Position Paper: Cyber-Technology to Improve Transportation Resiliency during Emergencies (CITRE)

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While transportation systems provide vital functions to society, they are currently facing significant challenges arising from congestion, accidents, energy consumption, and emissions. Most of the existing work focus on taking advantage of the latest advances in cyber technologies (i.e., sensing, computing, communications and automated control) to improve the efficiency, road safety, and environmental friendliness of transportation systems have focused on common, day-to-day operational aspects of transportation, or conducting experiments for proof-of-concept, validation and field study of V2X communications. Besides, Google and others have been developing and demonstrating self-driven (or automated) cars which can operate under most situations.

It is worth noting that transportation plays a vital role during and after emergencies and extreme events, which has recently been described by a report requested by Congress and funded by the Federal Transit Administration [1]. While the report discussed the pivotal role of transit in reducing the exposure of citizens to unnecessary risks during both the 9/11 attacks and the 2005 Katrina disaster, these incidents also revealed the vulnerabilities of the transit systems. We believe that an effective integration of cyber technologies and transportation systems will enable robust and resilient transportation operations in face of extreme events, such as vehicle routing in response to serious road accidents, bridge/tunnel failures, Hazmat incidents, power grid failures and operations during severe inclement weather such as snow/blizzard/flooding, e.g., during Super-storm Sandy. Conducting research on such integration will not only benefit *Connected Vehicles* but also autonomous vehicles (which cannot yet handle extreme events such as inclement weather. i.e., heavy rain or ice/snow covered roads [2]).

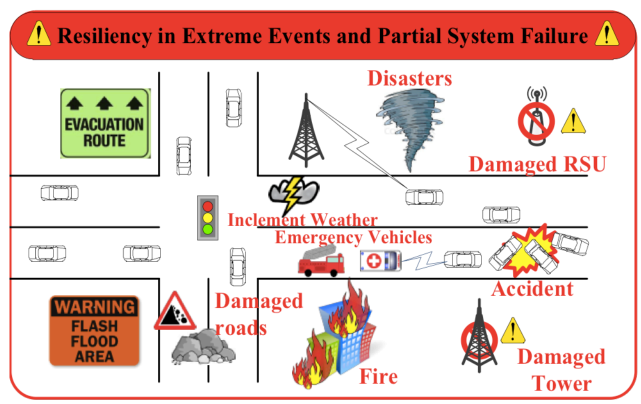

Fig. 1. An Application Scenario of CITRE

However, there are many open challenging issues related to the use of cyber technologies to enable interactions, information sharing, and coordination between multiple vehicles in emergency situations. For example, currently, no microscopic-level data on real-world driving environment (including traffic and road conditions) and driving conditions (e.g., vehicle dynamics) under inclement weather is available to the research community. Although a large number of traffic simulators exist, they only model traffic patterns and roads under normal weather conditions. Moreover, they typically generate traffic according to a certain probability model, and also use predefined lane-changing and car-following models. Accordingly, they are not suitable to analyze human factors, such as message responses of drivers, driver distractions, reaction and acceptance to new technologies in connected vehicles, intelligent infrastructure and autonomous driving environment. Also, due to costs and other practical constraints, it is not feasible to conduct realistic road tests under inclement weather to evaluate unproven technologies and designs involving connected vehicles and autonomous driving.

In general, emergency situations introduce two major changes in the CTS. Firstly, during emergencies, the transportation system itself may be impaired (e.g., structural failure of a bridge, reduced capacity and highway accidents during a snow storm or flooding, etc.). Secondly, the cyber components such as cellular towers may also suffer damage (due to e.g., power outage) or congestion (due to e.g., increased amount of voice and data traffic). Fig. 1 illustrates the general application scenario of the proposed research effort on Cyber-Technology to Improve Transportation Resiliency during Emergencies (CITRE).

As a first step, we need to identify fundamental problems and potential approaches and solutions related to the use of cyber technologies to improve transportation resiliency during emergencies through a joint multi-disciplinary research effort. One of the main topics to be studied is how to improve the resiliency of Cyber Transportation Systems (CTS) in face of emergencies and extreme events (e.g. hurricanes, snow storms) by leveraging our research on both safety-related CTS applications and on V2I (vehicle-to-infrastructure) and V2V (vehicle-to-vehicle) wireless communications. More specifically, we need to explore open issues and tackle challenges such as how to model emergencies and their effects on all human driver behavior, the cyber system (e.g., communication channel and infrastructure) and the transportation system (e.g., roads, bridges and traffic lights). We will also need to investigate new schemes that are robust in the presence of failures in both cyber and transportation infrastructures in an emergency situation. The ultimate objective is to develop systems that can smoothly transition from regular behavior to dealing with failures in the transportation and cyber domains.

Since the requirements and usage patterns of both transportation and communications in emergencies differ greatly from those in non-emergency situations, there are several unique aspects of communications network protocols and transportation control strategies that have not been adequately addressed in existing research. Therefore, it is imperative to explore, among other open issues, how to model traffic emergencies, what type and amounts of information need to be communicated between vehicles and the infrastructure during emergencies, and how to design and evaluate network protocols and transportation control strategies.

We propose to leverage our existing work by enhancing the unique and award-winning 3-in-1 Integrated Traffic, Driving, and Networking Simulator (ITDNS) [3], with necessary capabilities to model both the traffic and cyber technologies during emergency situations, and use it to validate the proposed designs and also evaluate how effective the proposed designs are in handling emergency situations.

Our Preliminary Research and Proposed Work

We have been developing over the last few years: 1) a detailed agent-based transportation model of the Greater Buffalo-Niagara metropolitan area which tracks mobility patterns of travelers in the region on a person-by-person and second-by-second basis, and techniques to profile mobility patterns; and 2) the unique and award-winning 3-in-1 ITDNS for validation/evaluation of CTS designs. We propose to investigate: 1) how CTS could be utilized to better understand (and model) the unique mobility patterns, communication requirements, and transportation system performance in an emergency, and also quickly (and automatically) detect emergencies; 2) how the cyber/transportation infrastructure components of CTS may be impacted by such emergencies, and how to make CTS operation resilient; and 3) how CTS may help improve evacuation and emergency response and rescue operations.

New Agent-Based Transportation Models: We propose to take advantage of the tremendous amount of work that went into developing, calibrating and validating the Buffalo-Niagara model to serve as our initial test bed for exploring the research topics mentioned earlier, with a focus on modeling and predicting traffic in emergencies. We will consider three different types of emergencies with increasing levels of severity and scope in terms of the impacted area, namely: 1) an incident that affects only a specific link of the transportation network (e.g., a highway incident or collision that totally blocks a freeway link; 2) a severe snow storm that overwhelms the winter maintenance and snow plowing operations of a given town or city; and 3) an emergency which requires the evacuation of a significant portion of the metro area's population. More specifically, we propose to leverage the users' mobility traces and human factors [4], and investigate the likely mobility patterns (where they are likely located and where they will likely need to go during emergencies), and the transportation system performance under inclement weather. We will also investigate promising cyber enabled approaches to detect emergency situations from sensed anomalies in the system. For example, during snowstorms, information about drivers' acceleration and deceleration profiles may be utilized to estimate road surface condition.

Enhancement to Integrated Transportation- Driving-Network (ITDNS) Simulator: In a recent NSF-funded CPS Medium project, we designed and developed the ITDNS which consists of a driving simulator or DS (e.g., UB's surround-screen, 6 D.O.F. motion simulator), a network simulator or NS (e.g., NS-2), and a microscopic traffic simulator or TS (e.g., PARAMICS). The ITDNS uses a federated mode to enable realistic simulation by overcoming the limitations of each individual simulator; these limitations include the lack of realistic background traffic in a typical DS and NS, lack of capability to simulate the possible delay and loss of the CTS messages in DS and TS, etc..

We propose to use a few probe vehicles equipped with video cameras, GPS devices, and accelerometers as well as other on-board sensors to collect data including both traffic patterns of the surrounding vehicles and the dynamics of the probe vehicles under inclement weather in Buffalo, NY. Also, we propose to construct new simulation environments in ITDNS for inclement weather by using real-world data from the probe vehicles as shown in Figure 2, and simulate and analyze the performance of communications network protocols and transportation control strategies

[5]. To mitigate the negative impact of the failures in the cyber infrastructure, we will also determine which messages are more critical and thus should be given a higher priority for transmission, and in addition, how we can extend our work on flexible message composition [6] to aid in message fusion, in order to reduce the amount of information to be sent/received.

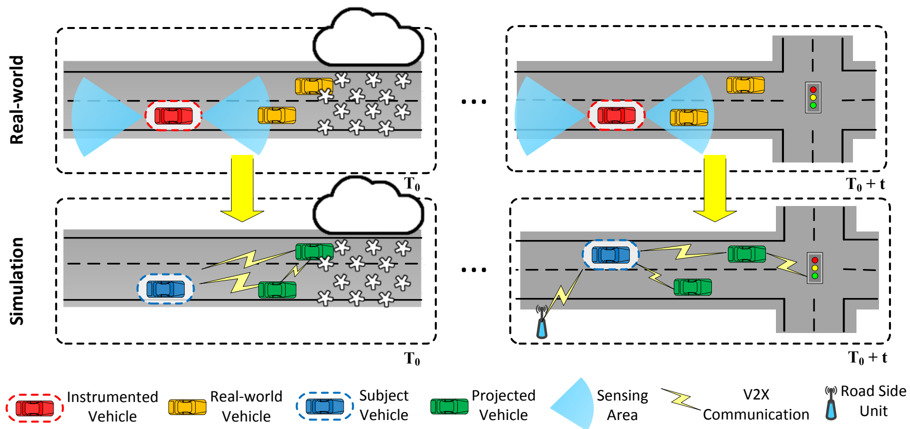

Fig. 2. Use real-world data in the ITDNS to simulate driving under inclement weather

The proposed research is expected to generate a significant societal impact by addressing the critical needs related to improving resilience of transportation systems under extreme events. More specifically, it is expected, for the first data to produce data and new models for traffic patterns and vehicle dynamics in emergencies and extreme events. Moreover, by enhancing our ITDNS, the proposed work will provide researchers with unprecedented capabilities for evaluating unproven technologies in a low-cost, safe and yet sufficiently realistic environment. The research will advance understanding related to driving under inclement weather, which in turn will not only *enable new research* on resilient cyber transportation systems, but also *improve road safety,* and reduce loss of life and other damages caused by disasters. The results from this project regarding traffic patterns, road conditions, vehicle dynamics and human factors in emergencies (and under inclement weather in particular), may *greatly impact various aspects of autonomous driving and connected vehicles* including: technology development, evolutional deployment strategies, government and industrial regulations, insurance policies, and consumer acceptance.

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