INTEGRATED FLOOD AND SOCIO-ENVIRONMENTAL RISK ANALYSIS FOR PRIORITIZING ABC ACTIVITIES

Quarterly Progress Report
For the period ending May 31, 2021

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1. Background and Introduction

The need to accelerated bridge construction (ABC) activities due to flooding (e.g., accelerated bridge upgrade prior to flood events and accelerated bridge repair after flood events) has complex interdependencies with many physical, social, and environmental factors in urban areas. The interdependencies get exacerbated in coastal areas, such as southeast Florida, because of the pronounced effects of climate change such as extreme storm events and sea level rise impacts on surface and ground waters. Flood related factors can also contribute to bridge scour, the biggest cause of bridge failure in the United States. Due to the limited available budget for accelerated upgrade/repair processes, a comprehensive decision support tool is needed to prioritize bridges in terms of the vulnerability of bridge location and risk level of each bridge to support Department pf Transportation (DOT) decision makers in project selection.

To refine funds allocation for the ABC there is a need for a simplified, yet accurate, methodology to estimate bridge vulnerability to several interdisciplinary factors. The methodology should practice existing data and display important variables to assess the vulnerability of urban areas and risk of bridges against urban flooding considering various flood-related and socio-environmental factors. Considering factors such as excessive precipitation, extreme storm events, storm surges, and sea level rise mostly in coastal areas, flooding is not only the natural hazard with the distinguished impact on bridge failures and the amount of damage and costs resulting from that, but it is difficult to model and accordingly plan for as well. Furthermore, due to population growth rates, urbanization, and poor land use practices in flood-prone areas, flood risk has increased significantly recently. Floods and associated hazards will become more persistent, extreme, and regular along with climate change and socio-environmental effects, notably in already vulnerable areas.

The project first performs a vulnerability/risk assessment considering urban flooding and bridge scouring, social, and environmental factors, and then develops a multi-criterion, multi-stakeholder decision analysis framework in geographic information systems (GIS) environment to assign a risk factor to each bridge in the study area. The framework is applicable as a decision support tool for selecting accelerated bridge upgrade or accelerated bridge repair projects by decision makers. As a case study, the developed framework will be used for a risk-based prioritization of existing bridges in Miami-Dade County with the purpose of selecting projects for accelerated bridge upgrade or repair.

2. Problem Statement

The success of ABC projects depends on several factors which ends up improving safety, reducing road load, costs, and yielding better overall travelling experience (Wang et al., 2011). Decision-makers need to assure that the ABC techniques are thoughtfully viewed since many of the projects will have only limited budgets and time (Chaphalkar et al., 2013). Feasible candidates for ABC may be suspended or cancelled due to safety hazards, standardization, inexperienced contractors and manufacturers and technical problems related to its strength and long-term performance and the lack of program funding. Therefore, the decision-making process considers one basic stage as an early involvement in ABC projects to propose a decision support tool for prioritizing ABC activities in the presence of limited budgets before the construction process. ABC projects interact with traffic loads in the roads, but ABC need in urban areas potentially has complex interdependencies with several natural hazard (e.g., flood), environmental, and social factors (Jia et al., 2018). Past studies have asserted that flood has been the most common natural disaster, accounting for 43% of all disasters between 1995-2015 in the world (CRED, 2015). A study by Wardhana and Hadipriono (2003) found that 53% of bridge failures in the United States between 1989 to 2000 were because of scour due to floods. In point of fact, the rapid water flow generated by flood often gives rise to accumulated debris, which yields a compounded loading impact on bridges and may cause structural damage or failure (Kalantari et al., 2017). Meanwhile, the structural integrity of a bridge may be degraded by the corrosion of steel reinforcements. In this case the failure risk of bridges under flood hazards magnifies and their failure can become more sever (AASHTO, 2008). Reducing the construction time through ABC methods can potentially minimize the risk of flooding due to temporary flood diversions during the construction phase. High temperatures cause health issues for human, impacting ABC progress, and affect flooding conditions due to the effects on soil hydraulic properties and evapotranspiration processes. Social and demographic factors in adjacent areas of bridges (e.g., population, residents' age, race, and income, and age of the buildings) have implications in the need to an ABC process and can impact the construction speed. For example, ABC can help faster revitalization of a high crime rate neighborhood based on urban master plans while ABC activities may also be negatively impacted in those neighborhoods.

To obtain more realistic and accurate vulnerability assessment of bridge failure against floods, the flood-related factors and interdependence factors should be included in the risk analysis (Arneson et al., 2012). Complexity, multidimensionality, and inherent uncertainties of urban systems require the risk analysis to be comprehensive and able to address different criteria, multiple stakeholders, and spatial aspects of the problem (Glas et al., 2019). The proposed study addresses the need to a comprehensive risk-based multi-criteria multi-stakeholder decision analysis framework that can be used as a decision support tool for prioritizing ABC activities in the presence of limited budgets. Developing the multi-criteria multi-stakeholder decision analysis framework option will consider, among other things, early contractor involvement in order to ensure the project can be constructed in the construction site considering the time and budget allotted. The proposed project once would be focused on the vulnerability assessment of bridge failure against floods and will also be geared towards addressing socio-environmental factors.

3. Objectives and Research Approach

The objective of this study is to develop a multi-criterion, multi-stakeholder decision analysis framework in GIS environment to assess the vulnerability of urban areas and risk of bridges against flooding and socio-environmental factors. The framework can be used as a decision support tool for selecting accelerated bridge upgrade or accelerated bridge repair projects by decision makers. As a case study, the developed framework will be used for a risk-based prioritization of existing bridges in Miami-Dade County with the purpose of selecting projects for accelerated bridge upgrade or repair.

The overall approach is to introduce GIS to assess the vulnerability of urban areas and risk of bridges against flooding and socio-environmental factors. The project also describes the use of GIS during the case study for different tasks including, but not limited to the collection and pre-processing of physical, social, and environmental data.

Figure 1 presents the flowchart of the proposed methodology. This study considers three types of vulnerability: physical, social, and environmental vulnerability. Definition and details of each group are discussed in Task 2. Once the GIS data discussed in Task 2 are collected, two major steps of the proposed methodology are as follows:

1. Creating vulnerability maps: By using the collected physical, social, and environmental GIS data, the developed framework will identify vulnerable urban areas against flooding and socio-environmental factors and creates vulnerability maps. A vulnerability map is first created for each major criterion (i.e., physical, social, and environmental vulnerability maps). Then, the vulnerability maps will be combined using the developed MCDA (multi-criteria decision analysis) framework. The output of this step would be an integrated vulnerability map against flood and socio-environmental factors. The framework is capable of handling problems with multiple stakeholders or decision makers. Therefore, the opinions of decision makers about the relative importance of physical, social, and environmental factors will be incorporated into the framework through a group decision making process.

2. Creating risk maps: The vulnerability map will be combined with existing data about history of flooding, traffic loads and structural conditions of the bridges to generate risk maps that provide risk levels for each of the existing bridges in the study area. Example of bridge related data include type, number, and configuration of piers, scour countermeasures such as rip raps, collars, and sacrificial piles, age of bridges, and structural conditions based on inspections to assess scour potential. High risk bridges can be selected by decision makes (e.g., state DOTs) for accelerated upgrade (retrofit) prior to flood events or accelerated repair after flood events.

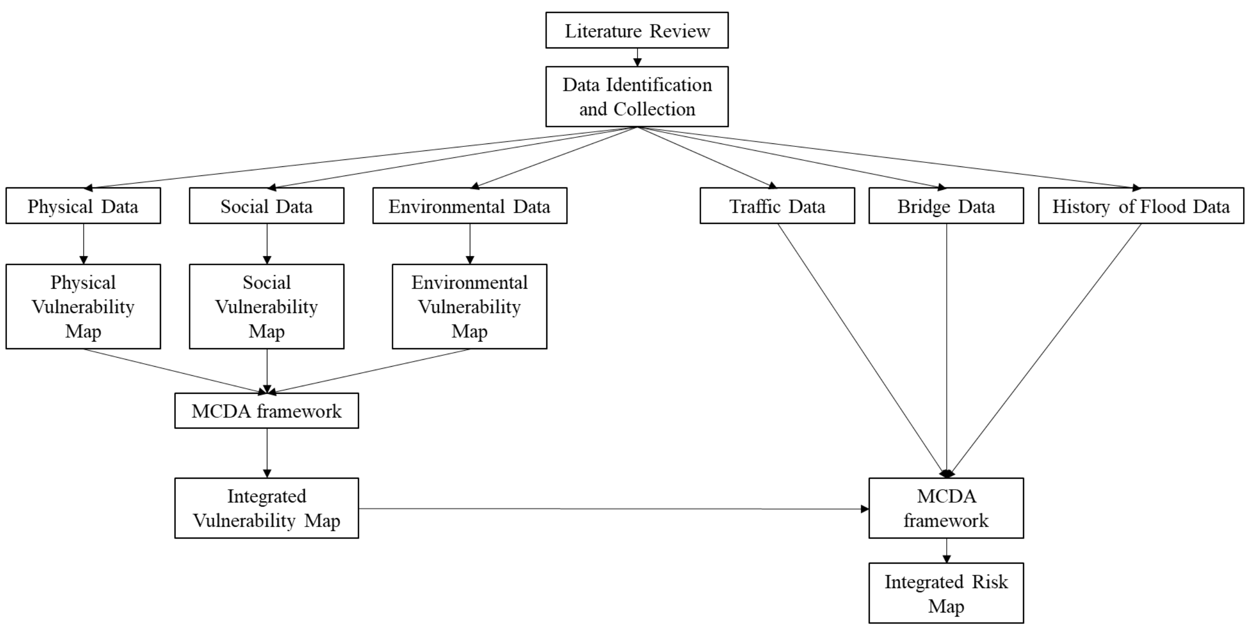

Figure 1. Flowchart of the proposed methodology. Comprehensive vulnerability map for the study area and comprehensive risk map indicating a risk level for each bridge are two final products of the study.

4. Description of Research Project Tasks

Task 1 – Literature Review

The objective of literature review is to identify existing state of the knowledge and practice about socio-techno-environmental risk analysis approaches for natural hazard problems in urban areas. Also, another literature review is performed to identify the existing studies on the interdependencies of climate factors, land factors, bridge characteristics, and bridge scour to be leveraged in the study.

According to the United Nations Office of Disaster Risk Reduction (UNDRR) risk is the combination of the probability of a hazardous happening and its negative consequences which develop out of interactions between natural or man-made hazard(s), vulnerability, exposure and capacity (Birkmann et al., 2010). Vulnerability can be the combination of multi criteria categories, including physical, social, economic, environmental, psychological, structural, and institutional (Pescaroli and Alexander, 2019; Ghajari et al., 2017). The Intergovernmental Panel on Climate Change (IPCC) considered the risk concept, as a function of hazard, exposure and vulnerability, instead of the vulnerability definition (IPCC 2012b). This new IPCC concept determines that the damaging effects of a hazard depend on the local vulnerability of an exposed society. Considering the vulnerability as one element of the hazard risk is required to decrease the vulnerability before and after the hazard's occurrence (IPCC 2014) and boost resilience (Golz, Schinke, and Naumann 2014), yet in many applications, vulnerability still is considered only as the impacts of a hazard (Yang et al. 2018; Weis et al. 2016; Kc, Shepherd, and Gaither 2015).

In recent years, a better representation of hazard, and vulnerability along with spatial science (e.g. GIS) has been challenging. Recent studies used 'integrated' (Weis et al. 2016), 'hybrid' (Roodposhti et al. 2016), 'multicriteria decision analysis' (MCDA) and 'system-thinking' terms (Gomez Martin et al. 2020). However, most definitions are not fitting to different areas and hazards because of geographical differences, human interactions and inadequate data (Robinson et al. 2019), governance ordering (Driessen et al. 2018), the involvement of stakeholders and dynamism of cities (Ciullo et al. 2017). The vulnerability also varies over different time periods and due to different causes, which provide challenges for the assessment in different areas (Pescaroli and Alexander 2019). For flood analysis, GIS technologies, remote sensing, and numerical models have been widely used recently.

A geographic information system (GIS) is able to integrate data from various sources, analyze, and report the results, which makes it a valuable tool in the management process (Eastman et al. 1997). GIS is applicable for damage assessment due to its ability to combine results from the hydraulic model and socio-environmental information. Complex decision making situation like flood risk assessment that consists of several spatial criteria can be developed through Geographic Information Systems' capability of visualization, analysis, and management of spatial data (Meyer et al., 2009, Papaioannou et al., 2015, Tang et al., 2018). GIS is an important tool in analyzing and assessing the effects of natural hazards (Haq et al., 2012, Kanani-Sadat et al., 2014, Karimipour and Kanani-Sadat, 2016, Pourghasemi et al., 2013); therefore many studies have investigated flood analysis and developing flood risk assessment map using the capabilities of GIS (Sanyal and Lu, 2009, Strobl et al., 2012, Tehrany et al., 2014a, Tehrany et al., 2014b, Termeh et al., 2018, White et al., 2010, and Khosravi et al. 2018)

Considering mapping approaches, the discussion of selecting an appropriate indicator is a challenge (Malczewski and Rinner 2015). Indicators assignment and the quality of available data require a deep conception of the complex system. Another challenge is the criteria weights allotment as the complexity of systems is limiting the criteria to have equal influence in a hazard (Jung et al., 2011). For vulnerability and exposure mapping assessments, studies mostly assess equal weighting (Hazarika et al. 2018) or either subjective or objective (Birgani and Yazdandoost 2018) methods for weights calculation. Furthermore, data collection and preparation is the most important step and can be the most time-consuming part of an analysis. Generally, study of natural hazards requires multiple datasets to distinguish the spatial changes and the processes of hazards (Martinez and Le Toan 2007). Natural hazards could be under the effects of several factors, namely the geomorphology, vegetation, geologic and hydrologic parameters and patterns that must be considered in providing of the flood risk assessment maps. Therefore, risk assessment mapping is a Multi Criteria Decision Analysis (MCDA) process (Hwang and Lin, 2012, Malczewski, 2006).

Multi-criteria decision analysis (MCDA) has been recognized as an essential tool for analyzing complex decision problems that often concern for incomparable data or criteria (Hwang and Yoon 1981; Malczewski 2006). Analytical Hierarchy Process (AHP) is a well-liked method of MCDA (Pourghasemi et al. 2012), based on experts' knowledge in assignment groups and weighted grading. Fernandez and Lutz (2010) have estimated the efficiency of MCDA and GIS for mapping any area adjacent to a river, lagoon, or lake likely to have floods anytime the water level rises in Tucuman Province, Argentina. According to this study, the AHP method in the GIS environment is effective in generating natural disaster hazard maps with reasonable accuracy. Zou et al. (2013) described the AHP technique as a cost-effective with a clear understanding and effective analysis method for flood hazard evaluation. Subramanian and Ramanathan (2012) applied the AHP technique in urban and regional research. To evaluate natural disaster risks there are other methods of MCDA, namely Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Multi Attributive Border Approximation Area Comparison (MABAC). TOPSIS has been indeed used in flood hazard management due to its ability to cope with multiple attributes (Brito and Evers 2016). Mojtahedi and Oo (2016) presented an integrated non-parameter resampling bootstrap technique and TOPSIS to assess the flood risk of Australia's states. Zhu et al. (2018) extended a TOPSIS-based model for Reservoir flood control operation (RFCO) problem. Luu et al. (2019) developed the brand-new multiple linear regression TOPSIS for Vietnam's evaluation flood risk. Several studies also have used the fuzzy-TOPSIS technique (Jung et al. 2011; Lee et al. 2014). In general, MCDA methods are approaches that have been most popular in flood hazard assessment applied by many researchers in recent studies (Rahmati et al. 2016; Rahman et al. 2019; Ogato et al. 2020). Improving the accuracy of these models has always been one of the main concerns of researchers and decision makers. While all papers have shown no universal guideline in finding the best model in a region due to the models limitation, some researches (Shafapour Tehrany et al. 2019; Hong et al. 2018; Costache et al. 2020; Rahman et al. 2019) proved that combining several methods may lead to higher accuracy in flood susceptibility assessment.

Task 2 – Data Identification, Collection, and Analysis

Hazard indicators include the physical factors that make the floodplain community prone to flooding. The indicators that emerged as a result of participatory GIS are discussed below. Each hazard indicator is subdivided into classes, and a value is assigned to them, which represents the hazard category. Buffer zones are created based on these classes that represent the spatial extents that might get affected due to flooding influenced by the hazard indicators.

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hazard indicator is subdivided into classes, and a value is assigned to them, which represents the hazard category.

The geographic information system (GIS) is a system which uses data referenced by spatial co-ordinates. Observation and collection of data as well as storage and analysis to the use of the information derived are crucial part of a decision-making process. The choice of the major indicators that influence socio-environmental and physical vulnerability represents a critical point as it depends extremely on both the quality of the available data and time period of their selection (Nardo et al., 2005). Indeed, no solid guideline concerning which data to choose and how to analysis is reported. In terms of social factors, social and cultural heterogeneity changes in different urban communities and, then, many various methodologies can be applied to assess social vulnerability at each scale and system. This process of identifying data consists of a number of processes, including acquiring satellite or aerial photographs, maps, collecting demographic information or data on rainfall/ runoff, and conducting field surveys. After a careful review of related literature (Cutter et al., 2003; Cutter & Emrich, 2006; Rygel, O'sullivan, & Yarnal, 2006; Birkmann, 2006; Utami, 2008; Cutter, Emrich, Webb, & Morath, 2009; Wood, Burton, & Cutter, 2008), the most relevant factors that influence socio-environmental and physical vulnerability are being considered as follows:

- Physical Data: Groundwater Level, Precipitation, Flood, Storm, Air Temperature, Thunderstorm Wind, Humidity, Surge, Slope, Land Cover, Impervious, Sediment, Digital Elevation Models (DEM), Flood Zone, Soil Type, River Shape, Soil Permeability, Road Networks, Water Bodies, Shore Line, Lake, Bridge Networks, Stream Networks, Channel Networks, Highways.
- Social Data: Drainage Density, Traffic Accident, Daily Traffic, Land Use, Building Age, Road Age, Population, Public Health, Crime Rate, Income Rate, Education.
- Environmental Data: Water and Groundwater Quality, Air Quality, NDVI, Brownfield Area, Vegetation Type, Leaf Area Index, Tree Canopy.

Resources have been used to collect GIS data:

- Manual of Federal Geographic Data Product (http://www.fgdc.gov/FGDP/title.html);
- U.S Department of Agriculture Natural Resources Conservation Services Data Clearinghouse (http://www.ncg.nrcs.usda.gov/nsdi_node.html);
- Esri Open Data Hub (https://www.esri.com/en-us/arcgis);
- United States Geological Survey (USGS) (http://www.usgs.gov/);
- Geography Network (http://www.geographynetwork.com/);
- U.S. Department of Agriculture (https://www.usda.gov/);
- National Oceanic and Atmospheric Administration (http://www.noaa.gov/);
- National Oceanographic Data Center (http://www.nodc.noaa.gov/);
- Geographic Data Technology (GDT) Inc. (http://www.geographic.com/home/index.cfm);
- Natural Earth Data (https://www.naturalearthdata.com/);
- Global Land Biosphere Data and Resources (http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/LAND_BIO/GLBDST_main.html);
- Global Surface Temperature (http://lwf.ncdc.noaa.gov/oa/climate/research/blended/blended.html);
- OpenStreetMap (https://www.openstreetmap.org/);

- Open Topography (https://opentopography.org/);
- UNEP Environmental Data Explorer (https://geodata.grid.unep.ch/);
- NASA (http://www.gsfc.nasa.gov/);
- Sentinel Satellite Data (https://scihub.copernicus.eu/);
- National Weather Service (https://www.weather.gov/);
- Federal Emergency Management Agency FEMA (https://www.fema.gov/);
- Other online resources also contain the U.S. Flooding Public Information Map (www.esri.com/services/disaster-response/flooding). This map has constantly updated flooding information from the NWS and presents observed flooding locations, current and forecast rainfall, flood warning sites, the locations of stream gauges and provides flooding height data. The USGS Flood Event Viewer (FEV) (water.usgs.gov/floods/FEV) for existing high-water mark data provides a national database of high-water mark information for flood events and flood response data. The FEV also displays location of and flood height data gathered by temporary deployed USGS stream gages.

Task 3 – Framework development

An effective, MCDA technique that is compatible with the problem in hand and is capable of handling group decision making will be used in GIS environment to develop the decision support framework. The details and interrelationship between the elements in the framework will be determined based on the available data from Task 2.

Task 4 – Spatial multi-criteria group decision analyses

The developed framework will be applied to the case study and vulnerability and risk maps will be generated.

Task 5 – Reporting

The results and findings of the study will be reported in a manner consistent with existing protocols. Future directions and recommendation for applying the framework to other geographic regions will be provided in the final report.

5. Expected Results and Specific Deliverables

The proposed framework can be used as a decision support tool by state or regional decision makers in prioritizing ABC activities (e.g., accelerated upgrade/repair solutions) for existing bridges as part of the maintenance/rehabilitation programs. The framework can be leveraged to develop an online (cloud-based) decision support tool that generates vulnerability and risk maps by taking several spatial input data from the user (or automatically from public databases) and the decision maker’s opinion on the relative importance of different physical, social, and environmental factors. Applicability of the framework to different geographic regions hinges on the availability of the input GIS data. Most of the required input data are available for the entire country through national, state, or regional datasets. Therefore, the methodology is not limited to any specific geographic region. However, the decision making criteria and their associated GIS data need to be determined for each study region. For example, groundwater data may be more important in coastal regions with shallow water tables compared to inland areas with deeper groundwater levels. Also, the importance of social criteria and socio-cultural/demographic data may be different when the study region houses underrepresented communities and minority groups.

The project is planned for future extensions in multiple phases, providing opportunities for developing larger proposals to seek funding from other agencies. Future extensions of the project include, but are not limited to, the consideration of larger case studies (e.g., the entire bridge and road networks in Florida), incorporation of climate change effects into the framework, development of risk management scenarios in concert with ABC activities to address the identified risks, and addition of uncertainty analysis to further assist the end users (e.g., state DOTs) in practical applications. As an example, development of risk management scenarios to address the identified risks are expected to result in complementary elements in the ABC project site (e.g., implementing storm water green infrastructure to alleviate flood effects and risk of bridge scouring) or additional activities related to site preparation and geotechnical tests that can be included in bridge specifications to increase the efficiency of ABC activities.

6. Schedule

Progress of tasks in this project is shown in the table below.

Item	% Completed
Percentage of Completion of this project to Date	20

Research Task	2021										2022	
	M	A	M	J	J	A	S	O	N	D	J	F
Task 1. Literature review												
Task 2. Data identification, collection, and analysis												
Task 3. Framework development												
Task 4. Spatial multi-criteria group decision analyses												
Task 5. Reporting												
		Work Performed										
		Work To Be Performed										

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