The Hidden Crisis : Developing Smart Big Data pipelines to address Grand Challenges of Bridge Infrastructure health in the United States

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ABSTRACT

The American Society of Civil Engineers (ASCE) Report Card for America's Infrastructure gave bridges a C+ (mediocre) grade in 2017. Approximately, 1 in 5 rural bridges are in critical condition, which presents serious challenges to public safety and economic growth. Fortunately, during a series of workshops on this topic organized by the authors, it has become clear that Big Data could provide a timely solution to these critical problems. In this work in progress paper we describe a conceptual framework for developing SMart big data pipelines for Aging Rural bridge Transportation Infrastructure (SMARTI). Our framework and associated research questions are organized around four focus areas:

- Next-Generation Health Monitoring: Sensors; Unmanned Aerial Vehicle/System (UAV/UAS); wireless networks
- Data Management: Data security and quality; intellectual property; standards and shared best practices; curation
- Decision Support Systems: Analysis and modeling; data analytics; decision making; visualization,
- Socio-Technological Impact: Policy; societal, economic and environmental impact; disaster and crisis management.

Keywords

Bridge Structural Health, Next-Generation Health Monitoring, Data Management, Decision Support Systems, Socio-Technical Impact.

INTRODUCTION

Out of 138 economies worldwide, the US ranks 11th when it comes to infrastructure competitiveness, according to the World Economic Forum's Global Competitiveness Index. America's infrastructure, particularly, its 50-100+ year-old bridges are in poor health and constitute a **hidden crisis** not being discussed publicly. This is illustrated by the Interstate 35W bridge collapse in Minneapolis on Aug. 1, 2007. According to news reports, during that Wednesday evening's rush hour, the bridge spanning the Mississippi River suddenly gave way, killing 13 people and injuring 145. An article in Govtech.com concluded that "for 17 years leading up to the collapse, reports cited structural problems with the bridge, and the federal government rated it as 'structurally deficient' — a rating given to approximately 75,000 other U.S. bridges in 2007. Transportation experts across the public and private sectors agree that the U.S. infrastructure is in peril, a sentiment that's supported with startling statistics from a 2011 study called Failure to Act, by the American Society of Civil Engineers (ASCE). The American Society of Civil Engineers (ASCE) Report Card for America's Infrastructure gave bridges a C+ (mediocre) grade in 2017. The number of structurally deficient bridges, (those needing significant attention or replacement) exceeds 57,000, is slightly over 9% of the 614,000 bridges that are part of the Federal Highway Administration's National Bridge Inventory (NBI) (ASCE 2017). Bridges included in the NBI are structures over a depression/obstruction whose opening along the roadway centerline is greater than 20 feet that carry a public road, which is classified as any road open to public travel because it is under public jurisdiction and maintained by a public authority (USDOT 1996). Furthermore, the US Department of Transportation estimates it could cost as much as $1 trillion just to bring the current Interstate and highways system in the US up to date.

While it is recognized that the number of structurally deficient bridges has dropped from 12% since 2007, ASCEs Report Card includes Midwest states of Iowa, Missouri, Nebraska, Oklahoma and South Dakota in its "bottom five" states having the highest number of structurally deficient bridges or the "bottom five" based on percentage of total inventory. This constraint ignores many "off-system" bridges that are shorter than 20 feet and/or support roads that do not strictly conform to the definition of being "public." Many such structures exist in the Midwest and are very important links in the transportation infrastructure "chain," especially in association with agribusiness. Another important transportation sector with deep ties to the Midwest and strong influence on its economy are the railroads. Railroads have existed in the Midwest since the mid-19th century and, as they expanded, placement of bridges and trestles naturally increased. ASCE identifies 100,000 in service rail bridges, with many in use for decades.

NBI data shows that approximately 1 in 5 rural roadway bridges in Nebraska are structurally deficient. Similar challenges exist for our aging rail infrastructure. The reality that both state and private industry have shrinking budgets for bridge inspection and repair exacerbates these problems. Fortunately, during a series of workshops on this topic run by the authors it became clear that Big Data could provide a timely solution to these critical problems. Our past workshops, surveys and other events have generated tremendous interest in using Big Data for efficiencies related to rural bridge transportation infrastructure. These efforts have led to partnerships between bridge owners, maintainers and researchers at the forefront of Big Data, machine and deep learning, data governance, and civil engineering domains for structural health monitoring. This community has identified four focus areas (next generation health monitoring; data management; decision making; and socio-technical impact) to address the grand challenges for bridge health assessment using Big Data technologies as listed on the left hand side of Figure 1.

Our research work in each focus area collectively form the interconnected components of a SMart Big Data pipeline for Aging Rural bridge Transportation Infrastructure (SMARTI). Important, data-driven, research questions for each focus area have been identified by the Research Team and industry partners and are summarized under Project Deliverables along with assigned responsibilities. Aging, rural bridges will be selected in consultation with State Department of Transportation and railroad owners to serve as testbeds for delivering data products that facilitate decision-making and ultimately, economically, reliably improve bridge life and safety. Datasets will be prioritized to address challenges faced by private, local, state, and federal bridge owners. The proposed project will build upon past successes from the Research Team's BD Spokes Planning Grant activities related to building partnerships, hosting workshops and hackathons, cataloging bridge health datasets across sectors, building schemas, and enabling broad access to the

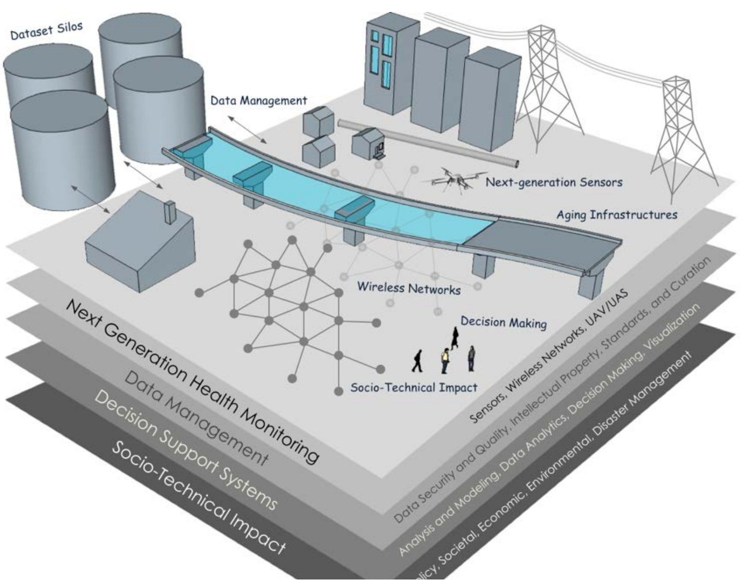

Figure 1: Interconnected layers and elements of the SMart Big Data pipeline for Aging Rural Bridge Transportation Infrastructure (SMARTI)

bridge inspection datasets using a combination of access control and anonymization techniques (Domingo-Ferrer et. al 2016) deemed acceptable by data owners.

SMARTI FRAMEWORK AND FOCUS AREAS FOR FURTHER RESEARCH

Bridges in rural areas often do not warrant the costs associated with continuous monitoring solutions or state-of-the-art planning solutions for proactive maintenance of their health. Nebraska has the 7th highest percentage of structurally deficient rural bridges in the US. With 60% of those bridges constructed between the 1930s and 1960s, the aging infrastructure must receive periodic inspections to assess potential deficiencies (Nebraska Legislature, 2014). Other states having many rural bridges, such as Midwest states, are in similar situations. While inspection and management/maintenance processes may differ for the railroad industry, a similar situation exists solely based on the age of many key assets within that transportation sector. These situations provide timely and necessary opportunities for bringing to bear efficiencies of Big Data and next-generation monitoring technologies.

Big Data solutions are integral components for effective bridge health monitoring not solely because the data is "large", "diverse", and "fast" but also because analytics may identify hidden, important relationships between datasets that have traditionally been housed in different silos. For example, data collected from multiple bridges could provide additional, significant and previously unknown information associated with the effects of "systems-of-systems" decisions on their health (e.g., construction contractors, techniques and materials used to construct a group of bridges). Ambient or differential temperatures collected from various structures are examples of data that can be used in population health analysis, which may help better define drivers of excessive bridge stresses and deformations and long-term effects of their cycles over time. The effects of technology advancements on measuring, monitoring, and examining bridge health also offer myriad opportunities for impactful Big Data solutions. For example, video and pictures are becoming easier to collect during manual visual inspection, but the effective integration of this information into the data "stream" has not been fully utilized.

FOCUS AREA 1: NEXT-GEN HEALTH MONITORING

SMARTI is heavily dependent on mined and collected data. In the bridge industry, a common term associated with data collection is health monitoring. When rural bridges are those whose "health needs monitoring," approaches currently used to assess their health vary widely and often almost exclusively rely on qualitative and subjective data provided through human (manual and visual) inspections. The Federal Highway Administration's (FHWAs) Bridge Inspector's Reference Manual (USDOT, 2012) mandates that roadway bridges in the NBI have an inspection every two years. However, many of the rural bridges may not have any data due to inspection policies (bridges shorter than 20 feet not included in the inspections) or due to lack of resources/skilled engineers. ASCE notes that the number of structurally deficient bridges consist 33% of the total bridge deck area in the country. These statistics indicate a demand for research that considers innovative, next-generation monitoring technologies which can offer necessary, inexpensive insights via contact or non-contact data collection and intelligent, computationally based decision-making. Our goal is to integrate durable, low-cost sensing systems with Big Data pipelines that will automate the health monitoring process to provide advanced warning of deficiencies that could be a concern, including cracks, spalling, corrosion, material degradation, substructure deterioration, and extreme demands imposed by natural or man-made events such as tornados, hurricanes, earthquakes, high-wind events, fire, scour, vandalism, impact, and blast. We envision the bridge being the sensor and would become smart information "nodes" in the transportation network that continually provide health information to owners and suggest reliable mitigation schemes. Such an approach would require durable, low-cost sensing to be performed with on-site fusion techniques to bring down the number of sensors and bandwidth requirements.

FOCUS AREA 2: DATA MANAGEMENT

This focus area focuses on long-term usefulness and quality of important, collected and shared data while preserving security and privacy expectations. As sensing technologies with different modalities (data feeds, pictures, videos, audio files) proliferate, the resulting data deluge experienced by bridge inspectors and decision makers is a real challenge. The authors have observed during workshops and collaboration meetings with stakeholders that data deluge and resulting interpretation and misinterpretation have emerged as some of the most significant impediments to sharing within and between public and private sectors. To improve data usage and sharing, data management is essential. Improvements in data security and portability are essential for long-term preservation and trust in any smart and connected infrastructure data pipeline. Data discovery and reuse are additional challenges that usually follow smart infrastructure sensing.

FOCUS AREA 3: DECISION SUPPORT SYSTEMS

One of the key components associated with developing, improving, and commoditizing SMARTI is the creation and integration of confident decision support systems (DSSs). These would consist of physical and statistical model development efforts that can create and enhance the big data pipeline by:

- providing accurate, relevant snapshots of current and future health of a bridge or a system of bridges;
- covering nontraditional, aspects associated with rural bridge systems, e.g. socio-technical implications;
- utilizing Big Data decision-making tools and technologies to make SMARTI "smarter;" and
- efficiently and accurately visualizing current and future condition of all bridges at various time scales.

DSSs have long been shown to help various industries become safer and more efficient (Wang, Gang, et al 2016). Unfortunately, there is often reluctance for their adoption in many industries and the bridge industry is no different. We recently classified common barriers to DSS adoption in the bridge industry: fear of losing control by relying on decision support systems; data security concerns; data "deluge" concerns; fear of technology and the need to acquire new skills; and concerns about impact on the workforce (Gandhi et al., 2017). We also observed in small collaborative sessions with industry partners, that few advanced analytics tools are available to assist public and private owners with the management of bridge health. Even when traditional sensor information (e.g. material strains, deformations) is collected, data-driven decision support and risk assessment process are largely rudimentary or non-existent. Many recent efforts focus on improving past visual inspection methodologies (Washer et al., 2014), improved component degradation models and robotic inspection devices that work alongside bridge inspectors (Szary and Roda, 2014). Machine/deep learning techniques that indicate deterioration of bridge health coupled with intuitive data visualization techniques and tools are needed to provide an optimal user experience through data exploration and interaction.

FOCUS AREA 4: SOCIO-TECHNOLOGICAL IMPACT:

Bridges are essential to the functioning of the transportation infrastructure. Bridge closures, maintenance or load restrictions have a significant impact on the local regions that they serve, especially in agricultural/rural areas with limited alternatives. Team partnerships with a large university transportation center, the Nebraska Transportation Center (NTC), and the regional Mid-America Transportation Center (MATC), along with the EU Horizon 2020 Smart Mature Resilience project will help us integrate Big Data enabled decision support systems into cases for socio-technical impact determination. This focus area will investigate institutional challenges in the transition to a focus from just building bridge infrastructure to a mindset of continuously monitoring the health of our infrastructure and how this transition contributes to building resilient rural communities that can deal with disasters. This investigation should include governance strategies for developing flexible, resilient, and sustainable systems, technologies, processes and methods for addressing the impacts associated with maintaining the health of critical infrastructure such as bridges to transition to a focus from just building infrastructure to a mindset of continuously monitoring the health of our infrastructure.

CONCLUDING REMARKS

America is facing an infrastructure crisis in general; however, aging bridges and their "health" is in dire condition. In our research described briefly in this work in progress paper, we explain our SMart Big Data pipeline for Aging Rural bridge Transportation Infrastructure (SMARTI). Our primary objective with this framework is to provide the foundation for a platform to share bridge health data across stakeholders. It integrates expertise from computer science and engineering disciplines to pave the way for bringing Big Data opportunities to bridge health assessment with particular emphasis in rural areas. We believe that our effort will bring together stakeholders to leverage a common data set and technologies for bridge health monitoring and risk mitigation.

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