An Information Centric View to Scalable, Resilient CyberPhysical Transportation Systems

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Over the past 15 years, explosive growth of sensing, computation, and communication technologies has brought profound improvements in many aspects of our everyday life -- the way we work, live, travel, interact and communicate. The impact of these advances on the future of large societal-scale infrastructures such as transportation systems, communication networks and services such as emergency response and healthcare delivery is promising. Embedded sensors and data capture devices in these settings enable the possibility of digitally capturing the state of the evolving physical systems and processes which can then be used to gain situational awareness. This awareness can then be used to implement new functionalities or improve existing ones, and to adapt the configuration of the system itself – creating smart and adaptive systems.

Transportation systems form a major lifeline for society today – the ability to access information and interact via rich media anytime, anywhere has created a new populace that is “on-the-go” - involving millions of interacting entities (people, vehicles, goods, and applications) that create volumes of “moving data and information”. The role of information technologies in transportation spans almost all aspects of intelligent transportation -- e.g., traffic control, safety, congestion control, autonomous vehicle operation, entertainment while driving, reduced emissions and carbon footprint. Transportation networks are especially critical in extreme scenarios (e.g. emergencies, natural and manmade disasters, large urban events) since (a) impacted urban populations are increasingly mobile and often in transit and (b) transportation corridors serve as a conduit for citizens and agencies who must respond to the evolving crises and unexpected events.

To bring focus to this discussion and our work, we will capitalize on our expertise in the domain of IT in crisis response - to explore transportation CPS systems when they are subjected to extreme situations - whether it be a sudden increase in traffic due to phenomena such as mass evacuation, or influx of people to shelters, or when the transportation systems are damaged as a result of a large crisis. Such situations are amongst the most important in which higher level information technologies can be very beneficial to the transportation infrastructure; yet, it presents significant technical challenges since the transportation and communication lifelines are BOTH subjected to extreme situations and under duress. Adding resilience to solutions when both the system/process and the underlying IT infrastructure may be failing simultaneously is a difficult challenge from the perspective of designing robust / resilient CPS systems in general. During response, many layers of government, public authorities (such as state-managed transit authorities), commercial entities, volunteer organizations, media organizations, and the public work together as a loosely coupled virtual mobile organization to save lives, preserve infrastructure, and reestablish normalcy within the community. To ensure the safety of burgeoning urban populations on regional transportation corridors, two key challenges must be addressed

- Scalability of solutions to urban-scale transportation networks, impacted populations and users,
- Robustness of the underlying infrastructure under duress and in the face of changing events.

We argue for an ***information centric approach*** that can help the next generation of transportation infrastructures ***scale, add new efficiencies and robustness*** to societal scale processes. Today, sensing capabilities on vehicular networks are far more sophisticated than they have ever been - data capturing devices(inductance loop sensors, GPS-enabled sensing devices, smartphones, in-vehicle navigation systems) can provide rich information about the state of evolving physical infrastructure and processes. A multitude of networks (cellular, WiFi, BlueTooth, DSRT) can help transport this information to platforms (roadside units, agency servers, cloud platforms) where they can be assimilated and further analyzed. The awareness, thus gained, can then be used for to implement new functionalities or improve existing ones, and to adapt the configuration of the system itself. This information can be used to drive long and short term adaptations including (a) dynamic on-board control to deal with local system perturbations and (b) system-wide mechanisms to capture and manage traffic flow needs across a large number of vehicles and users. Such information can also be used to identify vulnerabilities and to explore options for retrofitting and augmenting regional transportation systems. Higher level semantic information also has the potential to bring changes to policy planning organizations.

In the context of the response process, the availability of rich information can help reduce the severity and impact of major disasters. Our group has, through a variety of projects in the CERT center at UC Irvine, gained significant prior experience building information-driven systems to help with crisis response. One of our flagship projects, RESCUE(funded by NSF through its large ITR program), explored and developed a range of solutions for improved information flow including robust crisis site networking, extraction of situational awareness from multimodal inputs, open information exchange and customized dissemination to people at large including mobile populations. Through the notion of human-as-a-sensor, RESCUE was amongst the earliest projects to seriously explore participatory sensing in this context; more recently, the impact of human input has significantly increased due to social media. RESCUE and subsequent projects such as SAFIRE and SMART-C (DHS-funded) have also created a sleuth of technologies for sensor driven situational awareness. These efforts have illustrated that cross-layer modeling and adaptations can help scale, bring new levels of robustness and resilience and hence dramatic improvements to the response process. As a concrete example, through Inlet, a transportation simulator developed in RESCUE, we studied the role accuracy and timeliness of information have on evacuation times showed that when drivers are offered dynamic up-to-the-minute information about road closure, traffic speeds (obtained through loop sensors), and status of evacuation routes, the evacuation time for Long Beach downtown can be cut to about half. Given this wealth of prior work, our goal is now to address more holistically the challenge of transportation networks in extreme situations. Some sample questions driving driving this investigation are listed below.

- Can sensing and networking technologies be designed to provide appropriate situational awareness for different participants -- motorist, traffic controllers, police, etc. ? This task requires an understanding who the participants are and their information needs, determining where such information resides and whether we can design tools to collect, analyze and disseminate the information,
- Given a large scale response plan and urban-scale populations, what transportation modalities are required to evacuate th region within a fixed time period (few hours). What are ideal routes to utilize and how can dynamic changes to these routings be deployed when new conditions become evident (e.g. damage detected on bridge)?
- How can IT help in the design of systems that implement graceful degradation under extreme scenarios?

Additional challenges include the design of cross-lifeline platforms that addresses the interaction of transportation and communication systems jointly to support cross-lifeline interactions. Challenges that arise due to societal-scale deployments include those due to interaction of lifeline systems with humans, public policy and environment. Cross-layer security mechanisms/techniques must be designed to ensure that complexity of the IT infrastructure to intelligently monitor and control lifelines itself does not introduce additional new vulnerabilities. Barriers to achieving these goals poses substantial research challenges including heterogeneity of the types of data generated by diverse sources of information, autonomy of organizations that own and monitor the infrastructures and the corresponding sensor data, concerns of privacy, security and potential lack of inter-organization trust.

While the efficacy of the transportation infrastructure and quality of processes such as response is ultimately based on the decisions made as a result of this information – the premise is that better information can lead to better decision making capabilities as a whole. The proposed “Information-

Driven" approach embodies the "observe-analyze-adapt" design methodologies that are gaining wide acceptance within the IT community. While such methodologies have been applied at various levels of computing -- architectures, computer networks, middleware, application software – our goal is to bring new optimizations, efficiencies, savings and resilience to next generation transportation systems.

Additional information on CERT: CERT (www.cert.ics.uci.edu) , formed in 2008 by the University of California at Irvine is a multidisciplinary unit with the mission to enhance the ability of emergency response organizations and the public to mitigate crises, save lives, and prevent secondary losses by radically transforming the way in which these organizations gather, process, manage, use and disseminate information during natural and manmade catastrophes. Through multiple grants, CERT facilitates multi-institutional collaboration with researchers all over the country including researchers at UIUC, BYU, UCSD, University of Maryland, and the Natural Hazards Center at University of Colorado at Boulder. CERT also provides a forum for its member faculty to collaborate with a va riety of government agencies and industrial partners. CERT's government partners include southern California cities (City of Irvine, San Diego, Los Angeles, Dana Point and Ontario, county (LA County Office of Emergency Management) and state agencies (California Emergency Management Agency, California Governor's Office of Emergency Services) and federal agencies such as FEMA and SPAWAR. CERT's industrial partners include companies such as ImageCat and Deltin that are dire ctly involved with crisis management, as well as, companies such as 5G wireless, IBM, Canon, Boeing, and Raytheon, that deal with developing hardware/software tools for the first responder community. In 2009, the United States Department of Homeland Security, Science and Technology Directorate partnered with UCI's CERT Center to host a Workshop on Emergency Management: Incident, Resource and Supply Chain Management with over 200 attendees from various government organizations, academic institutions and industry partners. Through the efforts of the CERT Center, the Responsphere testbed and associated projects, we have accomplished multiple technology transfers to first responders, created a large-scale emergency response dataset repository, and have established ongoing connections with response organizations Our Disaster Information Portal technology has been in use by the City of Ontario (California) since 2007 including the wild fire events. Conducting several drills, evacuations, and other emergency response activities, the testbed serves a vital function for technology development, testing, and transfer.