

Rockfield
Reimagine. Transform.

*Structural Health Monitoring
.....the next frontier
- Govinda Pandey*

OVER 25 YEARS OF ENGINEERING EXCELLENCE

*A technology-driven approach to asset and infrastructure
management.*



Bridge Asset Management Challenges

Many ageing bridges fail modern standards

Many of them have proven past performance

Freight loads have increased over time

Recent failures have fueled public anxiety

Strengthening/replacement too costly

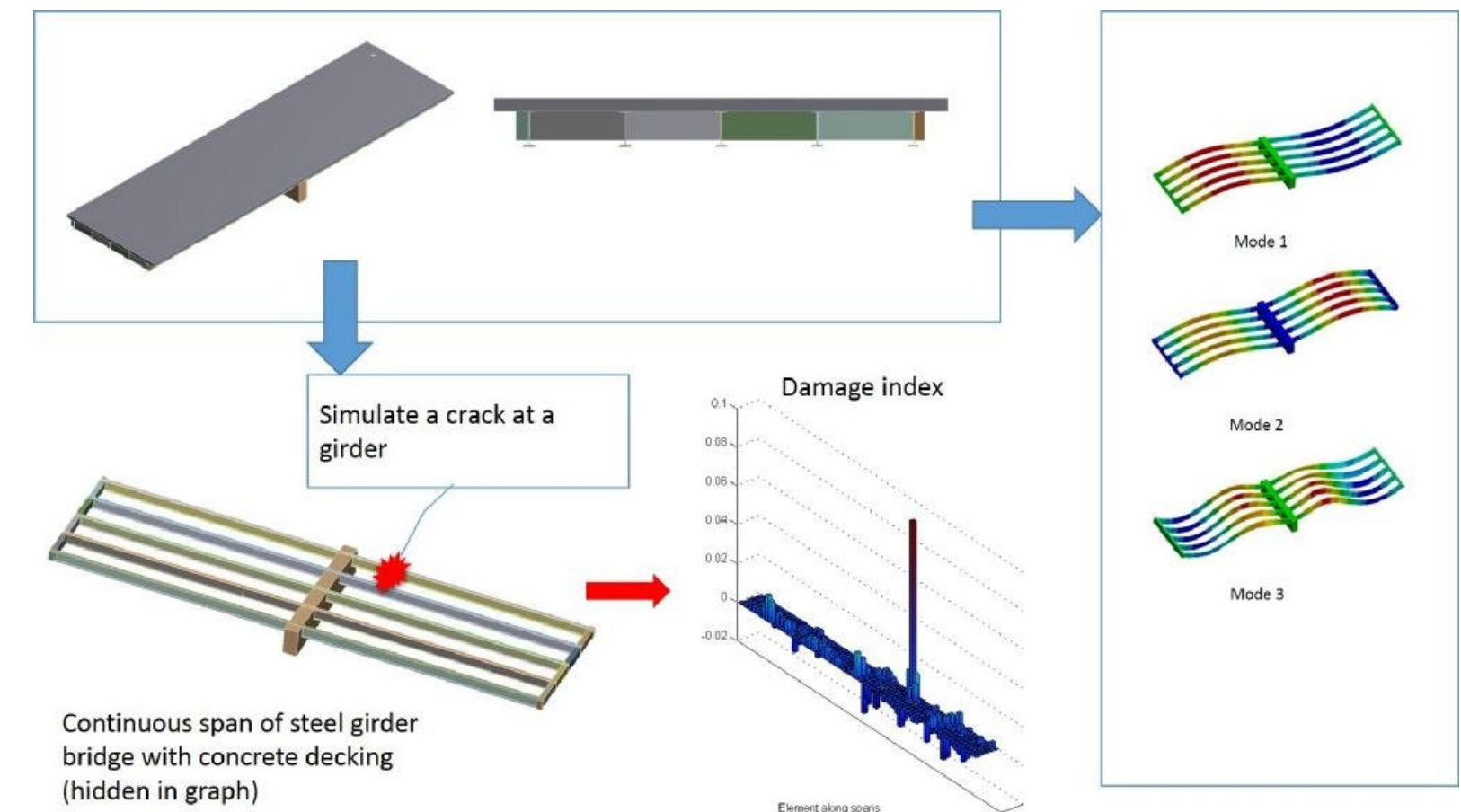
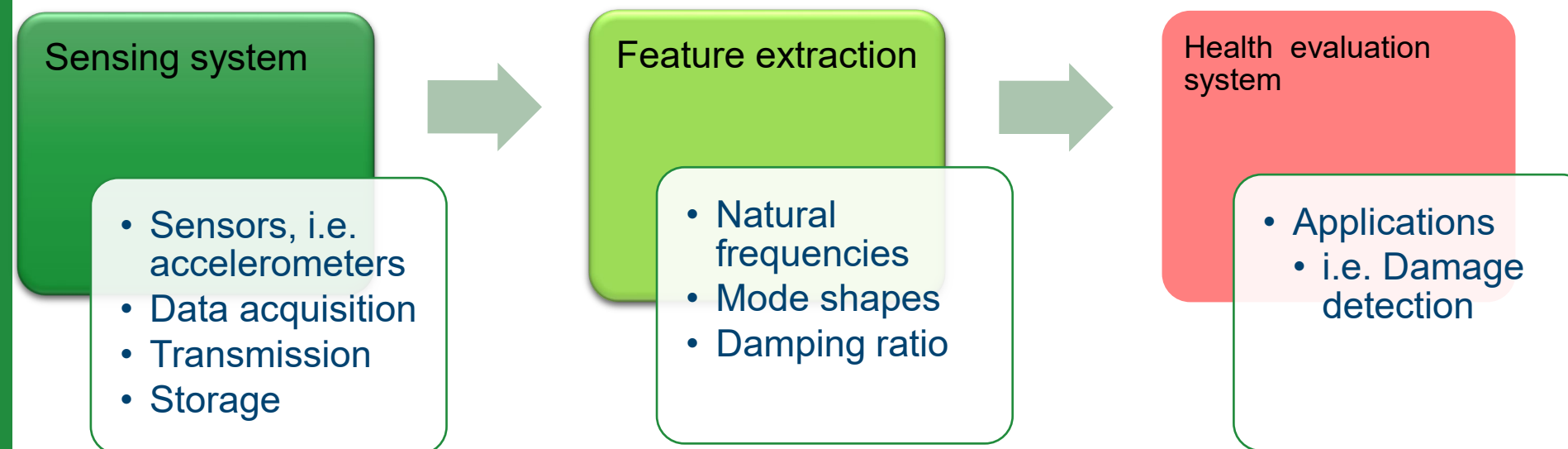
Restrictions trigger economic pain

No real performance data to guide decisions



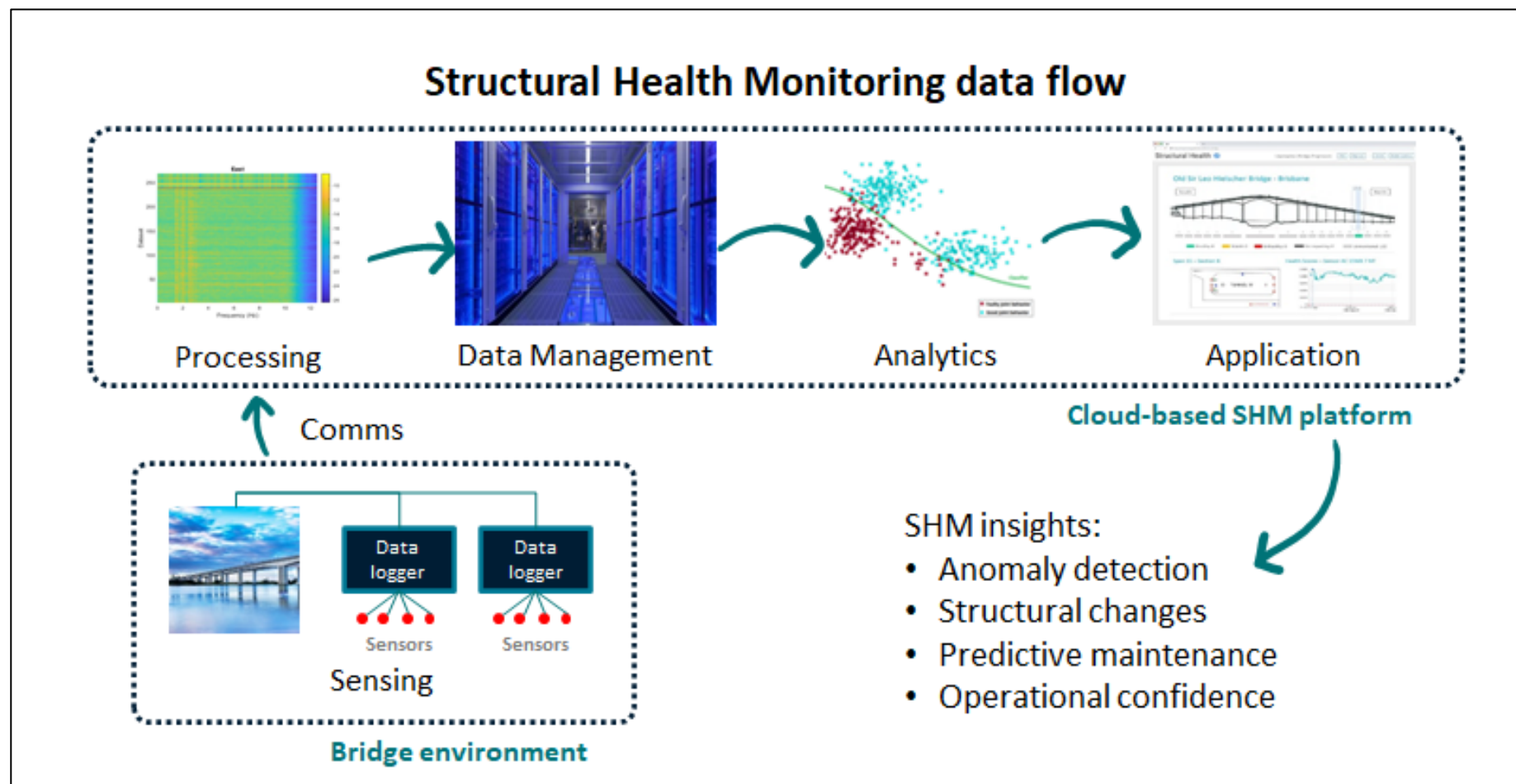
SHM for Damage Detection

- Use of on-structure sensing systems to monitor the performance of the structure, evaluate its health state, and detect early damage using vibration-based methods.
- The outcome showed promise, but the damage must be very large, and the sensing system needs to be pervasive for reliable and timely detection.

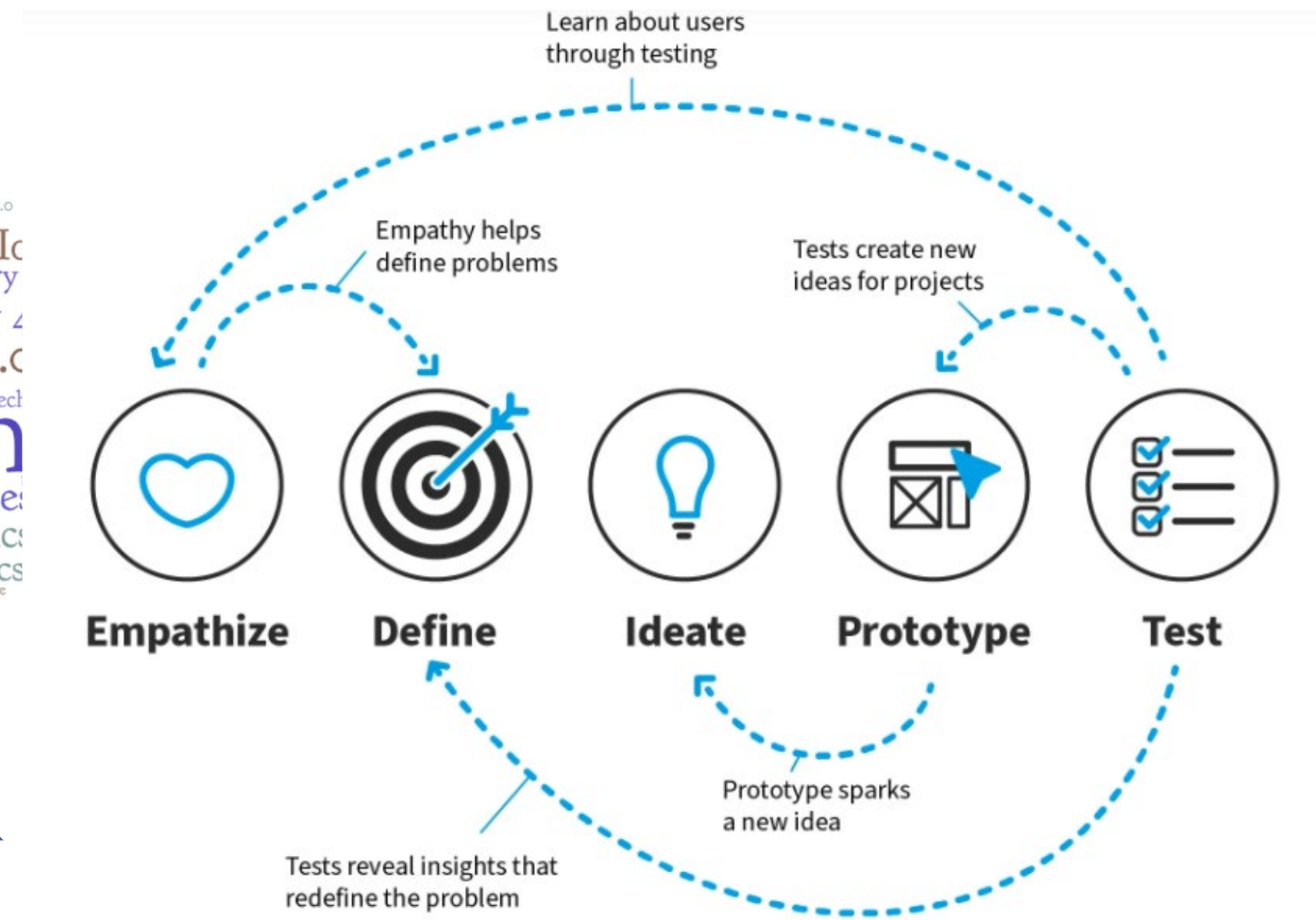
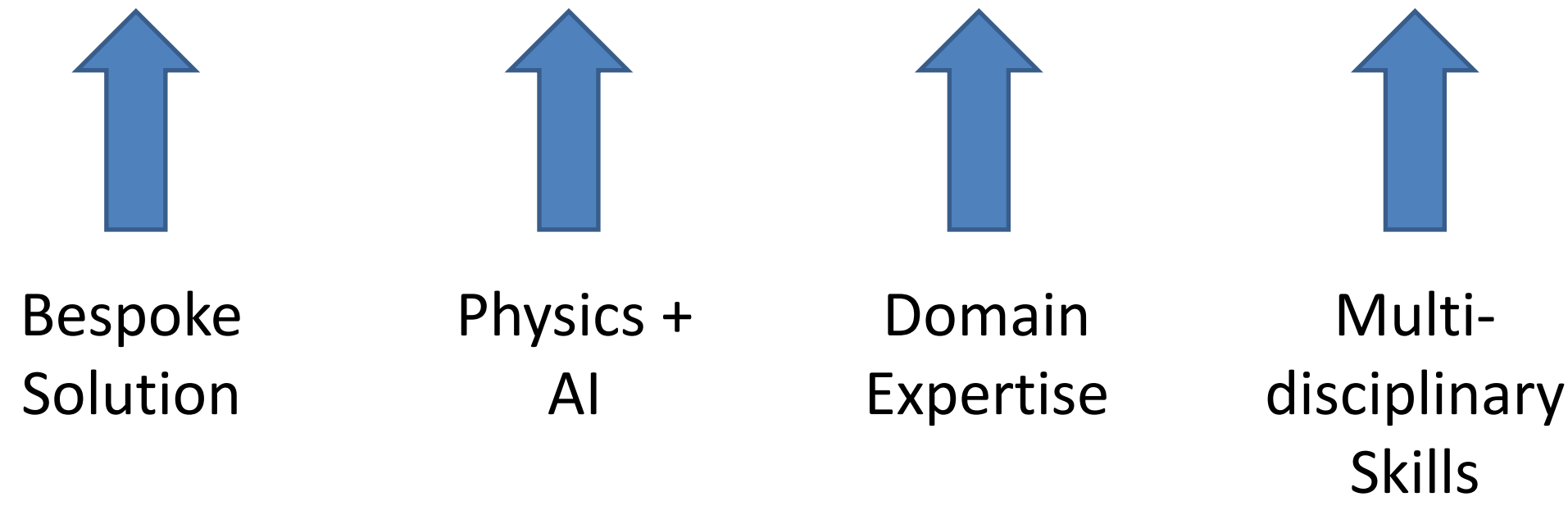


SHM with AI/ML

- Structural Health Monitoring of Critical Infrastructure.
- Real-time monitoring of the asset performance, alerts, and user interface.
- Demonstrable power of machine learning and health score algorithms.
- The gap was on linking the health score with bridge performance.



Key Learnings



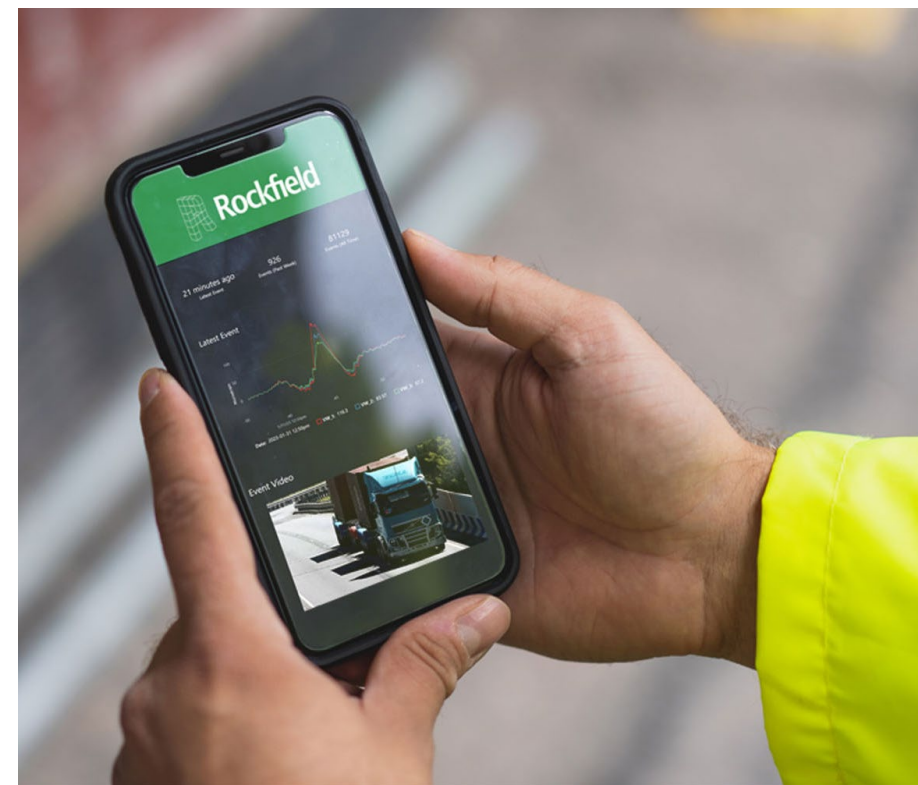
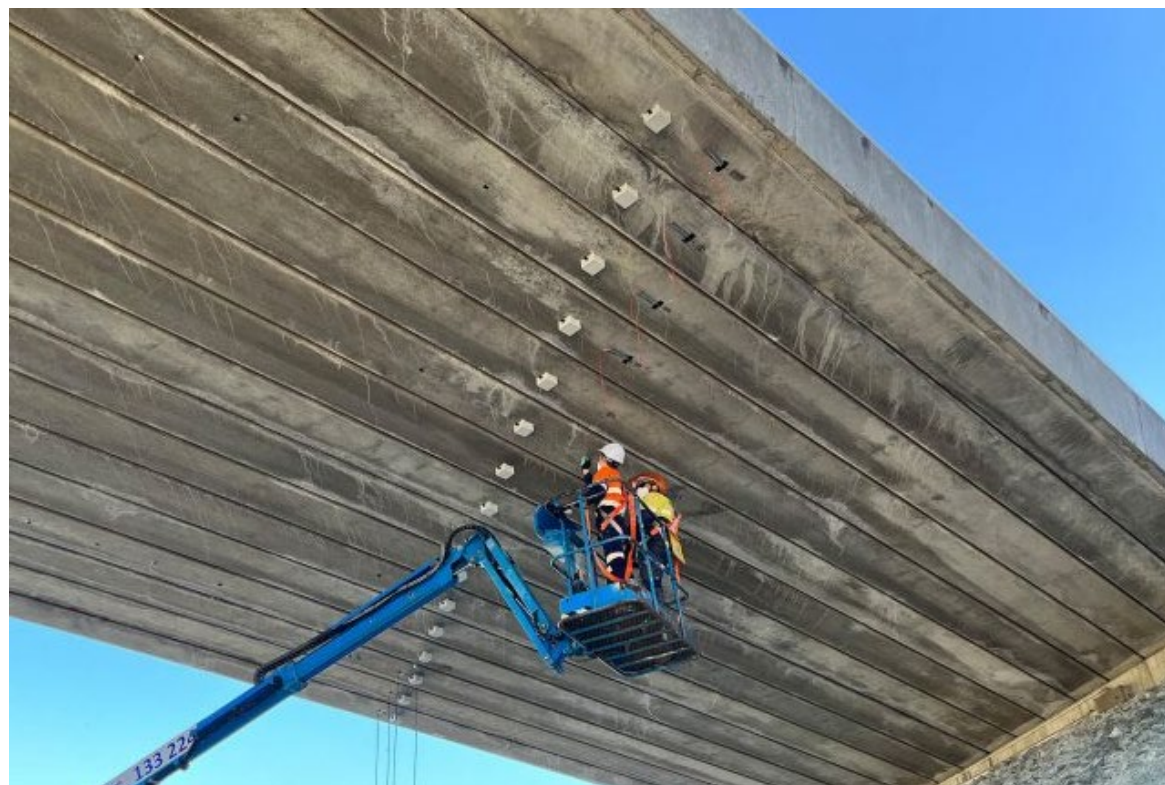
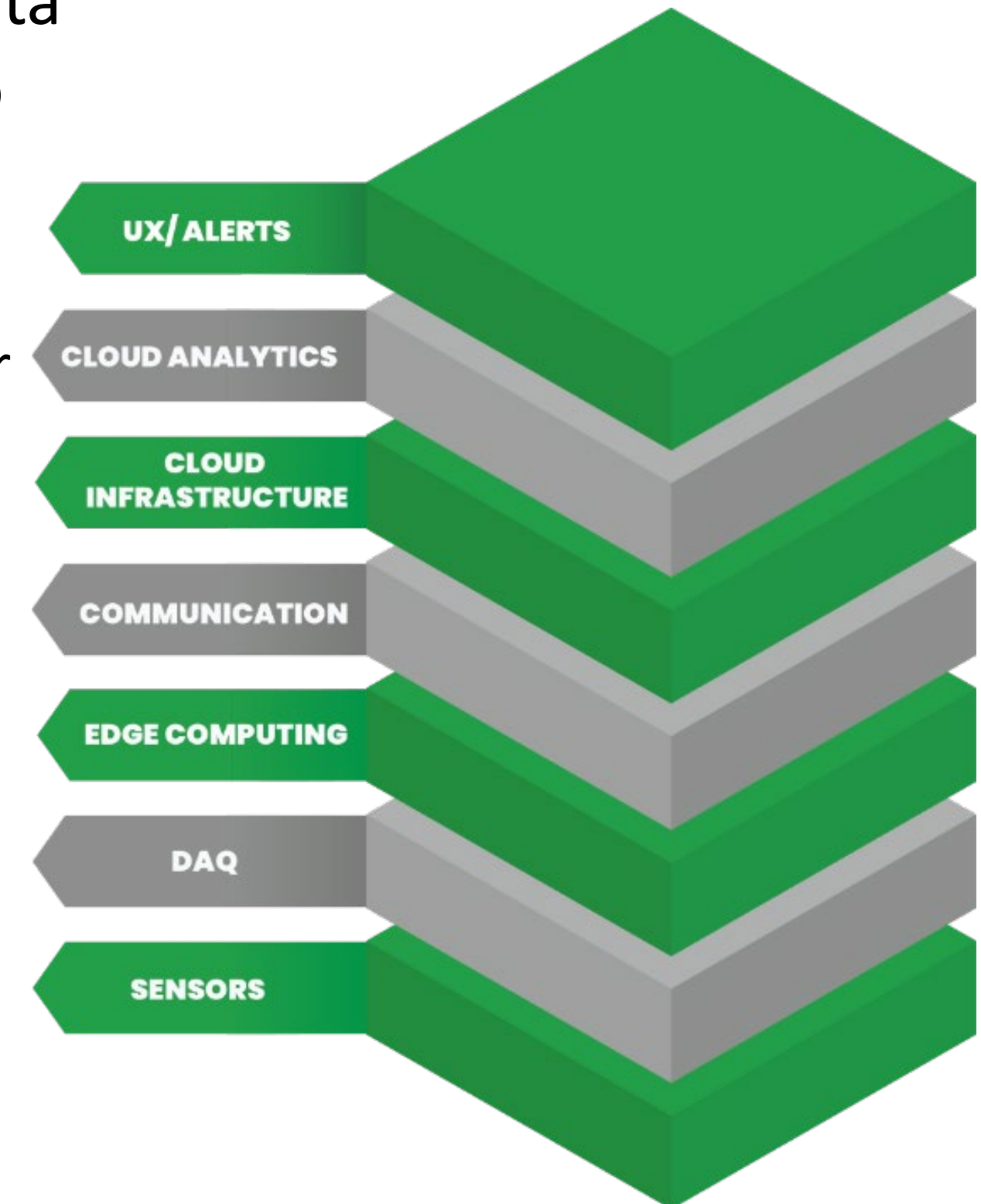
Design Thinking

Source: interaction-design.org

Full - stack SHM Technology

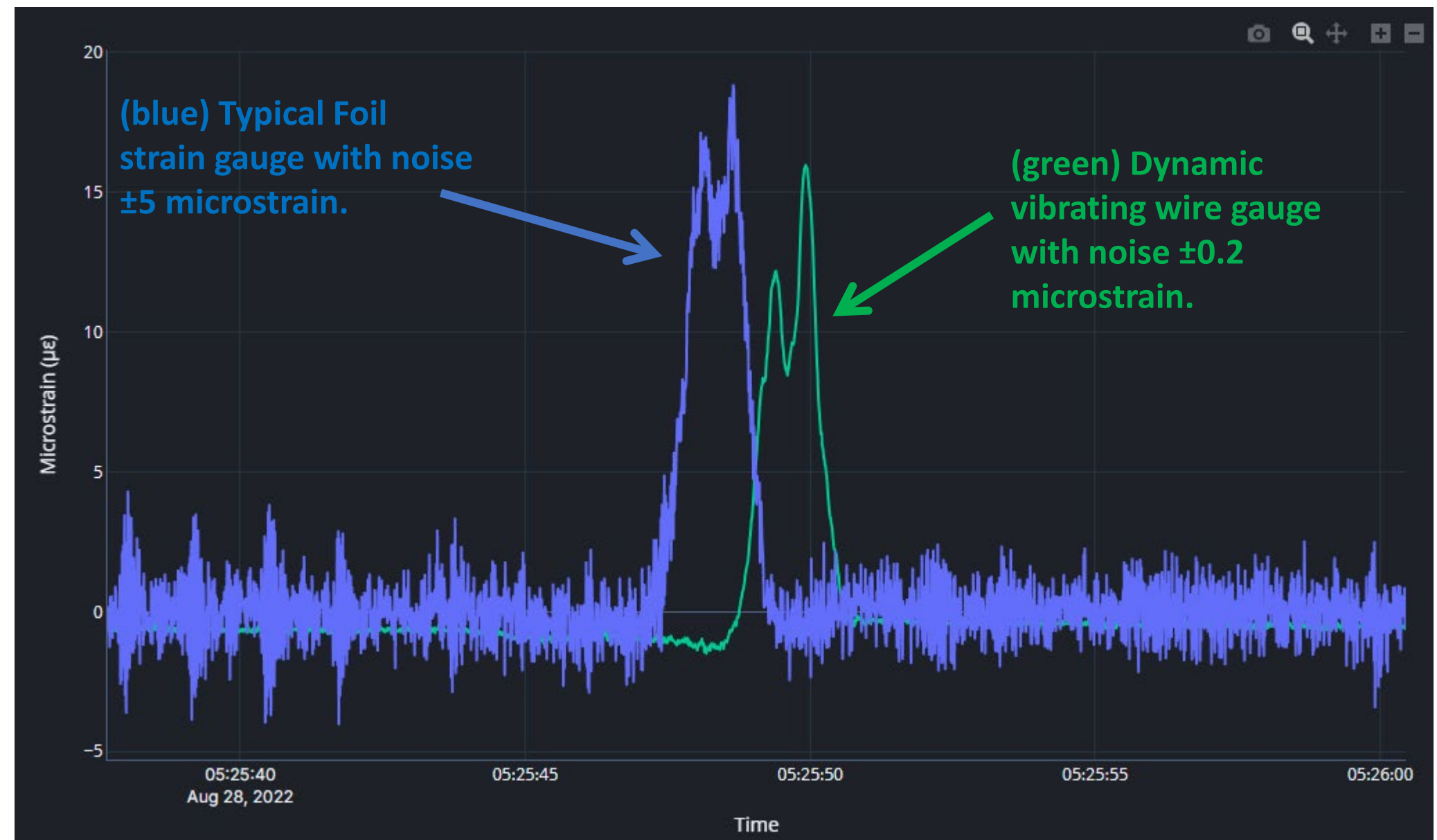


- Mercuto was developed to fill the gap in event-based data platforms, enabling advanced bridge analytics and video synchronisation.
 - A full-stack in-house solution
 - Uses Advanced Dynamic Vibrating Wire, fibre optics and other high performance dynamic measurement techniques



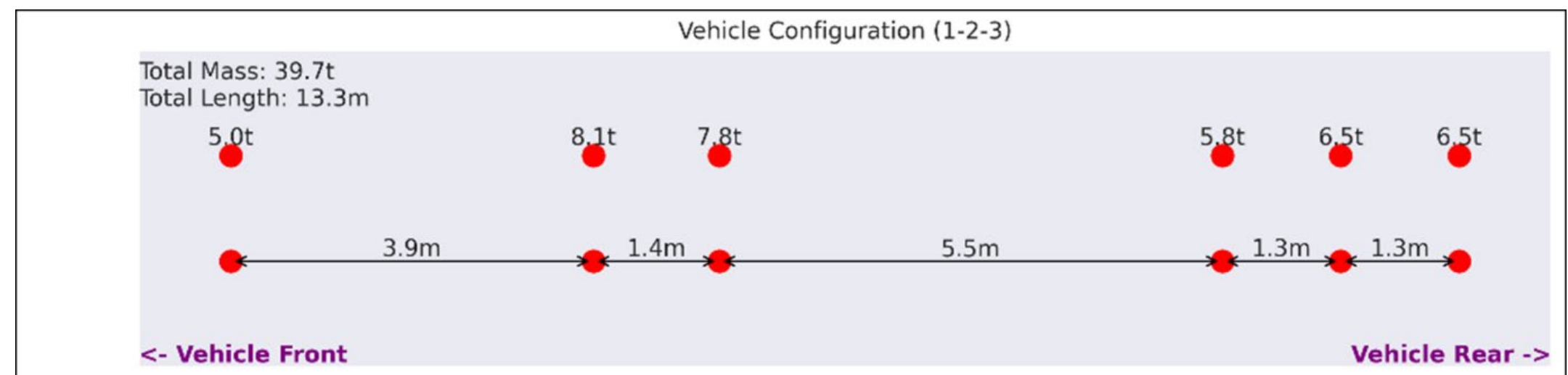
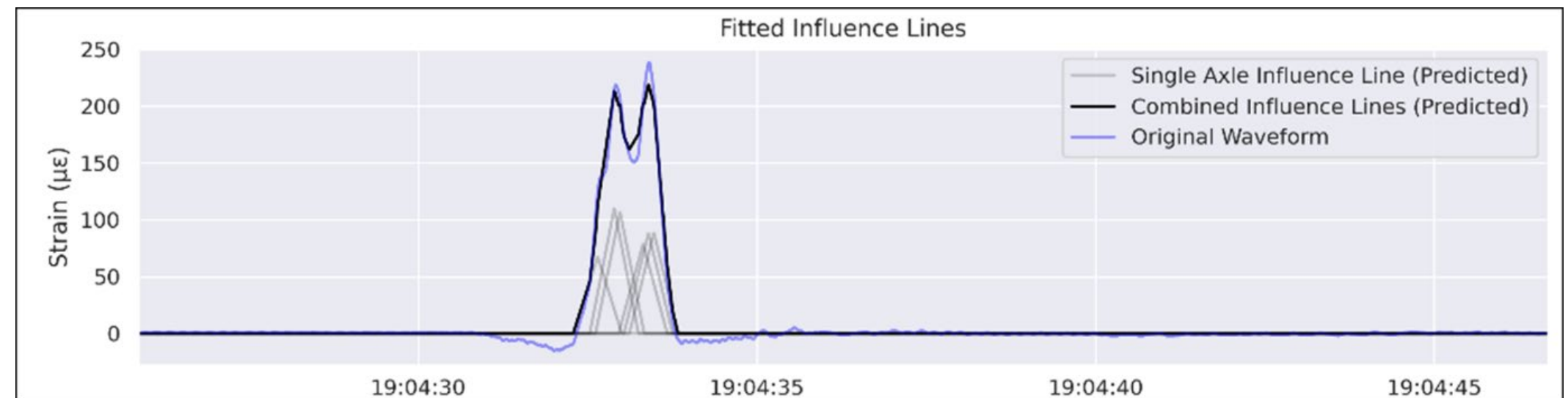
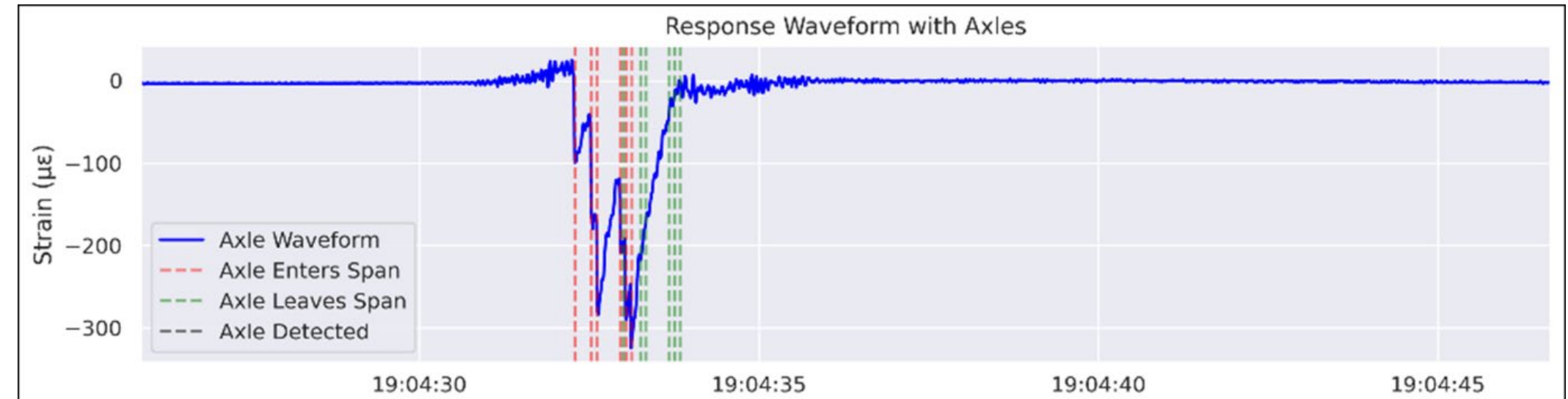
Sensor Technology

- Vibrating wire technology is well regarded for low noise, accuracy, and robustness.
- Vibrating wire sensors can be used in dynamic monitoring applications
- Sampling rates $>200\text{Hz}$
- Higher signal quality, longer lifespan, and lower noise compared to typical analogue strain gauges



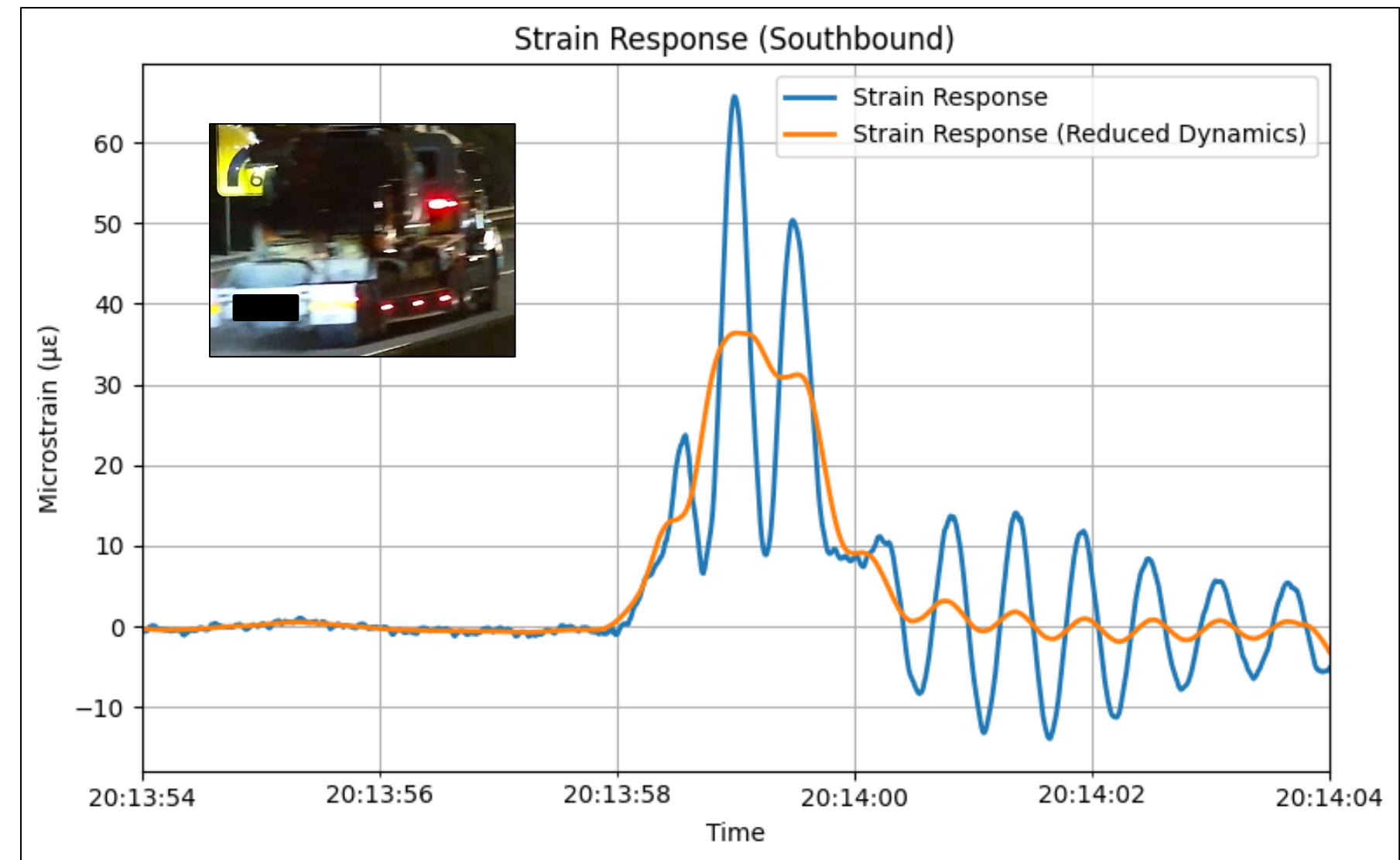
Bridge Weigh - in - Motion

- Bridge response data isolates vehicle axles entering and exiting a bridge span
- Theoretical influence lines derived from axle positions fit to the measured response.
- Output of vehicle classification showing individual axle masses, total mass and vehicle length.
- Effectively estimating GVM consistently within a few %.



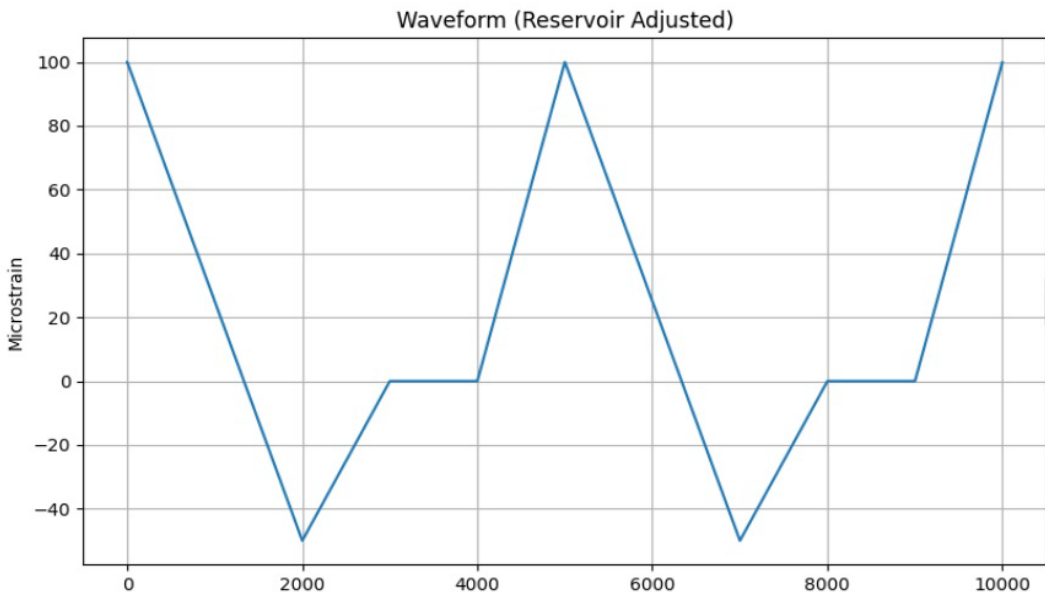
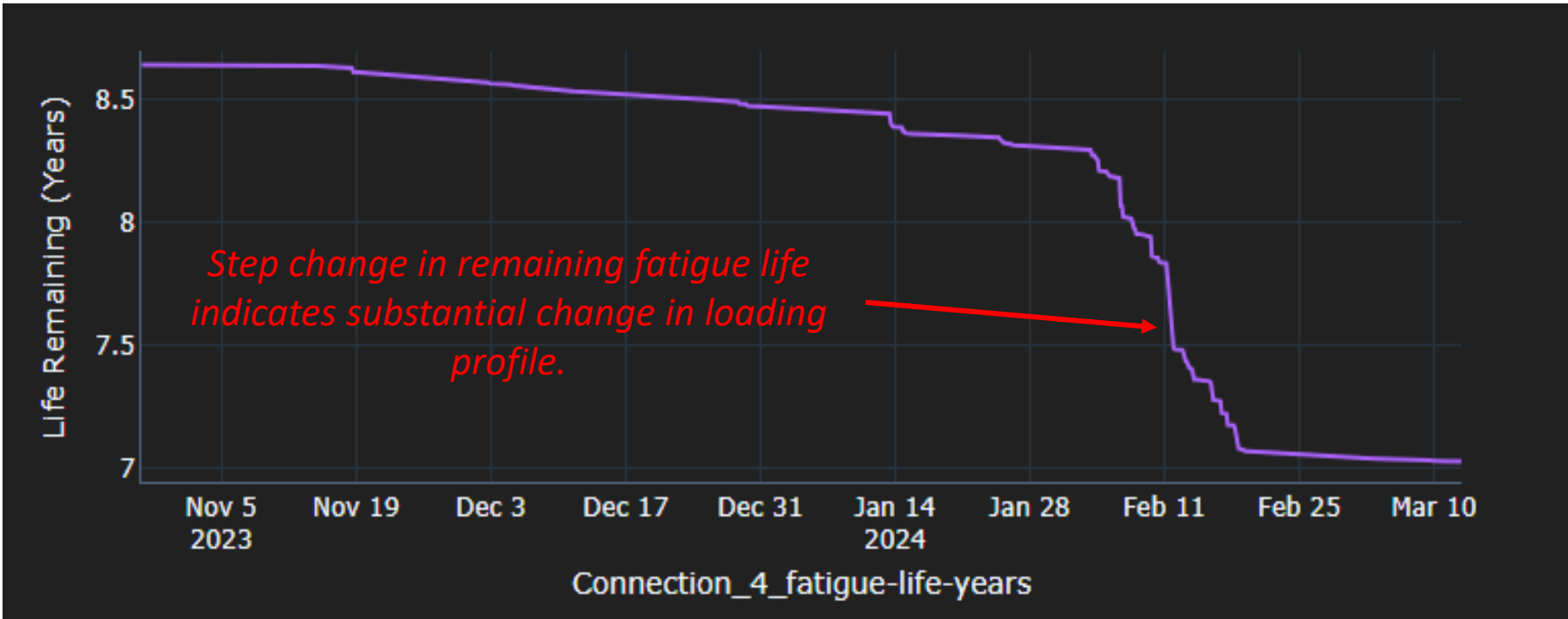
Dynamic Amplification Factor

- Understand the dynamic amplification for live data. How does vehicle speed, lane position, and vehicle class influence forced dynamics and increased loading?
- Perform a low-pass filter on measured response data to remove high frequency dynamics.
- Automatically isolate the optimal filter cutoff frequency based on dynamics present in the waveform.
- Plot and interrogate events that induce higher dynamic loads on the structure. Find offending vehicles and reasons for increased dynamics.



Fatigue Life Assessment

- Automatic counting of fatigue damage using rainflow cycle counting algorithms.
- Strain to stress conversion and input of material properties
- Damage accumulation using Miner's rule summation and S-N stress cycle curve for given material
- Remnant fatigue life and damage estimates based on BS7608 standard or similar
- Forward extrapolate damage accumulation based on real-measured data. E.g. estimate number of years remaining until fatigue cracking occurs based on the current loading conditions.
- Reservoir adjustment mechanism to suit event-based monitoring.
- Visualize changes in vehicle patterns that impact remaining fatigue life.

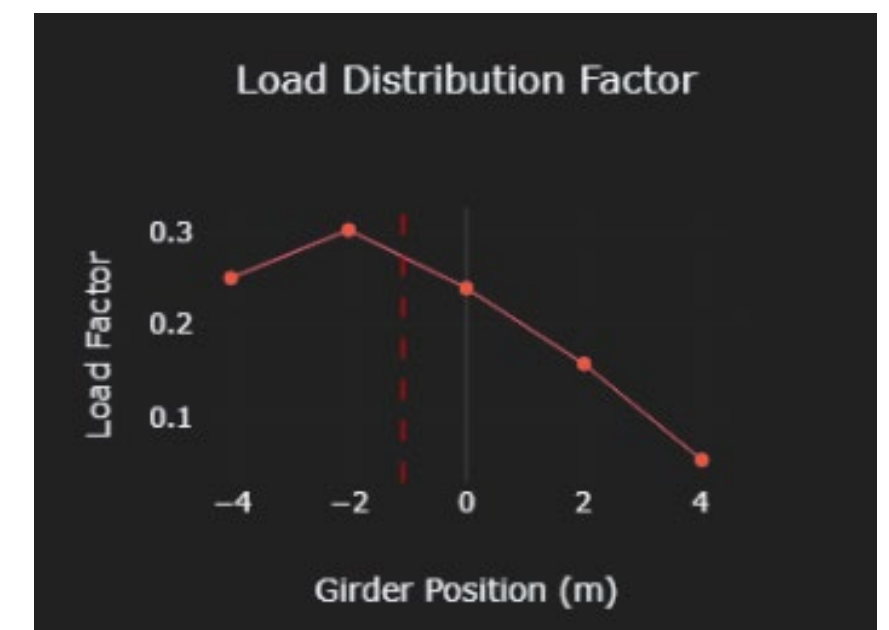
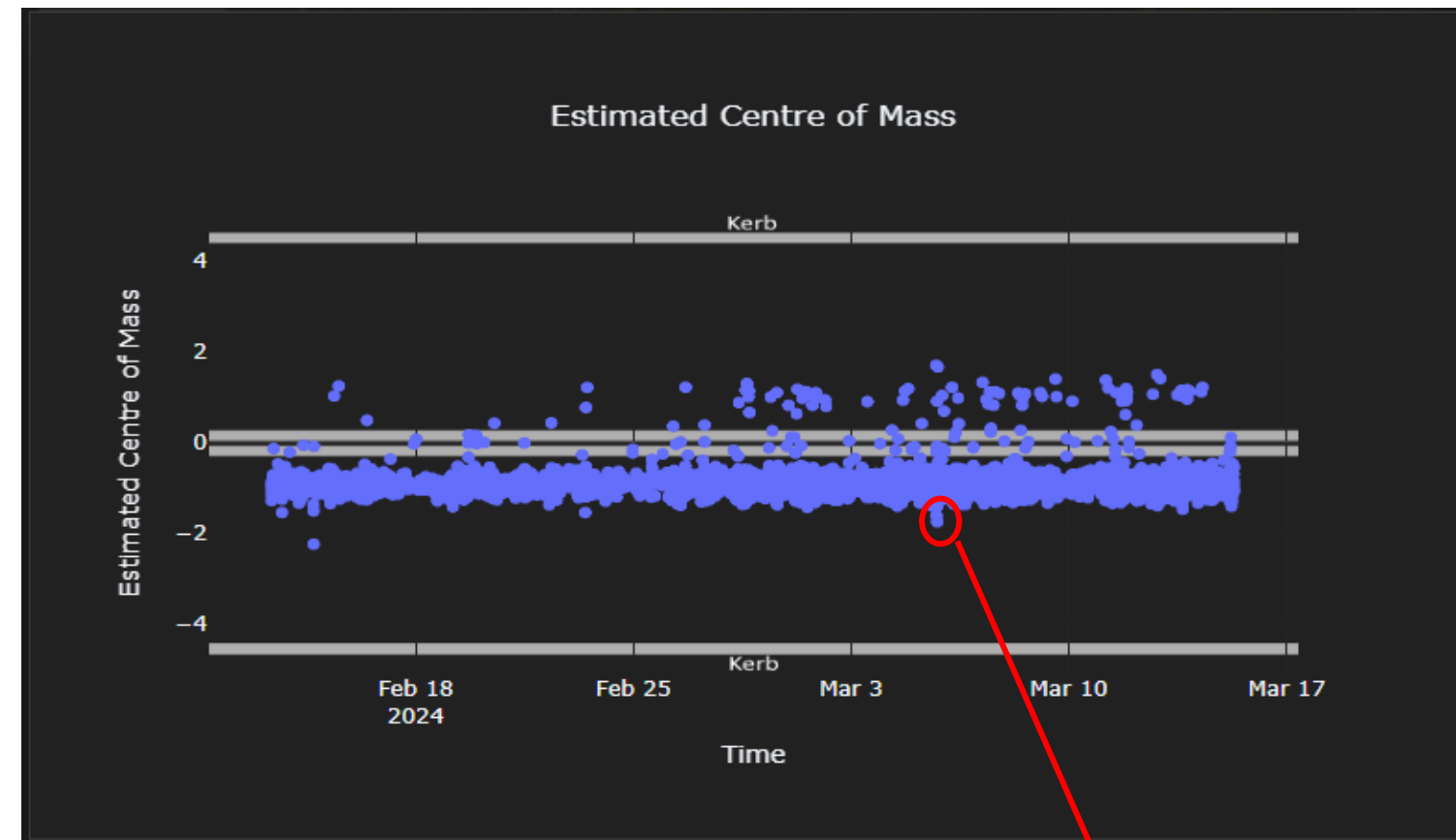


CONNECTION ↑	ESTIMATED REMAINING LIFE ↑
☑ S6G1-Spl	42.1 Years
☑ S6G2-Spl	49.3 Years
☑ S8G3-Spl	154.0 Years
☑ S6G3-Spl	162.9 Years

Strain Bin	# Cycles
149.5	2.0

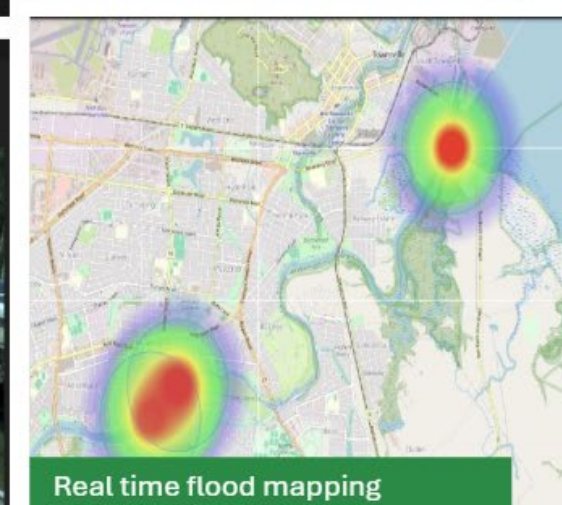
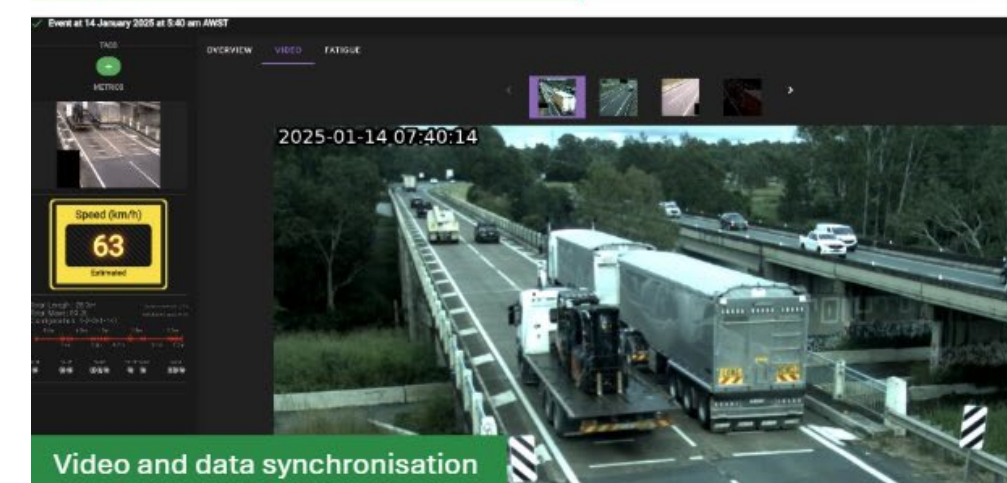
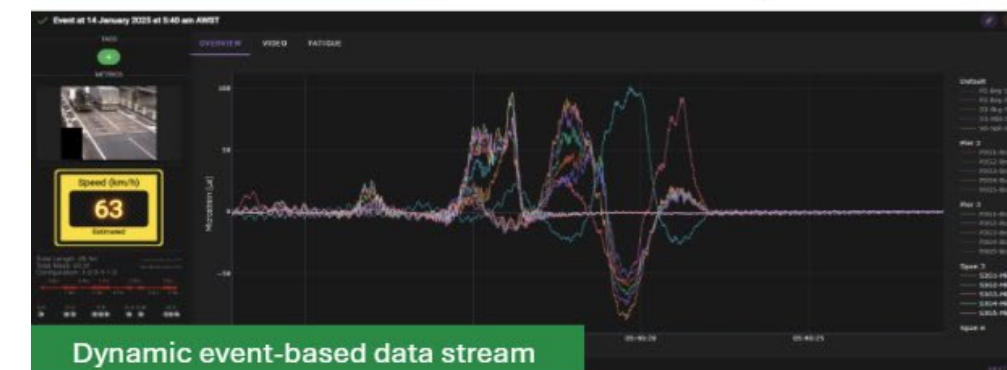
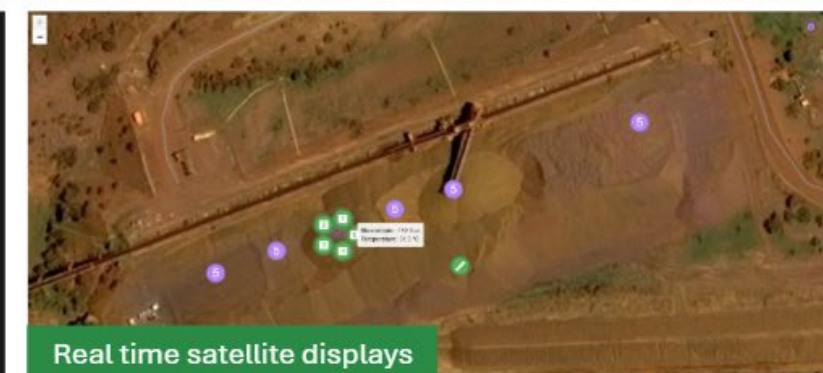
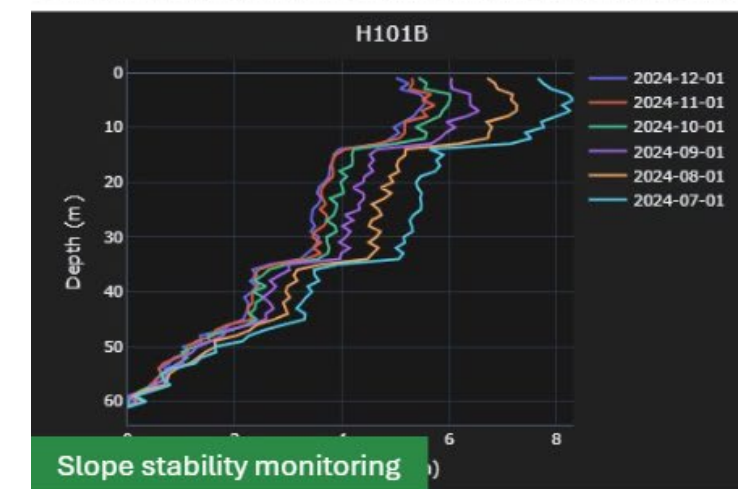
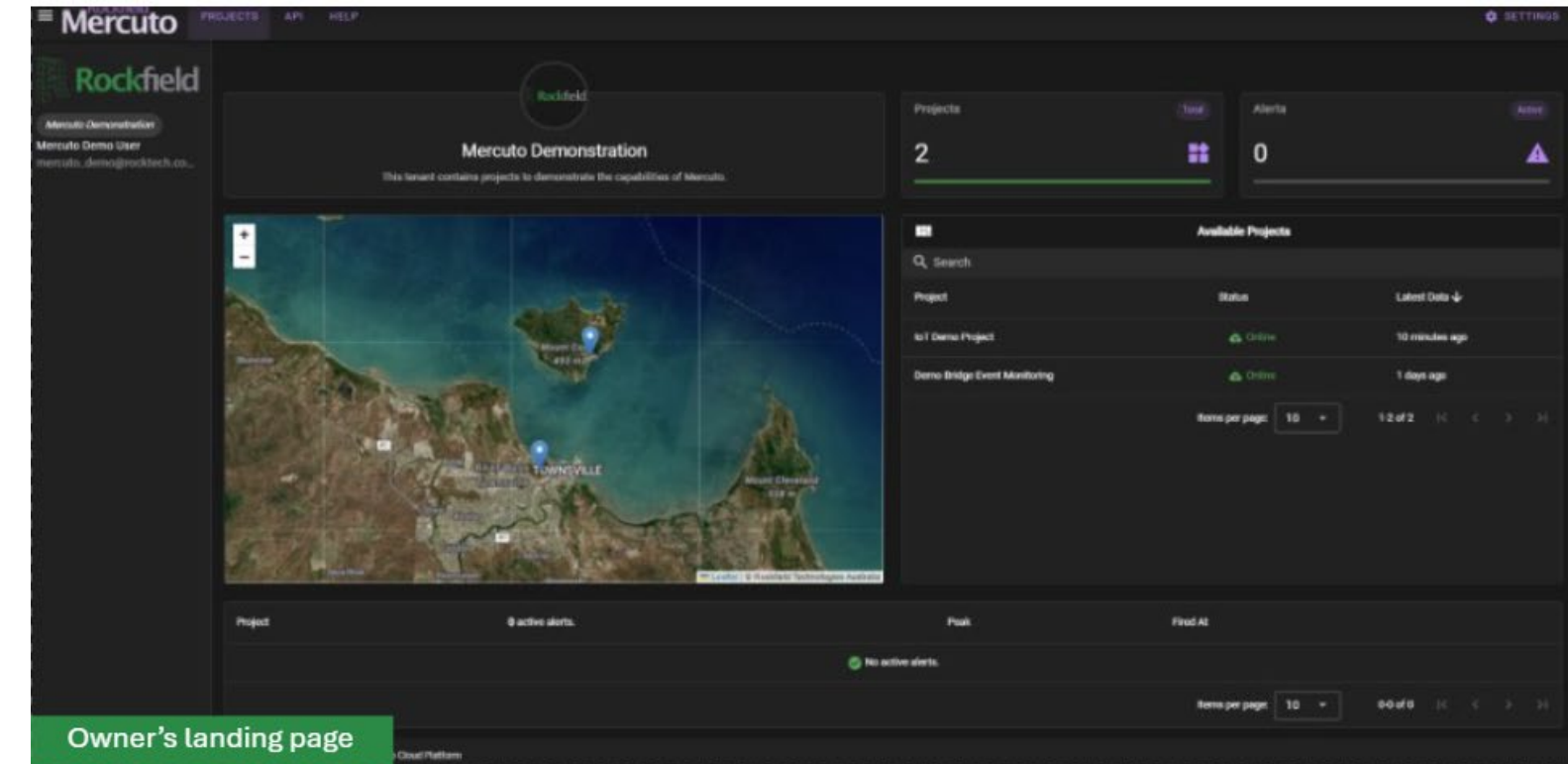
Compliance: Vehicle Speed & Lane Position

- Bridge load restrictions often enforce lane limits and drive line limits for heavy vehicles.
- Mercuto can use strain data to estimate the drive line and speed of heavy vehicles on the bridge
- Combine with vehicle mass estimation and cameras to identify non-compliant vehicles.
- Identify trends in traffic patterns and drive lines to optimize fatigue loading.
- Support for Automatic License Plate Recognition (ANPR) cameras.



Where are we today?

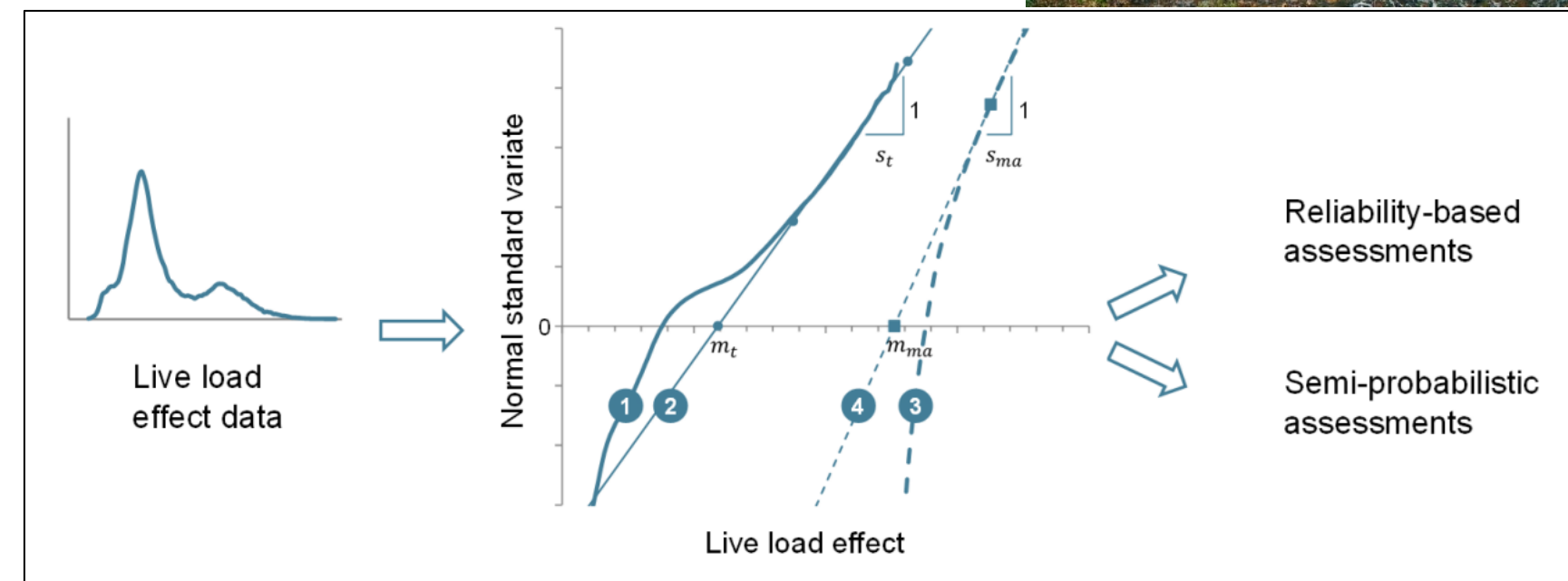
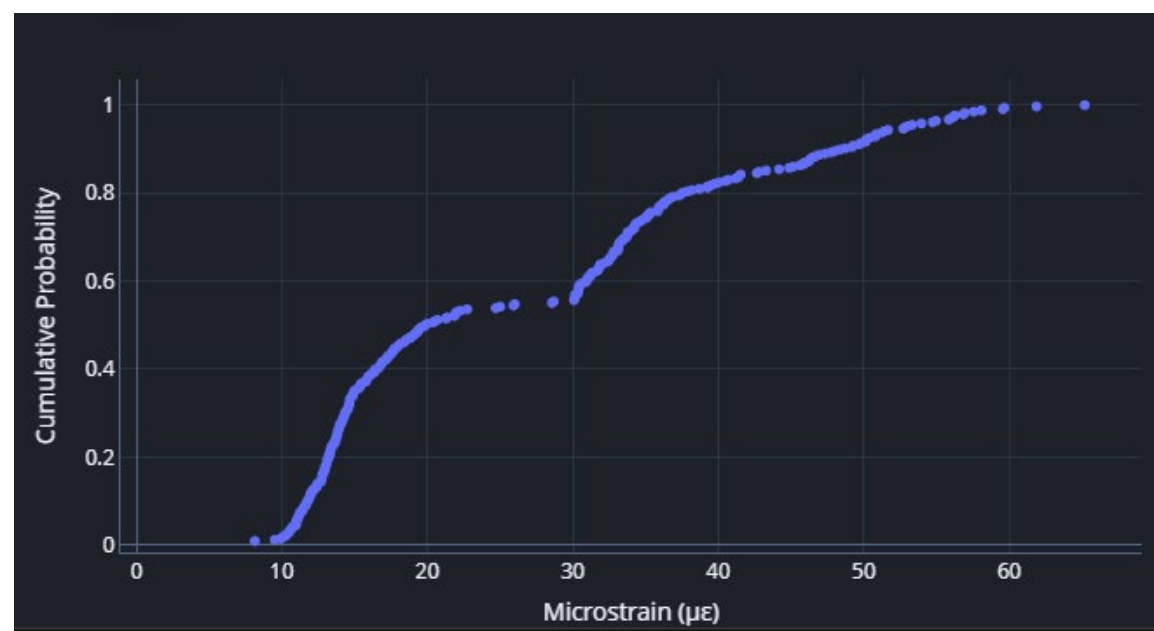
- Near real-time event-based bridge monitoring
- Secure cloud data hosting and management
- Advanced analytics including B-WiM, fatigue life, etc.
- Bridge Performance Monitoring
- Interactive data visualization and interrogation of high frequency event-based data
- Map views, bridge-specific data analysis tools, custom widgets
- Email and SMS alarms
- Scheduled reports and custom graphics
- Videos and images linked to events



Next steps: Closing the Plausibility Gap



- Closing the gap between poor theoretical rating and adequate performance
- Probabilistic based assessment of bridge live loading
- Estimate 1 in 50- and 1 in 100- year extreme loading scenarios
- Categorize and classify high strain events based on vehicle type. E.g. top 5% of load events are caused by vehicles of type X.
- Enable bridge specific live load modelling



Next Steps: Beyond B - WiM

- Network wide asset monitoring.
- Enabling network resilience and safety management
- Integration with ITS and GIS to enable traffic control and management
- Best bridge to install a WiM system may not be the critical bridge but the one several kms up stream.



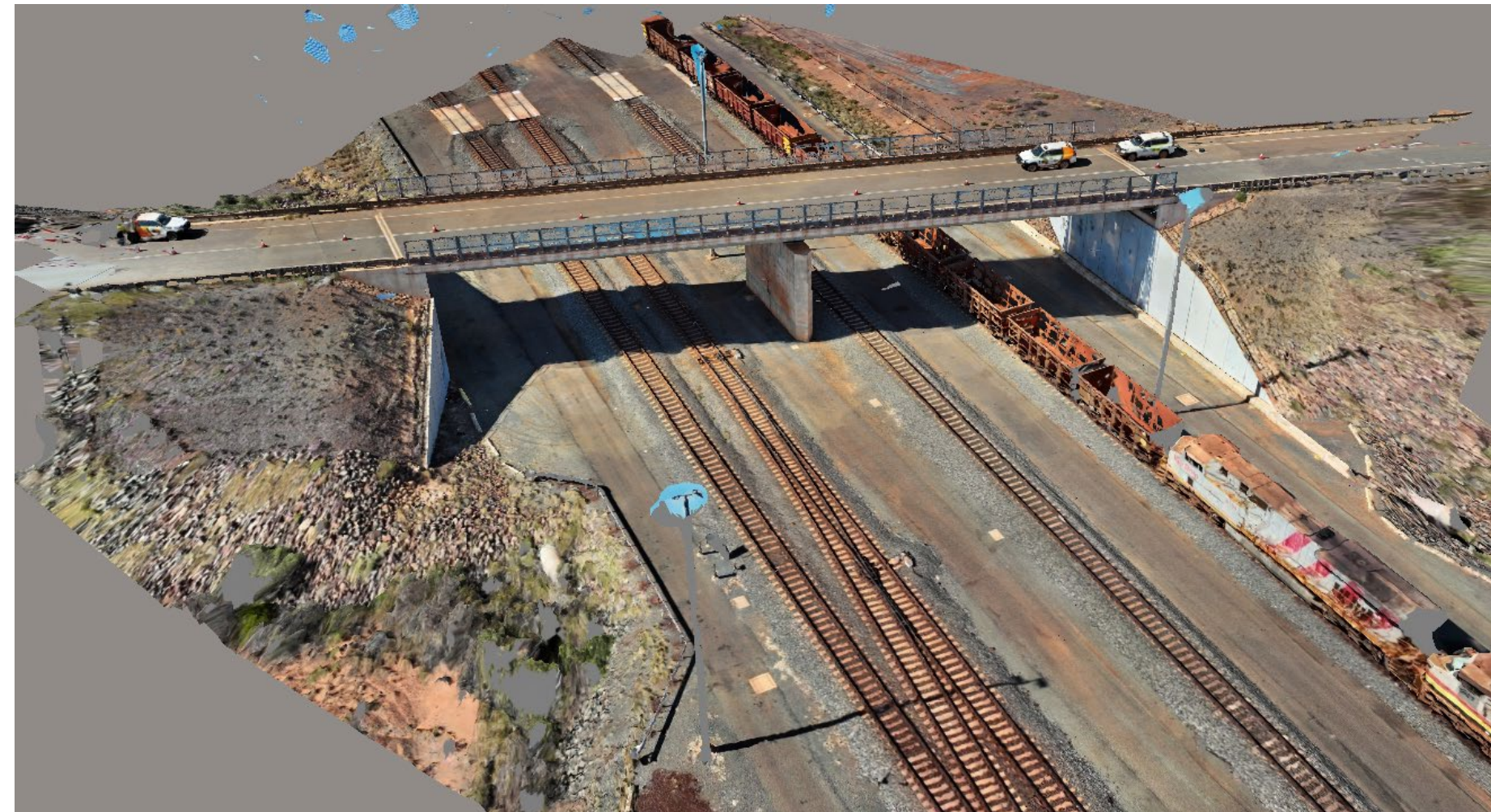
Next Steps: Smart Cities Integration

- Smart Cities initiatives and SHM operate in silos
- Smart Cities initiatives generally focus on environmental monitoring and liveability
- Interaction of built and natural environments
- Disaster resilience
- Network asset management in disasters such as flood / bushfire



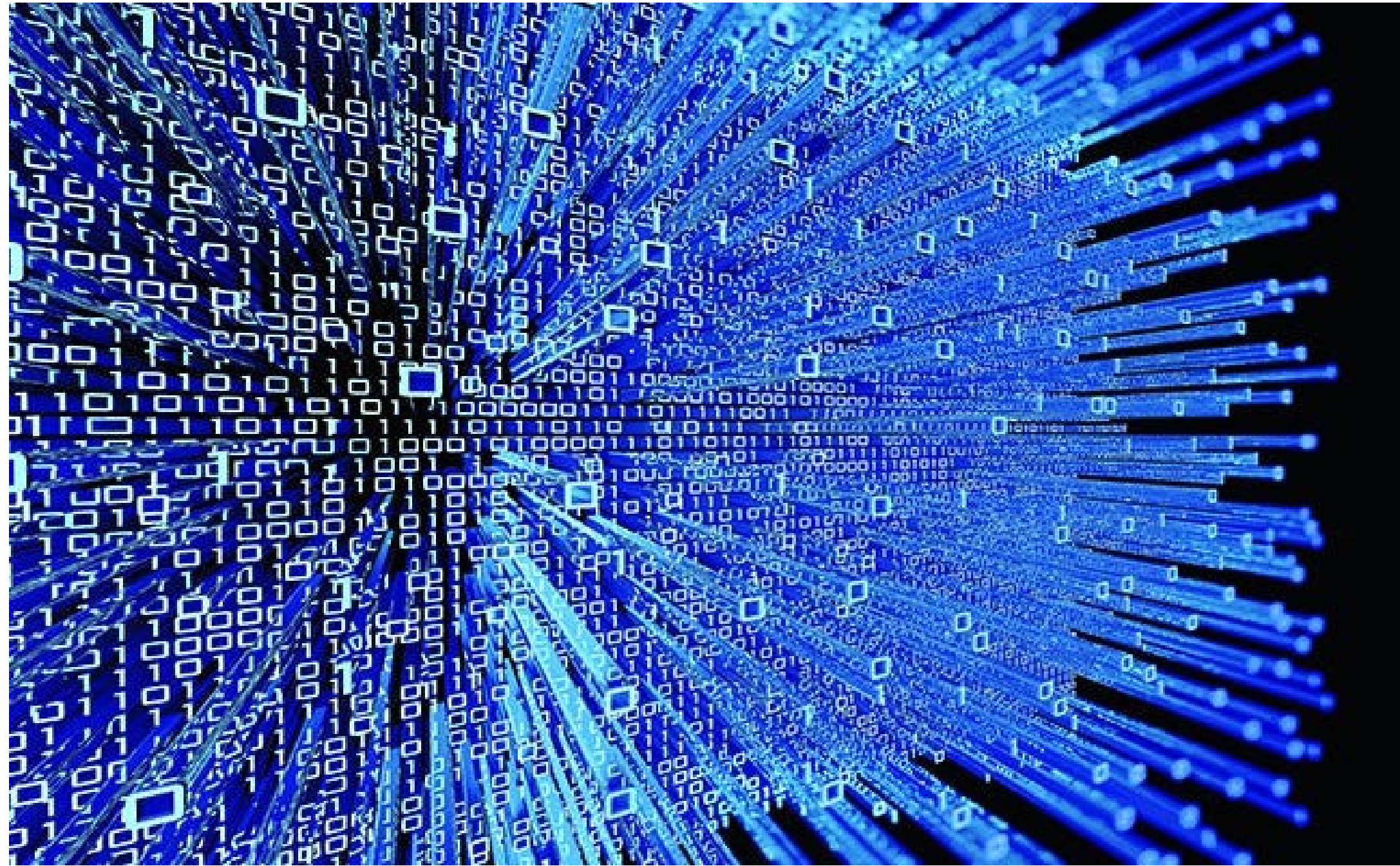
Next Steps: Dynamic Digital Twins

- Digital twin technologies have been well accepted in L2 Inspections and Condition Monitoring
- Fusion of sensing data with condition monitoring
- Turn digital twins into dynamic digital twins
- Digital twins simulate stress scenarios and forecast structural performance with high accuracy.



Next Steps: Data Mining

- Collecting a huge amount of sensor, image and environmental data
- Sensor data often exists in isolated silos, complicating comprehensive analysis and decision-making.
- AI/ML
- Development of algorithms
- Digital marketplace for monitorisation
- Collaboration with the University and data owning agencies.



Next Steps: Driving Cost Efficiency

- Current SHM systems are reactive, highlighting the need for integrated and predictive infrastructure monitoring.
- Better planning
- Coordination (time with inspection cycles)
- Wireless technologies
- Drone deployment / robotics



Next Steps: Standardisation of Best Practices

- Improved data consistency: Standardised methods ensure comparable data across assets, projects, and organisations.
- Greater interoperability: Sensors, platforms, and analytics tools work seamlessly together, reducing integration effort.
- Enhanced reliability and confidence: Common procedures improve the credibility of monitoring results and support better engineering decisions.
- Reduced cost and complexity: Standard protocols streamline deployment, training, procurement, and long-term maintenance.
- Scalable implementation: Consistent frameworks enable broader adoption of SHM across networks, moving from pilots to system-wide programs.



Closing Remarks

- The industry has made some great progress over the past few years
- The next leap forward requires deep multi-disciplinary collaboration amongst academia, government and industry.
- Organisations such as ANSHM has a key role to play in pushing boundaries.



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