DYNAMIC TRANSPORTATION NETWORK VULNERABILITY ASSESSMENT ALGORITHMS

Statement of Work

This project will implement several software applications to enable algorithms to assess the dynamic (time varying) vulnerability of a transportation network. These assessment techniques will enable decision support tools for dynamic defense allocation and surveillance as well as promote the coordination of orderly evacuation and response.

Project Technical Description

1. Theme Area: Risk and Decision Analysis
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6. Keywords: transportation network vulnerability, dynamic demand profiling, transportation network graph extraction, risk modeling, decision analysis, risk mitigation

7. Brief Description:
The goal of this research is to develop dynamic transportation network vulnerability assessment algorithms. Two primary inputs are needed to execute these algorithms: (1) the static graph representation of a transportation network and (2) an accurate profile of the volume of traffic wishing to utilize links within the network throughout the day. Thus, to enable application of our algorithms to any city or region of interest, we will first implement a static map extraction tool to translate data contained in open source map software into a standard format used by the transportation engineering research community [B14]. To obtain dynamic demand profiles, we will develop a platform-independent smartphone application to collect anonymous data on travelers utilizing various modes of transportation, including automobiles, public transportation, and pedestrian flows. From this data, we will construct empirical time series models to characterize the congestion typically experienced at a given time and location within the network. We will also utilize Google traffic data if CREATE's Federal Coordinating Committee (FCC) or Scientific Advisory Committee (SAC) can facilitate access. The static graph representation of the network and travel demand time series will serve as inputs to game theoretic transportation network vulnerability assessment algorithms to identify the critical links and nodes of a network as a function of time. This time varying vulnerability assessment will be significantly more informative than the current state of the art [FRL], which is limited to static methods that cannot consider potentially rapid changes in vulnerability over time. Defenses allocation based on static vulnerability assessment may therefore only approximate an optimal strategy. Moreover, an accurate snapshot of transportation network congestion at the time of an incident will be essential to coordinate evacuation and emergency response.

Dynamic transportation network vulnerability assessment will enhance the realism of decision support systems for the National Planning Scenarios [NPS06], the 15 high consequence scenarios encompassing CBRNe (Chemical, Biological, Radiological, and Nuclear explosives) events as well as natural disasters such as earthquakes, hurricanes, and severe winter weather. We will also search the recent homeland security literature for other more up to date scenarios to ensure the applicability of our methods to contemporary concerns. Our methods will support risk analysis for the Securing the Cities program, the DHS effort to protect major metropolitan areas against illicit radiological and nuclear weapons and materials. Our intermediate vision is to scale our methodology to major cities such as New York, Washington, DC, Boston, and Los Angeles with the ultimate goal of internationalization to likely targets of terrorism such as London, Paris, Tokyo, and Mumbai, to promote risk assessment for the Global Nuclear Detection Architecture.

8. Research Objectives:

The objectives of the proposed research are to: (a) develop a software application to extract the static graph representation of a transportation network from an open source map application and encode it in a format employed by transportation engineering researchers; (b) implement a smartphone application to collect anonymous statistics on congestion in various modes of transportation and securely transmit to a central server; (c) analyze congestion data to establish time series and machine learning models of network demand; (d) propose a dynamic transportation network vulnerability assessment methodology to quantify and visualize changes in network vulnerability over various time scales; (e) incorporate the dynamic network vulnerability assessment methodology into a game theoretic framework to minimize an attacker's payoff by distributing network defenses both spatially and temporally; (f) prepare a formal white paper for submission to the Resilient Systems Division (RSD) within the Office of Science and Technology, articulating the challenges that must be overcome to scale the approach and mature the vulnerability assessment algorithms for the intended applications. Specifically, RSD topic three point two, *Modeling, Simulation, and Gaming technologies* for Decision Support Systems, will be targeted. A similar white paper will also be prepared for the Research and Development Directorate of the Defense Threat Reduction Agency (DTRA) Fundamental Research to Counter Weapons of Mass Destruction (C-WMD) Program, targeting Thrust Area 2: *Network Sciences*.

9. Research Transition Objectives

The Research Transition Lead, Lance Fiondella, will work closely with Erroll Southers, Director of Transition and Research Deployment (DTRD), during and between monthly research transition meetings to ensure that the research maintains the highest level of relevance to the DHS and achieves its full transition potential. Given, that the CREATE transition goals are to move “knowledge to practice” by (i) delivering research to an end-user, (ii) commercializing a product and, (iii) disseminating research results through scholarly publication, the PI and research team will first develop models and tools to assess the dynamic vulnerability of transportation networks under general conditions. We will then work with the DTRD to identify specific end-users within federal, state, and local agencies. For example, systems and risk analysis engineers at the DHS Homeland Security Systems Engineering and Development Institute (HS-SEDI) Federally Funded Research and Development Center (FFRDC) support several of the major customers identified in Section 12 by conducting basic research on how to effectively respond to manmade and natural threats to critical infrastructure and key resources. Identifying specific application areas will allow us to further refine our ongoing research so that it can be tailored to the needs of potential users.

We will also disseminate the research results in the form of one or more research papers. The proposed project will build upon our CREATE FY2015 project: L. Fiondella and N. Lownes, *Mitigating the Impact of Transportation Network Disruptions on Evacuation*. We have already submitted results from our present project:

V. Basavaraj, D. Noyes, N. Lownes, and L. Fiondella, Mitigating the Impact of Transportation Network Disruptions on Evacuation. In Proc. of the *IEEE International Symposium on Technologies for Homeland Security*, Waltham, MA, April 2015.

and will continue to disseminate the results of our research to conferences and journals that will reach a broad spectrum of researchers from the fields of homeland security, transportation, and reliability and risk analysis.

While commercialization of research can be an effective method to accelerate transition in many cases, especially engineering, commercialization of the results of this research will not be sought immediately because the technologies upon which the tools will be developed are open source. Thus, we intend to preserve the open source nature of our work to preserve flexibility as well as to encourage adoption by helping government and academic researchers avoid unnecessary fees. However, if in the future it is determined that commercialization would be beneficial the PI will utilize the resources available to him through his Office of Commercial Ventures and Intellectual Property (CVIP) to transition the research.

10. Interfaces to CREATE Projects:

This project will maintain interfaces with CREATE's research activities in the areas of risk assessment and management as well as decision analysis. Our proposed research is a novel synthesis of classical transportation engineering and modern computing paradigms, which overlap with research interests of multiple members of the CREATE team. Specifically, the PI has corresponded with Milind Tambe to identify common themes between our proposed work and that of the Teamcore Research Group on Agents and Multiagent Systems. Attacker/defender games based on our dynamic transportation data and simulation algorithms will allow us to identify the optimal combination of place and time to attack to disrupt a network, which is similar to Teamcore research on randomized patrols to guide the allocation of defenses. The project will also enable additional interfaces with DHS, including opportunities to pursue collaborative funding through the Resilient Systems Division within HS-ARPA and the DTRA.

11. Previous or current work relevant to the proposed project:

The vast majority of network vulnerability assessment algorithms are static. Our recent research [FRL] developed a discrete vulnerability assessment method to assess the evolving criticality of the U.S. High-speed rail network in five year increments from 2015 to 2030. Static graph extraction tools are not broadly available to the transportation engineering research community. This commonly limits research studies to a local city or region [B14]. Researchers at the Virginia Modeling, Analysis and Simulation Center (VMASC) [DTC12] assess the utility of effective information dissemination on evacuation, but limit the analysis to a case study with three primary evacuation routes. Recent transportation demand measurement studies [HWH10] have implemented virtual trip lines, where smart phones collected the location and speed of vehicles as they cross these lines. However, this approach limits data collection to fixed locations and hence cannot capture dynamic information on individual vehicles, which in turn constrains model detail. The graph extractor and travel demand time series developed as part of this project will enable dynamic transportation network vulnerability assessment of cities widely believed to be candidates for a major terrorist attack, thus promoting the identification of time varying bottlenecks in the network that may be particularly attractive targets or potential choke points that would prevent efficient evacuation and emergency response.

To ensure the relevance of our proposed work to the DHS mission, we contacted Kenneth Crowther who serves as a risk analyst, systems engineer, and project leader at the HS-SEDI

FFRDC. In addition to the National Planning Scenarios he identified several broad areas where transportation network vulnerability algorithms could play a beneficial role, including transport of hazardous chemicals, supply chain risk management, data integration and sharing, and security logistics. He also expressed his willingness to connect us with individuals within the DHS enterprise to reach potential customers of our research.

12. Major Deliverables Research Transition Products and Customers

Customers of dynamic transportation network vulnerability assessment tools include city planners responsible for crisis management and the Transportation Security Administration. The National Level Exercises organized by the Federal Emergency Management Agency often involve cities and implicitly their transportation networks. Thus, the research will also be applicable to National Planning Scenario stakeholders such as first responders to terrorist incidents, cyber-attacks, and natural disasters. The longer term research objectives include stakeholders of the Securing the Cities Program such as the Domestic Nuclear Detection Office, which coordinates the development of the global nuclear detection and reporting architecture. Thus, this research will advance the state of the art in system level risk analysis to promote the adaptive deployment of limited defensive resources in networks, where vulnerabilities are constantly changing with the progression of time.

Research transition products (**deliverables**) include: (a) a dynamic vulnerability assessment methodology for transportation networks, (b) papers for publication, and (c) draft white papers for submission to the RSD and DTRA. Program managers from DHS and research administrators attend the HST conference, making it a relevant target for potential sponsors.

13. Technical Approach:

The map extraction tool will be based on an open source map such as OpenStreetMaps, which provides and application programming interface (API) that relies upon a combination of HTTP and XML. Such tools implement methods to design custom queries from a user-defined polygon that can be used to precisely specify the boundaries of a map for a particular study. Maps extracted in this manner can be published [B14] for use by the broader transportation engineering research community who use these maps for a spectrum of performance, sustainability, and resilience related studies. Thus, this functionality will be especially useful to transportation researchers and should have the added benefit of promoting awareness of the need for transportation network vulnerability studies that can benefit DHS while simultaneously equipping researchers with maps of cities that are of particular interest to DHS stakeholders.

To ensure the smartphone application is widely usable, we will explore alternative platform independent mobile development frameworks such as PhoneGap and Sencha Touch, which enable the development and deployment of apps to all major smartphone platforms such as Android, iOS, and Windows. The advantages and supportability of multiple platform specific implementations will also be evaluated. A combination of local server and third party tools such as the Google Maps API Web Services will be used to process location data. Technologies such as PHP and SQL Server will be used to store trip data on one or more secure servers located behind the UMass Dartmouth firewall administered by Computing and Information Technology Services (CITS). Trip data will be anonymized to random key values in order to protect the identities of users. This will enable us to reconstruct individual trips of limited duration, but will assign new key values to different trips by the same user. Thus, trip dynamics will be recoverable, but individual travel patterns will not be recorded explicitly. Institutional review board approvals will be sought from the beta testing stage, when members of the PI's lab will be requested to help pilot the app to facilitate debugging and refinements. Large scale experiments will target the undergraduate residential and commuter populations, which will provide us with a quantitative means to assess the density and frequency of data needed to make accurate predictions about the movement of vehicle and pedestrian flows around the campus.

Methods such as dynamic traffic assignment (DTA) [AM98, DTC12] and agent-based simulation will serve as the foundation of the dynamic transportation network vulnerability assessment techniques. The number of possible locations and times of attack can be extremely large. Therefore, exhaustive enumeration of all hypothetical attacks would be computationally intensive for networks of even moderate size. Game theory [FRL] provides a systematic method that can reduce this complexity significantly by considering combinations of attacker/defender strategies because players naturally gravitate toward high payoff strategies. Thus, during these games players consider many strategies in parallel, with the attacker seeking to disrupt traffic and the defender to reroute traffic to minimize the negative impact of an attack. The result of these games are attacker and defender strategies, which suggest times and locations within the network where an attack would be highly disruptive and therefore most critical to patrol and defend. Optimization frameworks can utilize this game play as an objective function to guide the allocation of finite defensive resources, effectively allowing security planners to alter the playing field in a manner that maximizes the home court advantage of the defender. Such an approach will also promote real-time evacuation planning because the underlying transportation models will provide an accurate estimate of the average speed and number of vehicles on each link at the exact moment of an attack.

14. Major Milestones and Dates:

1. Implement smartphone application and configure server. (July-Aug 2015)
2. Obtain Institutional Review Board approval and run preliminary experiment. (Sept 2015)
3. Refine application and run campus wide experiment. (Oct-Dec 2015)
4. Build time series models of network demand. (Dec 2015-Jan 2016)
5. Implement map extraction tool. (Dec 2015-Jan 2016)
6. Develop dynamic transportation network vulnerability assessment algorithm. (Jan-Apr 2016)
7. Prepare whitepapers for submission to the Resilient Systems Division and DTRA. (June 2016)

15. References:

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