WALLACE, RPI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Community Supply Resiliency (COMSURE)

Principal Investigator Name/Institution: William A. Wallace, Yamada Corporation Professor, Industrial & Systems Engineering (ISE), Rensselaer Polytechnic Institute (RPI)

Co-Principal Investigators and Other Partners/Institutions: John Mitchell, Professor, Mathematical Sciences, RPI; Thomas Sharkey, Associate Professor, ISE, RPI; Richard Little, Research Scholar, ISE, RPI

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"): The resilience of a coastal community to an extreme event depends upon the resilience of its critical infrastructures, one of which is the system of supply chains that provide the goods and services that make a community livable – Community Supply Resiliency (COMSURE).

Summary Abstract: The capability of communities to withstand and recover from the disruptions of extreme events will determine, to a large extent, the degree to which the social, economic, and psychological impacts of these events can be reduced. It is well recognized that civil infrastructures (e.g., transportation, power, water supply and sewerage, and communications) are critical to the wellbeing of a community; our past work has focused on these systems. However, it is the social infrastructures (e.g., emergency response, banking, and food, fuel, and pharmaceutical distribution) that play a crucial role in societal functioning; the availability of these systems following an extreme event is a key element in determining the resilience of a community. Therefore, the objective of the proposed research is to better understand, describe, and portray the supply chains that provide the goods and services needed to respond to and recover from an extreme event, such as a hurricane impacting a coastal community. With this knowledge, models and algorithms will be developed to support emergency management in planning, community development, training and education, thereby enhancing overall community resilience.

PROJECT NARRATIVE:

1. Research Need: Infrastructure restoration is one of the most difficult challenges that must be addressed during a disaster and emergency managers are faced with many decisions during preparation, response, and recovery from extreme events such as hurricanes. Implementation of these decisions involves actors from both the public and private sectors who normally don't work and train together for such rare events, which can hinder their effective collaboration when the event actually occurs. Computer-based simulation tools such as COMSURE can be used for education and training to construct and display multiple scenarios that can raise the

awareness of public officials and corporate managers to the interdependent complexity of hazard events. This training and preparedness aid for response and recovery from extreme events is also less costly and more time-efficient than drills or full-scale exercises. At the present time, there are no such training aids that account for the interdependencies that exist between civil and social infrastructures which are readily available to the practitioner community. COMSURE has established that these linkages exist and has developed algorithms that can translate this research into a readily deployable education and training tool for practitioners that will make the nation and its critical infrastructures more resilient in the face of multiple hazards.

The results of this research contribute directly toward the achievement of Goal 5.4: Enable Rapid Recovery: "Ensure continuity and restoration of essential services and functions; and support and enable communities to rebuild stronger, smarter, and safer" as noted in *The 2014 Quadrennial Homeland Security Review* under Mission 5: Strengthen National Preparedness and Resilience.

2. History: Our previous work on the restoration of critical civil infrastructure systems focused on network models of the integrated restoration assignment and scheduling of multiple interdependent infrastructure systems. The research was expanded to include: (1) network models of social infrastructure systems, (2) a damage assessment model, and (3) a disruption of services model. An artificial community (CLARC) was developed for the purpose of research, education, and training. In addition to the contribution to knowledge in the form of theses and scholarly articles, an innovative suite of decision technologies, MUNICIPAL/CRISIS/COMSURE, has been developed. Its development and ongoing assessment were accomplished in partnership with the emergency management department of New Hanover County, NC. A stakeholders' workshop was held to provide guidance for the integration of the MUNICIPAL model with DHS's SUMMIT toolkit. Based upon the information from that workshop, a SUMMIT-compatible version of MUNICIPAL was completed with user documentation and delivered to Sandia National Labs in Livermore, California in May 2015. COMSURE, the current iteration of this work, is based on extensive interaction with the convenience store, pharmaceutical, and banking industries and provides: (1) the theoretical foundations for COMSURE, (2) an artificial community (CLARC) for experimentation and elaboration, and (3) a partnership with Healthcare Ready in Washington, DC to specifically assess the impacts of extreme events such as Hurricanes Harvey and Maria on the pharmaceutical and medical device supply chains.

   The focus on community supply resilience required the development of models of the supply chains that provide goods and services for social infrastructures. The construction of such models entailed data collection on-site at a coastal community facing a hazard – in our case, hurricanes. The result is GIS visualizations of the supply chains for review by both the provider of the critical good and emergency management. For example, the supply chain for the fuel distribution system for gasoline for New Hanover County would be shown in a GIS map for review. These supply chain models are then integrated with those of the social and civil interdependent infrastructure systems developed in past research. These new mathematical formulations have been incorporated into an interdependent integrated network design and scheduling framework. Using these mathematical representations, we modeled: (1) relationships between supply chains and support infrastructure networks that influence supply

chain operations, such as power, communications, and transportation; and (2) interactions among emergency managers and infrastructure managers in the context of coordination and information sharing in determining mitigation and restoration activities. These formulations coupled with models of damage and disruption of services, databases and a GIS interface form the basis for the COMSURE model. The project provided funding for a graduate student to participate both in the data collection and the modeling activities. The graduate student drew heavily upon recently completed doctoral research on the modeling of social infrastructures.

Primary Steps Taken To Carry Out The Project

MUNICIPAL was developed to assist state, county, and local emergency managers, as well as managers of public and private infrastructure systems, in preparing for a hurricane or other extreme event leading to the loss of infrastructure services. New Hanover County, North Carolina was selected as an ideal prototypical location to develop and test MUNICIPAL. It is located in southeastern North Carolina at the confluence of the Cape Fear River and the Atlantic Ocean and has had a long history of hurricanes and tropical storms. New Hanover County is 849.5 km^2 (328 square miles) in area and had an estimated population of 209,234 in 2012. It is home to the City of Wilmington, the International Port of Wilmington, Wilmington International Airport, the University of North Carolina at Wilmington, Cape Fear Community College, and the New Hanover Regional Medical Center which serves southeastern North Carolina and northeast South Carolina. Public safety services are provided by New Hanover County and the City of Wilmington within their respective jurisdictions. New Hanover County Emergency Management (NHCEM) coordinates disaster response during emergencies. The five infrastructure systems modeled in MUNICIPAL are managed by a mix of public and private entities within the boundaries of New Hanover County and City of Wilmington.

The COMSURE effort required outreach to a new community of stakeholders engaged in the provision of critical commercial and other "social" infrastructure services.

Commercial Service Providers (requests for information on the impacts of Hurricane Matthew and other storms)
Grocery Chains – Food Lion, Lowes Food, Harris Teeter
Drug Chains – Walgreens, CVS, Rite Aid, Healthcare Ready, Southeastern Health
Banks – Wells Fargo, Bank of America, Sun Trust
Convenience Stores – Circle K (Kangaroo Express), National Association of Convenience Stores

North Carolina Emergency Management (requests for information on the impacts of Hurricane Matthew; possible demonstrations to potential users of the technology)
City of Lumberton – Bill French
Cumberland County – Randy Beeman
Johnson County - Kim Robertson
Nash County – Brent Fisher
Pitt County - Allen Everette
Robeson County - Stephanie Chavis
Scotland County - Roylin Hammond

Wayne County - Mel Powers

Problems Or Challenges During The Project

As the model development and initial assessment phases in New Hanover County proceeded, two data-related complications became apparent. The first was that it was time consuming and expensive to collect data on the design and content of multiple infrastructure systems as well as on historic damage and disruption scenarios for those systems. It took approximately two years to organize the original infrastructure dataset for New Hanover County and even after this time, it was still difficult to validate the accuracy of the composite data due to inconsistent formats and the reluctance of many private and public organizations to supply complete datasets. The second complication was the realization that the release of vulnerability data on actual infrastructure systems in academic papers or public reports could raise legitimate security concerns. Of the two issues, the latter was more problematic.

Data on the location and vulnerability of critical infrastructure components is considered critical infrastructure information, and its handling and dissemination is subject to DHS regulations. Despite no single piece of data being subject to these provisions, the sum of the parts created security concerns and the data was deemed not publishable. This created two problems. It greatly restricted the ability of the research team to discuss the model and its capabilities in open sessions and present results in academic and technical journals and perhaps more importantly, it limited the use of the models to New Hanover County. If MUNICIPAL and its related models were to achieve their desired potential as a planning and educational tool, it would have to operate with a dataset that did not have these security concerns nor require two years of data collection to build a new dataset for each area under study.

To overcome these obstacles, the research team created an artificial community called CLARC (Customizable Artificial Community) to support further development and validation activities. This robust and sharable dataset can support additional infrastructure and emergency management research without compromising potentially sensitive information regarding the location and/or vulnerabilities of actual infrastructure. The development of the CLARC dataset is discussed in "CLARC: An Artificial Community for Modeling the Effects of Extreme Hazard Events on Interdependent Civil and Social Infrastructure Systems" which is currently under review by the *Journal of Infrastructure Systems.*

In preparation for validating the COMSURE algorithms at the locations of potential partners, the research team needed a method to quickly develop an accurate dataset of critical commercial facilities. Working from the websites of major commercial chains and independent search engines, the team was able to compile an inventory of banks, supermarkets, convenience stores, pharmacies, and other commercial operations near or within a zip code or major landmark. The street addresses were convertible to GPS coordinates using Google Maps and could be digitally plotted on base maps. The resultant mapping was also valuable for observing how multiple suppliers of the same service tend to group together in shopping plazas or at highway intersections. This empirical knowledge was used to populate the artificial community CLARC with commercial facilities.

3. Results: The research outcomes for Community Supply Resiliency (COMSURE) are as follows:

- A dataset that describes the supply chains for goods and services critical to the response and recovery of a coastal community subject to a hazard, e.g. a hurricane. Recognizing security considerations, the results of this effort were used in augmenting the data in CLARC, our artificial community, to include these supply chains.
- Visual and mathematical representations of the supply chains that form the basis for COMSURE.
- The results of this effort have been described in "Modeling the Recovery of Critical Commercial Services and their Interdependencies on Civil Infrastructures" which is currently under review by *The International Journal of Critical Infrastructures."*
- The research team has also developed a deeper understanding of the implications for community resilience that are created by the interdependencies between civil and social infrastructures, particularly in the areas of food, fuel, and pharmaceuticals. This understanding will underpin continuing research in this relatively unexamined area.

End Users and Transition Partners:

We envision the end users for our research to be local emergency managers, DHS analysts tasked with providing guidance on policies that effect community resilience to extreme events, and educators who wish to incorporate computer-aided decision support tools into their curricula. Data on the supply chains for the goods and services provided by social infrastructures has been compiled based on the attributes of several coastal communities in North Carolina as well as Puerto Rico. This information has been incorporated into the CLARC dataset for research and analysis purposes. We have met with representatives of DHS's Office of Cyber & Infrastructure Analysis and presented our decision support tool MUNICIPAL for their review.

MUNICIPAL has been integrated into the U.S. Department of Homeland Security (DHS) Standard Unified Modeling, Mapping & Integration Toolkit (SUMMIT). SUMMIT is a software toolkit that enables the emergency management community to access integrated suites of modeling tools and data sources for planning, exercises, or operational response. Making the decision support technology compliant with SUMMIT will enable emergency managers to use the planning and training capabilities of SUMMIT in concert with the modeling and simulation capabilities of MUNICIPAL. Integration with SUMMIT databases will also help to reduce the data collection burden mentioned earlier.

Additional funding to carry on this research was sought from various sponsors as shown below:

Title	Submitted to	Date	Outcome
MUNICIPAL+4: A Stakeholder-Guided Educational and Training Tool to Improve Decision-Making for Critical Infrastructure	NOAA	July 2015	Not Selected

Subject to Extreme Weather Events and Storm Surge			
Demonstration and Deployment of Education and Training Technology for the Restoration of Critical Infrastructure Following Extreme Weather Events	Critical Infrastructure Resilience Institute (CIRI)	October 2016	Not Selected
Deployment of MUNICIPAL: An Education and Training Technology for the Restoration of Critical Infrastructure Following Extreme Events	DHS	May 2017	Not Selected
Determining the Impacts of Interdependent Infrastructure Failures on the Production and Supply of Pharmaceuticals and Medical Devices Following Hurricane Maria	NSF	May 2018	Not Selected

Project Impact:

The MUNICIPAL/COMSURE technology has three potential levels of application that could be utilized by different cohorts of the EM community.

- An educational application designed for university-level curricula in emergency management that would make use of the CLARC community dataset
- A training application designed for working professionals in emergency management that would make use of the existing technology coupled with the HSIP Gold dataset specific to the location in question
- A field application to be used as a real-time decision-support tool in an actual emergency; it would also utilize the HSIP Gold dataset

All of these applications would produce usable tools for the education and practitioner communities. The educational tool would make students more familiar with the complex interactions that occur between civil and social interdependent systems; the training tool would supplement or replace costly "boots on the ground" field exercises; and the decision-support tool would increase understanding of the important role of service restoration priorities in designing effective response and restoration activities.

Overall, the work completed to date validates the previously developed algorithms and their applicability to critical commercial services as well as civil infrastructures. It also affirms the important role of the Emergency Manager as the sole owner of the "Big Picture" of how the various systems interact and the importance of restoration priorities in designing the most effective response and recovery program for these interdependent systems.

Although the research necessary to develop and deploy MUNICIPAL/COMSURE has been completed, this technology is not readily usable by the practitioner community. If additional funding were available, this research could be translated into a readily deployable education and training tool for practitioners that will make the nation and its critical infrastructures more resilient in the face of multiple hazards. The full impact of this research is in its application; without the funding to build workable tools based on the research, its full potential for education, training, and real-time decision support will never be realized.

Student involvement and awards:

Over the lifetime of the project, the following students were involved:

Ryan A. Loggins, Ph.D. awarded 2015, RPI Department of Industrial and Systems Engineering
Aaron Rowen, Ph.D. candidate, RPI Department of Industrial and Systems Engineering
Ni Ni, Ph.D. candidate, RPI Department of Industrial and Systems Engineering

Loggins, R. A., & Wallace, W. A. (2015). Rapid Assessment of Hurricane Damage and Disruption to Interdependent Civil Infrastructures Systems. *J. Infrastruct. Syst.*, doi: http://dx.doi.org/10.1061/(ASCE)IS.1943-555X.0000249.

Loggins, R. A. (2015). Improving the Resilience of Social Infrastructure Systems to an Extreme Event. Ph.D. Thesis. Troy, NY: Rensselaer Polytechnic Institute.

Loggins, R.A., W.A. Wallace, and B. Cavdaroglu. (2013). "MUNICIPAL: A Decision Technology for the Restoration of Critical Infrastructures," in Proceedings of the 2013 Industrial and Systems Engineering Research Conference, A. Krishnamurthy and W.K.V. Chan, eds.

Interactions with education projects: A formal "Request for Input" entitled "Adapting a Computer-aided Emergency Management Research Tool for Educational Purposes" was sent to CRC educational partners. No interest was expressed in incorporating the technology into existing curricula.

Publications: Provide a comprehensive list of your CRC-funded publications that have already been published or accepted for publication. Make sure citations are complete and in the accepted format for your discipline.

Ni Ni, R. Little, T. Sharkey, and W. Wallace. "Modeling the Recovery of Critical Commercial Services and their Interdependencies on Civil Infrastructures." *International Journal of Critical Infrastructure Systems.* (in review).

Little, R., R. Loggins, J. Mitchell, T. Sharkey, and W. Wallace. "CLARC: An Artificial Community for Modeling the Effects of Extreme Hazard Events on Interdependent Civil and Social Infrastructure Systems." *Journal of Infrastructure Systems*. (in review).

Loggins, R., R. Little, J. Mitchell, T. Sharkey, and W. Wallace. "CRISIS: A Tool for Modeling the Restoration of Interdependent Civil and Social Infrastructure Systems Following an Extreme Event," *Natural Hazards Review.* (in review).

Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
N/A			

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
NONE			

Table 2B: Documenting Leveraged Support

Description (e.g., free office space; portion of university indirects returned to project; university-provided student support)	**Estimated Total Value**
Free office space	**$2,000**
Visiting Scholar's time	**$ 9,600**

Table 3: Performance Metrics:

WALLACE PERFORMANCE METRICS

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)	Year 3 (7/1/17-6/30/18)
HS-related internships (number)	--		
Undergraduates provided tuition/fee support (number)	--		
Undergraduate students provided stipends (number)	--		
Graduate students provided tuition/fee support (number)	--		
Graduate students provided stipends (number)	1	2	1
Undergraduates who received HS-related degrees (number)	--		
Graduate students who received HS-related degrees (number)	--		
Graduates who obtained HS-related employment (number)	--		
SUMREX program students hosted (number)	--		
Lectures/presentations/seminars at Center partners (number)	1	1	1
DHS MSI Summer Research Teams hosted (number)	--		
Journal articles submitted (number)	--	1	3
Journal articles published (number)	--		
Conference presentations made (number)	--	3	
Other presentations, interviews, etc. (number)	2	1	1
Patent applications filed (number)	--		
Patents awarded (number)	--		
Trademarks/copyrights filed (number)	--		
Requests for assistance/advice from DHS agencies (number)	1		
Requests for assistance/advice from other Federal agencies or	1	1	
Total milestones for reporting period (number)	3		
Accomplished fully (number)	2	2	2
Accomplished partially (number)	1	0	
Not accomplished (number)	0	0	

Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Assessment of results of analysis	8/1/17	100%	
Adjust models based on assessment	9/1/17	100%	
Format data for decision support tool	9/1/17	100%	
Research Milestones			
Paper on COMSURE	10/1/17	100%	
Formal Knowledge Report	12/15/17	100%	

Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Data formats and visuals for decision support tool	9/1/17	100%	
Meet with representatives of the Association for Convenience & Fuel Retailing and Healthcare Ready, an association that focuses	10/1/17	100%	

on the preparation of healthcare supply chains for natural and manmade disasters.			
Meet with representatives of the International Association of Emergency Managers	10/1/17	100%	
Transition Milestones			
Formal Knowledge report	12/15/17	100%	
Paper on assessment of COMSURE	10/1/17	100%	