System-of-Systems Integration for Civil Infrastructures Resiliency Toward Multi-Hazard Events

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Introduction

Civil infrastructure systems are facilities that supply principal services, such as electricity, water, transportation, etc., to a community. Cities and states rely on these systems every day. Unfortunately, infrastructure systems are frequently subject to multi-hazard events, such as natural disasters, which result in human casualties and economic losses every year. How do different civil infrastructure systems operate and how do they interact and communicate with each other in a resilient infrastructure system? To address these challenges, this research uses a systems engineering approach that builds on the proposal that the infrastructure systems be equipped with state-of-the-art sensor networks that continuously record the condition and performance of the infrastructure and share it with a data analysis system. This research models the resilient infrastructure problem as a System of Systems (SoS) comprised of the abovementioned components. It discusses system integration and operability challenges and proposes solutions to meet the requirements of the SoS. An integration ontology, as well as a data-centric architecture, is developed to enable infrastructure resiliency towards multi-hazard events.

Study Methods

This study builds on the hypothesis that the engagement of civil infrastructures within a city, along with the communities that live there, could be improved by continuously collecting data on the performance and resiliency conditions of the city's civil infrastructures. Information on the resiliency of infrastructures can be derived continuously if all the infrastructures are equipped with smart sensors that constantly report their condition. Each infrastructure is to have a database as well as a main server to store all the data received from the sensors. A computing component is to be implemented in each infrastructure to connect to the server and retrieve performance data, analyze it, and evaluate resiliency as well as the sustainability status of the infrastructure. All the infrastructures' databases are to be connected to a central data warehouse that stores and consolidates all the information and analyzes the resiliency and sustainability of the infrastructures at a city level. The primary objective of the system is to provide resiliency for the infrastructures within a city. Therefore, a centrally managed system is necessary to align the individual infrastructures' resiliency levels with the city's resiliency requirements. While the system components, i.e., the infrastructures, maintain their independent operations to maintain their resiliency, their behavior is subordinate to the overarching goal of the city's resiliency.

Findings

The overall architecture of the proposed System of Systems is intended to address the complexity of integrating diverse infrastructures within a city. While specific details of the architecture are not provided in this brief, it envisions a unified framework that encompasses various components, systems, and databases. This holistic approach allows for a comprehensive evaluation of the resiliency of individual infrastructures, as well as the city as a whole. Developing a unified System Integration ontology holds immense potential for simplifying the integration process and enhancing the resiliency of civil infrastructure systems. By identifying stakeholders, their requirements, concerns, integration resources, and mechanisms for developing an SI ontology, this research project aims to create a directed System of Systems that aligns the resiliency of infrastructures with the city's overarching objectives. Such an approach would contribute to the safety and well-being of citizens, ensuring a more robust and adaptable civil infrastructure system. Although the SoS is constituted of multiple systems and databases, a Directed SoS approach is preferred over an Acknowledged SoS. This preference stems from the exclusive focus on

resiliency as the primary purpose of all the systems involved. By centralizing the management and coordination efforts, a Directed SoS can ensure that the resiliency objectives are effectively pursued, minimizing potential compromises in information transfer and access. This strategic decision prioritizes the safety and well-being of citizens, mitigating the risks associated with inadequate system performance.

Developing a unified System Integration (SI) ontology for civil infrastructure can reduce the complexity and enhance the resiliency and adaptability of infrastructures within a city.

Policy Recommendations

There are several system components involved in this study. These components, at the infrastructure level, are operated and managed independently, and their functionalities do not necessarily depend on each other. However, integrating these components creates a new system that can evaluate the resiliency of all the infrastructures within the city and, consequently, of the city itself. Due to many components, the independence of the involved components in operation and management, and the large geographic extent of the component systems, the system is modeled and studied as an SoS. A complex SoS is undesirable since any compromise in information transfer and access would jeopardize the objective of the system and would potentially put citizens in danger. The author adopts a Directed type of SoS because the system's objective is to provide resiliency for the infrastructures of a city and, therefore, the system needs to be centrally managed to align individual infrastructures' resiliency levels with the city's resiliency requirements. The system components (infrastructures within the city) operate independently to maintain their resiliency. However, their behavior is subordinate to the city's resiliency. Although the SoS is comprised of multiple systems and databases, a Directed SoS is preferred over an Acknowledged SoS since the purposes of all the systems deal exclusively in resiliency.

About the Author

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Dr. Balali is an Associate Professor in the Department of Civil Engineering and Construction Engineering Management at California State University Long Beach. Dr. Balali's research focuses on visual data sensing and analytics, virtual design and construction for civil infrastructure and interoperable system integration, and smart cities in transportation for sustainable decision-making.

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