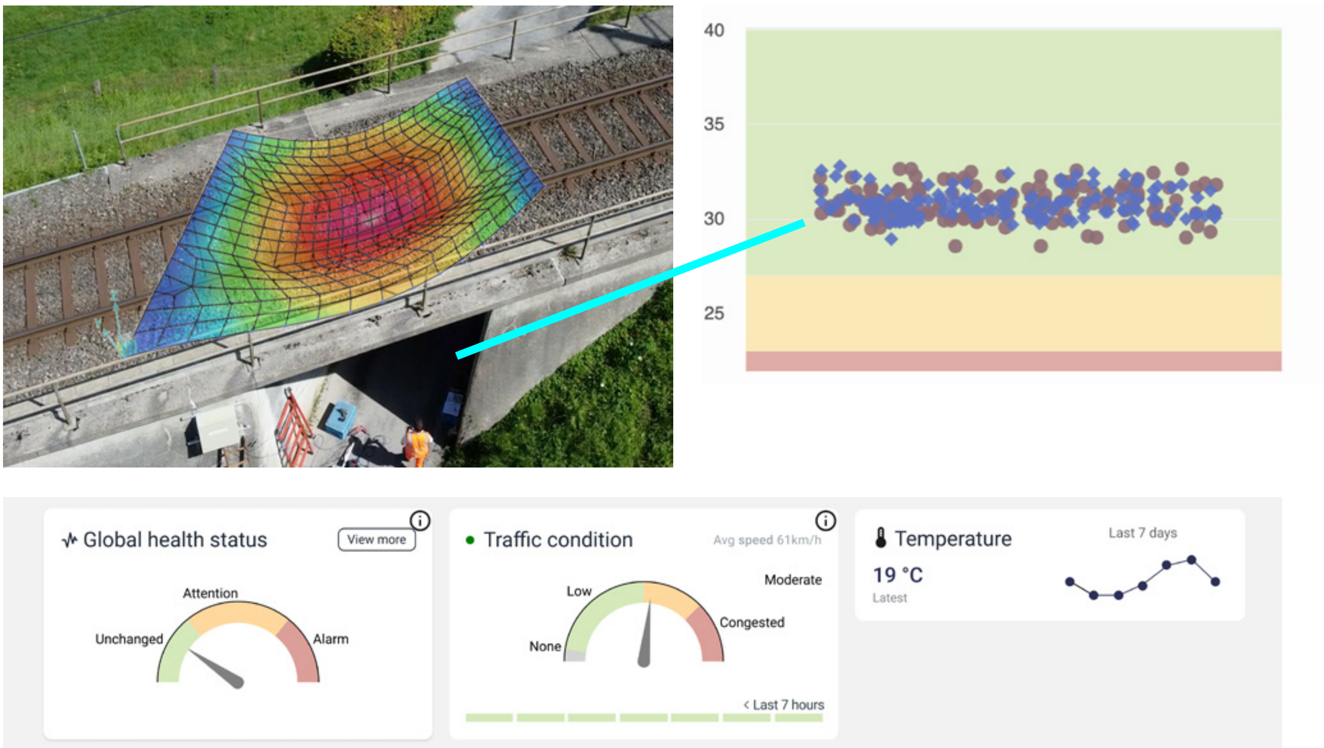


Figure 3: View of the dashboard for continuously monitoring the condition of the bridge based on traffic loads

03. Sandbox project: Südostbahn and irmos technologies

Model calibration and scenario development
The measurement data made it possible to derive real load profiles and calibrate the existing engineering models. AI-assisted methods helped to account for temperature influences and identify characteristic patterns. This allowed the previous, rather cautious assumptions about the bridge's behaviour to be verified (e.g. regarding dynamic amplification factors and assumed ***stiffness***). At the same time, functionality was developed to create remaining service life scenarios by combining historical data with assumptions about future train types, frequencies and loads. In addition, a function was developed that can be used to calculate scenarios for the remaining service life. It combines historical data with assumptions about future train types, frequencies and loads. Together with the measured load data, operators can now simulate how different operating conditions affect the service life of the bridge.

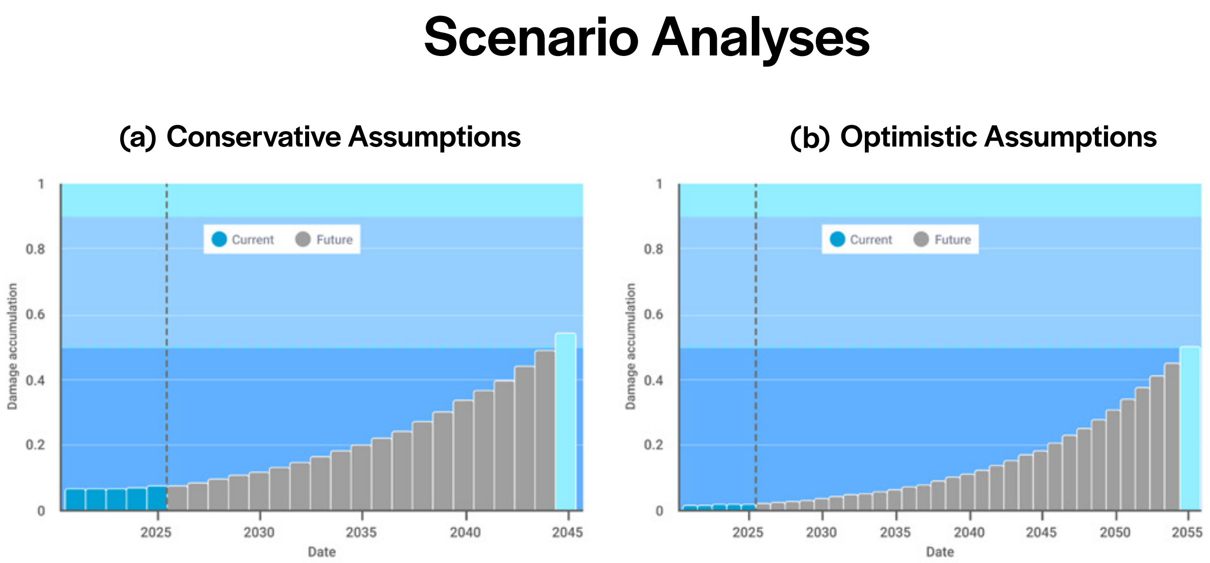


Figure 4: View of a scenario analysis of the remaining service life based on conservative or optimistic assumptions about traffic load.

03. Sandbox project: Südostbahn and irmos technologies

Insights and added value for operators

The results show that even short measurement periods allow robust conclusions to be drawn about fatigue and stiffness. There is a clear benefit for the individual asset: infrastructure operators can evaluate the bridge based on data, even if standards-based models suggest it is approaching the end of its service life. This improves the basis on which decisions are made as to extending the bridge's service life or replacing it. The method also offers significant added value at portfolio level. Many existing bridges are similar in terms of age and construction, meaning that the approach is scalable and can be used to prioritise and selectively monitor entire bridge portfolios. At the same time, it must be taken into account that the statements are based on a limited measurement period without complete seasonal coverage and without longterm historical load data, and the results must therefore be interpreted with appropriate safety margins.

«Based on sensor data, the system helps infrastructure operators to identify risks at an early stage and plan targeted maintenance measures.»

Dr Panagiotis Martakis,
Founder & CEO, irmos technologies

04.
Legal issues: *liability and data protection*

The Innovation Sandbox tests new technologies not only from a technical perspective, but also in terms of the relevant legal requirements. Monitoring bridges with sensors, cameras and cloud-based analysis systems raises numerous questions about liability, availability, data protection and operational organisation. The pilot project provides an example of the framework conditions that infrastructure operators and technology providers must take into account when using data-driven methods in security- and safety-related areas.

Liability for damage to sensors or cameras
Sensors and cameras can be damaged by improper operation, structural interventions or vandalism. In such cases, the party that caused the damage is generally liable. If the damage is made worse by incorrect installation or inadequate securing, the technical provider may be responsible. On the other hand, damage caused by natural events such as storms, snow loads or flooding is considered force majeure and does not generally give rise to any liability. In practice, a clear allocation of roles is recommended: operators are responsible for access to the structure, while technical providers ensure safe assembly and regular maintenance.

Liability for incorrect measurement data
Wrong or incomplete data can arise if sensors are incorrectly calibrated, external influences are not properly accounted for, or technical faults occur. Liability always presupposes culpability or a breach of duty. From a contractual perspective, a contractor may be liable if installation errors, inadequate data processing or a lack of monitoring mechanisms are the cause. Non-contractual liability towards third parties only arises if bad data leads to damage and it would have been obvious that the measured values were incorrect. In the case of personal injury, product liability law may apply in addition; for damage to property, the provisions of the Swiss Code of Obligations apply.

Liability for misinterpretation
Data-driven systems provide indicators, but they do not replace engineering judgement. Operators must consider the measurement data in the operational context and make safety-related decisions themselves. Accordingly, the technical provider will only be liable if it provides incorrect analyses through gross negligence or if it breaches contractual obligations. One example is the failure to take account of obvious anomalies in the data, leading to incorrect recommendations. For operators, a risk arises if data is misinterpreted or used outside its intended scope of application. Clear responsibilities and training help to avoid misinterpretations.

04. Legal issues: liability and data protection

«Data-driven monitoring systems support operations, but they do not shift the responsibility for safety-related decisions from the operator to the technology.»
Stephanie Volz,
Managing Director ITSL, University of Zurich

Availability and system failures
Cloud-based platforms are central to operations. If the platform fails, or if its availability falls below the guaranteed minimum level, the provider may be held liable under the contract. Typical measures to minimise risk include redundant systems, automatic failure alerts, or local buffers to secure measurement data even in the event of connection problems.

Data protection and camera use
The data protection requirements depend on whether personal data is processed. Sensors that record purely technical measurements such as temperature, strain or acceleration are not covered by data protection legislation. Camera footage, on the other hand, may contain identifiable features, such as faces, licence plates or clothing of employees.

In such cases, operators must take appropriate measures. This includes:

- Information signs on site explaining the purpose, data controllers and retention period.
- Restriction of the image and camera angle so that only the relevant infrastructure areas are captured.
- Pixelation or automatic obliteration of individuals or licence plates in the analysis system.
- Swift deletion of the raw footage after it has been validated.

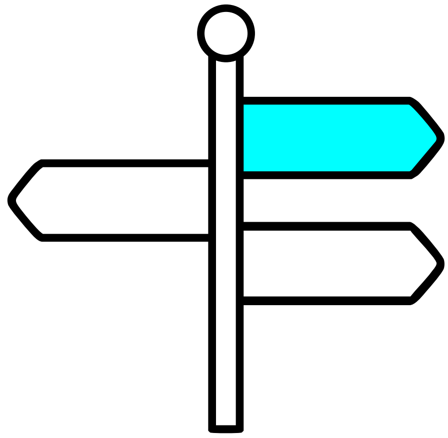
These measures reduce the risk of personal data being processed unintentionally.

Handling data securely
Technical and organisational protection requirements apply to all data (e.g. measurement values or camera images). This includes encrypted storage, access restrictions, regular security tests and defined deletion periods. Employees who work with the data must also be trained accordingly. The aim is to ensure that only the information needed for the intended purpose is processed, and that it is used responsibly.

Contractual provisions to mitigate risk
Carefully drafted contracts help to clearly delineate liability risks and responsibilities. This includes liability limitations per event, precise role descriptions and defined system availabilities, as well as provisions on data processing and data security. Liability for wilful misconduct or grossly negligent conduct cannot be excluded by law.

Overall, the use case shows that data-driven monitoring is legally and organisationally manageable – provided that operators set out clear responsibilities, take appropriate protective measures and embed the operation of the systems in robust processes.

05. Conclusion: *recommendations and outlook*



Data-driven monitoring approaches are not yet widely established in the area of bridge infrastructure. Nevertheless, they offer considerable potential. Continuous measurement data makes it possible to assess the condition of bridges more accurately, identify risks at an earlier stage and plan maintenance in a more targeted manner. This allows operators to manage their infrastructure more safely, cost-effectively and sustainably. What matters is that data-driven methods solve a specific operationally relevant problem – such as the question of how long a bridge can realistically remain in service or when which investments will be required. The following points summarise the key findings:

Only collect data if it creates clear added value
Data collection is not an end in itself. Operators need information to support clear operational decisions:

- How long will the bridge actually last compared to standards-based estimates?
- What investments have to be made and over what period of time (e.g. in the context of service agreements between the infrastructure operators and the Federal Office of Transport?[8]
- Does the data-driven monitoring indicate acute damage that requires immediate action?

Data-driven methods provide an objective basis for this, especially where conservative models may lead to unnecessary interventions or premature replacement.

From single property to portfolio: scaling as the key factor
The use of data-driven methods delivers the greatest added value when it goes beyond individual objects. Monitoring entire bridge portfolios enables comparisons, prioritisation and longterm investment strategies. Programmes such as the federal government's MODI initiative also show that a national framework for data-driven infrastructure policy is emerging.[9] At the same time, operators have to weigh up how much data they want to collect and how sensitive it is. In times of heightened geopolitical tension,

[8] Federal Office of Transport: Service agreements: objectives and indicators
[9] Federal Office of Transport: Mobility data infrastructure (MODI)

05. Conclusion: recommendations and outlook

infrastructure data is critical, which is why protection and governance measures remain essential.

Developing relevant skills and strengthening collaboration
For data-driven monitoring solutions to work effectively, engineering firms and operators must be confident in using new methods. They need skills in areas such as data interpretation, model validation and digital infrastructure. Open technology platforms with high interoperability are also important for harnessing the data potential. However, cultural change is just as relevant as technological change: openness to new approaches and a willingness to collaborate with specialist partners are key success factors.

Innovation at the intersection of costs, safety and established processes
In the Swiss infrastructure sector, safety is the top priority. As a result, conservative methods continue to dominate and cost pressure remains limited. This can slow down innovation. At the same time, the question arises as to when continuous monitoring makes sense: for a bridge that is likely to last for decades, a permanent monitoring system may be disproportionate. By contrast, if a bridge is close to the end of its service life, monitoring can reduce significant uncertainties and provide a stronger basis for justifying major investments. At portfolio level, data-driven monitoring approaches enable better planning and prioritisation.

Integration instead of parallel structures
Data-driven monitoring approaches are still in their infancy and are not yet an integral part of the established standards-based condition assessment. However, without early integration, there is a risk that parallel structures will emerge in the future, leading to additional costs. In the long term, both methods must be interlinked in a meaningful way, so that measurement data can be used to refine, supplement or – where it provides greater insight – gradually replace existing models.

Data creates scope for action
The key insight gained from the sandbox project is: data creates new scope for action. It enables more nuanced decisions, reduces uncertainty and allows operators to not only maintain their infrastructure but also actively control it. The outlook is clear: as experience grows and skills, models and interoperable systems improve, data-driven monitoring will become an important part of modern, resilient and forward-looking infrastructure maintenance.

«Data-driven monitoring provides a reliable basis for decision-making and will complement the planning and maintenance of infrastructure in the future.

Raphael von Thiessen,
AI Sandbox Programme Manager,
Canton of Zurich

Glossary

Deflection
The vertical deformation of a bridge under load. An increase or change in deflection may indicate structural problems.

Dynamic amplification coefficient
A factor which takes into account that moving loads such as trains place more stress on a bridge than stationary loads. It quantifies how much higher the actual load is under operating conditions.

Fatigue
Gradual deterioration of the material due to repeated load cycles over many years. Fatigue can lead to cracking and a reduced service life.

Structural reassessment
Engineering reassessment of an existing structure based on current standards and assumptions. It does not reflect reality directly, but instead depicts it with conservative models.

Remaining service life
The amount of time for which a bridge can still be operated safely. It is based either on standard assumptions or – more precisely – on measured loads and stress cycles.

Stiffness
Describes how much a bridge deforms under load. Low stiffness or an unexpected reduction in stiffness may indicate structural changes or damage.

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Case studies from the Innovation Sandbox for Artificial Intelligence (AI)
The company irmos technologies served as a case study within the Innovation Sandbox for AI. The organisation submitted a project proposal to the Sandbox in summer 2024. In collaboration with the implementation partner Schweizerische Südostbahn AG, the project team tested sensor-based bridge monitoring through to the end of 2025. The content of this report was developed on the basis of this specific case study.

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