PEER "Research Nuggets"

Title: Sensing and Monitoring Technologies for Natural Gas and Pipeline Systems: A Report for the "Performance-based Earthquake Engineering Assessment Tool for Natural Gas Storage and Pipeline Systems" Project.

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Motivation: California relies on the combination of renewables and fossil fuels to meet its energy demand but is also situated in an area of high seismicity. The damage to natural gas infrastructure from earthquakes can cause component breakages and release methane-rich natural gas into the atmosphere, which has 25 times more warming potential than carbon dioxide if released into the atmosphere. Therefore, keeping natural gas within the transmission, storage, processing, and distribution systems is thus critical for California's efforts to reduce global warming.

Various monitoring technologies can be implemented to provide ground-truth observations of the actual gas infrastructure performance in real time. The collected valuable information can be used to increase confidence in the predictive models, complement modeled behaviors, and help with decision-making. However, the challenge is that many of the latest monitoring capabilities are unknown to natural gas utility owners and operators.

Objectives: The overall goal of the *OpenSRA* Project is to create an open-source research-based seismic risk assessment tool for natural gas infrastructure that can help utility stakeholders to understand state-wide risks better, prioritize mitigation, plan new gas infrastructure, and focus on post-earthquake repair work.

The scope of Task Group E: Smart gas infrastructure sensing of wells and pipeline connections performance is to guide the latest monitoring technologies in the context of the model variables needed in *OpenSRA* risk models that are developed in other tasks. It aims to identify the technologies that can inform the risk models at the input, intermediate, and final output stages while guiding state-of-the-art monitoring technologies that natural gas infrastructure owners can understand and implement quickly.

Methodology: A comprehensive review of sensing and monitoring technologies includes (1) reviewing an extensive list of available technologies, (2) receiving feedback from technical advisors (such as members from Pacific Gas and Electric (PG&E) and Southern California Gas Company (SoCalGas)) on the most relevant technologies, (3) coordinating with other task groups to identify the critical variables of their risk models, and (4) demonstration testing of a select subset of technologies having potential for significant impact. The sensing technologies used for obtaining variables of *OpenSRA* risk models were categorized (from associated PEER reports) for buried pipelines (Task B), storage wells (Task C), and surface facilities (Task D).

Results: The report provides guidelines on selecting state-of-the-art sensing and monitoring technologies that can be applied to natural gas infrastructure in order (i) to evaluate various input, intermediate, and final output parameters of the *OpenSRA* risk models (ii) to be used for

real-time remote monitoring; and (iii) to assist the development of methodologies for detection of anomalies for early-warning system and hazard mitigation (Figure 1). The technologies reviewed include (a) distributed fiber optic sensing of temperature, strain, and vibration for real-time structural health monitoring, (b) long-range wireless sensor network for remote monitoring, (c) remote sensing technologies including LiDAR, InSAR, and computer vision with satellite images for ground and structure movement monitoring, (d) high-performance gas sensors, (e) flow monitoring at smart meters level for large-scale system-level operational monitoring, and (f) in-line inspection using smart PIG. Applications of selected emerging sensing technologies, such as distributed fiber optic sensors for measuring distributed strains and vibrations in pipelines for static and dynamic loading conditions, are demonstrated to show their performance to the stakeholders.

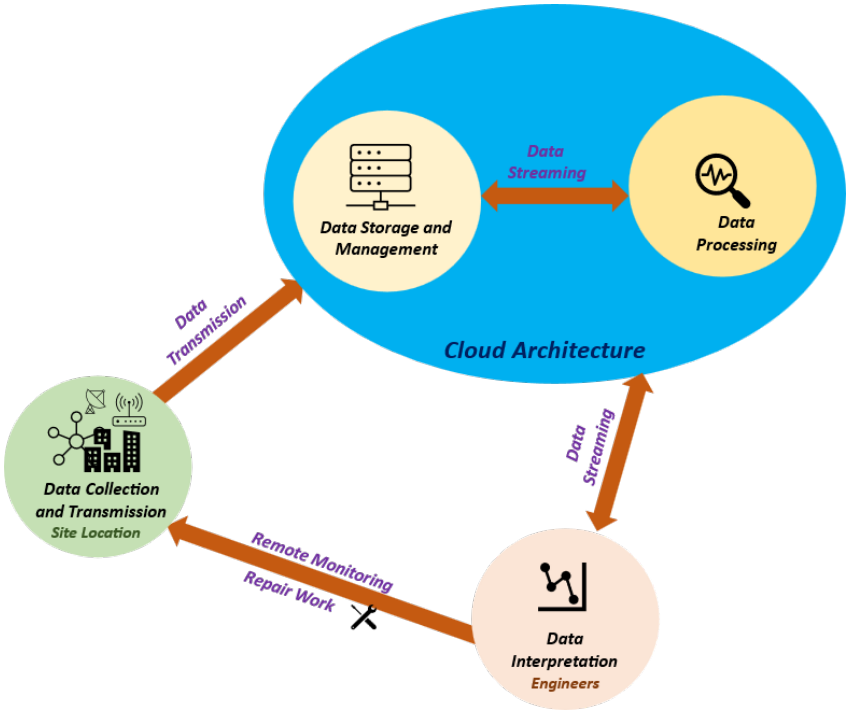

Figure 1. Illustration of the framework for real-time monitoring of civil infrastructures.

Conclusions: This report reviewed monitoring and sensing technologies that can be applied to make California's natural gas infrastructure safer. The technologies presented were in the context of *OpenSRA* input, intermediate, and output variables defined in other tasks. The descriptions of these technologies included (i) their fundamental measurement principles, (ii) capabilities, (iii) limitations, and (iv) costs. The report proposes that with better data, real-time, remote sensing, and early anomaly detection using data-driven models, the natural gas infrastructure's construction, maintenance, and safety can be significantly improved, leading to enhanced reliability and a safer system.

Keywords: Pipelines, Real-Time and Remote Monitoring, Anomaly Detection, Sensor Systems, Distributed Fiber Optic Sensors (DFOS), Wireless Sensor Networks (WSN), Leakage Detection.