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Operationalizing the Pressure and Release Theoretical Framework Using Risk Ratio Analysis to Measure Vulnerability and Predict Risk from Natural Hazards in the Tampa, FL Metropolitan Area

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Operationalizing the Pressure and Release Theoretical Framework Using Risk Ratio Analysis to Measure Vulnerability and Predict Risk from Natural Hazards in the Tampa, FL Metropolitan Area

by

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of the requirements for the degree of
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ABSTRACT

Significant damage and loss is experienced every year due to natural hazards such as hurricanes, tornadoes, droughts, floods, wildfires, volcanoes, and earthquakes. NOAA's National Center for Environmental Information (NCEI) reports that in 2016 the United States experienced more than a dozen climate disaster events with damages and loss in excess of a billion dollars (NOAA National Centers for Environmental Information, 2017). Identifying vulnerabilities and risk associated with disaster threats is now a major focus of natural hazards research. Natural hazards research has yielded numerous theoretical frameworks over the last 25 years that have explained important elements of risk and vulnerability in disasters (Birkmann, 2016b). However, there has been much less progress made in operationalizing these frameworks. While the theory is well established, one of the more pressing challenges before us is the lack of development of user-friendly and flexible risk assessment techniques for emergency managers (Mustafa et al., 2011).

The trend in operationalizing natural hazards, theoretical frameworks has been the development of general, all-purpose, static models to measure vulnerability. However, important missing elements in the current hazards literature is the need for an operationalized risk model that is (1) simple, quick and easy to use, (2) flexible for changing conditions, and (3) site-specific for various geographic locations. Many of the current models for determining risk and vulnerability are very complex and time consuming to calculate and thus make them of little use for emergency and risk

managers. In addition, little analysis has been conducted to see if a flexible risk identification measurement system could be developed. As vulnerability and risk become fluid due to changing conditions (environmental—hazard and location) and circumstances (social, economic, and political), our measurement tools need to be able to capture these differences in order to be effective.

This dissertation examines whether the Pressure and Release (PAR) natural hazards, theoretical framework can be operationalized using financial risk ratio methods. Specifically, it analyzes risk ratios using key vulnerability indicators to identify escalating vulnerability and ultimately predict risk. A structured modeling approach was used to identify key vulnerability indicators and develop risk ratios. These are applied to a case study to demonstrate whether this new approach can identify emerging risk trends. My research suggests that instead of operationalizing natural hazards theoretical frameworks using the current static, aggregate index method, a flexible risk ratio method could provide a new, viable option.

CHAPTER ONE:

INTRODUCTION

1.1 Introduction

Significant damage and loss is experienced every year due to natural hazards such as hurricanes, tornadoes, droughts, floods, wildfires, volcanoes, and earthquakes. NOAA's National Center for Environmental Information (NCEI) reports that in 2016 the United States experienced more than a dozen climate disaster events with damages and loss in excess of a billion dollars (NOAA National Centers for Environmental Information, 2017). From 2000-2017 annual billion dollar loss events have steadily increased. See Figure 1.1 below. Evaluation from the National Climatic Data Center (NDCD) expects this trend to continue (Sun et al., 2015). A number of prominent researchers in the natural hazards field have also noted this same trend of escalating, catastrophic economic losses as a result of natural hazards (Boruff et al., 2005; Gall et al., 2011, Lott & Ross, 2015). Disaster losses will likely adhere to the current trajectory and negatively impact the nation due to increased exposure of vulnerable populations and structural assets; however, with better understanding of risk and how vulnerability contributes to these losses it may be possible to develop effective mitigation measures to intercept this financial calamity.

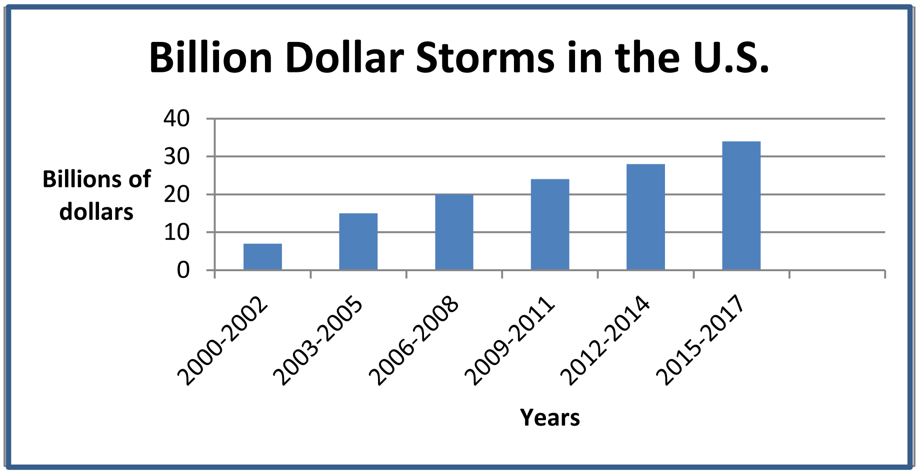


Figure 1.1 Billion Dollar Storms in the U.S. from 2000-2017 (Created by J. Wilder with data from National Centers for Environmental Information)

Identifying vulnerabilities and risk associated with disaster threats is now a major focus of natural hazards research. While the theory is well established, one of the more pressing challenges before us is the lack of development of user-friendly and flexible risk assessment techniques for emergency managers (Mustafa et al., 2011). Better tools to measure and identify vulnerability, could help to determine at-risk populations and escalating conditions and allow more responsive and effective mitigation policies to be created.

This research examines vulnerability with an attempt to develop a new vulnerability measurement protocol to detect changes in risk associated with natural disasters. By developing and comparing risk ratios compiled from key performance indicators it may be possible to identify vulnerabilities long before they turn into expensive disasters. This chapter outlines the research goals and objectives, background of the problem, study site characteristics, problem statement, research questions and hypotheses, research design, and finally, how the dissertation is organized.

1.2 Research Goals and Objectives

The following goals express the broad outcomes that are expected and the general strategies (approaches) used to achieve them. The primary goal of this research is to offer an alternative model for examining vulnerabilities as a component in determining risk to a variety of natural hazards. In addition, this research is expected to offer predictive capabilities to emergency managers and other disaster personnel to determine risk threats in their particular geographic locations. It may be possible that this information could be leveraged with local, state, and national officials to initiate more effective disaster planning. The final goal of this research is to provide a way to alleviate unnecessary human suffering and loss from natural disasters due to delayed emergency planning and mitigation strategies because risk trends were not recognized early enough.

The following objectives are presented as measureable steps used to achieve the research goals.

(1) To identify and report on the application and challenges of the newly developed operational risk model and add to the natural hazards research literature.

(2) To build a comprehensive library of key performance indicators, ratio measures, and data sources of vulnerability to natural hazards and make them publically available.

(3) To determine best practices of natural hazards planning and preparedness with regard to identifying vulnerable populations and assets.

1.3 Background

Prior to 1990, natural hazards research was in its infancy and lacked the deep theoretical foundation to support the discipline. The scientific community recognized the need for an international focus on advancement of natural disaster research prompting the United Nations General Assembly to designate the 1990s as the International Decade for Natural Disaster Reduction (IDNDR). This released a substantial amount of funding and precipitated a flurry of natural hazards theoretical frameworks that has continued to populate the hazards literature for the last 15 years. More than a dozen conceptual models have been developed addressing critical aspects of hazards theory and promoting advancement of hazards research (Birkmann, 2006b).

Now that the discipline has adequate theory from which to ground future research, the next step is to bridge the gap between theory and practice by operationalizing these theoretical frameworks. The most common method in use today is the aggregate index method which combines a number of vulnerability indicators into a vulnerability or risk score. Examples include the Disaster Risk Index (Peduzzi et al., 2009) and the Social Vulnerability Index (Cutter et al., 2003). The aggregate index method is effective when using the outcomes to compare or rank entities. However, since they are static, general purpose measures, their use is limited in volatile emergency situations. Other methods to operationalize the current theoretical frameworks have been very slow to materialize, particularly measurement methods that can accommodate the fluid nature of disasters and differences in geographic locations. A hurricane in one location rarely has the same impact and damage as in another although they are of the same magnitude. The variety in social, economic, political, and environmental systems in the hazard location is just too vast and our measurement systems need to be able to reflect these unique differences in order to be useful.

1.4 Study Site

Tampa, FL metropolitan area, located in Hillsborough County, was selected as the research site to demonstrate the newly developed disaster risk ratio measurement protocol, a viable alternative to the aggregate index method in current use. This location was considered optimal because it occupies a geography that consists of more than a dozen identifiable natural hazards (LMSWG, 2015). The Tampa, FL metropolitan area also has a significant population and high recurrent risk for hurricanes, storms, and persistent flood events which makes this site very suitable for natural hazards research. The following is a description of Tampa, FL metropolitan area's geography, climate, geology/hydrology, ecology, demographics, political structure, economy, and natural hazards risk profile; critical elements that can influence the research outcomes.

1.4.1 Geography

The history and geography of Florida and the Tampa, FL metropolitan area forms a unique and interesting dynamic. Historically, the Tampa, FL metropolitan area was inhabited by indigenous peoples including the Seminole Indians. Florida was purchased from Spain in 1819 by the U.S. government as part of a trade deal to relinquish parts of Spanish Texas and became the 28th state in 1845. Tampa was officially incorporated in 1849 and consists of a metropolitan area located on a 400 square mile natural, open-water estuary with a highly concentrated population occupying a large, low-lying coastal area in Hillsborough County with a current population of 1.3 million people.

Florida is an elongated, low-lying peninsula, approximately 450 miles long and 350 miles wide located between 24-31^{o} North latitude and 80-87 ^{o} West longitude. The peninsula is situated between the Atlantic Ocean on the east and the Gulf of Mexico on the west. The state of Florida has a population of 20.3 million people, making it the 3rd most populous state after California and New York. The major population centers, as listed in Table 1.1, are located in Jacksonville, Miami, Tampa, and Orlando; the government seat is centered in Tallahassee.

Table 1.1 Florida Cities Ranked by Population Size. (Created by J. Wilder with data from the U.S. Census)

MAJOR POPULATION CENTERS IN FLORIDA		
Rank	**Name**	**Population (# of people)**
1	Jacksonville	868, 031
2	Miami-Hialeah-Ft. Lauderdale	856,662
3	Tampa	369, 075
4	Orlando	270, 934
5	St. Petersburg	257, 083
6	Tallahassee	189,907

Hillsborough County is the economic center of the Tampa, FL metropolitan area and is made up of three incorporated jurisdictions, Tampa, Plant City, Temple Terrace and one unincorporated jurisdiction. See Figure 1.2 below. This study will be concerned with Tampa and Temple Terrace jurisdictions and is referred to as Tampa, FL metropolitan area.

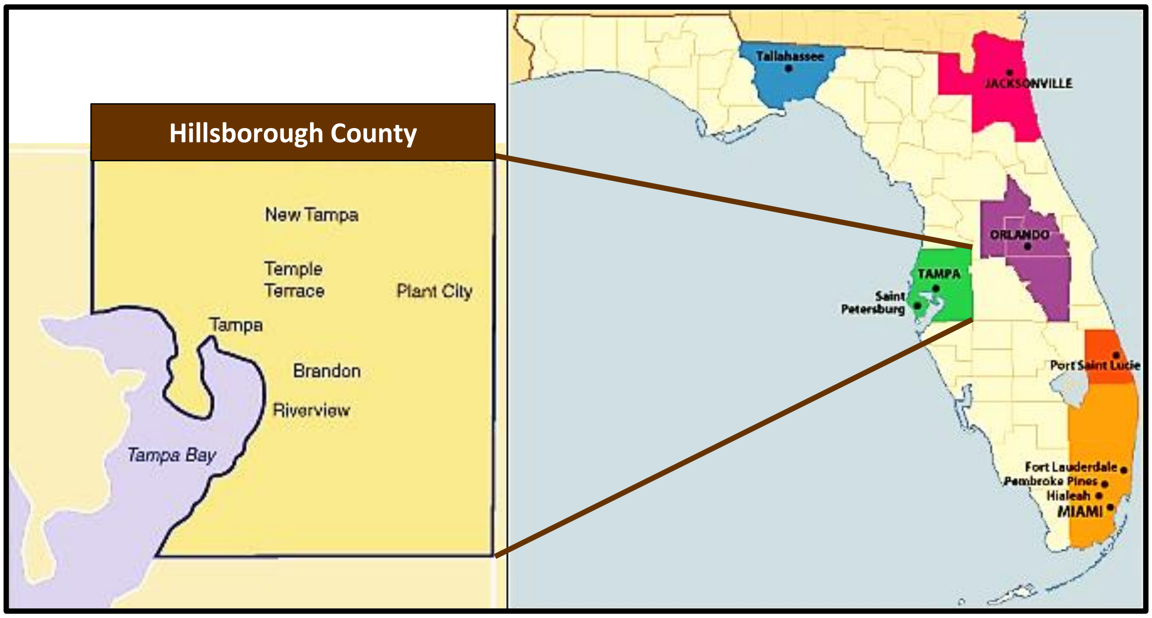


Figure 1.2 Major Population Centers in Hillsborough County and Florida. (Source: FL State Government)

1.4.2 Climate

Climate is the average weather conditions of a location, usually measured over one year. Climate in the in the state of Florida is classified as humid subtropical (NOAA Climate Data, 2017). This zone is characterized by hot, humid summers and mild winters where tropical air masses dominate along coastal locations between 25 and 35 degrees latitude. Because of this, high levels of atmospheric moisture feed tropical storms over the state, including hurricanes and frequent thunderstorms during the warm, rainy season of June through September.

Since Florida is a peninsula with warm, oceanic water on three sides, the maritime effect produces milder and less variation in temperatures compared to similar continental (land-locked) locations. As illustrated on Table 1.2 below, the annual temperature ranges from to 52^{o}F to 90^{o} F. Florida's warmest temperature on record was 109^{o} F in 1931 and the coldest was -2^{o} F in 1899. With all the water that surrounds

Florida including 58 inches of rain annually, it is still susceptible to drought (precipitation deficits) causing crop damage, wildfires, and water supply shortages particularly during the late spring and early summer months. Weather records show that a serve and widespread drought has occurred somewhere in Florida every decade since the 1900s with the most recent being in 2006, 1998, and 1984 (NOAA Climate Data-Storm Events, 2017).

Table 1.2 Average High and Low Temperatures and Precipitation for Tampa, Florida. (Source: Florida Climate Data Center)

Ave.	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
High Temp. °F	70.1	71.6	76.3	80.6	86.3	88.9	89.7	90.0	89.0	84.1	78.0	72.0
Low Temp. °F	52.4	53.8	58.5	62.4	68.9	74.0	75.3	75.4	74.3	67.6	60.7	54.7
Precip. Inches	2.27	2.67	2.84	1.80	2.85	5.50	6.49	7.60	6.54	2.29	1.62	2.30

1.4.3 Geology and Hydrology

The geology of Florida is classified as a porous plateau of karst limestone coral sitting on top a bed rock of silt, clay, and sand. Many interconnected networks of caves, sinkholes, and springs are found throughout the state. Large deposits of phosphate are located in the central region of Florida including Hillsborough County. The mean elevation is 100 feet above sea level with flat terrain and sand is a major component of most substrate soils in this state. In addition, because of low elevation, adequate drainage and storm surge issues are problematic (Florida Geological Survey, 2017).

Hydrological features of Florida consists of a complex system of rivers, aquifers, springs, reservoirs, impoundments, and wetlands all fed by precipitation. There are several major rivers in Hillsborough County including the Hillsborough River, Alafia River and the Little Manatee River that provide watersheds into the Tampa Bay estuary. Florida and the Tampa metropolitan area are prone to frequent flood events and government management of flood prone areas is of high priority (LMSWG, 2015). The map in Figure 1.3 below shows the flood prone areas of Tampa Bay metropolitan area in blue.

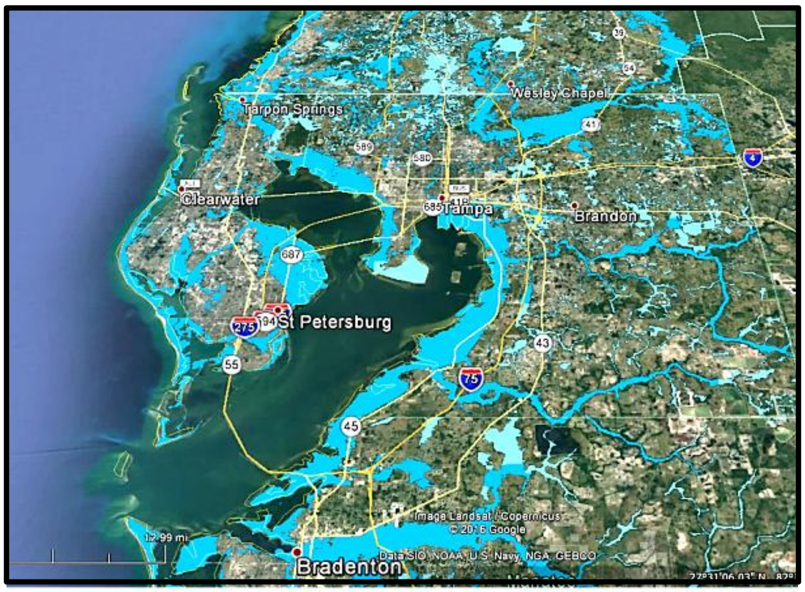


Figure 1.3 Flood Prone Areas in Tampa Bay, FL Shown in Blue. (Source: FWCC: FL Fish and Wildlife Conservation Commission)

1.4.4 Ecology

Florida ecosystems experience significant pressures from development, population growth, habitat destruction, and increasing numbers of invasive and exotic species. Natural hazard events often disrupt the delicate balance of these micro ecosystems. Florida also has several notable sensitive ecosystems including (1) coral reefs, (2) natural springs, (3) temperate hardwood forests, (4) wetlands--mangrove forests, Cypress swamps, and sawgrass marshes, (5) nearshore seagrass beds, and

(6) beaches and dunes. The Everglades, a natural tropical wetland, has one of the largest concentrations of nonnative species in the world that routinely cause extensive ecosystem damage including the Burmese python, lionfish, and tegu (large black and white lizard). In addition, the Florida Fish and Wildlife Conservation Commission managed species include alligator, bald eagle, black bear, Gopher tortoise, manatee, Florida panther, sea turtle, waterfowl such as ducks, and migratory birds (FFWC, 2016).

Tropical storms and other natural hazards impact sensitive ecosystems by destroying habitat; corals, sea turtles, manatees, and birds are particularly impacted by natural hazards. Damage and loss of wetlands, particularly to swamps and grassland marshes, are accelerated by urban development, filling, and dredging activities. This is of great concern as these ecosystems offer a buffer zone to flooding and wave impact (turbidity) from storms and protect against saltwater intrusion as well as provide critical fish and bird habitat. In addition, solid waste disposal and pollution continue to be problematic. In 2010 there were 44 Superfund sites (long-term cleanup of hazardous materials) and 101 brownfields (industrial contamination) in the state of Florida (FL-EPA, 2017).

1.4.5 Demographics

Major demographics of Florida are summarized in Table 1.3 and include ethnic/race, religion, language, and education. According to the most recent U.S. Census (2017), Florida is predominantly Caucasian, English-speaking, Christian group with a high rate of education. Median age is 41.6 years. More than 27 % of Floridians speak languages other than English with Spanish (20%) being the most common foreign language spoken. Hispanics account for 22.5% of the population.

Table 1.3 General Demographic Data of Florida. (Created by J. Wilder with data from the U.S. Census)

DEMOGRAPHIC DATA		**Florida**
Race/Ethnic Groups	White	77.7 %
	Black or African-American	16.8%
	American Indian and Alaska Native	0.5%
	Asian	2.8%
	Hispanic or Latino	24.5%
	White, not Hispanic or Latino	55.3%
Religion	Christian	70%
	Jewish	3%
	Other non-Christian	3%
	Unaffiliated	24%
Languages	English	73%
	Spanish	20%
	French or French (Haitian) Creole	3%
Education	High school graduate	86.9%
	Bachelor's Degree or higher	27.3%

Florida has a number of notable sensitive populations including a sizeable transient group (snowbirds) and elderly retirees that can make emergency management during natural hazards challenging. Florida snowbirds consist of seasonal resident retirees who relocate to Florida from about October to April to escape harsh winter weather in the north such as Canada, New York and Michigan. While no formal "snowbird" statistics exists, it is estimated to be about 20% of the total population in Florida or about 2 - 7 million people in any given year. Florida also has a higher number of elderly (65 and older) compared to the rest of the nation as it is a popular retirement destination. The Pew Research Center reports that 53 of 67 counties in Florida have an above-average share of people 65 and older (Pew, 2017).

1.4.6 Economy

Economic health of a region is often determined by GDP or gross domestic product and is a measure of all the goods and services produced over a time period usually a year. It is also representative of the size of the economy. Florida currently ranks 4th in the nation with a GDP of nearly $1 billion. See Figure 1.4 below.

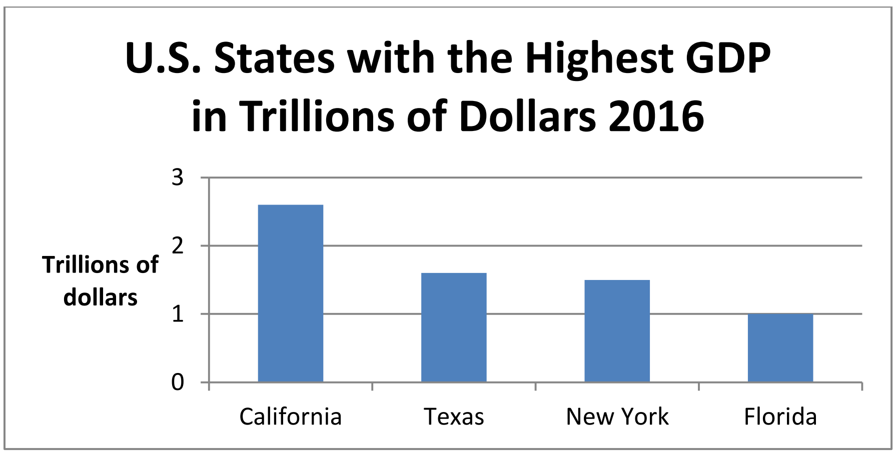


Figure 1.4 U.S. States with the Highest GDP in Trillions of Dollars (Created by J. Wilder with data from the National Bureau of Economic Research)

Six industries drive GDP in Florida and include: (1) tourism, (2) agriculture, (3) international trade, (4) aerospace and aviation, (5) life sciences—biomedical and pharmaceutical and (6) financial services (U.S. Dept. of Labor, 2017). Tourism plays a critical role in Florida's economy with 31.1 million tourists in 2017. Florida is the leading state in the nation's cruise industry and home to 8 of the top 20 amusement parks in North America. Walt Disney World in Orlando, FL is the largest single site employer with over 66,000 employees. In addition, Florida produces 70% of the annual U.S. production of citrus and 40% of the worlds orange juice supply. It also ranks 2nd in the

U.S. production of fresh vegetables. It is also home to 2 of the 9 active space ports in the U.S. including Cape Canaveral Spaceport. Florida is listed second in the nation for FDA-registered medical device production facilities and has over 200 pharmaceutical and medicine manufacturing companies.

The Tampa-Hillsborough County area economic statistics are very consistent with the U.S. national averages in household income, household size, home ownership, median home values, unemployment rate and poverty rate. See Table 1.4 below.

Table1.4 Economic Statistics Comparison for Tampa-Hillsborough County and the U.S. National Average (Created by J. Wilder with U.S. Dept. of Labor-- Bureau of Labor Statistics and U.S. Census data)

	Tampa-Hillsborough County Average	**U.S. National Average**
Median household income	$49,597	$56,516
Average household size	2.6 people	2.5 people
Homeownership	60%	67.4%
Median home value	$198,900	$188,900
Unemployment rate	4.1%	4.4%
Poverty rate	15%	14.3%

Nearly half of Hillsborough County's workforce is located in the greater Tampa, FL metropolitan area. As illustrated in Figure 1.5, the top major employer is the Hillsborough County School District with 25,776 employees followed by the University of South Florida with 16,693 and MacDill Ari Force Base with 14,500 employees. The Tampa, FL metropolitan area future job growth rate over the next 10 years is predicted to be 38.5%. Current unemployment rate is 4.8%. The sales tax rate is 7% and income tax is 0%.

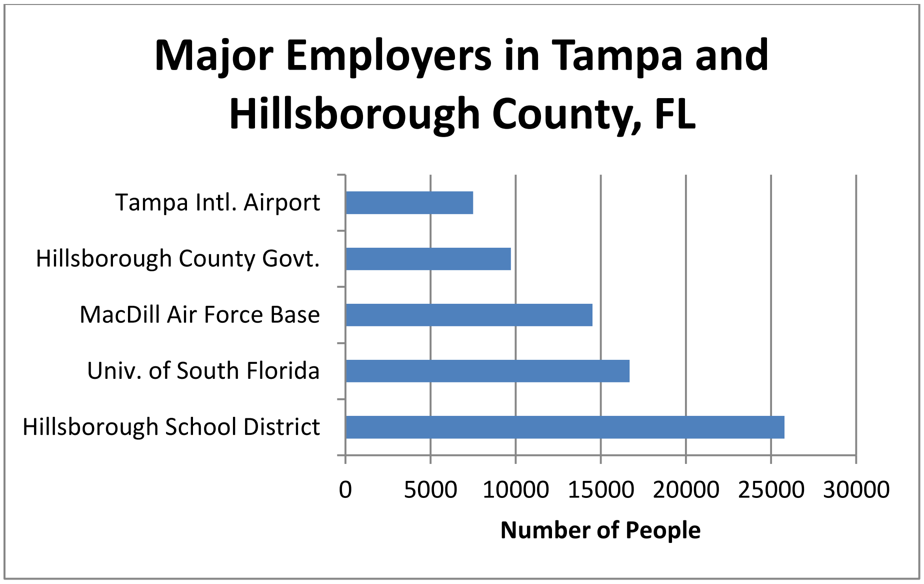


Figure 1.5 Major Employers in Tampa and Hillsborough County, FL (Created by J. Wilder FL with data from U.S. Dept. of Labor--Bureau of Labor Statistics)

1.4.7 Natural Hazards Risk Profile

As the greater Tampa, FL metropolitan area continues to increase in population it remains vulnerable to a wide range of natural, technological, biological and public health hazards. While technological and public health hazards are important, this risk profile examination will limit the scope to natural hazards only. Natural hazards will be divided into 2 broad groups and discussed as either meteorological or geological hazards. Meteorological hazards include natural hazards from atmospheric and weather forming processes, while geological hazards result from geologic processes in the earth's landforms and surfaces. Table 1.5 below presents the major hazards that affect the Tampa, FL metropolitan area.

Table 1.5 Hazards Affecting Tampa, FL Metropolitan Area (Created by J. Wilder using data from LMSWG, 2015)

Natural Hazards	Public Health Hazards
	Disease Outbreak and Incident
Meteorological	Water Contamination
Hurricanes and Tropical Storms	Chemical Emergencies
Thunderstorms	Radiation Emergencies
Tornadoes	Foodborne Illness
Flooding	Animal and Plant Disease Outbreak
Droughts	
Extreme Heat	**Technological Hazards**
Winter Storm	Hazardous Materials
	Dam/Levee Failures
	Port Vessel Collision or On-Water Hazardous Materials Spill
Geological	
Coastal or Riverine Erosion	Terrorism/Homeland Security/ Cyber Security
Suspect Soils: Sinkholes	Utility Failure/Power Outages
Wildland Fires	
Tsunamis	

Due to its coastal-low latitude and geographic location, the Tampa, FL metropolitan area experiences reoccurring natural hazards particularly those associated with storms and flooding. Below, in Figure 1.6, is a matrix that summarizes the natural hazards risk as “High”, “Medium”, or “Low” with regard to both Impact and Likelihood of occurrence. The natural hazards with the highest impacts and most likelihood of occurrence are Category 1- 2 hurricanes and flooding events. Other natural hazard threats with significant impact and likelihood of occurrence are Category 3-5 hurricanes, coastal/riverine erosion, thunderstorms, and tornadoes.

Historically, hurricanes and tropical storms pose the greatest threat to Florida and the Tampa, FL metropolitan area and have a “High” risk designation.   While passing hurricanes and tropical storms are typified by damaging winds and torrential rain falls, they often are accompanied by tidal flooding, storm surge, lightning, and/or tornadoes.

Impact				
	High	Tsunami	Hurricane: Cat 3-5	Hurricane: Cat 1-2 Flooding
	Medium		Winter Storm Wildland Fires Drought	Coastal/riverine erosion Thunderstorm Tornado
	Low	Extreme Heat	Sinkholes	
Risk Profile Matrix		Low	Medium	High
		Likelihood		

Figure 1.6 Natural Hazards Risk Profile Matrix for Tampa, FL Metropolitan Area (Created by J. Wilder with data from LMSWG)

Hurricanes commonly approach Florida from the south and track to the east due to the earth's Coriolis Effect and include winds 74-155 mph on the Saffir-Simpson Hurricane Wind Scale. The Tampa, FL metropolitan area is susceptible to winds greater than 70 mph on a regular basis. About 40 hurricanes and tropical storms have travelled within 60 nautical miles of the Tampa metropolitan area since 1871 and probability of a hurricane hit to the Tampa, FL metropolitan area is about 1 in 25 (National Climatic Data Center, 2017). While hurricanes are exceptionally dangerous, minor (but prolonged) tropical storms historically have produced very damaging flood events in the Tampa, FL metropolitan area.

Thunderstorms and tornadoes are also of concern in this region. Hazardous conditions associated with thunderstorms include tornadoes, lightning, hail storms, flooding, and strong winds. Microbursts, or narrowly concentrated down drafts, are often experienced and winds can exceed speeds of 150 mph causing extensive damage in a very short period of time. Florida leads the country with the greatest number of thunderstorms as well as death and injury due to lightning strikes (NOAA Climate Data, 2017).

Geological hazards with “High” risk of occurrence ratings for the Tampa metropolitan area also include coastal and riverine erosions. To a lesser extent are sinkholes and wildland fires. Coastal-riverine erosions are most noticeable along the bay and river shorelines particularly after a heavy rain and/or tidal surge weather incident putting shoreline development and populations at risk. According to the flood insurance study for Hillsborough County, there are more than 700 linear miles of floodway that are potentially susceptible to erosion (FEMA Statistics for Flood Insurance, 2017). Much of the developed coastal shoreline has been hardened by seawalls to minimize erosion to some degree. FEMA’s 100 year flood zone map, in Figure 1.7, shows the extent of water inundation. Note that the majority of the northern part of Hillsborough County is completely submerged including MacDill Air Force Base and the Tampa International Airport.

One of the more unusual natural hazards in this area is suspect soils, particularly sinkholes**.** Sinkholes tend to open up during droughts and heavy rainfall events and have been known to swallow up homes and cars. However, most sinkholes are less than 10 feet in width and damages are usually confined to structural cracks and large potholes in yards and roadways. Sinkhole threats are particularly acute in the northern part of Hillsborough County.

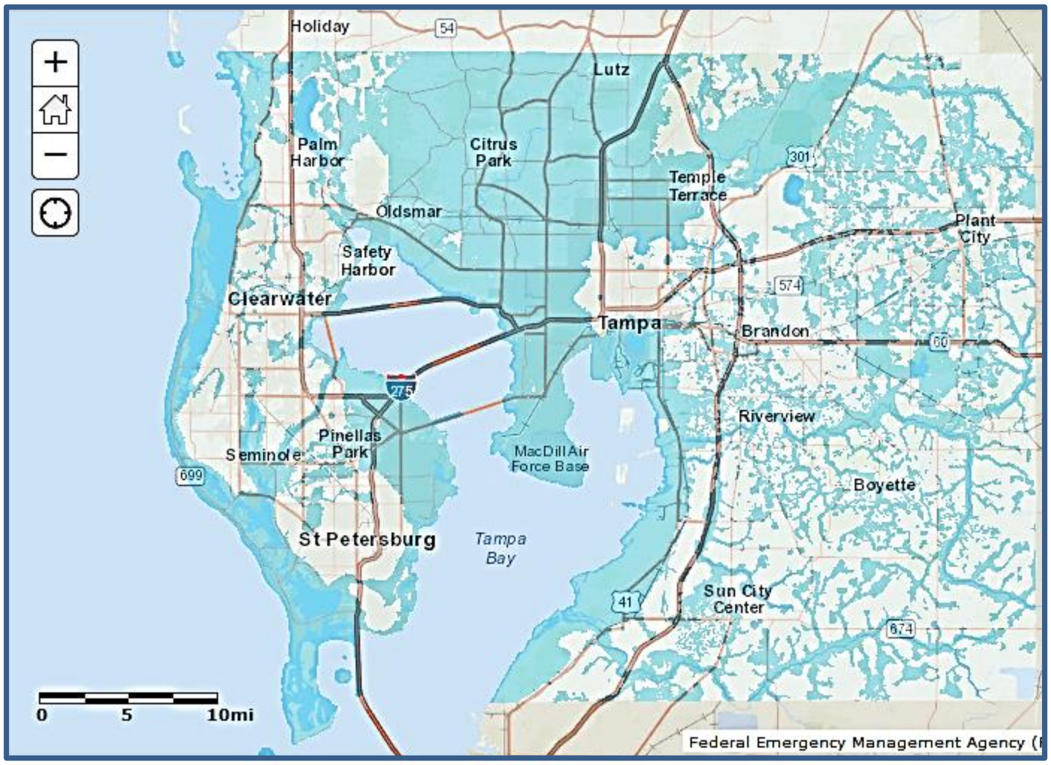


Figure 1.7 Tampa Bay, FL100 Year Flood Zone Map—Flood Zones in Blue (Source: FEMA Statistics for Flood Insurance)

Another natural hazard to monitor are tsunamis or oceanic waves generated by underwater earthquakes and/or landslides. A tsunami is considered a low-probability but high-impact event for Florida. Our extreme overall low elevation and proximity to geologic features that could result in a landslide particularly from the Bahamas and Cuba puts us at risk for this type of natural hazard. While there are no current historical data trends, the resulting damage could be catastrophic. And one final note on natural hazards risks profiles, while we described natural hazards as singular, independent events; they are often accompanied by compounding (two or more events at the same time that often reinforce each other) and cascading (one event is triggered by another or a series of events) circumstances which often leads to increased situational complexity.

While some hazards may pose a medium or low probability threat, if they are combined with another hazard, the impact could be very high.

1.5 Problem Statement

Natural hazards research has yielded numerous theoretical frameworks over the last 25 years that have explained important elements of risk and vulnerability in disasters (Birkmann, 2016b). However, there has been much less progress made in operationalizing these frameworks. It is been known for some time that certain populations tend to suffer the same losses and damages over and over from natural disasters in a disturbing cycle and little is known about how to mitigate this problem. Because of this, there exists a large gap in hazards research literature with regards to accurate risk identification based on quantitative data due to the lack of a smooth transition from theory to practice.

The trend in operationalizing these theoretical frameworks has been the development of general, all-purpose, static models to measure vulnerability. One of the major strengths of this approach is that comparisons can easily be made across locations since everyone is using the same metrics. However, important missing elements in the current hazards literature is the need for an operationalized risk model that is (1) simple, quick and easy to use, (2) flexible for changing conditions, and (3) site-specific for various geographic locations. Many of the current models for determining risk and vulnerability are very complex and time consuming to calculate and thus make them of little use for emergency and risk managers. In addition, little analysis has been conducted to see if a flexible risk identification measurement system could be developed. As vulnerability and risk become fluid due to changing conditions (environmental—hazard and location) and circumstances (social, economic, and political), our measurement tools need to be able to capture these differences in order to be effective. Because of these shortcomings, emergency managers lack the tools to systematically identify the onset of risk and its subsequent escalation. If these issues could be addressed, planning for disasters and their attendant mitigation strategies might be vastly improved.

1.6 Research Questions

The focus of this study is to examine the possibility of applying financial risk ratio methods to identifying vulnerability to natural hazards and then applying this as a strategy for managing disaster mitigation. The following research questions were examined within the context of the defined project problem and study site.

(1) Can the Pressure and Release theoretical framework for evaluating natural hazards risk be operationalized?

(2) Can the financial risk ratio methods using key performance indicators (KPIs) be used to determine vulnerability to natural hazards?

(3) Does the new operational model improve disaster risk prediction?

1.7 Research Hypotheses

(1) It is hypothesized that the Pressure and Release theoretical framework for evaluating natural hazards risk can be operationalized.

(2) It is hypothesized that the financial risk ratio methods using key performance indicators can be used to determine vulnerability to natural hazards.

(3) It is hypothesized that the new operational model can improve disaster risk prediction.

1.8 Research Design

The following research design presents the overall strategy to address the research questions and provide a plan of action for collection, measurement and analysis of the data. This study uses a model development approach coupled with a case study demonstration. The study design is supported by a comprehensive literature review to ensure that the project is consistent with current research practices in the field and is relevant and comparable with those studies that surrounded the research gap. This project is designed to frame the issue from a transformative perspective and apply unique, untried methods to address the persistent problems outlined above.

Model development will be based on a driver-centric modeling technique often used in computer threat modeling. The foundation of the modelling process includes a multi-step structured decision making matrix. This will be coupled with the development of a comprehensive collection of tracking and analysis tools including process flowcharts, decision trees, matrices, and checklists. Once the modeling process has been designed and verified, a suite of risk ratios based on key performance indicators will be created to measure vulnerability. This will be supported by an extensive library of archival data sources and creation of a detailed data dictionary used to populate the ratios and determine their function as risk indicators. Finally, the model and attendant risk ratios will be demonstrated in a selected case scenario featuring Tampa, FL metropolitan area to see if the disaster risk ratios can effectively quantify vulnerability and identify escalation patterns of risk over time.

1.9 Organization of the Dissertation

In order to meet the goals and objectives of this study the research dissertation is presented in seven chapters. The first three chapters are devoted to defining context, scope and design of the research study. The last four chapters focus on interpreting the results, discussion of the findings, and placing the value of the study in a broader discipline of natural hazards research.

Chapter two identifies and places the study within the body of relevant scholarly literature. This section begins with a discussion on key hazards terminology and foundational concepts in the discipline and proceeds with a brief historical overview of hazards research and concludes with a discussion on the major natural hazards theoretical frameworks and current attempts to operationalize them. Chapter three details the design and methods of the research project. This chapter describes the overall strategy used to address each research question and provides details on model development, data collection, and case study analysis. Finally the strengths and limitations of the study design are carefully examined and impacts assessed.

Chapter four, five and six discuss the results of the research study and explores their implications and significance. A comprehensive explanation of (1) the development process of the disaster risk ratio measurement system is presented along with (2) the results of the demonstration of the performance of the risk ratios to identify vulnerability and (3) results of the case study demonstration and their subsequent predictive capabilities of the model by identifying emerging risk trends. Results of the data analysis are presented in a systematic collection of process maps, flowcharts, checklists, comparative matrixes, and wire trees used for structured decision making.

Finally, chapter seven provides a brief review of the research project, a summary of the general conclusions, and findings of the three research questions. The contribution of this project to natural hazards research and related disciplines is presented. The dissertation closes with recommendations of future research trajectories emanating from this research that could provide forward momentum to the field of geography, hazards research, risk, and disaster management.

CHAPTER TWO:

LITERATURE REVIEW

2.1 Introduction

The following chapter examines where and how this dissertation study fits in relation to the current body of knowledge in geography and natural hazards research. This research is uniquely situated at the nexus between the disciplines of natural and social sciences or the human – environment interface. This unique position allows the study to take advantage of the strict, tangible laws of the natural world with the intangible values of the human condition. This dynamic interface is a merging of the need to explain and predict the natural physical world with the need to examine human relations and understand the social world.

FEMA's Disaster Cycle, illustrated in Figure 2.1 below establishes a framework for the study of hazards and vulnerability analysis in order to assess risk. Within the Disaster Risk Management Cycle: (1) Risk Identification, (2) Prevention and mitigation, (3) Preparedness, and (4) Recovery, this study is specifically a part of the Risk Identification/Assessment quadrant. The risk identification phase would correspond to the preparation/planning phase of the FEMA Emergency Management Cycle.

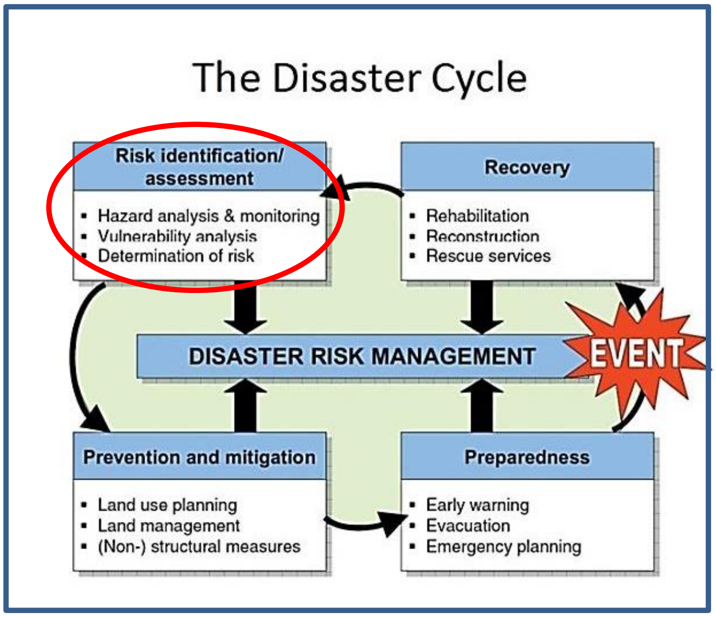


Figure 2.1 FEMA Disaster Cycle (Source: Federal Emergency Management Agency)

This cycle comprises 4 or 5 phases depending on the version you reference; the other phases include response, recovery, and mitigation. The rest of this chapter addresses important natural hazards terminology, history of hazards research, natural hazard theoretical frameworks and attempts to operationalize them to fill the theory-to-practice gap, and where my study fits into this architecture.

2.2 Natural Hazards Terminology

Defining foundational concepts provides a shared understanding that is critical in an interdisciplinary subject area such as geography where thinking across traditional knowledge boundaries is standard. Often, terminology difficulties arise, such as (1) the same terms with multiple definitions being used because they originated from different disciplines or used under different circumstances and (2) different terms used interchangeably within the same discipline; both cause confusion and hinder the discovery progress (Chakraborty et al., 2005). This section will discuss important debates of several key terms (disaster, vulnerability, risk, and emergency management) and their various definitions which are used regularly in natural hazards scholarly literature and are critical to establishing context of the study.

2.2.1 Defining Natural Hazard and Disaster

The term disaster can have a variety of meanings based on geographic location and social, economic and political circumstances and is often used interchangeably with the term natural hazard (Eshghi & Larson, 2008). The distinguishing difference between a disaster and a natural hazard is that a hazard represents the “potential” threat or damaging event and a disaster is the actual event with a set of real problems and losses (UN/ISDR, 2004; ESPON, 2003; and Tobin & Montz, 1997). From this perspective, disasters are triggered by or flow from hazards. Natural hazards in themselves are not disasters, but may lead to disasters if they have a negative impact on human-use systems. As long as humans and their activities are exposed to natural forces, hazards will always exist but disasters (damages and loss) are optional (Eshghi & Larson, 2008).

The term disaster has been defined from several major perspectives; (1) either by the damages it causes or (2) by human contributions that influence it. The diagram below in Figure 2.2 illustrates the two basic viewpoints and the scholars who support them. One approach views disasters from a predominately natural or environmental science perspective and the other from a social science perspective. The first camp understands disasters as a natural phenomenon (hurricane, earthquake, storm, volcanoes) and emphasizes a geophysical event guided by extraneous natural forces; while the second group understands disasters as any hazard (natural, anthropogenic, technological) and emphasizes a human event guided by social forces. A discussion of disaster will be presented first in terms of (1) damages, followed by (2) human contributions.

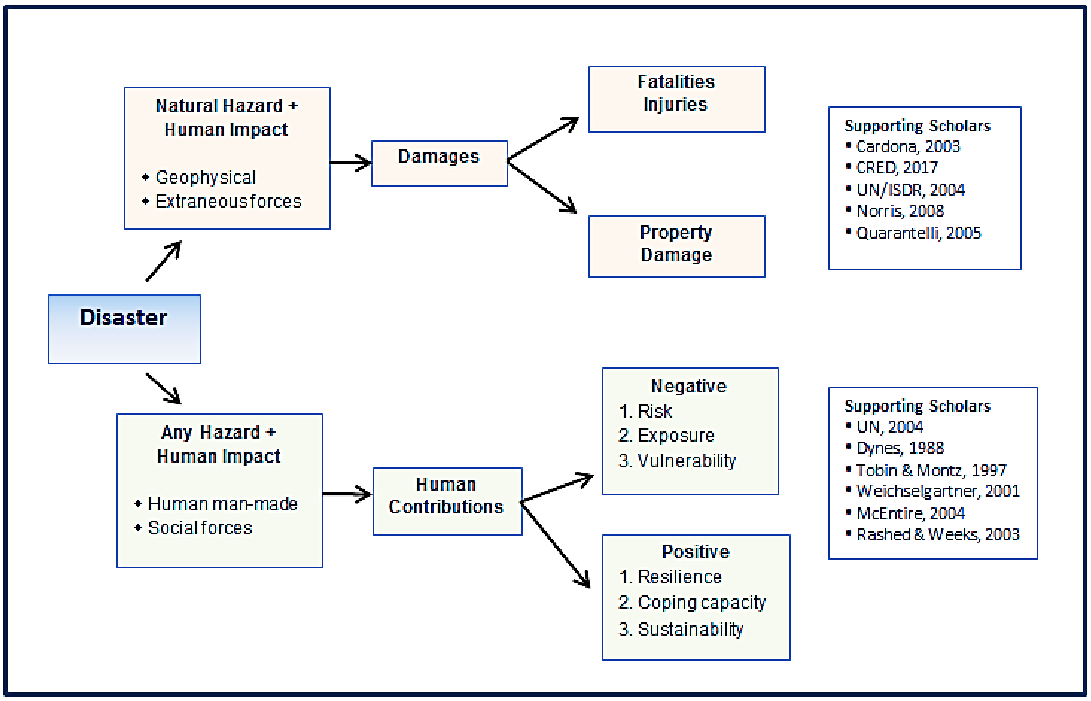


Figure 2.2 Categories of Disaster Definitions and Scholars Who Support Them (Created by J. Wilder)

Damages from natural hazards include fatalities, injuries and property damage. The most basic definition of a disaster is from Cardona et al. in which they describe a disaster is a damaging natural phenomenon (2003). Others have defined damage as the number of people killed or injured. For example, the World Health Organization Collaborating Center for Research on the Epidemiology of Disasters (CRED) defines a disaster as an event with wide spread destruction and at least 2 of the following: 10 or more people killed; 100 or more people affected; and/or a call for international assistance or a declaration of state of emergency (EM-DAT, 2017).

The United Natation's International Strategy for Disaster Reduction--IDSR further expands the definition of a disaster to include not only human injury and loss of life, but also property damage, any type of social/economic disruption, and environmental degradation (UN/ISDR, 2004). A number of other researchers have expanded the meaning to include not only the number of fatalities and injuries but also destruction to community systems and the resources they depend on for well-being and survival, (Norris et al., 2008; Quarantelli, 2005). This approach to defining disaster in terms of physical damage and loss is also often used by insurance companies, economists and the media to report damages from natural hazards. One of the advantages is that damage and loss are relatively easy to identify and calculate. One can estimate the number of people injured or killed and the economic loss to destroyed buildings. The weakness of this approach is that vulnerability and risk are defined in terms of loss of tangible assets and public policy and mitigation efforts tend to be based on a singular defensive strategy usually by reinforcing the infrastructure and protecting from loss of life.

The other group approaches this debate from a sociological perspective and recognizes that human activity plays a significant contributing factor to the understanding of disasters, both negative and positive. The United Nations has defined the term disaster to include not only natural phenomena but also any human activity including technological disasters and biological disasters such as overgrazing and misuse of water resources (UN/ISDR, 2004). A number of researchers including Dynes

(1988), Tobin & Montz (1997), and Weichselgartner (2001) have also identified the elements of severe social disruption and impact on societal structures, not just merely fatalities and injuries. Finally, McEntire (2004) points to human – induced triggering agents as contributing to the definition of disaster and Rashed & Weeks (2003) assert that a disaster involves people as not only victims but as contributors and modifiers as well. By recognizing our role in disasters, we can possibly exercise more control over the extent and types of damages. From a sociological perspective, the meaning of disaster has evolved to include not only negative human contributions such as vulnerability, exposure and risk but also positive elements such as resilience, coping capacity, and sustainability (Zakour & Gillespie, 2013).

2.2.2 Defining Vulnerability

Disaster events and resulting damage reveal the weak links in our human use systems; this weakness is known as vulnerability. Because vulnerability is recognized as a critical element in reducing losses from disasters, there has been quite a bit of scholarly literature published in this area. The literature is divided between those who view vulnerability in terms of a (1) loss or harm and those who view it in terms of a (2) susceptibility combined with the ability to cope or recover.

Below, in Figure 2.3, is a diagram of the two groups of definitions and the scholars who support them. A clear temporal pattern emerges where vulnerability as loss or harm was generally promoted during the early 1980’s through the early 1990’s while the more complex definition of vulnerability emerged in the mid 1990’s and early part of the 21st century when the natural hazards discipline was actively developing its theoretical base of frameworks.

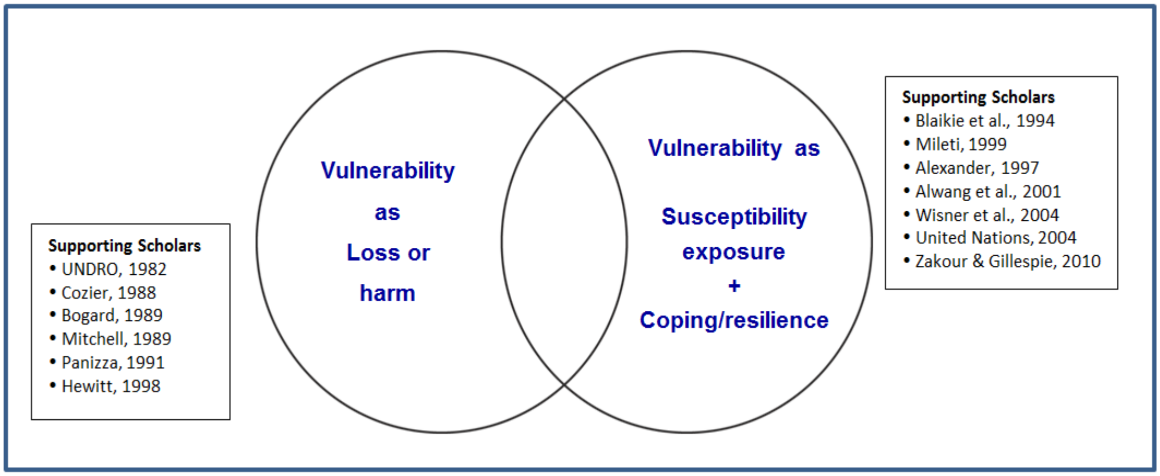


Figure 2.3 Definitions of Vulnerability and Scholars Who Support Them (Created by J. Wilder)

For those scholars who define vulnerability in terms of harm or loss , UNDRO (1980) and Cozier (1988) defined vulnerability as the degree of loss of the elements at risk and Mitchell (1989) defined vulnerability similarly to a hazard and emphasized the "potential" for loss. Panizza (1991) defined it as an adverse reaction to a hazardous event, whereas Bogard (1989) defined the term as the inability to protect against loss. Finally, Hewett (1998) thought that the definition should include those attributes and activities that add or increase damage. The strengths of defining vulnerability as a harm or loss is the same as with the definition "disaster" discussed above; it is easy to identify and quantify for research and communication purposes. The draw-backs are that it does not take into consideration many of the sociological factors that influence vulnerability. It is interesting to note that many of these definitions on loss and harm trend toward the idea of exposure and coping capacity by highlighting "elements at risk" and "adverse reaction".

The second group of scholars emphasizes a combination of forces in defining vulnerability; (1) susceptibility/exposure and (2) coping/resilience. Resilience is the ability to recover as opposed to coping which is the ability to respond. The United Nations (2004) described vulnerability as conditions which increase susceptibility. Blaikie et al. defined vulnerability as an insecure condition combined with a physical exposure to a hazard (1994) and Alexander (1997) described it as a measure of exposure to loss. Often framed within vulnerability is coping capacity or the ability to absorb impacts and quickly return to a previous state of functioning; this usually builds resilience, the process of withstanding damage (Mileti, 1999; European Spatial Planning, 2003). Wisner et al. (2004) expressed the definition as capacity to anticipate, cope, resist and recover from a natural hazard impact. Alwang et al. (2001) defined vulnerability as the capacity to cope and recover from a natural disaster. And finally, Zakour & Gillespie have defined vulnerability as a ratio of community susceptibility to their resilience (2013). By expanding the definition of vulnerability to include susceptibility, exposure, coping, and resilience, it opens up a wide variety of social factors to examine. However, the down-side is that some of these elements are very difficult to identify and measure accurately.

2.2.3 Defining Risk

The term risk in natural hazards can be approached from at least 4 different schools of thought depending on what you are measuring and whether you view risk through the lens of natural or environment science which emphasizes probability/loss or from the social science in terms of vulnerability. Below is a diagram (Figure 2.4) of the major categories of risk and the scholars who support them and include: (1) Risk as a probability, (2) Risk as expected loss, (3) Risk as a hazard times a vulnerability, and (4) Risk as a mixed or general definition. As with the definitions of disaster and vulnerability, we find an emergent temporal pattern of risk where the emphasis of damage and loss in the 1980's progressed to include a variety of social dimensions in the mid- 1990s and into the 21st century.

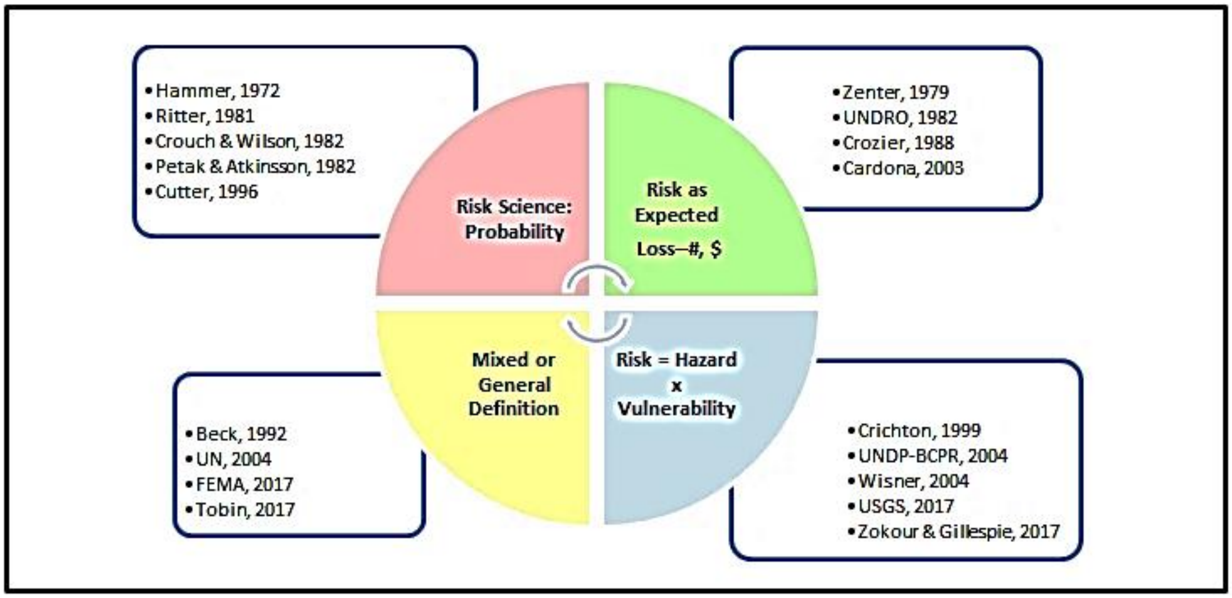


Figure 2.4 Risk Definitions and the Scholars Who Support Them (Created by J. Wilder)

The study of risk has a rich history in probability science and is often defined by calculating probabilities of occurrence using sophisticated tools such as Monte Carlo simulations and probability distributions (Gorris & Yoe, 2014). Numerous natural hazards scholars hold to this traditional definition of risk using probability theory including Hammer (1972), Crouch & Wilson (1982), and Petak & Atkisson (1985). As Cutter (1996) asserts, risk is the probability that an event will occur. Risk can also be thought of as potential loss resulting from a hazard; the higher the potential loss the higher the risk (UNDRO,1982; Cardona, 2004). This loss is often reported as number of deaths/injuries and/or financial loss or expected costs (Crozier,1988). Again, the strengths in these definitions are their capacity to identify and calculate probability and loss, while the weakness is that they exclude any intangible social contributions to risk.

Because disaster managers need to know more than the probability of a natural hazard event, risk is often defined using other variables such as loss and vulnerability as proxy indicators. In addition, risk can also be defined as a hazard times a vulnerability (R = H x V). There are many scholars who adopt this view and approach natural hazards research from the perspective of vulnerability theory (UNDP, 2004; Wisner et al., 2004; Zakour & Gillespie, 2013). Finally, several authors have recognized that there may need to be more than one option for researchers in defining risk; in some cases probability may be more appropriate, in others losses would better represent risk, or proxy measures such as vulnerability would need to be used (Beck 1992; Tobin et al., 2017; UN, 2004; FEMA Risk Mapping, 2017). Their definitions either include a combination of these approaches or they merely provide a general definition of risk in which the researcher would need to clarify for their particular research study.

2.2.4 Defining Emergency Management

Emergency management, often referred to as disaster management, is the organization and distribution of resources for dealing with the harmful effects of hazards (FEMA Emergency Cycle, 2017). While the terms “emergency” and “disaster” are often used interchangeably, a disaster usually refers to an event that requires more than normal response particularly from government agencies to assist in recovery with local, federal, and/or international aid, while an emergency is a condition that requires immediate action. The emergency management cycle consists of 4 phases; (1)

preparedness, (2) response, (3) recovery, and (4) mitigation. This cycle can be divided into risk management and crisis management. See Figure 2.5 below.

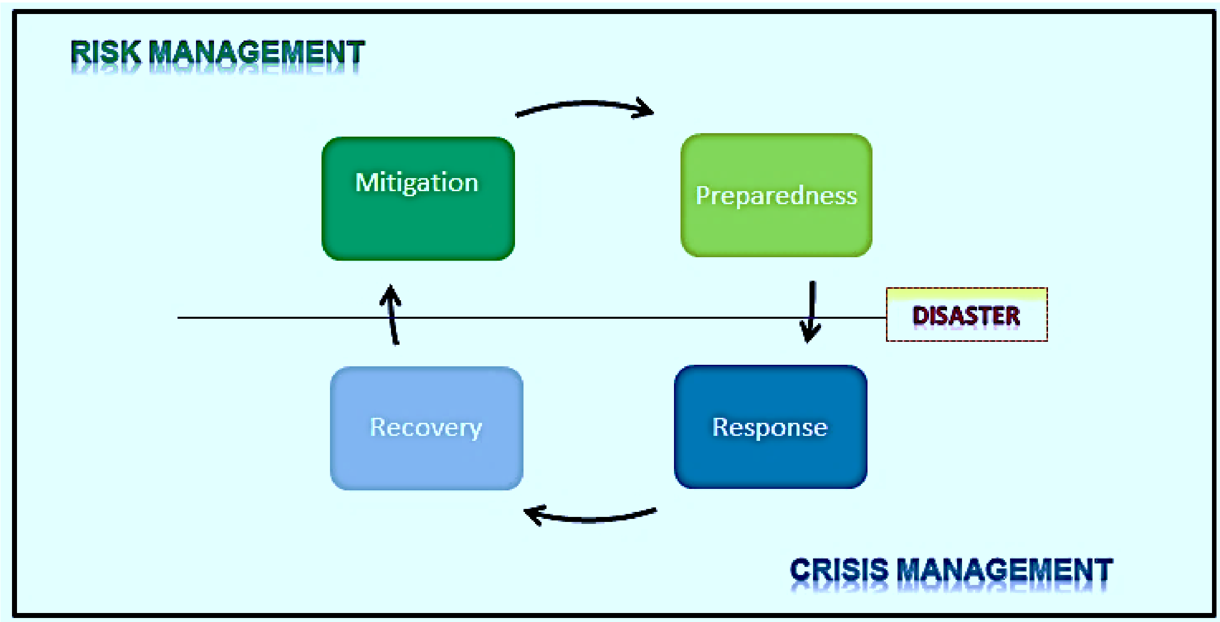


Figure 2.5 Risk Management and Crisis Management Cycle. (Modified by J. Wilder based on FEMA, 2017)

Crisis management comprises response and recovery phases; activities include impact assessment, rescue, and reconstruction. First responders are generally the ones who address crisis management. Risk management comprises the preparedness and mitigation phases of the emergency management cycle. Activities include mitigation: prevention/reduction of impacts, protection/reduction of exposure), and review and implementation of early warning risk and prediction systems or a state of readiness. While risk management and crisis management are both an active part of the emergency management cycle, this study will focus on the risk management portion of the cycle.

To summarize the natural hazards terminology, a disaster is a hazard event (natural or man-made) intersecting with any human-use system causing damage. Risk is the probability of occurrence of a hazard intersecting with a vulnerability or sensitivity and exposure of a system and how well it can cope and recover. We often use vulnerability as an indicator of risk by assuming that as vulnerability increases so does the risk.

2.3 History of Natural Hazards Research in Geography

Risk research has its roots in many different disciplines including finance, engineering, public health, insurance, environmental protection, nuclear power industry and geography. Modern natural hazards research and the study of risk have a rich history spanning more than eight decades. Because risk does not exist in a vacuum, understanding risk and how it behaves in the human-use architecture we can better mitigate the impacts and losses derived from natural hazard events. This section will present the major themes running through hazards risk research in relation to the four spheres of human influence: (1) environment--geophysical systems, (2) social systems--demographics, (3) political--policy making and (4) economic--allocation of resources.

2.3.1 Hazards Risk and Environment

Early hazards research centered on understanding the geophysical processes that drove natural hazards. Processes and patterns in the natural environment including atmospheric, hydrospheric, biospheric, and geospheric characteristics were used to discover properties of natural hazards such as such as floods, snowstorms, landslides, earthquakes, and hurricanes to reduce risk. Morisawa (1994) published a collection of case studies highlighting geomorphic processes and how they shape natural hazards. In addition, the literature is rich with studies on flooding and flash flooding (Gruntfest & Eve, 1997; Gruntfest & Handmer, 2001; Magilligan et al., 1998). Finally, Aspinall (2010) provided a collection of studies looking at the physical dimensions such as precipitation and hydrology and how they affect climate change.

White (1945) was one of the first to question whether natural hazards were also influenced by social forces. Early researchers such as White (1945, 1964), Kates (1962), and Hewitt and Burton (1971) were instrumental in establishing hazards research as a human based discipline. White, widely considered the father of natural hazards research (Mileti, 1999), questioned whether geographers were adequately dealing with the human–environment relationship (White,1973). White continued his research throughout the 1960s and 1970s emphasizing an interdisciplinary approach to natural hazards research as well as establishing the link between physical and social sciences (1962, 1974). By the 1970s natural hazards research went beyond the natural and environmental sciences discipline and became a focused theme within the broader discipline of geography. Instead of viewing natural hazards as a collection of underlying physical processes which increased risk including loss of life and structural damage, researchers began an interdisciplinary approach to natural hazards research emphasizing a social component which could either increase risk through susceptibility and exposure or mitigate risk through resilience and coping capacity.

This section on risk and the environment would not be complete without a brief discussion of the advancements in geospatial technologies such as GPS (global positioning systems), GIS (geographical information systems), and RS (remotesensing). These tools have greatly increased our capacity to collect data and analyze information from the physical environment and the human--use system. For example, Amdahl (2001) and Green (2002) highlighted the value of GIS as a tool to map risk and vulnerability not only in our environmental systems also in social systems and provide key decision-making information to emergency managers and others in disaster research. Hazards planning and mitigation may benefit from the use of these technologies including (1) remote viewing and communication techniques such as drone technology that can remotely view damage from a natural hazard and (2) medical diagnostic strategies that can provide medical help through cell phones and other electronic media during a disaster (Tobin & Montz, 2004).

2.3.2 Hazards Risk and Social Systems

The social vulnerability perspective (Cannon, Twigg & Rowell, 2003; Cutter, Boruff & Shirley, 2003) serves an important development of earlier theories of hazard vulnerability (Burton, et al., 1978). As a societal idea, social vulnerability has been characterized as ones “capacity to anticipate, cope with, resist and recover from the impacts of a natural hazard” (Wisner et al., 2004, p. 11). OKeefe et.al (1977) made some striking revelations concerning vulnerability; (1) they notice that even though the number of disasters was constant, losses were rising and (2) disasters of the same magnitude in different regions often produced very different outcomes. They theorized that the primary causes were not geophysical but social. It has been long noted that communities often get caught in the Disaster-Damage-Repair Disaster Cycle where a disaster strikes, damage results and the system is returned to the previous disaster state until the next disaster strikes and the cycle repeats; no improvements are ever attained. Mileti (1999) postulated that disasters were actually by design, in other words, we create our own problems. He argued that if we can change our approach to hazards mitigation of merely returning communities to pre-event conditions, we could end the destructive build and repair cycle and move toward sustainability and building disaster resilient communities.

Social characteristics can significantly affect levels of vulnerability. White (1974) and Okeefe et al. (1976) were two of the first to address perceptions of risk and compare how vulnerabilities differ across geographic locations. Since then, a number of other scholars have also evaluated place and how vulnerability integrates with the social structure including Colton (2006) who studied the uneven patterns of risk and vulnerability in New Orleans. Two prominent demographic groups found to be regularly susceptible to vulnerability are gender and race. Enarson & Marrow (1998) edited a book on social construction and gender vulnerability and compiled a series of case studies on the role of women in disasters. Enarson & Chakrabarti (2009) presented a collection of papers that explored gender – sensitive risk and ways to reduce it and Fothergill (1996) reviewed various aspects of vulnerability including exposure, perception, and behavior on women in disasters. Race, class, and ethnicity and susceptibility to disasters have also been a keen topic of research. Vulnerabilities can include language barriers, housing patterns, community isolation and cultural insensitivities. One landmark publication, presented by Lindell & Perry (2003), highlighted risk communication, ethnicity, and culture.

Other variables can play a significant role in vulnerability and risk scenarios including risk perception (Slovic, 2017); risk communication (Fischhoff, 1995), risk acceptance and risk amplification/attenuation (Kasperson et al., 2003). Perception is the range of judgments, beliefs and attitudes that affect behavior, in some very surprising and unexpected ways. Behavior depends on the perceived environment, and a rational response, those in which an individual selects options with the greatest benefits that reduce risk and vulnerability in a hazardous situation is not always the result. In reality, people often make completely different decisions than planned due to stressful conditions that alter perception. Slovic conducted a number of studies on this topic (1981, 2004, 2007) including the book the *Perception of Risk* (2000) which is an excellent synthesis of his research. Slovic & Fischhoff are considered leading scholars in the field of risk perception. Another key publication on the social amplification of risk is Kasperson et al. (2003). This book highlights various theories and concepts on how social processes underlie and amplify risk perception and response. How we perceive, communicate, and accept risk can have significant impacts on exposure and vulnerability.

2.3.3 Hazards Risk and Politics

How people organize themselves to collectively solve problems and develop public policy greatly influences risk levels to natural hazards. Without well-developed organizational systems, emergency and recovery can be hindered and recovery efforts significantly diminished. Turner (1976) produced a seminal paper examining organizational failure during disasters and the elements at play such as complexity of information and delayed decision-making. Platt & Dymon (1999) investigated the politics of disaster management and mitigation in the U.S. using a case study approach. Finally, Burby (2006) examined effects of Hurricane Katrina and government policy and found that there was a critical need for comprehensive disaster planning at the local level.

Public policy including preparedness and mitigation in response to natural hazards involve complex decision-making processes that must compete with multiple interests within the political agenda. FEMA reported that a quick fix, ad hoc, piecemeal response, so often used, is ineffective and only promotes a disaster – damage – repair – disaster cycle (FEMA, 2008). Whether regulatory approaches such as building codes and land use and zoning or cooperative and mandated programs such as financial incentives, subsidies, loans, and insurance programs are implemented, one thing is agreed upon and that is the approach must be integrated and comprehensive with cooperative planning at all levels of government and between all key stakeholders (Tobin et al., 2017).

2.3.4 Hazards Risk and Economics

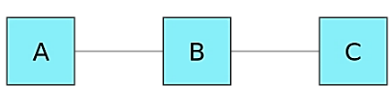
Recovery from disasters is always constrained by economics; unlimited resources do not exist. This recovery is often a very long process and is typically uneven across business and social sectors. In addition, costs often can be difficult to identify and calculate. The literature is quite varied on the topic of economic vulnerability and risk. Below is a small sample of the research that has been published. A number of scholars have conducted studies on the economics of property value and effects of flood hazards. Bin & Polasky (2004) compared home prices to evaluate the impacts of flooding from hurricanes and correlated this with greater declines in value. Tobin & Montz (1994) examined several communities with respect to their flood regimes to evaluate the effect that location had on residential house values. Calculating costs can also be challenging. Heinz (2000) examined the hidden costs of coastal hazards and presented strategies for reducing the costs.   Several scholars have put together comprehensive reviews including Guha-Sapir et al. (2012) who assembled the annual disaster statistical review and looked at the number of disasters, fatalities, and economic losses; temporal and regional comparisons were made. Finally, the World Bank published a discourse in which they argued that with proper planning, preventative measures, and mitigation that areas with dense urban populations did not necessarily need to become more vulnerable to natural hazards as populations increased (2010).

One common way to mitigate economic losses is through risk transfer or the purchase of insurance. By distributing risk, losses are distributed or leveraged over a number of different policyholders. Reinsurance is insurance purchased by insurance companies as a risk management technique to hedge losses. Munich RE is one of the world's leading reinsurance companies and annually publishes extensive data and information on (1) environmental and climactic changes and (2) disaster prevention including losses associated with natural disasters (2014). The National Flood Insurance Program (NFIP) is administered by the U.S. government agency FEMA (Federal Emergency Management Agency) and was designed to provide an insurance alternative to disaster assistance caused by flooding. Burby (2001) details some of the challenges and limitations with the NFIP such as flood hazard identification and exposure mitigation issues.

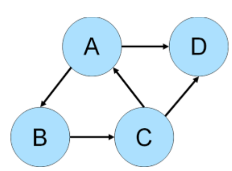
2.4 Theoretical Frameworks in Hazards Research

Theoretical frameworks allow us to anchor or ground the research problem under study. They describe, explain, and predict relationships, events and behaviors as we attempt to construct models of reality. If the theoretical framework is logically sound there is a strong possibility that the resulting hypotheses evolving from that framework will be supported. There are a number of excellent theoretical frameworks present in natural hazards literature. However, attempting to operationalize these theoretical frameworks can be challenging. This process involves defining the measurement of a phenomenon that is not directly measurable although it is indicated by other proxy measures. Operationalizing these natural hazards frameworks with reliable and accurate metrics has proven to be even more difficult.

The U.N. General Assembly designated the 1990s the International Decade for Natural Disaster reduction (IDNDR) which precipitated the development of a dozen or more risk and vulnerability natural hazards frameworks. Nine major natural hazards theoretical frameworks were developed between 2000 and 2013. They are listed chronologically in Figure 2.6 below. These models can be categorized into 2 broad groups (1) linear type models and (2) systems type models. Linear type models break things into component pieces and analyze properties in a sequential fashion whereas systems type models are concerned with underlying dynamics of the network as a whole.



Linear-type Model



System-type Model

The rest of this section will compare and contrast these model types analyzing them for strengths, weaknesses and research applications.

	Theoretical Model	Author(s)	Date
1	Holistic Approach	Cardona & Barbat	2000
2	Double Structure of Vulnerability	Bohle	2001
3	Disaster Risk Community	Bollin et al.	2003
4	Risk-Hazard Model (RH)	Turner et al.	2003
5	Global Environmental Change Community	Turner et al.	2003
6	Pressure and Release Model (PAR)	Wisner et al.	2004
7	BBC Conceptual Framework	Bogardi & Birkmann	2004
8	ISDR Disaster Reduction	ISDR/UN	2004
9	Key Spheres of Vulnerability	Birkmann	2005
10	Disaster of Resiliency of Place (DROP)	Cutter et al.	2008
11	Vulnerability +	Zakour & Gillespie	2013

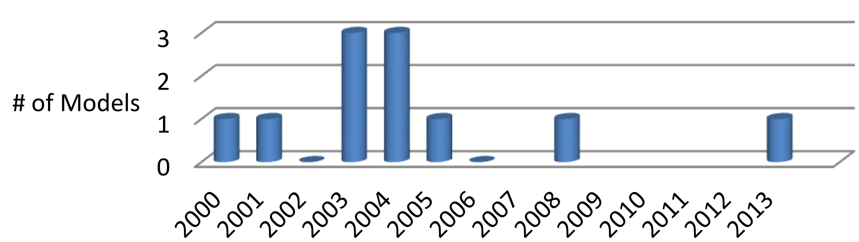


Figure 2.6 List of Natural Hazards Theoretical Frameworks and Timeline (Created by J. Wilder)

2.4.1 Systems Type Models

Systems type models are characterized by a set of components or processes working together as parts of an interconnected network that function as a uniform unit. They often have feedback loops and interdependent elements that can amplify or modify expected outcomes. The table below lists examples of natural hazards theoretical frameworks that represent systems type natural hazards models and some distinguishing characteristics of each.

Table 2.1 Systems Type Natural Hazards Models (Created by J. Wilder)

Model	Author	Distinguishing characteristics
1. Global Envtl. Change Community Model	Turner et al., 2003	Addresses vulnerability scale: spatial, functional, and temporal
2. Intl. Strategy for Disaster Reduction Model	ISDR/UN, 2004	Focuses on disaster management and emphasizes political commitment and education
3. Double Structure of Vulnerability Model	Bohle, 2001	Views vulnerability as exposure and coping capacity
4. BBC Conceptual Framework Model	Bogardi & Birkmann , 2004	Views vulnerability as exposure and coping capacity nested within the 3 spheres of influence (environmental, social, and economic)
5. Holistic Approach Model	Cardona & Barbat, 2000	Uses risk as a consequence of vulnerability, Focuses on actuation systems and interventions
6. Disaster Resilience of Place (DROP) Model	Cutter et al., 2008	Focuses on social components that create inequalities and vulnerable groups

There are number of superb systems type risk and vulnerability natural hazards frameworks in the literature. A good example of this type of model is the Vulnerability Framework by Turner et al. (2003). The model addresses system operations at multiple spatial, functional, and temporal scales including world, region, and place. Vulnerability is described as the function of exposure sensitivity and resilience and attempts to more evenly balance human influence with environmental differences. Below, in Figure 2.7, is a modified version of this model illustrating the network of components and processes that link them together. While this framework is excellent at explaining the whole, it is very difficult to isolate individual drivers. While this category contains a diverse group of models, they all tend to frame risk and vulnerability as a systematic whole containing a complex web of inter-dependent components such as examining how the system operates at multiple spatial, functional and temporal scales nested within macro political economic, institutions, global trends and transitions, state of the biosphere, state of nature, and global environmental changes. Isolating specific drivers of vulnerability is difficult using this type of framework due to the level of detail and interaction.

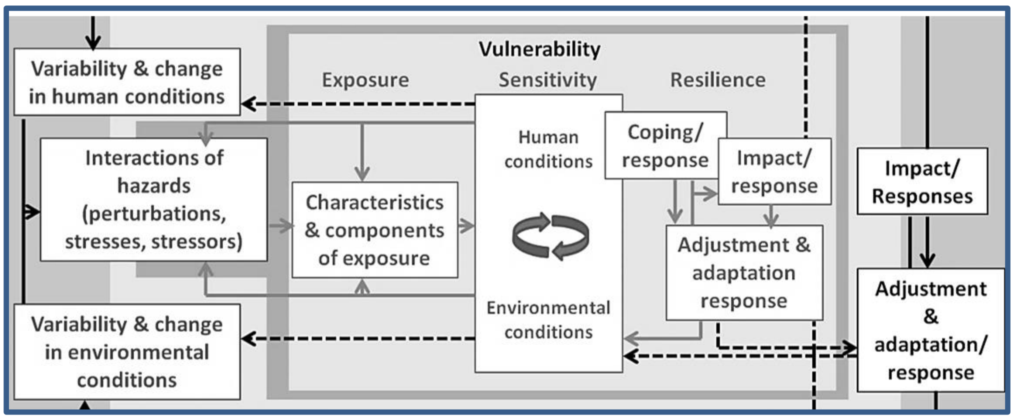


Figure 2.7 Systems Type Natural Hazards Models (Modified by J. Wilder from Tuner et al., 2003)

How you frame and approach a problem will determine what you can observe. The tools one chooses are critical; a telescope will give you a very different view of the issue than a microscope. Many systems type models take a more telescoping approach, which can be very useful for research endeavors that focus on holistic approaches and overall model behavior. However, my research focuses on exposing and observing individual drivers of vulnerability, therefore, I have used a more microscopic approach and chose a linear type theoretical framework to work from. Linear type models are discussed below. And while it has been argued that system type models are more useful than linear type models because they look at the whole rather than component parts, the closer reality is more likely that both types of models are necessary to understand complex processes.

2.4.2 Linear Type Progression Models

Linear type models are arranged or extend along a straight line and progresses from one stage to another in a single series of steps or sequential narrative. The advantages of these one-dimensional frameworks are that they provide clarity and simplicity at the individual component level. They are particularly useful in exposing drivers of processes that are often obscured in more complex structural models. Table 2.2 below lists the linear type models in natural hazards.

Table 2.2 Linear type Natural Hazards Models (Created by J. Wilder)

Model	**Author**	**Distinguishing characteristics**
1. Disaster Risk Community Model	Bollin et al., 2003	Disaster risk is a function of hazard, exposure, vulnerability, and capacity
2. Risk-Hazard (RH) Model	Turner et al., 2003	Vulnerability = exposure x sensitivity
3. Key Spheres of Vulnerability Model	Birkmann, 2005	Vulnerability is a nested an ever widening concept
4. Pressure and Release (PAR) Model	Wisner et al., 2004	Disaster = hazard times vulnerability vulnerability is progressive (root causes, dynamic pressures, and unsafe conditions)
5. Vulnerability + Model	Zakour & Gillespie, 2013	Merges resilience theory with the PAR model

However one of the main criticisms of the linear type model is that it is too simplified to accurately represent reality. This criticism may be valid when looking at the integrated process as a whole. Linear type models abstract away details to provide a look at the critical processes at work, not necessarily all the processes. There is clearly a complex trade-off between model simplicity and complexity. Too much simplicity and the model usefulness and clarity suffers; too much complexity and the model adds little to the understanding of the system and often complicates it.

The natural hazards literature provides several excellent linear type conceptual frameworks. One of the earliest of these types of models was the Risk-Hazard (RH) Model by Turner et al. (2003). Illustrated in Figure 2.8, this model was based on the work of Burton et al. (1978) and Kates (1985) and emphasizes vulnerability as a function of exposure to the hazard event and impacts resulting from sensitivities. The linear progression of the Risk-hazard model is clear and very straight forward; exposure and sensitivity are the vulnerability drivers. While many have criticize this model for not be a comprehensive systems type framework, I think it is very beautiful in its simplicity and clarity.

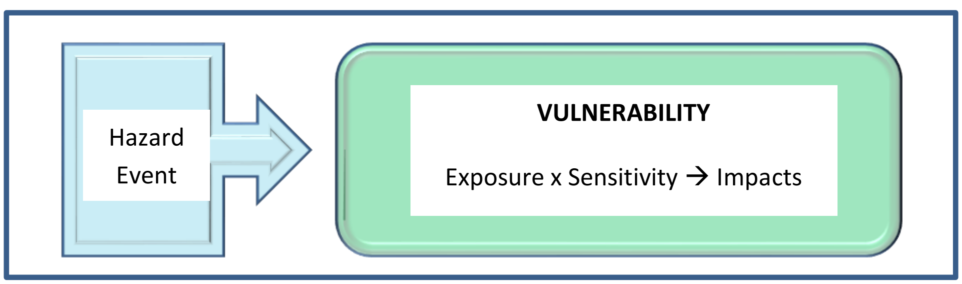


Figure 2.8 Risk–Hazard (RH) Model (Modified by J. Wilder based on Tuner et al., 2003)

Another model with similar linear characteristics is the Disaster Risk Framework by Bollin et al. (2003) based on work done by Davidson & Shah (1997). In this case disaster risk is made up of 4 components; hazard, exposure, vulnerability, and capacity and measures. See Figure 2.9. In this model (Disaster Risk Framework), risk is emphasized whereas vulnerability was emphasized in the R-H model.

Figure 2.9 Disaster Risk Framework (Modified by J. Wilder based on Bollin et al., 2003)

The simplicity of these models allows the researcher to focus on direct drivers of complicated processes. By identifying and controlling these inputs or drivers, it may be possible to predict the outcomes that are generated by these processes more accurately. The natural hazard's Pressure and Release (PAR) Model was selected for this study, another linear type model that has been instrumental in moving the hazards discipline forward and will be discussed in the next section.

2.4.3 Vulnerability Theory and Pressure and Release (PAR) Framework

Disaster vulnerability theory focuses on why people and communities are susceptible to loss from disasters. Vulnerability as a theory originated in the 1970s when researchers reported that even though the number of disasters remained about the same, the losses were rising significantly and further, disasters of the same magnitude often produced vastly different consequences. It was hypothesized that disasters were influenced not only by the physical environment but also deeply rooted in social systems thus vulnerability became a central focus in reducing losses from disasters (Hewitt, 1983; Cuny, 1994; Wijkman & Timberlake, 1984).

Since vulnerability to disaster is influenced both by the physical (natural, built, and technological) and social (economic, political, and cultural) environments, it was noted that vulnerability was not evenly distributed. Different populations in a community as well as different geographical locations had very different levels of vulnerability producing unsafe conditions. This was embodied by the 2004 work of Wisner, Blaikie, Cannon, and Davis and in their theoretical framework the Pressure and Release (PAR) Model (Wisner et al., 2004, Blaikie et al.,1994). See Figure 2.10 below.

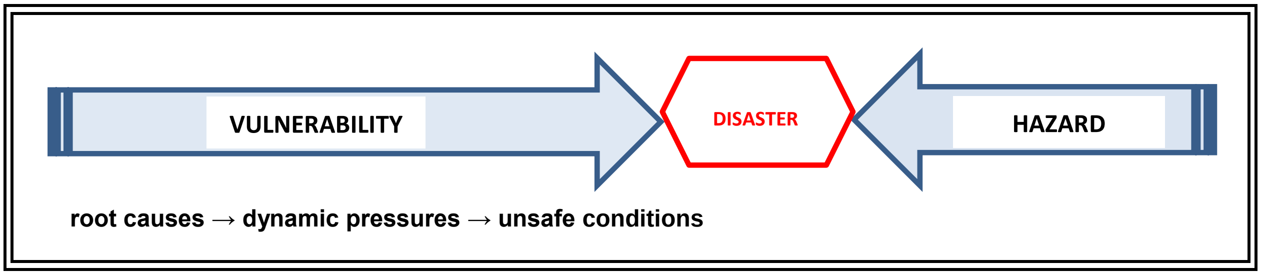


Figure 2.10 Pressure and Release (PAR) Model (Modified by J. Wilder based on Wisner et al., 2004)

The PAR model takes its starting point from the Risk--Hazard framework defining risk as the product of hazard and vulnerability (Wisner et al., 2004; Cannon, 1994). The Disaster Risk Framework adds the element of capacity to disaster risk, while the PAR model computes risk as a hazard and vulnerability; vulnerabilities are defined as a progression of root causes, dynamic pressures, and unsafe conditions. The main premise of this model is that social pressures over time drive vulnerability and root causes such as uneven power and resource distributions that set up dynamic pressures (rapid urbanization, community deficits, and ethical climates) which translate into unsafe conditions. The root causes of disaster or social disasters occur when unsafe conditions intersect with environmental hazards. The "release" part of the model suggests that these conditions can be reversed and vulnerability reduced if we know what they are and mitigate them. Below is a modified list of empirical support for important elements of vulnerability theory by Zakour & Gillespie (2013, p. 151)

(1) "Vulnerability of social systems is a reduced capacity to adapt to environmental circumstances."   Major contributing researchers include Benight et al., 1999; Gillespie et al., 1993; Gillespie & Murty, 1994."

(2) "Vulnerability is not evenly distributed among people or communities. Major contributing researchers include Chakraborty et al., 2005; Gillespie et al., 1993; Cutter et al., 1999; Rogge, 1996; Rustemli & Karanci, 1999; Wisner et al., 2004."

(3) "Social and demographic attributes are associated with but do not cause disaster vulnerability. Major contributing researchers include Bolin, 2007; Cutter et al., 2003; Burnside et al., 2007; Girard & Peacock, 1997; McGuire et al., 2007."

(4) "Unsafe conditions in which people live and work with most proximate and immediate societal causes of disaster. Major contributing researchers include Borden et al., 2007; Wisner et al., 2004."

(5) "Root causes, the socio-cultural characteristics of a community or society, are the ultimate causes of disasters. Major contributing researchers include Burnside et al., 2007; Wisner et al., 2004."

(6) "Disasters occur because of the chain of causality: root causes interact with dynamic structural factors to produce unsafe conditions which trigger a disaster. Major contributing researchers include Renfrew, 2009 & 2012; Wisner et al., 2004."

(7) “The environments of communities are growing in complexity and are increasingly global in scale. Major contributing researchers include Girot, 2012; Mascarenhas & Wisner, 2012; Renfrew, 2009 & 2012.”

The PAR model has several strengths and weaknesses as applied to natural hazards research. One of the main strengths of this framework is that the framework lays out the basic drivers of risk and vulnerability to isolate root causes of vulnerability and provide better understanding of disasters for public policy decision-makers. In addition, the PAR model is general enough to allow for an application to a wide variety of socioeconomic situations. A model is a simplified description of a system and this is one of the PAR model’s criticisms is that there is not sufficient detail to provide adequate structure and explanation of system behavior. While linear type architectures such as the PAR model have been criticized as being too simple to be useful in risk and vulnerability analysis; it does recognize that the direct underlying dynamics (root causes and pressures) need to be carefully examined. In order to do this, you need to simplify the system to observe these patterns. Arguably the PAR model does not do everything, but what it does do (expose and identify direct risk and vulnerability drivers) it does very well.

2.5 Operationalizing Theoretical Frameworks

Natural hazards research is both a theoretical based and applied science discipline. A strong theoretical base is required to contribute to the solutions of practical problems emergency managers face. Operationalizing conceptual frameworks is the process of defining concepts to make them clearly understandable and measurable. Identifying and measuring critical variables allows theoretical frameworks to be empirically tested. The overarching goal of this research is to attempt to operationalize one of these natural hazards theoretical frameworks; the Pressure and Release Model. This next section will critically discuss the two most common ways that many natural hazards conceptual frameworks have been operationalized. They include (1) aggregate index approaches and (2) direct driver approaches.

2.5.1 Aggregate Index Approaches

An aggregate index method consists of a group of factors that are combined in a standardized way, usually by adding them up into a single value and comparing or ranking them against other aggregate index values. There are more than a dozen natural hazards aggregate indices that measure risk and vulnerability. Below, in Table 2.3, is a list of the more common aggregate indices developed since 2005. Aggregate indices can be very useful statistical measures of overall performance and in benchmarking baseline conditions. Many natural hazard risk and vulnerability indices are used to rank regions and nations to determine resource allocation and monitor risk trends over the years. These horizontal analyses are used to monitor progress and provide early warning capabilities.

Table 2.3 List of Natural Hazards Indices (Created by J. Wilder)

DRI---Disaster Risk Index	CCI—Coping Capacity Index
DDI—Disaster Deficit Index	CVI---Composite Vulnerability Index
LDI---Local Disaster Index	HDI---Human Development Index
PVI---Prevalent Vulnerability Index	SIDS---Small Island Developed States Index
RMI---Risk Management Index	SVI---Social Vulnerability Index
HIS---Human Security Index	UBNI---Unsatisfied Basic Needs Index
CBRI---Community Based Risk Index	WRI---World Risk Index

A good representative example of an aggregate index approach is the Disaster Risk Index (DRI) developed by Peduzzi et al. (2009) and sponsored by the United Nations Development Program. This index aggregates 32 socioeconomic and environmental indicators and calculates weighted average and multiplicative formulas in order to determine which countries have greater risk for specific types of natural hazards and is useful for ranking comparisons. However, gathering data on 32 socioeconomic and environmental indicators can be quite challenging in itself, let alone determining weighted averages. In addition, analyzing which of the socioeconomic and environmental indicators are actually driving risk and vulnerability is time-consuming and not useful for emergency managers who need data quickly.

Another common approach is to combine aggregate indices. Cardona (2006) proposed a suite of four aggregate indices designed to detect vulnerability and show a country's progress in managing risk; the Prevalent Vulnerability Index (PVI) includes the Human Poverty Index, the Human Development Index, the Gender-related Development Index, and Environmental Sustainability Index along with 20 other indicators in its calculation. Drilling down to individual drivers of risk and vulnerability is extremely challenging with this system, although it does give a good average of the overall view of risk and vulnerability at the macro level.

Another example is the United Nations Human Development Index (HDI). It aggregates 4 indicators: life expectancy at birth, mean years of schooling, expected years of schooling, and gross national income per capita. When developing policy it is not enough to know the HDI value, one needs to know what is driving the number so that policies can be built around the specific driver and not the general HDI value. Even though several countries may have the same HDI value, their public policies in addressing this could and should be very different. Another issue with aggregate indices is that they are static and are not flexible enough to accommodate changing conditions and different aspects of geographic locations. Many of these aggregate indices introduce modifications and rename them as “adjusted” indices; for example the HDI now has another version called the Inequality – Adjusted Human Development Index. These modified composite indices become very cumbersome and confusing to use. Another drawback is that there is a tendency for models to accumulate complexity. Aggregate indices usually start out with a handful of well-chosen indicators, but usually over time are modified into combining hundreds of indicators and then, to make matters worse, weighted adjustments are also included. Finally, many of these indicators have never been tested for independence and intend to influence each other when aggregated, distorting outcomes. The benefits of using an aggregate index are that it is a quick and easy way to operationalize many types of conceptual frameworks. They are excellent for a general understanding of the issue. However they should be used with caution when determining specific public policy. A better method could be a direct driver approach to understanding risk and vulnerability.

2.5.2 Ratio and Direct Driver Approaches

While a whole range of internal and external factors can affect processes, it is critical in this method to focus only a handful of key drivers. Direct drivers or key indicators are anything that has a significant influence on the process or object being observed and usually consist of elements that can be measured and acted upon. While individual key performance indicators are important, it is also important to understand the processes that are taking place. This is usually done through flowchart diagraming. Rather than just selecting indicators of risk and vulnerability, the overall process at work must also be thoroughly understood.

Direct driver approaches to operationalizing theoretical frameworks to detect vulnerability and risk are rare in the natural hazards scholarly literature. While aggregating indicators are more effective at providing information at the macro level, it is also recognized that drivers of these processes need to be exposed and made more visible. This is usually addressed by attempting to look at performance benchmarks of various vulnerability indicators (Cutter et al., 2010). However this, too, has met with marginal success. The discipline most successful in using direct drivers to detect risk and vulnerability has been the financial sector both in accounting and economics. Both of these disciplines regularly use financial risk ratios, which never aggregate, weight, or introduce complicated computations. Individual risk ratios are compared in a horizontal analysis over time examining for slope trends (increasing or decreasing risk). For example, the International Monetary Fund (IMF) regularly calculates Financial Soundness Indicators using economic ratios. No complicated aggregating or weighting is allowed, the two drivers are simply observed over time.

One of the main advantages of the direct driver approach in determining vulnerability and risk is that simplicity and clarity are preserved at the most basic level. One does not need to do any additional work or drill down into calculations to find direct drivers of processes. They are never obscured in the first place. However, one of the key elements to making this process work is carefully choosing key performance indicators and the data used to populate them. Because so few data indicators are used, it is critical that careful evaluation of the selected variables be the best ones available. This approach uses the idea of quality over quantity; a handful of vulnerability indicators are used rather than all of the indicators that could possibly be influencing risk. The next section will describe financial risk ratio methods and how it could be applied to natural hazards risk and vulnerability determination.

2.5.3 Financial Risk Ratio Method

While the theoretical framework of this study is based on the Pressure and Release Model, the platform to operationalize this model is based on financial risk ratio methods. Ratios are mathematical comparisons based on proportions used to analyze performance strengths and weaknesses, make policy decisions, and are routinely used in strategic planning. A financial ratio, also known as an accounting ratio, is a relative magnitude of two values which quantify certain aspects of a business entity. Data do not occur in a vacuum but are defined by context. Ratios allow one to establish context as the numerator is number bounded or defined by the denominator. While many risk measurement systems use key performance indicators, the more sophisticated financial analysis uses ratios. Numbers tend to be very helpful when framed or compared to other numbers. Financial risk ratio method is very flexible, you can use predefined ratios and key indicators or you can develop your own that are unique to your situation. It is one of the most common tools used to examine the health of a business and they are easy to understand and simple to compute.

Financial risk ratio analysis emerged in the 1890s during the Industrial Revolution as world economic power shifted to financial institutions and credit became available to the manufacturing industry (Horrigan, 1968). Ratio analysis rapidly developed with the creation of the Federal Income Tax code in 1913 and the Federal Reserve monetary system in 1914. The IRS still runs tax returns through computerized ratio analysis to determine if fraud is likely and an audit required. The Theory of Ratio Analysis emerged in the 1920s and was used as a predictor of financial difficulties in business. The predictive power of ratios was in full swing by the 1930s and ratio analysis could reliably predict financial failures up to 5 years in advance (Horrigan, 1968). By the 1940s financial ratios were used to describe various characteristics of economic entities.

Financial ratio analysis is now routinely used to detect issues with business credit approval, financial fraud, business failure and to assess corporate risk (Altman, 1968; Ohlson, 1980; Livingstone & Lunt, 1992; DeVaney & Lytton, 1995). Financial ratio analysis is also used at the individual level to assess and benchmark the financial well-being of families (Greninger et al. (1996). Prather (1990) conducted a landmark study applying ratio analysis to personal financial statements and the development of household norms. Finally, Devaney was one of the first researchers to examine the progressive change in household financial ratios and how this affected their financial status including risk and vulnerability to economic stress (1993).

The objective of my dissertation is to build a measurement system to detect risk and vulnerability in disasters using financial risk ratio methods. Maricica & Georgeta presented a study on business failure risk analysis using financial ratios by comparing means of ratios using a t-test and found that there was substantial support for the power of financial ratios to give early warnings about future negative financial health (2012). It is hypothesized that this same method could be applied to natural hazards risk determination. It may be possible to standardize risk ratios for natural hazards research similar to the standard financial ratios. Financial ratios allow flexibility for users to develop or alter the ratios and indicators based on what stakeholders consider important to their situation. This allows for a wide variety of situations and fluid conditions to be addressed, as is often the case in natural hazards events.

2.6 Discussion

The literature review seeks to define key terminology, critically review the relevant published scholarly work, and establish a theoretical framework for the study. Critical concepts were reviewed and different schools of thought were identified and evaluated both as a whole and in relationship to this research inquiry. A thorough review of the scholarly literature allowed me to identify similar work done in this area and note potential areas for future research, and where my study is positioned within this greater body of knowledge. This process enabled me to identify the knowledge gap between theoretical and operational natural hazards frameworks and put my study into context to set the stage for the study's purpose and rationale. Further, this research provides original contribution to the body of published work and highlights exemplary studies in the field that promote advancement of understanding. The following chapter will present in detail how the study was conducted.

CHAPTER THREE:

METHODS

3.1 Introduction

The methods of the research study are explicitly laid out to support the objectives and research questions and ensure reliability and validity of the results. The purpose of the study was to provide a method to operationalize the Pressure and Release (PAR) theoretical framework using financial ratio methods often used in business models to detect financial irregularities and risk. The study design was intended to develop an operational model that could be used to identify emerging vulnerability to natural hazards and predict risk. Below, in Figure 3.1, is a conceptualized view of the research framework. The research process framework is a dance between research, theory, and stakeholder needs each reinforcing the other into an interlocking whole.

In this case, the research consists of building an operational model according to stakeholder needs (emergency managers) but based on natural hazards theory. While this might seem straightforward, more often than not stakeholder needs are usually the driving force behind model building. What this framework reminds us is that there should be a balance between theory and stakeholder needs. Models need to be well grounded on a theoretical framework including methodology, constructs, data analysis, techniques, verification, and validation. This chapter will explain the methods used in this study and provide rational on why they were selected to meet the research goals.

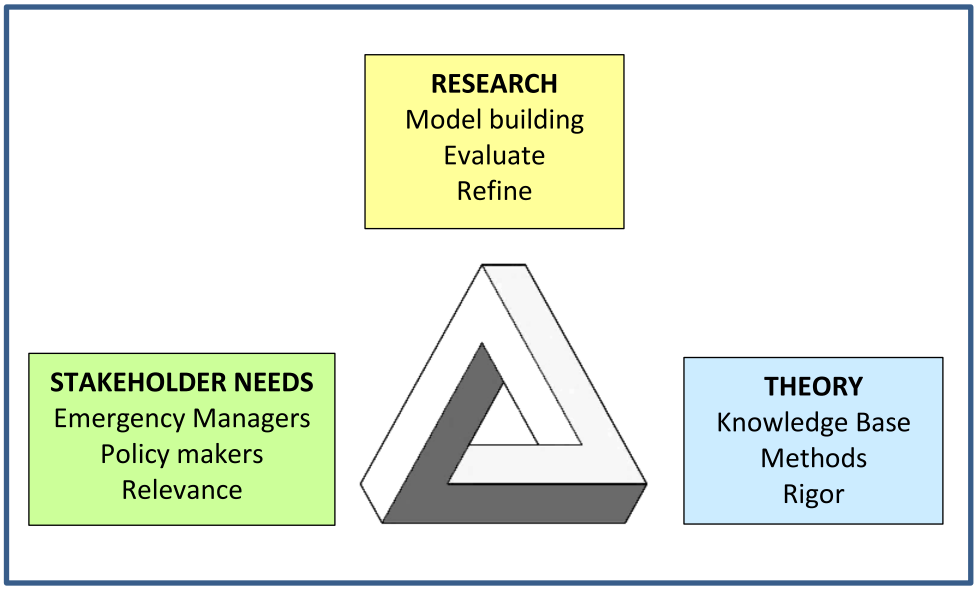


Figure 3.1 Research Process Framework (Created by J. Wilder)

3.2 Background

The study of risk and risk management has a very long history particularly in government and private industry (Bernstein, 1996; Covello & Mumpower, 1985). The quantitative traditionalists contend that the only way to measure risk is to consider it through the lens of probabilistic analysis where Risk = probability x consequence. Probability is the chance that something will or will not occur and often includes very complex mathematical calculations and sophisticated computer software support. While this approach is important in understanding risk, natural hazards researchers need to know more than the probability of a disaster. Because of this, the natural hazards discipline has shifted focus from uncertainty to vulnerability as a proxy for understanding risk.

Disaster vulnerability theory attempts to explain the susceptibility of systems (social, economic, environmental) to losses from a disaster event. This has often been accomplished through rating, rankings, weighted averages, and a variety of aggregate methods with limited success. Two major limitations that have hindered the use of these measurement tools are (1) complexity and (2) inflexibility. Many of these measurement systems are too complex to be understood by the average emergency manager in the field. In addition, complexity often hides or obscures the real drivers of vulnerability particularly when aggregate scoring systems are used. Secondly, disaster events are well known for their inherent and often rapidly changing conditions; most measurement systems are static snapshots of the past with little flexibility built in and do not take into consideration variability of geographic location in their measurement models. A hurricane in one city can have vastly different results, impacts, and recovery than in another city because the systems (social, economic, environmental) in which they operate are quite different.

This study and the methods chosen will attempt to address and resolve these concerns by developing a new operational model to measure vulnerability that is (1) simple, easy to use in the field; (2) flexible for changing conditions; and (3) can be site specific to a particular geographic location. The methods selected in this study included creating a suite of risk drivers and key performance indicators that can be used to develop risk ratios to quantify vulnerability and identify risk trends over time. The study design methods are intended to take these risk ratios and establish feasibility of the process using natural hazards data from Tampa, FL metropolitan area. If this process works and risk trends can be identified and quantified earlier, mitigation efforts could have greater impacts and be more successful at limiting damage and loss.

3.2.1 Research Objectives

1. Develop a new hazards-vulnerability operational model using risk ratio methods.
2. To build a comprehensive data repository for key performance indicators, risk ratios, and corresponding data sources.
3. To determine best practices using this operational model to identify vulnerability to natural hazards.

3.2.2 Research Questions

1. Can the Pressure and Release theoretical framework for evaluating natural hazards risk be operationalized?
2. Can financial risk ratio methods using key performance indicators be used to determine vulnerability to natural hazards?
3. Does the new operational model improve disaster risk prediction?

3.2.2 Research Hypotheses

The research hypotheses are central to all research endeavors. It is hypothesized that the three research questions in this study will be answered in the affirmative and the research objectives will be met through the study design and methods selected by providing measureable results.

3.3 Methods

The research design study includes a structured-model development process using a driver-centric modeling technique (common in computer threat modeling) with a time-series, scenario-driven demonstration using archival data. A three stage framework will be employed; each stage dependent upon the former and all three stages and their specific methods will be discussed individually.

Stage 1 Operational Model Development

1. Create a list of model input/output requirements with justification.
2. Develop a conceptual process flowchart of model to determine scope.
3. Evaluate the model design using a predetermined criteria checklist.

Stage 2 Risk Ratio Development

1. Develop data source library that has been quality tested.
2. Select and evaluate key performance indicators using a wire tree analysis.
3. Create and test risk ratios using KPIs with artificial scenario-driven data.

Stage 3: Case Demonstration using Risk Ratios

1. Select Target Projects using predetermined criteria to apply risk ratios.
2. Apply risk ratios to project site using data library sources.
3. Evaluate for escalating vulnerability and risk using slope analysis.

Below is the *Study Activity and Deliverables Summary* chart (see Table 3.1) that will be used to track progress and insure verification and validity. Each part of the study comprises 2-3 principle activities and 3 deliverables that consist of quantifiable components that are then evaluated as a product of the development process. The nine deliverables will be briefly discussed in detail in the following discussion.

Table 3.1 Study Activity and Deliverables Summary (Created by J. Wilder)

Study Activity and Deliverables Summary			
Part	**Activity**	**Deliverables**	**Status**
STAGE 1: Model Development	1. Conceptualized design	Process Input/output (I-O) Analysis	
	2. Model development	Process Flowchart of Model Design	
		Design Cycle Audit Checklist	
STAGE 2: Risk Ratio Development	1. Data Library dev.	Data Library Criteria Checklist	
	2. KPI generation	KPI Evaluation using Wire Tree Analysis	
	3. Risk Ratio dev.	Risk Ratio Selection Analysis	
STAGE 3: Case Demonstration	1. Project Selection	Project Selection Criteria Checklist	
	2. Case Scenario Application	Risk Ratio Data Sheet Results	
		Graphical Data and Slope Analysis	

3.3.1 Model Development

Stage 1 of the research study is to conceptualize the design and model development. The first step in conceptualizing the design will be to compile key information input and actionable output requirements. The model framework design process will identify and gather the data inputs and information outputs which snap together by linking processes with the inputs and outputs that ultimately form the model.

Because all of the stages are interlinked and interdependent, it is important that the input and output requirements be accurately identified before actual model development begins. Errors at this stage will only carry through and amplify to the next. While it is often assumed that input requirements are the beginning, we do start with output requirements because they are the external events which drive activity. By examining the desired outputs, we can work backwards or forwards to figure out the input and output requirement. Below, in Table 3.2, is a sample of the Process

Input/output Requirements Chart. Based on these findings, inputs and outputs will be linked with processes in a flowchart.

Table 3.2 Process Input/Output Requirements Matrix (Created by J. Wilder)

Process Input/output Requirements Matrix							
Input requirements				**Output requirements**			
1.				1.			
2.				2.			
3.				3.			

A structured, driver–centric modeling approach will be used to construct the architecture of the model. This top-down modeling approach will be used by starting with features at the highest level and attempting to diagram processes and link them in a coherent model. Top-down modeling is more effective than bottom-up modeling because many components must merge together seamlessly (Shostack, 2014). This type of modeling can lead to the generation of a lot of information and very good tracking mechanisms are essential. Below, in Figure 3.2, is an example of a cross functional process map that will be used in this study. Elements of a process flowchart include identification of data flow (inputs and outputs), processes, data storage or databases, documents, and decisions categorized according to swim lanes (stags of the study). The purpose of the operational network model is to bring together structure, behavior, and interaction diagrams. The following are elements needed in a well-developed diagram 1) identify events that drive the system; (2) show the processes that are driven; (3) identify data sources; and (4) identify recipients (Shostack, 2014).

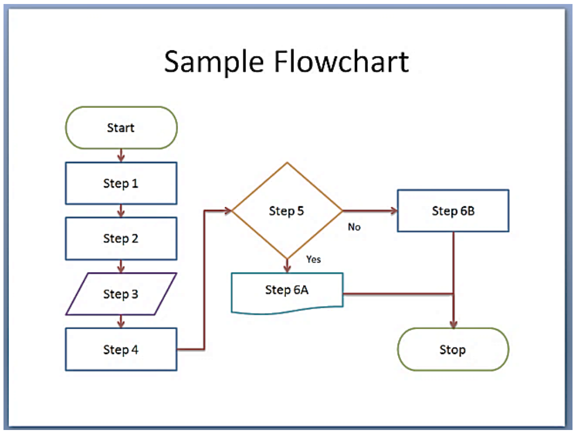


Figure 3.2 Process Flowchart Template

Once the model has been mapped, a test-retest method using a checklist to analyze for structural problems will be completed. Structural problems are identified by noting inconsistencies or undesired outputs of the model. Corrections, debugging, and fine-tuning the model will occur at this stage. The audit checklist will ensure that all tasks are completed and processes are accounted for. This modeling approach focuses on procedures that can deal with complexity and uncertainty where other research techniques fail to build a comprehensive model. This gives us a structured understanding of the overall model and how each component interrelates and allows us to catch problems before they fully manifest.

Below, in Table 3.3, is a sample of the design cycle audit checklist data sheet. The goal is to build a diagram that represents the reality of the system and to communicate how the system works. Making an explicit model or diagramming helps to look for issues without getting bogged down in the details. The advantage of this approach is that individual components can be modified if necessary without having to re-create the entire model from scratch. It provides a complete end-to-end overview of the process. It'll also allows others to easily duplicate the process and diagrams are a good way to communicate what is being built and how it was tested.

Table 3.3 Design Cycle Audit Checklist (Created by J. Wilder)

DESIGN CYCLE AUDIT CHECKLIST				
Requirements		Was the step completed successfully? If not—why?		
		Yes	No	Remarks
A. INPUT/OUTPUT ANALYSIS and FLOW CHART DESIGN				
1				
2				
B. KEY PERFORMANCE INDICATOR (KPI) SELECTION				
3				
4				

3.3.2 Risk Ratio Development

Stage 2 of the study is risk ratio development and involves selecting key performance indicators to create risk ratios to detect emerging vulnerabilities to natural hazards. The first activity will be to develop a data library. A list of 25 national data sources and 25 local data sources will be compiled using 6 criteria to evaluate the websites (Dalhousie University, 2012). These 6 criteria will include authority, purpose, coverage, currency, objectivity, and accuracy. Each database must meet at least 5 of these criteria to make the final list. One of the critical features of this stage of the process is to provide an easy accessible reference library of performance data to populate the risk ratios. Online databases tend to vary greatly in the quality of their archival data. The advantage of this method is that when emergency managers use this system they are all pulling data from a common pool of resources that has been rigorously quality tested. Some challenges for databases are that data parameters and measurement protocols can change and data often have a shelf-life where at some point they become outdated and less relevant. Another issue is maintaining consistent sampling intervals and sampling rates. All of these issues affect the quality of the database. Below, in Table 3.4, is a sample data library selection criteria checklist.

Table 3.4 Data Library Criteria Checklist (Created by J. Wilder)

Data Library Criteria Checklist							
Database Name and Web Address		Authority	Purpose	Coverage	Currency	Objectivity	Accuracy
1							
2							
3							
4							

The next step will be to compile a list of 20 key performance indicators that drive each of the following domains; social, economic, and environmental risks using a quick populated KPI (key performance indicator) shortlisting matrix that prioritizes importance and availability. To document the KPI journey a wire tree analysis will be used to determine what the risk driver is and how it should be measured. See Figure 3.3 below. This process will be reinforced by examining the supporting natural hazards literature in which key performance indicators were successful (Birkmann, 2006). The wire tree analysis criteria will include the name and definition of the key performance indicator, stakeholders, measurement intent, units of measure, target values, data availability, and any assumptions, issues and concerns of each candidate measure. A wire tree analysis approach has the advantage that it is a simple graphical tool that can show the linkages between the strategic objectives and direct drivers of that parameter. There are number of benefits that come from using key performance indicator wire trees including summing up complex situations with just a few indicators and understanding how measures interact particularly (1) cause-and-effect, (2) companion and (3) conflicting relationships. They link the strategic objectives with tactical enablers and measurement parameters. Through this structured decision-making process, the best key performance indicators of risk can be evaluated and selected.

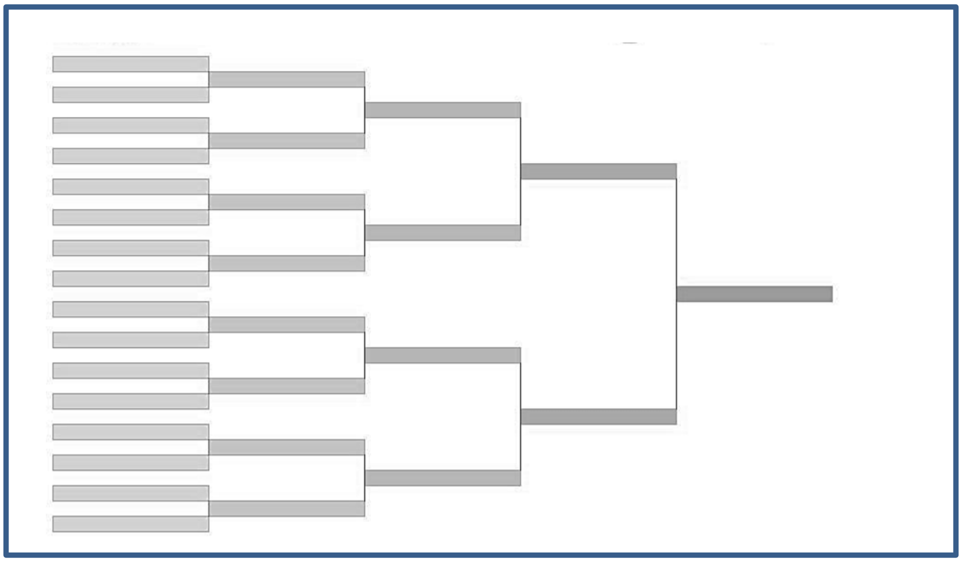


Figure 3.3 Example of a Wire Tree Analysis (Created by J. Wilder)

The final activity of Stage 2 will be to develop a suite of a dozen risk ratios; these will be distributed over of each of the three systems (social, economic, environmental). A comparative method will be used to determine which risk ratios will be selected. This means coming up with 2 or more designs and then comparing them. A limited pilot implementation or artificial scenario-driven test will be used to evaluate the risk ratios for performance. A simple prioritization technique, an intuitive ranking approach, or fitness for purpose approach could also be used to answer the question: does the ratio do the job it was intended to do?

Developing risk ratios with a quality test database and building upon carefully developed key performance indicators, the resulting risk ratios demonstrate optimal output with high confidence levels. A Risk Ratio Selection Analysis template can be found below in Figure 3.5 and allows each step of the process to be carefully developed and analyzed.

Table 3.5 Risk Ratio Selection Analysis Template (Created by J. Wilder)

Category	KPI Subcategory	Name	Ratio	Ratio behavior: as vulnerability ↑	Type of Ratio			
					Proportion or %	Rate	Density	General

3.3.3 Case Study Demonstration

The final stage of the study is a case demonstration of the risk ratios to determine whether they have the ability to detect escalating vulnerability due to natural hazards and predict risk. Evidence of increasing risk will be determined by looking for changes in vulnerability to determine trends in a time series design. The case demonstration will include selecting a project from the Hillsborough Local Mitigation Strategy (LMS) plan which is a part of the Comprehensive Emergency Management Plan (CEMP). The LMS is a local government plan designed to reduce or eliminate risks to people and property from natural and man-made hazards and was mandated through the Federal Disaster Mitigation Act. The goal of the LMS is to establish and maintain ongoing processes that assess potential disasters and vulnerabilities of the community to a variety of hazards and identify a comprehensive list of plans, programs and projects to mitigate this. Currently, federal regulations require the local mitigation strategy to be reviewed and revised every 5 years. The latest local mitigation strategy for Hillsborough County is 2015 and was an update from 2009. The goal is to identify emerging risk trends and patterns before the implementation of the all-hazards Local Mitigation Strategy (LMS) project initiative. This could be used as a benchmark to determine at what point a risk was perceived by the government and if any risk escalation can be detected before that point. If risk trends can be observed and quantified earlier, it is possible that mitigation efforts could be started earlier.

The Local Mitigation Strategy Project List is found in appendix G of the 2015 Local Mitigation Strategy report for Hillsborough County. There are several hundred projects listed and each project is recorded by number, name, project description, hazard mitigated, funding source, jurisdiction location, agency responsible for implementation, estimated costs, status, timeframe, and when it was last updated. A project selection criteria checklist, in Table 3.6, is presented below. Criteria include a significant, current flood, hurricane or storm event in the Tampa Florida metropolitan area.

Table 3.6 Project Selection Criteria Checklist (Created by J. Wilder)

LMS Project Selection Criteria Checklist							
Project Name & #		Description	Location	Hazard Type	Size in cost	Last Updated	Agency
1							
2							
3							
4							

Once the LMS project has been selected, the risk ratios will be applied to archival data from the Data Library sources collected about this area and recorded on the risk ratio data sheet. Output from the risk ratio calculation will be recorded on the risk ratio data sheet and scatterplots will be constructed and evaluated on the graphical data sheet evaluating for linear relationships using slope and slope direction, positive or negative. Risk ratio analysis will include the determination of normal distribution of the data by looking at mean, median, mode, and linear relationship by analyzing slope. See Table 3.7. Further detailed description of the statistical analysis is provided in the section below under Data Analysis.

Table 3.7 Graphical Data Sheet and Statistical Analysis (Created by J. Wilder)

Risk Ratio	Mean	Median	Range	Slope (+/-)
Environmental				
#1	--	--	--	--
#2	--	--	--	--
Social				
#1	--	--	--	--
#2	--	--	--	--
Economic				
#1	--	--	--	--
#2	--	--	--	--

3.3.4 Verification and Validation

Verification or reliability is a critical step in the model-building process; it ensures that the model is built correctly and operates the way it was intended. This process verifies that the computational model is consistent with the specification model to establish confidence in the output. To achieve this, the model design process will include structured checklists and summary data sheets implementing a test-retest protocol. Results of each test using simulation data must be documented and fall within acceptable parameters (Maricica & Georgeta, 2012*)*. If not, the model must be debugged and changes made and the model retested for consistency. Once the model is verified that it operates in the way planned, validity will be addressed.

While verification is necessary, it alone is not sufficient; the model must also be valid. Validity is one of the main concerns with research. Validity determines if the model represents reality closely enough to provide information to support decision making and accurately describes the system being modeled. Below is a summary chart, in Table 3.8, of five groups of design evaluation methods (Hevner & Chatterjee, 2010) and which were selected for each part of the study.

Table 3.8 Model Design Evaluation Methods (Modified from Hevner et al., 2004)

Design Evaluation Methods					
Category	**Type**	**Description**	**Used in Stage**		
			1	2	3
Observational	Case study	study of a specific group or situation			x
	Field study	observe under real-world, holistic conditions			
Analytical	Static analysis	study for static qualities--structural components	x	x	
	Architecture analysis	how well does it fit into the overall system			
	Optimization	is the model the best it can be for the use			
	Dynamic analysis	review dynamic qualities--performance, usability			x
Experimental	Controlled experiment	study in a controlled environment			
	Simulation	test for failures and defects with artificial data	x	x	
Testing	Functional testing	execute under artificial conditions for defects/failures	x	x	
	Structural testing	perform coverage testing for implementation			
Descriptive	Informed argument	build convincing argument for utility			
	Scenarios	construct scenarios to demonstrate utility			x

A triangulation approach will be used employing a combination of 3 evaluation methods selected for each part to increase reliability and validation of the development process. For example, Stages1: Model development and 2 Risk Ratio Development uses a combination of analytical, experimental and descriptive methods to establish validity and Stage 3: Case Demonstration uses a group of observational, analytical and descriptive methods. This process should be sufficient to lend a high degree of confidence in the model.

3.4 Data Application and Analysis

Archival data of key performance indicators will be collected from sources evaluated and selected from the Data Library. The key performance indicator data will then be used to compute the risk ratios. Risk ratios will be developed and tested in Stage 2 of the modeling process thru a specified set of criteria and benchmarks. Once the risk ratios have been selected and verified, data for specific time periods will be collected from sources in the Data Library to use in the case demonstration. Data collected from the Hillsborough County 2015 Local Mitigation Strategy Appendix G—Hillsborough Country LMS in Process Project List will be used to select several projects for Stage 3: Case demonstration of the study.

A time series approach will be used to flag possible escalation patterns. In this study we are looking for escalating vulnerability and risk over time. The time series data will be plotted on line charts and evaluated for slope. Results from Stage 3: Case demonstration will be analyzed by looking at slope to identify possible escalating risk trends using graphing techniques. Slope is a ratio of the rise over run or vertical to horizontal change ($\Delta y/\Delta x$) as graphed on a coordinate system. The slope or linear relationship can be positive, negative or zero and describes the direction and steepness of the line generated. Slope comparisons can be made between outcomes of various risk ratios in each case demonstration of a single time series. While linear patterns do not necessarily imply causation they may indicate that a relationship exists.

Finally, the direction of the slope as positive (upward trend) or negative (downward trend) will be evaluated and compared with what was expected in relation to the ratios performance compared to vulnerability. While regression analysis can be a powerful tool for predicting future values based on historical values and strength of the correlation between the variables on the graphs should at some time be tested by using the Pearson Correlation Coefficient test, it is beyond the scope of this particular study. In addition, the Granger Causality Test can be used to determine if one time series is useful in forecasting another time series. Again, this is beyond the scope of this study. This study focuses on whether it is even procedurally possible to operationalize the PAR theoretical framework using with financial risk ratio methods, not how well it does it. Descriptive statistical such as mean, median, range and will also be recorded for the sequence of discrete-time data and evaluated for normal distribution.

3.5 Strengths & Limitations of the Study Design

A model is a simplified representation of the real world. It is useful for structuring problems and understanding complex situations and systems. By modeling, we can more clearly see the cause and effect linkages as it applies to a variety of scenarios. The disadvantages of models are that they are incorrect. There’ll always be an error factor associated with a model. Other limitations include bias, tendency to accumulate complexity, and the ability to build a really good model with highly unrealistic assumptions and expectations. However, models do not have to be perfect in order to contribute useful information to the discovery process.

In addition, a retrospective time series study design is observational in nature. One advantage of this research method is that observations are made without manipulating the data and by observing the events in temporal order. The same key performance indicator or risk driver is observed many times usually over the course of years. Another important advantage of performing a time series study is the ability to show patterns of variable behavior over time. This clearly highlights the relationships of cause and effect and developmental trends where events otherwise may not be linked. One of the drawbacks to the study design is that data is required to be consistently collected over a long period of time and observation periods are predetermined. If data is missing from a particular year there is no way to get it back. In addition what happens between observation points is unknown. However, with a good data set, these limitations can be mitigated to a large extent.

3.6 Summary

This chapter described the methods planned for this study to operationalize the Pressure and Release (PAR) natural hazards theoretical framework. See Figure 3.4 below. This approach allows for a baseline understanding of vulnerability to natural hazards in environment, social and economic systems and the mechanisms impacting risk prediction by model development design, key vulnerability indicator selection process, risk ratio development, and case study demonstration. Methods and design were evaluated to support the goals and objectives of the study. Also presented was an overview of how this research fits into and is comparable to current research in the field as well as a brief discussion on study verification and validation. Strengths and weaknesses of the study design were considered. In summary, this research will attempt to operationalize the Pressure and Release (PAR) theoretical framework using financial risk ratio methods.

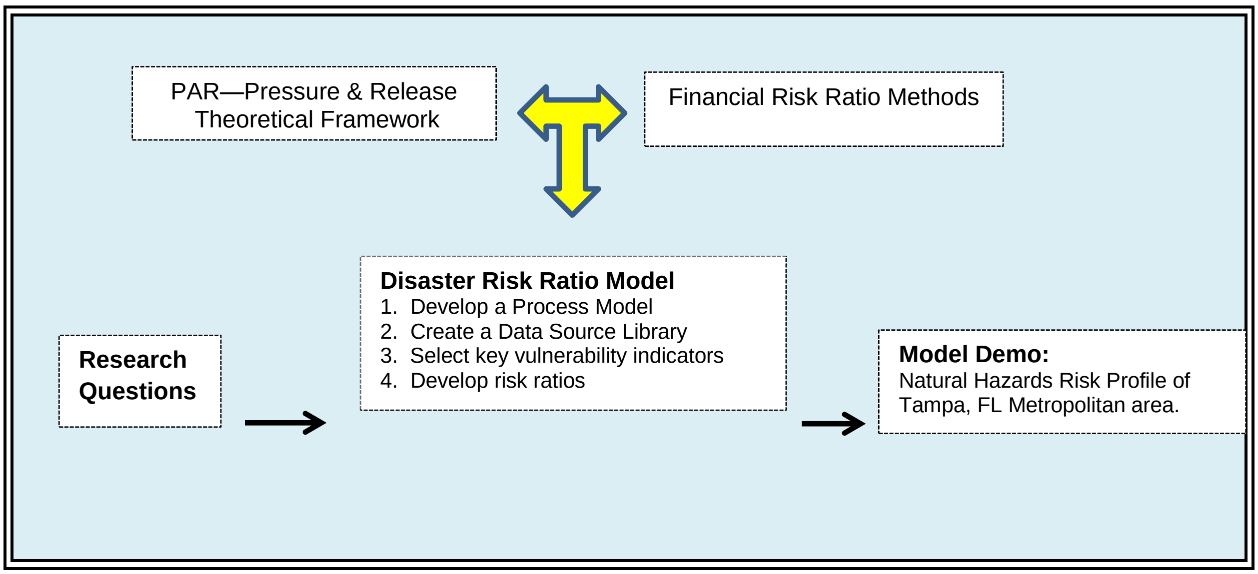


Figure 3.4 Study Methodology Flowchart (Created by J. Wilder)

CHAPTER FOUR:

RESULTS OF MODEL DEVELOPMENT

4.1 Introduction

The intention of this study was to see if it was possible to operationalize the Pressure and Release (PAR) theoretical framework using something other than the current method of aggregate indexes. The approach employed a structure decision-making process using model development with a case demonstration. It was hypothesized that financial risk ratio methods might be able to address some of the challenges in the current aggregate indexing method including lack of model (1) flexibility, (2) simplicity, and (3) specificity. This chapter will address Stage 1: Conceptual Model Design. Below, in Table 4.1, is a summary table of the study design process. The results of Stage 1 will be discussed and analyzed in this chapter.

Table 4.1 Study Activity and Deliverables Summary (Created by J. Wilder)

Study Activity and Deliverables Summary			
Part	**Activity**	**Deliverables**	**Results**
STAGE 1: Model Development	1. Conceptual design	Process Input/output (I-O) Analysis	Ch. 4
	2. Model development	Process Flowchart of Model Design	
		Design Cycle Audit Checklist	
STAGE 2: Risk Ratio Development	1. Data Library dev.	Data Library Criteria Checklist	Ch. 5
	2. KPI generation	KPI Evaluation using Wire Tree Analysis	
	3. Risk Ratio dev.	Risk Ratio Selection Analysis	
STAGE 3: Case Demonstration	1. Project Selection	Project Selection Criteria Checklist	Ch. 6
	2. Case Scenario Application	Risk Ratio Data Sheet Results	
		Graphical Data and Slope Analysis	

4.2 Results: Model Development

Stage 1: Model Design of the study was concerned with model development and the conceptual design. This stage used a structure decision technique which was a carefully organized analysis of a set of problems focused on attaining core targets and grounded in decision theory and risk analysis. By examining each element separately within the overall comprehensive decision framework, it was possible to develop a framework to improve the quality of decision-making (Failing et al., 2012). This structured assessment was accomplished by defining the problem, examining the alternatives, linking them with objectives, and choosing the optimal outcome. The study model development took place in a predetermined and sequenced design. This was not intended to be a rigidly prescribed approach but a framework to provide transparency of the process during analysis of internal defects and for test-retest reliability. This process involved two tasks: (1) conceptual design, which determined the input and output requirements and (2) model development, which identified processes that linked these inputs with the outputs and was captured in a flowchart and tested using a performance an audit check.

4.2.1 Conceptual Design: Inputs and Outputs

The Pressure and Release theoretical framework was subject to an Input-output (I-O) analysis and the results are presented below in the matrix in Table 4.2. This simple analysis tool provided a systematic breakdown of a complex system into its component parts, highlighted relationships between elements, provided structured organization and transparency in an easily understood format. The analysis began by identifying input/outputs for *vulnerability* and then inputs/outputs for *natural hazards*.

Table 4.2 Theoretical Framework Input-output (I-O) Analysis Matrix (Created by J. Wilder)

THEORETICAL FRAMEWORK INPUT/OUTPUT ANALYSIS MATRIX

Pressure and Release (PAR) Model (Wisner et, al. 2004)

VULNERABILITY

INPUTS			OUTPUTS	
	Socio-economic Inputs			**Socio-economic**
Root causes	Economic inequality Political influence Political/economic Ideology Social dev./Cultural norms	⇨	**Unsafe conditions**	↑ Fatalities and injury ↑ Losses ↑ Costs ↑ Complexity ↑ Social disruption ↑ Social isolation ↑ Economic stress/dysfunction ↓Integration ↓Quality of life ↓Healthcare/↑Infant mortality ↓ Education ↓Life expectancy ↑ Violence ↓Housing ↓Clean water/food
Dynamic Pressures	Social structures Resources Distribution Displacement Disadvantaged class Rapid population growth Slow economic growth Building codes/safe housing Fragile economies/political sys.			
Unsafe conditions	Poor public health care Disease—Lack of public health Few economic opportunities Substandard housing Lack of emergency management Lack of evacuation Low search and rescue activity Low recovery aid			

NATURAL HAZARDS

INPUTS			OUTPUTS	
Natural Hazards	**Environmental Inputs**			**Ecosystem**
Meteorological Hurricanes Tropical Storms Tornadoes Flooding Droughts Extreme Heat **Geological** Erosion/Suspect Soils Wildland Fires Tsunamis	Number of events Frequency of occurrence Intensity Pressures Ecosystem damage Climate change Climate volatility Ecosystem stress	⇨	**Unsafe conditions**	↑ Deaths and injury ↑ Number of events ↑ Frequency of occurrence ↑ Intensity ↓Biodiversity ↑ Ecological risk index ↑ Endangered species ↑ Climate volatility ↑ Ecosystem stress ↑ Cascading events ↑ Compounding events

The Input-Output analysis matrix was carefully designed with the following elements built into it: (1) bringing clarity to a complex system; (2) providing transparency so everyone knows the reasoning behind the model built; (3) delivering tracking capabilities so changes and modifications are recorded and time is not wasted on repeating failures, and (4) incorporating verification through a test-retest protocol. By using this tool, a foundation could be laid for the conceptualized design of the operational model. This would be a critical component and lay the ground work for the rest of the operational model development. If this part could be laid down correctly, the rest of the model has a better chance of success. It also allows other researchers to explicitly repeat the process and possibly improve the model output.

This analysis tool began with a graphical representation of the theoretical framework to be operationalized. The selection criteria for the I-O analysis matrix were taken directly from the Pressure and Release (PAR) framework which indicated that escalating vulnerabilities intersecting with the hazard precipitate a disaster. Matrices and models are initially read from left to right and top to bottom. On the left side of the matrix, inputs were examined and on the right side, outputs were examined. Socioeconomic vulnerabilities were evaluated on the top half of the matrix and environmental vulnerabilities were evaluated on the bottom half. The two sources of inputs leading to disasters were vulnerabilities and hazards. Beginning with vulnerabilities, the model stated that the sources or inputs result from escalating root causes, dynamic pressures, and unsafe conditions. These elements were viewed through the lens of social and economic domains and formed the matrix of Vulnerability Inputs. There are number of scholars are working in this area and the following studies were used as a starting point for my I-O analysis (Cardona, 2006; Cutter et al., 2010; Alvandi et al., 2012; Birkmann et al., 2013; Peduzzi et al., 2009). It was found that building as much structure into the I-O analysis with the use of relational subcategories made the analysis process more fluid and much easier. In addition, it was found that the more detail in the input output analysis matrix the more successful the key performance indicator selection and risk ratio development was.

The other sources of a disaster, according to the PAR framework, were natural hazards. Natural hazards could also escalate as well through intensity or physical properties and environmental pressures such as climate change, instability and ecosystem stress. In addition, some natural hazards exhibited cascading and compounding traits. Natural hazard inputs were examined by specific types of hazards as well as using environmental impacts as a proxy to escalating natural hazards. This was viewed through the environmental domain and formed the section Hazard Inputs. While the PAR model does not address the escalation of hazards directly, I have included it in the analysis matrix as intensity, pressures, and other forces. In addition I further broke down the categories of natural hazards into meteorological and geological.

Next, the structure for the output analysis was examined. According to the Pressure and Release framework the outputs consist of "disaster". In other words, what do social, economic and environmental systems look like after disasters strike; what character traits manifest? It became clear very quickly that this lack of attention to outputs was going to be problematic and would limit the effectiveness of the I-O analysis. Upon reflection, many of our theoretical frameworks emphasize inputs over outputs. Through this process I discovered that outputs were just as critical as inputs because they influenced the inputs; in other words, outputs often became the inputs for the next cycle. Having a clear understanding of the outputs was critical as it was observed they could enter a system at any entry point and influence how the whole network functioned.

In spite of this setback or weakness, it was discovered that the I-O analysis served as an excellent tracking system, so if changes or modifications need to be made the blueprint was available to easily see the foundation and avoid unnecessary duplication or replication of failed attempts. In addition, system wide interdependencies were more clearly represented and outputs and impacts were found to be more easily estimated. This I-O analysis matrix was successful in that it made clear the direction and criteria used for the selection of the key performance indicator and resulting risk ratios; it could all be linked back to the Input-Output Analysis.

4.2.2 Model Process Flowchart

The next activity in Stage 1 included taking the conceptualized design and creating a tangible model of the process to operationalize the Pressure and Release theoretical framework. Model development was accomplished through the development of (1) the process flowchart of the model design and (2) the design cycle audit checklist. The creation of the process flowchart which linked inputs and outputs with an action or process is presented below in Figure 4.1. Flowcharts are read from top to bottom and left to right. A simple symbol key is included at the bottom of the chart to give additional information such as start and end points, direction of information flow, decisions, and documents, as well as a sequential hierarchy of the overall process.

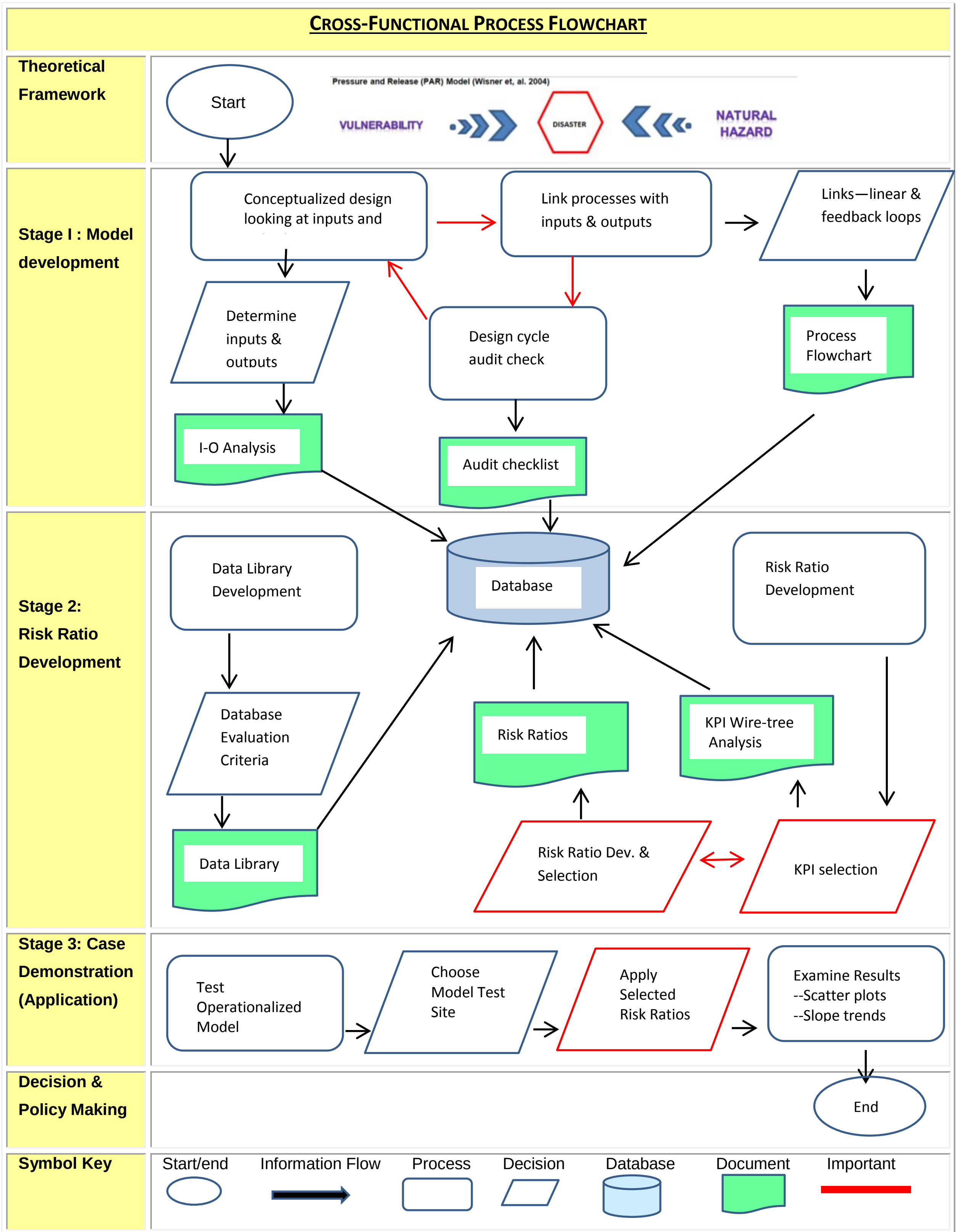


Figure 4.1 Model Development Flowchart—Operationalizing the PAR Framework Using Risk Ratio Methods (Created by J. Wilder)

Construction of the flowchart for this study was accomplished by taking the information from the input /output requirements matrix and linking it with information flow arrows, processes, decisions, and required databases. Standard flowcharting methods were employed including applying appropriate key symbols, using a cross functional, swim lane architecture, and information arrows flowing in a left to right and top to bottom configuration. A cross-functional flowchart is read from top to bottom according to swim lanes, and left to right. A swim lane is a visual element used in process flow diagrams to distinguish or demarcate units or sub-processes and can be arranged either horizontally or vertically. In addition there are simple symbols to indicate a process, a decision, the document, a database, and flow. Some elements are in red to highlight that they are important or distinguishing components of the flowchart. The steps in the process flowchart are as follows:

Swim Lane 1: Start

Select the theoretical framework to operationalize using risk ratio methods.

Swim Lane 2: Stage 1: Model Development

Examine the theoretical framework for inputs and outputs using a structured I-O Analysis then link these with processes using a flowchart diagram. Evaluate the system using a design cycle audit checklist. This part of the flowchart requires 2 decision-making units along with their corresponding document outputs. In addition there was an important feedback loop between the selection of inputs/outputs, linking them with processes, and auditing the process. One reinforces the other, if you error in one you will create distortions in the others. In addition, there were process flowchart will be stored in the database found in the next swim lane.

Swim Lane 3: Stage 2: Risk Ratio development

This swim lane described the risk ratio development process. A data library was developed first and the results were stored in the database.   Next was the risk ratio development which involved selecting key performance indicators and creating risk ratios from them. Both are highlighted in red because they are important decision-making processes, careful attention to detail is required. Also each feeds into the other. Both output documents are fed into the database. The database is important because all of the necessary elements needed to test and calibrate this model are readily available; the researcher does not have to re-construct the framework again.

Swim Lane 4: Stage 3: Case demonstration

The next step is to drop down to the 4th swim Lane which is the case demonstration in this study or it could be model testing in future studies. The risk ratios were applied to a specific location and the results were analyzed using graphs and slope trends. The decision box labeled “Apply risk ratios” is highlighted in red because of its importance. This step differs from all other attempts to operationalize the Pressure and Release Model because it allows the user to choose and create their own ratios that reflect the conditions of their particular circumstances and location.

Swim Lane 5: Decision and policy making

The final swim lane leads to better decision and policy making. By examining the data from the risk ratios, the user determines whether risk is escalating or not. If risk is found to be escalating to a satisfactory degree, mitigation efforts need to be initiated.

Several important findings were made during this process. First of all, initial flowcharting is very time-consuming, that is probably why researchers don't complete this phase or the I-O Analysis. However it was found to be critical in analyzing, designing, and documenting the entire network. Viewing the system holistic gave a very different perspective than the piecemeal understanding I had at the beginning (although I thought I understood the PAR framework exceptionally well). In addition it was found that running through the process flowchart forward (start to end) and backwards (end to start) revealed important relationships that were not initially apparent; a number of glaring errors and omissions were discovered. Several other discoveries included the realization that flowcharts could be used to analyze for defects and debug more effectively, and they allowed for effective documentation and recording of the system so that changes or modifications that needed to be done later could be easily accomplished. In addition, even though this was a very time-consuming process, once the flowchart has been established it never has to be done again.

To ensure that all necessary elements were included in the flowchart, a design cycle audit checklist was completed. An audit checklist is a tool used to collect evidence to permit an informed judgment and ensure consistent results and proper documentation and provide structure and continuity. This was carefully planned out to incorporate safety precautions and verification into the checklist. Several unique elements of this audit checklist include a tracking mechanism to determine if steps were completed and a cross-check protocol to reinforce each critical element. Cross-check principle allows for multiple confirmations. Below, in Figure 4.3, is the completed design cycle audit checklist divided into four major categories and 5 specific audit elements.

Table 4.3 Design Cycle Audit Checklist (Created by J. Wilder)

DESIGN CYCLE AUDIT CHECKLIST				
Requirements		**Was the step completed successfully? If not—why?**		
		Yes	**No**	**Remarks**
A. INPUT/OUTPUT ANALYSIS and FLOW CHART DESIGN				
1	Inputs and Outputs from theoretical model were itemized	✓		
2	Flowchart components/processes were identified	✓		
3	Review the processes both forward and backward	✓		Cross checked with #2
4	Flow chart complete and comprehensive	✓		Cross checked with #1, 2, 3
5	Test-retest for reliability—same results/conclusions	✓		Walk-through—one step analysis
B. KEY PERFORMANCE INDICATOR (KPI) SELECTION				
6	Data library criteria met for selection checklist	✓		
7	Input criteria for KPI identified and analyzed	✓		
8	KPI wire tree analysis complete and comprehensive	✓		Cross checked with #7 and #1
9	Review the analysis both forward and backward	✓		Cross checked with #8
10	Test-retest for reliability—same results/conclusions	✓		Walk-through—one step analysis
C. RISK RATIO DEVELOPMENT AND SELECTION				
11	Risk ratio inputs and outputs were itemized	✓		
12	Risk ratio artificial data trials complete	✓		Cross checked with #8
13	Review the analysis both forward and backward	✓		Cross checked with #11
14	Risk ratio analysis and data complete and comprehensive	✓		Cross checked with #11 and 12
15	Test-retest for reliability—same results/conclusions	✓		Walk-through—one step analysis
D. APPLICATION—ANALYSIS OF THE CASE DEMONSTRATION				
16	Case study selection process complete	✓		
17	Risk ratios applied and data collected	✓		
18	Review the process and results both forward and backward	✓		Cross checked with #2, 11, 12
19	Data analysis complete and comprehensive	✓		Cross checked with #17
20	Test-retest for reliability—same results/conclusions	✓		Walk-through—one step analysis

All elements must be addressed in order for the flowchart to be considered complete. Benefits of this type of tracking are that (1) critical elements are identified before-hand, (2) they can be checked in different time periods without forgetting one, and (3) different people can be using the same model with the same level of confidence.

At this point we are not running data through the model, only looking at processes and their relationships to make sure that the foundation is complete and sound; everything is included that should be there. Of the 20 elements most of them are cross checked or referenced with a previous element to ensure consistency and reliability. Several findings are of special note: (1) like the flowchart development, the checklist development was also extremely time-consuming and meticulous attention to detail was required, however these steps only need to be done once; (2) in complex systems the checklist proved to be invaluable, it ensured consistency and completeness as well as provided transparency; and finally (3) it was found that designing the audit checklist to be as generic as possible but with maximum effectiveness, it could possibly be used with any conceptual framework that one would want to operationalize.

4.4 Summary and Discussion

The following provides a summary of the results of Stage I: Model Development of the study.

1. Activity 1: Conceptual Design results showed that the Pressure and Release theoretical framework could be evaluated using an Input-Output Analysis.

2. Activity 2: Model Development results demonstrated that the Pressure and Release theoretical framework could be conceptually operationalized using process flow charting and verified using a design cycle audit checklist.

3. Using carefully designed structured tools (flowcharts, matrix, and audit checklists) are very important when working in complex systems. They highlight issues that might not otherwise be detected and acts as safeguards for transparency and tracking.

4. One weakness of the process was the I-O analysis: the PAR theoretical framework emphasized inputs over outputs which left the I-O analysis asymmetric. Since outputs often become inputs for the next cycle, this could affect the system and resulting decisions made from it.

5. A valid counterargument is that there is some subjectivity in the selection of inputs/outputs and flowcharting process allowing bias to enter the system. We see what we want to see or are capable of seeing and this is reflected in the model as distortions. However, despite these issues, it should be remembered that models do not have to be perfect; they just have to be useful.

6. Using structured decision-making process could have significant implications in operationalizing natural hazards theoretical frameworks by providing a robust standardization protocol. Providing a reliable foundation with strong verification components, transparency, and a holistic view of the system could be invaluable in incremental research efforts.

CHAPTER FIVE:

RESULTS OF RISK RATIO DEVELOPMENT

5.1 Introduction

This chapter presents results of the risk ratio development process. Stage 2: Risk Ratio Development integrated the model design with the risk ratios to detect changing levels in vulnerability and ultimately risk to natural hazards. First, a data library was developed along with key performance indicator selection used to construct the risk ratios. The outputs were analyzed using a criteria checklist, wire tree analysis, and artificial test data. Below, in Table 5.1, is a summary of the study design process and Chapter 5 activities and deliverables. The study was broken down into 3 stages each with a specific goal. The results of each task and deliverable of Stage 2 will be discussed and analyzed in this chapter.

Table 5.1 Study Activity and Deliverables Summary (Created by J. Wilder)

Study Activity and Deliverables Summary			
Part	**Activity**	**Deliverables**	**Results**
STAGE 1: Model Development	1. Conceptual design	□ Process Input/output (I-O) Analysis	Ch. 4
	2. Model development	□ Process Flowchart of Model Design	
		□ Design Cycle Audit Checklist	
STAGE 2: Risk Ratio Development	1. Data Library dev.	□ Data Library Criteria Checklist	Ch. 5
	2. KPI generation	□ KPI Evaluation using Wire Tree Analysis	
	3. Risk Ratio dev.	□ Risk Ratio Selection Analysis	
STAGE 3: Case Demonstration	1. Project Selection	□ Project Selection Criteria Checklist	Ch. 6
	2. Case Scenario Application	□ Risk Ratio Data Sheet Results	
		□ Graphical Data and Slope Analysis	

5.2 Results: Risk Ratio Development

Stage 2 of the study developed risk ratios from key performance indicators based on the Input-output analysis and flowchart developed in Stage 1. Similar to Stage 1, this stage also used a structure decision-making protocol, carefully evaluating individual components. This structured assessment was accomplished by defining the problem, examining the alternatives, linking them with objectives and choosing the optimal outcome. This process involved three target actions: (1) data library evaluation and construction, (2) key performance indicator-KPI generation, and (3) risk ratio development using artificial test data to determine risk ratio behavior in relation to increasing vulnerability. Deliverables developed for this stage included a data library criteria checklist, KPI evaluation wire tree analysis, and risk ratio selection analysis data sheet.

5.2.1 Data Library

A Data Library Selection checklist was created to evaluate the quality of online databases that could be used for natural hazards key performance indicators used to detect vulnerability and risk and other disaster related information. To ensure that the web database was reliable, up-to-date, and unbiased the following six criteria were used evaluate the entries in the data library for quality and reliability. These protocols are common for web content evaluations including websites, databases, and web documents (Dalhousie University, 2017).

1. Authority: the author/database manager is clearly stated along with contact information and credentials.

2. Purpose: the purpose of the database is clearly stated along with information on how the database is constructed and populated.

3. Coverage: the coverage is comprehensive with reputable outside links provided to verify and compare information.

4. Currency: all information and links are current; a schedule of site creation, maintenance, and regular updates should be clearly posted.

5. Objectivity: the website is clearly presented and objective with a minimum of bias; there should be no persuasive language or conflicting advertising.

6. Accuracy: reliability—the database is associated with a respectable institution, are there proper literature citations and references?

Five out of six criteria must have been satisfactorily met in order for the database to be included in the Data Library Selection Checklist. A minimum of 20 sources were evaluated and selected for both the national level and local/regional levels. Web databases where chosen for their statistical data on natural hazards, environmental, and socioeconomic indicators as well as access to GIS shapefiles. Below, in Tables 5.2 and 5.3, are the final selected database sources with their name and web address both at the national and local levels.

Table 5.2 National Database Sources (Created by J. Wilder)

Data Library Selection Checklist--National Sources			
Name		**Web Address**	**Meets 5 out of 6 Criteria**
1	Federal Emergency Management Administration (FEMA)	www.fema.gov	✓
2	National Oceanographic and Atmospheric Administration (NOAA)	www.noaa.gov	✓
3	U.S Geological Survey (USGS)	www.usgs.gov	✓
4	Socioeconomic Data	https://catalog.data.gov/dataset?tags=socioeconomic	✓
5	U.S. Dept. of Health and Human Services	www.hhs.gov	✓

	Name	Web Address	Meets 5 out of 6 Criteria
6	U.S. Forest Service	www.fs.fed.us	✓
7	CDC—Center for Disease Control	http://www.cdc.gov/datastatistics/	✓
8	Department of Transportation (DOT)	hazmat.dot.gov	✓
9	Environmental Protection Agency (EPA)	www.epa.gov	✓
10	National Drought Mitigation Center	drought.unl.edu	✓
11	National Fire Protection Association	www.nfpa.org	✓
12	U.S. Nuclear Regulatory Commission	www.nrc.gov	✓
13	NASA Earth Data	http://gcmd.gsfc.nasa.gov/search/Titles.do?search=#titles http://gcmd.gsfc.nasa.gov/add/portals.html	✓
14	EM-DAT	www.emdat.be/database	✓
15	National Bureau of Economic Research	nber.org.	✓
16	Ready America:	http://www.ready.gov/	✓
17	USA.gov: Disasters and Emergencies	https://www.usa.gov/disasters-and-emergencies	✓
18	NOAA National Center for Environmental Information	http://www.ngdc.noaa.gov/ngdcinfo/onlineaccess.html	✓
19	RealityTrac 2015 U.S. Natural Disaster Housing Risk Report	http://www.realtytrac.com/news/data-lab/	✓
20	NOAA Natural Hazards—National Centers for Environmental Information: formally the National Geophysical Data Center (NGDC):	https://www.ngdc.noaa.gov/ http://maps.ngdc.noaa.gov/viewers/hazards/	✓
21	FEMA—Federal Emergency Management Agency:	https://www.fema.gov/ https://www.fema.gov/national-disaster-recovery-framework/community-recovery-management-toolkit	✓
22	National Disaster Recovery Framework (NDRF):	https://www.fema.gov/pdf/recoveryframework/ndrf.pdf https://www.fema.gov/community-resilience-indicators	✓
23	Presidential Disaster Declarations and Disaster Assistance	DisasterAssistance.gov	✓
24	NOAA National Hurricane Center	http://www.nhc.noaa.gov/	✓
25	Economic Research—FRED Economic data	https://research.stlouisfed.org/fred2/categories/32263	✓
26	USAID Development Data Library (DDL)	https://www.usaid.gov/data	✓
27	NOAA Natural Hazards Data	https://www.ngdc.noaa.gov/hazard/	✓
28	Prevention Web Disaster Risk Datasets	http://www.preventionweb.net/risk/datasets	✓
29	US Census Bureau	http://www.census.gov/data.html	✓
30	US Census Bureau—International Database	https://www.census.gov/population/international/data/idb/informationGateway.php	✓
31	Centre for Research on the Epidemiology of Disasters (CRED)	http://www.cred.be/	✓
32	CE DAT—Complex Emergency Database	http://cedat.be/	✓
33	Historical Natural Hazards Database: USGS & NOAA ArcGIS	https://www.arcgis.com/home/item.html?id=c0f434fcc25343c79db610a5bdc7ac77	✓
34	Data.gov—Disasters	https://www.data.gov/disasters/	✓
35	Natural Hazards Center—Disaster Statistics Databases	http://www.colorado.edu/hazards/resources/web/statistics.html	✓
36	USGS Natural Hazards	http://www.usgs.gov/natural_hazards/	✓
37	UNISDR Disaster Statistics	https://www.unisdr.org/we/inform/disaster-statistics	✓
38	Spatial Hazard Events and Losses Database--SHELDUS	hvri.geog.sc.edu/SHELDUS/	✓
39	Natural Catastrophes Our World in Data	https://ourworldindata.org/natural-catastrophes/	✓
40	GIS Shapefiles and Datasets	https://freegisdata.rtwilson.com/	✓

Table 5.3 Regional and Local Database Resources (Created by J. Wilder)

Data Library Selection Checklist--Local and Regional Sources			
Name		**Web Address**	**Meets 5 out of 6 Criteria**
1	Florida Disaster—FL Division of Emergency Management	http://www.floridadisaster.org/index.asp	✓
2	Florida Division of Emergency Management:	www.FloridaDisaster.org	✓
3	Florida Agency for Persons with Disabilities	http://apd.myflorida.com/disaster/	✓
4	Shelter Status - State of Florida, Current Shelters	http://floridanss.comunityos.org/csm/openshelters	✓
5	Florida Chapter of the Red Cross:	http://www.redcross.org/where/chapts.asp#FL	✓
6	Florida Health Departments by County:	http://www.doh.state.fl.us/chdsitelist.htm	✓
7	Florida Emergency Management Local Offices by County	http://www.floridadisaster.org/fl.county.em.asp	✓
8	Florida General Population Shelters by County:	http:://floridadisaster.org/shelters/	✓
9	Tampa Bay Regional Planning Council	http://tampabaydisaster.org/Statewide Regional Evacuation Study (SRES) for the Tampa Bay region (2010)	✓
10	Tampa Bay Regional Planning Council: The 2016 Tampa Bay Disaster Planning Guide	http://www.tampabayprepares.org/	✓
11	Project Phoenix:The Tampa Bay Catastrophic Plan	http://www.tbrpc.org/tampabaycatplan/scenario.shtml	✓
12	City of Tampa, FL Emergency Management	http://www.tampagov.net/emergency-management/info/tampa-hazards	✓
13	City of Tampa's Local Mitigation Strategy (LMS)	http://www.hillsboroughcounty.org/en/residents/public-safety/emergency-management/local-mitigation-strategy	✓
14	Tampa Office of Emergency Management	Citizens Guide to Natural Disasters https://tampa.maps.arcgis.com/apps/MapSeries/index.html?appid=df0f2aec513648cdb6a58afb8da6f6a	✓
15	BEBR Bureau of Economic and Business Research	https://www.bebr.ufl.edu/	✓
16	FL Fish and Wildlife Conservation Commission Socioeconomic data	http://geodata.myfwc.com/datasets/c876d50d2cb94fea89371383f6ef93e3_22	✓
17	FL Bureau of Labor Statistics—US Dept. of Labor	https://www.bls.gov/eag/eag.fl.htm	✓
18	FL Division of Forestry	fl-dof.com	✓
19	New England States Emergency Consortium	www.nesec.org	✓
20	North Carolina Emergency Management Agency	www.dem.dcc.state.nc.us	✓
21	Oklahoma Mesonetwork	www.mesonet.ou.edu	✓
22	Univ. of Illinois Dept. of Atmospheric Science	www. atmos.uiuc.edu	✓
23	FL Geographic Data Library	fgdl.org; https://www.fgdl.org/download/	✓
24	Florida Department of Environmental Protection Geospatial Open Data	http://geodata.dep.state.fl.us/	✓
25	Florida Geographic Data Library Data Source Links	https://www.geoplan.ufl.edu/fgdl_source_links.htm	✓
26	EDR-Office of Economic and Demographic Research	http://edr.state.fl.us/Content/	✓

Findings from this portion of the study revealed that while there are many databases available online, not all of them have the same quality, some of them are quite poor and misrepresentative, few are regulated or have any oversight, and even fewer are properly secured. The function of the data library or data repository in this study is to support the creation of risk ratios by providing reliable resources that can quickly be accessed for key performance indicator data. A well-developed data library is critical for this analysis technique to function; otherwise it has minimal utility value for emergency managers.

Locating reliable databases with appropriate data was more challenging than expected. It was discovered that some databases with the same category headings contained very different data definitions and were essentially not comparable. For example, if an emergency manager wants to analyze ratios between similar years, it is critical that the data be comparable which means data needs to be collected from the same database and evaluated periodically to make sure that the data-collection procedures have remain consistent. Many scholars using natural hazards models prefer to use U.S. Census data believing it to be of good quality. After analyzing this website and several other data repositories considered to be reputable; it was found that data collection and reporting protocols routinely have changed or been modified over the years. It was also apparent that the database is only as good as its database administrator. Qualities that are part of a good database are consistency, reliability, and relevance; these can and should be tested frequently using a structured protocol, however in reality, this is probably rarely done.

5.2.2 Key Performance Indicators

A key performance indicator (KPI) is often used in business as a metric to measure how well a business is meeting its goals. It is similar to a "vulnerability" indicator that is often referenced in the natural hazards literature. Sometimes the term "vulnerability" indicator is used for a trait such as "population growth" which may or may not contribute to vulnerability. Not all population increases trigger vulnerability. For this reason, I will be referring to a key performance indicator (KPI) as an indicator that is important or has a disproportional effect on or contribution to an event or circumstance. A wire tree (decision tree) analysis was the model of choice to help identify a strategy most likely to reach a goal. Important insights could be generated based on describing the situation choosing optimal alternatives and outcomes. It helps to determine the worse, best, and expected values of different scenarios and is often used with structured decision-making protocols. Its benefits also included transparency and it was a great organizational and tracking tool.

An individual wire tree analysis was completed for each of the 3 systems or categories; social (Table 5.4), economic (Table. 5.5), and environmental (Table 5.6). Each category was further divided into 4 subcategories each with 5 specific key performance indicators for a total of 20 key performance indicators for each category. The 60 KPIs evaluated for this study are presented in the tables below as well as their behavior in relation to vulnerability. Variables were selected in accordance with the I-O (input/output) Analysis Matrix of the PAR theoretical framework completed in Chapter 4. The inputs were dictated by the PAR model and outputs were the result of the analysis and are reflected in the KPI measures below.

Table 5.4 Wire Tree Analysis: Social Key Performance Indicators (Created by J. Wilder)

Category	Tactical goal	KPI Measure	KPI behavior with test data as vulnerability increases: KPI ↑	KPI ↓
SOCIAL	Social inclusion	people with a cell phone/computer		yes
		access to public transportation		yes
		# of community groups/online		yes
		# divorces	yes	
		# nonnative language speakers	yes	
	Health	# of ambulances and fire stations		yes
		health insurance coverage		yes
		drug addiction rates	yes	
		# hospital beds		yes
		mortality rates	yes	
	Education	high school dropout rate	yes	
		# technical colleges		yes
		job training programs		yes
		college enrollment		yes
		youth incarceration rates	yes	
	Social structure	# of charities/community org.		yes
		# of minorities	yes	
		# of religious institutions		yes
		homeless population	yes	
		pop. distribution: age, ethnicity	yes	

Development of social key performance indicators included several important tactical goals: social inclusion, health, education, and social structure and were taken from the I-O Analysis performed in Chapter 4. Each tactical goal was supported by five key performance indicators that represented the measurement of the goal. In addition, there was a column that gave information on how the key performance indicator behaved with test data as vulnerability increased.

Table 5.5 Wire Tree Analysis: Economic Key Performance Indicators (Created by J. Wilder)

Category	Tactical goal	KPI Measure	KPI behavior with test data as vulnerability increases: KPI ↑	KPI ↓
ECONOMIC	Income	# people below poverty	yes	
		job growth rate		yes
		average household income		yes
		weekly jobless claims/unemployment	yes	
		# of new homeowners		yes
	Productivity	# new businesses		yes
		# skilled jobs added		yes
		GDP		yes
		sales tax collected		yes
		economic expansion--		yes
	Debt	# of bankruptcies	yes	
		# of credit card/mortgage holders		yes
		house foreclosures	yes	
		auto repossessions	yes	
		% savings deposits		yes
	Standard of living	# restaurants		yes
		median house value/new residential sales		yes
		# banks and interest rate		yes
		social/income disparity	yes	
		disposable income		yes

Development of economic key performance indicators included several important tactical goals: income, productivity, debt, and standard of living and were taken from the I-O Analysis performed in Chapter 4. Each tactical goal was supported by five key performance indicators that represented the measurement of the goal. In addition, there was a column that gave information on how the key performance indicator behaved with test data as vulnerability increased.

Table 5.6 Wire Tree Analysis: Key Performance Indicators: Environment/Natural Hazard (Created by J. Wilder)

Category	**Tactical goal**	**KPI Measure**	Vulnerability behavior with test data	
			KPI ↑	KPI ↓
ENVIRON-MENTAL	Natural Hazards--physical dimensions	low elevation		yes
		regular occurrence: hurricane “season”	yes	
		# of types of natural hazards	yes	
		# of natural hazards and severity	yes	
		climate: temps and moisture	yes	
	Ecosystem health	habitat diversity		yes
		threatened and endangered species	yes	
		population pressures—urbanization	yes	
		sensitive habitats: coral reefs, wetlands, coastal	yes	
		# collapsed /damaged ecosystems	yes	
	Physical exposure	building codes		yes
		# shelters, capacity, funding		yes
		# people living in flood zones…	yes	
		evacuation plans and transportation		yes
		# elderly, sick, poverty, young	yes	
	Disaster services	communications network		yes
		budgeted disaster reserve funds		yes
		state/federal emergency operations		yes
		NGOs—Red Cross…community groups		yes
		adequate security and assistance		yes

Development of the environmental key performance indicators included several important tactical goals: natural hazards, ecosystem health, exposure, and disaster services and were taken from the I-O Analysis performed in Chapter 4. Each tactical goal was supported by five key performance indicators that represented the measurement of the goal. In addition, there was a column that gave information on how the key performance indicator behaved with test data as vulnerability increased.

Complex processes require a structured decision-making architecture. The selection process of key performance indicators to detect vulnerability to natural hazards and disasters was based on a carefully structured decision-making platform and includes the following ten steps:

EVALUATE STUDY SETTING

(1) Define the goals
(2) Determine the scope/scale
(3) Identify the target group
(4) Establish the purpose for which the indicators will be used

SET INDICATOR CRITERIA

(5) Set indicator framework selection
(6) Define selection criteria--soundness, comparability, reproducibility…
(7) Identify “key” or most influential indicators

WIRE TREE ANALYSIS

(8) Identify potential indicators using a wire tree categories and goals
(9) Assess indicator behavior and performance using artificial test data.
(10) Deselect ineffective indicators and re-evaluate as necessary

Verifiability and validity were purposely built into the wire tree analysis. The system was too complex to leave it to chance. Verifiability was established using a test-retest protocol and validity was established by using artificial data to determine how the key performance indicators performed in relation to vulnerability. However, it was recognized that the key performance indicators eventually need to be validated against real-world data, which can be challenging due to the difficulties in quantifying some of the intangible aspects of vulnerability.

Findings from this process indicated that ideally, each subcategory should be represented so that the key performance indicator is represented holistically. I have noticed in the scholarly literature that researchers have a tendency to pull key performance indicators from categories that they are familiar with, not realizing that they are possibly skewing their results. The wire tree analysis that was created addressed this issue by requiring subcategories to be developed.

Another advantage of the wire tree analysis approach was that it required key performance indicators be tested with artificial data to view their behavior in relation to vulnerability. As vulnerability increases, we need to know whether the chosen key performance increases or decreases. This was found to be a critical step in creating the risk ratios and the resulting slope analysis. It also helped to focus the key performance indicator to a measurable outcome. Often in the literature when trying to identify key performance indicators or vulnerability indicators, they are articulated too generally to assign a measurable metric. Finally, while we present key performance indicators as being discreet individual representations, in reality they probably overlap quite a bit. Some of the environmental indicators such as hazards exposure and disaster services could be thought of in terms of social indicators as well.

5.2.3 Risk Ratio Development

The final step of the risk ratio process was the Risk Ratio Selection Analysis to develop and select the risk ratios used to detect changes in vulnerability and hazards risk. The goal of the Risk Ratio Data Test Sheet was to track a considerable amount of information in the creation of the risk ratios in order to assure reliability and repeatability. This document made sure that a variety of ratios were created spanning several KPI subcategories. This is a process can be used by anyone to create their own risk ratios. The risk ratio development process results are presented in Table 5.7 below.

Table 5.7 Risk Ratio Data Test Sheet (Created by J. Wilder)

Category	KPI Subcategory	Name	Risk Ratio	Ratio behavior: as vulnerability ↑	Type of Ratio			
					Proportion or %	Rate	Density	General
SOCIAL	Social inclusion	Homeless or displaced persons	$\frac{\#\ homelss\ meals\ served}{month}$	Ratio ↑		x		
	Health	Comparing physicians to facilities	$\frac{\#\ of\ physicians}{\#\ hosptials\ and\ clinics}$	Ratio ↓				x
	Education	Graduation rate %	$\frac{\#\ high\ school\ graduates}{total\ \#\ of\ students}$	Ratio ↓	x			
	Social structure	Support structures	$\frac{\#\ religious\ inst.}{square\ mile}$	Ratio ↓			x	
ECONOMIC	Income	Poverty	$\frac{\#\ people\ below\ poverty}{total\ population}$	Ratio ↑	x			
	Productivity	Business/job growth	$\frac{\#\ new\ businesses}{month}$	Ratio ↓		x		
	Debt	Financial stability	$\frac{\#\ home\ foreclosures}{\#\ homeowners}$	Ratio ↑				x
	Standard of living	Luxury activities	$\frac{\#\ restaurants}{squre\ mile}$	Ratio ↓			x	
ENVIRON-MENTAL	Natural Hazard	Frequency of flood events	$\frac{\#\ flood\ events}{each\ year}$	Ratio ↑		x		
	Ecosystem health	Ecosystem sensitivity	$\frac{\#\ threatened\ FL\ species}{total\ \#\ of\ FL\ species}$	Ratio ↑	x			
	N.H. Exposure	Flood zone density	$\frac{\#\ people\ living\ in\ flood\ zones}{square\ miles\ of\ flood\ zones}$	Ratio ↑			x	
	Disaster services	EM support structure	$\frac{\#\ disaster\ agencies}{disaster\ budget}$	Ratio ↓				x

The table was purposely crafted to organize and track critical information concerning each risk ratio. Each system or category (social, economic, and environment) is supported by four key performance indicators subcategories each with the risk ratio that was developed using the key performance indicator wire tree analysis. Selection criteria for the risk ratios are reflective and dependent upon the KPIs that were generated previously using the wire tree analysis. In addition, each risk ratio is categorized according to type and how it behaves in relationship to escalating vulnerability.

A number of failsafe protections were purposely built in to the development process. For example, by tracking KPI subcategories, ratio behavior, and ratio type a number of biases and errors can be flagged and eliminated before they manifest. There is a tendency to choose things we are familiar with, however measuring the same elements is not going to give you an accurate picture of the vulnerability and risk of the system as a whole. Completing each element in the table above helps to mitigate this. The importance of choosing a variety of key performance indicators subcategories has been discussed above. In addition each subcategory was measured using a different type of ratio. A ratio is a quantitative relation between 2 amounts and explains relationships. When creating ratios we want to observe how the “x” variable or numerator changes in respect to the “y” variable or denominator. Some examples of common ratios include proportions/ percentages, rate, and density. The following categories listed below were used as general guidelines to craft the vulnerability risk ratios.

(1) Proportions and percentages compare the part to the whole such as number of individuals/total population.

(2) Rates measure a temporal element such as miles/ hour or dollars/day.

(3) Density managers a spatial element such as number of people/square mile.

(4) General ratios are any combination of numerator and denominator such as GDP/ capita.

The table above forces the creator to represent each type of ratio for each subcategory of key performance indicator. That way it ensures a variety of ratio types are selected. Scholarly literature is heavily tilted towards using proportions or percentages; however ratios that have temporal and spatial components such as density and rate are extremely valuable too.

Finally, the risk ratio must be analyzed by watching how it behaves as vulnerability increases. This is done by using artificial test scenarios. If you cannot tell how the ratio behaves and cannot answer this question clearly, then your ratio is too ambiguous or complex and needs to be simplified by choosing different key performance indicators until it is clear whether the ratio increases or decreases with increasing vulnerability. One of the key findings in this research, and after much testing and retesting, found that it is helpful to have the numerator value vary while the denominator stays is fairly stable or constant. For example, when measuring homeless or displaced persons a good proxy measure is to take a look at the number of homeless meals served per month. The actual number of meals served each month can vary quite a bit, but the time metric measured in months, is constant—30 days. When both the numerator and denominator are fluctuating it is very difficult to tell how the ratio is going to behave as vulnerability increases. The simpler one can keep this system the better. Crafting good risk ratios to detect vulnerability is an art form, however, with a few good heuristics it can be done by anyone.

5.3 Summary and Discussion

The following provides a summary of the results of Stage 2: Risk Ratio Development of the study.

1. Activity 1: Data Library Development results demonstrated that with a good set of evaluative criteria quality databases both at the federal and local levels could be identified. Now that we are in the age of Big Data, there are new databases coming online every day, however, models are only as good as the data you put into them. Databanks must be regularly and systematically monitored for quality.

2. Activity 2: KIP Generation results demonstrated how to evaluate and select key performance indicators to vulnerability using a structured decision-making process and wire tree analysis. Part of the problem with key performance indicator selection is that users tend to focus on and choose what they are familiar with so they select the same types of KPIs repeatedly. This often does not give a holistic representation. The KPI wire tree analysis forces recognition of diversification of tactical goals.

3. Activity 3: Risk Ratio Development findings showed that risks ratios could be developed using a structured decision-making process.   One important point to make about key performance indicators and risk ratios is that they tend to be lagging indicators; they tell us what happened after the event. Identifying leading indicators of risk could provide better results. Another challenge dealing with KPIs and risk ratios is

that data has a shelf-life; it is important to evaluate the quality of the data going in as well as the ratio itself. These checklists and wire tree tools must be concise, actionable, and up to date.

5. A valid counterargument is that nothing was actually tested with real data, so how do you know risk ratios measure what they're supposed to measure? One will never know the answer to this definitively until the risk ratios are tested under real-world conditions using regression analysis or some other statistical tool. During the development stage, the best one can do is to have (1) a highly structured decision-making protocol (2) with rigorous verification and (3) some testing using artificial data; all three of these were present this stage of the research project.

6. The implications for this stage of the research suggests that it may be possible to systematically select key performance indicators, evaluate them, and use them to construct risk ratios to measure vulnerability. The next stage in this study will be to demonstrate the use of the risk ratios and observe if they can predict risk from natural hazards.

CHAPTER SIX:

RESULTS OF THE CASE STUDY DEMONSTRATION

6.1 Introduction

This chapter will address the final stage of the research project, Stage 3: Case Demonstration and report the findings of the case project selection and study demonstration. Using the model design from Stage 1 and risk ratios developed in Stage 2; these elements were applied to a natural hazards case scenario from Tampa, FL metropolitan area to demonstrate how the risk ratios operated in detecting vulnerability over time. Below, in Table 6.1, is a summary of the study design process. The results of each task and deliverables of Stage 3 are presented and discussed in this chapter.

Table 6.1 Study Activity and Deliverables Summary (Created by J. Wilder)

Study Activity and Deliverables Summary			
Part	**Activity**	**Deliverables**	**Results**
STAGE 1: Model Development	1. Conceptual design	□ Process Input/output (I-O) Analysis	Ch. 4
	2. Model development	□ Process Flowchart of Model Design	
		□ Design Cycle Audit Checklist	
STAGE 2: Risk Ratio Development	1. Data Library dev.	□ Data Library Criteria Checklist	Ch. 5
	2. KPI generation	□ KPI Evaluation using Wire Tree Analysis	
	3. Risk Ratio dev.	□ Risk Ratio Selection Analysis	
STAGE 3: Case Demonstration	1. Project Selection	□ Project Selection Criteria Checklist	Ch. 6
	2. Case Scenario Application	□ Risk Ratio Data Sheet Results	
		□ Graphical Data and Slope Analysis	

6.2 Results: Case Study Demonstration

The results of Stage 3 of the study are presented and summarized in a structured-decision making process embodied in the (1) project selection criteria checklist, (2) risk ratio data sheet, and (3) graphical trend analysis and report. The purpose of the project selection criteria checklist was to identify a key timeframe in which the local government recognized a problem caused by a natural hazard. The risk ratio data sheet recorded and tracked the data and results and summarized the ratio performance using graphing techniques and slope analysis looking for trends of escalating vulnerability. The results of the project selection, case study demonstration, and model validation are presented in the following three sections.

6.2.1 LMS Project Selection

The results of the Local Mitigation Strategy (LMS) project selection criteria checklist are presented in Table 6.2 below organized by project number, name, description, hazard, location, TTC--time to complete, and the date the project was last updated. The table of LMS Critical Facilities Project list was created using data from the 2015 Hillsborough County Local Mitigation Strategy (LMS) project list. A significant number of local government flooding-hazards mitigation projects were clustered in the Tampa, FL metropolitan area in the year 2011. This was the year that was selected for the time-series analysis and included the 5 years previous or the timeframe between 2007 and 2011 to apply the risk ratios. The selection criteria for this decision is explained and discussed in the paragraph below.

Table 6.2 LMS Critical Facilities Project List (Created by J. Wilder using Hillsborough LMS 2015 data)

Proj. #	Name	Description	Hazard	Location	TTC	Up-dated	Proj. Used
123.4	Channel Improvement – Eastside Canal	Part of Eastside Canal master plan. Side slope stabilization. Storm water improvements	Flooding	Tampa Downtown	>12 mo.	9/15/09	
124.4	Reynolds Street to CSX Railroad Channel Improvements	Part of Eastside Canal master plan. Storm water improvements	Flooding	Plant City	>12 mo.	9/15/09	
125.4	Laura St. Culvert and Flood Improvements	Community development	Flooding	East of Hwy 75	>12 mo.	9/15/09	
286.4	Backup Generators for Shelters	Retrofit hurricane shelters listed in 2009 hurricane guide	Flooding	Tampa	>12 mo.	12/10/13	
346.4	Wind Mitigation Tampa General Hospital	Hardin trauma one hospital to withstand category 5 hurricane--Tampa Gen.	Flooding	Tampa Downtown	>12 mo.	12/10/13	
355.1	Big Bend Bridge Approach – 100270	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Apollo Beach	>12 mo.	6/01/11	
355.2	Dickman Road Bridge Approach – 104322	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Apollo Beach	>12 mo.	6/01/11	
355.3	Dickman Road Bridge Approach – 104323	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Apollo Beach	>12 mo.	6/01/11	
355.4	Port Sutton Bridge Approach – 104136	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Tampa	>12 mo.	6/01/11	✓
355.5	Port Sutton Bridge Approach – 104137	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Tampa	>12 mo.	6/01/11	✓
355.51	CR 587 – Westshore Bridge Approach – 105909	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Tampa	>12 mo.	6/01/11	✓
355.6	CR 587 – Westshore Bridge Approach 105911	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Tampa	>12 mo.	6/01/11	✓
355.7	2nd St., Northeast Bridge Approach 104317	Install approach slab to a critical bridge susceptible to flood damage	Flooding	St. Pete	>12 mo.	6/01/11	
355.8	36th Ave. Bridge Approach 104107	Install approach slab to a critical bridge susceptible to flood damage	Flooding	St. Pete	>12 mo.	6/01/11	
355.9	May Dell Drive Bridge Approach 104155	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Tampa	>12 mo.	6/01/11	✓
355.11	Pebble Beach Blvd. Bridge Approach 104316	Install approach slab to a critical bridge susceptible to flood damage	Flooding	Apollo Beach	>12 mo.	6/01/11	

The 2015 Hillsborough County Local Mitigation Strategy (LMS) project list was used to select a cluster of projects around a specific timeframe. The LMS is updated every 5 years and the Hillsborough County LMS in Process Project List maintains a list of potential mitigation initiatives (projects) to reduce risks associated with hazards that are likely to occur in Hillsborough County. The first LMS list was published in 2009. The LMS is ongoing process that continually assesses potential disasters and vulnerability to a variety of hazards, develops mitigation blueprints and measures, and provides preparedness to the entire community of Tampa and Hillsborough County. This list was obtained from the Hillsborough County Emergency Management office and is a part of the Comprehensive Emergency Management Plan (CEMP) and is guided by the Florida Division of Emergency Management (DEM) and the Federal Emergency Management Agency (FEMA).

The Hillsborough County LMS In Process Project List was used as a proxy to determine when the government thought that a risk from a natural hazard was high enough that something had to be done about it. The objective was to examine a number of vulnerability indicators before this point in time to see if these vulnerability indicators were escalating. The projects that make it onto this project list are prioritized according to those that demonstrate mitigation that minimizes the effects from an all-hazards catastrophic occurrence. Projects must be (1) warranted by the countywide vulnerability analysis, (2) impact an essential or critical service, (3) passes a cost-benefit analysis, (4) measure a long-term improvement, and (5) be consistent with goals and objectives of the Comprehensive Emergency Management Plan. The projects were classified according to the following objectives: (1) public education; (2) coordination; (3)

development management; and (4) critical facilities. The criteria that were chosen for the selection of the projects cluster was that the project had to be from the Critical Facilities list and the hazard to be mitigated had to be a “flooding” event. A flood event was chosen because it is chronically problematic for the Tampa area. A number of projects met this criteria particularly during the year 2011, the cutoff year chosen to test the risk ratios from 2007-2011.

6.2.2 Case Application

The risk ratios selected are presented in the risk ratio data sheet (Table 6.2) and statistical results (Table 6.3) below and include a total of 6 ratios, two from each of the following spheres of influence: social, economic, and environment. The slope results of the social performance ratio (1) Population Exposure, expected to increase with vulnerability, showed a mixed slope result--there was no consistent trend in the graph line; the second social performance ratio (2) Unemployment, expected to increase with vulnerability, showed a positive slope result and an increasing trend in the graph line. See Figures 6.2 and 6.3. The economic performance ratios (1) Average Income and (2) Productive Output, both expected to decrease with vulnerability, showed negative slope results and a decreasing trend in the graph line. See Figures 6.4 and 6.5. However, the environmental performance ratios of (1) Hurricane Season Impacts Measured as Cost and (2) Storm Frequency, both expected to increase with vulnerability, did not perform as expected. Hurricane Season Impacts Measured as Cost demonstrated a mixed slope result; there was no single trend in the slope of the graph line. Storm frequency risk ratio was expected to increase with vulnerability but actually decreased, the slope graph line was negative. See Figures 6.6 and 6.7.

Table 6.3 Risk Ratio Data Sheet Results (Created by J. Wilder)

Category	Description Measure	Risk Ratio	As Vulnerability ↑ the ratio	Slope Results
Social Performance Ratios	Population Exposure	$\frac{Population}{Mean\ Elevation}$	Increases	Mixed
	Unemployment	$\frac{\#\ Unemployed}{Population}$	Increases	Positive (+) Increases
Economic Performance Ratios	Average Income	$\frac{Income\ \$}{\#\ of\ Wage\ Earners}$	Decreases	Negative (-) Decreases
	Productive Output	$\frac{GDP\ of\ Tampa}{Capita}$	Decreases	Negative (-) Decreases
Environmental Performance Ratios	Hurricane Season Impacts Measured as Cost	$\frac{\$\ Cost\ of\ Hurricane\ Season}{year}$	Increases	Mixed
	Storm Frequency	$\frac{\#\ FL\ Storms}{\#\ of\ Atlantic\ Storms}$	Increases	Negative (-) Decreases

Table 6.4 Statistical Results: Mean, Median, Mode, and Slope (Created by J. Wilder)

Risk Ratio	Mean	Median	Range	Slope
Social				
#1 Population Exposure	7093.48	7085.58	248.65	Mixed
#2 Unemployment	8.02	9.4	7.4	Positive
Economic				
#1 Average Income	49295.2	48674	7084	Negative
#2 Productive Output	747.19	727.66	77.35	Negative
Environment				
#1 Hurricane Impacts by Cost	15.65	8.03	46.76	Mixed
#2 Storm Frequency	34.1	31.3	27	Negative

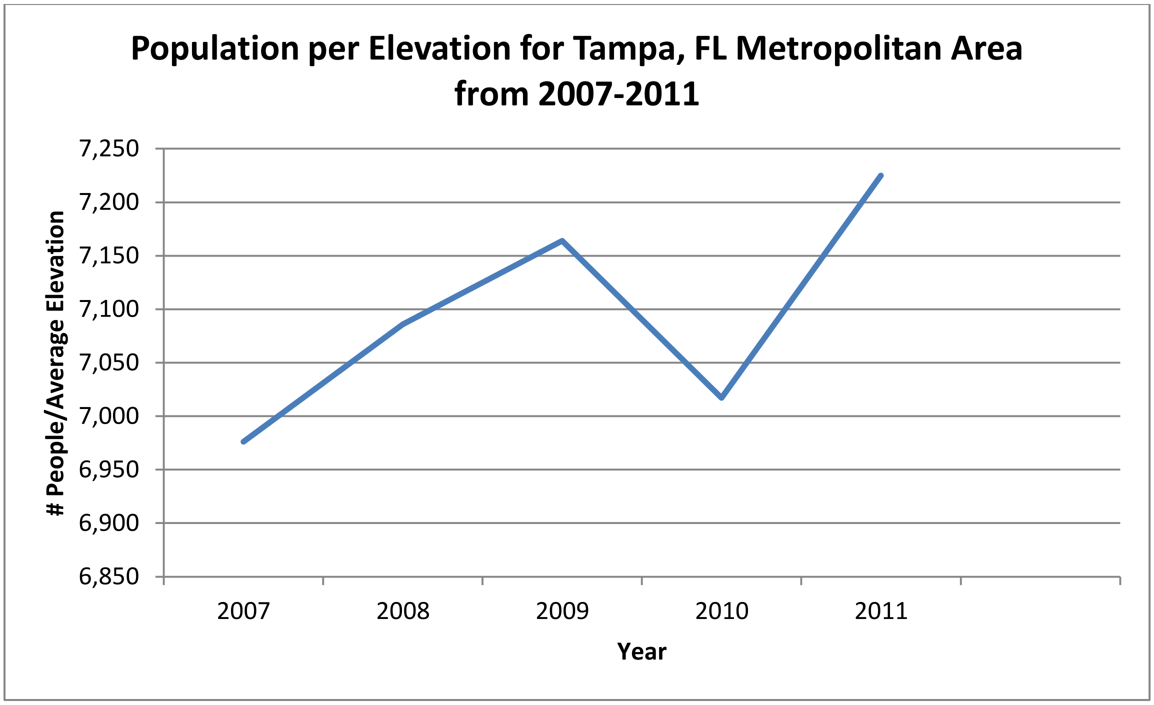


Figure 6.1 Social Risk Ratio Graph for Population Occupying Low Elevation (Created by J. Wilder)

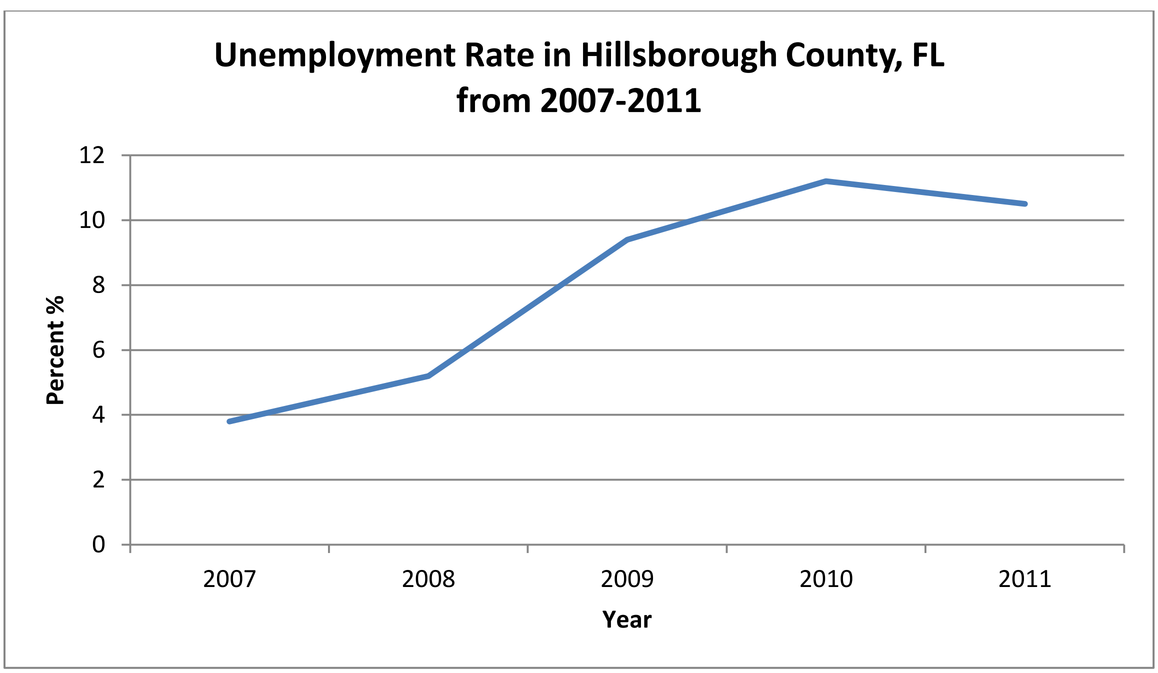


Figure 6.2 Social Risk Ratio Graph for Unemployment (Created by J. Wilder)

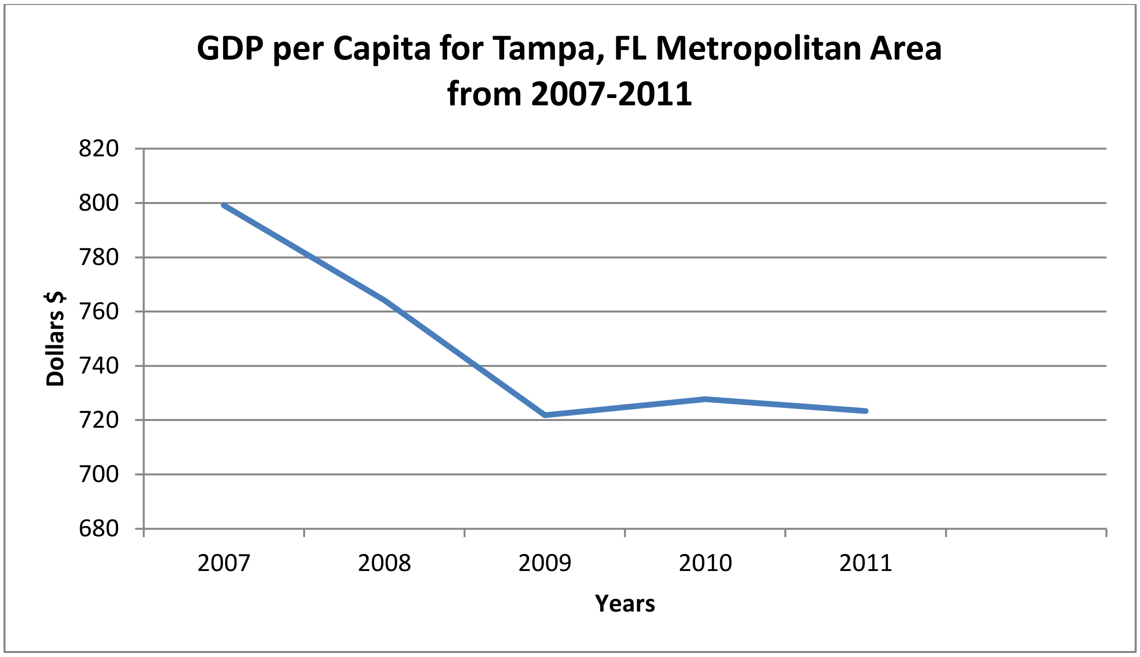


Figure 6.3 Economic Risk Ratio Graph for GDP/Capita (Created by J. Wilder)

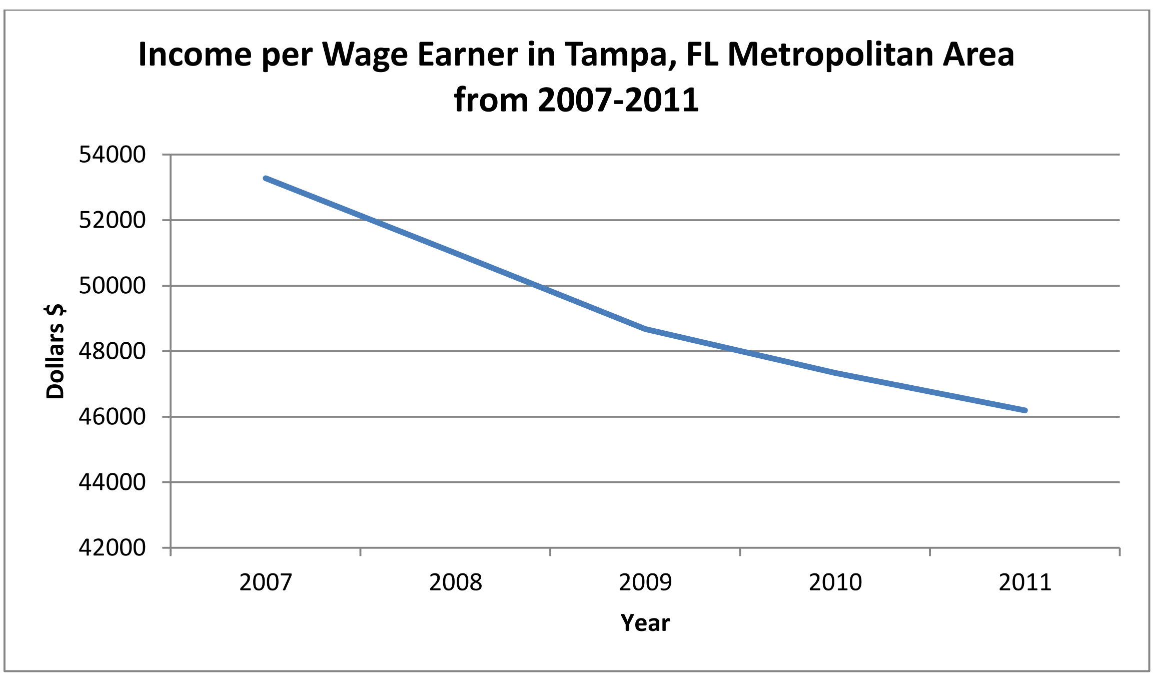


Figure 6.4 Economic Risk Ratio Graph for Average Income (Created by J. Wilder)

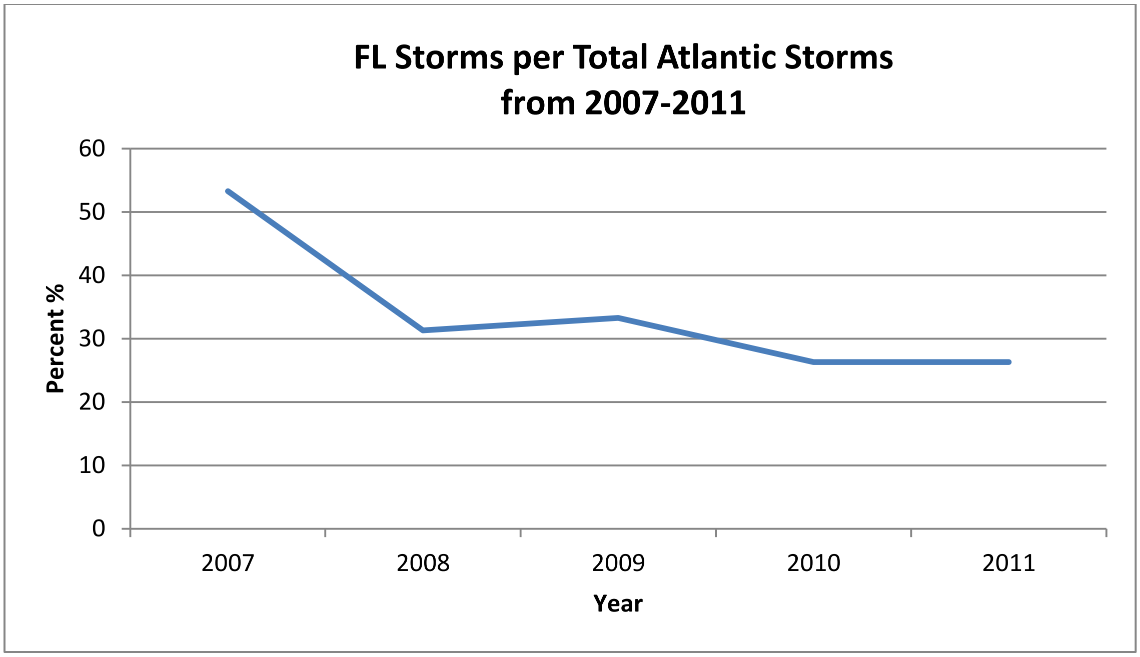


Figure 6.5 Environmental Risk Ratio Graph for Number of FL Storms per Total Atlantic Storms (Created by J. Wilder)

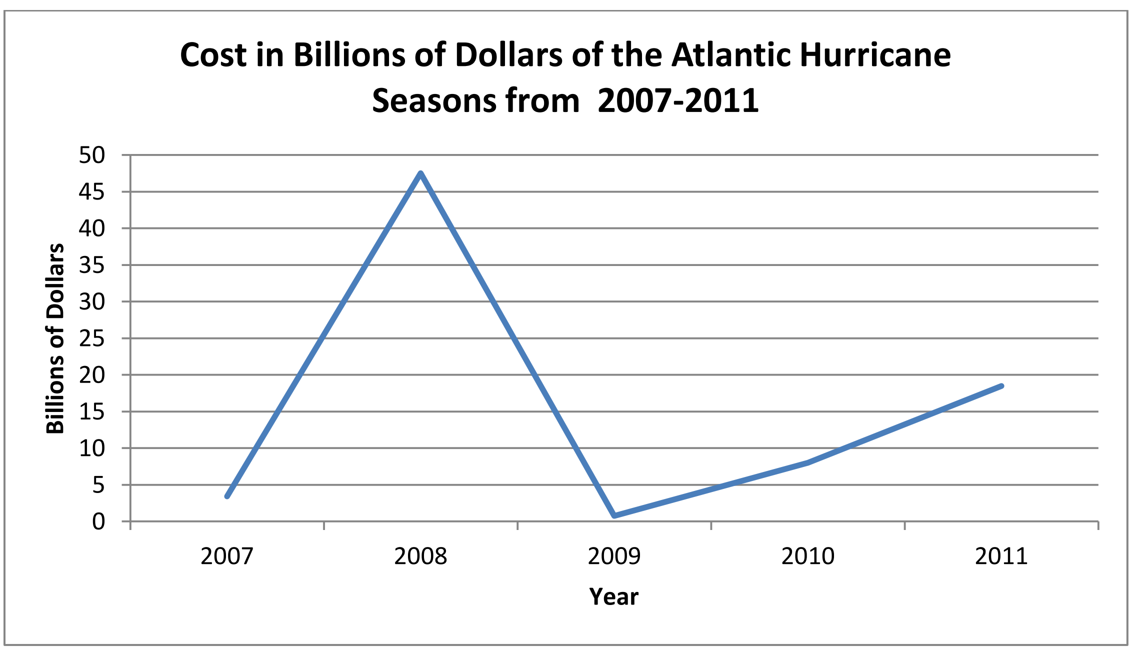


Figure 6.6 Environmental Risk Ratio Graph for Population/Elevation (Created by J. Wilder)

The overall performance of the risk ratios was fair. Three of the 6 risk ratios performed as expected in relation to vulnerability, particularly the economic ratios. This could be in part due to a relatively long history (60 years or more) of collecting detailed national and local economic data in a consistent manner. One of the more surprising results was the mixed slope results of the social indicator Population Exposure. There appeared to be a significant decrease in population between 2009 in 2010, this could be in part due to differences in measurements and estimates from previous years by local authorities as the 2010 population data figure is based on the National U.S. Census and considered to be very accurate but conservative. When measurements or estimates in data collection procedures are changed from one system to another, this can cause inconsistencies in data comparisons from one period to the next.

Another ratio that gave mixed slope results was Hurricane Season Impacts Measured as Cost. The estimate for the cost of the 2008 Atlantic hurricane season was exceptionally high, this was likely due to the unprecedented number of storms that led to one of the deadliest and most destructive hurricane seasons on record particularly with hurricane Ike which impacted the coast of Texas and was the 4th costly hurricane in the Atlantic. Natural hazards can be highly variable from year to year, and this can lead to problems with a time series slope analysis of short durations such as 5 years or less.

The other environmental indicator, Storm Frequency, measured by the percentage of Atlantic storms that also impacted Florida showed storm activity was expected to increase. The data trends for both the number of Florida storms and Atlantic storms for this time period showed that frequencies have slightly decreased over this 5 year period. A possible contribution to this outcome is that the El Niño

Southern Oscillation was active during this time (NOAA Climate Data, 2015). El Nino tends to suppress Atlantic hurricanes while La Nina fuels them, hence the slight decline in the number of Atlantic and Florida storms. It must be recognized that while we look at Florida specifically, it belongs and responds to global environmental climate patterns of the entire biosphere.

6.2.3 Model Reliability and Validation

Verification is the process to make sure that the model does what it intends to do. There are number of verification (debugging) techniques used in the design and development stages of this study including static analysis, test-retest, tracing, and a structured walk-through (one-step analysis) and were all used in the development and design stages. This study used an evaluation-by-design approach. Verification was built into the study design stage assessment procedures that are carefully embodied in the deliverables.

Static analysis in this study evaluated components and processes for static qualities such as complexity, flexibility, scope, resolution, sensitivity, distortion, consistency and should remain constant or very minimally over time. Static analysis was built into the process and was critical to the design stage of the study. Test-retest demonstrates that research findings are reliable and retest should be consistent over time. This feature was built into the design cycle audit checklist. Another verification method used was tracing; this is analyzing inputs and making sure the outputs are reasonable. Tracing was run forward and backwards through the system, similar to reverse engineering, in order to identify missing or erroneous components and correct them early in the process. Tracing was fundamental in both the model flowchart and wire tree analysis. The final verification technique was a structured walk-through or a one-step analysis where a final walk-through was undertaken of the individual components as a whole making sure that the system was complete and comprehensive. This was very critical in all stages of the study. Table 6.5 below identifies which of verification and validation techniques were used in each stage of the study.

Table 6.5 Verification and Validation of the Research Study (Created by J. Wilder)

	Verification				**Validation**	
	Static analysis	Test-retest	Tracing	Structured walk-through	Artificial data measurements	Real system measurements
Stage I—Model Design	x	x	x	x	x	
Stage 2—Risk Ratio Dev.	x	x	x	x	x	
Stage 3—Case Demonstration	x	x	x	x		x

Validation is demonstrating that the model is a reasonable representation of the actual system and is usually measured by (1) expert intuition, (2) real system measures, and/or (3) theoretical system measures. Stage I and 2 of the study used a theoretical measurement system for validation which employed artificial test data to run through the process is and checked for reasonableness in an informal manner. Stage 3 of the study attempted to use a real system measure for validity by employing a case demonstration.

In addition, a functional argument approach leading to a conclusion of verification and validity can be used in a representational process where successive steps operate on the output of preceding ones as is the case with this study. In this study, the utility and creation of the risk ratios were dependent upon the key performance indicator development process which was dependent upon the development of the data library which was dependent the model development output in the flowchart which was dependent upon the conceptualized design or input output matrix. Under these conditions, an IF-THEN argument can be used to establish holistic utility of the overall process.

> IF validity is satisfactorily established at the micro level (individual parts and processes);
> THEN verification and validity is likely present at the macro (holistic) level.

In this functional model approach, the evaluation process was embodied in the deliverables of various matrices, flowcharts, checklists, wire tree analysis which mirrors the structure of the design process and the validity of the overall product and validation was established using artificial testing data scenarios of real world events. I would argue that because verification and validation were systematically built in to the individual components and processes and evaluated in each step of the process and was dependent upon the development of the previous step, the overall model likely has the same attributes as well as well. From this assertion, the conclusion can be made that the resultant model (components and process) is likely sound and the outputs can be relied upon and benefits can be derived from the predictive use of model.

The verification counter argument could be that a process or model is more than merely the sum of its parts. By simply verifying the individual components or unit processes does not necessarily add verification robustness to the entire system. Verifying parts does not verify the whole because the whole behaves differently. In addition, there are two counter arguments to validity. The first validity counter argument could be that Stage I and Stage II of the study used theoretical or artificial measurement systems and not a real world scenario with robust statistical evaluation such as a regression analysis. Based on this argument, it cannot lend validity to the model as a whole. A second related counter argument to the models overall validity would be that this study did not subject the model to a real world test but merely conducted a demonstration using real data. I would have to agree to some extent on all 3 counterarguments-- a demonstration is not a robust test and just because subcomponents have characteristics doesn't necessarily always mean that the parent will to. However, establishing validity for models in theory is a lot easier than establishing full validity in practice. It is more likely that some situations can only achieve partial validity. I would also contend that the goal of this study was to see if it was even possible to operationalize the Pressure and Release model using risk ratio measurement methods. However the model built is deemed likely to be fit for the purpose for which it was intended. The underlying objective in assessing design is not to maximize validity, but to optimize it.

6.3 Summary and Discussion

The following provides a summary of the results of Stage 3: Case Demonstration of the study.

1. Activity 1: Project Selection results concluded that the year 2011 was a significant year in which the Hillsborough Local Mitigation Strategy committee and emergency management officials recognized a number of significant flood issues in Tampa, FL that needed to be addressed. This year was used as a benchmark to examine the 5 previous years for vulnerability escalation during the time period of 2007-2011.

2. Activity 2: Case Scenario Application results demonstrated that the risk ratios could be applied to a specific area and set of natural hazards conditions to test for escalating vulnerability by determining if the expected slope of the data set was the same as the actual slope. The results were fair with 3 of the 6 ratios performing as expected in relation to vulnerability over the 5 year time period.

3. Whether the risk ratios could detect escalating risk to natural hazards was inconclusive. More research is needed to make this determination although it looks very promising.

4. One of the main pinch points of this model is the data, particularly data resolution. It is a common problem that nearly everyone in this field attempting to operationalize natural hazards theoretical frameworks has—the data resolution is often not fine enough. Finding the right data at the right level is very time-consuming and often doesn't yield a good cost-benefit. Other data issues include small or insufficient sampling sizes, data is not mutually exclusive – they tend to overlap conceptually, and data are inconsistent and collected using different methods jeopardizing comparability. Models are only as good as the data you feed into them.

5. A valid concern of this study would be considering the impact of the size of the hazard as reflected in a number of dimensions including geographic size, intensity, and duration. Often in research studies we observe cause and effect of natural hazards in general, without taking into consideration their relative sizes. A larger and more intense natural hazard would be expected to have a greater impact on vulnerability and potentially increase risk; this could significantly impact empirical results. While this study did not compare relative sizes of natural hazards and their impacts on vulnerability, it

should be examined in greater detail as it could be a significant factor in future natural hazards vulnerability studies.

6. Another aspect of the study that should be examined is the duration of the time series. This study looked at data from a 5 year timeframe. It is possible that dealing with natural phenomena, that often run in cycles of decades or more, the time frame may need to be extended. In addition, many social and economic cycles also have cycles that extend from 5 to 30 years or more. When dealing with very large and complex social, economic, and environmental cycles, analyzing data from 10 or more consecutive years may yield better results.

7. While this study was confined to examining vulnerability as defined by the Pressure and Release Model which included (1) root causes, (2) dynamic pressures, (3) unsafe conditions it is possible that coping capacity, resilience, and sustainability also play important roles in determining vulnerability and risk. However, I would caution against the practice of “tacking on” or adding these components to already established theoretical frameworks. A model is holistic in nature and functions as a dynamic system. When one part of the model is changed it can affect the entire architecture in ways that are unforeseeable. Some well-intentioned changes or “improvements” can actually destroy the integrity of the model. Competent model developers take changes to their models very seriously and devote a good deal of time to comprehensive, change – based testing. It is my opinion, that the researcher should choose a different or more appropriate theoretical framework rather than tweak it to their specifications and needs.

8. A valid counterargument is that there is some subjectivity in the creation and selection of the risk ratios allowing bias to enter the system. I would submit that natural

hazards research takes place in very complex social, economic and environmental systems; there will always be some subjectivity and expert knowledge required. I would also argue that it is this subjectivity or the ability of the user to create and choose specific ratios that reflect their unique circumstances is what makes this approach valuable. However, there is clearly a tradeoff between flexibility and relative certainty of static systems.

9. While this study set out to see if it was even possible to operationalize the PAR theoretical framework and how to go about this task using the newly developed risk ratio measurement system, it still needs some adjustments to the risk ratios for them to be successful. Once this is completed, then testing could begin possibly using statistical measures such as a t-test, regression, and correlation analysis. And while it is inconclusive as to whether this risk ratio measurement system used to operationalize the PAR theoretical framework can predict risk to natural hazards by observing the behavior of key risk ratios and vulnerability, I can conclude that it is probable that this could be accomplished using the proceedures developed and presented in this dissertation.

10. The larger implications of this study suggests a need for a standardized operational protocol and broad-based application to transition from theoretical frameworks to operationalized models. It may be possible using the results from Stage I of this study to establish this by the use of an (1) input-output analysis, (2) process flowchart, and (3) audit checklist. By laying this foundation and making these documents publicly available, other researchers could more easily build upon previous attempts to operationalize these theoretical frameworks without having to reinvent the

wheel every time. In addition, these carefully crafted structured decision-making documents force the researcher to conform tightly to the theoretical model constraints and be transparent with their work. Development of these documents were largely precipitated by the observation that a number of studies claimed to be operationalizing a specific natural hazards framework but included elements that were not a part of that model. This was particularly true for indicators such as resilience, sustainability, and coping capacity. While these elements are certainly important in vulnerability and risk analysis, researchers should be very diligent about being transparent and have a system to document this clearly.

Another important implication from this study is that there needs to be critical input from academicians and practitioners on risk ratio analysis before this method can be widely used. This would include the establishment of suggested guidelines, development of norms, and recommended benchmark values to establish tolerances and ranges for specific ratios. Having this type of data would make ratio development markedly easier and probably much more effective. Until this body of work has been established, the documents used in Stage 2-- a wire tree analysis and ratio selection analysis--could be useful to those researchers working in this field. Better documentation on how and why we select vulnerability indicators/metrics is sorely needed. This, along with documents such as audit checklists, can also help to reveal where we go wrong in the process as well as provide confidence of the robustness of the results.

Finally, as long as we insist on using static measurement systems in volital and complex environemnts results will continue to be marginal. We must match our measurement systems to our environment. No matter how many times you dress up, modify, and rename them, the underlying foundation of a static system is still static. As we transition from a linear to a networked world, things are getting faster and more complex giving rise to greater uncertainty. Under these conditions flexibility and adaptability are becoming more important. Our natural hazards theoretical frameworks need to be operationalized with flexibility as a key component of the measurement system even though it does introduce some subjectivity into the process. The goal of this study was to show that it is possible to devise a flexible system to detect vulnerability and risk to natural hazards by developing risk ratios that can be created by anyone to reflect their information needs. Emergency managers and practitioners in the disaster field need to be able to have access to reliable measurement systems that mirror their unique circumstances and geographic location. This research moves the discipline in that direction.

CHAPTER SEVEN:

SUMMARY, CONCLUSIONS AND CONTRIBUTIONS

7.1 Introduction

My research study, *Operationalizing the Pressure and Release Model Using Ration Analysis to Measure Vulnerability and Predict Risk from Natural Hazards in the Tampa, FL Metropolitan Area*, sought to answer the following questions:

1. Can the Pressure and Release theoretical framework for evaluating natural hazards risk be operationalized?

2**.** Can financial risk ratio methods using key performance indicators (KPIs) be used to determine vulnerability to natural hazards?

3. Does the new operational model improve disaster risk prediction?

This chapter provides a summary of the study and results that were obtained along with important concluding remarks. In addition, contributions of this research to the discipline of geography and natural hazards in future research trajectories are considered.

7.2 Study Summary

Significant damage and loss is experienced every year due to natural hazards such as hurricanes, tornadoes, droughts, floods, wildfires, volcanoes, and earthquakes. NOAA's National Center for Environmental Information (NCEI) reports that in 2016 the

United States experienced more than a dozen climate disaster events with damages and loss in excess of a billion dollars (NOAA National Centers for Environmental Information, 2017).   From 2000-2017 annual billion dollar loss events have steadily increased. Evaluation from the National Climatic Data Center (NDCD) expects this trend to continue (Sun et al., 2015). Disaster losses will likely adhere to the current trajectory and negatively impact the nation due to increased exposure of vulnerable populations and structural assets; however, with better understanding of risk and how vulnerability contributes to these losses it may be possible to develop effective mitigation measures to intercept this financial calamity.   Identifying vulnerabilities and risk associated with disaster threats is now a major focus of natural hazards research. While the theory is well established, one of the more pressing challenges before us is the lack of development of user-friendly and flexible risk assessment techniques for emergency managers (Mustafa et al., 2011). Better tools to measure and identify vulnerability, could help to determine at-risk populations and escalating conditions and allow more responsive and effective mitigation policies to be created.

This research examined vulnerability with an attempt to develop a new vulnerability measurement protocol to detect changes in risk associated with natural disasters. By developing and comparing risk ratios compiled from key performance indicators it may be possible to identify vulnerabilities long before they turn into expensive disasters. The primary goal of this research was to offer an alternative model for examining vulnerabilities as a component in determining risk to a variety of natural hazards. In addition, this research was expected to offer predictive capabilities to emergency managers and other disaster personnel to determine threats in their particular geographic locations. This information could then be leveraged with local, state, and national officials to initiate more effective disaster planning. The final goal of this research was to provide a way to alleviate unnecessary human suffering and loss from natural disasters due to delayed emergency planning and mitigation strategies because risk trends were not recognized early enough. The objectives of this study were to (1) identify and report on the application and challenges of the newly developed operational risk model and add to the natural hazards research literature; (2) build a comprehensive library of key performance indicators, ratio measures, and data sources of vulnerability to natural hazards and make them publically available; and (3) to determine best practices of natural hazards planning and preparedness with regard to identifying vulnerable populations and assets.

Natural hazards research has yielded numerous theoretical frameworks over the last 25 years that have explained important elements of risk and vulnerability in disasters (Birkmann, 2016b). However, there has been much less progress made in operationalizing these frameworks. It is been known for some time that certain populations tend to suffer the same losses and damages over and over from natural disasters in a disturbing cycle and little is known about how to mitigate this problem. Because of this, there exists a large gap in hazards research literature with regards to accurate risk identification based on quantitative data due to the lack of a smooth transition from theory to practice.

The trend in operationalizing these theoretical frameworks has been the development of general, all-purpose, static models to measure vulnerability. One of the major strengths of this approach is that comparisons can easily be made across locations since everyone is using the same metrics. However, important missing elements in the current hazards literature is the need for an operationalized risk model that is (1) simple, quick and easy to use, (2) flexible for changing conditions, and (3) site-specific for various geographic locations. Many of the current models for determining risk and vulnerability are very complex and time consuming to calculate and thus make them of little use for emergency and risk managers. In addition, little analysis has been conducted to see if a flexible risk identification measurement system could be developed. As vulnerability and risk become fluid due to changing conditions (environmental—hazard and location) and circumstances (social, economic, and political), our measurement tools need to be able to capture these differences in order to be effective. Because of these shortcomings, emergency managers lack the tools to systematically identify the onset of risk and its subsequent escalation. If these issues could be addressed, planning for disasters and attendant mitigation strategies might be vastly improved.

7.3 Overview of Methods

This study used a model development approach with structured decision making techniques coupled with a case study demonstration. The study design was supported by a comprehensive literature review to ensure that the project was consistent with current research practices in the field and relevant and comparable with those studies that surrounded the research gap. This project was designed to frame the issue from a transformative perspective and apply unique, untried methods to address the persistent problems outlined above.

Model development was based on a driver-centric modeling technique often used in computer threat modeling. The foundation of the modelling process included a multi-step structured decision making matrix. This was coupled with the development of a comprehensive collection of tracking and analysis tools including process flowcharts, decision trees, matrices, and checklists. Once the modeling process was designed and verified, a suite of risk ratios based on key performance indicators was created to measure vulnerability. This was supported by an extensive library of archival data sources and creation of a detailed data dictionary used to populate the ratios and determine their function as risk indicators. Finally, the model and attendant risk ratios was demonstrated in a selected case scenario featuring Tampa, FL metropolitan area to see if the disaster risk ratios could effectively quantify vulnerability and identify escalation patterns of risk over time.

7.4 Key Research Findings

RESEARCH QUESTION ONE: Can the Pressure and Release Model for evaluating natural hazards risk be operationalized? The results demonstrated that through the process of model design with structured decision-making and risk ratio development using a wire tree analysis the pressure and release model could be operationalized. The Conceptual Design results showed that the Pressure and Release theoretical framework could be evaluated using an Input-Output Analysis. Model Development results demonstrated that the Pressure and Release theoretical framework could be conceptually operationalized using process flow charting and verified using a design cycle audit checklist. Using carefully designed structured tools (flowcharts, matrix, and audit checklists) are very important when working in complex systems. They highlight issues that might not otherwise be detected and act as safeguards for transparency and tracking. One weakness of the process was the I-O analysis: the PAR theoretical framework emphasized inputs over outputs which left the I-O analysis asymmetric. Since outputs often become inputs for the next cycle, this could affect the system and resulting decisions made from it. A valid counterargument was that there was some subjectivity in the selection of inputs/outputs and flowcharting process allowing bias to enter the system. We see what we want to see or are capable of seeing and this is reflected in the model as distortions. However, despite these issues, it should be remembered that models do not have to be perfect; they just have to be useful. Using structured decision-making and a standardized protocol for conceptualizing model – building could have significant implications in operationalizing theoretical frameworks. Providing a strong foundation with strong verification components and a holistic view of the system could be very helpful.

RESEARCH QUESTION TWO: Can the Financial Risk Ratio method using key performance indicators (KPIs) be used to determine vulnerability to natural hazards? Through this research a new risk ratio measurement system was established using key performance indicators. Although the theoretical framework was operationalize some application difficulties still existed. The relative subjective nature of creating and choosing the risk ratios could be a possible source of error and bias. It was recommended that the methods be refined to ensure consistency in use. Possibly a more detailed and structured set of guidelines could be developed to mitigate this issue. However, there is a trade-off between robustness and flexibility. In order for the model to be flexible and adaptable there may need to be a small sacrifice in consistency. Data Library Development results demonstrated that with a good set of evaluative criteria quality databases both at the federal and local levels could be identified.

Now that we are in the age of Big Data, there are new databases coming online every day, however, models are only as good as the data you put into them. Databanks must be regularly and systematically monitored for quality. KIP Generation results demonstrated how to evaluate and select key performance indicators to vulnerability using a structured decision-making process and wire tree analysis. Part of the problem with key performance indicator selection is that users tend to focus on and choose what they are familiar with so they select the same types of KPI repeatedly. This often does not give a holistic representation. Risk Ratio Development findings showed that risks ratios could be developed using a structured decision-making process. One important point to make about key performance indicators and risk ratios is that they tend to be lagging indicators; they tell us what happened after the event. Another challenge dealing with KPIs and risk ratios is that data has a shelf life; it is important to evaluate the quality of the data going in as well as the ratio itself. These checklists and wire tree tools must be concise, actionable, and up to date. A valid counterargument was that nothing was actually tested with real data, so how do you know risk ratios measure what they're supposed to measure? One will never know the answer to this definitively until the risk ratios are tested under real-world conditions using regression analysis or some other statistical tool. During the development stage, the best one can do is to have (1) a highly structured decision-making protocol (2) with rigorous verification and (3) some testing using artificial data; all three of these were present this stage of the research project.   The implications for this stage of the research suggests that it may be possible to systematically select key performance indicators, evaluate them, and use them to construct risk ratios to measure vulnerability.

RESEARCH QUESTION THREE: Does the new operational model improve disaster risk prediction? Project Selection results concluded that the year 2011 was a significant year in which the Hillsborough Local Mitigation Strategy committee and emergency management officials recognized a number of significant flood issues in Tampa, FL that needed to be addressed. This year was used as a benchmark to examine the 5 previous years for vulnerability escalation during the time period of 2007-2011. Case Scenario Application results demonstrated that the risk ratios could be applied to a specific area and set of natural hazards conditions to test for escalating vulnerability by determining if the expected slope of the dataset was the same as the actual slope. The results were fair with 3 of the 6 ratios performing as expected in relation to vulnerability over the 5 year time period. Whether the risk ratios could detect escalating risk to natural hazards was inconclusive. More research is needed to make this determination.   One of the main pinch points of this model was the data, particularly data resolution. It is a common problem that nearly everyone in this field attempting to operationalize natural hazards theoretical frameworks has—the data resolution is often not fine enough. Finding the right data at the right level is very time-consuming and often doesn’t yield a good cost-benefit. Other data issues included small or insufficient sampling sizes, data is not mutually exclusive – they tend to overlap conceptually, and data that were inconsistent and collected using different methods jeopardizing comparability. Models are only as good as the data you feed into them. A valid counterargument was that there is some subjectivity in the creation and selection of the risk ratios allowing bias to enter the system. Because natural hazards research takes place in very complex social, economic and environmental systems; there will always be some subjectivity and expert knowledge required. It is this subjectivity or the ability of the user to create and choose specific ratios that reflect their unique circumstances is what makes this approach valuable. However, there is clearly a tradeoff between flexibility and relative certainty of static systems. While this study set out to see if it was even possible to operationalize the PAR theoretical framework and how to go about this task using the newly developed risk ratio measurement system, it still needs some adjustments to the risk ratios for them to be successful. Once this is completed, then testing could begin possibly using statistical measures such as a t-test, regression, and correlation analysis.

And while it was inconclusive as to whether this risk ratio measurement system used to operationalized the PAR theoretical framework could predict risk to natural hazards by observing the behavior of key risk ratios and vulnerability, it is probable that this could be accomplished using the proceedures developmed and presented in this dissertation. As long as we insist on using satic measurement systems in volital and complex environemnts results will continue to be marginal. We must match our measurement systems to our environment. No matter how many times you dress up, modify, and rename them, the underlying foundation of a static metric is still static. As we transition from a linear to a networked world, things are getting faster and more complex giving rise to greater uncertainty. Under these conditions flexibility and adaptability are becoming more important than certainty and standardization. Our natural hazards theoretical frameworks need to be operationalized with flexibility as a key component of the measurement system even though it does introduce some subjectivity into the process. This study moves the discipline in that direction.

7.5 Contributions

This study provided one of the first attempts to develop a flexible measurement system to operationalize the PAR model. While several scholars have used the composite indexing approach to operationalizing natural hazards theoretical frameworks, my research reveals that it is possible use a more flexible and adaptable approach such as a risk ratio measurement system; showing the importance of addressing the unique characteristics in disaster research such as complexity, volatility, and uncertainty. I expect this research to contribute to the debates on how to effectively operationalize our natural hazards risk and vulnerability frameworks and play an important role in shaping research on finding better ways to address weaknesses in our current models including lack of context and flexibility in the ability to change with rapidly changing environmental and socio-economic conditions before, during and after disaster events. Our future mitigation responses could be vastly improved through the use of this modeling process.

Models become useful when broad applications can be made under real world conditions. While this study focuses on natural hazards and vulnerability it may be possible to apply this operationalized model to a wide variety of practical uses. It is expected that emergency managers and policy makers certainly could use this application to identify escalation of vulnerability from natural hazards over time. There may also be some practical field application for this model as a short-term, early warning detection system. The strength of this model is that it's extremely flexible for changing and dynamic conditions. Coupling real-time data and ratio analysis with a spreadsheet software tool or GIS mapping capabilities could give emergency managers valuable information in making critical decisions under developing natural hazards conditions.

Finally, I do see this model providing a universal baseline understanding of particular geographic locations. By observing how specific ratios change over time in a specific place, it could reveal unique characteristics of hazard locations and how best to deal with escalating vulnerability and mitigate risk. Many of our current operationalized models can deal with vulnerability and risk at a national and global scale, however there are a few that have the capacity to focus in on specific local conditions and microenvironments. I believe that this model could fill that gap.

A good operational model must be able to explain as many of the characteristics of the system as possible, but also balance with simplicity. No scientific model can possibly explain everything and is therefore never totally accurate or comprehensive; all models have limitations. However a model doesn't have to be perfect, it just has to be useful in making predictions. The goal of any research endeavor is to move the discipline forward. It is hoped that this discovery process has added to the scholarly literature and that this operational measurement system could be useful in natural hazards research and the discipline of geography as a whole.

7.6 Recommendations and Future Research

Finally, I would make several recommendations with regards to this research study. Operationalizing theoretical frameworks is a complex process and very time-consuming. Providing a generalized structured approach such as conducting Process Input/Out Analysis with a detailed Process Flowchart of the model design and a Design Cycle Audit Checklist could be very beneficial for those researchers who want to continue on trying to operationalize a theoretical framework that someone else has begun. By having these background documents you don't have to start from square one every single time.

It is also recommended that more research be done examining flexible measurement structures that could be applied to natural hazards research. We tend to gravitate towards static systems because they're reliable and the variables are more predictable and manageable. However, we need to explore other ways to operationalize natural hazards frameworks that specifically deal with flexibility and adaptability.

There are a number of future research implications that have emerged from this study. First we need support and encourage long-term studies. Natural hazards research deals with very complex social, economic, and environmental systems and processes that develop over long periods of time. In addition, there has been a call for more transformative and integrative type research. Incremental research, where the researcher has a starting platform to make small changes may be too slow to deal with an increasingly fast-paced world fueled by technology. Cross discipline and multi-functional team work is going to be required for the future to solve these large and interdependent problems. The natural hazards discipline is moving toward the concepts of resiliency and sustainability and this approach will require us to design systems with flexibility and adaptability built in to deal with the volatility inherent in natural hazards and the ability to correct and real time to unexpected contingencies so often present during disasters. To confront a constantly shifting threat in a complex setting, we are going to have to pursue adaptability and cross functional team work.

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Appendix A: Database Evaluation Results

National Database Sources Data Library Selection Checklist as of 3.20.2017 Yes/No: meets the minimum criteria							
Name and Web Address		**Criteria 1** Authority	**Criteria 2** Purpose	**Criteria 3** Coverage	**Criteria 4** Currency	**Criteria 5** Objectivity	**Criteria 6** Accuracy
1	Federal Emergency Management Administration (FEMA): www.fema.gov	Yes	Yes	Yes	Yes	Yes	Yes
2	National Oceanographic and Atmospheric Administration (NOAA): www.noaa.gov	Yes	Yes	Yes	Yes	Yes	Yes
3	U.S Geological Survey (USGS): www.usgs.gov	Yes	Yes	Yes	Yes	Yes	Yes
4	Socioeconomic Data: https://catalog.data.gov/dataset?tags=socio economic	Yes	Yes	Yes	Yes	Yes	Yes
5	U.S. Dept. of Health and Human Services: www.hhs.gov	Yes	Yes	Yes	No: broken links	Yes	Yes
6	U.S. Forest Service: www.fs.fed.us	Yes	Yes	Yes	Yes	Yes	Yes
7	CDC—Center for Disease Control: http://www.cdc.gov/datastatistics/	Yes	Yes	Yes	Yes	Yes	Yes
8	Department of Transportation (DOT): hazmat.dot.gov	Yes	Yes	Yes	No: broken links	Yes	Yes
9	Environmental Protection Agency (EPA): www.epa.gov	Yes	Yes	Yes	Yes	Yes	Yes
10	National Drought Mitigation Center: drought.unl.edu	Yes	Yes	Yes	Yes	Yes	Yes
11	National Fire Protection Association: www.nfpa.org	Yes	Yes	Yes	Yes	Yes	Yes
12	U.S. Nuclear Regulatory Commission: www.nrc.gov	Yes	Yes	Yes	Yes	Yes	Yes
13	NASA Earth Data: http://gcmd.gsfc.nasa.gov/search/Titles.do?search=#titles http://gcmd.gsfc.nasa.gov/add/portals.html	Yes	Yes	Yes	Yes	Yes	Yes
14	EM-DAT: www.emdat.be/database	Yes	Yes	Yes	No: broken links	Yes	Yes
15	National Bureau of Economic Research: nber.org	Yes	Yes	Yes	Yes	Yes	Yes
16	Ready America: http://www.ready.gov/	Yes	Yes	Yes	Yes	Yes	Yes
17	USA.gov: Disasters and Emergencies:	Yes	Yes	Yes	Yes	Yes	Yes

	https://www.usa.gov/disasters-and-emergencies						
18	NOAA National Center for Environmental Information: http://www.ngdc.noaa.gov/ngdcinfo/onlineaccess.html	Yes	Yes	Yes	Yes	Yes	Yes
19	RealityTrac 2015 U.S. Natural Disaster Housing Risk Report: http://www.realtytrac.com/news/data-lab/	Yes	Yes	Yes	Yes	Yes	Yes
20	NOAA Natural Hazards—National Centers for Environmental Information: formally the National Geophysical Data Center (NGDC): https://www.ngdc.noaa.gov/ http://maps.ngdc.noaa.gov/viewers/hazards/	Yes	Yes	Yes	Yes	Yes	Yes
21	FEMA—Federal Emergency Management Agency: https://www.fema.gov/ https://www.fema.gov/national-disaster-recovery-framework/community-recovery-management-toolkit	Yes	Yes	Yes	Yes	Yes	Yes
22	National Disaster Recovery Framework (NDRF): https://www.fema.gov/pdf/recoveryframework/ndrf.pdf https://www.fema.gov/community-resilience-indicators	Yes	Yes	Yes	Yes	Yes	Yes
23	Presidential Disaster Declarations and Disaster Assistance: DisasterAssistance.gov	Yes	Yes	Yes	Yes	Yes	Yes
24	NOAA National Hurricane Center: http://www.nhc.noaa.gov/	Yes	Yes	Yes	Yes	Yes	Yes
25	Economic Research—FRED Economic data: https://research.stlouisfed.org/fred2/categories/32263	Yes	Yes	Yes	Yes	Yes	Yes
26	USAID Development Data Library (DDL): https://www.usaid.gov/data	Yes	Yes	Yes	Yes	Yes	Yes
27	NOAA Natural Hazards Data: https://www.ngdc.noaa.gov/hazard/	Yes	Yes	Yes	Yes	Yes	Yes
28	Prevention Web Disaster Risk Datasets: http://www.preventionweb.net/risk/datasets	Yes	Yes	Yes	No: broken links	Yes	Yes
29	US Census Bureau: http://www.census.gov/data.html	Yes	Yes	Yes	Yes	Yes	Yes
30	US Census Bureau—International Database: https://www.census.gov/population/internati	Yes	Yes	Yes	Yes	Yes	Yes

	onal/data/idb/informationGateway.php						
31	Centre for Research on the Epidemiology of Disasters (CRED): http://www.cred.be/	Yes	Yes	Yes	Yes	Yes	Yes
32	CE DAT—Complex Emergency Database: http://cedat.be/	Yes	Yes	Yes	Yes	Yes	Yes
33	Historical Natural Hazards Database: USGS & NOAA ArcGIS: https://www.arcgis.com/home/item.html?id=c0f434fcc25343c79db610a5bdc7ac77	Yes	Yes	Yes	Yes	Yes	Yes
34	Data.gov—Disasters: https://www.data.gov/disasters/	Yes	Yes	Yes	Yes	Yes	Yes
35	Natural Hazards Center—Disaster Statistics Databases: http://www.colorado.edu/hazards/resources/web/statistics.html	Yes	Yes	Yes	Yes	Yes	Yes
36	USGS Natural Hazards: http://www.usgs.gov/natural_hazards/	Yes	Yes	Yes	Yes	Yes	Yes
37	UNISDR Disaster Statistics: https://www.unisdr.org/we/inform/disaster-statistics	Yes	Yes	Yes	Yes	Yes	Yes
38	Spatial Hazard Events and Losses Database—SHELDUS: hvri.geog.sc.edu/SHELDUS/	Yes	Yes	Yes	Yes	Yes	Yes
39	Natural Catastrophes Our World in Data: https://ourworldindata.org/natural-catastrophes/	Yes	Yes	Yes	No: broken links	Yes	Yes
40	GIS Shapefiles and Datasets: https://freegisdata.rtwilson.com/	Yes	Yes	Yes	Yes	Yes	Yes

Regional and Local Database Resources Data Library Selection Checklist as of 3.20.2017 Yes/No: meets the minimum criteria							
Name and Web Address		**Criteria 1** Authority	**Criteria 2** Purpose	**Criteria 3** Coverage	**Criteria 4** Currency	**Criteria 5** Objectivity	**Criteria 6** Accuracy
1	Florida Disaster—FL Division of Emergency Management: http://www.floridadisaster.org/index.asp	Yes	Yes	Yes	Yes	Yes	Yes

2	Florida Division of Emergency Management: www.FloridaDisaster.org	Yes	Yes	Yes	No: broken links	Yes	Yes
3	Florida Agency for Persons with Disabilities: http://apd.myflorida.com/disaster/	Yes	Yes	Yes	Yes	Yes	Yes
4	Shelter Status - State of Florida, Current Shelters: http://floridanss.comunityos.org/csm/openshelters	Yes	Yes	Yes	Yes	Yes	Yes
5	Florida Chapter of the Red Cross: http://www.redcross.org/where/chapts.asp#FL	Yes	Yes	Yes	Yes	Yes	Yes
6	Florida Health Departments by County: http://www.doh.state.fl.us/chdsitelist.htm	Yes	Yes	Yes	Yes	Yes	Yes
7	Florida Emergency Management Local Offices by County: http://www.floridadisaster.org/fl.county.em.asp	Yes	Yes	Yes	Yes	Yes	Yes
8	Florida General Population Shelters by County: http://floridadisaster.org/shelters/	Yes	Yes	Yes	Yes	Yes	Yes
9	Tampa Bay Regional Planning Council: http://tampabaydisaster.org/Statewide Regional Evacuation Study (SRES) for the Tampa Bay region	Yes	Yes	Yes	No: broken links	Yes	Yes
10	Tampa Bay Regional Planning Council: The 2016 Tampa Bay Disaster Planning Guide: http://www.tampabayprepares.org/	Yes	Yes	Yes	Yes	Yes	Yes
11	Project Phoenix: The Tampa Bay Catastrophic Plan: http://www.tbrpc.org/tampabaycatplan/scenario.shtml	Yes	Yes	Yes	Yes	Yes	Yes
12	City of Tampa, FL Emergency Management: http://www.tampagov.net/emergency-management/info/tampa-hazards	Yes	Yes	Yes	Yes	Yes	Yes
13	City of Tampa's Local Mitigation Strategy (LMS): http://www.hillsboroughcounty.org/en/residents/public-safety/emergency-management/local-mitigation-strategy	Yes	Yes	Yes	Yes	Yes	Yes
14	Tampa Office of Emergency Management: Citizens Guide to Natural Disastershttps://tampa.maps.arcgis.com/apps/MapSeries/index.html?appid=df0f2aec513648cdb6a58afb8da6f6a	Yes	Yes	Yes	Yes	Yes	Yes
15	BEBR Bureau of Economic and Business Research: https://www.bebr.ufl.edu/	Yes	Yes	Yes	Yes	Yes	Yes
16	FL Fish and Wildlife Conservation Commission Socioeconomic data: http://geodata.myfwc.com/datasets/c876d50d2cb94fea89371383f6ef93e3_22	Yes	Yes	Yes	Yes	Yes	Yes
17	FL Bureau of Labor Statistics—US Dept. of Labor: https://www.bls.gov/eag/eag.fl.htm	Yes	Yes	Yes	No: broken links	Yes	Yes
18	FL Division of Forestry: fl-dof.com	Yes	Yes	Yes	Yes	Yes	Yes
1	New England States Emergency Consortium:	Yes	Yes	Yes	Yes	Yes	Yes

9	www.nesec.org						
20	North Carolina Emergency Management Agency: www.dem.dcc.state.nc.us	Yes	Yes	Yes	Yes	Yes	Yes
21	Oklahoma Mesonetwork: www.mesonet.ou.edu	Yes	Yes	Yes	Yes	Yes	Yes
22	Univ. of Illinois Dept. of Atmospheric Science: www.atmos.uiuc.edu	Yes	Yes	Yes	Yes	Yes	Yes
23	FL Geographic Data Library: fgdl.org; https://www.fgdl.org/download/	Yes	Yes	Yes	Yes	Yes	Yes
24	Florida Department of Environmental Protection Geospatial Open Data http://geodata.dep.state.fl.us/	Yes	Yes	Yes	No: broken links	Yes	Yes
25	Florida Geographic Data Library Data Source Links: https://www.geoplan.ufl.edu/fgdl_source_links.htm	Yes	Yes	Yes	Yes	Yes	Yes
26	EDR-Office of Economic and Demographic Research: http://edr.state.fl.us/Content/	Yes	Yes	Yes	Yes	Yes	Yes

About the Author

Jessica Wilder received a Bachelor's Degree in Biological Sciences from the University of Minnesota. She then received a Master's Degree in Accounting from Strayer University. Mrs. Wilder has had a long career in education and for the past 10 years has been a college instructor and currently teaches geoscience, environmental science, and human ecology at Saint Leo University, Florida. Her research interests are in risk and vulnerability analysis at the social-economic-environment interface including the disciplines of geography and environmental science as well as financial risk; she also also currently teaches forensic accounting and forensic science.