



I-90 DIGITAL TWIN BRIDGE PROOF OF TECHNOLOGY EVALUATION

Final report to FHWA Washington Division/ Mobility Innovation Center, CoMotion
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UNIVERSITY *of* WASHINGTON



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PROJECT DESCRIPTION

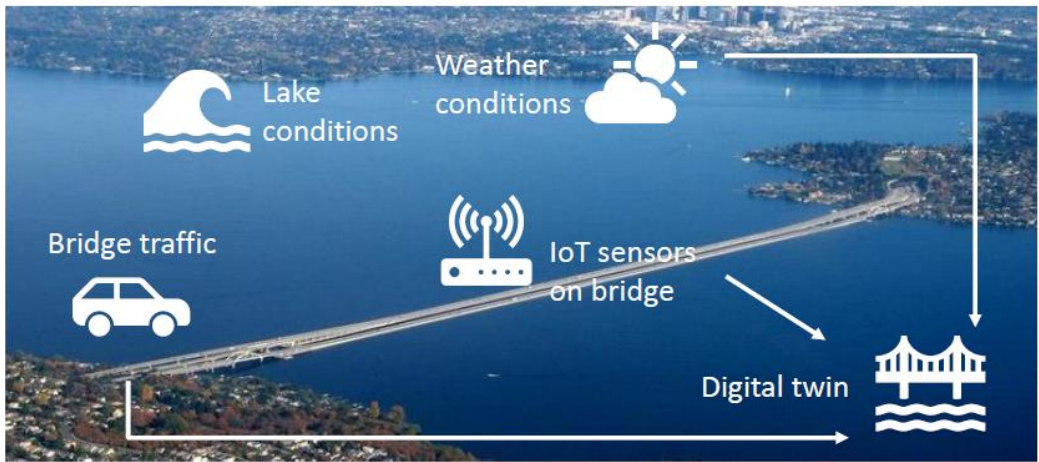
The I-90 Digital Twin Proof of Technology Evaluation is a proof-of-concept research initiative led by the University of Washington in collaboration with the Washington State Department of Transportation (WSDOT), Sound Transit, and multiple industry partners. The project evaluates the benefits, limitations, and tradeoffs of implementing Internet of Things (IoT) digital twin (DT) technologies for bridge asset management, maintenance, and operations.

Project location: I-90 Homer M. Hadley Memorial (Floating) Bridge, Seattle, Washington

Key Research Tasks:

- Connect IoT sensors to the Microsoft Azure Digital Twins platform
- Conduct stakeholder workshops to evaluate cost-effective implementation approaches
- Co-create an instrumentation plan with bridge engineers and maintenance crews
- Install IoT sensors at select bridge locations
- Develop alerts and visualizations for maintenance and engineering teams
- Collect and analyze 12 months of seasonal data
- Deliver training workshops for end-users.

Core Objective: To develop and implement a functional digital twin system for a critical bridge infrastructure asset under real-world conditions, demonstrating how IoT sensors, cloud computing platforms (Microsoft Azure Digital Twins), and advanced analytics can improve bridge health monitoring and operational decision-making.



OVERALL BUDGET

Budget Category	Amount
Federal Funds Allocated (FY 25)	\$52,400
Federal Funds Obligated	\$52,400
Federal Funds Expended	\$52,400

Additional contributions included \$19,000 in cash from Challenge Seattle, \$45,000 from UW IT for sensor equipment, \$41,000 from the Advanced Bridge Construction University Transportation Consortium for student support, \$5,000 in Microsoft Azure cloud computing credits with a commitment for an additional \$75,000 to continued monitoring, ~\$5,000 from T-Mobile for 5G cellular connectivity, ~\$5,000 from Bentley Systems for software licenses, \$3,000 from Semtech Wireless for routers, ~\$10,000 from WSP USA for technical advice, and ~\$5,000 from Compass IoT for traffic data. Estimated \$265,400 from cash and in-kind contributions.

The project operated within budget constraints, requiring creative problem-solving such as leveraging legacy equipment to reduce sensor procurement costs while maintaining system functionality.



MEETING PROGRAM CRITERIA

The I-90 Digital Twin project directly aligns with STIC Incentive Program objectives:

Innovation and Technology Advancement

- Demonstrates proof-of-concept for digital twin technology in bridge infrastructure, a critical gap identified in the literature where prior digital twin studies were limited to laboratory experiments.
- Provides empirical evidence of how digital twin systems function under real-world operational conditions with legacy systems, multiple stakeholders, and organizational complexity.

Safety and Asset Management

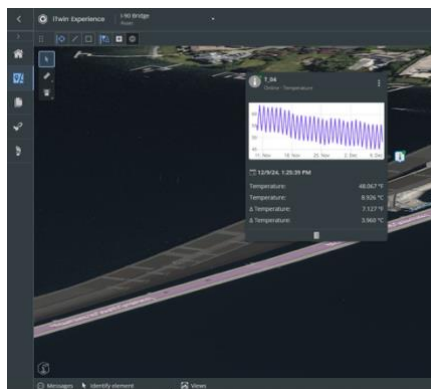
- Addresses Washington State's aging bridge inventory (average age: 51 years) by providing real-time structural health monitoring.
- Enables predictive maintenance through data-driven insights, improving safety and extending infrastructure lifespan.
- Demonstrates integration of disparate data streams (sensors, weather, operations) for comprehensive asset understanding.

Multi-Agency Collaboration

- Exemplifies successful coordination among academia (UW), government (WSDOT), transit operators (Sound Transit), and industry partners (Microsoft, Bentley Systems, T-Mobile).
- Establishes replicable models for cross-organizational partnerships in infrastructure technology adoption.

Operational Efficiency

- Reduces monitoring costs through optimized sensor placement and cloud-based analytics.
- Provides maintenance crews with actionable insights for preventive interventions.
- Supports Sound Transit's operational planning (e.g., pontoon positioning, track sensor integration).



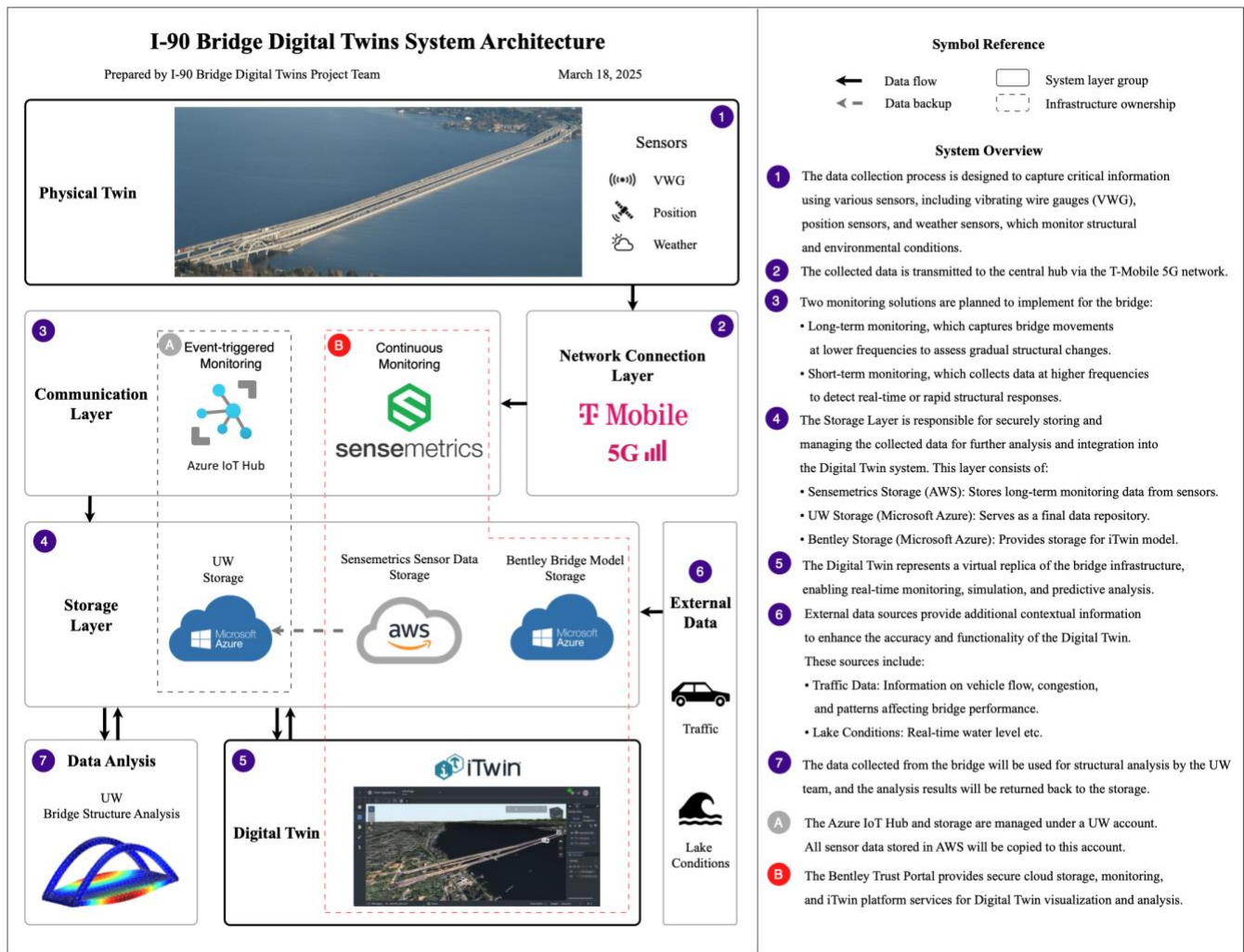
PROJECT RESULTS

Completed Milestones

1. **Lab-Based Sensor Integration:** Successfully connected IoT sensors to the Azure Digital Twins platform.
2. **Stakeholder Engagement Workshop:** Conducted with WSDOT personnel and research team to identify cost-effective implementation strategies.
3. **Instrumentation Plan:** Co-created with bridge engineers and maintenance crews.
4. **Sensor installation:** IoT sensors deployed at select bridge locations.
5. **Digital Twin Development:** Functional DT model created with data stream visualizations and alert capabilities.
6. **System Deployment and Field Integration:** Sensors operational; maintenance crews accessing DT platform.
7. **Data Collection:** 12-month collection cycle ongoing, ending May 2026, capturing full seasonal variation.
8. **Stakeholder Coordination:** Regular briefings with WSDOT staff, agency directors, and engineering personnel.

Key Findings

- **Operational Value Demonstrated:** WSDOT maintenance teams now have direct access to the digital twin platform and are using it for enhanced bridge condition insights.
- **Multi-Agency Applications:** The system has proven useful for Sound Transit's cathodic protection monitoring and pontoon positioning analysis, demonstrating broader applicability.
- **Data-Driven Insights:** The digital twin has successfully correlated bridge conditions with cathodic protection system behavior, providing valuable information to multiple public agencies.
- **Sensor Adjustments:** Initial sensor placement issues were resolved; the system is now operating stably with data flowing reliably.



CHALLENGES

Technical Challenges

1. **Legacy System Integration:** Integrating older sensing equipment with modern IoT hubs required custom solutions due to proprietary programming languages and non-standardized protocols. Significant effort was needed to bridge compatibility gaps.
2. **Lack of Standardization:** The IoT domain operates with multiple competing management protocols and frameworks, increasing complexity and reliance on vendor-specific expertise.
3. **Cybersecurity Considerations:** Multiple cloud storage solutions and system interfaces increased the attack surface. Data classification issues (Protected Critical Infrastructure Information) required coordination with WSDOT IT and Department of Homeland Security.
4. **Sensor Equipment Constraints:** Budget limitations required reuse of legacy equipment, necessitating creative workarounds and limiting sensor placement options.

Organizations Challenges

1. **Organizational Silos:** Communication gaps between WSDOT's IT and Operations Technology (OT) departments delayed system integration and created misalignment on priorities. IT teams were engaged late in the process, limiting proactive security planning.
2. **Multi-Stakeholder Coordination:** Balancing competing interests and priorities among WSDOT, Sound Transit, UW, and industry partners required continuous negotiation and adaptive communication strategies.
3. **Staffing Transitions:** Personnel changes among industry partners and within WSDOT created gaps in project continuity and required ramp-up time for new team members.
4. **Changing Organizational Commitments:** Shifting priorities and administrative changes occasionally reduced stakeholder engagement, requiring persistent relationship-building and clear articulation of project value.

LESSONS LEARNED

Organizational Interoperability

- **Early IT Involvement Is Critical:** IT departments should be engaged from project inception, not late stages, to address cybersecurity and system compatibility proactively.
- **Shared Goals Transcend Silos:** Establishing clear, shared objectives and demonstrating tangible value (e.g., actual bridge data) help align diverse organizational interest.
- **Leadership and Communication Matter:** Dedicated project leadership with strong stakeholder relationships and transparent communication is essential for sustaining multi-agency collaboration.
- **Flexibility Is Key:** Willingness to adapt plans in response to organizational constraints and changing priorities enables progress despite uncertainties.

Technical Interoperability

- **Standardization Gaps Are Real:** The absence of universal IoT standards significantly increases implementation complexity. Future DT projects should plan for extensive customization and vendor coordination.
- **Legacy Equipment Integration Requires Planning:** Balancing innovation with existing infrastructure demands careful planning, custom interfaces, and acceptance that perfect interoperability may not be achievable.
- **System Architecture Complexity:** Multiple platforms, cloud services, and data protocols create cybersecurity and performance challenges. Simpler architectures may be preferable where feasible.

Project Management

- **Proof-of-Concept Scope Is Appropriate:** Limiting the project to a single bridge with optimized sensor placement allowed for manageable complexity while demonstrating real-world applicability.
- **Data Drives Engagement:** Stakeholders became significantly more engaged once actual bridge data became available, highlighting the importance of early data collection and visualization.
- **Patience and Persistence Pay Off:** Digital Twin implementation can be a complex, iterative process. Long-term commitment and flexibility in timelines are necessary for success.

CONCLUSION

The I-90 Digital Twin Proof of Technology Evaluation successfully demonstrated that digital twin systems can be developed and deployed in real-world bridge infrastructure contexts, delivering operational value to transportation agencies. The project revealed that successful implementation depends equally on technical integration and organizational alignment. By addressing both dimensions—establishing clear communication channels between IT and OT teams, securing early stakeholder buy-in, and demonstrating tangible benefits through actual data—transportation agencies can effectively adopt DT technologies to enhance asset management, safety, and operational efficiency.

The findings provide valuable guidance for future digital twin initiatives in infrastructure, emphasizing that interoperability is a dynamic process requiring continuous negotiation across technical, organizational, and institutional boundaries.