FEMA

Ph.D. Research Developed Using Hazus-MH in a Decision Support System to Improve Resilience of Critical Infrastructure

The two most recent major disasters in the United States, the 9/11 attacks and Hurricane Katrina, underscored the need for improvements in both safety and security. At the same time, a difficult economic period started reflecting smaller budgets to manage critical infrastructure systems, current and growing maintenance, and construction-development needs. Looking in particular to post-disaster policies for recovery and mitigation of damaged and disrupted critical infrastructure, a research opportunity to develop an approach to improve the resilience of these systems taking advantage of the Federal Emergency Management Agency's (FEMA) Hazus-MH tool was identified. A case study included Hazus-MH original data inventory and analysis results in a Decision Support System model that demonstrated the possibility and benefits for using an integrated approach of recovery and mitigation focusing on improving resilience of critical infrastructure systems.

Defining the Scope for Research

Considering the disaster management cycle of preparedness, response, recovery and mitigation, starting the research approach in the post-disaster phase allows for looking at mitigation in a proactive way taking advantage of recovery activities. In a "what if" scenario, initially a specific location would have assessed its vulnerability and risks, including looking at possible types of failure, then defined strategies and taken actions to improve the resilience of its infrastructure system. With the occurrence of a disaster it is time for response and recovery to be evaluated. Recovery actions, including damage assessment, enables verification for the threshold of eligibility to apply for Federal aid is met, and infrastructure can receive repairs. A results comparison between mitigation and recovery enables the development of new or revised plans for mitigation with the objective of improving resilience of critical infrastructure systems.

Introduction

Dr. Silvana Croope worked under the supervision of Dr. McNeil and finished her degree at the University of Delaware in the spring of 2010. Using Geographic Information Systems she started her research in the fall of 2005) to build initial vulnerability assessments for areas at risk to flooding. Her focus was on the impact of transportation; she tested mitigation alternatives for the road network considering flooding impacts and the need for traffic flow detour routes. Upon the release of Hazus-MH MR3 she added its organizing principle and analytical capabilities to the investigation, which allowed her to consider mitigation options such as warning systems. Dr. Croope used Hazus in researching concepts and principles of civil infrastructure systems, resilience engineering and the social science approach to disasters.

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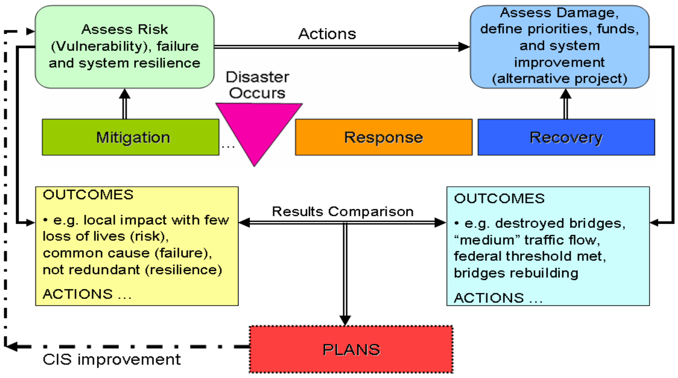
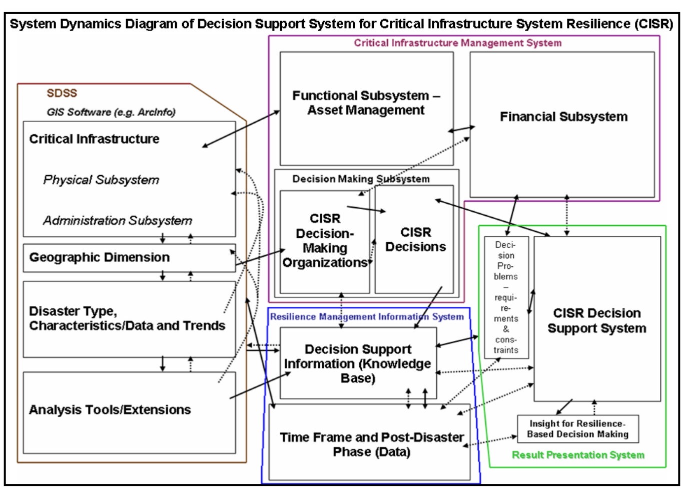
RiskMAP
Increasing Resilience Together



Improving the resilience of an infrastructure system in terms of a resilience network implies looking at the system as a whole, where despite the different loads of stress the system will continue to work. This entails considering several alternative strategies and projects, which will be feasible depending on existing policies and related organizations. The choice of strategy and/or project depends on eligibility and stakeholder options.

These factors and elements make improving resilience of critical infrastructure systems a complex problem. In an effort to capture real-world dynamics involved in such a problem, a framework was developed in a systems dynamics diagram: System Dynamics Diagram of Decision Support System for Critical Infrastructure System Resilience (CISR).



The definition of location, type of infrastructure system, type of disaster and trends are part of a Spatial Decision Support System (SDSS) that existing GIS tools can handle. To do analyses considering post-disaster policies and bring analyses to financial results and complementary metrics Hazus-MH was identified as the best tool with accepted analyses results. However, both GIS tools and Hazus-MH were still not sufficient to capture all the interactions between the elements in the developed system dynamics framework because of the asset management component, inclusion of the decision makers, types of decisions, actual decisions, data problems and constraints and data and analysis changes. Complementary software was used to develop a model to include all variables in a system dynamics environment to test and validate the framework.

Case Study

To test and validate the developed framework, a real and recent disaster declared at the Federal level was chosen: Delaware flooding on June 25-26, 2006 focusing in Sussex County.

The selected elements to be used in the framework and model included: U.S. 13 road segments for the Seaford area (Sussex County, DE), flooding, road condition and performance measures prior to, during and immediately after the disaster, as well as recovery and mitigation approaches.

It also included four Decision Makers: Delaware Department of Transportation (DelDOT), the Federal Emergency Management Agency (FEMA), Delaware Stakeholders and the Federal Highway Administration (FHWA). The FHWA policies related to transportation infrastructure recovery and mitigation were not included in the initial decision support system model developed.

Reports generated at DelDOT's Transportation Management Center identified where, when and what type of damage and/or disruption occurred to roads and bridges. These reports made it possible to compare GIS analysis such as vulnerability assessment to real-world detected problems. It also guided the development of the system dynamics model.

Integrating Hazus-MH Data and Analysis Results in the Critical Infrastructure Resilience Decision Support System

Hazus-MH focuses analyses on buildings more than other types of infrastructure. The software developed considers the U.S. Federal Government policies, FEMA's methods and methodologies for doing analyses, training people and making general inventory available for the different types of infrastructure. The existing Hazus-MH documentation and how-to guide gave a starting point to integrate data and analyses results to further analyses.

It is important to note that for the research to be successful, it was very important to bring in Hazus-MH in many aspects, such as:

- The existing data, data sources, inventory and documentation existing within Hazus-MH;
- Available access to concepts and principles included in Hazus-MH;
- Easy to find and use analysis enabled in Hazus-MH made available all in a same location versus having to do manual import of data in many different calculations, improving accuracy and reducing errors in the analysis process; and
- Open "end" enabling extracting data and information to be used within other tools to complete analysis on resilience of critical infrastructure system.

It is also important to note that because Hazus-MH is regularly updated and improved, many of the limitations at the time of this research are now obsolete. Newer versions of Hazus-MH expand its benefits and analysis capabilities.

An example of this is shown in the table below with road segments, length, and cost of segments available from the Hazus-MH inventory for Delaware. The fields for "NumLanes, Pavement and Capacity" were already available although empty. These fields were needed to do the analysis on resilience and be part of the decision support system. They were completed the best way possible to reflect real conditions at that location in Seaford. Also, Hazus-MH road segment lengths did not match with DelDOT's segmentation. However, because they carried the "financial" value related to each segment, which is vital information in the research, a visual comparison between the two layers to properly identify and select the Hazus-MH segments that matched the specific Seaford road network was performed. If Hazus-MH did not carry segment replacement-cost information, this would significantly delay getting the research completed because it would require fieldwork.

OBJECTID	ID	Name	Length	Traffic	Cost	NumLanes	Pavement	Capacity
4	DE000060	Sussex Hwy	10.83	0	$32,206.20	4	0.7	7600
5	DE000066	Sussex Hwy	0.88	0	$2,628.59	4	0.7	7600
6	DE000068	Sussex Hwy	2.54	0	$7,543.82	4	0.7	7600
7	DE000069	Sussex Hwy	0.33	0	$987.21	4	0.7	7600
8	DE000085	United States Highway	3.62	0	$21,534.23	4	0.7	7600
21	DE000509	United States Highway	0.77	0	$4,555.43	4	0.7	7600
22	DE000511	United States Highway	0.27	0	$1,623.54	4	0.7	7600

The road capacity for U.S. 13 is considering 4 lanes multiplied per 1,900 passenger cars per lane per hour = 7,600. The carrying/service capacity classification was defined as good (5,070 - 7,600), fair (2,530 – 5,070), poor (1 – 2,530), or none (0). The "Pavement Condition Index" (PCI) was considered good prior the disaster, reflected as 0.7 in a scale of zero to 1.

Impact and damage assessments to transportation originally shown in reports following FEMA's field visit assessment in Delaware were revisited when developing the analysis for resilience of the system in the customized model. It consisted of using the cost of segments given by Hazus-MH to calculate values to road infrastructure vulnerability assessment, impact assessment and damage assessment.

Hazus-MH makes available a basic initial value that can be used as a general vulnerability value, which for transportation is given as the direct value for exposure; in other words, the value of all existing infrastructure in that location. This approach enabled further analyses considering elevation and proximity to rivers. In this same aspect, it allowed thinking about the physical condition of the infrastructure that impacts the assessment of the resilience of the system.

Another parameter used in the model, initially used in Hazus-MH analyses, the “Warning System” mitigation strategy chosen to be 10% in the allowed range from 0-35% was also brought into the final system dynamics model (SDM). This value was used as an adjustment value to the reduced loss or damage of the transportation infrastructure in terms of savings (avoided bigger damage). For example, considering that the approach adapted to vulnerability in the SDM was a function of impact decreased from adaptive capacity, the warning system value that decreased the value of vulnerability had to be increased back to the value of vulnerability. Other adjustments to the value of vulnerability (not included in this document) changed the initial value extracted from Hazus-MH. Again Hazus-MH enabled more in-depth analysis by providing the initial values and considerations without which it would have been more difficult to move the research analyses ahead.

The overall result of the analysis developed in Hazus-MH, given the value of the amount of debris, underscored the need for continuous operational transportation infrastructure.

When the decision support model reached the point to quantify costs for normal operations of transportation considering the infrastructure life cycle, the “cost” of segments was needed again.

Again it is important to remember Hazus-MH is used for loss estimation and risk assessments giving insight on mitigation. It does not include the design or evaluation of mitigation projects. Evaluating mitigation projects requires field analysis and might also include use of the FEMA Benefit-Cost Analysis (BCA) tool. Nevertheless, Hazus-MH inventory can and is used for/by BCA.

An example is the loss of direct and indirect economic elements due to damage and/or disruption of transportation not calculated in Hazus-MH. When the SDM got to the point of analyzing projects to fix and put damaged transportation back into operations, the FEMA Benefit-Cost Analysis methodology was incorporated. Initially the policy parameters for FEMA’s Hazard Mitigation Grant Program were used to define the cost of recovery and mitigation projects all based on Hazus-MH inventory costs of road segments. Then, the approach to how FEMA sees and calculates benefits was incorporated at large in the SDM.

	Categories of Damages/Benefits	**Notes for Mitigation Projects**
1	Physical Damages	Consider vulnerability according to flooding.
2a	Loss-of-Function Impacts (e.g. displacement costs)	Not applicable (road and bridge cannot be displaced to temporary other locations).
2b	Loss-of-Function Impacts Other (e.g. loss of service - economic impact)	Road/bridge closures - generally the largest category of benefits.
3	Casualties	Generally not significant for flood.
4	Emergency Management Costs	Generally not considered; road/bridge mitigation projects neglect impact on a communities overall emergency management costs.

An assumption that transportation mitigation projects were 100% effective instead of 80% as FEMA specifies was used. Frequency of similar events was also relevant to help determine which and when recovery or mitigation strategies should be adopted.

Hazus-MH considers frequencies of events in the analyses giving different loss and impact results. The BCA enables refining such an approach to look at specific projects.

The “functional downtime” for road and bridge closures used in the calculation of direct economic impacts that considers number of days for repair and reopening for traffic, average delay or detour time for motorists (loss of time) and standard values determined by FEMA to evaluate this loss of time (US$32.23) were used to find the benefits of projects in terms of avoided delay.

Other parameters used for calculating hazard mitigation projects for roads and bridges included the average daily vehicle count. The project's Benefit-Cost-Ratio to determine project effectiveness helped put information in the requested format for FEMA.

Results

Hazus-MH's role in the research was fulfilled by linking the initial GIS analysis with more in depth analysis to the final piece of analysis for resilience in the systems dynamic model (SDM). And because Hazus-MH is a "standard" tool with reports accepted and used by FEMA, it transfers its benefits to the developed "Critical Infrastructure Resilience Decision Support System". The direct benefit to the research was in terms of saved time and money, and makes this work attractive to further discussions and possible refinement.

The results in terms of the research are the following: The modeling and simulation of the Delaware 2006 flooding revealed the importance of considering, and being prepared to work with mitigation projects, taking advantage of the recovery efforts, and including the improvement of the resilience of systems. The best opportunities to conduct mitigation projects are usually at locations where there are more frequent disasters.