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Sustainable Infrastructure Development: A Holistic System Based Decision Making Framework Integrating Vulnerability Indicators and Stakeholders Objectives

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Sustainable Infrastructure Development: A Holistic System Based Decision Making Framework Integrating Vulnerability Indicators and Stakeholders Objectives

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DEDICATION

I would like to dedicate this work to my wife, Rasha; daughter Habibah; and son, Youssef. Without your support, love, and patience I would not have made it this far. I also dedicate this work to my parents who continue to provide their endless support.

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ABSTRACT

Infrastructure systems enable the host communities to expand, develop, and prosper in adequate socioeconomic conditions and healthy environment. Thus, the strategies for sustainable infrastructure development should aim to increase the individual utility of the local stakeholders, while reducing the vulnerability of the built environment to perturbations. Nevertheless, the available frameworks consider the development of the infrastructure systems as isolated projects and do not simultaneously address the needs of the stakeholders or the vulnerability of the built environment. The goal of this research is to provide decision makers and the research community with a novel infrastructure development framework that holistically balances between the short-term development objectives and long-term sustainability goals.

This research presents an innovative decision making framework that assimilates the needs of the broad community stakeholders while decreasing the vulnerability of the built environment (i.e. social, economic, and environmental). The framework utilizes a bottom-up agent based modeling approach to account for the needs, decision actions, and learning behaviors of the different stakeholders. The framework integrates well-established vulnerability indicators into the objective functions of the associated stakeholders to guide the infrastructure development strategies. Finally, the developed framework utilizes a multi-dimensional evaluation module to balance between the needs of the stakeholders and the vulnerability of the built environment.

The developed framework was implemented on the post-Katrina housing and infrastructure redevelopment projects in three Mississippi coastal counties. The proposed framework was tested against the existing conditions and null hypothesis tests. Each of the infrastructure development strategies had its positive and negative impacts on the vulnerability and/or redevelopment of the community. Through utilizing the proposed framework, a set of Pareto optimal strategies were

developed that dominated the existing conditions and the null hypothesis tests. Those strategies increased the individual utility of the stakeholders, and decreased the social, economic, and environmental vulnerabilities of the host community.

This novel infrastructure development decision making framework will enable the communities to identify strategies that balance between the short-term development objectives and the long-term sustainability goals. Thus, this innovative approach will ensure the prosperity of the current and future generations.

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CHAPTER ONE

INTRODUCTION

1.1. Overview

Per the United Nations estimates, the world population will rise from 7 billion (2014) to 9.3 billion in 2050, and 10.1 billion in 2100 (Ferdinand and Yu 2014, Lee 2011). To provide sustainability to such population, infrastructures should be *less vulnerable* to perturbations and hazards (Ingram et al. 2006, Folke et al. 2002). Upon addressing the vulnerabilities of the communities, the sustainability of the infrastructure systems will be achieved (Pratt et al. 2004). Nonetheless, our host communities still suffer from rapid infrastructure degradation due to: (1) lack the comprehensive integration of vulnerability measurements, (2) neglect the interactions and preferences of the associated stakeholders,(3) focus on design alternatives and evaluations rather than the community sustainability and vulnerability, and (4) lack the holistic consideration of the sustainability and the important system details (Boz and El-adaway 2014, Haimes 2012, Guikema 2011; Guhnemann 2007; Hueting and Reijnders 2004).

The host communities face the three dimensions of vulnerability: social, economic, and environmental (Burton 2010, Ingram et al. 2006, Pratt et al. 2004). Vulnerability is considered in general as “the potential for loss” (Mitchell 1989). Accordingly, infrastructure development should aim to decrease the built environment vulnerability to increase the welfare of the societies and ultimately achieve sustainability (Ingram et al. 2006). Nevertheless, the recent infrastructure development practices and decision making procedures proved otherwise. A series of land-use problems (i.e., decrease in food production, deforestation, water and air pollution, and depravation of future land supply) occurred in the developing countries due to massive land conversions from non-urban to urban (Li and Liu 2008). This is the consequences of decision making processes that aimed to accommodate for the population growth, and coping with the developed countries, regardless of the adverse effects on the vulnerability of the host communities. The land usage complications and sustainability is not merely coinciding in the developing countries. In the United States, researchers estimated that there are between 500,000 to 1 million brownfields (Ferdinand and Yu 2014, Greenberg and Issa 2005). Moreover, Haimes (2012) reported that more than fifty percent of the developed transportation infrastructure of the United States is vulnerable to hazards and perturbations.

The infrastructure and its development are interdependent on the various stakeholders within the host community; owners, contractors, designers, material suppliers, users, etc. The different stakeholders in the infrastructure development and construction industry are variant and most of the time face contradicting preferences. This disconnection between the stakeholders in the decision making and development processes created infrastructure development activities that left the built environment more vulnerable to shocks and eventually less sustainable. To this end, it is suggested that an effective and efficient infrastructure development plan should be based on broad community involvement, readily available information to create policies and actions, horizontal and vertical coordination between associated organizations, and continuous assessment and evaluation strategies (Eid and El-adaway 2016a, Smith and Winger 2007, Olshansky et al. 2006, Mileti 1999).

Meanwhile, the utilized infrastructure development decision making approaches rely on the available sustainability rating tools that: (1) generally focus on evaluating design alternatives rather than sustainability of the community; (2) often so general that important system details are lost because they focus on snapshots of sustainability; and (3) neglect the host community stakeholders' interactions and preferences (Boz and El-adaway 2014, Haimes 2012, Guikema 2011; Hueting and Reijnders 2004). Thus, these sustainability tools and rating systems fail to incorporate the broad human-built environmental system components (Daniell et al. 2005, Turner et al. 2003). Accordingly, the need for a novel decision making support tool for holistic infrastructure sustainable development is noticeable as decision makers (both in public and private sectors) are concerned about their infrastructure investments in terms of vulnerability and sustainability.

1.2. Problem Statement

As mentioned above, it is noticeable the need for a holistic infrastructure development decision making framework that aims to decrease the built environment social, economic, and environmental vulnerabilities while increasing the welfare of the associated stakeholders. Such framework should consider the needs of the different stakeholders in the community, their interdependent and complex relationship with the built environment, and the undergoing development surrounding them. The framework must be able to aid the communities in highlighting their shared goals and common grounds to know how and where to build. Accordingly, such tool will enable communities to attain optimal infrastructure development processes that would achieve the short-term development objectives and the long-term sustainability goals.

Recent research was attempted to investigate and address the different components within the complex sustainable infrastructure development processes. Those can be highlighted as follows:

1. In regard to the built environment vulnerability to perturbations, many research had been carried out to understand, model, and evaluate the host communities' vulnerability. Such research can be categorized into three: (1) social (Cutter et al. 2006, Olshansky et al. 2006, Olshansky 2006, Cutter et al. 2003, Watts and Bohls 1993), (2) economic (Briguglio et al. 2009, Guillaumont 2009, Rose 2009, Rose 2004), and (3) environmental (Esty et al. 2005, Pratt et al. 2004, Wackernagel and Rees 1997). *However, the above research was neither extensively applied in the infrastructure sustainability assessment tools nor utilized for decision making processes.*

2. To study the different relationships between the various stakeholders and the built environment, different modeling and simulation techniques were utilized. One of the most influential and promising technique is Agent Based Modeling (ABM). ABM is a bottom-up computational approach to simulate autonomous agents, that represent the different stakeholders of the system (Eid and El-adaway 2016a). This approach is able to evaluate the performance of the system, based on the collective interactions of the associated stakeholders. ABM was utilized through various research to understand and quantify sustainability of the infrastructure. Daniell et al. (2010) introduced an ABM for assessing housing developments sustainability utilizing the "Sustainability Scale" for resource usage. In addressing the Pearl River Delta land usage utilization, Li and Liu (2008) introduced an ABM to capture the complex interactions between the different stakeholders utilizing Geographic Information Systems (GIS) that illustrates their spatial attributes. From an ecological point of view, Manson and Evans (2007) introduced an ABM to address the deforestation of Southern Yucatan, Mexico, and reforestation in the Midwest, United States. The authors approach simulated the rule of thumb strategies while identifying social and environmental factors in the study region. ABM was also utilized to understand and assess the impact of the users' behavior on the commercial buildings overall energy consumption (Azar and

Menassa 2012). *Nevertheless, the aforementioned models did not integrate the different vulnerability indicators into the agents' decision making processes to provide optimal development strategies. Moreover, most of the models focused on a single agent approach that leaves the models unable to represent the complex interactions among the various stakeholders, and their interdependencies on the infrastructure development processes.*

Table 1.1 summarizes the recent research studies and the current knowledge gap. In light of the above, this research was initiated to fill in the aforementioned research gap in relation to the integration of the different vulnerability indicators and the preferences of the stakeholder into the decision-making processes. This is carried out through the utilization of a bottom-up simulation model that is able to account for the multi-sector stakeholders and the three-dimensional vulnerability indicators, and propose optimal strategies for sustainable infrastructure development.

Table 1.1: Summary of Recent Research and Knowledge Gap

	Purpose		**Vulnerability**			**Account for Stakeholders**
	Evaluation	Decision Making	Social	Environmental	Economic	
Watts and Bohle (1993)	X		X			
Briguglio (1995)	X				X	
Wackernagel and Rees (1997)	X			X		
Kweku-Muata et al. (2002)		X				
Cutter et al. (2003)	X		X			
Daniell et al. (2004)	X					X
Pratt et al. (2004)	X			X		
Esty et al. (2005)	X			X		
Miles and Change (2006)	X	X				X
Manson and Evans (2007)	X			X		X
Cutter et al. (2008)	X		X			
Li and Liu (2008)	X					X
Guillaumont (2009)	X				X	
Rose (2009)	X				X	
El-Anwar et al. (2010)		X				
Daniell et al. (2010)	X			X		X
Azar and Menassa (2012)	X			X		X
Burton (2012)	X		X	X	X	
Nejat and Dmanjonovic (2012)	X	X				X

1.3. Research Goals, Objectives, Methodology, and Hypothesis

The ultimate goal of this research is to achieve sustainable infrastructure development through increasing the welfare of the host community and decreasing the vulnerability of the built environment. This can be achieved through developing a holistic framework that integrates the assessment of the three dimensional vulnerably into the objectives of the stakeholders to better guide the infrastructure development decision making processes. *The proposed research hypothesis is that integrating the interdependent relationships between the different vulnerability indicators and the objective functions of the associated stakeholders will result in more effective decision-making processes, that increase the overall community welfare, and consequently, achieve a more sustainable civil infrastructure system.* The proposed research follows the succeeding objectives, that are summarized in Figure 1.1.

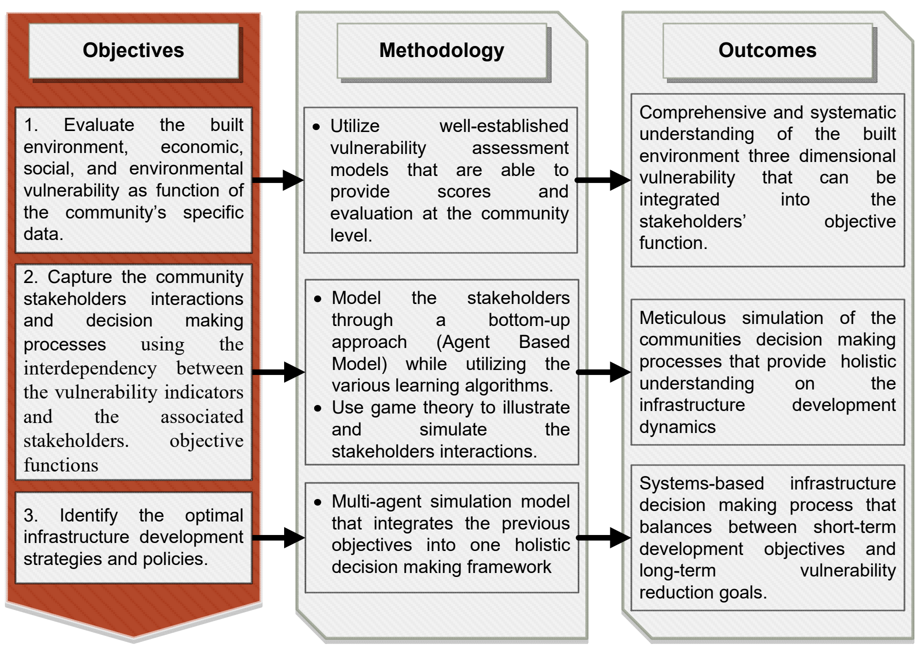

Figure 1.1: Research Objectives, Methodology, and Expected Outcomes

1. Establish a thorough systematic measurement for the social, economic, and environmental vulnerability indicators as functions of community-specific data inputs. This will better guide the decision-making framework and inform the decision makers on the status of the host community as well as the impact of the different infrastructure development on the vulnerability and sustainability of the built environment.

In order to attain this objective, different well-established indicators are utilized that require (for example) multivariate analysis including factor analysis and principle component analysis. Such techniques help to underline the factors that affect the host community vulnerability and provide score values for the different regions understudy.

2. Capture the broad community interdependency between the different vulnerability indicators and the objective functions of the associated stakeholders. To achieve such objective, an ABM is developed that captures the different stakeholders in the host community. Through mimicking the individual and collective behavior of the different stakeholders, the ABM enables the research to fully understand the host community interdependent complex interactions.

In order to depict the complex and competitive interactions of the different agents in the proposed ABM, Game Theory is utilized. Game theory helps in attaining the stable strategies/equilibria for the different stakeholders that would increase their objectives as well as the host community welfare while maintaining the built environment resilience.

3. Eventually, and most importantly, create a holistic system approach to assess the infrastructure sustainability through the vulnerability of the built environment. This is achieved through integrating the two previously mentioned steps into one holistic decision making framework. Moreover, via simulating the behaviors of the different stakeholders and through utilizing game theory, the proposed research model is able to predict the overall infrastructure

sustainability and thus optimize the strategies and policies of the stakeholders to determine the optimal sustainable development approaches.

1.4. Research Benefits

This project is distinctive from prior related research with respect to focus, purpose, and methods. A more advanced and comprehensive interdisciplinary framework is developed that integrates research methods from engineering, economics, computer, and social sciences. First, this project measures social, economic, and environmental vulnerability indicators as function of community-specific data inputs. This provides a comprehensive understanding of the vulnerability of the human-built environment that avoids the disagreements over the different definitions and focuses instead on measurable quantities that are correlated with the most common definitions. Second, this research employs game theory and various learning algorithms (social and individual) within an agent-based modeling framework to capture the broad community relationships using the interdependency between the different vulnerability indicators and the objective functions of the associated stakeholders. Such approach was never ventured before on such scale and will have a positive impact on the current body of knowledge.

The proposed approach helps in attaining systems-based infrastructure decision-making processes that mutually satisfy short-term development objectives and long-term sustainability goals. The proposed framework: (1) creates predictive engineering models for the built environment considering the current status of the infrastructure systems, and (2) determines the optimal sets of infrastructure development strategies that increase sustainability of the built environment through decreasing the vulnerability of the associated host communities. Finally, the research methodology is scalable and transferable for applications both nationally and internationally.

CHAPTER TWO

LITERATURE REVIEW

Sustainable infrastructure development of host communities depends on the built environment social, economic, and environmental vulnerability, as well as the host community interaction with the built environment and the development processes. This chapter aims to illustrate through a literature review the need for a holistic system-based sustainable infrastructure development framework that considers the infrastructure, economic, environment, and social aspects in addition to the associated stakeholders needs and preferences.

This chapter discusses the infrastructure sustainability and sustainable development in addition to the available sustainability assessment tools. Moreover, this chapter discusses the various vulnerability and resilience dimensions and points out the different vulnerability and resiliency indicators and their relation with the host community's sustainability. Finally, this chapter presents the various tools and techniques utilized in the current research that will allow the integration and simulation of the different associated stakeholders in the infrastructure development process.

2.1. Sustainability and Sustainable Development

In 1987, the World Commission of Environment and Development published "Our Common future" report that identified the need for sustainable development. Since then, the term was adopted by the UN and the EU as a policy principle, as well as many other countries, NGOs and companies. The term is commonly divided into three main dimensions; (1) social; (2) economic; and (3) environmental.

Nevertheless, the terms had suffered a great deal of debate on whether there is a difference between sustainability and sustainable development. Gilman (1992) defined sustainability as "*the ability of a society, ecosystem, or any such on-going system to continue functioning into the indefinite future without being forced into decline through exhaustion or overloading of key resources on which the system depends*". This definition embraces the idea of maintaining and preserving the existing system functionality state and regarding the resources on which the system depends on. Georg (1999) also defined sustainability as not just merely environmental improvement, but rather a community development aspect that is linked to the proximity and self-sufficiency.

On the other hand, sustainable development is focused on the changes through the processes of development and modifications. Sustainable development was defined by Greene (1997) as the "*integration of conservation and development on a long-term basis to provide social and economic benefits, without compromising the needs of future generations*". As such, sustainable development considers the dynamic nature of the community in rebuilding, modifications and development.

The ultimate goal of sustainable development is to provide the future generations with an improved built environment that is less vulnerability in the environmental and socioeconomic dimensions (Pratt et al. 2004). This is carried out through decreasing the host communities' social, economic, and environmental vulnerability to future perturbations and increasing their inherent resiliency. This goal can be achieved via a series of development, modification, and improvement of the infrastructure and current systems. Furthermore, sustainable development goals focus on the long term positive effects of the infrastructure development on the community rather than the immediate economic effects of the project itself (World Summit on Sustainable Development

2002). However, sustainable development concept finds itself in between the technologies and tools available to the industry and the needs and policies of the communities and governments.

It is of the utmost necessity to compare and measure the wide range of impacts of the infrastructure development processes, from planning to completion and beyond, while maintaining the system's resilience to insure future sustainability (Boz and El-adaway 2014). To this effect, several assessment tools has been introduced to measure sustainability and sustainable development in the built environment in attempt to provide the needs of today without compromising the needs of the future. Those tools should aim to evaluate the built environment as a whole regarding the construction process, the community performances, end product, the socio-economic, and environmental impacts of the infrastructure and its development. Moreover, the tools should provide solid and sound bases for decision making at all level of the community, thus contribute to the host community's sustainable development (United Nations, 1992). However, current sustainability assessment tools and rating systems: (1) lack the comprehensive integration of vulnerability measurements, (2) neglect the interactions and preferences of the associated stakeholders,(3) focus on design alternatives and evaluations rather than the community sustainability and vulnerability, and (4) lack the holistic consideration of the sustainability and the important system details (Boz and El-adaway 2014, Haimes 2012, Guikema 2011; Guhnemann 2007; Hueting and Reijnders 2004). The following section summarizes some of the widely recognized sustainable development models and tools. It is worth noting that most of these tools utilize the Life Cycle Assessment model.

2.1.1. Sustainable development assessment models

CASBEE: The Comprehensive Assessment System for Built Environment Efficiency (CASBEE) was developed by Japan and China to comprehensively evaluate the various regional sustainability issues. The assessment tool is designed to be used for the pre-design and construction phases. (CASBEE 2012).

BREEAM: even though considered as a design alternative evaluator model, Building Research Establishment Environmental Assessment Method (BREEAM) is one of the well-known environmental assessment tools for facilities (Boz and El-adaway 2013). BREEAM utilizes LCA to evaluate the overall value of the facility during the design phase, while considering the design, construction, and implementation processes. It evaluates both the internal environmental conditions and the waste control management of the facility. (Boz and El-adaway 2013, BREEAM 2012, Anderson et al. 2003).

UrbanSim: Developed by the University of California Berkeley, UrbanSim is a simulation system that was intended to be utilized by governments, non-governmental organizations and different planning stakeholders. UrbanSim integrates the land use patterns with the different transportation aspects along with the economy and environmental issues. UrbanSim also considers different impacts of the infrastructure development; greenhouse gas emissions, housing affordability, accessibility, etc. (UrbanSim, 2012).

LEED: Widely recognized and adopted by many private and public organizations as well as governmental bodies, the Leadership in Energy and Environmental Design (LEED) rating system goal is to environmentally evaluated the effects of the building through its life cycle (utilizing LCA) as well as providing a standard for green buildings. Five environmental aspects are evaluated through LEED; (1) Sustainable Sites (SS), (2) Water Efficiency (WE), (3) Energy and Atmosphere (EA), (4) Materials and Resources (MR), (5) Indoor Environmental Quality (IEQ) (Scheuer and Keoleian, 2002).

GreenLITES and Greenroads: In addressing the sustainability of transportation infrastructure projects, the New York State Department of Transportation created GreenLITES, while the University of Washington developed Greenroads as a third-party rating system. However, both systems are only qualified to assess the sustainability of transportation projects, and cannot be utilized for non-transportation projects (University of Washington & CH2MHILL, Inc., 2011; NYSDOT, 2012).

Nonetheless, the aforementioned valuable sustainable development assessment tools do not simultaneously (1) account for the stakeholders' needs and preferences, (2) address the three-dimensional vulnerability aspects that impacts the built environment sustainability, or (3) consider the impact of the projects on the host community overall welfare.

2.2. Vulnerability and Resilience

Closely tied to sustainability and sustainable development are the concepts of *Vulnerability* and *Resilience* (Robinson et al. 2011). In order to have a holistic understanding of sustainable development, one should understand the issues of vulnerability and resiliency of the communities (Pratt et al. 2004). We certainly need to account for vulnerability and resilience if we aim to achieve good quality of life and growth through sustainable development (Ingram et al. 2006). This can only be done through considering the factors that affect the vulnerability of the host communities either through internal or external influences.

Resilience was first studied by ecologist more than 30 years ago (Holling 1973). In defining resilience, different researchers stated that; (1) it is the amount of change the system can undergo while sustaining the same functionality, structure and, ability to develop (Nelson et al. 2007); (2) the physical properties of the system that enables it to withstand change, damage, and function loss (Tierney and Bruneau 2007) and (3) the ability of the social system through its adaptive capacity, including their inherent condition, that allows it to respond and recover from changes and damages and learn in response to a threat.

On the other hand, though might be thought of as opposite of resilience, vulnerability was thoroughly researched in an attempt to quantify it. Vulnerability research is categorized into three branches; (1) vulnerability as pre-existing condition, (2) vulnerability as tempered response, and (3) vulnerability as hazard of place (Cutter et al. 2003).

Vulnerability as pre-existing condition evaluates the sources or potential exposure of the biophysical to technological hazards (Cutter et al. 2003). These researches consider the distribution of hazards and the occupancy of this hazardous zones by humans as well as the degree of loss associated with the occurrence of the hazardous event. The estimation of natural disaster impact on structural losses and vulnerability reduction of the built environment is a subset of this category (Cutter et al. 2003). The second vulnerability research group is the vulnerability as tempered response. This category focuses on coping responses including societal resistance and resilience to shocks, which points out the overlapping between resilience and vulnerability. In this perspective, the studies focus on the social structure for vulnerability as historical, cultural, social and economic process that affects the individual and society to cope and respond to shocks. The third category; vulnerability as hazard of place, combines both previous two groups as well as the geographical conditions. In other words, vulnerability is considered as a biophysical risk as well as a social, economic and environmental response but within a specific geographic domain.

As an effect to the different perspectives to vulnerability and resilience among the different fields, the relationship between vulnerability and resilience is not well articulated (Cutter et al., 2008). This is mainly due to the different definitions depending on the field of study, in addition to the context in which the terminologies are used (hazard, sustainability, etc.). The different approaches in understanding this complex relationship mainly follow either; (1) that vulnerability is part of the resilience; (2) resilience is a subset of vulnerability; or (3) they are both opposite to each other.

This research, however, considers vulnerability and resilience factors to be neither mutually inclusive nor mutually exclusive. Thus, some of the vulnerability and resilience attributes are shared among each other. Such attributes are considered as inherent properties of the host community (size of land, available resources, entitlement, etc.) and are considered an overlap between vulnerability and resilience. Meanwhile, some host communities' characteristics fall either into vulnerability or resilience aspects. This approach is well recognized in the literature and better describe the complex nature of the host communities (Eid and El-adaway 2016a).

The following section presents a more thorough literature on the understanding of communities' resilience and vulnerability across its three dimensions (social, economic, and environmental), in addition to the various attempts to quantify and measure those traits.

2.2.1. Social Vulnerability and Resilience

Cutter et al. (1996) pointed out that literature is divided when it comes to understanding the causes of social vulnerability; (1) Causal structure, which is more of a political-economic perspective that focuses on the differential social impacts and the ability to cope with the perturbations; and (2) vulnerability/exposure assessments, that are more location driven and are affected by the proximity of the community to the sources of shocks and perturbations.

To this end, social vulnerability may be defined as:

- Vulnerability is "the degree to which a system acts adversely to the occurrence of a hazardous event. The degree and quality of the adverse reaction are conditioned by a systems' resilience (a measure of the system's capacity absorb and recover from the vent)" (Timmerman, 1981).
- "Vulnerability is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude" (UNDRO, 1982).
- "Vulnerability is the degree to which different classes of society are differentially at risk" (Susman et al. 1984).
- Vulnerability is "the capacity to suffer harm and react adversely" (Kates 1985).
- Vulnerability is "the potential for loss" (Mitchell 1989).
- Human vulnerability is a "function of the costs and benefits of inhabiting areas at risk from natural disaster" (Alexander, 1993).
- Vulnerability is the "differential capacity of groups and individuals to deal with hazards and changes, based on their positions within physical and social worlds" (Dow 1992).

- Vulnerability is the “likelihood that an individual or group of individuals will be exposed to an adverse effect by a hazard. It is the interaction of the hazards of place (risk and mitigation) with the social profile of communities” (Cutter 1993).
- “Vulnerability is defined in terms of exposure, capacity and potentiality. Accordingly, the prescriptive and normative response to vulnerability is to reduce exposure, enhance coping capacity, strengthen recovery potential and bolster damage control “(Watts and Bohle, 1993).
- “By Vulnerability we mean the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone’s life and livelihood are put at risk by a discrete and identifiable event in nature or in society” (Blaikie et al., 1994).
- Vulnerability is the “differential susceptibility of circumstances contributing to vulnerability. Biophysical, demographic, economic, social and technological factors such as population, ages, economic dependency, racism and age of infrastructure are some factors which have been examined tin association with natural hazards” (Dow and Downing, 1995).

Cutter et al. (2003) pointed out that there are several factors that influence social vulnerability that in return will influence the post-perturbation losses. Those factors include lack of access to resources (material, food, information and technology); limited access to political power, social capital, beliefs and customs, age, type and density of infrastructures as well as other characteristics that identify special needs population; physically and mentally challenged, etc (Cutter et al. 2003).

Watts and Bohle (1993) also defined social vulnerability, as in form of causal structure, that it is “*a multi-layered and multi-dimensional social space defined by the determinate political, economic and institutional capabilities of people in specific places at specific times*”. This creates the notion of relationship between the different stakeholders in the system, the government actions and strategies, the different applied policy and the overall system vulnerability and sustainability.

Furthermore, Watts and Bohle (1993) pointed out the need to research and understand the host communities' entitlement, empowerment, and enfranchisement as they are related to the social vulnerability. Entitlement is the most commonly used approach in understanding vulnerability of individuals or households to extreme events and has been widely and effectively used in explaining severe food crises specially in radical shift of food entitlements (de Waal 1989 Shepherd 1988, Dreze and Sen 1989). To this end, vulnerability in terms of entitlement can be defined as the risks associated with the threat of large-scale entitlement deprivation. This can be easily adapted to food, shelter, water and any other essential basic needs and resources to sustain the host community.

The second proposed approach by Watts and Bohle (1993) is empowerment and enfranchisement, which is in the heart of political decisions and theories of power. Through this approach, vulnerability can be defined as a political space and as a lack of rights that are broadly understood and recognized. For example, hunger is a massive violation of the most basic human rights, and it is considered as an imposed violence on the powerless (Watts and Bohle 1993). Watts and Bohle (1993) elaborates more that indeed reduction in vulnerability requires some changes in entitlements, but these enhancements can only be applied through political powers. Ribot (1995), adopting this approach, stated that "State policies have played major roles in both security and vulnerability through their effects on resource access and population movements". Thus, enfranchisement is considered an important element in understanding vulnerability. Enfranchisement is referred to "*the degrees to which an individual or a group can legitimately participate in the decisions of a given society about entitlement"* Appadurai (1984).

Recognizing the above, empowering the stakeholders of the host community in the decision-making processes increases the overall system resilience, decrease its vulnerability and maintain a healthy sustainable development. Recent sustainable infrastructure development in addition to sustainable disaster recovery studies suggest that in order to achieve a successful infrastructure development or recovery that meets the need of the society, a broad community involvement and participation is needed at both the planning and implementation phases (Eid and El-adaway 2016a, Haimes 2102, Smith and Wenger 2007, Olshansky et al. 2006). Moreover, as permanent construction constitutes an important part of sustainable development of the different infrastructure systems, poor decision making during the planning and construction processes – due to lack of empowerment to the systems' users - can increase societal vulnerabilities. It is suggested that an effective and efficient infrastructure development plan should be based on broad community involvement, readily available information to create policies and instill actions, horizontal and vertical coordination between associated organizations, action-oriented procedures, continuous assessment and evaluation strategies, and adequate funding sources (Smith and Winger 2007, Olshansky et al. 2006, Mileti 1999). Nevertheless, it seems planning efforts remain weak at all federal, state, and local levels. For example, in response to natural and/or human-caused hazards, local governments might seem unaware of the potential of sustainable recovery due to their close concentration on the physical/financial/emotional sides of the disaster.

Cutter et al. (2008) pointed out another challenge; how to construct a measuring technique for resilience and vulnerability concerning its different aspects. The conditions that defines resilience are dynamic, change through time and depend on the spatial, social and temporal scales. For example; a society that adopts certain types of mitigation plans may be more/less resilient to natural disaster compared to other societies adopting the same plan due to the different social structure.

As such, several social vulnerability and resilience models and indicators were developed in both context, natural disaster and built environment sustainability. The following sub-sections illustrate some of those models indicators.

2.2.1.1. Social Vulnerability Index (SoVI)

Cutter et al. (2003) proposed a social vulnerability measuring index which is an integrated part of Cutter (1996) proposed framework. The Social Vulnerability Index (SoVI) is an attempt to fill the knowledge gap of the social vulnerability metric analysis in the United State. As the authors stated "*socially created vulnerabilities are largely ignored, mainly due to the difficulty in quantifying them, which also explains why social losses are normally absent in after-disaster cost/loss estimation reports*".

SoVI is considered the most widely recognized social vulnerability assessment model in the social science field (Eid and El-adaway 2015). SoVI is a comprehensive socioeconomic and demographic model that assess the host community's vulnerability to disaster based on the community socioeconomic specific data. SoVI measures the relative vulnerability of the host community to hazardous events based on their specific data. The socioeconomic variables including: income, age, household values, education attained, percentage of mobile homes, etc. The socioeconomic data can be categorized mainly under: social equity, economic standard, adaptive capacity, occupation, and ethnicity.

Utilizing multivariate analysis, factor analysis and principal component analysis, SoVI can underline the socioeconomic factors that develops the social vulnerability of the studied region.

Moreover, scoring those factors will create relative vulnerability indices between the different regions understudy. The utilization of factor analysis and principal component analysis allow for the calculation of such relative vulnerability scores among the different regions under study. Even though the interpretation of the factors produced from factor analysis is subjective (Yang and Bozdogan, 2011), this relative vulnerability scoring approach nominates the SoVI to be integrated into the infrastructure development decision support tools in order to optimize the redevelopment strategies depending on the relative vulnerability of the different regions. The following sections discuss the socioeconomic attributes discussed introduced by Cutter et al. (2003).

The first attribute consists of; Personal Wealth, identifies the individual wealth for each county per capita income, percentage of households earning more than $75,000 per year, median house values, and median rents. Wealth surely would affect vulnerability; as lack of resources will decrease the society's recovery and will affect its resilience to the disaster. Moreover, sufficient wealth will enable the community to recover and absorb the damages created by the disaster in more efficient manner.

The second social vulnerability attribute consisted mainly of age, which contains two demographic groups, children and the elderly, as they are the most vulnerable to shocks and will affect the social vulnerability.

Single-Sector Economic Dependence attribute describes regions that are relying on one economic sector for its income generation like fishing, oil development and agriculture. Those regions may have better income and prosperity, but when a perturbation happens, the impacted regions take more time to recover from the losses and regain production levels making them more vulnerable to shocks and hazards.

The nature of the housing stock, ownership, and location produce the Housing Stock and Tenancy factor that is an important component of vulnerability. For example, the destruction of small and mobile homes is potentially greater in rural areas than urban ones. However, the displacement of affected population in urban regions will most probably be greater than rural ones.

Cutter et al. (2003) also pointed out that "Race contributes to social vulnerability through the lack of access to resources, cultural differences, and the social, economic, and political marginalization that is often associated with racial disparities". The authors also noted that such attribute correlates more with African-American female headed households whom are the most vulnerable to hazardous events. Ethnicity, like race, contributes to vulnerability and mostly correlates to Hispanic and Native American.

Another attribute is Occupation. Several previous literatures suggest that this factor affects the vulnerability level of societies. The factor distinguishes counties based on occupation especially lower wage services. As a result, the regions that are more dependent on those occupations are more likely to suffer impacts from disasters and will have lower recovery and adaptation behavior. The last attribute is a hybrid one that takes into account large debt to revenue ratio and percent employed in public utilities. The revenue generating capability of a region indicates its ability to effectively use resources for mitigation and rapidly recover from a hazardous event.

Upon implementing the SoVI on the U.S. counties, the authors indicated several findings including; (1) majority the counties within the United States have moderate levels of social vulnerability, (2) the southern half of the States are mostly more vulnerable stretching from south Florida to California, and (3) a total of 393 counties were classified as the most vulnerable counties (Cutter el al 2003).

Cutter et al. (2006) studied the SoVI as well as space vulnerability for the regions affected by hurricane Katerina in August 2005, which impacted around 90,000 square miles, killed more than 1,300 people and cost the nation more than $80 billion (FEMA 2005). Interestingly, hurricane Katrina was not the strongest storm of this season – compared with hurricane Rita and Wilma by wind speeds and central pressures – which implies that the natural disaster by itself is not the only cause of loses either in human lives or infrastructure, rather than it is the "combination of natural forces and human failures". The authors debated that the human factor who are socially vulnerable due to marginalization and lack of power, was the main reason for human loses as much as the space vulnerability caused structural damages. Or in other words, the combination of physical hazard with the social inability to adequately rebound from the disaster events reduce the resiliency of such communities and cause the most hardship for residents.

The work presented by the Cutter et al. (2006) is divided into two main parts, space vulnerability and social vulnerability. The authors pointed out the space vulnerability of Louisiana and Mississippi to hurricanes that contributed for about 50 percent of the states total losses from natural hazards in the last 50 years. Hurricane Betsy (1965), Hurricane Camille (1969), Hurricane Andrew (1992), Hurricane Opal (1995) and Hurricane Georges (1998) were all among the costliest hurricanes in the U.S. with over than a total of $34.6 billion. However, Hurricane Katrina cost more than them all combined, both in terms of infrastructure losses and fatalities.

On the social vulnerability, the authors addressed that the poor, uneducated, young and old people are the most vulnerable to disaster as well as being the slower in recovery as a result of "marginality that makes their life a permanent emergency" (Bankoff 2004), and that Hurricane Katrina exposed the social vulnerability of the coast community especially for New Orleans. For example, in the evacuation of New Orleans, the poor could not comply with the evacuation orders as hurricane Katrina struck the region two days before the pay check would arrive, leaving them unable to pay for transportation. Moreover, in the process of reconstruction and recovery, the poor marginalized communities of African Americans and Asians who cannot afford insurance for their homes, waited more time for the government to rebuild their homes, in comparison to the rich who had extra resources.

2.2.1.2. Social Vulnerability and Resilience Metrics (Burton 2010)

Adopting Cutter et al. (2003) SoVI framework, Burton (2010) proposed a social vulnerability and resilience metrics for the Hurricanes impacts that addresses the missing link between hurricane physical losses prediction models, social vulnerability and society component with a reflection on the overall built environment sustainability. Burton divided vulnerability into three main; (1) exposure, which is the physical risk of being within the proximity of the disaster; (2) sensitivity, the percentage or degree of people and places that can be harmed; and (3) adaptive capacities, the ability of the current system to adjust, mitigate and cope with disturbance. The model development consisted of five components; (1) surface wind analysis; (2) storm surge inundation component; (3) index of social vulnerability, (4) FEMA hurricane Katrina damage assessment layers; and (5) FEMA residential damage estimations (Burton 2010).

Due to limited availability of data, only 32 variables socioeconomic, demographic and built environment were used. Positive and negative directional values were assigned to factors indicating their increase and decrease of vulnerability, respectively. All the components were input into the model allowing for visual and quantified representation of social vulnerability across the studies areas.

The model results show that the physical storm parameters are the main factor of hurricane impact at all damage categories. Regarding the hurricane Katrina case study for Mississippi's counties, Waveland and Hancock were found the most residential structures damaged counties. However, social vulnerability and resilience are significant at the extensive and catastrophic levels and in respect to hurricane Katrina case study in Mississippi's counties, Hancock, Harrison and Jackson were found the most socially vulnerable to hurricanes given their socioeconomic, demographics and built environment.

2.2.1.3. Disaster Resilience of Place (DROP)

Realizing the challenges in identifying standards and metrics for measuring disaster resilience (socially, economically, physically, etc.) as well as overcoming the drawbacks in the existing vulnerability and resilience models, Cutter et al. (2008) proposed Disaster Resilience of Place (DROP) model. The objective of the model is to present the relationship between vulnerability and resilience by proposing a framework for future work regarding social system resilience and vulnerability to natural disasters (Cutter et al. 2008). Adaptive capacity, which is considered sometimes a subset of vulnerability or/and resilience is defined as the system's ability to adjust to changes, moderate the effects, and cope with a disturbance (Burton et al. 2002, Brooks et al. 2005).

Cutter et al. (2008) also illustrated the dynamic framework of DROP. The model consisted of Antecedent Conditions that are the product of the natural system of the studied region combined with social system and built environment. This structure determines social resilience and vulnerability. The Antecedent Conditions interaction with the hazardous event creates immediate effects on the system depending on the events characteristics of rate, magnitude, duration and intensity. Depending on the coping responses of the system – which is a function of the antecedent condition - the hazardous events impact is amplified or reduced to create the disaster impact. The coping includes the presence or absence of predetermined evacuation plans, shelters and, emergency response plans.

Depending on the cumulative outcome of the antecedent conditions, event characteristics and coping responses, the overall local impact is calculated and can then be moderated by the system absorptive capacity (Cutter el al. 2008). The absorptive capacity – which include the availability of resources to maintain the system functionality – is then checked if it is exceeded or not. If the absorptive capacity is exceeded then the system has a low degree of recovery, thus will take the overall system a long period to recover from the perturbation. If the system's absorptive capacity was not exceeded, then the system has a high degree of recovery, meaning it will recover in a faster rate and with less to none external resources.

Nevertheless, both degrees of recoveries allow the overall system for potential learning and gaining new experiences as well as changes in the adaptive resilience that influence the society and the built environment. This is carried out through mitigation of the current condition, mitigation plans and preparedness for the next events.

2.2.1.4. Host Community's Vulnerability Framework

Turner et al. (2003) proposed a framework for vulnerability analysis in sustainability science perspective for coupled human-environment systems. Realizing the importance of vulnerability analysis for sustainability and that vulnerability is based on a multifaceted coupled system that are connected in operations through different spatiotemporal scales, the authors presented a framework to provide a template "reduced form" vulnerability analysis that includes large systemic character of the human-environment coupled system. The authors debated that reduced form of vulnerability analysis is considered beneficial in comparison to vulnerability analysis that considers totality as they are not realistic. In real world, data sometimes are needed to be in a reduced form to be fully understood and carefully analyzed.

Turner et al. (2003) framework presented the complexity and interdependencies in the vulnerability analysis, due to various factors and links that may affect vulnerability in a coupled human-environment system. The model consists of; (1) links between human and environment; (2) perturbations and stress that may emerge from the links and their conditions; and (3) the coupled human-environment system including exposure and responses.

Different elements were selected by the authors as essential for any vulnerability analysis, especially in the sustainability perspective. These elements are used in the framework proposed as well as a guide for other research. The elements are; (1) taking into account different interacting perturbations and stresses; (2) considering the manner in which the coupled system experiences hazards; (3) measuring the human-environment coupled system sensitivity to the exposure; (4) accounting for the system's resilience in coping and responding to hazards and recovery; (5) allowing for the system's restructuring after response; and (6) taking into account the nested scales and scalar dynamics of hazards, the coupled system and their responses.

2.2.1.5. Technical, Organizational, Social and Economic (TOSE)

Another resilience framework was introduced by Tierney and Bruneau (2007) called TOSE – Technical, Organizational, Social and Economic – that aims to understand the variables and dimensions that affect resilience to help in defining and achieving acceptable levels of loss, disruption and system performance when a disaster strikes (Tierney and Bruneau 2007). The framework is part of the Multidisciplinary Center for Earthquake Engineering Research (MCEER) and based on realizing that resilience is both an inherent strength and ability to be flexible and adaptable after a disaster event considering cross disciplinary treatment (Tierney and Bruneau 2007). TOSE framework makes use of another resilience framework – R4 – developed by MCEER that is needed to be introduced first to fully understand the TOSE model.

R4 consists of four elements Robustness, Redundancy, Resourcefulness and Rapidity. Robustness is considered the ability of the system or the system's elements to tolerate and endure a disaster without a performance losses of the system. Redundancy is the sustainability of the system or system's element if a significant loss of functionality or performance occurs. Resourcefulness is the ability of the overall system to identify the problems and utilize the available material, information, and human resources to solve the most demanding problems. Rapidity is the ability of the system to avoid disruption through restoring the functionality of the system.

The four dimensions of the TOSE model (technical, organizational, social and economic) are described by the authors as followed; Technical domain refers mainly to the physical properties of the system which also include the system's ability to withstand damage and function loss, this includes the system's redundancy; Organizational resilience is related to the organizations and institutions that controls and manage physical components of the system. This also measures the capacity of the system to plan and train the information management to improve performance of the organization to disaster-related problems (Tierney and Bruneau 2007).

Tierney and Bruneau (2007) also pointed out that in measuring the organizational resilience, one must consider both physical components such as emergency operations centers, communication technology and emergency vehicles and the internal properties of the organizational emergency management (quality of disaster plans, ability to learn etc.) (Tierney and Bruneau 2007).

The social domain in TOSE involves the population and community properties that may conclude the community being vulnerable as well as being more or less adaptable to hazards and natural disasters. The authors suggested indicators such as poverty, low level of education, linguistic isolation and lack of access to resources for protective action as social indicators (Tierney and Bruneau 2007). The economic (local and regional) domain in this framework is considered an inherent property. These properties include the ability of the firms and business to make modification to adapt during non-disaster periods as well as their ability and capacity for post-disaster improvisation, innovation and resource substitution.

Tierney and Bruneau (2007) noted that the more limited options the communities (individuals and social groups) and business have when facing a disaster, the more vulnerable and less resilient they are. To this end, TOSE is considered another framework that strengthen the need of a holistic approach of social and community resilience model that address the problem beyond physical and organizational systems.

2.2.1.6. Deduced attributes affecting the host community's social vulnerability

To this end, five main attributes affecting vulnerability can be deduced: economic standard, equity, adaptive capacity, occupation, and ethnicity. Those factors are described below:

- Economic:

The economic subcomponent in social vulnerability is used to measure the communities' exposure to economic assets and the households' wealth. In such way, the community undergoing a disastrous event can survive, adapt and recover faster and more efficient in comparison to communities with personal wealth scarce (Blaikie et al., 1994, Tobin, 1999, Cutter et al., 2003, and Watts and Bohle, 1993). Several variables affect the social economic standard that are found in the social science with strong correlation with social vulnerability; per capita income; the percentage of high income families ($75,000 or more, as defined by Cutter et al. 2003); and median house value in dollars. These attributes can give indications to the overall community's economic standard.

- Equity:

The social equity measures the communities' resourcefulness. Resourcefulness is found to be a key factor in the social vulnerability to disaster events (Smith and Wenger, 2007, Watts and Bohle, 1993). Communities that have access to resources - i.e. transportation, communication, shelter, etc. – can cope with disasters and sudden shocks in the systems' functions. Moreover, the quality of assets is also important; for example, even though mobile homes are considered assets, it can affect the social vulnerability as they are of poor quality in resisting hazardous events. To this end, several variables were drawn from literature that are commonly used in the social science to measure communities' equity that are related to social vulnerability. The variables are; percentage of the population with vehicles, percentage of home ownership, percentage of mobile homes, percentage of population with telephone access and percentage of the population living in high intensity urban areas.

- Adaptive Capacity:

The social adaptive capacity is pointed out several times in the literature in terms of social vulnerability to disasters (cutter et al. 2003, Tuner et al. 2003, Cutter 2008, and Burton 2010). The adaptive capacity measures the community ability to respond to hazardous events. This include several variables; for example, age, disabilities, education level, etc. To this end, variables that are used in the social science research to define the adaptive capacity and are found to be correlated with the social vulnerability are; percentage of the population with disabilities, percentage of the population that are elderly, percentage of the of the population that speak English, median age of the population, percentage of the population with high school diploma or higher and percentage of population that are female.

- Occupation:

The type of occupation is found to affect the overall social vulnerability (Cutter et al. 2003, Burton 2010, Burton 2012 and Cutter et al. 2010). As literature pointed out; the type of occupation and its correlated type of wages and salaries affects the social vulnerability. Moreover, there are types of occupation that leaves the employers at high risk of losing income in case of disaster, i.e. fishing in case of an oil spill. To this end, several variables were collected to present the overall occupation of the community that is found with high correlation to the social vulnerability; percentage of population that are not infirmed or institutionalized, percentage of population working in service occupation, percentage of population working in transportation sector and percentage of population working in extracting (fishing, agriculture, mining, etc.).

- Ethnicity:

Ethnicity, in the social science literature, explains the social vulnerability of the community. The increase of one race over the other as well as the presence of more than one race in the same community explains the social vulnerability patterns in different regions through the different research (Cutter et al. 2003, Cutter et al. 2008, Burton 2012). Different variables that measure the ethnicity of the community were drawn from literature; percentage of population that are not minority, percentage of the population that are African Americans, percentage of the population that are Native Americans, percentage of the population that are Asians, and percentage of the population that are Hispanic or Latino.

2.2.2. Economic Vulnerability and Resilience

The need for better understanding and defining economic vulnerability and resilience has long been noticed (Guillaumont, 2009; Briguglio et al. 2009, Briguglio 1995). To this effect, different attempts were carried out to define the economic vulnerability and resilience of the community as well as creating different economic vulnerability and resilience indicators.

Economic vulnerability and resilience can be addressed on three levels: (1) microeconomics; where the study of individuals' economics resilience and vulnerability takes place as this approach targets the individual, household or single firm's behavior on dealing with risk, perturbation, and hazard (2) mesoeconomics; studying different economics sectors and segments, different markets and cooperative groups' resilience and vulnerability to exogenous shocks, and (3) macroeconomics; the study of all individual units and markets in the host community understanding their interrelationships and interactive effects on the economy (Eid and El-adaway 2016b).

Microeconomics resilience is referred in general as the ability to absorb and cushion against shocks, damages, stresses, and losses (Rose 2004; Holling 1973). It is also defined as "*inherent ability and adaptive response that enables firms to avoid maximum potential losses*" (Rose 2004). Thus, microeconomics resilience has two dimensions; (1) *inherent ability*, which is the ability under normal circumstance to deal with exogenous shocks; and (2) *adaptive response*, which is the ability in crisis to cope due to ingenuity and exerting extra efforts (Rose and Liao 2004).

Through the literature, it was found out that the infrastructure development affects microeconomics (as well as macroeconomics) vulnerability. Chandra and Thompson (2000) illustrated that infrastructure development increased counties' retail services industries earning revenues by 5-8% as well as framing by 10-30%. This also contributes to the counties' total revenue which increased in the case studies by 3-10%. Cohen et al. (2012) also pointed out that the construction of new non-residential structures contributes up to $1.96 of total estimated impact on the various economic sectors per dollar expenditure. To this end, the infrastructure development impacts the micro and meso economics vulnerability by contributing to the micro and meso economic variables of the host community.

On the other hand, Guillaumont (2009) defined macroeconomic vulnerability as "*the risk that economic growth is reduced markedly and extensively by shocks*". It was also referred that vulnerability is the likelihood of negative and long lasting adverse effect on the reduction of poverty in a given region due to an exogenous shock. In Guillaumont approach to vulnerability, three components where defined; shocks; exposure and resilience.

Guillaumont definition of vulnerability is in line with Briguglio et al. (2009) where economic vulnerability is defined as "*the exposure of an economy to exogenous shocks, arising out of economic openness*". On the other hand, economic resilience was defined by Briguglio et al. (2009) as the "*policy-induced ability of an economy to withstand or recover from the effect of exogenous shocks*". This underline the region's economic resilience is the ability to (1) recovery quickly from perturbations and shocks, and (2) endure the shocks' effects.

Shocks can be either natural (environmental) or external (i.e. world commodity price instability, international fluctuations in interest rates, etc.). Exposure to shocks depends on the regions properties; community's size, structure, and GPD. Guillaumont (2009) also pointed out that fragmentation and polarization of the community affect their economic vulnerability as it leaves them more exposed to risk (Arcand et al. 2002; Rodrik, 1999). Resilience (or capacity to react) in this context depends on economic policies and how easily they are reversed.

Briguglio et al. (2009) identified main components that constitute each of the macroeconomic vulnerability and resilience. For macroeconomic vulnerability; (1) a country economic openness (as measured by the ratio of international trade to the GDP) renders the country vulnerable to external perturbations; (2) export concentration, or depending on narrow range of exports, will increase the country's economic vulnerability; and (3) the dependence of strategic imports, like food and energy resources, affects the country's economic stability and vulnerability to exogenous economic disturbance.

On the other hand, the two components for macroeconomic resilience consists of (1) the ability to recover from adverse shocks, which is governed by the country's economic flexibility as part of their policies, and (2) the ability to withstand shocks (economic shock absorption). In this fashion, Briguglio et al. (2009) defined the macroeconomic risk of a region as a simple function of vulnerability and resilience, where economic risk is the different between economic vulnerability of the region and its economic resilience. To this extent, macroeconomic vulnerability is considered as the inherent properties of the region while resilience is "nurtured" and developed through their policies and strategies.

To this effect, Briguglio et al. (2009) categorized regions (countries) into four categories, depending on their inherent economic vulnerability and their nurtured resilience; Worst case, Best case, Self-made and Prodigal son. Worst case are countries with high vulnerability and adapting policies and strategies that decrease their resilience. Best case are countries that has minimal to no inherent economic vulnerability, yet still utilize policies that increase their economic resilience. Self-made category includes countries with high inherent economic vulnerability but they increased their resilience through adapting policies and strategies that increase their economic resilience to perturbations. Finally, Prodigal son category include countries with relatively low inherent economic vulnerability but are adapting policies that deteriorates the communities' economic resilience (Briguglio et al. 2009).

Nevertheless, researchers were challenged to quantify and measure the economic resilience and vulnerability (micro, meso and macro) throughout the last decades (Rose and Liao, 2004). Such challenges can be divided into three levels; (1) conceptual, where decision makers require the generalized actions that provide resiliency, that sometimes are not feasible as each region is unique with different inherent resiliency and vulnerability properties; (2) operational, modeling the different individuals, entities and community stakeholders within the same single framework is a laborious task, which this research is attempting to achieve; and (3) empirical, it is often hard to find and gather the required data to adequately evaluate the economic vulnerability and resiliency of the host communities.

The following section illustrates some of the models developed in attempt to assess the communities' economic vulnerability within the perspectives of infrastructure sustainability in addition to sustainable disaster recovery. Nevertheless, these models mostly fall in the country to large state category (macroeconomics).

2.2.2.1. Economic Vulnerability Index (by Committee for Development Planning - CDP)

The Economic Vulnerability Index, a macroeconomics vulnerability index, was developed as a recommendation by the Committee for Development Planning (CDP) after the report to the UN General Assembly in 1996. The priority was giving to both Small Islands Developing States (SIDS) and Least-Developed Countries (LDS). The index was first applied in 2000 as a criterion for identifying the economic vulnerability in LDS. However, major revisions and adjustments were made in 2006 (Briguglio et al. 2009; Briguglio 1995)

The current Economic Vulnerability Index consists of seven main sub components: economic openness, export concentration, dependence on strategic import, macroeconomic stability, market efficiency, good political governance, and social development (Briguglio et al. 2009). The model is able to explain the reasons behind some of the vulnerability of small islands states – in their exposure to risk – that could generate far more GDP per capita than expected. This was due to their inherent resilience as well as their policies (Briguglio et al. 2009). However, the model only assesses the macroeconomics vulnerability. Thus, it fails in capturing the community economic vulnerability; micro and meso economic vulnerability.

2.2.2.2. Economic Resilience Index for OECD Countries

Observing and understanding the global financial crisis and associated high economic costs, the Organization for Economic Co-operation and Development (OCED) developed an economic resilience index that claims to address the OCED economic vulnerability and resilience concerns. Through reviewing 70 indicators that affects the countries' economic vulnerability, the indicator is sub-categorized into: (1) financial sector imbalances, (2) non-financial sector imbalances, (3) assets market imbalances, (4) public sector imbalances, and (5) external sector imbalances (Röhn et al. 2015).

The proposed assessment model assumes that none of the imbalances should be examined on its own, but rather they should be concurrently studied as they interact and reinforced each other. To this effect, the model is claimed to enable the policy makers to detect the counties' vulnerabilities to perturbations on early stages.

Nevertheless, the developed model focuses on the macroeconomics vulnerability rather than the communities' micro and mesoeconomics vulnerability based on their specific data. The model does not propose the methodology for unavailable data or inapplicable indicator.

2.2.2.3. Economic Resilience to Disaster

In continuation of a long and thorough literature in regard to microeconomic resilience and vulnerability to hazard, Adam Rose (2009) proposed an economic resilience assessment tool as part of the Community and Regional Resilience Institute (CARRI). In this approach, economic resilience is divided into static and dynamic economic resilience. Static economic resilience is defined as "*the ability of an entity or system to maintain function when shocked*" (Rose 2009, Rose 2007). This term was coined static as it can be achieved without repair or reconstruction while it can affect the current and future economic vulnerability and resilience. Meanwhile, dynamic economic resilience is defined as "*the speed at which an entity or system recovers from a severe shock to achieve a desired state*" (Rose 2009). Understanding the complexity in disaster recovery, this term is used for the sole purpose of defining the system ability and rate of bouncing back to an equilibrium and stability.

The model assesses the aforementioned two dimensions of economic resilience (static and dynamic) through a mathematical model. This is carried out through the Direst Static Economic Resilience (DSER) which address a firm-level economics, and the Total Static Economic Resilience (TSER) which address the macroeconomics of the region.

Nevertheless, the mathematical model does not consider the community specific data, but rather measures the economic resilience (static and dynamic or micro and macro) as the change in production rate. Moreover, the model requires significant assumptions to develop the baseline for the model assessment. Such assumptions are subjective and can be abused to give favorable indicators.

2.2.2.4. Economic Resilience to Natural Hazards

Understanding the close relationship between disaster recovery and the economic resilience and vulnerability, Burton (2015) proposed statistical assessment of the community's economic resilience. In this approach, the inherent vulnerability and inherent resilience are the focal point, as they provide for preexisting and measurable traits of the community. Thus, through assessing those traits, the economic vulnerability and resilience can be reveled and thus furtherly addressed.

The model's approach is similar to SoVI, where the methodology consists of: (1) identification of relevant variables, (2) multivariate analyses, (3) aggregation, and (4) linking variables to an eternal validation metric. To this effect, the model development adopted the post-Katrina recovery in three coastal counties in Mississippi; Hancock, Harrison and Jackson. 14 economic variables were gathered for the aforementioned counties that are justified in the literature (i.e. percentage of homeownership, mean sales volume, ratio of small to big businesses, etc.). Such variables contribute to the community's micro and meso economic vulnerability. The model utilizes multivariate analysis to measure and assess the community's relative economic vulnerability to perturbations and natural disasters. To validate the model, the economic indicator was statistical compared to the disaster recovery data for the three counties in the years after Hurricane Katrina.

The model is able to measure the community's specific data in regard to micro and meso economic vulnerability. The utilization of multivariate analysis creates a relative vulnerability assessment that makes it optimal for infrastructure redevelopment decision makers to allocate the funds depending on the most vulnerable regions. However, the model development requires the gathering of a large set of data as well as thorough validation, which makes it hard to be replicable to other regions without custom made modifications.

2.2.3. Environmental Vulnerability and Resilience

"*Silent Spring*" by Rachel Carson (1962) debated the human-activities adverse effects on nature and the built environment. Silent Spring is considered one of the leading literature that illustrated the vulnerability of the environment and the dire need for sustainable actions in our host communities' development (Eid and El-adaway 2016a). Thus, several research was carried out in the last decades to identify and quantify the environmental vulnerability, resilience and, sustainability of the host communities.

On addressing the environmental vulnerability and resilience, different terms and directions take place. From an ecological point of view, Nelson et al. (2007) defines environmental resilience as the amount of change a system can undergo without losing functionality and structure while maintaining the ability to develop. From an environmental vulnerability perspective, three aspects of the problem should be addressed: (1) the natural resilience to perturbations, (2) the risk of hazard, and (3) the acquired resilience/vulnerability to damage that would increase future vulnerability due to past events (Eid and El-adaway 2016a, Pratt et al. 2004).

The vulnerability of the environment is a main factor in the infrastructure sustainable development of the host community (Eid and El-adaway 2016a). The environment provides the necessary resources for the infrastructure development, that eventually affects the community welfare. In return, the host community (residence, business, industry, etc.) may adversely affects the environment (through intensive utilization of natural resources or through pollution) that leaves it more vulnerable to perturbations and shocks (Eid and El-adaway 2016a). Meanwhile, the increasing rate of natural hazards exposes the environment to more shocks and increases its vulnerability (Eid and El-adaway 2016a). To this effect, the host community's environment is vulnerable to both internal and external influences (Pratt et al. 2004).

Since the 1990s, several indices have been developed to measure the environmental vulnerability and sustainability. The following sub-sections discuss three of the most recognized contributions to the literature in regard to environmental sustainability and vulnerability measurement; (1) Ecological Footprint, (2) Environmental Sustainability Index, and (3) Environmental Vulnerability Index.

2.2.3.1. Ecological Footprint

Introduced by Wackernagel and Rees in 1997, Ecological Footprint (EF) is considered one of the first and pioneering attempts to quantify the communities' sustainability and environment vulnerability to human activities. EF was introduced as a mean to overcome the shortage in the prevailing economic approaches that encourage the investment in "*natural capital*" (Wackernagel and Rees 1997); which would eventually lead into the depletion of the natural resources.

Wackernagel and Rees argue that (1) marginal prices based models cannot reflect the host communities' ecological necessities, (2) risk pooling behavior in the host community's economics encourage resource liquidation and depletion, and (3) local and global trades undermine ecological stability. EF objective is to create a measurement tool for the human demand and pressure on nature through assessing how much the biological productivity of the land and sea is needed to sustain the host community's consumption. EF was adopted by a number of government and private organizations as an ecological performance measure (Environment Waikato, 2003; EPA Victoria, 2003; WSP Environmental and Natural Strategies, 2003, NRG4SD, 2004).

Wackernagel and Rees (1997) in developing and introducing EF defined the term "*natural capital*". Generally, it is considered as the biophysical resources and wastes needed to maintain the host community functionality in addition to the relationship between the entities and processes that provides life support to the ecosphere. The utilization of monetary values as the sole measure of natural capital persistence inappropriate from an ecological perspective. This is a reflection to the fact that a change in dollar value of a given resource may result in the depletion of the stock and its functionality (Wackernagel and Rees 1997). Thus, there is a need to understand the amount of occupied natural capital by the host community to maintain the biophysical goods and services, and the required level to be utilized to keep the host community's functionality without compromising the future production and needs.

Any nation's or region's EF corresponds to the agglomeration of the land and water districts that are – in continuous basis - able to (1) produce resource for the host community productivity or (2) absorb the waste generated from the community's consumption using the prevailing technology. To this effect, calculating EF basically requires the following steps considering each product category (fishery, forestry, agriculture… etc.):

1. Calculation of Footstep

Consumption X Equivalence Factor / Global Yield

2. Calculation of Bio-Capacity

Bio-productive area X Yield Factor X Equivalence Factor

3. Calculation of the Ecological Balance

Bio-Capacity – Footprint

If an Ecological Balance is greater than unity, then it is considered a stable system. While otherwise, i.e., footprint is greater than the bio-capacity, this implies that the system demands exceed the regenerative capacity of the natural capital, thus this system is unstable and unsustainable.

Nevertheless, this approach has several drawbacks. EF was widely criticized for not allocating responsibility (McGregor et al., 2004; Herendeen, 2000). The EF approach does not account for time and the dynamic nature of the resource utilization which increased the criticism on reflecting the consumption impact accurately (Wiedmann et al. 2006). The unstandardized utilization of data made the EF's results comparability harder. In addition, gathering of data for small regions with small population is comparatively difficult which increases the EF's results inaccuracy. This rendered the model to be less useful for the policy makers (Ferng, 2002; Moffat, 2000; van den Bergh and Verbruggen, 1999).

2.2.3.2. Environmental Sustainability Index

Environmental Sustainability Index (ESI) is the result of the collaboration between the World Economic Forum, Center of International Earth Science Information Network, Columbia University, and Yale Center for Environmental Law and Policy (Esty et al. 2005). It was developed to measure the overall environmental sustainability of 142 countries. The first ESI was published in 2001 and followed by 2002 and 2005 versions and editions that attracted popular media (Siche et al., 2008). ESI is considered as an evaluation of the host community's ability to maintain the value of the environment while still managing the challenges from the ever-changing environmental conditions (Esty et al. 2005). ESI assesses the countries' environmental sustainability based on 21 indicators that aggregate the observations of 76 variables.

On developing ESI, five dimensions were considered; (1) environmental system (air, water, land and biodiversity); (2) stresses (excessive usage of natural resources or pollution); (3) human vulnerability; (4) social and institutional capacity (the capacity of coping and dealing with environmental challenges); and (5) global stewardship (sharing the global responsibilities towards the environment). Being a multi-dimensional concept, the ESI addresses the ability of the host communities' system to maintain the environmental assets value over the next several decades and being able to cope and manage the future needs and demands that emerges from the ever-changing environmental conditions (Esty et al. 2005).

According to the ESI 2005 methodology manual (Esty et al. 2005), ESI calculation methodology consists of the following six steps:

1. Country selection criteria

   The selection of countries for the study depends on: (a) the country size and population, countries must be of land area more than 5,000 square kilometers and more than 100,000 capita; (b) variables coverage within the country, countries should not be missing more than 45 observations of the 76 requested data points; and (c) indicator coverage, ability of the country to observe and cover all the 21 ESI indicators.

Note: ESI study was also carried out on number of small countries and states in a separate study (Siche et al 2007). This qualify ESI for measuring different countries and regions with different sizes and scales.

2. Variable standardization for cross-country comparisons

   To facilitate the aggregation of the variables and make sensible comparison across the different regions, data are standardized to an appropriate denominator, i.e., GDP, agriculture GDP, population density, etc.

3. Variable transformation

   To account for the different data distribution and skewness, different variable transformation procedures are utilized.

4. Multiple imputation of missing data

   Utilizing the Markov Chain Monte Carlo (MCMC) technique, the ESI can account for the missing data across the 76 variables.

5. Data Winsorization

   To avoid the domination of extreme values on the data set, the ESI methodology Winsorize, or trim, the tails of the variables' distributions.

6. Data aggregation and weighting

   The aggregation of the 21 variables is carried out using the *Weighted Sums* methodology.

ESI is considered one of the most widely recognized sustainability and vulnerability assessment tool in the environmental domain. Moreover, the ESI showed significant relationship to the ecological footprints' results (Siche et al. 2008).

2.2.3.3. Environment Vulnerability Index

The Global Summit on Small Island Developing States in Barbados in 1994 highlighted the need for better understanding of the relationship between sustainability and vulnerability (Eid and El-adaway 2016a). This started the development of the Environmental Vulnerability Index (EVI) by the South Pacific Applied Geoscience Commission (SOPAC) with the support of Ireland, Italy, New Zealand, Norway and the United Nations Environment Programme (Eid and El-adaway 2016a, Pratt et al. 2004). Even though the EVI was intended to be utilized for the small developing islands, it was tested, validated, and applied to different other scales (Eid- and El-adaway 2016a, Villa and McLeod 2002).

EVI has a unique approach in assessing the environmental vulnerability of the host communities. Unlike other vulnerability assessments, EVI considers the environment as the recipient of the different development activities and that the human interaction with the environment is an exogenous factor (Eid and El-adaway 2016a, Barnett et al. 2008). Accordingly, the built environment is considered as an integrated part of the ecosystem and not merely a responder (Villa and McLeod, 2002). Thus, EVI captures the overall environmental vulnerability of the host community and not just the human built environment.

The EVI is developed upon four main assumptions:

1- The environment is less vulnerable and more resilient when less damage (or undamaged) environment exists.
2- The natural environment that is in good condition would serve the human community better.
3- The host community human behavior, choices and socioeconomic conditions are an integrated part of the environmental vulnerability.

4- Some indicators may be found to summarize the complex host community processes that which vary in their final values and with largely immeasurable details, which are of interest in the system being measured.

EVI evaluates the environmental vulnerability of a region to internal and external hazards utilizing 50 “smart indicators” (Eid and El-adaway 2016a). Those indicators summarize the various factors and variables that directly affect the host communities’ environment vulnerability. (Barnett et al. 2008). The indicators are summarized in Table 2.1. Each of the smart indicators is assigned to one of the following three categories; hazards, resistance and damage (Eid and El-adaway 2016a). The Hazard category, which is also referred to the risk exposure, evaluates how the environment is at risk to natural and man-made events. This category accounts for both the frequency and the intensity of the different events that adversely impact the environment. The inherent/internal properties and the ability of the environment to cope with shocks is evaluated through the Resistance category. Finally, the Damage category evaluates the impact of the external forces on the degradation of the environment. As such, a more vulnerable environment will be a result to a more degraded environmental condition due to perturbations and hazards (Eid and El-adaway 2016a, Pratt et al. 2004).

Using a scalar approach, each of the 50 indicators across the three categories is assessed and evaluated. The indicators are mapped to their corresponding scales that scores them from 1 to 7, where 1 indicates the least vulnerable and most resilient and 7 is the most vulnerable and least resilient (Eid and El-adaway 2016a, Pratt et al. 2004), as shown in Figure 2.1. This approach of mapping all the different indicators onto a uniform and common scale, enables the EVI to provide a standardized measurement of the different indicators taking into account their heterogeneity; linear, nonlinear, etc. (Eid and El-adaway 2016a, Pratt et al. 2004).

Table 2.1: EVI Smart Indicators

Hazard	Resistance	Damage
1. High wind	2. Land area	3. Ecosystem imbalance
4. Dry periods	5. County dispersion	6. Introductions
7. Wet periods	8. Isolation	9. Endangered species
10. Hot periods	11. Relief	12. Extinctions
13. Cold periods	14. Lowlands	15. Vegetation Cover
16. Sea Temperature	17. Borders	18. Habitat fragmentation
19. Volcanos	20. Migrations	21. Degradation
22. Earthquakes	23. Endemics	24. Coastal settlements
25. Tsunamis		26. Conflicts
27. Slides		
28. Environmental openness		
29. Loss of cover		
30. Terrestrial reserves		
31. Marine reserves		
32. Intense farming		
33. Fertilizers		
34. Pesticides		
35. Biotechnology		
36. Productivity overfishing		
37. Fishing effort		
38. Renewable water		
39. Sulphur dioxide emissions		
40. Waste production		
41. Waste treatment		
42. Industry		
43. Spills		
44. Mining		
45. Sanitation		
46. Vehicles		
47. Population		
48. Population growth		
49. Tourists		
50. Environmental agreements		

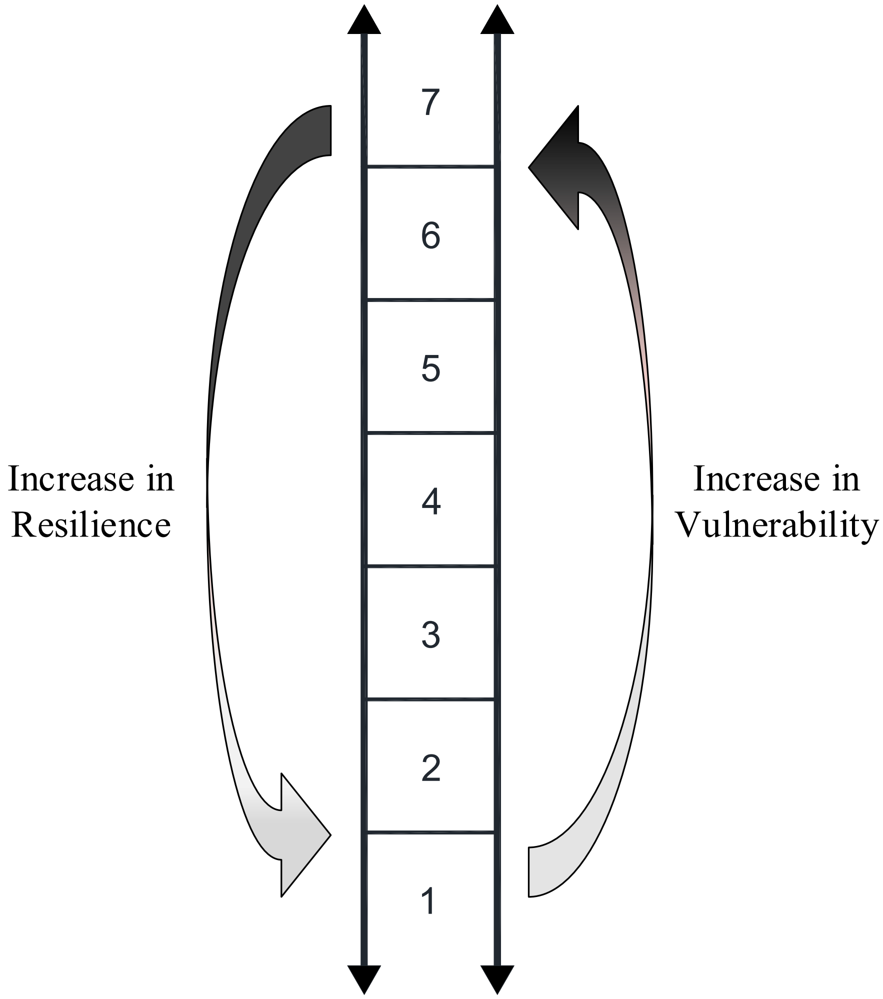

Figure 2.1: EVI Scale

The scale of each sub indicator was developed by expert committees and through consultation of the specialists in the associated fields, and after thorough revision of the existing body of knowledge. The EVI model is intended to be utilized throughout the different regions and conditions found on the planet (Eid and El-adaway 2016a, Pratt et al. 2004).

To evaluate each indicator, data needs to be gathered for the specific understudy region, and then the data is compared to predefined values for this indicator found in the EVI manual. The values of the 50 indicators can be uniformly evaluated while accounting for the indicators heterogeneity (linearity and non-linearity). For example, the Wind periods indicator, which evaluates the vulnerability to floods, cyclones, etc., is carried out by averaging the annual excess in rainfall (mm) over the past 5 years for all months with more than 20% higher than the 30-year monthly average. Then the value calculated is compared to 5.0, 9.8, 16.2. 24.2, 33.8, 45.0 (mm) that corresponds to 1 through 7 vulnerability indices, respectively.

The EVI's evaluation methodology takes into account the unavailability of the required data for one or more indicator. This can be tackled through removing such indicator(s) from the evaluation process and decreasing the average denominator by one (Eid and El-adaway 2016a, Barnett et al. 2008, Pratt et al. 2004, Villa and McLeod 2002). In addition, if one or more indicator is inapplicable (i.e., overfishing in a landlocked country) a value of 1 should be given to the associated indicator as the EVI methodology assumes its least vulnerable to this specific indicator(s) (Pratt et al. 2004, Villa and McLeod 2002). Finally, an EVI score can be obtained for each region through calculating the average value across all the utilized sub-indices.

2.3. Agent Based Modeling

Acknowledging the aforementioned research, it is noticeable the need for a holistic systematic sustainable development tool that integrates the different vulnerability and resilience indicators as well as the assimilation of the different stakeholder in the decision-making process. Such tool should account for the fine structure of the host community (socio-economic factors, vulnerability, resilience, etc.), able to mimic the different and complex interactions between the various stakeholders, and can predict the impact of the different sustainability policies and strategies imposed on the host community. Thus, said, this section demonstrates Agent Based Modeling (ABM) and simulation. ABM is utilized in this research to present the different stakeholders in the sustainable development of the host community. This method will provide the ability to capture the fine grains of the community, with their different attributes and indicators.

In 1978, Nobel Prize laureate Thomas C. Schelling published "Micromotives and Macrobehavior" that examined and illustrated the complex relationship between the individual behavior and the overall performance of a system. Throughout the book, Schelling explained the "system aggregated properties" because of a bottom-up analysis of the "individuals' characteristics" and their interdependencies. Such innovative approach led to numerous research that investigated the various systems' aggregated performance and behavior due to its stakeholders' behavior, attributes, and decision making processes (Eid and El-adaway 2016b). Utilizing the aforementioned research approach and taking advantage of the ever-growing computation power, ABM was developed. ABM is a computational approach to model the different entities of a system in form of autonomous agents and simulate their interactions and interdependencies throughout their environment (Eid and El-adaway 2016b). Such approach enables researchers to examine the overall system behavior through a bottom-up simulation.

Recently, ABM provided great advantages in understanding complex systems of systems, where the various participating entities contribute to the collective welfare of the system (Eid and El-adaway 2016a, Mostafavi et al. 2015; Crooks and Wise 2012; Du and El-Gafy 2012; El-Adaway and Kandil 2009; Miller and Page 2004; Epstein 2002; Epstein 2001; Peña-Mora and Wang 1998; and Axelrod 1986). Unlike top-down approaches, ABM builds the systems in a root-to-grass approach that enable for evaluating and capturing the systems' fine grains. "*ABM provide theoretical leverage where the global patterns of interest are more than the aggregation of individual attributes, but at the same time, the emergent pattern cannot be understood without a bottom up dynamical model of the microfoundations at the relation level*" (Macy and Willer 2002). One major characteristic of ABM is the ability to produce non-linear and emergent phenomena system based on the behavior of the system's individuals. ABM has been used to examine various real life problems in sociology, economics, engineering, biology, etc. to explain the impact of social norms, emerge of collective behavior, the standing ovation problem, civil violence, etc. (Miller and Page 2004, Epstein 2002, Epstein 2001, Axelrod 1986).

2.3.1. Agents

In an abstract point of view, anything in the built environment can be considered as an agent; residents; governments; service providers; structures; nature; etc. In such sense, agents can be either pseudo or autonomous. Pseudo players, such as environmental elements, does not have preference on their actions but rather constrained to their God given nature. On the other hand, autonomous agents, such as residents and different stakeholders in the host community, choose their actions depending on their own preferences and utility functions. To this end, research – as well as this current research – focuses on the autonomous agents to understand the complex systems.

Autonomous agents (agents from hereafter) can be in different forms; zero-intelligent; near zero-intelligent; informed; uniformed and complex agents. Padgham and Winikoff (2004) defined intelligent agents to be reactive to the surrounding changes in the environment, take actions that meet its objectives, and learn its own and others' experiences. Depending on the type of system and research scope, different research has been carried out utilizing the different aforementioned agents.

Three assumptions are made for the agents (Macy and Willer 2002):

1. Interdependent; agents influence each other through interactions and communications.
2. Follow simple rules; agents follow simple rules to take actions, either in form of norms, social habits, heuristics, etc.
3. Adaptive; agents can adapt to the changes around them learning or replications (discussed in later section).

2.3.1.1. Zero-intelligent agents

Modeling a zero-intelligent agent can be significantly beneficial for different research areas. Gode and Sunder (1993) utilized zero-intelligent agents to model the market efficiency proposed by Becker (1962) where it was observed that even though households may be irrationals, markets are quite rational. Gode and Sunder (1993) defined Zero-intelligent agents as "agents that *have no intelligence, does not seek or maximize profits, and does not observe, remember, or learn. It seems appropriate to label it as a zero-intelligence trader*".

Different economic research on market prediction had been carried out utilizing zero-intelligent agents (Othman, 2008 and Framer et al. 2004). Zero-intelligent agents may sound overly simplified as they do not provide an accurate model for human behavior. However, they provide a near accurate estimates on the market performance and efficiency as they are completely rational. Nevertheless, Zero-intelligent agents are not capable to demonstrate stakeholders that act on their beliefs, information, experience, and other attributes.

2.3.1.2. Informed and complex agents

In order to simulate informed and complex agents, different models were developed to mimic the human learning behavior. Such informed agents thus can be able to impact their objective functions through receiving inputs and taking the appropriate actions, based on learning their own and others past experience. Agents of this sort are able to simulate the human complex behavior, thus enables for prediction and evaluation of the complex system at hand. The learning modules can be divided into individual and social learning modules. The following section discusses some of the learning modules used to attain such agents.

2.3.1.3. Agents Learning Models

Agents learning behavior can be categorized into two: (1) individual; learning from one's own past experience, and (2) social; learning through communication and observing the other agents' actions and past experiences. In addition, the learning process is affected by the is the anticipation (look ahead) behavior of the agent throughout the learning process. Learning can be reactive when an agent determines which action to be utilized depending on its outcome. As such, the agent will strengthen or weaken the action utilization probability in relation to the current state. Anticipatory learning on the other hand allows the agents to estimate the impact of the actions based on the current state (Eid and El-adaway 2016a).

Various learning algorithms that depict the human learning behavior were developed throughout the last decade (Heuristic learning, Bayesian Learning, Roth Erev, Modified Roth Erev, Markov Hidden Process (MHP), Q-learning, Genetic Algorithms, Derivative Follower Algorithms, etc.). Such algorithms are the outcome of the interdisciplinary research in Artificial Intelligence, social science, phycology, and mathematics. The following sub-sections illustrates some of the individual and social learning for both anticipation and anticipatory techniques.

2.3.1.3.1. Individual learning

Reinforcement learning (RL) technique is considered one of the most recognized individual learning module utilized for agents. Reinforcement learning technique is an approach inspired by behaviorist phycology. The approach is based on rewarding/penalizing the agent while interacting with the surrounding environment to maximize their cumulative reward. In such sense, the agents not only learn from their immediate actions, but also from their experience.

2.3.1.3.1.1. Derivative-Follower Algorithm

Considered more of an adaptive method than reactive, Derivative-Follower Algorithm (DFA) was developed by Greenwald and Kephart (1999) for selecting a scalar action. DFA is considered computationally simple as it requires virtually no information. The algorithm works by experimenting the incremental decrease (or increase) of Δa in some scalar action a, and continuing to move in that direction until the observed reward falls, at which point the direction of movement in (a) is reversed.

2.3.1.3.1.2. Roth Erev Reactive Reinforcement Learning

Roth and Erev (1995) introduced a reinforced learning model based on experiments and observations of actual players in extensive game theory settings. The basic assumptions in the Roth Erev model is that humans follow two main rules in making decisions: (1) the Law of Effect (Thorndike 1898); individuals will more likely utilize the choices that led to good outcomes in the past, and (2) the Power of Practice (Blackburn 1936); individuals' learning curves start steep but tapper at the end. The model consists of two main steps that include calculating propensity and probability. Utilizing the immediate reward and the used decision action, the algorithm updates the propensity and thus strengthens or weakens the probability of the associated actions. Thus, adjusting the probability of choosing the decision actions that increases the agent's immediate reward and ultimately the objective function.

Roth Erev model initiates all actions' j propensities with unity. As such, equal chances are given to all actions $j \in K$. Each agent is then allowed to select an initial random action. The agent then observes the payoff x associated with the action, and compare it to x_{min}, which is the smallest possible payoff. x_{min} is also considered as an *aspiration level* for action j. The reward is calculated as seen in Eq. (2.1). The propensities are then updated and finally translated into actions probabilities using Eq. (2.2) and Eq. (2.3), respectively.

$$R(x) = x - x_{min} \quad \text{Eq. (2.1)}$$

$$q_j(t+1) = q_j(t) \times (1 - \phi) + \begin{cases} R(x)(1-\varepsilon) \\ R(x)\varepsilon/(K-1) \end{cases} \quad \text{Eq. (2.2)}$$

$$pr_j(t) = q_j(t) / \sum_{j=1}^{K} q_j(t) \quad \text{Eq. (2.3)}$$

where; $q_j(t)$ is the propensity of action j in time t, ϕ and ε are the forgetting and experimenting parameters, respectively, and pr is the probability distribution of action j.

The agent explores the impact of the different strategies utilizing both ϕ and ε, which balance between information exploration and exploitation. Through experiencing and experimenting the outcome of the various decision actions, the agent can weaken the probability of the poor strategies, and strengthening the probability of the most rewarding strategies. Moreover, the Roth Erev learning model can represent and illustrate the agent's learning behavior through time, and how the different actions may affect the outcome through time and not instantly.

2.3.1.3.1.3. *Bayesian Learning*

Bayesian learning is a probabilistic learning that calculates probabilities of each hypothesis, given the specific data and priories. Thus, Bayesian Learning can make predications on the actions' outcomes (Russell and Norvig, 1995) given the current status, in this way, learning is reduced to probabilistic inference. Through Equation (2.4), one can attain the probability of action X knowing the hypothesis h (hypothesis prior) and the observed value d (utilizing the likelihood method).

$$P(X|d) = \sum_i P(X|h_i)P(h_i|d) \qquad \text{Eq. (2.4)}$$

2.3.1.3.1.4. *Q-Learning and SARSA*

Q Learning is an anticipatory module. Q Learning first introduced by Watkins (1989) as a model free learning module which is driven from Markov Decision Process (MDP) where the decision-making process, as shown in Equation (2.5), is controlled by the current state, the action used, and the current reward. Q Learning is utilized in different fields (robotics, game theory and economics) where the decision variables are discrete. Q-Learning guarantees optimality if the agent is allowed to experience the environment for a sufficient number of iterations (Watkins and Dayan 1992).

$$Q(s,a) \leftarrow Q(s,a) + \alpha(R(s) + \gamma \, max_{\acute{a}} \, Q(\acute{s},\acute{a}) - Q(s,a)) \quad \text{Eq. (2.5)}$$

Where, Q is a table of actions (a) and states (s), and R is the reward at state (s).

State-Action-Reward-Action (SARSA) approach is a similar reinforced learning approach utilized in machine learning. SARSA is utilized mostly when the states are not fully observer able, and thus the actions (policies) are optimized through updating the error. This can be observed in Equation (2.6)

$$Q(s,a) \leftarrow Q(s,a) + \alpha[R(s) + \gamma Q(\acute{s},\acute{a}) - Q(s,a)] \quad \text{Eq. (2.6)}$$

2.3.1.3.2. Social learning

Humans tend to learn from each other, mimicking the most successful of their neighbors. Social learning is observed in many situations and fields; standing ovation (Miller and Page 2004); Evolution of Norms (Axelrod 1986); Insurance Selection (Eid et al. 2015), etc. In social learning, agents who are not able to optimize their objective functions, tend to look around and observe what other agents achieved, and thus mimic them to increase their own objective functions.

2.3.1.3.2.1. Genetic Algorithms

Genetic Algorithms (GAs) is one of the most commonly used social learning module utilized for ABM (Eid and El-adaway 2016a). In the 1970’s John Holland proposed his formal GAs for optimization. Since then, it was applied in different and various fields and have proven to be a solid and effective methodology for optimizing stochastic problems (Moon et al. 2013, Eid et al. 2012, Hyari and El-Rayes 2006, Elbeltagi et. al. 2005, Hegazy and Ayed 1999, and Li and Love

1997, Feng et. al. 1997). GAs is a metaheuristic that simulated Darwin's' theory of natural selection and survival of the fittest through evolution (Holland 1975). GAs form a set of random solutions that search the solution space for the optimum set of solutions through evaluating the solutions depending on their fitness. The solutions in GAs are subject to evolution processes like in nature through crossover of inherited genes and mutation. These solutions are called chromosomes, and each chromosome consists of numbers of genes which carries the values of the problem's decision variables.

Vriend (2000) and Reichmann (2000) illustrated the efficiency of GAs in social learning (as well as individual learning). The GAs social learning enables agents to transfer their knowledge (chromosomes) to each other and apply the aforementioned evolution process.

2.3.1.3.2.2. *Particle Swarm*

Inspired by the migration of flock of birds in their attempt to reach an unknown destination, Particle Swarm (PS) was developed by Kennedy and Enerhart in 1942. PS is an evolutionary algorithm that utilizes stochastic search in order to imitate the different species social behavior (Elbeltagi 2013). The simulated system can self-organize to determine the optimal actions that increase the utility functions of the individuals through collective decentralized behavior (Eid and El-adaway 2016b). Each agent is represented by a particle that observes its surroundings, determine the most fit neighbor, and mimic it. This approach is referred to Memetic Particle Swarm (MPS) that is based on Dawkins notion of memes (Dawkins 1976). Meanwhile, agent (particles) can go through mutation to explore new solutions that was never encountered before by the population. Such solutions can affect the population collective optimal output. Unlike GAs that create new solutions per iterations, MPS evolve through changing the social behavior of the same particle to a better social status according the its fitness among its peers. (Elbeltagi et al. 2005). PS proved to be an effective social learning model to simulate the different entities social learning behavior (Eid and El-adaway 2016b, Cheng and Jin 2015, Oca et al. 2011)

2.4. Game Theory

The competing nature of the various stakeholders in the host community results in a complex culture in the infrastructure development. Such conflicting environment increases the built environment vulnerability and decreases the sustainability of the host community. Game theory can be applied to capture this complex nature, optimize the different stakeholders' decision making processes, and thus, describe the resulting equilibrium for the host community. Assimilating game theory and ABM will aid in achieving the need for a holistic systematic approach for assessing the infrastructure sustainable development as well as the predication of the different sustainability policies impacts on the host community. Nevertheless, not all stable strategies result in a socially desirable equilibrium. In such a case, alternative actions may be found to improve, if possible, the outcome of the game and consequently improving the host community's overall welfare.

In 1944, John Von Neumann and Oskar Morgenstern published "Theory of Games and Economics Behavior" laying the mathematical foundation for Game Theory. Myerson 1991 defined game theory as the "*study of mathematical models of conflict cooperation between intelligent rational decision makers*". Generally, it is considered as a substantial contribution to social and behavioral sciences through providing a tool to develop a framework for decision making in the presence of conflict of interest.

Through representing the interactions and strategic decision making processes between the different individuals and organizations, game theory was utilized in different areas of study (i.e.

economics, biology, engineering, political science, computer science, philosophy and construction) (Eid et al. 2015, Son and Rojas 2011, Drew and Skitmore 2006, and Ho 2001). Recently, game theory was applied in the field of construction industry. Ho (2001) analyzed the procurement process within the BOT projects using game theory, assuming the presence of asymmetric information problems, and investigated such assumption on the project financing and government policies. The construction claims between the contractors and owners were investigated through a dynamic game theory by Ho and Liu (2004). Drew and Skitmore (2006) analyzed the schemes of the different competitive biddings in the construction projects utilizing game theory. In addition, game theory has been also applied to examine strategies for subcontractor selection (Ahmed et al. 2015; Unsal and Taylor 2011).

2.4.1. Elements of Game Theory

In order to develop any game theoretical model, it is essential to define the elements of this game (model). According to Gibbons (1992), these elements are: (1) players, the entities involved in the problem under investigation; (2) strategies, either pure strategy that gives a plan of actions for the player at each decision point in the game, or mixed strategy that is based on a randomization with certain probabilities; (3) information, complete or incomplete information, perfect or imperfect information, or asymmetric information; and (4) payoff functions, determine what the player gets based on the strategies chosen by the player himself, his rivals, and the nature (current state) which is considered as pseudo player who takes random actions at certain points of the game with specified probability distributions.

2.4.2. Types of game theoretical models

Game theoretic models can be classified according to information completeness, as previously mentioned, or as through the way in which games are played. There are two types of games (Ahmed et al. 2016); (1) Static games, where players simultaneously take actions without prior knowledge of the other players' actions; and (2) Dynamic games, where players sequentially take actions through observing each other (Ho and Hsu 2014).

In addition, games can be divided into: (1) Cooperative game theory, in which the stakeholders cooperate to gain more benefits and defining the fair share of each player; and (2) Non-cooperative game theory, where players compete to win over each other and increasing their own individual utilities and payoffs (Ahmed et al. 2016, Eid et al. 2015, Asgari and Afshar 2008).

According to Nash (1950), Nash Equilibrium is considered as the solution to non-cooperative games under the assumption that all players are rational. Nash Equilibrium was introduced by the Nobel Prize laureate John Nash in 1950's. Nash equilibrium opened a wide field of research and benefitted the economics filed worldwide. Nash equilibrium does not merely take one's interest to gain the highest utility function, but rather it is the player's best response on the other player strategies – knowing that they are also considering the other players' best responses. Thus, by finding the Nash equilibrium (where each player gained his maximum utility/payoff), there will be no interest (rationally) to deviate from the current strategy.

One significantly related branch of game theory to the infrastructure development is the *evolutionary* game theory. In evolutionary games, a number of individual players continuously and randomly meet within the environment. Through their encounter, the players attempt to find the optimal strategy to be utilized in order to increase their average payoff (Eid et al. 2015, Samuelson 1997). In evolutionary game theory, imperfect players learn through observations and replication which strategy is better of them (Eid et al. 2015). The assumption of the replication dynamics of an evolutionary is that each strategy is represented by a fraction of players throughout the encounters (Eid et al. 2015, Turocy et al. 2001). The fraction of the strategy increases if its outcome is providing a positive impact on its user. As such, an Evolutionary Stable Strategy (ESS) will emerge when the population is divided among the different strategies. Such ESS is stable and final, if and only if no new (mutant) strategy introduced to the game will have higher payoff than the utilized strategies in the ESS (Eid et al. 2015, Weibull 1995; Smith and Price 1973). Evolutionary game theory has been applied in Economics (Cressman 1996, Friedman 1998), explored by mathematicians (Hofbauer and Sigmund 2003) and disaster impact mitigation (Eid et al. 2015).

Such approach can be integrated into modeling the infrastructure associated stakeholders to simulate and evaluate their utilized strategies' evolution. Achieving an Evolutionary Stable Strategy will then determine the equilibrium strategies that needs to be followed by the community in order to achieve a common ground of sustainable and resilient infrastructure development that meets the various stakeholders' individual utility functions.

2.5. Summary

Understanding the sustainability of the built environment and the impact of the infrastructure development on the welfare of the community, requires a comprehensive evaluation of the societies' resilience and vulnerability. As such, various research was carried out to understand and evaluate the vulnerability, resilience, and sustainability of the communities across three dimensions; social, environmental, and economic.

This chapter provided a thorough literature review on the concepts of sustainability, sustainable development, resiliency, and vulnerability of the host communities and built environment. Moreover, this chapter also presented various evaluation models for the built environment three-dimensional vulnerability and pointing out their advantages and drawbacks.

Furthermore, to lay down foundations for the following chapter, a thorough discussion on ABM, game theory and other important issues were presented in this chapter.

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CHAPTER THREE

METHODOLOGY AND MODEL DEVELOPMENT

3.1. Introduction

As mentioned in Chapter One, the current research goal is to increase the welfare of the host community through maintaining the infrastructure sustainability of our built environment via decreasing its overall vulnerability. As such, the current research hypothesis is that integrating the vulnerability indicators into the objective function of the associated stakeholders will develop more effective infrastructure development process that meet the stakeholders' needs and decrease the community vulnerability to perturbations. Thus, to achieve such goal and test the research hypothesis, the current research objectives are: (1) Evaluate the built environment social, economic, and environmental vulnerability as function of the communities' specific data; and (2) capture the community stakeholders' interactions and decision making processes using the interdependency between the vulnerability indicators and the associated stakeholders. Table 3.1 summarizes the objectives along with their methodologies and outcomes.

Table 3.1: Objectives, Methodology and Outcomes

Objectives	Methodologies	Outcomes
Evaluate the built environment social, economic, and environmental vulnerability as function of the communities' specific data	Utilize well-established vulnerability assessment models that are able to provide scores and evaluation at the community level.	Comprehensive understanding of the resilience as related to the coupled systems of the human-built environment that avoids disagreements over the definition of sustainability and focus instead on measurable quantities correlated with its most commonly used definitions.
capture the community stakeholders' interactions and decision making processes using the interdependency between the vulnerability indicators and the associated stakeholders.	Model the stakeholders through a bottom-up approach (Agent Based Model) while utilizing the various learning algorithms. Use game theory to illustrate and simulate the stakeholders' interactions.	Systems-based infrastructure decision making process that balances between short-term development objectives and long-term vulnerability reduction goals.

The aforementioned activities and objectives represent significant advances in the fields of civil infrastructure systems, economics, and game theory. Together they collectively progress towards better theoretical and practical understanding of sustainable infrastructure development. As shown in Figure 3.1, the researcher developed an innovative and transformative framework that integrates the interdependent relationships between the different sustainability indicators together with their impact on the associated stakeholders' objective functions.

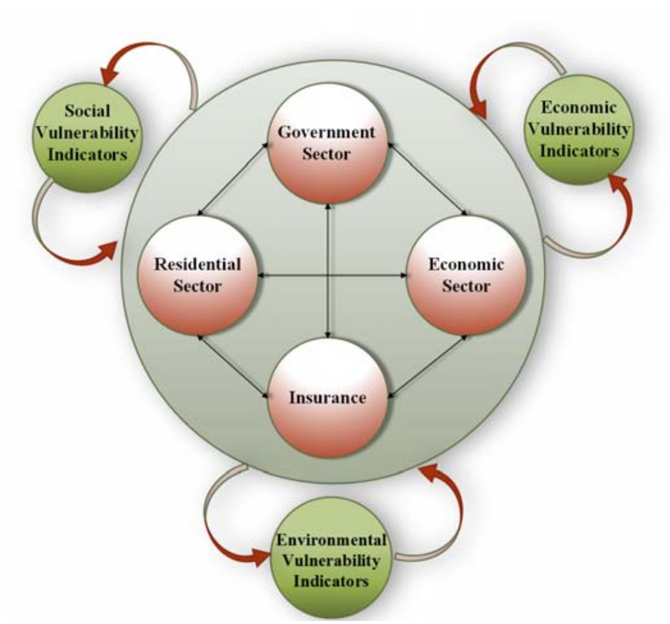

Figure 3.1: Proposed Research Framework

3.2. Problem Domain

In ordered to focus the research efforts, test the research hypothesis, and achieve the aforementioned goal, the proposed research adopts the post-Katrina infrastructure redevelopment for three Mississippi coastal counties, namely; Hancock, Harrison and Jackson (West to East), shown in Figure 3.2. The utilization post-Katrina recovery as a problem domain is due to accessibility of the required data to develop the associated stakeholders, their strategies, and decision actions in addition to measure the three-dimensional vulnerability assessments.

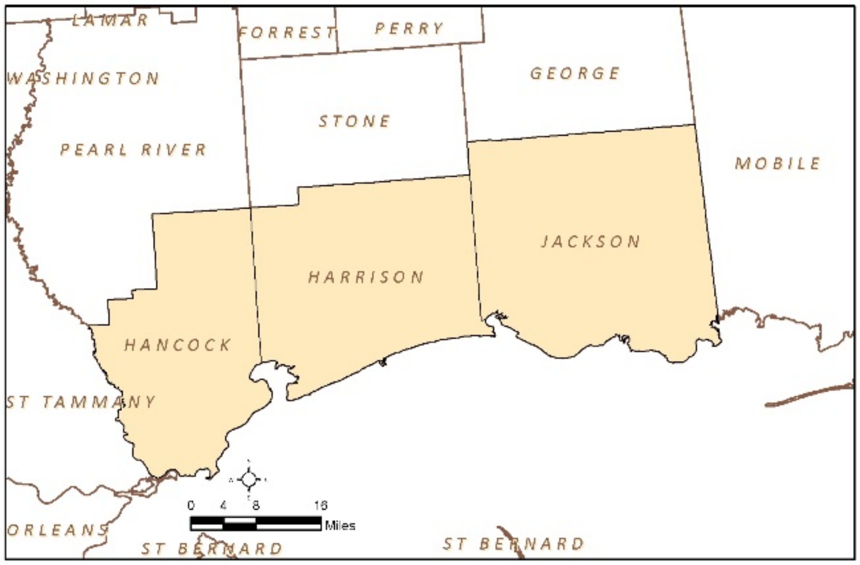

Figure 3.2: Problem Domain – Mississippi Coastal Counties

3.3. Research Methodology

The researcher utilized the following research methodology to develop the model and test the research hypothesis: (1) gather the data required for (i) evaluating the three dimensional vulnerability of the host community, (ii) modeling the various stakeholders decision actions and attributes, and (iii) simulating the impact of Hurricane Katrina on the associated stakeholders, (2) implementing well-established vulnerability assessment tools to measure community's three dimensional vulnerability; (3) model the objective functions, strategies, decision actions, and learning behaviors of the multi-sector stakeholders, (4) simulate the impact of Hurricane Katrina on a census tract level and the host community's infrastructure redevelopment; and finally (5) interpret and analyze the results generated from the developed model, and compare it to the actual post-Katrina outcomes and a null hypothesis test.

3.4. Data Gathering Overview

To implement the aforementioned methodology, the researcher gathered seven different data sets on the census tract level regarding the post-Katrina disaster recovery for the three Mississippi coastal counties. The data was collected at the census tract level to enable for modeling the community at a fine scale using ABM while providing for adequate vulnerability analysis using the available community specific data. As such, the current research focused on the census tract level in order to: (1) avoid over aggregating the stakeholders' attributes and properties, and (2) ensure that all the collected data are on the same scale level. The associated data sets gathered are as follows:

- Ex-Katrina socioeconomic data for the three aforementioned counties were collected. This allowed for generating the initial population as well as to develop the comprehensive social vulnerability indicator to the pre-event conditions. Post-Katrina socioeconomic data were also gathered for the comparison of the proposed model outcome. The socioeconomic data were collected from the available US Census Bureau for each of the 78 census tracts across the three counties (2000, 2007, 2010, 2011 and 2012 US Census).
- Utilizing GIS maps from the National Land Cover Database (2000-2012), the National Agricultural Statistics Service Cropland Data Layers (2000-2012), and the Mississippi Automated Resource Information System (2000-2012), the researcher gathered the required environmental data in order to evaluate the environmental vulnerability of the three counties. Such data allowed for the initialization of the model to the pre-event conditions in addition to comparing the model's outcome to the post-Katrina environmental vulnerability data.

- The researcher collected the required economic data to initiate the model to the pre-event conditions through the US Census Bureau (2000, 2009, 2010, 2011 and 2012 US Census) as well as through ReferenceUSA (2000, 2009, 2010, 2011 and 2012) for each of the 78 census tracts across the three counties. This also allows for the evaluation of the economic vulnerability, and the comparison of the actual and proposed economic vulnerability.
- In regard to the actual governmental strategies and actions utilized by the disaster recovery agency, the housing sector redevelopment data was gathered utilizing the Mississippi Development Authority (MDA) and Mississippi Recovery Division (MRD) federal reports that are publicly accessible website for years 2007 to 2012. Through reviewing the MDA's federal reports, three residential recovery plans were determined that contributes to around 65% of the total MDA's expenditure (Mississippi Development Authority 2015). The most recognized disaster recovery strategies were;
  1. *Homeowner Assistance*; which includes repair, rebuild, and relocation financial aid to the damaged privately owned household. This plan was the most utilized post-Katrina event with expenditure over than $2.8 billion (2012), which is around 80% of the four plans' expenditure. The *Homeowner Assistance* plan has been reported to have a high demand among the residents as it provides the illegible applicants with up to $150,000 (Eid and El-adaway 2016, Mississippi Development Authority reports 2015). Such plan is assumed to impact the recovery of the damaged households, and in return will positively affect the social vulnerability of the community in the form of adaptive capacity and resourcefulness. Minimal effect would then be observed from the environmental and economic dimensions.
  2. Public Home Assistance; a plan to assist low income families to rebuild damaged building and house them through building new affordable homes. The rebuilding of new low income

and affordable homes cost up to $50,000 (Mississippi Development Authority reports 2015). Such plan is assumed to aid the residential recovery process through meeting the needs of the poor income families. This will in return positively impact the social vulnerability by meeting the need of the less empowered members of the communities. Building new homes also positively affect the economic sector and the economic vulnerability by increasing the retail sector's revenue. Nevertheless, such would negatively impact the environmental vulnerability through building the new homes on existing vegetation cover.

3. Elevation Grant; an upgrade to the households through elevating them up to 6 feet and 4 inch, thus making the households more flood resilient. Such upgrade requires more materials and increases the household's value. As such, the Elevation Grant is expected to increase the total recovery of the residential sector and positively affect the social vulnerability of the community through increasing their median households' value. Moreover, due to the addition on new materials, the Elevation Grant would also increase the retail sector revenue and positively affect the economic vulnerability of the community while it does not affect the environmental vulnerability dimension.

In addition, the MDA and MRD budget and expenditure federal reports to FEMA were gathered to compare the model's outcome (in regard to the budget distribution).

- In regard to utilized actions plans for the economic sector recovery, only one plan was found to have direct impact on the businesses in the impacted region; Small Business Loans Guaranty Program (SBLGP). The SBLGP plan provides financial support for small businesses via loans (MDA-FRD 2015). The SBLGP plan provides small businesses (250 or less full time employees and less than $7,000,000 gross revenue) a maximum of $500,000 (and $50,000 minimum) to recover, expand, or renovate the physical structure of the business. Thus, this plan incentivized the economic sector to stay in the impacted region by increasing their recovery rate. Such plan impacts the economic financial recovery in addition to decreasing the economic vulnerability of the community by increasing their adaptive capacity.

- In regard to the infrastructure projects, the researcher reviewed the MDA various developed projects. Accordingly, the data for the wastewater treatment facilities projects (WWTF) that were developed by the MDA post-Katrina disaster were gathered. Such projects served the three impacted counties. The researcher collected the data in regard to the projects' locations, capacity, size, service coverage, and cost of the different WWTFs, utilizing the Mississippi Department of Environmental Quality (MDEQ) resources, the associated counties' authorities and the MDA federal reporting for year 2007-2012 (Eid and El-adaway 2016a). Table 3.2 summarize the different WWTFs, their capacities and their associated counties.

Table 3.2: Utilized WWTFs

WWTF#	County	Capacity (MG/day)
1	Hancock	1.5
2	Hancock	0.2
3	Harrison	0.4
4	Harrison	0.2
5	Harrison	1.5
6	Harrison	0.2
7	Harrison	2.0
8	Jackson	0.125
9	Jackson	2.0

- To simulate the impact of Hurricane Katrina on the stakeholders of the host community (residential and economic sector), Hazards U.S. Multi-Hazard (HAZUS-MH) was utilized. HAZUS-MH can simulate historical disastrous events like Hurricane Katrina through wind gust, surge, and floods based on storm parameters of the hurricane which is embedded in

HAZUS-MH databases. As such, a level 1 analysis (basic losses estimates based on national databases) was carried out to determine the damages proportions (none, minor, moderate, sever, and destructive) for each census tract within the impacted region. Such damage considers the direct damages on building structures (residential and businesses) as well as induced physical damages from debris on each of the 78 census tracts. The output was then distributed on the corresponding agents (depending on their associated census tract). The researcher also collected the historical data (1953-2012) available at the Mississippi Emergency Management regarding Tornados impacting the three counties. This enabled for the development of a tornado hazard micro module based on the 155 Tornadoes occurrence data points, event occurrence and magnitude (based on Fujita-scale). As such a probability density functions were developed that replicates such events. The micro module was then integrated into the ABM to better simulate the agents' decision actions in the presence of new and recurrent shocks post-Katrina event. Such recurrent hazardous events will change the utilized insurance policies by the residents, the budget distribution by the State Disaster Recovery Agencies, etc.

3.5. Measuring Social, Economic and Environmental Vulnerability Indicators as Functions of Community-Specific Data Inputs

This section illustrates the development of the host community's vulnerability indicators; social, economic, and environmental. The following indicators will then be integrated into the decision-making processes of the stakeholders in the ABM, as shown later in this chapter. The indicators were selected based on the following criterion: (1) able to address the communities' resilience/vulnerability to hazards (as per the problem domain); (2) scalable, thus able to evaluate the variables on a census tract level; and (3) ease of implementation to avoid any complications that may lead to inaccurate or misleading results.

3.5.1. Social Vulnerability Indicator

In regard to the social vulnerability indicators, the researcher investigated the social science literature for vulnerability models as illustrated in Chapter Two. It was found out that the most widely recognized vulnerability assessment model in the social science filed is the Social Vulnerability Index model (SoVI) introduced by Cutter et al. in 2003. The SoVI model is a comprehensive socioeconomic and demographic model that asses the host community's vulnerability to hazards. SoVI measures the relative vulnerability of the studied regions to the hazardous events through evaluating the specific data and variables of the host community that affect the social vulnerability of the built environment. These variables include: income, age, household values, education attained, percentage of mobile homes, etc.

The SoVI methodology proposed by Cutter et al. (2003) is as follow:

1. Collecting socioeconomic variables that affects the community social vulnerability to hazards based on literature justifications
2. Multidimensional scaling of variables and evaluating their fitness to be utilized in the SoVI model
3. Statistical analysis to measure the variables internal reliability and reduce them to number of factors using dimension reduction techniques
4. Scoring the different regions based on their relative vulnerability.

3.5.1.1. Data Collection

The researcher identified the 23 socioeconomic variables commonly used from the social science literature and proved to correlate and affect the social vulnerabilities in the studies. Data was collected for the years 2000, 2007, 2010, 2011 and 2012 for the three Mississippi coastal counties; Harrison, Hancock and Jackson. The data were collected through the US Census Bureau (US Census 2000, 2007, 2010, 2011 and 2012). The purpose of collecting the data for the five aforementioned years is to evaluate the actual post-Katrina recovery social vulnerability indicator for the five years that illustrate the social vulnerability change patterns in the study regions, thus can be compared to proposed model's outcome regarding the projected social vulnerability changes.

Through the data collection, the researcher had the choice to collect them based on block level, census tract level or county level. After inspection of the data structure and reviewing the previous social vulnerability models, the census tract level was chosen as; (1) census tract level is the most commonly used data structure in the previous models (Cutter et al. 2010, Burton 2012); (2) county level would give an over generalized and over aggregated indicator for the different non-homogenous regions in the same county; (3) block level data would produce an enormous amount of data (up to 134 block for Harrison county alone) that would take relatively longer computation time to process and calculate, and will only create a little difference than census tract data; and (4) the other vulnerability indictors' data (environmental and economic) can only be found on county and census tract level. To this end, to produce consistent outcome through the three vulnerability dimensions, the census tract level was utilized. However, it is considered in the future work to investigate the block level data for more accuracy and precision.

Utilizing the aforementioned SoVI methodology, five different social vulnerability attributes (summarizing the different social variables) are defined that explains the social vulnerability to disaster based on the collected variables and as demonstrated by the social science researchers. Those attributes are as follows:

1- Economic
2- Equity
3- Adaptive Capacity
4- Occupation
5- Ethnicity

Accordingly, Table 3.3 presents variables collected from the different social science research that depicts the social vulnerability to disasters. The variables demonstrated are combined with their associated attributes – as described in the literature review - research justification from social science literature as well as the availability of the data for the researcher. Through the data collection phase, some variables were not found either due to lack of information, or unsound data structure. That led to the omission of those data from the current study. Thus, those variables are shown in Table 3.3 with no source availability.

To this end, the following variables are considered to evaluate the social vulnerability utilizing the Social Vulnerability Index (SoVI) methodology introduced by Cutter et al. (2003). A Total of 21 variables were collected with 78 observations (census tract) per variable per each year of study. Such variables will provide comprehensive evaluation on the census tracts' relative social vulnerability and will be integrated within the proposed model.

1. Per capita income

Table 3.3: Socio-Economic Factors Drawn from Literature

Variables	Justification	Availability	Collected Period
Economic			
Per capita income	Blaikie et al. (1994), Tobin (1999), Cutter et al. (2003), Watts and Bohle (1993)	U.S. Census	2000 – 2012
Percentage of population with $75,000 income or more	Cutter et al (2003), Blaikie et al. (1994)	U.S. Census	2000 - 2012
Median household value	Cutter et al. (2003), Cutter et al. (2010), Heinz Center for Science, Economics, and the Environment (2000)	U.S. Census	2009-2012
Equity			
Percentage of population with vehicles	Cutter et al. (2010), Burton (2012)	U.S Census	2000 - 2012
Percentage of home ownership	Cutter et al. (2010), Burton (2012)	U.S Census	2000 - 2012
Percentage of mobile homes	Cutter et al. (2010)	U.S Census	2000 - 2012
Percentage of population with telephone access	Cutter et al. (2010), Burton (2012)	U.S Census	2000 - 2012
Percentage of the population living in high intensity urban areas	Burton (2012)		
Adaptive Capacity			
Percent of population with Disability	Burton (2012), Cutter (2010)	U.S. Census	2012
Percent of elderly	Burton (2012), Cutter (2010), Cutter et al. (2003).	U.S. Census	2000 – 2012
Percent of population that speaks English	Burton (2012), Cutter et al. (2003), Cutter (2010).	U.S Census	2000-2012
Median age	Cutter et al. (2003), Cutter, Mitchell, and Scott (2000)	U.S Census	2000-2012
Percentage of Female	Blaikie et al. (1994), Cutter et al. (2003).	U.S Census	2000-2012
Percentage of the population with at least high school diploma	Burton (2012), Cutter et al. (2003).	U.S Census	2000-2012
Occupation			
Percentage of People Not Infirmed or institutionalized	Burton (2012), U.S. Indian Ocean Tsunami Warning System Program 2007.	U.S Census	2012
Percentage of population working in service occupation	Cutter et al. (2010), Heinz Center for Science, Economics, and the Environment (2000)	U.S Census	2009 - 2012

Table 3.3: Socio-Economic Factors Drawn from Literature – Continued

Variables	Justification	Availability	Collected Period
Percentage of population working in transportation sector	Cutter et al. (2010), Heinz Center for Science, Economics, and the Environment (2000)	U.S Census	2009 - 2012
Percentage of population working in extracting (Fishing, agriculture, mining, etc.)	Cutter et al. (2010), Heinz Center for Science, Economics, and the Environment (2000)	U.S Census	2009 - 2012
Ethnicity			
Percentage of population that are not minority	Burton (2012)		
Percentage of the population that are African Americans	Cutter et al. (2003), Cutter et al. (2010). Pulido (2000)	U.S Census	2000 - 2012
Percentage of the population that are Native Americans	Cutter et al. (2003), Cutter et al. (2010). Pulido (2000)	U.S Census	2000 - 2012
Percentage of the population that are Asians	Cutter et al. (2003), Cutter et al. (2010). Pulido (2000)	U.S Census	2000 - 2012
Percentage of the population that are Hispanic or Latino	Cutter et al. (2003), Cutter et al. (2010). Pulido (2000)	U.S Census	2000 - 2012

2. Percentage of population with $75,000 income or more
3. Median household value
4. Percent of population with Disability
5. Percent of elderly
6. Percent of population that speaks English
7. Median age
8. Percentage of Female
9. Percentage of the population with at least high school diploma
10. Percentage of People Not Infirmed or institutionalized
11. Percentage of population with vehicles
12. Percentage of home ownership
13. Percentage of population with telephone access
14. Percentage of the population that are African Americans
15. Percentage of the population that are Native Americans
16. Percentage of the population that are Asians
17. Percentage of the population that are Hispanic or Latino
18. Percentage of population working in service occupation
19. Percentage of population working in transportation sector
20. Percentage of population working in extracting (Fishing, agriculture, mining, etc.)
21. Percentage of mobile homes

3.5.1.2. Statistical Analysis

Following the SoVI methodology, different statistical analyses is needed to be carried out on the collected variables.

3.5.1.2.1. Internal Reliability

Internal reliability, which can be evaluated using Cronbach's alpha, is a measure to assess how similar different variables are, evaluating if they are hanging together in the same balanced pattern. To this end, it can be justified to combine those different and separate variables into one single index or scale to represent them (Pearson 2010). Cronbach's alpha is a technique used to measure the correlation between the different variable sets based on the sum of their correlations. That is to say, if the correlation is high, it is considered that the variables are measuring the same *latent* variable(s). The Cronbach alpha value is less than unity, with the value of 1 corresponds to the highest correlation, even though it is not preferred as it means the variables are measuring the same attribute. However, there is no specific rule to specify the significance of the Cronbach's Alpha value. In the social science research – where the Cronbach's alpha is used the most –Cronbach's Alpha is considered highly significant if its value is 0.7 or more.

To evaluate the Cronbach's Alpha between the collected socioeconomic variables for each year, SAS 9.4 is utilized. After checking for the data linearity - which is one of the assumptions of Cronbach's alpha - the Cronbach's alpha procedure is used to examine the variables internal reliability and determine, for this specific study region, the variables that are correlated with each other, thus giving a Cronbach's alpha of 0.7 or more. Multiple iterations are carried out on the collected data while omitting the data that decreases the overall internal reliability of the variables.

3.5.1.2.2. Dimension Reduction - Factor Analysis

Factor analysis (FA) is a dimension reduction technique used to illustrate the covariance relationship for a set of variables (based on their observations) in terms of fewer but unobservable random quantities or factors (R.A. Johnson, D.W. Wichern 1998). The utilization of reduction techniques for the collected variables can be beneficial in order to determine a set of consistent variables that can be monitored through time (Cutter et al. 2003). Factor analysis is carried out to determine the factors associated with the social vulnerability so as to calculate the host community social vulnerability using the factor scores, as illustrated in the Results and Analysis chapter.

3.5.2. Economic Vulnerability Indicator

Different economic vulnerability and resilience assessment models were discussed in Chapter Two. The economic vulnerability and resilience assessment models can be categorized into two categories; macro and meso-micro economics. The models' methodologies also varied from mathematical to statistical analysis. Nevertheless, few of the previously discussed models focus on the community specific data. In order to choose a model that best suits the current research and its problem domain the following three selection criteria were developed.

- Scalability and Transformability

In order to provide a transformable decision framework, the current research should utilize transformable modules that can operate and be implemented on different case studies regardless of their scale and size. The different economic vulnerability and resilience assessment models were evaluated, through previous literature reviews, in regard to the scalability and transformability. It was found out that the Economic vulnerability and Resilience assessment model developed by

Burton (2010) and validated in 2015 (Burton 2015), and the economic resilience model developed by Rose (2009) are scalable and can work at different regions and sizes. On the other hand, the various other economic vulnerability/resilient model are developed to evaluate countries' macroeconomic vulnerability, thus cannot be implanted in the current research problem domain.

- Objective and Standardized

Providing an objective and standardized evaluation for the economic vulnerability/resilient of the host community is essential. This can be achieved either through utilizing statistical methods (as previously discussed in the Social Vulnerability Index) or through utilizing a uniform scaler module to map the different indicators on it (as discussed below in the Environmental Vulnerability Index). Through the literature, it was found out that the economic vulnerability assessment model developed by Rose (2009) serves as the least objective as it relies on subjective inputs. Moreover, it was based on crude mathematical model (Rose 2009). On the other hand, the Economic vulnerability and resilience model developed by Burton (2010-2015), provides a full validation for the current problem domain as it was validated on the same counties; Hancock, Harrison and Jackson for the same period, post-Katrina recovery. The model utilized multivariate statistical analysis that would give objective relative economic vulnerability index among the different regions understudy.

- Implementation Ease

In order to avoid complications in the implementation phase which may lead in any inaccurate or misleading outcomes, the selected economic vulnerability and resilience module should be implemented with ease. Through reviewing the associated literature, it can be noticed that the model developed by Rose (2009) can be easily implemented. However, as previously discussed, it lacks the objectivity part as which may provide inaccurate results. On the other side, the Economic vulnerability developed for OCED can be also implemented with relative easiness. The economic vulnerability and resilience assessment model developed by Burton (2010) and validated in 2015 can be easily replicated, implanted and integrated within the simulation model as well through standalone statistical analysis tools.

To this end, it was found best that the optimal economic vulnerability assessment tool to be utilized in the current research is the economic vulnerability and resilience model developed by Burton (2010). The model is furtherly validated on the current problem domain (the post-Katrina recovery for the three coastal Mississippi counties). It can be easily replicated, and it provides consistent and objective results as it relies on statistical analysis tools. This qualifies the economic vulnerability assessment model for the current research.

3.5.2.1. Economic Vulnerability Index

The Economic Vulnerability Index (EconVI) developed by Burton (2010) is part of a multi-dimensional vulnerability assessment metric that is developed on the community specific data (Eid and El-adaway 2016b). Burton Utilizes the three coastal Mississippi counties (Hancock, Harrison and Jackson) as the basis for the model development which was furtherly validated in 2015 (Eid and El-away 2016b). This furtherly qualifies the model for the current research as it serves the same problem domain and thus will eliminate any undesired consequences through misleading index utilizations.

3.5.2.1.1. Data Collection

EconVI utilizes fourteen variables to assess the community micro and meso economic vulnerability to hazard. Those variables utilization is justified by previously peer reviewed published research and literature that discuss the economic vulnerability of the host communities. The variables are:

- Percentage of Homeownership
- Percentage of working age population that is employed
- Percentage of female labor force participation
- Per capita household income
- Mean sales volume of business
- Percentage of population not employed in primary industries
- Ratio of large to small businesses
- Retail center per 1,000 population
- Commercial establishments per 1,000 population
- Lending institutions per 1,000 population
- Doctors and medical professionals per 1,00 population
- Ratio percentage white to percentage nonwhite homeowners
- Percentage of commercial establishments outside of high hazard zones
- Density of commercial infrastructure.

Data for the aforementioned variables were collected on the census tract level for both ex and post Katrina, as discussed in Data Gathering section. This allowed for the assessment of the economic vulnerability of host community as well as the comparison to the model proposed outcome (as discussed in Chapter Four). The data were collected utilizing the US Census Bureau for years 2000-2012, ReferenceUSA, GIS maps from the National Land Cover Database (2000-2012), and the Mississippi Automated Resource Information System (2000-2012).

3.5.2.1.2. Statistical Analysis

Following the methodology for developing the EconVI, multivariate statistical analysis needs to be carried on the aforementioned collected variables. To carry out the statistical analysis, the data must be standardized in order to have a consistent output. First, the data is transformed into comparable scales (per capita, percentage or density functions). Then using the Min-Max rescaling method, the data is standardized across the different census tract per variable between 0 and 1, where 1 is the best value, and 0 is worst value.

Through utilizing Factor Analysis, the standardized variables can be reduced to a number of factors that summarizes the different variables. Moreover, and more importantly, this will allow for calculating an economic vulnerability index based on the data collected and their relation to each other. This carried out through simple additive model for the factors' scores per census tracts, a similar approach to the SoVI's methodology.

3.5.3. Environmental Vulnerability Indicator

Three different environmental vulnerability/sustainability indicators were previously discussed in Chapter Two (Literature Review); Ecological Footprint (EF); Environmental Sustainability Index (ESI); and Environmental Vulnerability Index (EVI). In order to select the most appropriate one of them to be utilized in the current research, three criteria were developed.

- Scalability and Transformability

In order to provide a transformable decision making framework, the current research should utilize transformable modules that can operate and be implemented on different scales and sizes. The three aforementioned environmental vulnerability/sustainability indictors were evaluated, through previous literature reviews, in regard to the scalability and transformability. It was ascertained that both ESI and EVI are scalable and can be utilized at different levels and regions (Barnett et al. 2008; and Pratt et al. 2004). On the other hand, EF was the least scalable as data required for the model implementation is comparatively difficult for small size countries and regions. Thus, this will leave the model with inaccurate results and will misguide the policy makers in those smaller sized regions (Ferng 2002; and van den Bergh and Verbruggen 1999).

- Objective and Standardized

Providing an objective and standardized evaluation for the environmental vulnerability/sustainability of the host community is essential. This can be achieved either through utilizing statistical methods (as previously discussed in the Social Vulnerability Index) or through utilizing a uniform scaler module to map the different indicators on. Through the literature, it was found out that EF lacked such criteria which renders it unsuitable for the proposed model. However, ESI utilizes statistical analysis methods to standardize the indicators' values. EVI utilizes predefined scale to map the 50 indicators values on, so as to give a uniform evaluation of the host community environmental vulnerability, this approach eliminates the different variables heterogeneity; linear, nonlinear, etc. (Pratt et al. 2004).

- Implementation Ease

In order to avoid complications in the implementation phase which may lead in any inaccurate or misleading results and outcomes, the selected environmental vulnerability/sustainability module should be easy to implement. Through reviewing the literature and manuals of the aforementioned environmental vulnerability/sustainability indicators, it was ascertained that EF has the advantage over the other indicators in regard to implementation ease. EVI would come second as it only requires data gathering and mapping the value to a predefined scale that would provide the model with the indicator's value per census tract. On the other hand, ESI relays on statistical analyses as well as different other techniques for standardization and trimming that would increase the module implementation complexity.

According to the aforementioned criteria, ESI and EVI are the strongest candidates to be utilized in the proposed model. However, EVI dominated ESI on two major properties, in addition to the easiness of implementation. First, EVI is more flexible when it comes to missing data or inapplicable variables. This is carried out by removing the data and decreasing the dominator by one in case of a missing data, or giving the indicator a value of 1 if the indicator is inapplicable. Meanwhile ESI does not account for inapplicable data and requires a minimum amount of data to be available for the model to work.

Moreover, EVI accounts the human interaction as an exogenous factor on the environment while ESI consider it as an endogenous effect. This property enhances the EVI objectivity and allows the model to assess the infrastructure development real impact on the environment vulnerability and sustainability. More importantly, unlike ESI, the EVI is able to capture the environment vulnerability to hazards and shocks.

Consequently, EVI is considered the most appropriate environmental vulnerability assessment tool to be integrated in the proposed model. The following sub-section discusses the 50 indicators, the data gathering and the elimination of the missing data and inapplicable variables for the three coastal counties in Mississippi that serve as the research problem domain.

3.5.3.1. Environmental Vulnerability Index

Through this section, a discussion on the 50 environmental vulnerability indicators is carried out, along with their descriptions, their availability and applicability to the research problem domain. To facilitate their representation in this section, the 50 indicators will be divided into four categories; utilized, inapplicable, unavailable, and others. The following description of the indicators is extracted from the EVI manual and Pratt et al. (2004).

3.5.3.1.1. Utilized Indicators

- Total Land Area (Indicator #11)

  Total land area in km^2 which indicates the richness of the habitat and the diversity in it as well as the availability of refuges.

- Vegetation Cover (Indicator #24)

  The percentage of natural vegetation cover remaining, which includes forests, wetlands, prairies, tundra, desert, and alpine. Thus, it indicates the amount of loss in vegetation cover which inconsequence will affect the different species and ecosystem as a whole.

- Loss of Cover (Indicator #25)

  The net percentage change in natural vegetation cover over the last five years. This indicator measures the rate of losing or gaining of vegetation cover.

- Habitat Fragmentation (Indicator #26)

  This indicator measures the total length of all roads divided by the land area. Thus, it gives a measure on the pressure exerted on the ecosystems as it is divided into discontinuous pieces.

- Terrestrial Reserves (Indicator #28)

  The percentage of terrestrial land area legally set aside as no-take reserves. Thus, this indicator assesses the protection and maintenance of the biodiversity and resources.

- Renewable Water (Indicator #36)

  The average annual water usage as percentage of renewable water resources over the last 5 years. Thus, this indicator measures the risk to terrestrial and aquatic ecosystems due to the over-extraction of freshwater resources.

- Waste Production (Indicator #38)

  Average annual net amount of generated toxic, hazardous and municipal wastes per square kilometer over the last 5 years. To this end, this indicator assesses the risk to terrestrial and aquatic ecosystems as well as the ground water that can polluted from such wastes.

- Vehicles (Indicator #44)

  Number of vehicles per square kilometer of land area. This indicator measures the risk to terrestrial ecosystems due to habitat damage and fragmentation as well as loss in biodiversity and pollution.

- Population (Indicator #45)

  This indicator measures the total human population density as the population per square kilometer of land area. Thus, will give an indication on the pressure applied on the ecosystem and the environment resulting from the human activity which is being supported by the land.

- Population Growth (Indicator #46)

  The annual population growth rate over the last 5 years. This measure the potential for damage relating to the human population expansion over the ecosystem that in return requires more land and resources and increases the habitat damage and fragmentation as well as generation of pollutants.

3.5.3.1.2. Inapplicable Indicators

Several indicators were deemed inapplicable as they are not relevant to the regions in the problem domain; the three coastal counties in Mississippi. The indictors are listed below with a brief description on them. Thus, variables as such are utilized with a vulnerability index of 1.

- Volcanoes (Indicator #7)

  This indicator measures the cumulative risk of weighted number of volcanoes with the probability of eruption that is greater than or equal to the Volcanic Explosively Index of two.

- Earthquake (Indicator #8)

  The Earthquake indicator assesses the host community risk to cumulative earthquakes with local magnitude greater than or equal 6.0.

- Tsunamis (Indicator #9)

  This indicator assesses the community risk to the number of tsunamis with waters run-up greaten that 2 meter above the mean high water spring tide.

- Slides (Indicator #10)

  The Slides indicator is calculated based on the recorded slides in the last 5 years divided by land area in square kilometers.

- Country Dispersion (Indicator #12)

  Through the calculation of ratio of length boarders to total land area, this indicator can evaluate the land area fragmentation.

- Isolation (Indicator#13)

  This indicator measures the community's proximity to the nearest continent.

- Relief (Indicator #14)

  The Relief indicator examines the biodiversity vulnerability by measuring the altitude range of the area under study, which in return affects the probability of endemic to the different species.

- Borders (Indicator #16)

  The indicator calculates the number of land and sea boarders that is shared with other countries.

- Biotechnology (Indicator #33)

  The Biotechnology indicator captures the vulnerability and risk to genetic diversity as well as genetic pollution in the ecosystem. This is carried out by the calculation of cumulative number of deliberate field trials of genetically modified organisms conduced in the country since 1986.

- Environmental Agreements (Indicator #49)

  This indicator measures the number of environmental treaties that is enforced.

- Conflicts

  The conflicts indicator measures the number of conflicts years per decades within the study region over the last 50 years.

3.5.3.1.3. Missing Data

- Environmental Openness (Indicator #18)

  This indicator evaluates the host community risk to the importation of foreign materials. This is carried out by calculating the average annual USD freight imports over the past 5 years per square kilometer of land area. However, there was no data found for this indicator at the census tract level for the current problem domain.

- Degradation (Indicator #27)

  The degradation indicator calculates the percentage of land area that is severely degraded. Thus, it captures the loss in the ecosystem in the host community. However, no data was found at the census tract for this indicator.

- Marine Reserves (Indicator #29)

  Through the calculation of the percentage of continental shelf set aside for marine protection, the Marine Reserves indicator evaluates the vulnerability of biodiversity. However, the data is not applicable to most of the census tracts as well as there is no significant difference between the coastal census tracts' Marine Reserves indicator value.

- Intensive Farming (Indicator #30)

  This indicator assesses the risk of pollution and loss/damage to the ecosystem through calculating the annual tonnage of intensively farmed animal products over the last five years per square kilometer. However, no data was found at the census tract level for this indicator.

- Fertilizers (Indicator #31)

  The fertilizers indictor calculates the average annual intensity of fertilizers used over the total land area through the last 5 years. This allows it to evaluate the risk to terrestrial and aquatic ecosystems as well as the risk on the groundwater quality from using chemical fertilizers. However, no data was found for this indicator at the census tract level.

- Productivity Overfishing (Indicator #34)

  In order to capture the risk of damaging the fisheries stocks (fishing beyond the capacity of the environment to replenish the stocks, this indicator measure the average ratio of productivity over the last 5 years. However, no data was available for this indicator on the census tract level within the problem domain.

- Industry (Indicator #40)

  This indicator captures all the major potential chemical and other industrial pollutants that can damage the ecosystem by calculating the average annual use of electricity for industry over the last 5 years per square kilometer. However, no data was found at the census tract level for this indicator to be integrated into the proposed model.

- Spills (Indicator #41)

  The Spills indicator measures the total number of spills of oil and other hazardous substances that were greater than 1000 liters during the last five years. However, there is no data on a census tract level for this indicator as well as it requires diving the value over million square km which inapplicable for this case.

- Mining (Indicator #42)

  This indicator evaluates the risk to terrestrial and aquatic ecosystems from the disturbances, accidents, oil spills and toxic leachates during the mining processes. This can be calculated through the average annual mining production per square kilometer of land over the last five years. However, the data was no available at the census tract level that rendered this indicator unusable for the proposed model.

- Tourists (Indicator #47)

  The average annual number of tourist per square kilometer through the last 5 years allows the EVI to measure the additional load of the human impacts on the ecosystem. However, there is no available data for this indicator that is on the census tract level in the current problem domain.

3.5.3.1.4. Others

Some of the EVI indicators were not utilized in this current research as their associated data: (1) were not available for every census tract, and (2) did not show any significant difference or variation amount the different census tracts. To this effect, the following indicators were eliminated from the current EVI development to decrease complexity and computation time as well as data gathering and data input into the model that would not show significant difference in the census tracts' outcomes in regard to relative environmental vulnerability. A list of this indicators associated with a brief description is presented in this section.

- High Winds (Indicator #1)

  The High Winds indicator calculates the average annual excess wind over the last five years. This allows the EVI to estimate the vulnerability to cyclones, tornadoes, hurricanes, storms, etc. However, given the current scale – census tract – there is no significant difference between the census tracts High Winds indicator values that would affect their relative vulnerability.

- Dry Periods (Indicator #2)

  This indicator estimates the vulnerability to drought and the stresses on the surface water resources. This is carried out through calculating the average annual rainfall (mm) over the last 5 years with more than 20% lower rainfall lower than the30 year monthly average.

- Wet Periods (Indicator #3)

  Through calculating the average annual excess rainfall (mm) over the last 5 years with more than 20% higher rainfall than the 30-year monthly average, this indicator can assess the vulnerability of the environment to floods and stresses on land surfaces and ecosystems.

- Hot Periods (Indicator #4)

  The Hot Periods indicator evaluates the vulnerability to heat waves, desertification, and stresses to water resources. This is carried out through the calculations of the average annual excess heat over the past 5 years for days more than 5ºC hotter than the 30 year mean monthly maximum. Yet again, there is no significance differences for this indicator values among the different census tracts in the current problem domain.

- Cold Periods (Indicator #5)

  This indicator estimates the environment vulnerability to cold snaps, frosts and stress on water resources and reproductive. This can be done through the calculations of the average annual heat deficit of the last 5 years for all days more than 5ºC cooler than the 30 year mean monthly minimum temperature.

- Sea Temperatures (Indicator #6)

  Through the calculation of the average annual deviation in sea surface temperature, the Sea Temperatures indicator can evaluate the vulnerability to productivity fluctuations and fisheries in addition to storms and cyclones. Nevertheless, this indicator is inapplicable to all the census tracts, as well as there is no significant value difference between such variables through the coastal census tracts in the current problem domain.

- Low Lands (Indicator #15)

  This indicator measures the percentage of land area that is less than or equal to 50 meters above the sea level.

- Ecosystem Imbalance (Indicator #17)

  The Ecosystem Imbalance indicator measures the ecosystem risk due to stresses, loss of diversity and damage to the trophic structure due to changes in the trophic levels. However, there is no significant changes among the different census tracts in the current problem domain in addition the data are not found to each census tract level.

- Migrations (Indicator #19)

  This indicator concentrates on the species that pass through or outside the region boarders. Thus, it focuses on the biodiversity of the host community. This is carried out through calculating the number of known species that migrate outside the territorial area divided be the land area in square kilometer. Yet, there is no significant difference of this indicator's value through the different census tracts in the current problem domain.

- Endemics (Indicator #20)

  Through the calculation of the number of known endemics per million square kilometers of land area, the Endemic indicator can assess the biodiversity and risk of losing unique species in the host communities' ecosystem.

- Introductions (Indicator #21)

  The Introductions indicator assesses the environment vulnerability due to impact from past and different species introductions to the ecosystem. This is carried out through the calculation of the number of introduced species per 1000 square kilometer of land area. Nevertheless, there is no data and no significant differences of the indicator's values among the different census tracts in the current problem domain.

- Endangered Species (Indicator #22)

  Through the calculation of the number of endangered and vulnerable species per 1000 square kilometer of land area, the Endangered Species indicator evaluates threats on the host communities' biodiversity and ecosystem integrity. However, there is no data and significant changes in the indicator's values through the census tracts in the current problem domain.

- Extinctions (Indicator #23)

  This indicator evaluates the vulnerability of the biodiversity and the ecosystem through the calculation of the number of species known to have become extinct since 1990 per 1000 square kilometer of land area. However, there is no significant changes in the indicator's values among the different census tract level.

- Pesticides (Indicator #32)

  Through the calculation of the average annual pesticides used ($kg/km^2/year$) over the total land area in the last 5 years, the Pesticides indicator can assess the risk to terrestrial and aquatic ecosystems as well as the risk to the groundwater from the use of chemical pesticides. Nevertheless, the indicator's values do not show any significant difference among the different census tracts within problem domain.

- Fishing Effort (Indicator #35)

  The Fishing Effort indicator assess the risk of damage to fisheries stocks through the human effort overcapacity. This is carried out through the calculation of the average annual number of fisheries per kilometer of coastline over the last 5 years. However, this indicator values do not have any significant variation among the coastal census tracts in addition to its inapplicability in the other census tracts in the current problem domain.

- Sulphur Dioxide Emissions (Indicator #37)

  Through the calculation of the average annual SO2 emission over the last 5 years, the Sulphur Dioxide Emissions indicator can capture the risk to the host community's ecosystem in regard to air pollution. Nevertheless, the indicator values do not show any significant variation among the different census tracts in the current problem domain.

3.5.3.1.5. Data Collection

To standardize the results and analysis across the three indicators (social, environmental and economic), the data collected for the utilized environmental indicators were collected for the same 78 census tracts among the three coastal Mississippi counties. The data collected were for the years 2000, 2009, 2010, 2011 and 2012 to match the data collected for the other vulnerability indices. This will allow to initialize the model based on ex-Katrina environmental data as well as comparison to actual post-Katrina data in regard to infrastructure development.

The data were collected through utilizing GIS metadata acquired from: (1) the Mississippi Geospatial Clearinghouse, (2) the National Agricultural Statistics Service Data Layers, (3) the Mississippi Automated Resource Information System (MARIS), and (4) U.S. Geological Survey – Land Cover Data. The data were stored in Excel files and GIS maps. Accordingly, the data were then introduced to the proposed model to map the variables to the utilized indicators in order to evaluate each census environmental vulnerability.

Following the EVI methodology, each of the collected and utilized indicator is mapped to the EVI's predefined scale. The unutilized indicators, due to missing data, were omitted from the study and decreased the total number of utilized variables by one per indicator. Furthermore, the inapplicable indicators were given a value of 1 when assessed in the EVI calculations. Finally, the EVI value per census tract is calculated as the average of the indicators' values, as shown in Eq. 3.1, where, *EVIc* is the average Environmental Vulnerability Index of census tract *c*, μ is the number of utilized indicators and *A* is the indicator's value.

$$EVI_c = \frac{\sum_1^{\mu} A_{\mu}}{\mu} \quad \forall\, c = 1, 2, \dots, C \qquad \text{Eq. (3.1)}$$

3.6. Capturing the Stakeholders Interaction Utilizing Agent Based Model

As previously discussed in the methodology section, in order to capture the broad community interactions, the proposed model utilizes a bottom-up approach; Agent Based Modeling. To this end, in the context of disaster recovery of the damaged infrastructure, the researcher modeled four different stakeholders that affects and are affected by the infrastructure re-development based on the recommendation of the National Disaster Recovery Framework (NDRF 2011). The modeled stakeholders are: (1) residents who are impacted by the infrastructure redevelopment, affect the vulnerability indicators, and the revenue of the economic sector; (2) economic sector which provides job opportunities and generates revenue; (3) insurance companies responsible for payouts in the event of losses; and (4) government agencies concerned about infrastructure redevelopment policies. Following the NDRF (2011), the government disaster recovery agencies are divided into Local Disaster Recovery Management (LDRM), State Disaster Recovery Coordinator (SDRC), and Federal Disaster Recovery Coordinator (FDRC). Figure 3.3 illustrates an overview of proposed model.

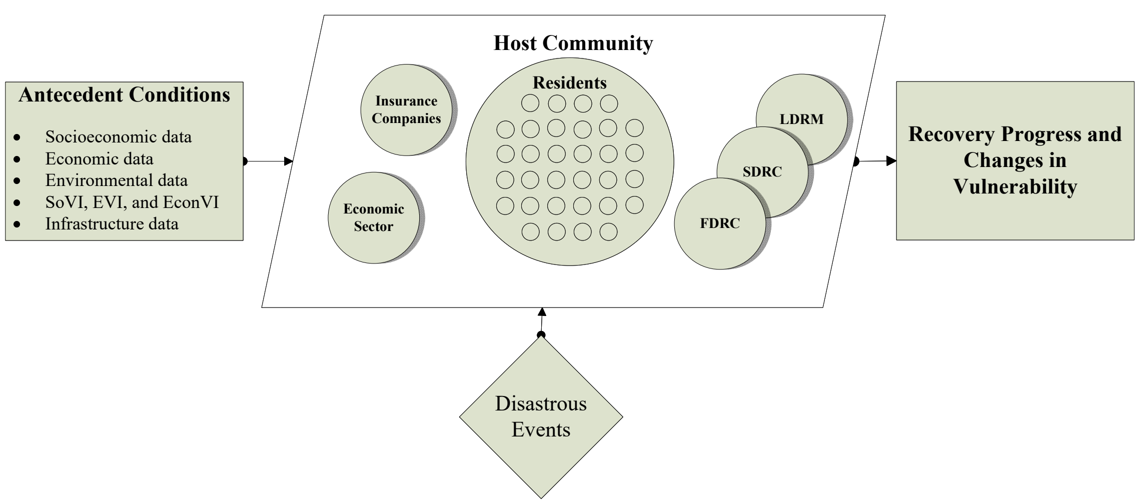

Figure 3.3: Proposed Model Overview

The objective for each community residents, economic sector, and insurance companies is to increase their personal or organizational utility functions that mathematically represents their wealth. Meanwhile, the objective of the government agencies is to increase the community welfare through meeting the needs of the stakeholders as well as decreasing the values of the vulnerability indicators. This four-prong stakeholder setting sheds light on the complexity and interdependency of host communities as related to sustainable infrastructure redevelopment. Thus, the adopted approach of this research (i.e. interdependent relationships between the different vulnerability indicators together with their impact on the associated stakeholders' objective functions) would decrease the built environment vulnerability and increase its sustainability.

The model utilizes the antecedent conditions of the host community as an input, (i.e., population size, median value of households, income level per household, education level per household, social, economic, and environmental vulnerability per region, etc). The antecedent conditions also account for the host community physical infrastructure vulnerability. The model is then subjected to a shock in form of a disastrous event which affects the host community. Through simulation, the ABM enables the various entities within the model to learn through own and other past experiences which is the optimal strategies to be utilized in order to recover. The model reports the overall recovery progress of the community, their utilized actions, and the vulnerability status of the host community.

It should be noted that the model was developed to be generalized to any infrastructure development project. In such case, the disastrous event will not initiate the model. The community will be initiated with a zero infrastructure development, and through their interactions, the impact of the infrastructure projects will be evaluated.

Figure 3.4 illustrates the ABM hierarchy and agents' interactions in the context of infrastructure redevelopment post a disastrous event. Through Figure 3.4, the learning behaviors of the different agents are presented along with their decision actions and messages/signals. Post a disastrous event that disturbs the system's equilibrium, the socioeconomic agent (residential and economic sector) evaluate the damages to their associated households and businesses. Accordingly, the agents will determine the cost of repair required to fully recover. Such repair cost is affected by the magnitude of the disastrous event, its impact on their infrastructure, and the insurance policy's compensation (if already purchased). The agents at this point may apply for government aid through the LDRM.

The LDRMs role is to communicate with the local residents and businesses, offer them the SDRC's recovery plans, evaluate the eligibility applicants, and report the community recovery progress. Meanwhile, the SDRC attempts to manage the recovery processes through prioritizing the different recovery plans depending on their impact on the community (Eid and El-adaway 2016a, NDRF 2011). SDRC decisions span across the infrastructure redevelopment and recovery of the socioeconomic agent as it aims to increase the host community overall welfare. The funds needed by the SDRC to recover is provided through the FDRC (Eid and El-adaway 2016b). The SDRC reports to the FDRC the current recovery and redevelopment. Finally, the insurance companies myopically offer different disaster recovery insurance policies for the host community's residents and business owners. The agents accordingly will determine the optimal insurance policy to be utilized to meet their objective functions.

The following sub-sections demonstrate the different stakeholders' objectives, decision actions, strategies, constraints and learning behaviors.

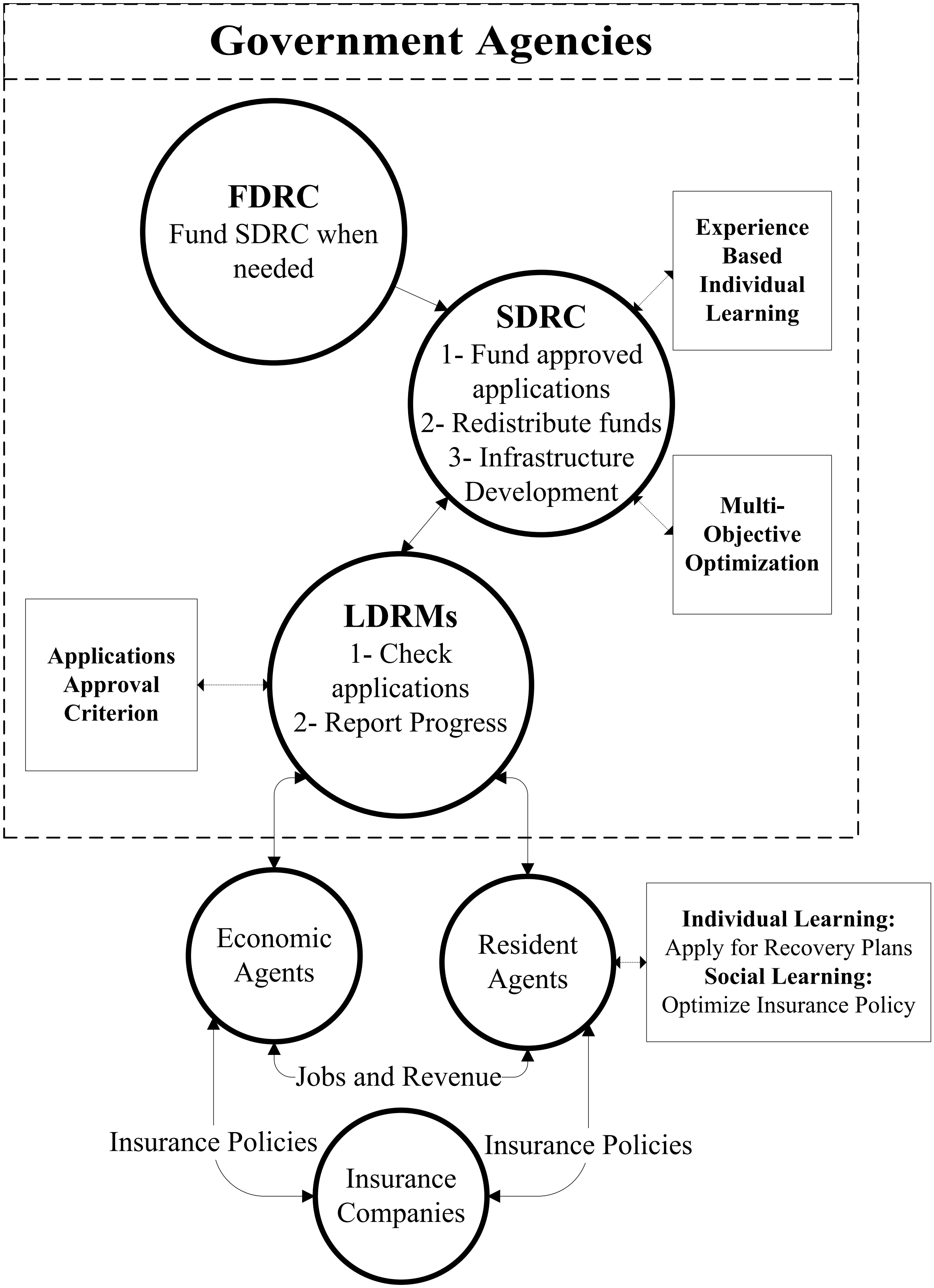

Figure 3.4: Agent's Interactions

3.6.1. Model Assumptions

In order to simplify the complex interactions and decision making processes among the various stakeholders, and to provide uncomplicated outcomes, the proposed model assumes the following:

- All agents are rational; thus, no agent will take any action that is known to have adverse effects on its objective function;
- The objective of the resident and economic agents' is to maintain and increase their wealth;
- The objectives of the disaster recovery government agencies are to: (1) increase the welfare of the community stakeholders, and (2) decrease built social, economic, and environmental vulnerability;
- Agents do not cheat, i.e., resident agents cannot apply for assistance if there is no damage or fully recovered;
- Resident and economic agents can only apply for one assistance plan per time step;
- Resident agents are all homeowners, and households are all paid off;
- Residents' expenditure ratio across the various goods and services offered by the economic agents does not hold significant variation;
- Resident agents cannot leave the impacted region and need to repair; and
- No new residents are introduced into the impacted community.

Finally, it is assumed that the various recovery plans affect the stakeholder redevelopment progress and in return affect the social, environmental, and economic variables and the vulnerability indicators.

3.6.2. Government Agencies

As previously discussed, the post-Katrina infrastructure redevelopment and restoration involves several government agencies on local, State, and Federal levels. Following the National Disaster Recovery Framework (2011), the governmental agencies were subdivided into FDRC, SDRC, and LDRM. Those three agencies actions and interactions follow FEMA's (Federal Emergency Management Agency) Recovery Support Functions (RSFs) in dealing with disaster recovery.

3.6.2.1. Federal Disaster Recovery Coordinator (FDRC)

The FDRC within the proposed model, and according to the National Disaster Recovery Framework (2011), is only activated in case of a catastrophe or if the disaster is exceeding the State's resources and capacity. The role of the FDRC in such case is to facilitate the financial aid and resources to the SDRC in order to carry out the different recovery plans.

The FDRC decision action is to fund the SDRC's disaster recovery plans. Meanwhile, the FDRC decision action is constrained by the total available funds, as shown in Eq. 3.2. where *TFF* is the total federal disaster fund for catastrophe *d*., and *FFMax* is the total available federal disaster fund

$$TFF_d \leq FFMax \qquad \text{Eq. (3.2)}$$

3.6.2.2. State Disaster Recovery Coordinator (SDRC)

3.6.2.2.1. Residential and Economic Financial Recovery

As mentioned earlier, the SDRC develops and funds the various disaster recovery and redevelopment plans. The funding of such plans depends on: (1) the available funds from the

FDRC, (2) the needs of the stakeholders for such plans, and (3) the impact of such plans on the community's vulnerability. Accordingly, the SDRC redistributes the recovery funding proportions at each time step in order to increase the utility function of the stakeholders and decrease the host communities' three-dimensional vulnerability. The researcher developed the following objective functions that mathematically illustrate this complex government optimization problem.

$$Max \sum_i^I \Delta Z_{i_k} \qquad \forall\, k = 1,2, \ldots, K \qquad \text{Eq. (3.3)}$$

$$Max \sum_e^E \Delta FR_{e_k} \qquad \forall\, k = 1,2, \ldots, K \qquad \text{Eq. (3.4)}$$

$$Min \sum_i^I SoVI_{i_k} + \sum_e^E SoVI_{e_k} \qquad \forall\, k = 1,2, \ldots, K \qquad \text{Eq. (3.5)}$$

$$Min \sum_i^I EVI_{i_k} + \sum_e^E EVI_{e_k} \qquad \forall\, k = 1,2, \ldots, K \qquad \text{Eq. (3.6)}$$

$$Min \sum_i^I EconVI_{i_k} + \sum_e^E EconVI_{e_k} \qquad \forall\, k = 1,2, \ldots, K \qquad \text{Eq. (3.7)}$$

where, ΔZ_i is the change in the resident's *i* objective function when applying for plan *k*, ΔFR_e is the change in financial recovery rate for economic agent *e*, *SoVI*, *EVI*, and *EconVI* are the social, environmental, and economic vulnerability indices, respectively, corresponding to agents applying for plan *k*.

On the other hand, Eq. (3.8) constraints the SDRC decision actions to the available funds allocated by the federal agency.

$$\sum_{k=1}^K SG_k \leq TFF \qquad \text{Eq. (3.8)}$$

SG is the state governmental funding for plan *k,* and *TFF* is the Total Federal Funding for the SDRC.

3.6.2.2.1.1. <u>SDRC's Decision Actions</u>

Regarding the SDRC's decision actions and strategies for the residential and economic sectors, the researcher investigated the actual SDRC post-Katrina infrastructure redevelopment and recovery plans. Data available from the MDA and MRD were utilized to determine the most plausible actions and strategies adopted by the SDRC. The data were acquired through the MDA and MRD publicly accessible website for years 2007 to 2012 to temporally match the acquired data for the vulnerability indicators.

Accordingly, four redevelopment plans were utilized as the modeled SDRC's decision actions in regard to the residential and economic sector recovery and redevelopment. Such plans aimed to redevelop the damaged households, thus meeting the residents needs. Moreover, the plans aimed to recover the economic financial disruption of the business sector to ensure the economic sustainability of the community, that in return impacts the residents' income and standard of living as well as the counties and state tax income. The plans utilized are as follows:

1. Homeowner Assistance: a financial aid to damaged privately owned households in order to repair, rebuild or relocate. The Homeowner Assistance plan provide up to $150,000 in financial aid to the eligible homeowners.
2. *Public Home Assistance*, which essentially targeted low income families to rebuild damaged building and house them.
3. *Elevation Grant*, which is an upgrade to elevate the household up to 6 feet and 4 inch, thus making it more flood resilient. Reaching only an expenditure share of $37.5 million, the Elevation Grant gave the households a higher value for they are now relatively more resilient than other buildings surrounding them.

4. Small Business Loans Guaranty Program (SBLGP): this plan provides capital for small business through providing loans though banks (MDA-FRD 2015). This plan provides small businesses (250 or less full time employees and less than \$7,000,000 gross revenue) a minimum loan of \$50,000 to a maximum of \$500,000 for expansion, recovery or renovation. Thus, this plan increased the recovery rate of the impacted businesses and gave them incentive to stay in business.

3.6.2.2.1.2. SDRC Learning and Budget Redistribution Optimization

An individual learning module is required to guide the SDRC budget distribution to achieve the aforementioned objectives. The module must be able to capture the experience-based learning of the SDRC. Moreover, the learning module must allow for the temporal effect of the different disaster recovery plans. To this end, it was found best that the reactive reinforced learning Roth Erev model would fit this learning methodology. This is due to the stochastic nature of the redevelopment process where the SDRC cannot deterministically know which plan the stakeholders will apply for or its impact on the objective functions. Eq. (3.9) illustrates the utilized Roth Erev RL propensity module that assimilates the SDRC's objective functions, while Eq. (3.10) presents the updated budget distribution for each plan *k*.

$$q_k(t+1) = q_k(t)[1-\phi] + IR_k \times (1-\varepsilon) \qquad \forall\, k = 1,2,\dots,K \qquad \text{Eq. (3.9)}$$

$$p_k(t) = q_k(t) / \sum_{k=1}^{K} q_k(t) \qquad \forall\, k = 1,2,\dots,K \qquad \text{Eq. (3.10)}$$

where; $q_k(t)$ is the propensity of plan k in time t, ϕ and ε are the forgetting and experimenting (exploring and exploiting) parameters, respectively, IR_k is the immediate reward for applying plan k, and p is the updated budget share for plan k, at time (t).

Both ϕ and ε allow the agent to explore more options further on which allow for the illustration of information exploration and information exploitation by the agents. This also insures not to fall into local suboptimal strategies due to premature convergence (Sun and Tesfatsion 2007).

3.6.2.2.1.3. *Immediate Reward – Pareto Front Sorting*

The immediate reward of plan *k* is its relative fitness to the other plans across the aforementioned objective functions. In order to determine the optimal redevelopment budget distribution for the SDRC, a multi-objective evaluation module needs to be utilized. Such module should be able to evaluate the impact of each disaster recovery plan on the different objective functions, simultaneously compare them, and provide non-dominated budget distributions that provide the optimal values for the corresponding the objective functions. To this effect, Pareto-Front Sorting (PFS) is utilized.

In general, a solution in an optimization problem is consider Pareto optimal if its corresponding value is not dominated by any other solution's value. As such, in a multi-objective optimization problem, a Pareto optimal solution provides values that no other solution can improve, without compromising at least one of the other objectives. That is to say, for *K* objectives, a Pareto optimal solution $x_i \in X$ dominates solutions x_{-i} if and only if:

$$\forall j \in K: f_j(x_i) \leq f_j(x_{-i}) \qquad \text{Eq. (3.11)}$$

And,

$$\exists j \in K: f_j(x_i) < f_j(x_{-i}) \qquad \text{Eq. (3.12)}$$

Figure 3.5 illustrates the concept of Pareto-optimality, and sorting, considering two generic minimization objectives (*f1, f2*). All of the solutions satisfy the problem constraints and are considered feasible. Nevertheless, only the solutions in the first Pareto Front (lower-left edge) are the ones that are not dominated by any other solutions in the other fronts.

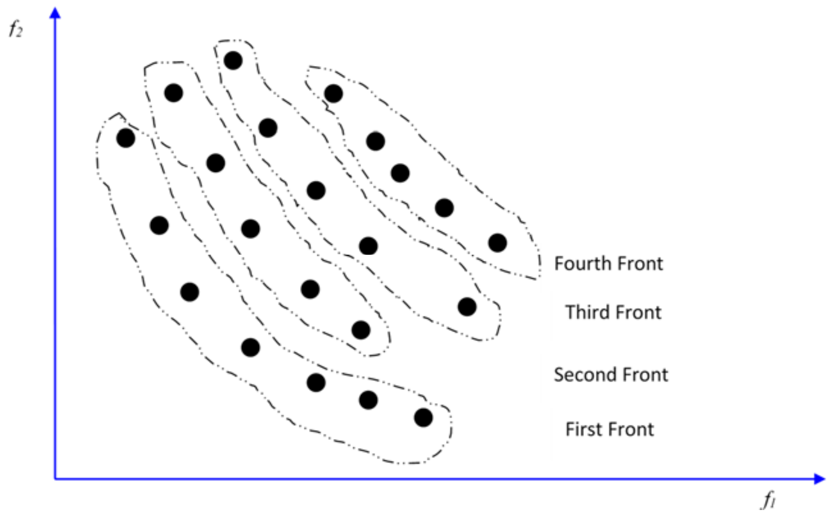

Figure 3.5: Pareto Front Sorting

The Pareto-Front sorting process starts by identifying a set of non-dominated solutions, which will be ranked as the first Pareto Front. Then the process continues to rank the other schedules to the second Pareto Front and so on till all the solutions are ranked to their fronts. Consequently, the fitness of any solution equals the inverse of its rank (Pareto Front index) (Eid et al. 2012, Elbeltagi et al. 2010).

The PFS concept can be integrated into the proposed model. This will guide the SDRC to determine the optimal budget distribution. This will be carried out through evaluating the impact of the different disaster recovery plans on the various objective functions, regardless of their units (maximizing residential recovery, maximizing economic recovery, minimizing social vulnerability, minimizing environmental vulnerability, and minimizing economic vulnerability).

PFS then will rank the different strategies across the five-dimensional objective functions. The frontiers will represent the effectiveness of the corresponding plans to meet such objectives without compromising one over the others. The obtained inverse of the ranks per strategy achieved through PFS is thus considered as the reward function per disaster recovery plan in the individual reinforced learning model.

Two main aspects should be noted: (1) all objective functions have the same importance and no subjective weights are introduced to prioritize one objective over the others, and (2) such approach can be utilized to account for any combination of objective functions that would provide different outcome with each permutation.

3.6.2.2.2. Infrastructure Projects Disaster Recovery

The Mississippi Development Authority carried out several major post-Katrina infrastructure projects through 2007 to 2015. The main constituent of such projects was the wastewater treatment facilities (WWTFs), which directly impacted the host community environmental vulnerability and sustainability status. To this end, data were collected from the MDA, MRD and Mississippi Department of Environmental quality (MDEQ) regarding the construction costs, duration, project descriptions, locations and service areas, as shown in the data gathering section.

The presented framework optimizes the development of the infrastructure projects to meet the needs of the different stakeholders within the host community, while minimizing the social, environmental, and economic vulnerabilities of the built environment. As per the problem domain, the model development focused on the WWTFs projects within the three Mississippi coastal counties. The actual nine WWTFs projects carried out by the MDA were developed to meet the needs of the increasing population to provide them with wastewater treatment. However, the MDA did not consider the vulnerabilities of the built environment as an objective of the WWTFs development (Eid and El-adaway 2016a).

The developed framework enables the SDRC agent to optimize the service allocation of the different WWTFs through integrating the host community's vulnerability using the SoVI, EVI, and EconVI, into the SDRC's objective functions, as show in Eqs. (3.13-15).

Minimize $\sum_{1}^{C} SoVI_{c_y} \quad \forall\, y = 1,2, \dots, Y$ Eq. (3.13)

Minimize $\sum_{1}^{C} EVI_{c_y} \quad \forall\, y = 1,2, \dots, Y$ Eq. (3.14)

Minimize $\sum_{1}^{C} EconVI_{c_y} \quad \forall\, y = 1,2, \dots, Y$ Eq. (3.15)

where *SoVI* is the Social Vulnerability Index, *EVI* is the Environmental Vulnerability Index and *EconVI* is the Economic Vulnerability Index for census tract *c* in county *y*.

It should be noted that according to the problem domain, the WWTFs only impact the environmental vulnerability dimension. As such, both the social and economic vulnerability indicators are not affected by the WWTFs projects. However, the utilized approach can be implemented on any other infrastructure development and integrate its impact across the three-dimensional vulnerability indicators.

As shown in Eqs. (3.16-3.17), the allocation of the WWTFs is constrained by: (1) the location of the WWTF, (2) the required quantity per census tract (taking into account the population growth), and (3) the maximum capacity of each WWTF.

$tw_c \geq tw_c^L \quad \forall\, c = 1,2, \dots C$ Eq. (3.16)

$cap_f \leq cap_c^U \quad \forall\, f = 1,2, \dots, F$ Eq. (3.17) where, tw_c is the treated wastewater for census tract c, and tw_c^L is the treated wastewater lower limit needed for census tract c. cap_f is the utilized capacity of $WWTF\ f$, and cap_c^U is the upper limit (maximum capacity) for such $WWTF$.

Contrary to the stochastic impact of the residential and economic sector recovery plans on the community redevelopment and vulnerability, the WWTFs project have a deterministic outcome on the overall environmental vulnerability at each census tract (Eid and El-adaway 2016a). Accordingly, the researcher investigated the various available search and optimization models that can be integrated into the SDRC agent to guide and optimize the WWTFs project development and service allocation. Such models span from heuristic to evolutionary algorithms: Genetic Algorithms, Simulated Annealing, Taboo Search, Dynamic Programming, etc.

Through this framework, a Simulated Annealing optimization module is integrated into the SDRC's decision making processes. This module attempts to optimize the service allocation of the different WWTFs projects to decrease the vulnerability of the built environment and meet the needs of the community. Unlike other optimization approaches, Simulated Annealing was reported multiple times in the literature to provide statistically optimal solutions (Eid and El-adaway 2016b, Goffe et al. 1994), and can capture the multi-objective optimization problem at hand (Eid and El-adaway 2016a).

Simulated Annealing is a hill climbing search algorithm with some random walk that renders it to be a complete search algorithm (Russell and Norvig 1995). Inspired by metallurgy, Simulated Annealing starts with random values and a "temperature schedule" for random walks. Those schedule controls the probability to search for new solutions. The longer the search continues the "cooler" the temperature is, and the lower probability the algorithm gives to randomly choose a new solution. Those, this approach allows for complete and effective search of the solution space. Figure 3.6 depicts the Simulated Annealing algorithm.

3.6.2.3. Local Disaster Recovery Management (LDRM)

Being in direct contact with the residents and the business owners of the host community, the LDRM is considered a pillar in the infrastructure recovery post a disastrous event. The LDRMs role in the recovery and restoration processes is to: (1) discuss with the stakeholders the recovery plans, (2) coordinate with State agencies, (3) evaluate the applications for funding; and (4) monitor and report the recovery and redevelopment of the infrastructure to the SDRC (NDRF 2011). The LDRM should also plan and undertake other activities beyond the current research scope, i.e. preparedness activities and exercises.

Through the model, the LDRM acts as a negotiator between the SDRC and the local residential and economic sectors. The action plans proposed by the SDRC is transmitted to the local stakeholders through the LDRMs, so the local community would choose one that will increase their individual objective functions. Moreover, according to the NDRF (2011), the LDRMs need to: (1) check the agents' applications for approval, and (2) manage the recovery and redevelopment process (Eid and El-adaway 2016b). The LDRM assesses the applications submitted by the agents for the selected recovery plan and determine if it is to be approved or denied depending on the predefined approval criteria. Such criteria can be found through the MDA federal reporting. The agents' selection of the recovery and redevelopment plan will be discussed in a later section.

The LDRM checks the current development progress of the residents through: (1) evaluating the initial values of the residential sector households through Eq. (3.18); (2) determine

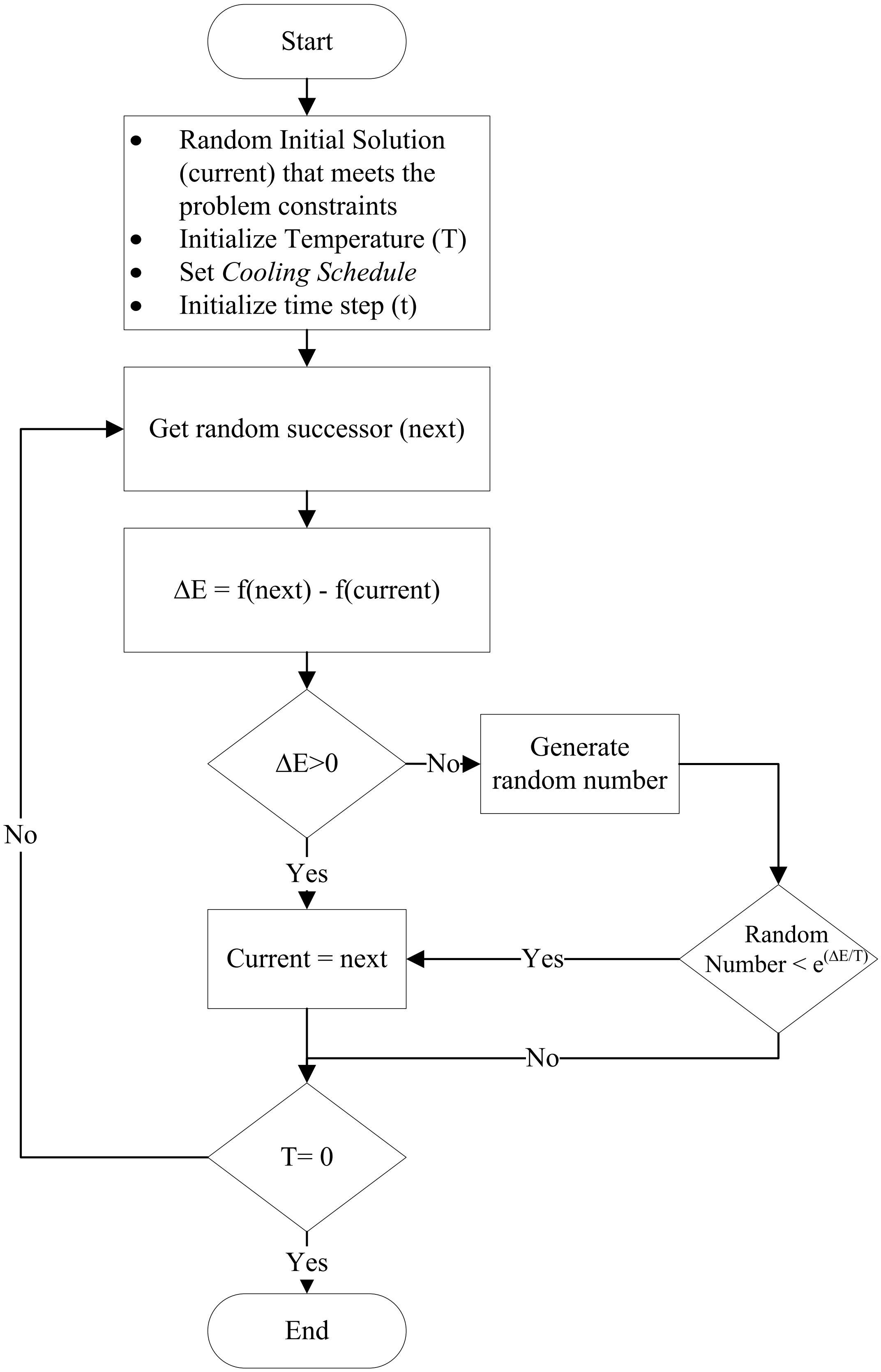

Figure 3.6: Simulated Annealing Algorithm

the current redevelopment and recovery progress at each time step through Eq. (3.19); and (3) calculate and report the overall development progress in the residential sector through Eq. (3.20).

$$D_{y_o} = \sum_i^I H_{i_y} \quad \forall\, y = 1,2,\dots,Y \qquad \text{Eq. (3.18)}$$

$$D_{y_t} = \sum_i^I H_{i_y} \quad \forall\, y = 1,2,\dots,Y \qquad \text{Eq. (3.19)}$$

$$\Delta D_{y_t} = \frac{D_{y_t}}{D_{y_o}} \quad \forall\, y = 1,2,\dots,Y \qquad \text{Eq. (3.20)}$$

Where D_{y_o} is the initial development status for county *y*, D_{y_t} is the current redevelopment status at time *t*, ΔD_{y_t} is the current change in development at time *t*, H_i is the household value for resident *i* in county *y* (Eid and El-adaway 2016a).

3.6.3. Residents

The residents are the main profiteers from the infrastructure redevelopment and recovery. The main objective of the resident agents is to increase their wealth. This is carried out through: (1) preserving the value of their households, (2) increase their monthly income, and (3) reducing their out of pocket expenses (Eid and El-adaway 2016a). The repair costs of the damaged households are covered either through the savings of the residents, their insurance coverage, or through financial/resource support by the government agencies. The utility function of the residents is shown in Eq. (3.21)

$$Z_i = H_i + I_i - T_i - P_{i(n,m)} + C_{i(n.m)} - R_i \qquad \text{Eq. (3.21)}$$

Where, *i* is the resident index, Z_i is the objective function of resident *i*, H_i is the household value for resident *i*, I_i is the monthly income for resident *i*, T_i is monthly distributed tax amount (income and property taxes), $P_{i(n,m)}$ is the monthly distributed insurance premium cost, if any, for plan m offered by insurer n, $C_{i(n,m)}$ is the insurance compensation value, if any, paid by insurer n for plan m, and R_i is the self-paid repair costs (Eid and El-adaway 2016a).

The available resources for the residents to repair and purchase insurance policies is constrained by their net income; the difference between the monthly income and living expenses (Eid and El-adaway 2016a). The Federal Highway Administration (2014) estimated the average household monthly expenses to be 45% of the gross income of the household. Accordingly, the total household's expenses within the model (T, P, and R) is constrained through Eq. (3.22).

$$T_i + P_{i(n,m)} + R_i \leq 0.55 I_i \qquad \text{Eq. (3.22)}$$

In order to maximize their objective functions, the residents need to (1) determine the optimal insurance policies that meet their repair needs with minimum expenses, and (2) choose the government recovery support plan that provides them with a positive impact (Eid and El-adaway 2016b). In order to simulate the residential sector decision making processes, two learning modules are needed that replicates their social (decision actions one) and individual (decision action two) learning behaviors. The social learning module should work within an Evolutionary Game between the residents and the insurance companies. Meanwhile, the individual learning module needs to illustrate the individual learning of the residents through their experiences.

3.6.3.1.1. Social Learning and Residents/Insurance Evolutionary Game

As previously discussed in Chapter two (Literature Review), in evolutionary games, several independent players (residents and insurance companies in the current game) try to find the best strategy to utilized based on its encounter with other players in the surrounding environment, and their corresponding payoffs (Eid et al. 2015, Samuelson 1997). Through observing and mimicking their peers (i.e., replicator dynamics), players choose and change their strategies to reach an Evolutionary Stable Strategy (ESS). Such strategy guarantees that each player plays a stable strategy given the other players' best responses. ESS needs to be immune to mutant strategies.

Furthermore, through evolutionary game theory, imperfect players learn through observing the other players, and replicate their actions (Eid et al. 2015). This fit in the model where residents do not always have perfect information as well as they cannot optimize such complex, dynamic, and stochastic decision making process without the communication with other residents. Thus, evolutionary game theory assumes that the dynamics of the game will let each strategy to be utilized by some portion or fraction of individual per time step (Eid et al. 2015, Turocy et al. 2001). A strategy that provide its user with a relative advantage over the other will remain in the game, while weaker strategies will gradually decay. Such approach also allows for the heterogeneousness representation of the different residents depending on their income, households' values, standard of living, savings, etc. Each insurance plan will be utilized by a fraction of the population depending on their endogenous attributes, until an ESS emerges.

Inspired by the theory of natural selection and survival of the fittest, the survival of a strategy is based on the fitness of the residents utilizing it. As such, a resident utilizing one strategy and has an average payoff that is better than the other residents, would insure the survival of the utilized strategy in the following rounds (Samuelson 1997). This replicator dynamic affects the different player depending on their group and type (residents, income level, etc.), and will govern the law of motion of the game (Eid et al. 2015).

In the context of an Evolutionary Game, the residents tend to communicate with each other to determine which insurance company and policy that would increase their utility function. To this effect, Particle Swarm (PS) was utilized for the residents' replicator dynamics in a form of social learning. PS is an evolutionary algorithm based on stochastic search that mimics social behavior of species (Elbeltagi 2013). Through collective decentralized behavior, the system can self-organize and optimize its actions to increase the utility of the individuals. Thus, the residents in the proposed model utilizes Memetic Particle Swarm (MPS) that is developed on Dawkins notion of memes (Dawkins 1976). Through this approach, each particle represents an agent that is allowed to observe the surrounding agents, in a form of local search, to determine the most fit among its peers. This will allow it to evolve through mimicking the best agent. Moreover, through mutation, new solutions can be derived that might affect the population collective optimal output.

Accordingly, after evaluating each resident's utility function, as shown in Eq. (3.21), the residents (swarm) are ranked. As illustrated in Eq. (3.23), each resident will then be allowed to mimic one of the "fitter" residents (*demonstrator*) in the swarm pool, choosing decision actions (*n,m*), insurance company and insurance policy. This is governed by a probability function that is dependent on the resident's rank, as shown in Eq. (3.24).

$$(n,m)_{i(t+1)} = \begin{cases} (n,m)_{j(t)} & if\ prob_{i(t)} \geq prob^{L}_{i(t)} \\ (n,m)_{i(t)} & otherwise \end{cases} \qquad \text{Eq. (3.23)}$$

$$prob^{L}_{i} = (1 - \frac{Rank(i)-1}{I}) \qquad \text{Eq. (3.24)}$$

where, $(n,m)_{i(t)}$ is the resident's *i* decision action on choosing insurance *n*, and policy *m* at time *t*. *j* is the demonstrator's index drawn from a uniform distribution $U\sim(1,Rank_{(i)})$. $prob_i$ is a randomly generated number, while $prob^{L}_{i}$ is the learning probability for resident *i*.

Mutation will also take place. Mutation occurs through the random change in any resident's decision action (either insurance company or policy). This allows for the investigation of the solution space while avoiding local optimum regions. Furthermore, the mutation procedure resembles the exploration of an agent (resident) beyond the current norm or socially known solution, which might be better than the current ones. An evolutionary game reaches its Evolutionary Stable Strategy when no mutant strategy is introduced to the current population and spreads among the non-mutant strategies through having a better payoff (Eid et al. 2015, Weibull 1995; Smith and Price 1973). This evolutionary stable strategy can be followed by the residents that would increase their utility functions. Such approach will ultimately guide the insurance companies to know the optimal set of plans to be presented to each class of residents.

3.6.3.1.2. Individual Learning and Residents/LDRM Interaction

As previously mentioned, the residents need to find the optimal government recovery plan that would increase their objective functions. Through interacting with the LDRMs that offer the different recovery plan by the SDRC, the resident agent evaluates the recovery plans and chooses one that increases its expected outcome, as show in Eq. (3.25).

$$E\left[U_j\right]_i = \left(U_i + G_j \times A_j\right) \times pr_j \qquad \text{Eq. (3.25)}$$

Where; $E\left[U_j\right]_i$ is the expected utility of plan *j* for the resident *i*, *G* is the government maximum award for plan *j*, *A* is the government average acceptance probability of plan *j,* and *pr* is the probability utilized from the reactive reinforced learning module discussed below (Eid and El-adaway 2016b).

Meanwhile, according to the NDRF, the LDRMs is responsible to review and evaluate the submitted recovery assistance applications by the residents and only accepting the eligible applications (NDRF 2011), as shown in Figure 3.4. In case of denying the application of the resident agent, either due to ineligibility or due to lack of fund for such plan by the SDRC, the resident agent needs to learn (based on its own experience) which other government recovery plan it needs to apply for in the next attempts (Eid and El-adaway 2016b). Such learning behavior can be depicted using an individual learning model. To this end, the developed model utilized Roth Erev Reactive Reinforced Learning (1998) to depict such learning process by the resident agents. Roth Erev model is able to mimic the human learning behavior based on their own past experiences and can depict the such interactions between the LDRMs and the residents (Eid and El-adaway 2016a). Eq. (3.26) illustrates the determination of the reward function (*E*).

$$E_j(k) = \begin{cases} \pm 1 & if\ j = k \\ 0 & Other\ wise \end{cases} \qquad \forall\, j = 1,2,\dots,J \qquad \text{Eq. (3.26)}$$

Where, for each available action *j*, *E* is the reward for applying action *k*. If *j=k, E* takes the value of *+1* or *-1* if the application is approved or denied, respectively. Otherwise, *E = 0.*

Thus, the model can update the decision variables' propensity and selection probabilities as shown below in Eq. (3.27) and (3.28), respectively:

$$q_j(t+1) = q_j(t) \times (1 - \phi) + E_j(k) \times (1 - \varepsilon) \qquad \forall\, j = 1,2,\dots,J \qquad \text{Eq. (3.27)}$$

$$pr_j(t) = q_j(t) / \textstyle\sum_{j=1}^{J} q_j(t) \qquad \forall\, j = 1,2,\dots,J \qquad \text{Eq. (3.28)}$$

Where; $q_j(t)$ is the propensity of action *j* in time *t*, ϕ and ε are the forgetting and experimenting parameters, respectively. *pr* is the probability distribution of action *j.*

The ϕ and ε parameters allow the resident agent to investigate the solution space to determine the optimal strategy. Through experiencing and experimenting the outcome of the various decision actions, the resident agent can weaken or strengthen the probability of the different strategies based on their associated outcome.

3.6.3.1.3. Residence Recovery Module

The impact of each residential recovery plans on the households, in regard to recovery rates, were collected through the MDA and MRD the federal reports for years 2007-2015. It was noticed that for:

1. *The Housing and Homeowner Assistance*, the recovery rate was 7.5% of the damaged value per month.
2. *The Public Home Assistance*, the redevelopment and recovery rate was 1.6% of the damaged value per month.
3. *The Elevation Grant*, the redevelopment rate was of 3.3% of the value per month.

To this end, the recovery module determines which redevelopment and recovery plan is approved, if any, then starts the recovery process for the residential building at each time step, as illustrated in Figure 3.7. Thus, the recovery rate can be calculated and reported back to the LDRM, as previously mentioned, to be evaluated per county.

3.6.4. Insurance companies

The proposed framework integrates the insurance companies that impact the recovery progress of the host community (Eid and El-adaway 2016b, NDRF 2011). The model accounts for various insurance companies that offer different insurance policies that provide different types of coverage. Each insurance company needs to define its pricing plan and the number of plans to be issued for a given pool of residents (Eid and El-adaway 2016a). To this end, the utility function of the insurance company is to increase their profit, as shown in Eq. (3.29). where the total utility gained by an insurance company would be the difference between the collected premiums paid by

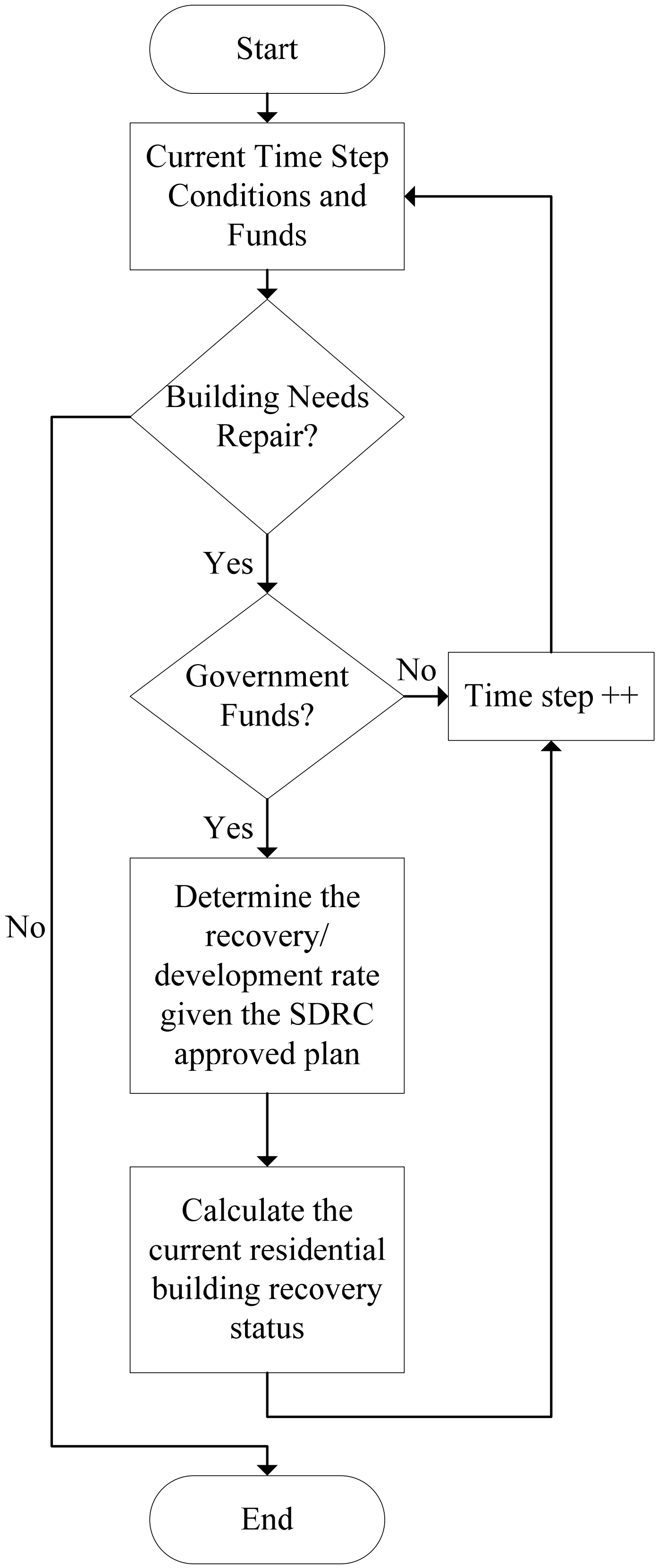

Figure 3.7: Residential Recovery and Redevelopment Module

the residents and the total paid compensation for the residents if a natural hazard event occurs (Eid et al. 2015).

The insurance companies follow risk assessment to guide their decision actions. Moreover, the insurance companies need to account for the insured pool's adverse selection that may contain mostly high risk residents and businesses that would force the insurance companies to alter the premium rate (Eid et al. 2015, Janssen and Karamychev 2005).

Nevertheless, following the aforementioned evolutionary game, the insurance companies were developed to be myopic. They offer their different insurance policies and plans, and let the resident agents choose from, and then learn the required distribution of the different plans to meet the needs of the residents and decrease their losses.

$$W_n^{t+1} = W_n^t + \sum_{i=1}^{I} \begin{cases} P_{i(x,m)} - C_{i(x,m)} & if\ x = n \\ 0 & Otherwise \end{cases} \quad \forall\, n = 1,2,\dots,N \qquad \text{Eq. (3.29)}$$

where, W_n^{t+1} is the insurance company *n* wealth at *t+1,* and $C_{i(x,m)}$ is equal zero if no disaster has occurred at time t+1.

The proposed model utilized a previous research by the researcher (Eid et al. 2015) to introduced three different insurers that offer three post-disaster insurance policies for the resident agents. Table 3.4 presents the different insurance policies per insurer, along with their premiums and compensation.

Table 3.4: Insurance Companies Plans' Premiums and Coverage Percentages

Insurance Company	Plan A		Plan B		Plan C	
	Premium%	Coverage%	Premium%	Coverage%	Premium%	Coverage%
Insurer # 1	1.8%	70%	2%	75%	2.8%	85%
Insurer # 2	2.2%	80%	2.8%	85%	3%	95%
Insurer # 3	2.8%	85%	3%	95%	3.28%	100%

3.6.5. Economic and Business Agent

The business sector provides prosperity to the host community in which it belongs (Eid and El-adaway 2016b). This is presented through job offering and work opportunity for the host communities' residents, while offering goods and services to the society in addition to contributing to the State and Federal tax. The economic sector is also highly affected by the perturbation to the system's equilibrium and the recovery and redevelopment processes. The perturbations affect the business sector through: (1) reducing the community ability to purchase goods or apply for the economic sectors' services as they are focused on the recovery processes, and (2) impacting and damaging the physical structure (stores, business centers, etc.) that leaves the economic sector unable to serve the community, make profit, and contribute the society welfare.

The economic agent within the proposed framework illustrates the privately-owned businesses. The economic agent presents a generic business, even though it was only implemented on the retail sector, as shown in a later sector. The economic agent also represents how the disastrous event's damage and recovery affects the business sector revenue, which in return affects the community's livelihood, the taxes collected, and the overall host community resilience.

3.6.5.1. Residents and Business Sector Relationship

As previously mentioned, there is a relationship between the business sector and the residents of the community. The different businesses within the community provide jobs and income to the residents. Meanwhile, the residents purchase the goods and services provided by the businesses that creates revenue for the business sector. Both the business sector and the residents pay State and Federal tax. The residents' purchase for goods or service d is controlled by the frequency of purchasing such a product or service ($freq_d$) and the ratio of income spent on such product or service per month (γ_d). The business job offering for the residents is governed by the capacity of each business (Eid and El-adaway 2016b). Figure 3.8 illustrates the relationship between the residents and the business sector.

The proposed framework assumes the resident agents are the main driving factor of the business sector prosperity and affect this resident/business sector interaction. Meanwhile, the economic agent is regarded as myopic and does not have any strategies that might affect such relationship. This assumption is simplification to reality that needs to be furtherly investigated. However, such simplification will allow for better analysis to the framework outcome and potentials.

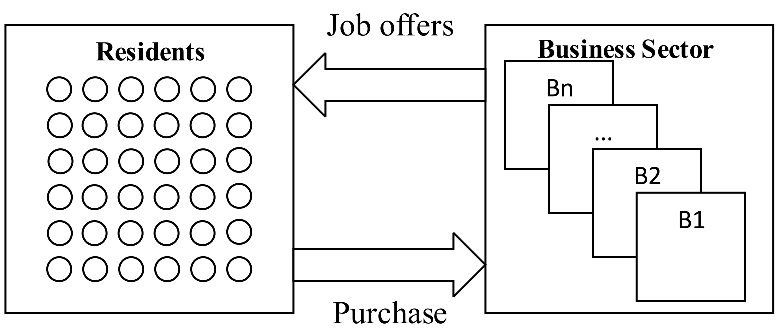

Figure 3.8: Residents and Business Sector Relationship

The residents' purchasing power, the purchasing frequency, and expenditure ratio for each product or service determine the monthly revenue for each business sector (Eid and El-adaway 2016b). To this effect, the following Eq. (3.30) demonstrates the residents purchase frequency for each product *d*, where the frequency takes as positive value between 0 and 1. For example, food and grocery will have a higher frequency than health care or construction services.

$$Freq_d = [0,1] \qquad \forall d \in D \qquad \text{Eq. (3.30)}$$

Meanwhile, as shown in Eq. (3.31), the expenditure *E* per product or service *d* is governed by the ratio of the income spent on such product or service. This ratio in denoted as γ, where γ takes a positive value between 0 and 1. Such values are obtained from the US Bureau of Labor Statistics (Consumer Expenditure Survey, 2014) and summarized in Table 3.5.

$$E_{i_d} = I_i \times \gamma_d \qquad \forall d \in D, \forall i \in I \qquad \text{Eq. (3.31)}$$

Thus, the business sector revenue will be the total residents' expenditure for such product or service per month minus the cost to provide such product or service, as shown in the following equation.

$$Revenue_d = \sum_i^I E_{i_d} \qquad \forall d \in D \qquad \text{Eq. (3.32)}$$

Table 3.5: Household's Income Expenditure (Consumer Expenditure Survey, 2014)

Product/Service	Household Income Expenditure Ratio (γ)
Housing and Accommodation	16%
Transportation	14%
Retail (food and groceries)	10%
Health Care	6%

3.6.5.2. Business Sector Redevelopment

The proposed framework accounts for the damages exerted by the disastrous event on the business sector physical structures. As shown in Figure 3.9, the model calculates the disaster impact on the physical structure of the business, depending on its location and proximity to the disaster. Also, depending on the size, the disaster insurance policy purchased by the business owner, and the government recovery fund, the proposed model calculates the disaster recovery rate for the business. Thus, at each time step, if the physical recovery reached a preset threshold, the business agent can start offering the service to the host community, otherwise, it will remain incapable to serve the residents, or pay tax.

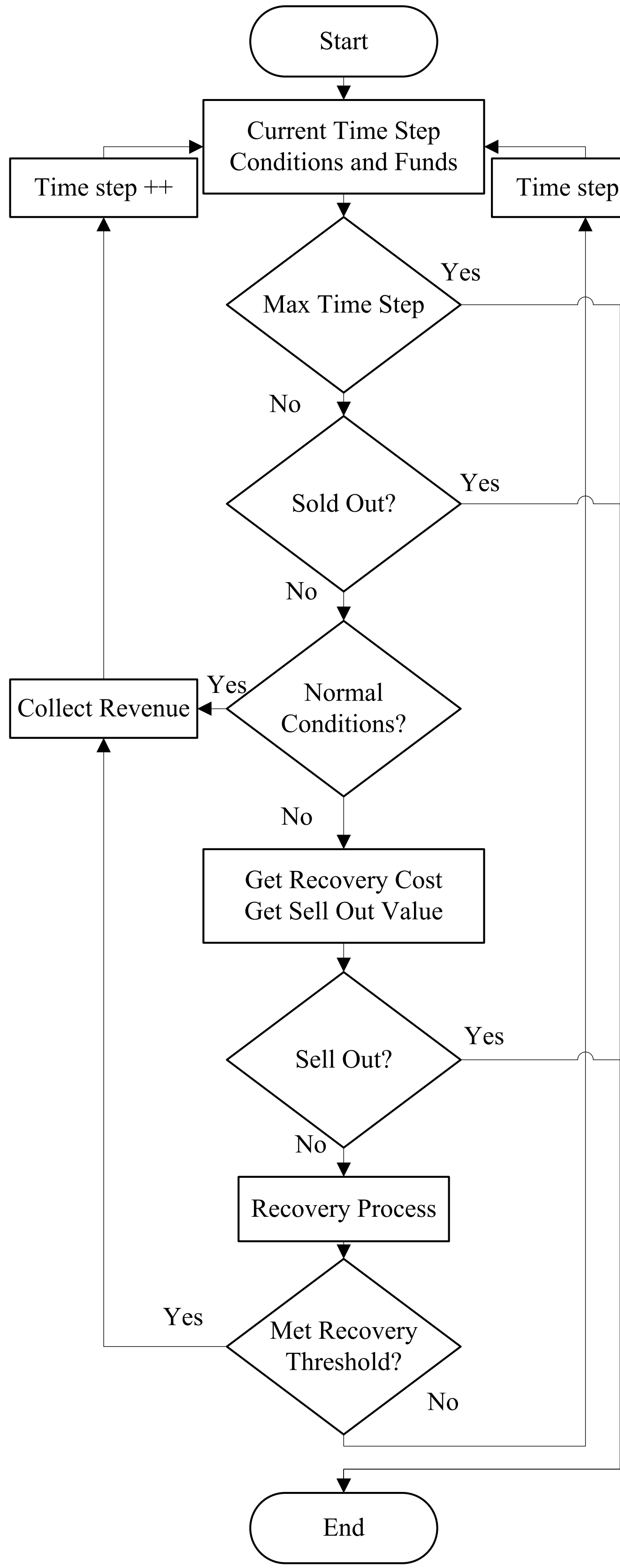

Figure 3.9: Business Sector Recovery

In case of a shock, the business owner might consider selling out. This depends on: (1) the impact of the disastrous event on the business physical structure, (2) the compensation provided by the insurance policy compensation, and (3) the government recovery aid (Eid and El-adaway 2016b). To this end, the business agent determines the recovery cost from the disaster impact, as shown in Eq. (3.33) and the sellout option value, as shown in Eq. (3.34). If the sellout value is greater than the recovery cost, the business agent will sellout, thus relocate and leave the impacted region. The researcher acknowledge that such approach is a simplification to the actual decision making processes of the business sector, that does not take into consideration the future projected revenues, the risk factors, or the heterogeneity of the business owners.

Nevertheless, in order to achieve simple understanding and analysis of the community redevelopment it was found best to simplify the agents' actions in this complex built environment.

$$RecoveryCost_e = St_e \times \sigma_e - C_{e(n.m)} - F_e \qquad \text{Eq. (3.33)}$$

$$SellOut_e = St_e \times \sigma_e \qquad \text{Eq. (3.34)}$$

where, St_e is the structure value for economic agent e, σ is the damage excreted on the physical structure as a factor of proximity of the natural hazard. $C_{e(n,m)}$ is the insurance compensation value for economic agent e utilizing insurance policy m from insurer n, F is the government fund.

3.7. Model Verification and Testing

The developed ABM is modular and scalable. Modularity is the flexibility of the model to changes with the different algorithms and processes without adversely affecting the primary aspects of the model (Eid and El-adaway 2016a). Meanwhile, scalability refers to the potential of the model to handle different case studies including different number of agents (resident, economic, insurance, or government), and different regions and sizes (Eid and El-adaway 2016b). More importantly, in order to provide a rigours model, the proposed ABM was subjected to several verification evaluations through a series of incremental tests.

First, using test agents, regression tests were carried out to examine the different developed agents and make sure they perform their desired and designed roles and that any new agent addition does not have negative impact on the model stability. (Eid and El-adaway 2016b). Moreover, the developed agents were tested in relation to their internal and external behaviors via structure and behavior validity testing (Eid and El-adaway 2016a, Vidal 2007; Vlassis 2003; Sterman 2000). Structure validity testing included structure-oriented behavior (behavior-sensitivity, extreme-condition, modified-behavior prediction, and boundary adequacy tests). Meanwhile, behavior validity testings are used to estimate the accuracy of the communication among the different agents (Eid and El-adaway 2016a).

Finally, a series of progression tests were applied through supplying definitions of all messages that a particular agent sends and receives. Such methodology ensures that the agents in the developed model function per their mathematical design, and collectively build the ABM to its desired objectives.

3.8. Research Hypothesis Testing

As previously discussed, the research hypothesis is that integrating the vulnerability indicators into the objective functions of the associated stakeholders will yield into a more effective decision making processes. According, the proposed framework needs to be compared and tested to a null hypothesis. The AMB was ran through “actual budget distribution” and “uniform budget distribution" scenarios for the SDRC to test the model output when no such integration takes place (null hypothesis). As such, a comparison between the proposed framework/hypothesis to the null hypothesis will provide adequate testing. If the proposed framework's outcomes provided better results than the null hypothesis (uniform and actual budget) then it can be concluded to accept the hypothesis. In addition, a comparison will be carried out between the outcome of the model and the actual/existing results and changes in the vulnerabilities of the counties and the changes in the disaster recovery rates.

3.9. Model Implementation

The presented framework was modeled and implemented via an open source multi-agent discrete-event simulation toolkit, using NetBeans IDE 7.4 platform. This was carried out utilizing GeoMASON (a GIS extension to MASON) developed by the Center of Social Capacity and the Evolutionary Computer Lab at George Mason University (Sullivan et al. 2010). GeoMASON is one of the fastest ABM platforms (Railsback et al. 2006). GeoMASON enables the model to gather required initial condition data through GIS files. Such initial conditions will affect the different attributes of the various agents within the study region. Thus, GIS files enabled for the collection of the socioeconomic and environmental data of the problem domain and integrate it into the computer model. More importantly, GIS facilitate the transformability of the model to any other case study. Utilizing GeoMason, the modeled framework was able to represent the residents, economic agents, the hazardous events, and the spatial relationship between them through GIS maps. Figure 3.10 illustrates a snapshot of the agent-based simulation running on GeoMason, showing the three counties (Hancock, Harrison, and Jackson) in addition to the population density and concentration.

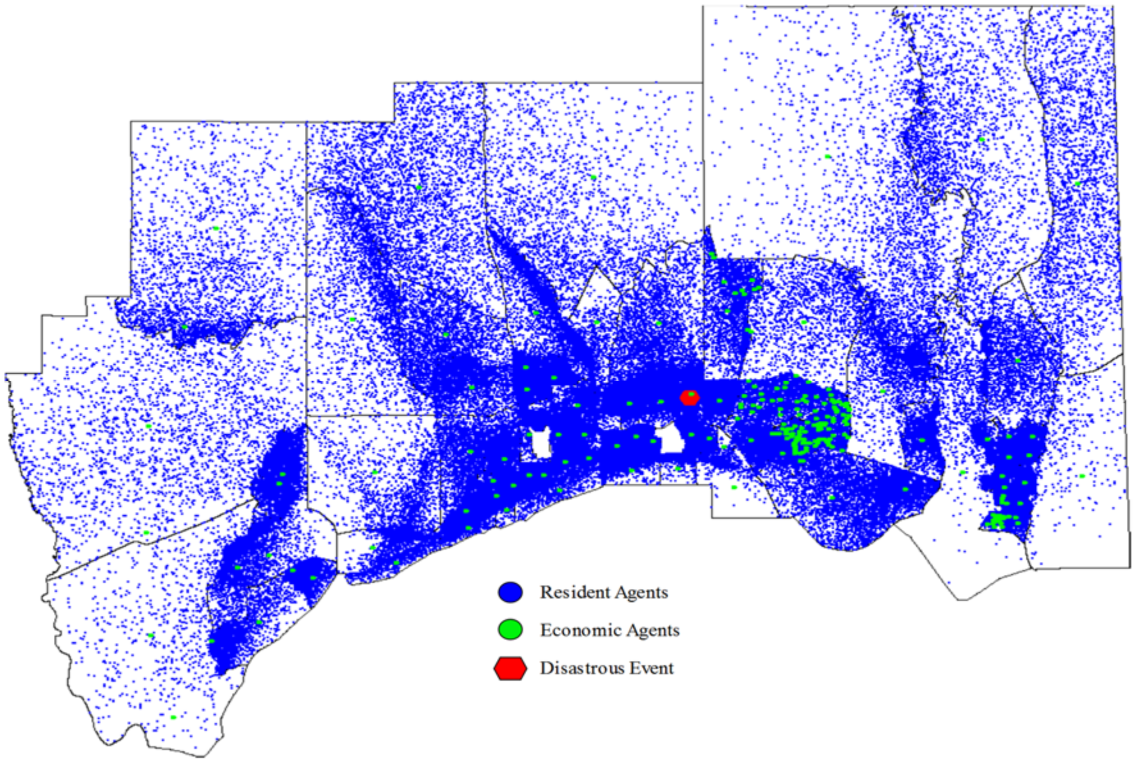

Figure 3.10: Problem Domain Implementation on GeoMason

3.10. Model Outcome and Sample Size Significance

The proposed model's expected outcomes are: (1) the SDRC's budget distribution, (2) WWTFs service allocation, (3) Residential Recovery per county, (4) Economic Financial Recovery per county, (5) average Social Vulnerability Index per county, (6) average Economic Vulnerability per county, and (7) average Environmental Vulnerability per county.

In order to assess the soundness of the outcome, a minimum significant sample size is required to account for the randomness within the model. The current research utilized Lorscheid et al. (2012) and Lee et al. (2015) methodology to determine the minimum required simulation runs. This is achieved via descriptive statistical analysis using the means and variances of the model's distinct outcomes (Lee et al. 2015). As such, using the coefficient of variation proposed by Lorscheid et al. (2012), the sample size can be calculated using the equation below:

$$n_{min} = \operatorname{argmax}_n |c_v^{x,n} - c_v^{x,m}| < E, \forall x \text{ and } \forall m > n \qquad \text{Eq. (3.35)}$$

where, n_{min} is the minimum sample size, x is a distinct outcome of interest, m is some sample size > n for which coefficient of variation $(c_v = \sigma/\mu)$ is measured.

As such, for each case scenario (i.e., framework, actual or uniform budget), after multiple simulations, say n=5, the aforementioned 7 outcomes are calculated. The mean, variance, and coefficient of variation is calculated. Then the next set of simulation is carried out, say n=10. For each outcome, the difference between the coefficient of variation in the last two sets (n=5 & n=10) is calculated. If, the difference does not exceed the value E, then we reached the minimum sample size (n=10). The current research utilized E=0.05 (5% error).

3.11. Summary

This chapter illustrated the research methodology and model development. Through this chapter the selected vulnerability indicators were presented for the social, environmental and economic dimensions. Such presentation included their criteria for selection, methodology, and data gathering. Moreover, this chapter presented the development of the agent based model and the learning algorithms of the different stakeholders.

Furthermore, this chapter presented the model's verification and testing methodologies. Finally, this chapter illustrated the methodology to test the research hypothesis along with the calculations for the significant sample size.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1. Introduction

Following the objectives stated in Chapter One and the methodology discussed in Chapter Three, this chapter illustrates the proposed framework's results in regard to the stakeholders' decision actions and how they collectively affected the redevelopment processes and the three-dimensional vulnerability of the host community. The MDA budget distribution and service allocation of WWTFs is presented. The impact of the MDA's decision actions on the existing vulnerability of the host community (Mississippi coastal counties; Hancock, Harrison and Jackson) is then illustrated. Consequently, the results of the proposed framework are presented on four vulnerability optimization cases: (1) social vulnerability, (2) economic vulnerability, (3) environmental vulnerability, and (4) simultaneous three-dimensional vulnerability. The results are compared across the vulnerability indicators, the residential recovery progress, and the economic financial recovery. Furthermore, the SDRC's decision actions are compared to illustrate the reasons behind such results. More importantly, the framework results are compared to the actual and uniform budget distribution scenarios to test the research hypothesis.

4.2. Problem Domain's Existing Conditions

4.2.1. Mississippi Development Authority Decision Actions

Through this sub-section, an illustration of the actual MDA decision actions is presented. This is carried out on the MDA budget distribution across the four residential/economic financial recovery and the utilization of the infrastructure development (WWTFs).

4.2.1.1. MDA Budget Distribution

Figure 4.1 illustrates the different funding proportions used by the MDA post-Katrina, where the Homeowner Assistance plan dominated the other three plans. This is mainly due to the external pressure exerted on the disaster recovery agency then as this plan provided the residents with the highest reward up to $150,000 (Eid and El-adaway 2016a, Mississippi Development Authority reports 2015). Nevertheless, such plan does not impact the poor income families and residents or increase the households' values. As such, this plan is unable to decrease the community's social vulnerability. In addition, the Homeowner Assistance plan does not contribute to the economic financial recovery and the economic vulnerability.

Meanwhile, the other three plans did not have more than 15% of the budget at anytime in the studied five years. As such, the utilized MDA budget distribution did not (1) meet the poor income families, (2) increase the households' resilience and value, and (3) sufficiently incentivized the economic sector to remain in the impacted region.

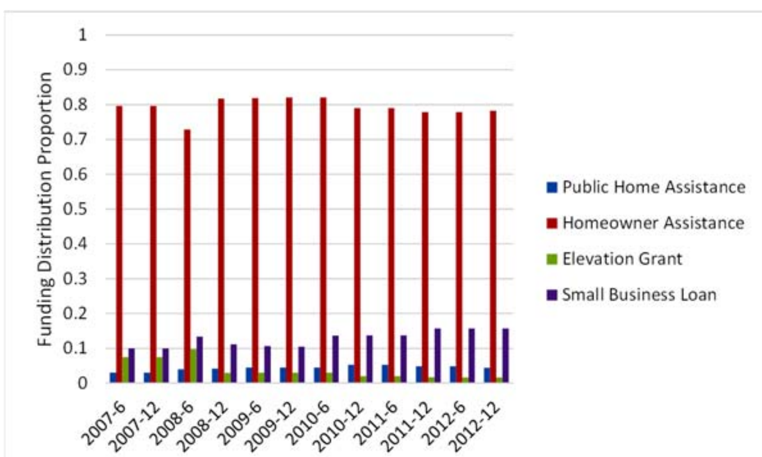

Figure 4.1: Actual MDA Funding Distribution

4.2.1.2. MDA WWTFs Utilization

To achieve a holistic understanding on the different development and recovery projects in the three Mississippi coastal counties, an infrastructure project was utilized as a case study that affects the vulnerabilities of the built environment (Eid and El-adaway 2016a). To this effect, the Wastewater Treatment Facilities projects (WWTF) carried out by the Mississippi Development Authority (MDA) and Mississippi Department of Environmental Quality (MDEQ) were utilized. This, subsection presents the actual WWTF projects, along with their capacities, service locations, and a discussion on them. Figure 4.2 presents the different WWTFs distribution among the different counties.

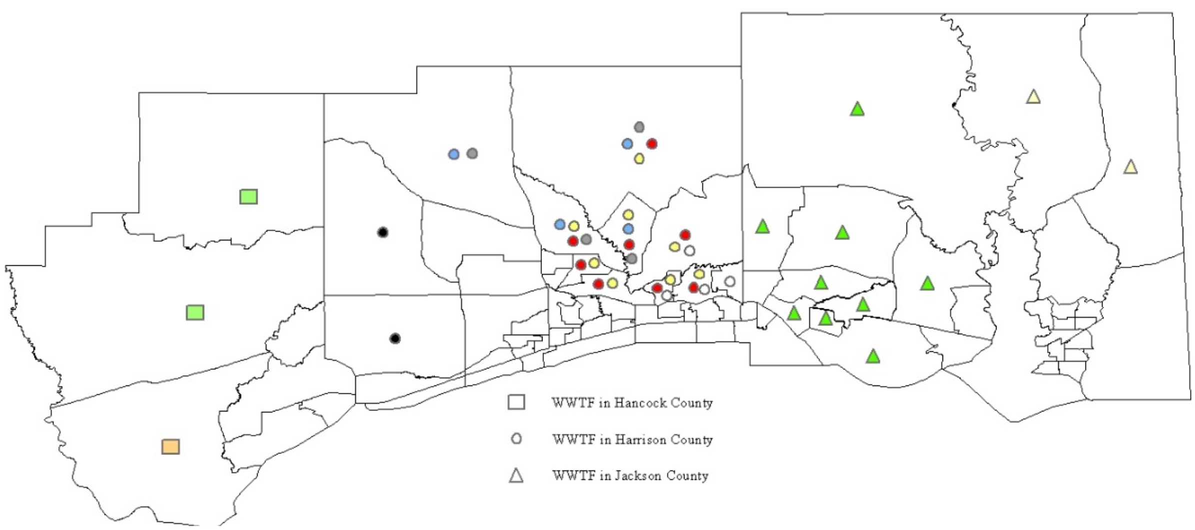

Figure 4.2: Actual WWTFs Service Allocations

- Hancock County:

Through Hancock County, there were two WWTF projects that affected the different census tracts within the study region. The first project was the Kiln WWTF that cost the county $20.8M and have a capacity of 1.5 MG/day of wastewater treatment. The second project was the Pearlington

WWTF that cost the county $5.5M and have a capacity of 0.2 MG/day. Table 4.1 presents those projects.

Table 4.1: Actual WWTF projects – Hancock County

Project	Cost (M$)	Capacity(MG/day)	Census Tracts Served	Served Population (2012)
Kiln WWTF	20.8	1.5	306.01, 306.02	13,798
Pearlington WWTF	5.5	0.2	304	1,942

- Harrison County:

Harrison County WWTF infrastructure was majorly enhanced through six projects (summarized in Table 4.2). The projects costs varied from $4.4m to $25M and capacities from 0.2 to 2.0MG/day.

- Jackson County:

In comparison to the population size across the three counties, Jackson County wastewater had limited development through only two WWTF projects. The First is the Big Point WWTF which costs $4.4M and with a capacity of 0.125MG/day. The second is the West Jackson WWTF that costs $35M and with a capacity of 2.0MG/day. The projects are summarized below in Table 4.3.

As can be noticed from the information above, the utilized WWTFs did not address the most populated regions. For example, only a total of 2.125 MG/day for a population of 77,789 for Jackson County, in contrast to 1.7 MG/day for a population of 15,740, Hancock County. Moreover, the utilized WWTFs allocation did not consider the environmental vulnerability of the different census tracts, as it was not addressed by the MDA federal reporting (2015).

Table 4.2: Actual WWTF projects – Harrison County

Project	Cost (M$)	Capacity(MG/day)	Census Tracts Served	Served Population (2012)
Saucier	9.6	.4	32.06, 34.03, 34.04, 35.01	20,975
South Woolmaket (project#1)	4.4	0.2	32.06, 32.07, 32.08, 33.03, 33.04, 34.02, 34.03, 34.04	46,947
South Woolmaket (project#1)	28	1.5	32.06, 32.07, 32.08, 33.03, 33.04, 34.02, 34.032, 34.04	46,947
West Harrison	25	0.2	31.02, 35.02	12,467
D'Lberbille	24.3	1.5	33.01, 33.03, 33.04, 34.02	31,110
US49-MS67	18	2.0	32.06, 34.03, 34.04, 35.01	24,609

Table 4.3: WWTF projects – Jackson County

Project	Cost (M$)	Capacity(MG/day)	Census Tracts Served	Served Population (2012)
Big Point	4.4	0.125	401.01, 401.02	13,863
West Jackson	34	2.0	402.01, 402.03, 402.04, 404, 405, 406, 407, 408, 409,	63,926

4.2.2. Social Vulnerability Assessment

According to the developed model presented in Chapter Three, 21 socioeconomic variables were gathered. Cronbach's Alpha analysis was utilized to determine their internal reliability. After examining the variables and their internal reliability, 12 variables where retained that correspond to Cronbach's alpha greater than 0.7. The four ethnicity variables as well as the occupation variables where omitted from further analysis as they were found to have the least correlation with the overall variables variation pumping the Cronbach's alpha from 0.2 to 0.73 (for year 2012). Moreover, the percentage of the population with disability and the percentage of the population not infirmed or institutionalized were removed from the analysis as they can only be found on a census tract level for year 2012. The Cronbach alpha's results obtained are shown in Table 4.4. It should be noted that for year 2007, the Cronbach's Alpha is below the 0.7 threshold. The model can achieve better results when omitting one more variable. However, in order to keep the number of variables consistent within the different years of study, it was found best to accept the 0.67 Cronbach's Alpha value.

Table 4.4: Cronbach's Alpha Values for years 2010, 2011, and 2012

Year	Cronbach's Alpha
2012	.7263
2011	.7879
2010	.7408
2007	0.6709

4.2.2.1. Dimension Reduction - Factor Analysis

Factor analysis (FA) is a dimension reduction technique that is used to describe for a set of variables, depending on their observations and their covariance relationships, in terms of fewer but unobservable random quantities or factors (Johnson and Wichern 1998). The use of reductionist technique for the collected variables can be beneficial to determine a set of consistent factors that can be monitored through time (Cutter et al. 2003). More importantly, the utilization of factor analysis allows for the calculation of relative vulnerability scores across the different regions under study. The interpretation of the developed factors may be subjective (Yang and Bozdogan, 2011), however such relative vulnerability scoring approach allows SoVI to be integrated into the infrastructure redevelopment decision support tools in order to guide the SDRC's redevelopment activities and strategies depending on the relative vulnerability of the different regions affected by the perturbations and shocks (Eid and El-adaway 2016b).

FA was carried out using SAS 9.4 for the predetermined 12 socioeconomic variables with their 78 observations (census tracts) for each of the study year to obtain the factors that will determine the social vulnerability index for each of the census tract in the study region. Table 4.5 illustrates the 12 variables with their code used in SAS 9.4 along with a small description. The obtained factors for years (2012, 2011, 2010 and 2007) are discussed below.

Table 4.5: SoVI FA Variables

Attribute	Variable	Variable Description
Economic	Income	Median income
	Median_House_Value	Median house value
	%High_Income	Percentage of the population with household income $75,000 or higher
Equity	%With_Vehicles	Percentage of the population with vehicles
	%Phone	Percentage of the population with Telephone access
	%Mobile_Home	Percentage of mobile homes
	%Home_Ownership	Percentage of home ownership
Adaptive Capacity	%Speak_English	Percentage of the population that speaks English
	%High_School	Percentage of the population with High school diploma or higher
	%Elderly	Percentage of the population that are elderly
	Median_Age	Median Age
	%Female	Percentage of Female

4.2.2.2. Discussion on 2012 obtained factors

The FA applied on the 2012 data obtained four factors (Table 4.6) with eigenvalue greater than 1.0. The first factor is dominated by the percentage of home ownership, the median house value, the percentage of the families with phone accessibility, as well as the percentage of high school education or higher. To this end, one can deduce that factor 1 for the year 2012 represents the economic standard and equity of the community. Also, one can understand the relation of these economic variables to education level attained.

The second factor obtained from the FA for year 2012 is dominated by income of the host communities with moderate relationship to the house ownership and percentage of elderly. To this end, factor 2 can be said to represent the community's income level and equity as well. The third factor with eigenvalue more than 1 obtained through the FA for year 2012 data is dominated by percentage of the population speaking English. This can lead to the conclusion that those factors' values correspond to the adaptive capacity to perturbations. The fourth factor is dominated by the median age of the population with moderate to low relationship to the median house value and the percentage of the population with high income. It can be deduced that this factor is related to the host community adaptive capacity and economic standards.

Table 4.6: SoVI Factor Analysis 2012

Attribute	Variable	Factor 1	Factor 2	Factor 3	Factor 4
Economic	Income	0.19627	0.96139	0.18625	0.05029
	Median_House_Value	0.84313	0.15392	0.15094	0.23135
	%High_Income	0.43503	0.11701	-0.04684	0.39508
Equity	%With_Vehicles	0.33593	-0.01174	0.32021	0.20581
	%Phone	0.72065	0.1449	0.03254	-0.06638
	%Mobile_Home	-0.64153	-0.03323	0.17089	-0.468
	%Home_Ownership	0.86254	0.41838	0.03807	-0.08159
Adaptive Capacity	%Speak_English	0.0443	0.05648	0.99506	0.0686
	%High_School	0.55196	0.29698	0.04883	-0.06554
	%Elderly	0.20798	0.53591	-0.08898	-0.08117
	Median_Age	-0.03396	-0.13652	0.21096	0.8399
	%Female	0.31867	0.07684	0.08515	0.09321

4.2.2.3. Discussion on 2011 obtained factors

Through the FA on the data collected for the 12 variables for year 2011, 4 factors were determined (Table 4.7). The first factor is dominated by the percentage of the population with high income, income, and median house value. Like 2012, Factor one can be considered as the economic standard of the community with more presence of the adaptive capacity illustrated in education level attained. The second factor is dominated by the percentage of elderly and the median age of the community with moderate relation to the percentage of the population with high school or higher as well as the income of the community. One can deduce that this is a hybrid factor for both the adaptive capacity and economic standard of the community to cope with the disaster events. Factor#3 is dominated by the percentage of home ownership, percentage of the population with vehicles as well as percentage mobile home and percentage of the population speaking English. As such, it is measuring the community equity and adaptive capacity. The final factor is dominated by the percentage of the population that are female, the percentage of the population with vehicles and the percentage of the population with high school or higher. Thus, it emphasizes that adaptive capacity is an important variable in the social vulnerability measurement.

Table 4.7: SoVI Factor Analysis 2011

Attribute	Variable	Factor 1	Factor 2	Factor 3	Factor 4
Economic	Income	0.86612	0.4024	-0.05037	0.22934
	Median_House_Value	0.79164	0.17522	-0.08469	0.10753
	%High_Income	0.91877	0.059	0.29366	0.03273
Equity	%With_Vehicles	0.20052	0.0441	0.51524	0.5166
	%Phone	0.26102	0.06421	0.04684	0.27482
	%Mobile_Home	-0.07819	-0.15123	0.54284	-0.13923
	%Home_Ownership	0.37729	0.22636	0.79748	-0.2075
Adaptive Capacity	%Speak_English	-0.04114	0.15148	0.53569	0.11161
	%High_School	0.53056	0.40875	-0.04282	0.49746
	%Elderly	0.21905	0.8989	-0.01082	-0.06198
	Median_Age	0.23374	0.87949	0.19541	-0.05602
	%Female	-0.02875	0.18254	0.15148	-0.5096

4.2.2.4. Discussion on 2010 obtained factors

The FA applied on the data gathered for the 12 variables in year 2010 produced four factors with eigenvalue more than 1 (Table 4.8). The first factor is dominated by the income, median house value, percentage of the population with high income, and moderate relation with percentage of the population with high school education or higher. That can be understood, again as years 2012 and 2011, as the community economic standard along with the adaptive capacity.

The second factor is dominated by the percentage of elderly, the median age and percentage of population with high school as well as income. This can be understood as a factor that illustrates adaptive capacity of the community as well as economic standard relationship. The third factor obtained from the FA of the data is dominated by percentage of home ownership, percentage of mobile homes as well as the percentage of population speaking English. One can deduce that this factor demonstrates the community equity and its relation to the adaptive capacity. Finally, the fourth factor in this year is dominated by the percentage of the population with high school education or higher, the percentage of female and the percentage of the population with vehicle accessibility. Thus, it can be related to the community adaptive capacity.

Table 4.8: SoVI Factor Analysis 2010

Attribute	Variable	Factor 1	Factor 2	Factor 3	Factor 4
Economic	Income	0.8542	0.41868	-0.03831	0.20695
	Median_House_Value	0.85264	0.1028	-0.03226	0.00098
	%High_Income	0.81643	0.1563	0.33283	0.10354
Equity	%With_Vehicles	0.24718	-0.0883	0.27843	0.4256
	%Phone	0.30219	-0.01279	-0.07797	0.23964
	%Mobile_Home	-0.06034	-0.25425	0.55303	-0.1085
	%Home_Ownership	0.26062	0.28763	0.87388	-0.15334
Adaptive Capacity	%Speak_English	-0.04085	0.14098	0.45547	0.0641
	%High_School	0.42243	0.53929	-0.05993	0.6373
	%Elderly	0.11168	0.85771	0.08045	-0.24755
	Median_Age	0.20322	0.82195	0.10945	-0.04199
	%Female	0.00652	0.14893	0.10668	-0.47062

4.2.2.5. Discussion on 2007 obtained factors

The FA applied on the data gathered for the 12 variables in year 2007 produced four factors with eigenvalue more than 1 (Table 4.9). Factor 1 is dominated by percentage of mobile homes as well as the percentage of home ownership as well as significant contribution by the median household value. Factor 1 is considered a hybrid factor representing the host community's equity as well as their economic standard. Factors 2 and 3 are significantly correlated to the economic standard and adaptive capacity. This is due to the contribution of percentage of high school and income variables to such factor as well as the significant correlation of the median household value. Finally, Factor 4 is dominated by the percentage of female, which affects the adaptive capacity, as previously mentioned in the literature. Also, there is a significant relation with the percentage of phone accessibility. Factor 4 is considered to represents the adaptive capacity and host community equity.

Table 4.9: SoVI Factor Analysis– 2007

Attribute	Variable	Factor 1	Factor 2	Factor 3	Factor 4
Economic	Income	0.1075	0.70098	0.69642	0.08683
	Median_House_Value	0.47794	0.5388	0.38824	0.1935
	%High_Income	-0.03246	0.20805	0.19926	0.0958
Equity	%With_Vehicles	-0.18206	0.17196	-0.04783	0.04745
	%Phone	0.11021	0.33085	-0.06504	0.48963
	%Mobile_Home	0.9072	-0.11693	-0.3349	-0.10942
	%Home_Ownership	0.748	0.09306	0.06204	0.15687
Adaptive Capacity	%Speak_English	0.38664	0.06612	-0.0375	0.09478
	%High_School	-0.00794	0.88604	0.04583	-0.01958
	%Elderly	-0.22932	0.00888	0.86224	0.1415
	Median_Age	0.25112	0.29677	0.42491	0.16328
	%Female	0.08361	-0.16211	0.3319	0.92466

In conclusion, the four years studied here had in common: (1) the first factor almost dedicated to the economic standard of the community; (2) the second and third factors are more regarding equity and adaptive capacity of the community; and (3) the last factor addresses the adaptive capacity. Nevertheless, it should be noted – as previously mentioned – that the interpretation of the factors produced from factor analysis is subjective to everyone's interpretation (Yang and Bozdogan, 2011). However, this relative vulnerability scoring approach nominates the SoVI to be integrated into the disaster recovery decision support tools in order to allocate the redevelopment funds depending on the relative vulnerability of the different regions affected by the natural disaster.

At this point, one should highlight two main issues; (1) domination of variables does not eliminate the presence or effect of the other variables on the same factor, it only gives an insight to the meaning of this specific factor; and (2) several other factors may be present, some with lower eigenvalue, and correspondingly lower loading of variables to this factor, thus giving low variation in the final score.

4.2.2.6. Social Vulnerability Index (SoVI) Scores

At this step, the SoVI scores can be calculated for each census tract in the three coastal counties under study. Following Cutter et al. (2003) methodology, the factors were added together using a simple additive model with no weighting, thus all factors had the same weight and equal contribution to the social vulnerability. This is concluded due to lack of defensible reasoning to use any weights as there is no literature discussing the importance of one attribute over the others in the formation of social vulnerability (Cutter et al. 2003). The SoVI scores for the 78 census tracts for the four years under study (2012, 2011, 2010, and 2007) can be found in Appendix A.

For better visualization, Figures 4.3-4.6 represent the three Mississippi coastal counties actual relative vulnerability utilizing the SoVI scores obtained for years 2007, 2010, 2011 and 2012, respectively. The color coding follows the statistical distribution of the SoVI scores, where

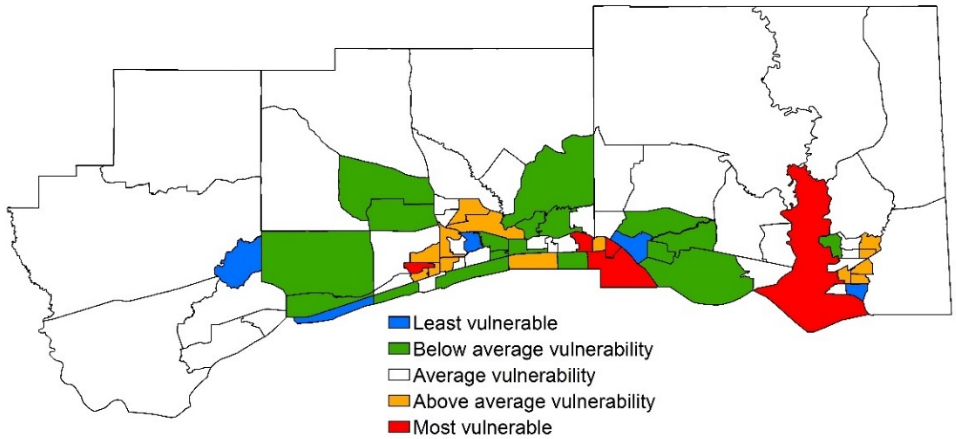

Figure 4.3: Actual Social Vulnerability in 2007

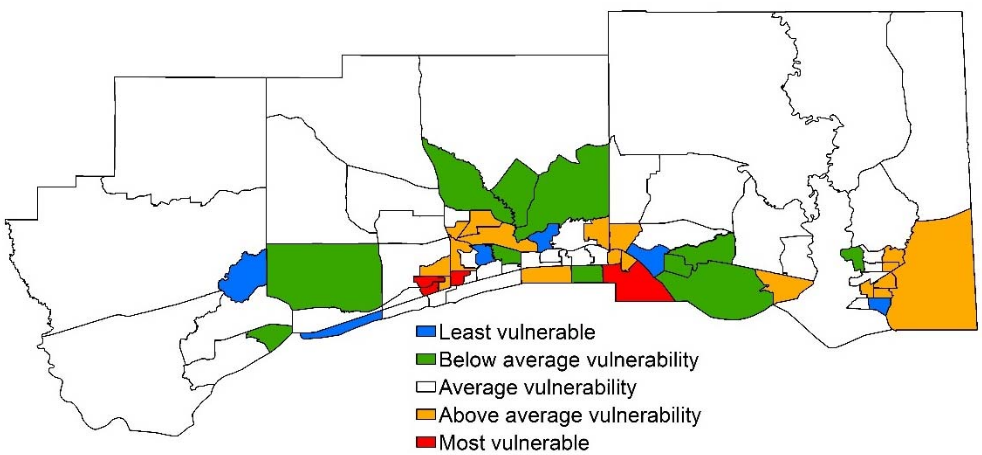

Figure 4.4: Actual Social Vulnerability in 2010

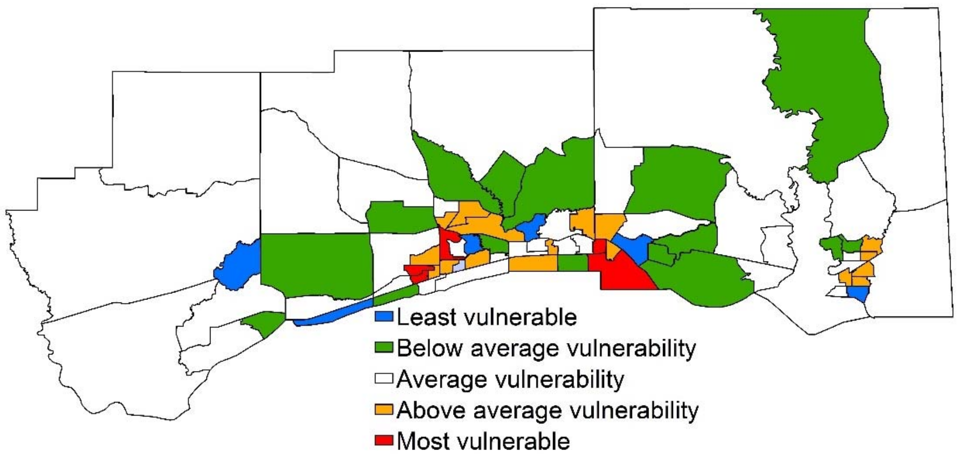

Figure 4.5: Actual Social Vulnerability in 2011

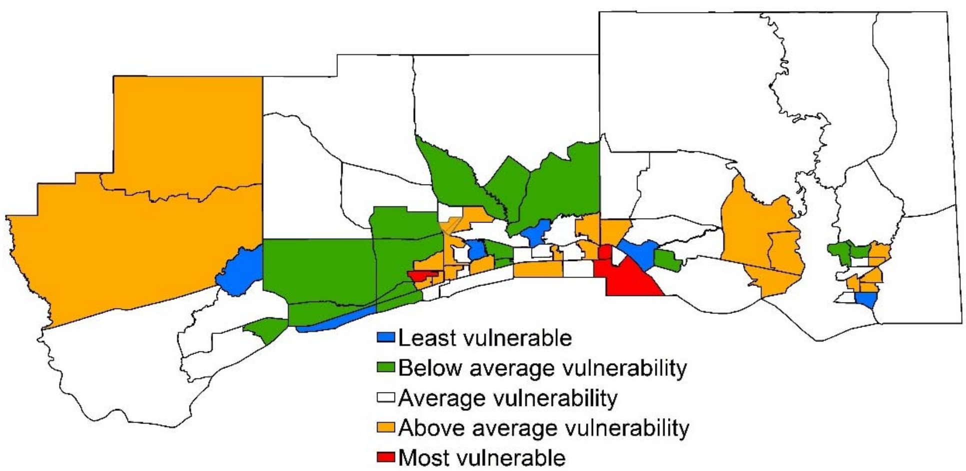

Figure 4.6: Actual Social Vulnerability in 2012

red denotes the most vulnerable (>1.5 Std. Dev.), orange is above average (1.5:0.5 Std. Dev.), white (transparent) is average vulnerability (0.5: -0.5 Std. Dev.), green is below average (-0.5: -1.5 Std. Dev.), and blue is the least vulnerable (< -1.5 Std. Dev.).

As previously mentioned, SoVI is a relative and comprehensive vulnerability assessment approach to evaluate the host community's social vulnerability to disastrous events. Thus, there will always remain census tracts that are more vulnerable in comparison to the other (red and orange zones in comparison to transparent, green and blue). And unlike scalar approaches, the elimination of red zones will not be present. Nevertheless, this approach helps the SDRC agent to allocate the fund to the most vulnerable census tracts at the corresponding time step. Figure 4.7 illustrates the changes in average social vulnerability per county. As can be observed, Harrison county (the most populated county) average social vulnerability increased from 1.706 to 3.212. Meanwhile, Hancock county's (least populated) average social vulnerability was maintained around 0.3 and Jackson county's average social vulnerability decreased from 1.513 to 0 1.087.

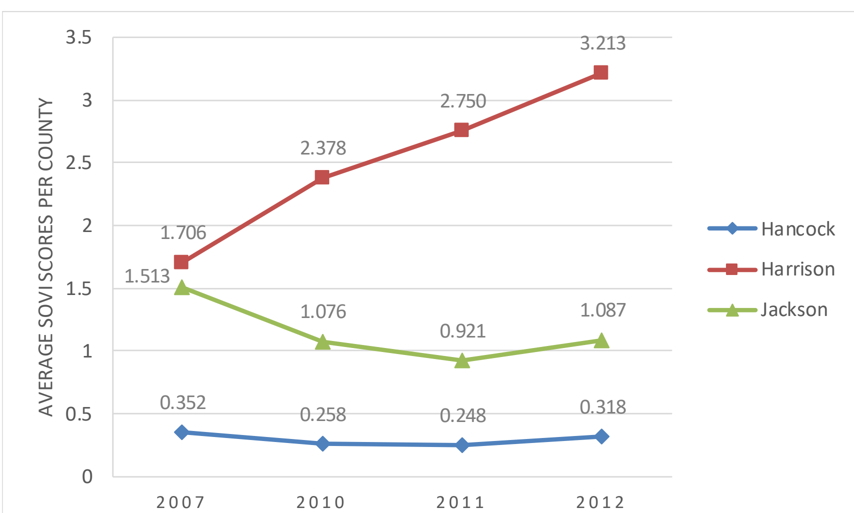

Figure 4.7: Actual Changes in Social Vulnerability

4.2.3. Economic Vulnerability Assessment

As previously discussed, the proposed model adopts the economic vulnerability and resilience metrics developed by Burton (2010). The model is part of a multi-dimensional vulnerability assessment metric to hazards that is developed on the community specific data (Eid and El-adaway 2016b). As such, the economic vulnerability assessment model is able to capture the problem domain scale; census tract. The model was developed and validated on the three coastal Mississippi counties (Hancock, Harrison and Jackson) for the post-Katrina recovery (Burton 2015). This enables the model to fully evaluate the problem domain's economic vulnerability based on the community-specific data with confidence on its potential in regard to the current problem domain. Moreover, the utilized model enables the framework to evaluate the built environment micro and meso economic vulnerability to hazards based on the community specific data (Eid and El-adaway 2016b). Following Burton model methodology, the Economic Vulnerability Index (EconVI) was developed utilizing 11 economic variables on the census tract level for the 78 census tracts across the three counties. Those variables are summarized in Table 4.10, along with their category and sources.

Table 4.10: Economic Vulnerability Variables

Variables	Category	Sources
Percentage of Homeownership	Microeconomics	US Census (2000-2012)
Percentage of working age population that is employed	Microeconomics	US Census (2000-2012)
Percentage of female labor force participation	Microeconomics	US Census (2000-2012)
Per capita household income	Microeconomics	US Census (2000-2012)
Percentage of population not employed in primary industries	Microeconomics and Mesoeconomics	US Census (2000-2012)
Mean sales volume of business	Mesoeconomics	ReferenceUSA (2000-2012)
Ratio of large to small businesses	Mesoeconomics	ReferenceUSA (2000-2012)
Retail center per 1,000 population	Mesoeconomics	ReferenceUSA (2000-2012)
Commercial establishments per 1,000 population	Mesoeconomics	ReferenceUSA (2000-2012)
Lending institutions per 1,000 population	Mesoeconomics	ReferenceUSA (2000-2012)
Doctors and medical professionals per 1,000 population	Mesoeconomics	ReferenceUSA (2000-2012)

To evaluate the vulnerability of the different census tracts utilizing the gathered variables, a statistical dimension reduction technique is utilized. This is done utilizing Factor Analysis. The aforementioned collected variables (Table 4.10) were transformed into comparable scales (per capita, percentage or density functions). Afterwards, Min-Max rescaling method was utilized to standardize the data across the different census tracts per variable between 0 and 1, where 1 is the best value, and 0 is worst value. Finally, via FA, the standardized variables can be reduced to several factors that summarizes the different variables and measure the latent variable (economic vulnerability). More importantly, similar to SoVI methodology, this approach allows for calculating a relative economic vulnerability index based on the data collected and the factor loadings (Eid and El-adaway 2016b). The scores are attained through simple additive model for the factors' scores per census tract in a similar fashion to the SoVI scores calculations. To this end, the following subsections discuss the obtained factor loadings per year.

4.2.3.1. Discussion on Economic Vulnerability Factor Analysis 2009

Factor analysis was carried out on the collected data for year 2009. As such, as shown in Table 4.11, three factors with eigenvalue greater than 1.0 were retained. Through examining the factors loading for year 2009, it can be observed that Factor 1 represents the mesoeconomics across the three counties. The first factor was dominated by the number of retail centers per 1,000 population, number of commercial center per 1,000 population, number of lending institutions per 1,000 population and mean sales volume of businesses. Factor 2 on the other hand is dominated by microeconomics, where percentage of employment, percentage of female labor and per capita income significantly contribute to this factor. Factor 3 is reflecting the number of lending institutions (banks, creditors, insurance, etc.). This goes in line with the importance of such institutions in the economic sustainability of the communities.

Table 4.11: EconVI Factor Analysis 2009

Variables	Factor1	Factor2	Factor3
% Homeownership	-0.30300	0.22506	0.03505
% Employment	-0.01902	0.84857	-0.00132
%Female Labor	0.02838	0.87961	-0.04030
Per Capita Income	0.02716	0.44666	-0.02851
% Employed in Non-Primary Industry	0.19877	-0.03247	0.01315
Ratio of Large to Small Businesses	0.01002	-0.01542	0.20185
Number of Retail per 1,000 Population	0.98511	0.07780	-0.11852
Number of Commercial per 1,000 Population	0.92027	0.02434	0.06120
Number of Lending institutions per 1,000 Population	0.78693	0.01826	0.61677
Doctors and medical professionals per 1,000 population	0.44153	0.00442	0.16345
Mean sales volume of business	0.86911	0.17819	0.07411

4.2.3.2. Discussion on Economic Vulnerability Factor Analysis 2010 -2012

Tables 4.12-4.14 illustrate the obtained factor loading for years 2010, 2011, and 2012, respectively. The three aforementioned year had similar factor loading patters for the economic vulnerability assessment. It can be observed that, like year 2009, Factor 1 is dominated by the mesoeconomics variables; number of retail centers, number of lending institutions, number of commercial centers, mean sales volume, and doctors and medical professionals per 1,000 population. Factor 2 is also dominated by the microeconomics variables; percentage of employment, percentage of female labor, and per capita income. On the other hand, factor 3 is mainly depicting the per capita income which affects the community's economic vulnerability to shocks.

4.2.3.3. Economic Vulnerability Index (EconVI) Scores

The EconVI scores can be calculated at each census tract depending on their variables and the obtained factor loadings. This is carried out following Burton (2010) methodology, utilizing a simple additive model with no weighting, thus all factors had the same weight and equal contribution to the economic vulnerability. The obtained scores per census tract for year 2009-2012 for each census tract can be found in Appendix A.

For better visualization, Figures 4.8 and 4.9 present a GIS map regarding the economic vulnerability across the three Mississippi coastal counties utilizing the obtained EconVI score for year 2009 and 2012, respectively. Ted denotes the most vulnerable (>1.5 Std. Dev.), orange is above average (1.5:0.5 Std. Dev.), white (transparent) is average vulnerability (0.5: -0.5 Std. Dev.), green is below average (-0.5: -1.5 Std. Dev.), and blue is the least vulnerable (< -1.5 Std. Dev.).

It can be observed that the MDA utilized redevelopment strategies did not significantly

Table 4.12: EconVI Factor Analysis 2010

Variables	Factor1	Factor2	Factor3
% Homeownership	-0.28181	0.16737	0.26815
% Employment	0.04562	0.71893	0.05786
%Female Labor	0.09317	0.96169	-0.25781
Per Capita Income	-0.05287	0.60361	0.55860
% Employed in Non-Primary Industry	0.09014	0.17592	0.00957
Ratio of Large to Small Businesses	-0.03715	0.04086	-0.14445
Number of Retail per 1,000 Population	0.99454	0.04666	0.05576
Number of Commercial per 1,000 Population	0.99323	0.04295	0.02069
Number of Lending institutions per 1,000 Population	0.76765	0.04087	-0.04762
Doctors and medical professionals per 1,000 population	0.42087	0.17074	-0.02883
Mean sales volume of business	0.83288	0.23362	0.27745

Table 4.13: EconVI Factor Analysis 2011

Variables	Factor1	Factor2	Factor3
% Homeownership	-0.21402	0.13506	0.34652
% Employment	0.15839	0.73136	0.16537
%Female Labor	0.18910	0.97466	-0.11947
Per Capita Income	0.02055	0.41153	0.56388
% Employed in Non-Primary Industry	0.10235	0.00728	0.02622
Ratio of Large to Small Businesses	-0.04621	0.08689	-0.23822
Number of Retail per 1,000 Population	0.99022	0.07533	-0.08583
Number of Commercial per 1,000 Population	0.98431	0.08333	-0.12591
Number of Lending institutions per 1,000 Population	0.75468	0.09497	-0.13375
Doctors and medical professionals per 1,000 population	0.41058	0.16872	-0.11764
Mean sales volume of business	0.90224	0.12541	0.24906

Table 4.14: EconVI Factor Analysis 2012

Variables	Factor1	Factor2	Factor3
% Homeownership	-0.18712	0.11660	0.30162
% Employment	0.13431	0.76180	0.15420
%Female Labor	0.17452	0.97854	-0.10955
Per Capita Income	0.10405	0.37611	0.43127
% Employed in Non-Primary Industry	0.14558	0.05962	-0.00356
Ratio of Large to Small Businesses	0.01061	0.04604	-0.27608
Number of Retail per 1,000 Population	0.98207	0.06486	-0.14970
Number of Commercial per 1,000 Population	0.98131	0.06907	-0.16403
Number of Lending institutions per 1,000 Population	0.75180	0.06177	-0.11489
Doctors and medical professionals per 1,000 population	0.43354	0.09964	-0.05045
Mean sales volume of business	0.93871	0.09494	0.31454

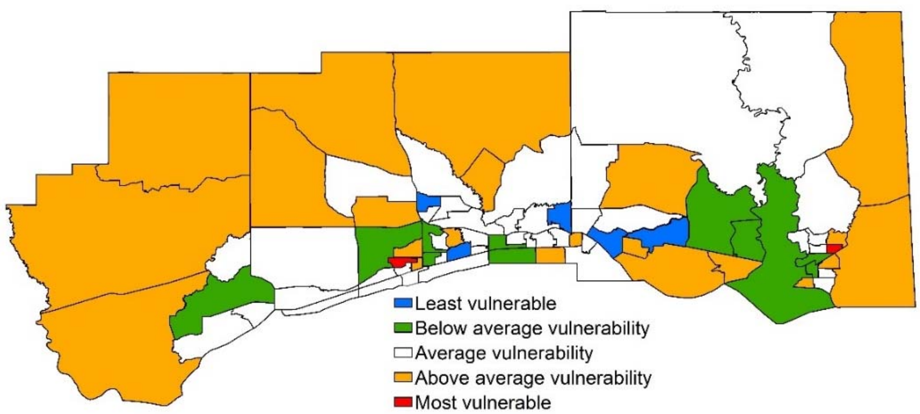

Figure 4.8: Actual Economic Vulnerability Distribution – 2009

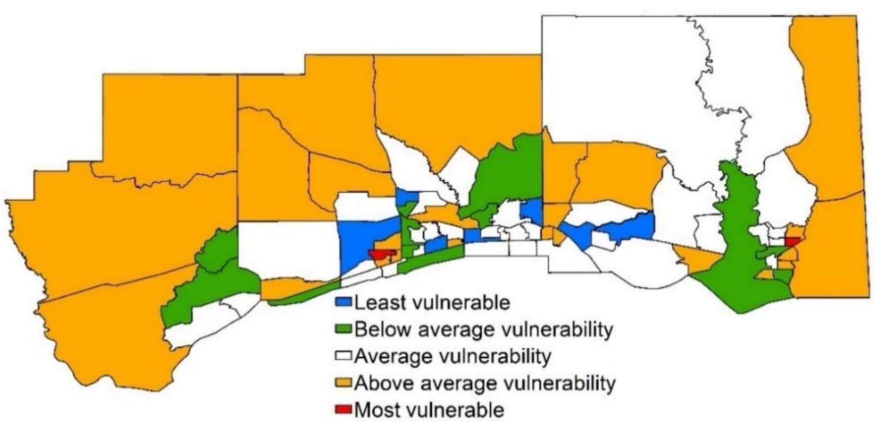

Figure 4.9: Actual Economic Vulnerability Distribution – 2012

decrease the host community's economic vulnerability to hazards. Even though it decreased the economic vulnerability at two census tracts in Harrison County, it increased the vulnerability of more census tracts across the three counties. Figure 4.10 illustrates the change in average EconVI per county.

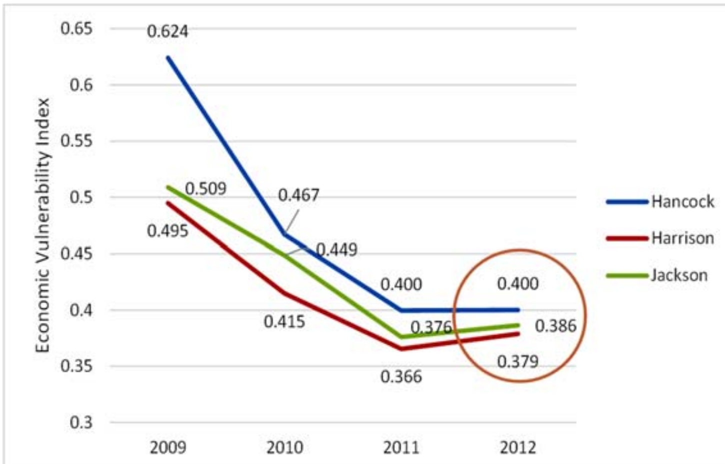

Figure 4.10: Economic Vulnerability Index – Existing Condition

4.2.4. Environmental Vulnerability Assessment

According to Chapter Three (Methodology and Model Development), the Environmental Vulnerability Index (EVI) developed by SOPAC is utilized for this research. The developed framework utilized 10 indicators that captures the actual, applicable, and accessible data that can be compared and assessed across the 78 census tracts in the three coastal Mississippi counties. Meanwhile 11 indicators were found inapplicable, thus having a value of 1. To this end, the 10 aforementioned indicators data were collected for the years 2000, 2009, 2010, 2011 and 2010. This section illustrates the indicators mapping onto the EVI scale along with comparison and visualization of the results.

According to the EVI manual (Pratt et al. 2004), each indicator has a predefined scale to be mapped on. The predefined scale values were set by expert committees in the associated fields to provide score values that illustrates the corresponding environmental vulnerability to any condition and location on the planet (Eid and El-adaway 2016a). The collected data was mapped on their corresponding scales to calculate the actual EVI for years 2000, 2009, 2010, 2011 and 2012 for the 78 census tracts. The mapped variables, and the corresponding EVI Score per census tract per year (2000-2012) can be found in Appendix A.

4.2.4.1. Discussion on EVI changes through years 2000-2012

To compare the actual environmental vulnerability for each county, an average EVI per county was calculated based on the previously calculated EVI per census tract. Figure 4.11 presents the calculated average EVI. It can be observed that environmental vulnerability of Hancock County peeked through years 2009, 2011 and 2012 to 3.86. This is contributed to the decrease in vegetation cover, along with the increase in population growth and waste production while lack in the utilization of the different WWTFs capacities.

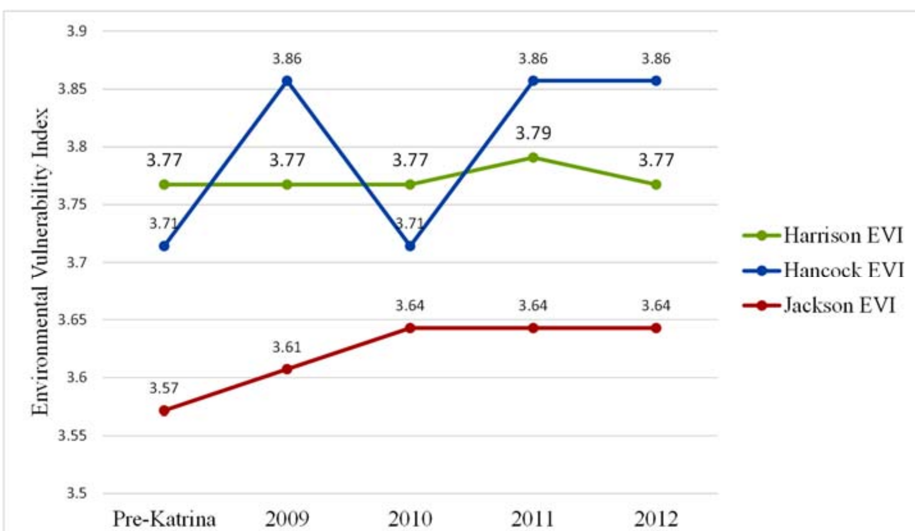

Figure 4.11: Actual EVI per county

Hancock County wastewater treatment plans were not able to significantly decrease the EVI scores for the county, in comparison to Harrison County, which developed more than six major WWTFs between years 2008-2010. Such projects improved the water quality of the county, which in return positively impacted the EVI scores of the county (Eid and El-adaway 2016a).

Meanwhile, as can be seen in Figure 4.11, Jackson County EVI scores increased steadily through the years as the county did not have significant post-disaster attention as the other two counties (both on the residential or infrastructure level). To this end, only two major WWTFs were developed Jackson County between years 2008-2010, and did not provide significant improvement in regard to the EVI scores of the county.

For a better visualization on the actual environmental vulnerability of the 78 census tracts, Figures 4.12-4.13 illustrate the utilization of EVI for years 2000 and 2012, respectively. The maps are color coded; Red for high vulnerability (≥6); Orange for above average vulnerability (5); White for average vulnerability (4); Green for below average vulnerability (3) and Blue for least vulnerability (≤2). It can be observed that there are few changes in the census tracts' EVI in the three counties.

Nevertheless, it is noticed that the actual budget distribution and infrastructure projects (wastewater treatment facilities) did not significantly improve the environmental vulnerability of the most populated regions across the three counties (Eid and El-adaway 2016a). Rather, the existing conditions show an increase in vulnerability in West-Jackson County, Mid-Harrison County, and East-Hancock County (east side). All the aforementioned regions are more populated in relative to the other census tracts. The utilized actions by the MDA failed to address such regions environmental vulnerability.

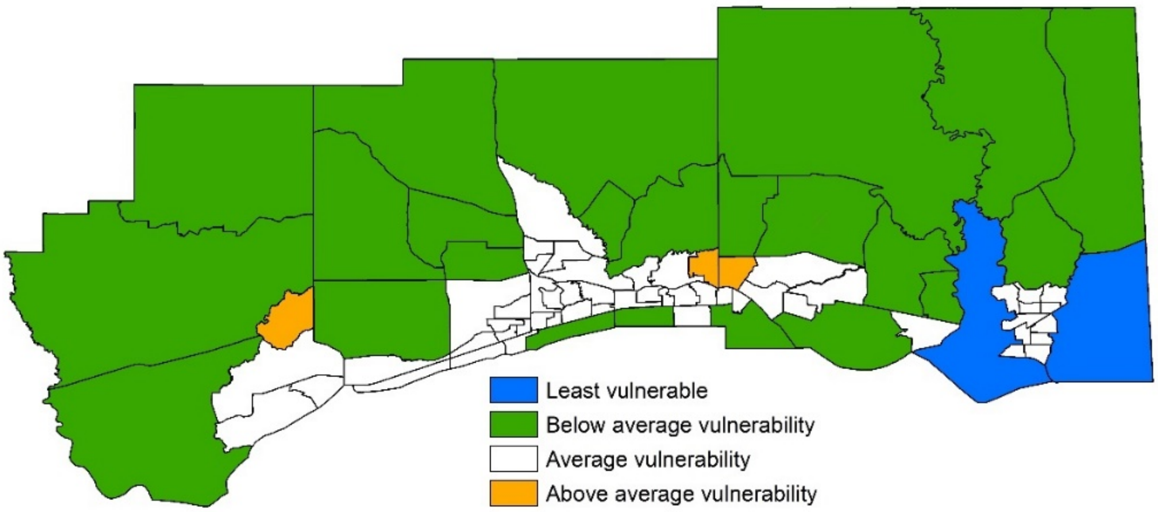

Figure 4.12: Actual Environmental Vulnerability – 2000

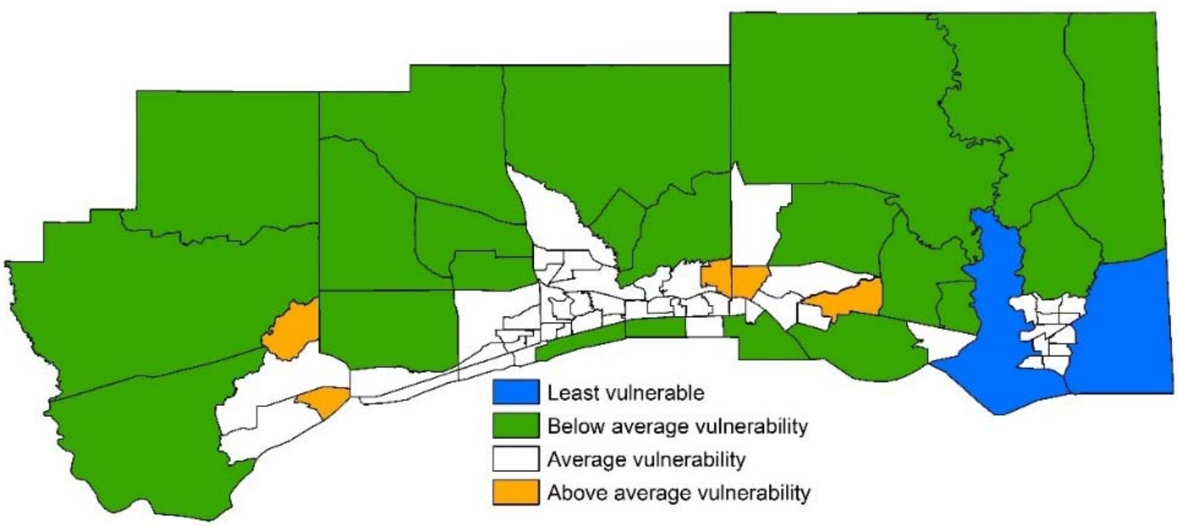

Figure 4.13: Actual Environmental Vulnerability – 2012

4.3. Proposed Model's Results

In contrast to the aforementioned results in regard to the actual MDA decision actions and the existing vulnerability conditions, this section illustrates the proposed model's outcome to holistically meet the needs of the stakeholders and decrease the built environment vulnerability. The model output is analyzed on four different vulnerability optimization cases: (1) social vulnerability alone, (2) economic vulnerability alone, (3) environmental vulnerability alone, and (4) three-dimensional vulnerability. Accordingly, the model's outcome is compared to the existing conditions in regard to the SDRC's decision actions and strategies, and the host community vulnerability. In addition, the two simulated scenarios are introduced to furtherly compare the model's results in regard to the redevelopment of the residential and economic sectors. Thus, two scenarios are: (1) actual budget distribution (using MDA's budget distribution and WWTFs), and (2) uniform budget distribution (and using MDA's WWTFs). Those cases will evaluate the proposed framework and testing the research hypothesis.

4.3.1. Model's Results - Social Vulnerability

4.3.1.1. Proposed Model's SDRC Budget Distribution – Social Vulnerability

The ABM initiated the simulation with a uniform budget distribution across the four action plans (Homeowner Assistance, Public Home Assistance, Elevation Grant, and Small Businesses Loan). This approach allows for fair and uniform chance for each plan to contribute to the host community's recovery and meet the associated stakeholders' needs.

Through the model simulation, the budget distribution evolved to meet the needs of the stakeholders while decreasing the social vulnerability of the host community. As such, the proposed ABM presented a dynamic budget distribution. As shown in Figure 4.14, even though the model started with uniform budget distribution, the Homeowner Assistance plan reached +35% at the end of year 2009 as it gave an immediate financial relieve to the affected homeowner residents. It is worth noting that the utilization of the disaster insurance plans (discussed in a latter section) affected the choices of the residents as the insurance plans provided the residents with financial compensation that drove some residents away from such plan. Moreover, due to the large compensation award from Homeowner Assistance plan in comparison to the other plans, residents tend to apply for it, in addition to being easily accepted by the LDRM (as shown in the Federal reports by MDA 2015). Furthermore, as this plan provides a significant rapid recovery rate, it was strengthened by the optimization module in order to maintain rebound from the disastrous event's shock.

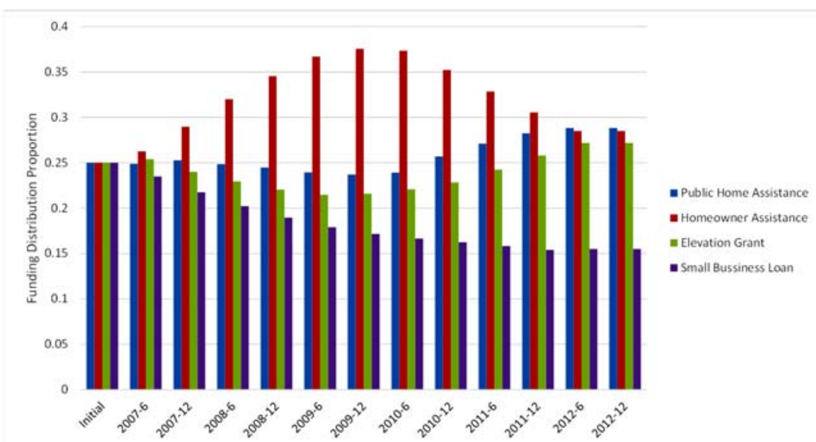

Figure 4.14: Proposed Funding Distribution (SoVI Version)

Also, throughout the model simulation, the model maintained and increased the Public Home Assistance plan. This plan targets the low-income families. Thus, this plan highly affects the host community's social vulnerability as those applicants are inherently more vulnerable to hazards, relative to the other residents. Such plan was mostly utilized by the low-income households in Hancock and Jackson counties.

Moreover, the model increased the Elevation Grant significantly to +25% by the end of the simulation run. Elevation Grant is an upgrade to the households to make them flood resilient. Such approach increases the households' value that in return affects both the objective functions of the residents and the resilience of the households. Consequently, this decreased the host community social vulnerability by increasing the regions' Median Household Value variable.

Finally, it can be observed that the model continued decreasing the Small Businesses Loan plan to 15% at the end of the simulation run. This plan incentivized the economic agents to stay in the impacted region and not to sellout their businesses due to physical structures damages. Even though the Small Business Loan enables the retail sector to remain in the impacted region, it did not contribute that much to the social vulnerability of the community. As such, the proposed model did not strengthen such plan, in comparison to the other disaster recovery plans.

4.3.1.2. Proposed Model's Social Vulnerability

As previously discussed, the developed ABM was initiated with ex-Katrina data. The projected SoVI scores per county post-Katrina was then calculated through multiple simulation runs. Figure 4.15 presents the projected SoVI (biannual) utilizing the proposed ABM optimized SDRC budget.

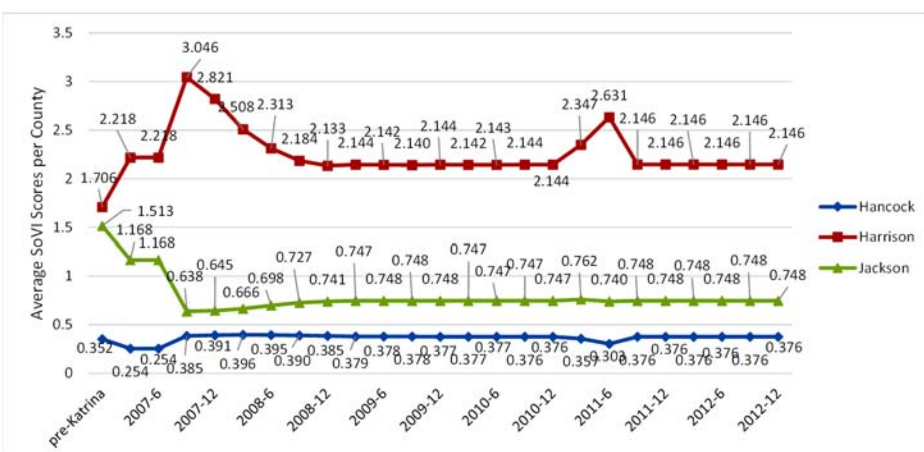

Figure 4.15: ABM Projected SoVI Scores

Through a quick comparison, it can be noticed that the proposed ABM achieved better SoVI scores for both Harrison and Jackson counties with final SoVI of 2.146 and 0.748, respectively. On the other hand, the actual average SoVI score (Figure 4.7) for Harrison and Jackson counties are 3.213 and 1.087, respectively. Nevertheless, the proposed model did not achieve better average SoVI for Hancock County (0.376 in comparison to 0.318). Hancock County is the least densely populated county across the three regions. As such, the proposed model did not prioritize it through the SDRC's budget distribution. Moreover, the county's average SoVI is far less than the other two counties.

For a more comprehensive evaluation on the proposed framework outcome, Figures 4.16 and 4.17 illustrate how the two simulation scenarios (actual and uniform budget distribution) affected the communities' social vulnerability. A comparison can be made to the outcome of the model (Figure 4.15) to demonstrate its capability while accounting for the model's limitations (for example, sudden change in population size and growth). Through the results, it is noticeable the superior performance of the proposed model in comparison to both of the hypothesis tests scenarios. This is the result of integrating the SoVI into the objective function of the SDRC to guide the strategies towards a less socially vulnerable community. It is worth noting that the communities' social vulnerability values require long time to change. This is due to the inherent social structure that affects the host communities' vulnerability.

To this end, changes shown in Figures 4.15-4.17 are slow. Nevertheless, it is noticeable that the proposed ABM was able to provide better changes in SoVI across the four cases. Also, it must be noted that the actual SoVI of the host community cannot be identically replicated (Figure 4.7 and 4.16) due to the various changes within the social structure of the host community that is beyond the scope of the current model (sudden population change, changes in social demographics

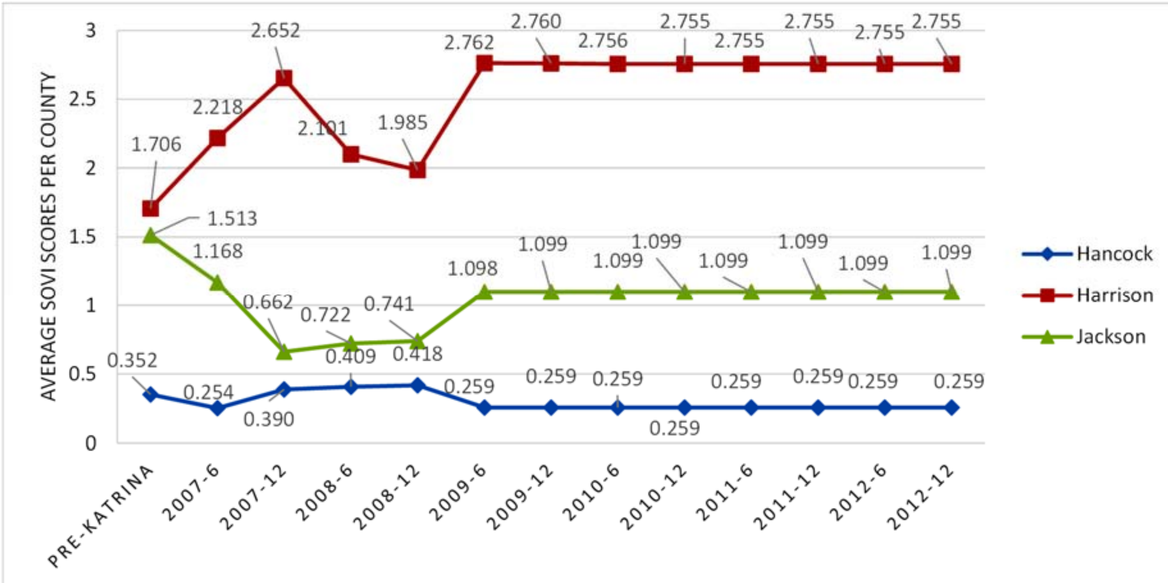

Figure 4.16: Actual Budget Distribution Scenario SoVI Scores

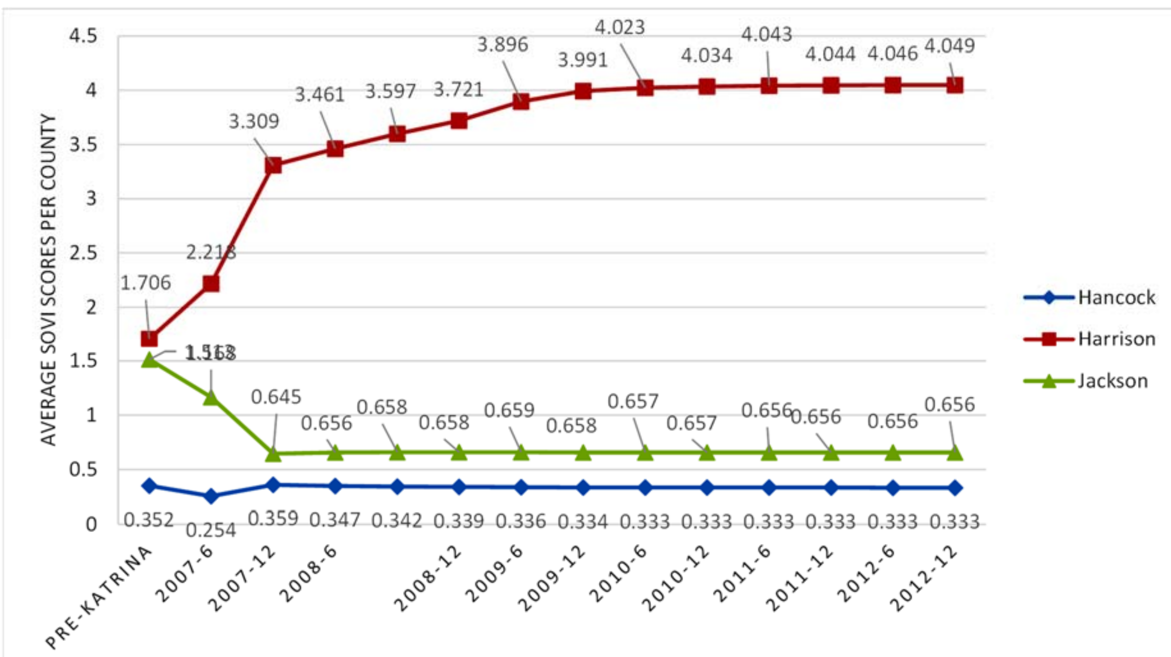

Figure 4.17: Uniform Budget Distribution Scenario SoVI Scores

, etc.). Nevertheless, the simulated actual budget distribution gave near values to the existing social vulnerability of the host community. For better visualization, Figure 4.18 presents a map for the ABM projected host community social vulnerability based on the SoVI acquired. Through the map, it can be noticed that the model decreased the social vulnerability (compared to Figure 4.6). The model prioritized the populated census tracts of Harrison County. On the other hand, the mid-Jackson County's relative social vulnerability decreased. This region is mostly wetlands with significantly fewer population.

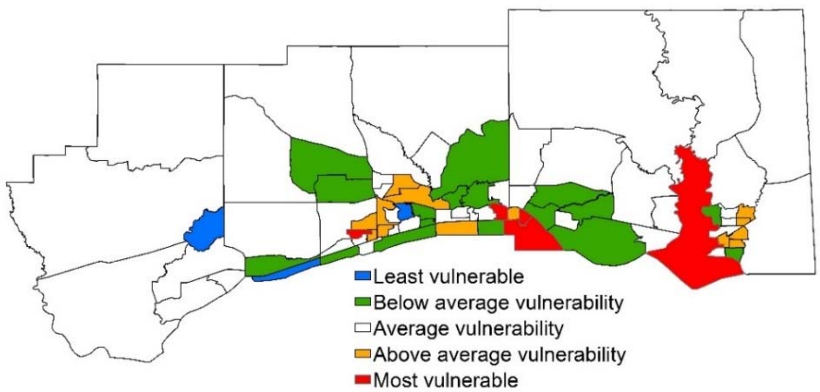

Figure 4.18: Project Social Vulnerability in 2012 Using the ABM Model

4.3.1.3. Proposed Model's Residential Recovery – Social Vulnerability

This section illustrates how the proposed framework affect the host communities' redevelopment in regard to the housing sector post-Katrina disaster, and thus evaluates the welfare of the host community. The recovery assessment is done through quantifying the initial household values of the residents and compare them to the damage and recovery per county per time step, as previously discussed in Chapter Three (Methodology and Model Development). Moreover, in order to test the effectiveness of the model, the two simulation scenarios (actual and uniform SDRC budget distribution) were utilized. This approach will allow for the comparison between the utilized ABM optimization methodology, the actual SDRC budget distribution, and the hypothetical uniform budget distribution. Thus, the model can have a fair comparison to more than one budget distribution; uniform and majorly skewed toward one strategy.

The residential recovery of the three counties is shown in Figures 4.19-4.21. The figures illustrate the model outcome, as well as the actual budget distribution scenario and the uniform budget distribution. Through comparing the redevelopment of the households presented in Figures 4.19-4.21, the model significance can be observed. The model domination over the other two scenarios is mainly due to the integration of the utility functions of the residential sector into the SDRC's objective function. Such approach guided the fund allocation to increase the community welfare (Eid and El-adaway 2016a). Moreover, as the social vulnerability is highly impacted by the residents' social status (income, household values, etc.), and that the social vulnerability assessment is assimilated into the SDRC's objective function through this current optimization scenario, the residential recovery rate was geared up to achieve both parameters; recovery and resilience.

It can be noticed that the overall recovery progress is higher in the proposed model. Unlike, the "actual budget distribution scenario" that is dominated by the Homeowner Assistance plan, and the "uniform budget distribution" that treats all the plans equally, the model provided an optimized budget distribution that meets the needs of the residents. This approach allowed for allocating the funds to the needs of the residents, thus, a faster and more effective recovery can take place. The simulated "actual budget distribution" scenario was not able to address the needs of the low-income residents, as shown in Hancock County. Those residents were not able to meet the Homeowner Assistance plan's criteria and there was no sufficient funding for the Public Home Assistance plan. On the other hand, the proposed model addressed the needs of the low-income residents and optimized the budget distribution to offer Public Home Assistance

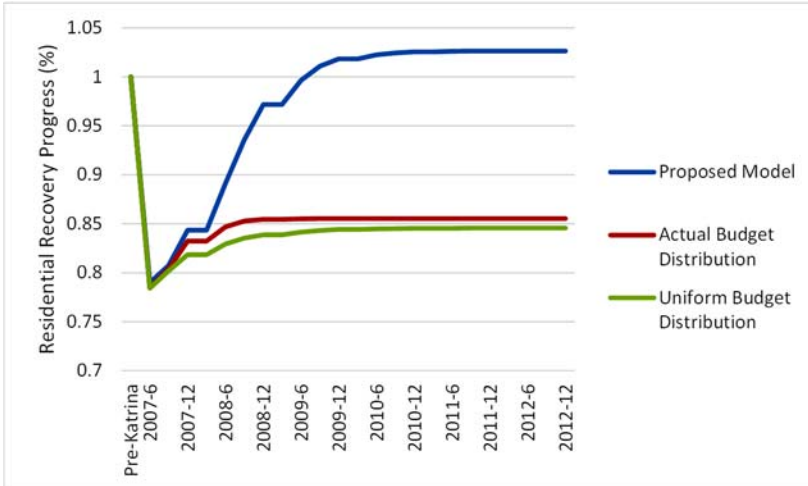

Figure 4.19: Hancock Residential Recovery Progress (Social Version)

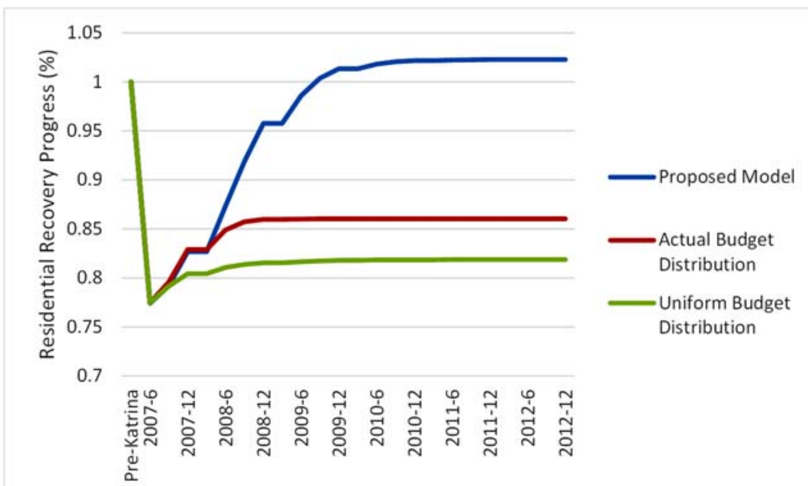

Figure 4.20: Harrison Residential Recovery Progress (Social Version)

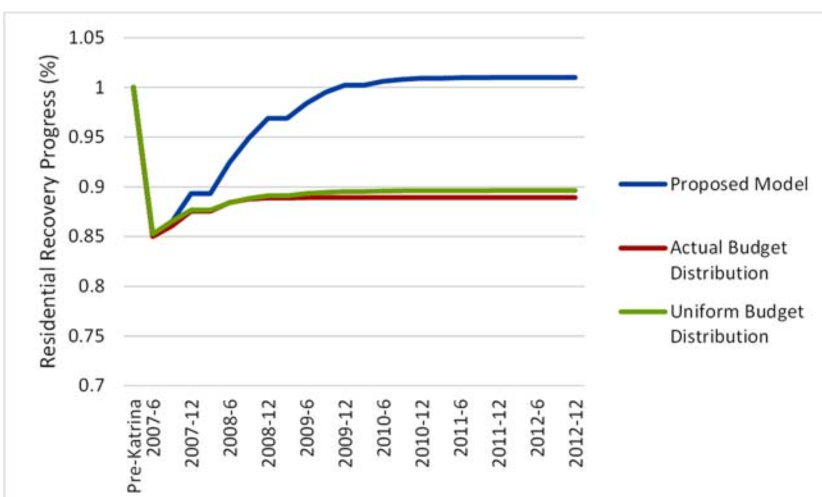

Figure 4.21: Jackson Residential Recovery Progress (Social Version)

for the low-income residents in addition to Homeowner Assistance plan that increases the counties' overall recovery rate.

Moreover, it can be observed that the residential recovery reached more than 100% throughout the three counties. This is due to the utilization of the Elevation Grant (Eid and El-adaway 2016a). This recovery plan increases the resilience of the households through elevating it up to 6 foot and four inches (Eid and El-adaway 2016b). Accordingly, and through utilizing new resources to retrofit the existing structure, this type of redevelopment increases the value of the households and thus increases the overall recovery to more than the pre-event conditions. As this plan increases values of the households, it also positively affects the social vulnerability. Moreover, such increase in household's values increases the residents' individual utility. As such, this plan was utilized by the proposed ABM throughout the recovery process to increase the community welfare and decrease the social vulnerability of the built environment. This can also be noticed through comparing the two simulation scenarios to the ABM. The two control test simulation scenarios reached on average 80% of the total recovery progress while the ABM provided for more than 100% residential household's recovery.

Nevertheless, it should be noted that the actual budget scenario had a significantly faster recovery rate than the proposed model for Harrison County through years 2007-2008. This is due to the extensive utilization of the Homeowner Assistance plan which gives a higher recovery rate in comparison to the other plans. However, in the long run, this approach did not prove to be effective, depleted the SDRC resources, and an optimized budget provided a better outcome for the built environment.

4.3.1.4. Proposed Model's Economic Financial Recovery – Social Vulnerability

This section illustrates the ability of the proposed research framework to restore the economic sector financial status. In parallel to the previous section, a comparison between the "actual budget distribution" scenario, "uniform budget distribution" scenario, and the proposed model outcome in regard to the retail sector financial recovery is presented. This is carried out through measuring the retail sector mean revenue per county and evaluate it to the pre-Katrina mean sales revenue. Figures 4.22-4.24 present the financial recovery for the economic agent (retail sector) for counties Hancock, Harrison and Jackson, respectively.

It can be observed from Figure 4.22-4.24 that the proposed model was only able to outperform the actual budget distribution (except for Hancock county), while the uniform budget distribution achieved a higher economic recovery rate throughout the three counties. The model's results were better than the actual budget distribution due to the initial Small Business Loan plan that incentivized the retail sector to remain in the impacted region. However, the actual budget distribution did not address such plan, and as such a significant portion of the economic agents sold out their businesses and moved, which in return affected the financial recovery across the three counties. This points out the need for holistic strategies to achieve comprehensive redevelopment across the host community that increases the welfare of the different stakeholders.

Meanwhile, the uniform budget distribution maintained a steady share of 25% for the Small Business loan, which prevented the retail sector from selling out their assets within the simulation. It should also be noted that both the Public Home Assistance plan and the Elevation Grant increase the retail sector revenue, as previously discussed in Chapter Three. Thus, both the uniform budget simulation and the proposed model were expected to provide such impact on the retail sector's

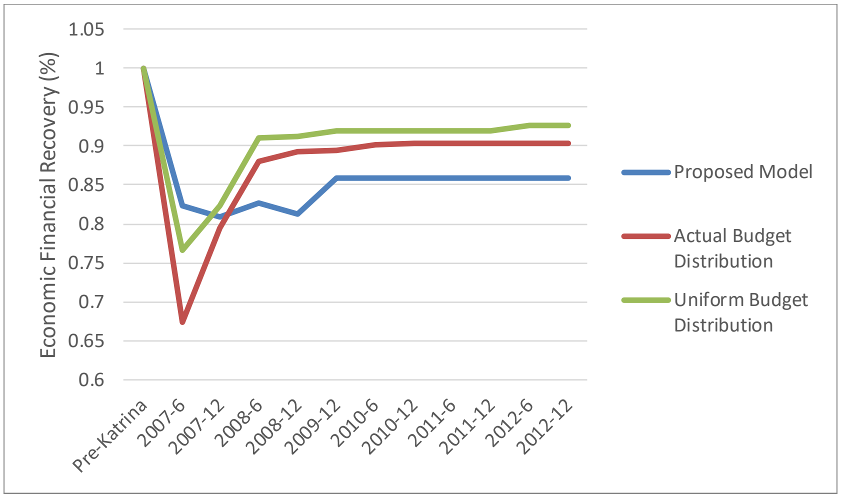

Figure 4.22: Hancock County Economic Financial Recovery (Social Version)

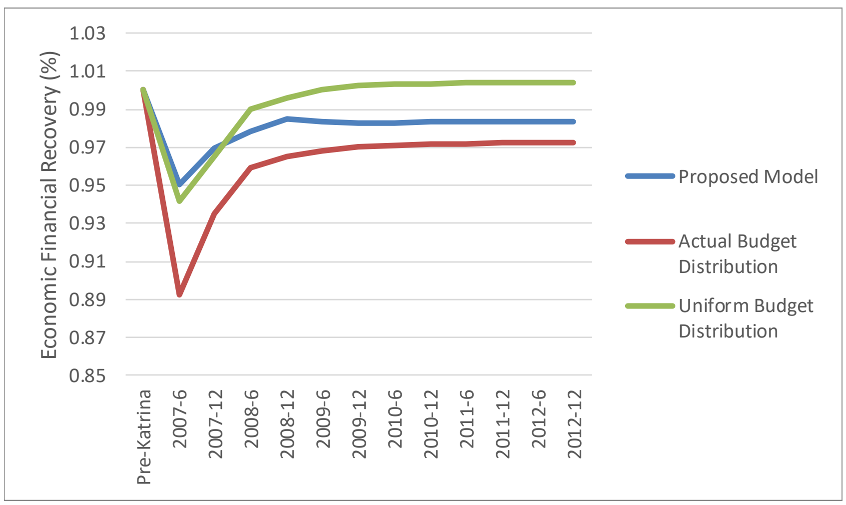

Figure 4.23: Harrison County Economic Financial Recovery (Social Version)

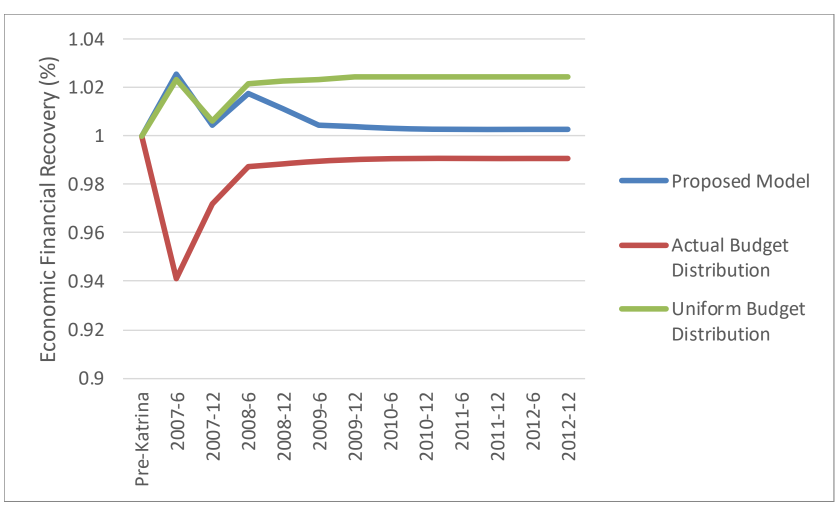

Figure 4.24: Jackson County Economic Financial Recovery (Social Version)

revenue in contrast to the actual budget distribution scenario. However, the uniform budget outperformed the proposed model. This is due the multi-dimensional optimization carried out by the SDRC to meet the need of the economic sector while decreasing the social vulnerability of the host community.

4.3.1.5. Residents Choices over Insurers and Insurance Plans -Social Vulnerability

Figure 4.25 illustrates the social learning process of the residents to choose between the different insurance companies, utilizing evolutionary game theory and Particle Swarm. Each resident was initiated with a random insurance policy. Through the utilization of Particle Swarms as a social learning technique, residents attempted to converge into the optimal policy that provide the highest possible utility function.

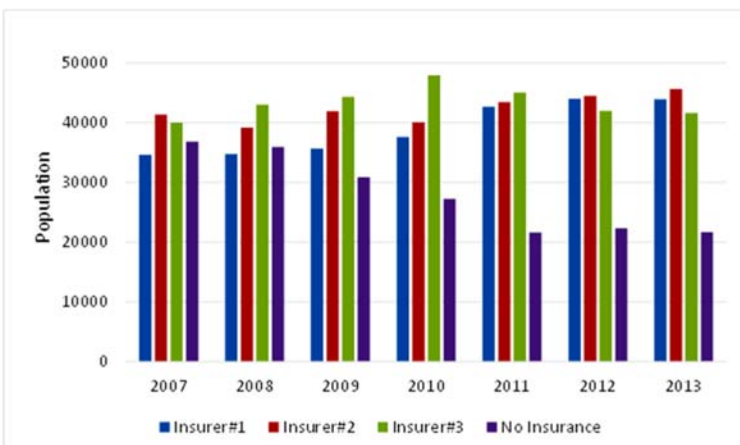

Figure 4.25: Residents' Choices over Different Insurance Options (Social Version)

Through the first half of the simulation, the residents converged to the third insurer. Even though it has the highest premiums, it provided up to 100% compensation. However, as the residents all achieved relatively the same recovery rate, residents were indifference between the three insurance companies. As such, the need for such insurance policies was not seen as a significant advancement, and residents were redistributed among the different insurance companies. The need for insurance plans is also affected by the presence of the Housing Assistance disaster recovery plan that would aid the residents in their recovery process. On the other hand, the insurance coverage would also affect the choices of the residents in regard to the SDRC's plans. Through initial stages of the simulation, the residents attempted to apply for the Elevation Grant as they had some means for recovery using the insurance policies.

4.3.2. Model's Results - Economic Vulnerability

4.3.2.1. Proposed Model's SDRC Budget Distribution – Economic Vulnerability

This section discusses the SDRC budget distributions (Figure 4.26) and explains how the SDRC actions affected the EconVI changes and recovery progress of the associated stakeholders, as shown in a following section. The proposed model presented a funding distribution pattern that evolves through time in order to address the dynamic needs of the stakeholders and decrease the built environment economic vulnerability.

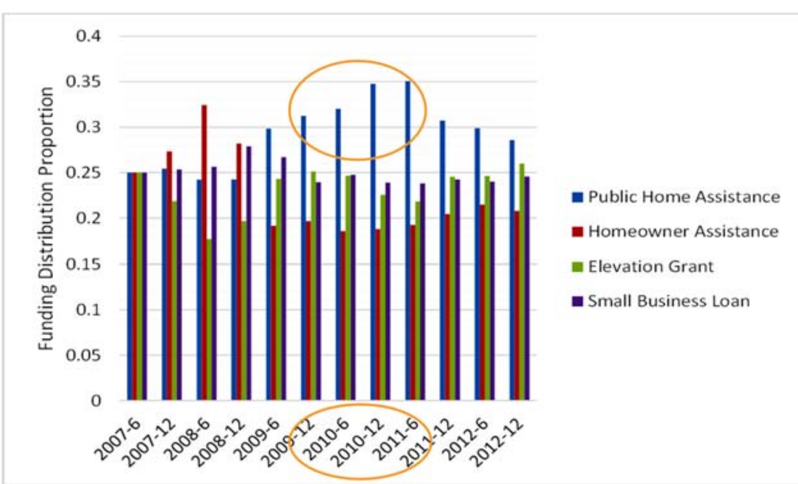

Figure 4.26: Proposed Funding Distribution (EconVI Version)

As can be observed in Figure 4.26, the model increased the Homeowner Assistance Plan through the first two years to +30%. This is the result of this plan impact of households' recovery via providing the residents with financial aid. However, such plan fails to meet the needs of the poor income households located in Hancock and Jackson counties as they are considered ineligible for it. Thus, through the following years, the model increased the Public Home Assistance, which in return increased the redevelopment of the community and decreased the economic vulnerability, as shown in the following section. This plan has a positive effect of the retail sector revenue by $0.0912 for each dollar spent on this plan (Eid and El-adaway 2016b, Cohen et al. 2012).

The proposed model increased the Elevation grant share from 18% to 25% through 2009-2010. Such plan increased the resilience of the households to future hazards and increased the households' values. Moreover, the Elevation Grant significantly contributes to the retail sector revenue, as previously mentioned, which in return affect the regions' mean sales, thus impacting the economic vulnerability of the built environment (Eid and El-adaway 2016b).

Unlike the Social Vulnerability version, model maintained the Small Business Loan share to 25% of the budget through the first year, and increased it to 30% in the second year. Such plan incentivized the retail sector to remain in the impacted region, thus prevented any possible increase in the economic vulnerability of the host community. It can be noticed as well that as the Small Business Loan plan has compounded effect (economic recovery and economic vulnerability), the SDRC's budget gave it the highest share in comparison to other vulnerability cases (Social, environmental, or three-dimensional vulnerability). This strategy impact can also be confirmed through the economic agent financial recovery that is furtherly explained in a later section. Such dynamic evolution in the budget distribution increases the residential and economic sector recovery rate, meets the stakeholders' objective functions. and decreases the overall built environment economic vulnerability.

4.3.2.2. Proposed Model's Economic Vulnerability

Through this subsection a comparison between the proposed model EconVI outcome and the existing condition is presented. Figure 4.27 illustrates the proposed model's project average EconVI per county, while Figures 4.28 and 4.29 present the actual and uniform budget distribution scenarios impact on the community's EconVI, respectively.

Through comparing Figures 4.27-4.29, the proposed framework's potential to decrease the economic vulnerability of the host community can be noticed as it was able to outperform the existing conditions as well as both the "actual" and "uniform" budget distribution scenarios. At The proposed model's EconVI reached a value of 0.319, 0.293 and 0.306 for the Hancock, Harrison and Jackson counties, respectively, at the end of the simulation run.

The steep EconVI slope for Hancock County is due to the learning module and the optimization of the SDRC's objective functions that allocates the disaster recovery funds in order to minimize the community's economic vulnerability (as shown in the following section). Meanwhile, the existing EconVI and both the actual and uniform budget simulation scenarios EconVI values were significantly higher which leave the community vulnerable to economic shocks due to shocks and perturbations.

Figure 4.30 presents better visualization on the impact of the SDRC's budget distribution on the host community economic vulnerability at the end of the simulation run. As previously mentioned, EconVI is a relative vulnerability assessment to the host community against disastrous events. Thus, there will always remain census tracts that are more vulnerable that the others (Eid

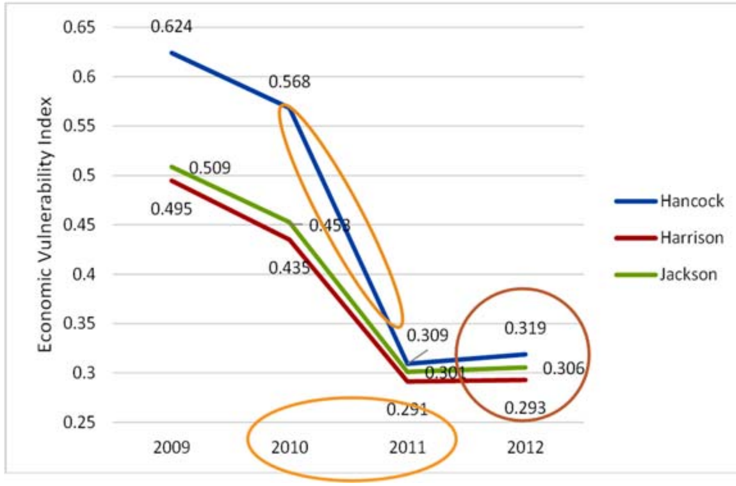

Figure 4.27: ABM Projected EconVI Scores

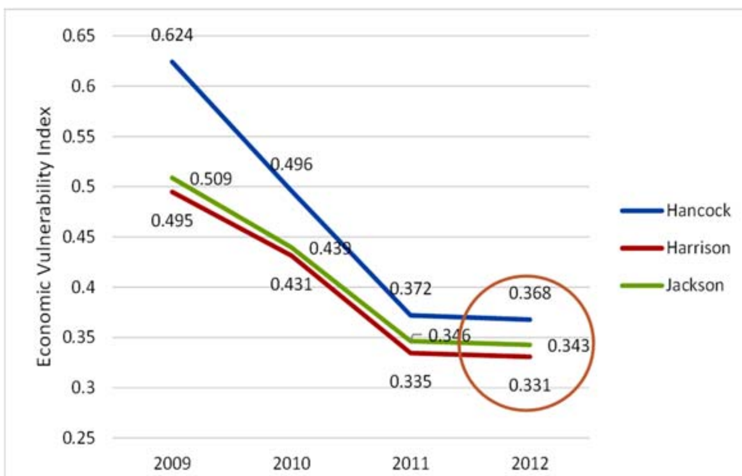

Figure 4.28: Actual Budget Distribution Scenario Projected EconVI Scores

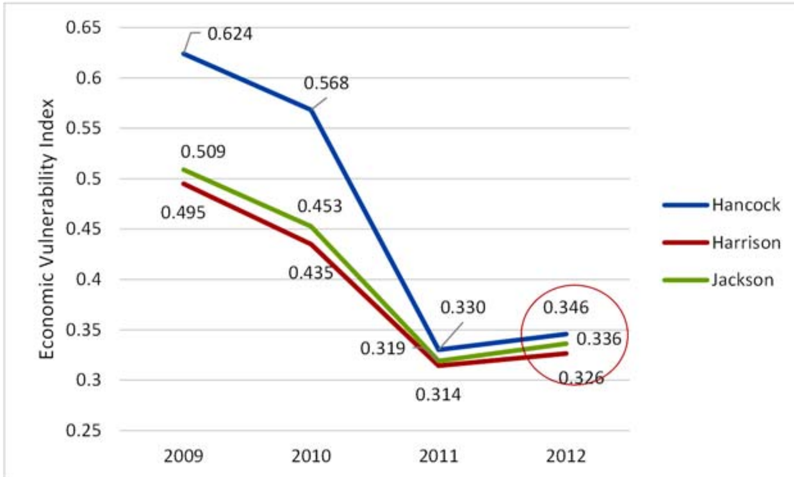

Figure 4.29: Uniform Budget Distribution Scenario Projected EconVI Scores

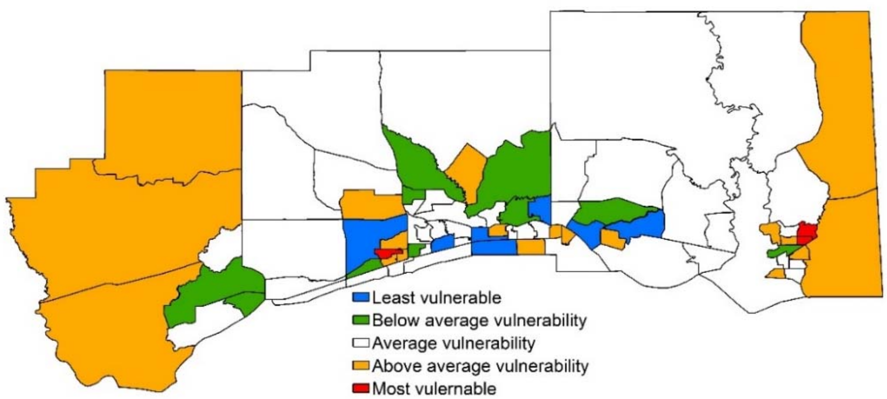

Figure 4.30: ABM Projected Economic Vulnerability – 2012

and El-adaway 2016b). Through Figure 4.30 and comparing it to Figure 4.8, the model potential to decrease the economic vulnerability for Harrison Count (which comprises more than half of the population across the three counties) can be noticed. Moreover, the model also decreased the economic vulnerability of the densely populated regions in West-Jackson County. As such, it can be deduced that the ABM was able to decrease the economic vulnerability for the different census tracts in contrast to the existing scores recorded in 2012.

4.3.2.3. Proposed Model's Residential Recovery – Economic Vulnerability

This section illustrates the potential of the framework to increase the residential sector recovery progress while decreasing the economic vulnerability indictor. The residential recovery evaluation was carried out through both the simulated "actual" and "uniform" budget distribution scenarios. The residential recovery across the three counties is shown in Figures 4.31-4.33 utilizing the simulated "actual" and "uniform" budget distribution scenarios and the proposed model outcome.

The proposed framework outperformed both the "actual" and "uniform" budget distribution scenarios across the three counties (Eid and El-adaway 2016b). It can be noticed that the overall residential recovery rate is higher, as the model met the needs of the different residents through changing the budget distribution, unlike the "actual budget distribution" which is dominated by the Homeowner Assistance, and the "uniform budget distribution" that did not meet the needs of the residential sector (Eid and El-adaway 2016b). The SDRC in the simulated "actual budget distribution" scenario was not able to address the needs of the low-income residents, as shown in Hancock and Jackson counties. The poor income residents were not able to meet the criteria of the Homeowner Assistance plan and there was no sufficient funding for the Public Home Assistance plan through this scenario. Moreover, the SDRC was not able to address the needs of

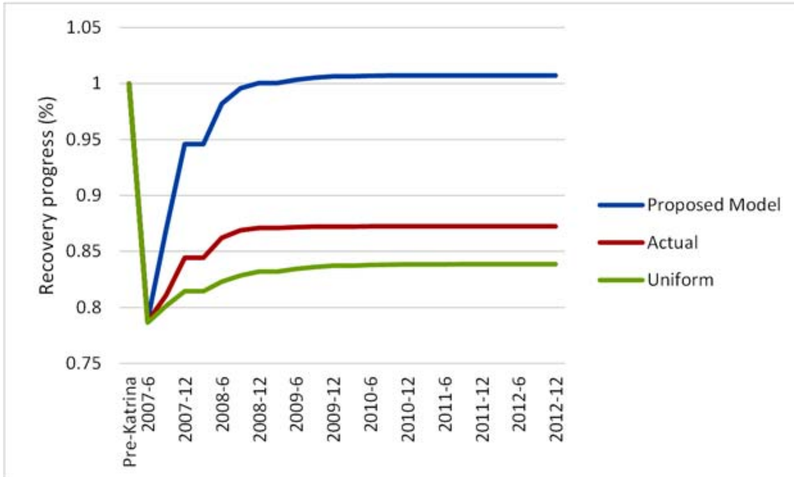

Figure 4.31: Hancock Residential Recovery Progress (Economic Version)

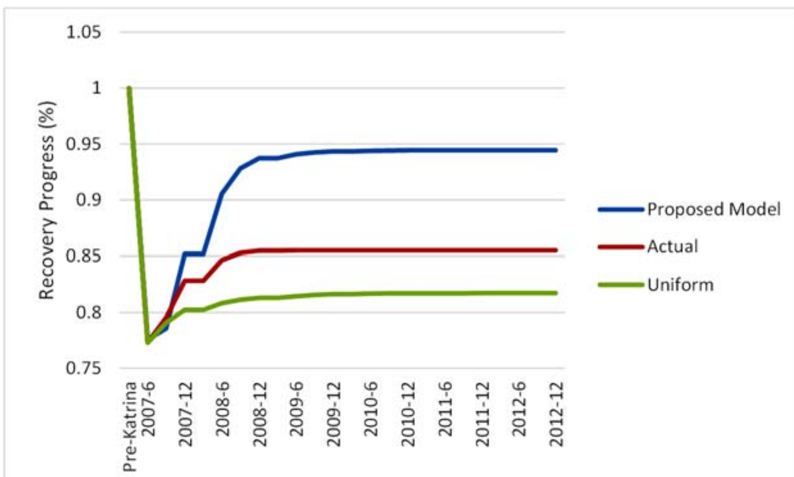

Figure 4.32: Harrison Residential Recovery Progress (Economic Version)

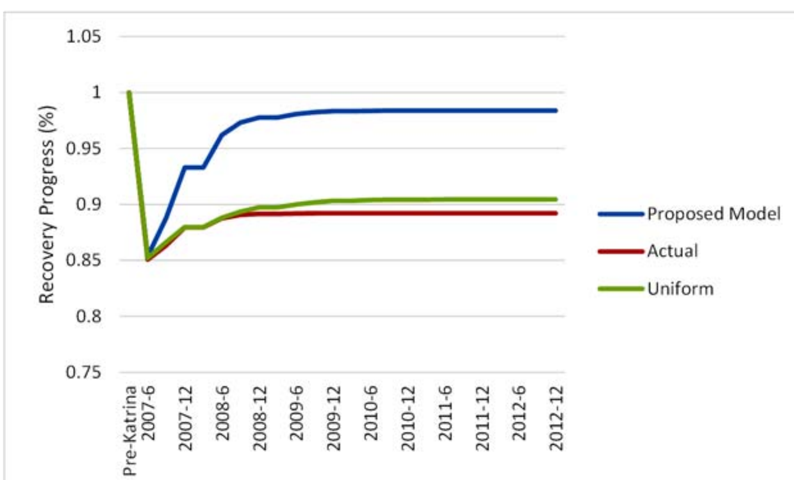

Figure 4.33: Jackson Residential Recovery Progress (Economic Version)

all the residents in Harrison County as the SDRC's budget was dominated by only one plan. Thus, the county only reached 85% overall recovery.

Meanwhile, the proposed framework presented a dynamic budget distribution that addressed the dynamic needs of the residential sector. This is observed in the higher recovery rate across the three counties, in addition to the higher overall recovery progress. The proposed framework increased the Homeowner Assistance plan in the first year of the simulation to meet the homeowners financial aid needs. However, in the later years, the model met the need of the poor income households through increasing the Public Home Assistance plan that in return increased the counties' overall residential recovery. The framework also used the Elevation Grant plan increase the residential sector utility function; by increasing their households' values and resilience. Nevertheless, the residential recovery progress in this economic vulnerability version of the model did not meet the same level reached through the social vulnerability version. This is due to the current model's incentive to meet the economic sector needs (through the Small Business Loan) which have a compounded effect on the economic vulnerability indicator. As such, as can be seen in the proposed budget distribution, the model significantly increased the Small Business Grant on the expense of the Elevation Grant, that eventually affected the residential recovery progress.

4.3.2.4. Proposed Model's Economic Financial Recovery – Economic Vulnerability

In order to evaluate the ability of the framework to restore the economic sector recovery while decreasing the community economic vulnerability, this section illustrates the retail sector financial recovery under the economic vulnerability indicator. The assessment is carried out on the proposed model outcome, the actual and uniform budget distribution scenarios. Figures 4.34-4.36

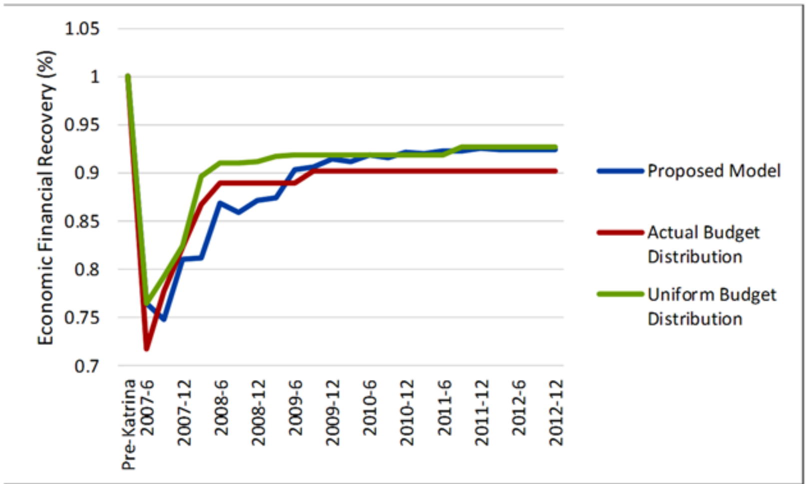

Figure 4.34: Hancock County Economic Recovery Progress (Economic Version)

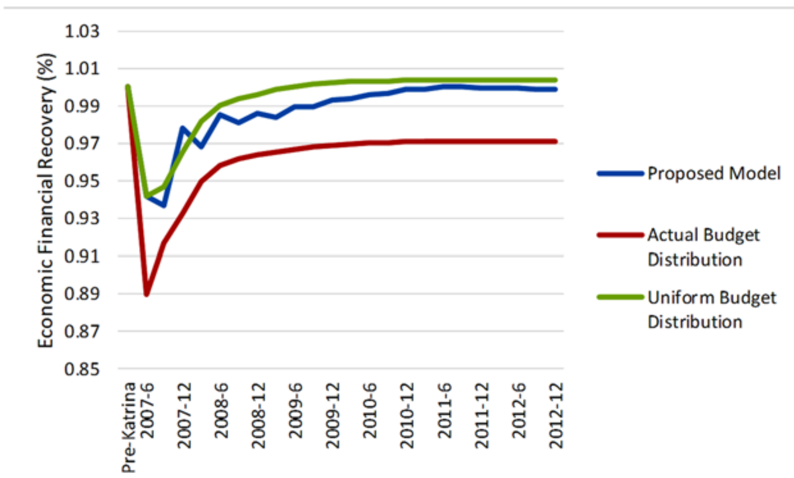

Figure 4.35: Harrison County Economic Recovery Progress (Economic Version)

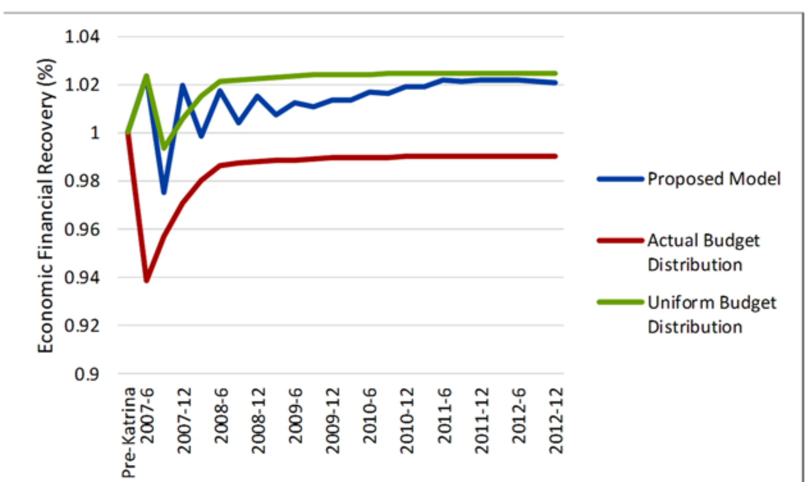

Figure 4.36: Jackson County Economic Recovery Progress (Economic Version)

present the economic sector recovery for Hancock, Harrison and Jackson counties, respectively. First, it can be observed from Figures 4.34-4.36 that proposed model was able to outperform the actual budget distribution in regard to the economic recovery across the three counties. This is due to the proposed model budget distribution, shown in Figure 4.26, that increased the Small Business Loan plan through the first two years of the simulation run. Such plan incentivized the economic sector to remain in the impacted region.

Meanwhile, the actual budget distribution did not incentive the retail sector to remain in the impact region, as such an observable and noticed relative decrease in financial recovery can be observed. On the other hand, there is no significant difference was found between the proposed model and the uniform budget distribution regarding the retail sector financial recovery. This is indeed intuitive as both budgets maintained a 25% of the budget share to the Small Business Loan Grant that incentivized the retail sector similarly.

It should also be noted that unlike the social vulnerability version of the model, the Small Business Loan in the current version has a compounded effect on the model. The Small Business Loan directly impacts the economic sector recovery. In addition, the economic sector recovery affects the economic vulnerability of community. The SDRC in the current version significantly increased this recovery plan budget share in comparison to the other vulnerability versions.

4.3.2.5. Residents Choices over the Different Insurance Companies – Economic Vulnerability

The choices of the residents over the different insurance plans changed throughout the simulation run, as shown in Figure 4.37. Through the utilization of Particle Swarm as a social learning technique, the residents changed their insurance policies to mimic the fittest residents among them

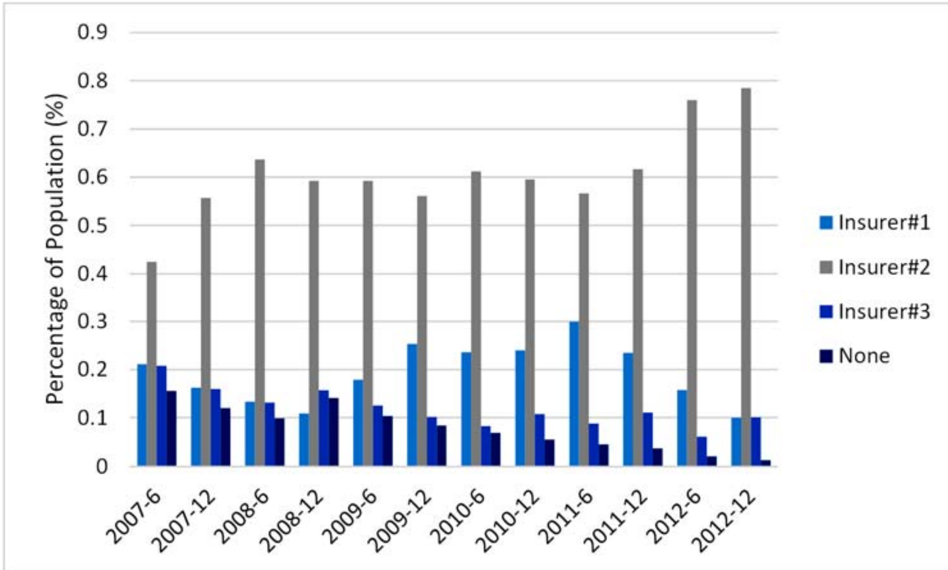

Figure 4.37: Choices of Residents over Different Insurance Options (Economic Version)

and maximize their objective functions. It can be noticed from Figure 4.37 that the residents under the SDRC's budget distribution, would be inclined towards insurance policies that would cover their losses in case of a disastrous event yet not with a 100% coverage. As such, the residents avoided expensive insurance policies offered by the third insurer. In addition, the residents also deviated from the least costly insurance plans – offered by the first insurer – as they do not sufficiently cover the recovery expenses. Thus, the population converged to insurer#2.

4.3.3. Model's Results - Environmental Vulnerability

4.3.3.1. Proposed Model's SDRC Budget Distribution – Environmental Vulnerability

Figure 4.38 illustrates the proposed SDRC budget optimization for the environmental vulnerability assessment that varied through the years of study. Through the framework multi-simulation runs, it can be observed that the Homeowner Assistance plan achieved 40% of the budget share, to meet the needs of the residents and facilitate their households' repair. However, as the eligible residents were sufficiently recovered and ineligible residents needed the fund, the SDRC decreased this plan's share of the budget in favor of the other plans.

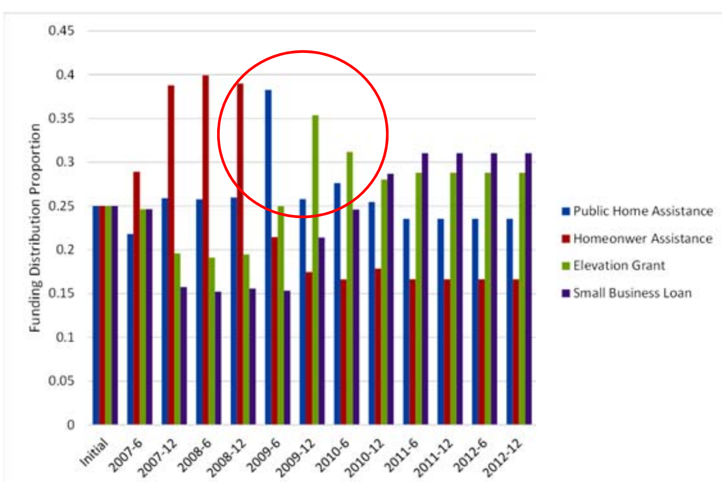

Figure 4.38: Proposed Funding Distribution (EVI Version)

Promptly, two residential disaster recovery plans shares started to increase; Public Home Assistance and Elevation Grant. The former increased the recovery rate of the poor income families. Those families were not able to apply for the Homeowner Assistance Plan. Nevertheless, such plan decreased the vegetation cover and adversely affected the environmental vulnerability of the host community, as discussed in a following section (Eid and El-adaway 2016a). The SDRC's reactive reinforcement learning module adjusted the share of the Public Home Assistance plan through the following years to decrease its adverse effect on the environment. Meanwhile, the Elevation Grant increased the resilience and value of the residential households without negatively impacting the environmental vulnerability of the host community (Eid and El-adaway 2016a). To this effect, the model maintained this disaster recovery plan to 30% to meet the needs of the residents and increase their overall recovery rate, as shown in the following section. Finally, it can be noticed that the SDRC's budget decreased the Small Business Loan for the first half of the simulation run. This plan did not contribute to the environmental welfare, nor to the residents, but just the economic sector. However, the model attempted to explore better utilization of the Small Business Loan as realized its importance to the economic agent, and as such increased its utilization rate to 30% in the second half of the simulation runs. However, it was a little too late, as the impacted economic retail sector already left the impacted regions.

4.3.3.2. Proposed Model's SDRC Wastewater Treatment Facilitates

As previously discussed, the WWTFs highly impact the environmental vulnerability of the host community. Meanwhile, there is no significant literature on the impact of the WWTFs on the economic or social vulnerability indicators. As such, it was found best to present the model's outcome in optimizing the WWTFs service allocations only in the environmental vulnerability section.

The WWTF projects carried out by MDA and their service distributions targeted the population needs for wastewater treatment. Even though such classical approach is applauded for and considers the residents needs for better wastewater treatment and avoid septic systems, it did not take into account the environment vulnerability of the host community. The projects' service distributions could be optimized to achieve better EVI values for the host community while maintaining the host community needs.

To this effect, the model utilized the optimization module, discussed in Chapter Three (Methodology and Model Development), to achieve a WWTFs' service distribution that meets the host community needs and decrease their environmental vulnerability. This is carried through introducing the aforementioned WWTF projects, limiting each project to its actual capacity and county to be served.

All census tracts per county were considered as a feasible solution for the model to choose from. This approach will allow for further exploration of better wastewater treatment service for all census tracts that would decrease the host community environmental vulnerability. Through the utilization of simulated annealing optimization approach, the following wastewater treatment service distribution was acquired from the proposed model.

- Hancock County:

The WWTF projects developed for Hancock County were introduced to the model for optimization. Thus, the model proposed better wastewater service distribution that would both meet the residents' needs and projected population growth, while decreasing the host community environmental vulnerability. Such approach targeted the densely populated areas in Hancock

County, as shown in Table 4.15. It must be noted that the WWTFs allocation does not mean it serves the whole population, but rather affects the census tracts EVI.

Table 4.15: Proposed WWTF projects - Hancock

Project	Census Tracts Served	Sum of Census Tracts' Population (2012)
Kiln WWTF	302, 303, 304, 305, 306.01, 306.02	38,567
Pearlington WWTF	304, 305, 306.01	17,700

- Harrison County

The six WWTF projects serving Harrison County where introduced to the model for optimization. Thus, the model attempted to find the best fitting wastewater treatment service distribution among the different census tracts that would meet the residents needs and their growth while decreasing the host community overall environmental vulnerability based on the EVI methodology. Table 4.16 illustrates the proposed WWTF extensive service distribution and allocation. As observed from Table 4.16, WWTFs in Harrison County were distributed among the census tracts in order to serve the most populated census tracts, meeting the residents needs and their projected growth while decreasing their environmental vulnerability. Multiple census tracts utilized more than one WWTF depending on the population size and needs (for example, census tract# 12.01).

- Jackson County:

Table 4.17 presents the proposed model WWTFs service distribution among the different census tracts in Jackson County. Such distribution took into consideration the residents' needs, their expected growth as well as decreasing the host community environmental vulnerability. It can be observed from the proposed model's WWTF service distributions presented in Tables 4.22-4.24 that more census tracts are served. Some of the census tracts share more than WWTF service. As such, the WWTFs capacities were utilized and optimized to meet the demand of the residents and decrease the environmental vulnerability. The proposed WWTFs service distribution provided a

Table 4.16: Proposed WWTF projects - Harrison

Project	Census Tracts Served	Sum of Census Tracts' Population (2012)
Saucier	3, 12.01, 13, 14, 16, 20, 23, 24, 32.04, 33.01, 34.03, 35.02, 35.04, 36, 38, 39	55,155
South Woolmaket (project#1)	3, 12.01, 14, 15.02, 17, 18, 19, 27, 28, 31.02, 32.04, 32.05, 32.07, 33.01, 33.04, 34.02, 34.04, 35.01, 35.02, 36	87,278
South Woolmaket (project#1)	12.01, 12.02, 13, 14, 15.01, 15.02, 16, 17, 18, 23, 26, 28, 29, 31.01, 31.02, 32.04, 32.05, 32.06, 32.07, 32.08, 33.03, 33.04, 34.04, 35.02, 35.04, 35.05, 36, 37, 38, 39	121,760
West Harrison	12.01, 12.02, 14, 15.01, 16, 17, 18, 20, 24, 27, 28, 30, 32.04, 32.05, 32.07, 32.08, 33.01, 33.04, 34.02, 35.01, 35.02, 35.04, 37	113,089
D'Lberbille	3, 6, 12.01, 14, 17, 18, 23, 32.05, 32.06, 32.08, 33.04, 34.03, 34.04, 35.01, 35.02, 35.05, 36, 37,38 ,39	139,176
US49-MS67	1, 3, 6,12.01, 12.02, 14, 16, 17, 18, 20, 23, 24, 25, 27, 28, 31.01, 31.02, 32.07, 32.08, 33.01, 33.03, 33.04, 34.02, 34.04, 35.01, 35.02, 35.04, 35.05, 36, 39	134,375

Table 4.17: Proposed WWTF projects – Jackson County

Project	Census Tracts Served	Sum of Census Tracts' Population (2012)
Big Point	401.01, 402.01, 402.03, 405, 406, 407, 408, 409, 411, 413, 415, 418, 419,421 ,422 ,425, 426, 429	89,473
West Jackson	401.01, 401.02, 403, 405, 406, 407, 410, 411, 415, 417, 418, 419, 420, 425, 426.	70,020

better EVIvalues for the host community as discussed in the following section. Figure 4.39 presents the proposed WWTFs service distribution allocation. It should be noted that the model can be modified to better optimize the WWTF service distribution through distributing the capacities on the block level. This cannot be carried out in the current research to maintain consistency as the vulnerability dimensions' data can only be found on the census tract level. The model also did not account for construction constraints (i.e., existing building in pipelines paths), that might affect the current optimal solution.

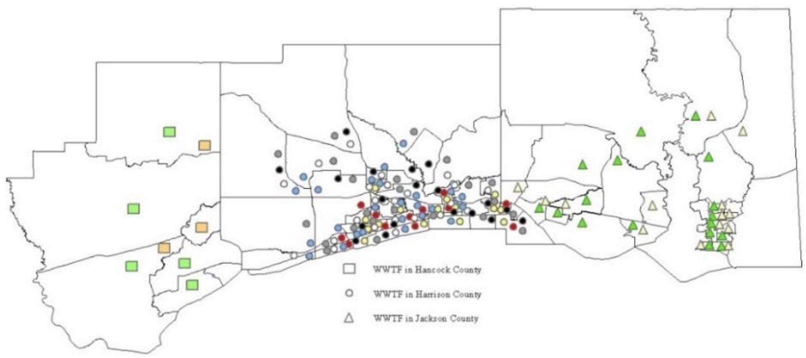

Figure 4.39: Proposed WWTFs Service Allocations

4.3.3.3. Proposed Model's Environmental Vulnerability

The projected EVI per census tract where calculated throughout the multiple simulation runs. The EVI's variables were affected by the utilized recovery actions that are optimized through the SDRC multi-objective optimization module to account for the environmental vulnerability of the host community. Thus, better EVI can be acquired through the integration of the host community's environmental vulnerability into the SDRC objective function. Figure 4.40 illustrates the host community's projected environmental vulnerability changes through the years of study based on the ABM simulation. Moreover, and for testing the proposed framework, the two-test simulation runs; actual and uniform budget distributions, are presented in Figures 4.41 and 4.42.

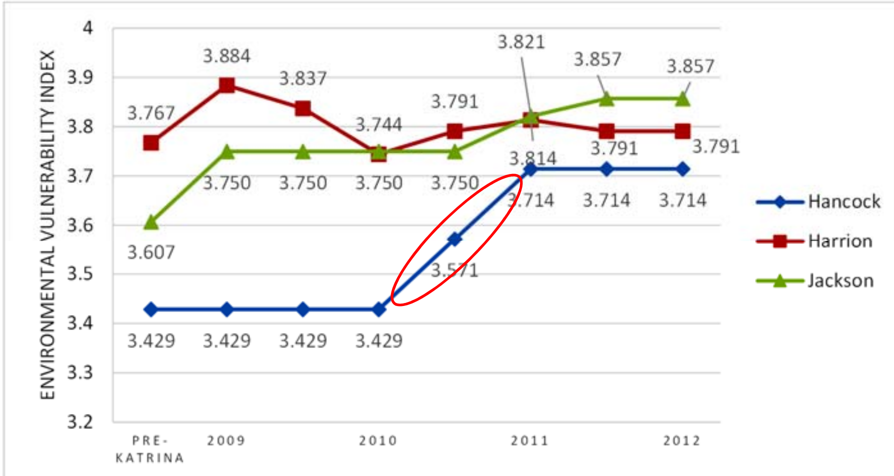

Figure 4.40: ABM Projected EVI per County

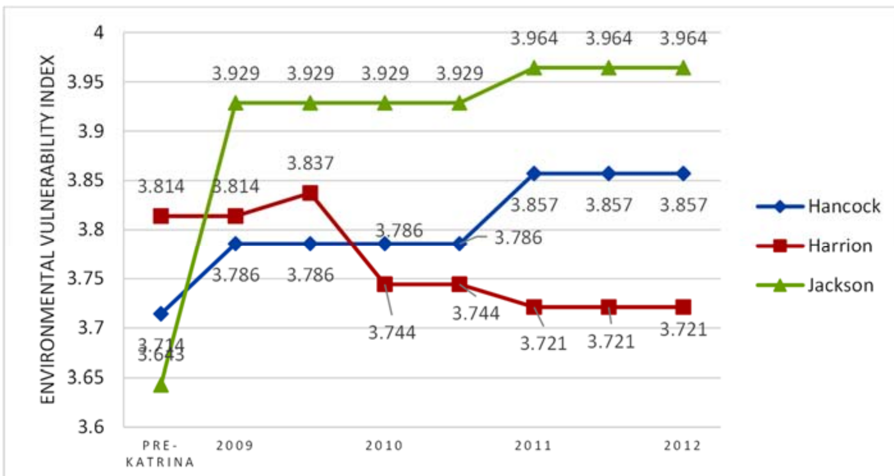

Figure 4.41: Actual Budget Distribution EVI per County

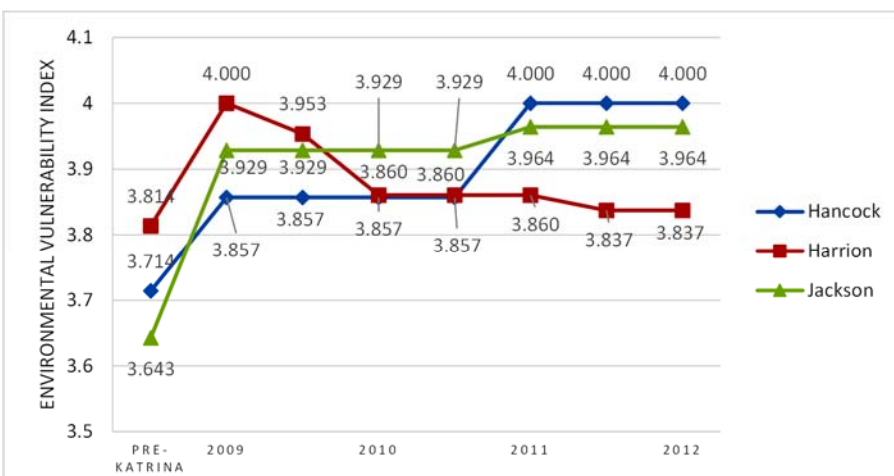

Figure 4.42: Uniform Budget Distribution EVI per County

Through comparing Figures 4.40-4.42, several observations can be made. The proposed framework's EVI scores outperformed the two budget distribution scenarios across the three counties. However, the "actual budget distribution" scenario provided a better EVI score for Harrison County. This is due to the minimal utilization of Public Home Assistance plan through actual budget distribution scenario (Eid and El-adaway 2016a). Such plan requires the construction of new homes on new lands, and thus decreasing the regions' vegetation covers. Nevertheless, this impacted the recovery process of the residents as furtherly discussed in a later section. Moreover, such plan was marginally utilized by the residents in Hancock County. As such, a significant increase in the proposed model's EVI can be noticed.

Moreover, it can be observed that the model started with better EVI scores, due to the optimum utilization of the WWTFs and distributing their services to decrease the environmental vulnerability of the host community while meeting the residents' needs and expected growth. This optimal service allocation decreased the counties' overall environmental vulnerability. Nevertheless, the model had some limitation that would have further impact on the overall EVI scores. The sudden change of population size, and in return the waste production, was not modeled. The model however accounts for the growth of the population based on the actual data for each census tract (Eid and EL-adaway 2016a). Furthermore, the limitation of the model also includes variables like the re-growing of vegetation cover, as there is no sufficient data to model it. Such variable will positively affect the EVI's Vegetation Cover variable (Eid and El-adaway 2016a).

For better visualization, Figure 4.43 illustrates the projected EVI per census tract at the end of the simulation run. EVI values are color coded; Red for high vulnerability (≥6); Orange for above average vulnerability (5); White for average vulnerability (4); Green for below average vulnerability (3) and Blue for least vulnerability (≤2).

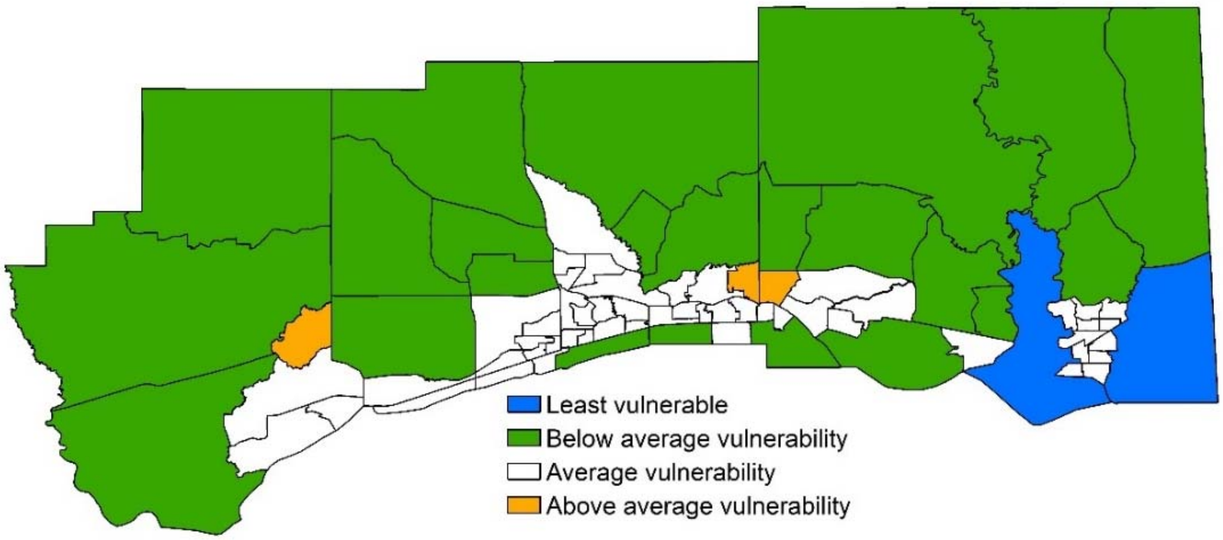

Figure 4.43: Projected EVI Per Census Tract – 2012

It can be observed that the proposed model, in comparison to the actual EVI in Figure 4.13, was able to decrease census tracts environmental vulnerability. An overall decrease in the environmental vulnerability of Jackson county can be noticed, especially in the most populated census tracts in West Jackson. Moreover, East Hancock (densely populated) environmental vulnerability was also decreased, in comparison to the existing conditions. This reduction in EVI across the different counties is contributed to the optimal utilization of the WWTFs to decrease the EVI scores while meeting the needs of the residents. Moreover, as the SDRC's learnt from past experiences, it avoided the utilization of the Public Home Assistance plan to prevent building new homes on vegetation covers and increase the community environmental vulnerability.

4.3.3.4. Proposed Model's Residential Recovery – Environmental Vulnerability

The residential recovery for the three counties is illustrated in Figures 4.44-4.46 for the proposed model as well as both the actual and uniform budget distribution scenarios. Through the households' recovery and redevelopment comparison in Figures 4.44-4.46, the proposed framework potential to meet the residential sector recovery needs while maintaining and decreasing the environmental vulnerability of the host community can be noticed (Eid and El-adaway 2016a). Such recovery is due to the integration of the stakeholder's individual utility functions into the SDRC's objective function.

This approach guided the fund allocation to increase the community welfare and meeting the needs of the residents. As such, an increasing rate in the residential recovery can be noticed across the three counties. It can also be noted that both the uniform and actual budget distribution scenarios did not meet the stakeholders' needs. As such, their recovery did not cope with the proposed model outcome.

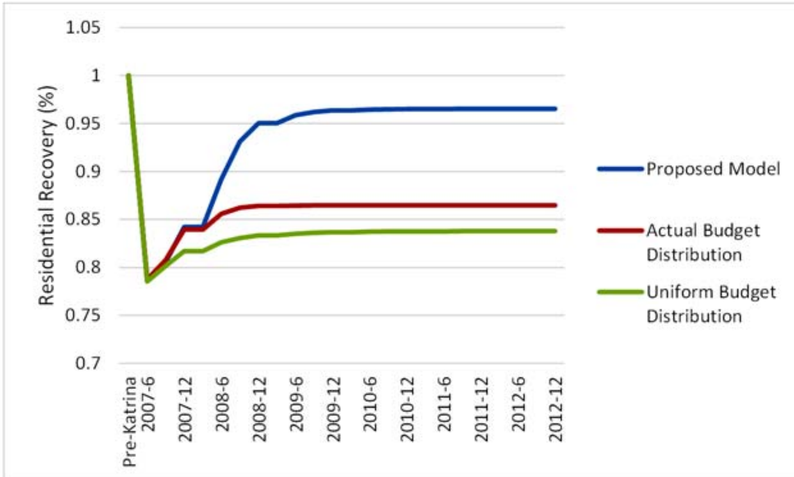

Figure 4.44: Hancock Residential Recovery (Environmental Version)

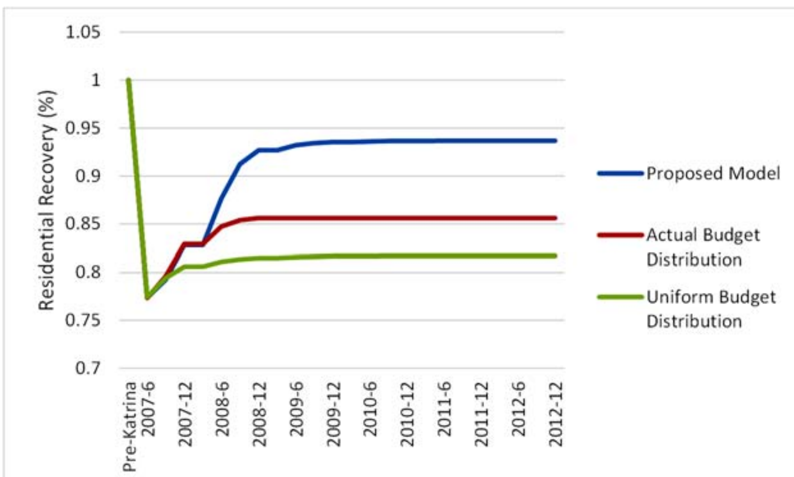

Figure 4.45: Harrison Residential Recovery (Environmental Version)

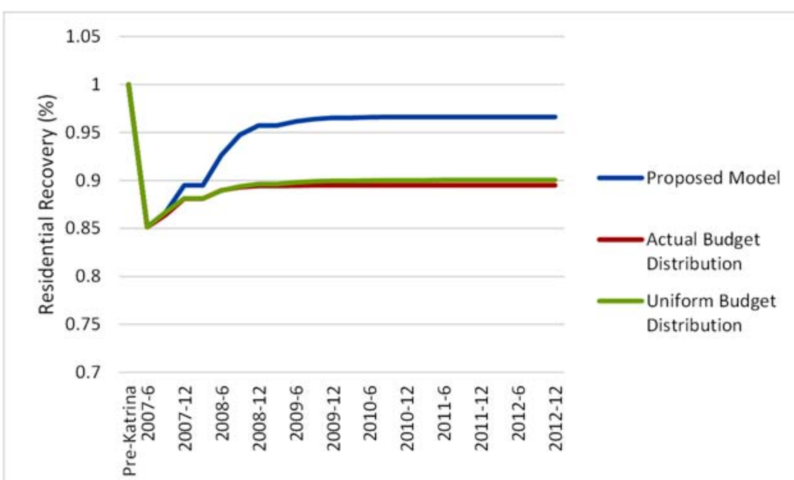

Figure 4.46: Jackson Residential Recovery (Environmental Version)

However, unlike the Social Vulnerability Index, the compounded effect of the Elevation Grant (residents' utility function and decrease in Social Vulnerability) is not present for the Environmental vulnerability. The SDRC's budget did not increase the Elevation Grant utilization. As such, none of the three counties reached more than 100% recovery, in comparison to the output from the Social Vulnerability version. Also, this is contributed by the sudden decrease in the Public Home Assistance plan. As such, some of the poor income residents were not able to recover.

4.3.3.5. Proposed Model's Economic Financial Recovery – Environmental Vulnerability

This section illustrates the model ability to restore the economic sector financial status. In parallel to the previous sections, a comparison between the actual and uniform budget distribution scenarios and the proposed model outcome in regard to the retail sector financial recovery is presented. This is carried out through measuring the retail sector mean revenue per county and evaluate it to the pre-Katrina mean sales revenue. Figures 4.47-4.49 present the financial recovery for the economic agent (retail sector) for counties Hancock, Harrison and Jackson, respectively.It can be observed from Figures 4.47-4.49 that even though the model proposed better financial recovery for Hancock County, it failed to achieve sufficient recovery rate for Harrison and Jackson counties (most of the retail sectors are located in those counties), in comparison to the uniform budget distribution scenario. This is due to the limited utilization of the Small Business Loan plan by the proposed model's SDRC. Meanwhile, the uniform budget distribution scenario outperformed the actual budget distribution in Hancock County, which confirms the need for the Small Business Loan plan to incentivize the retail sector to remain in the impact region. It should also be noted that the economic recovery does not have the compounded effect on the environment (neither positively nor negatively). As such, the model did not prioritize it as much as other plans.

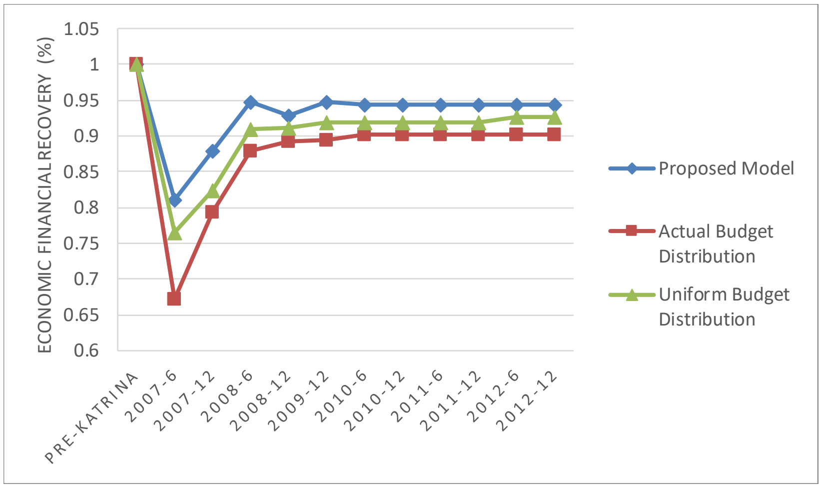

Figure 4.47: Hancock County Economic Recovery Progress (Environmental Version)

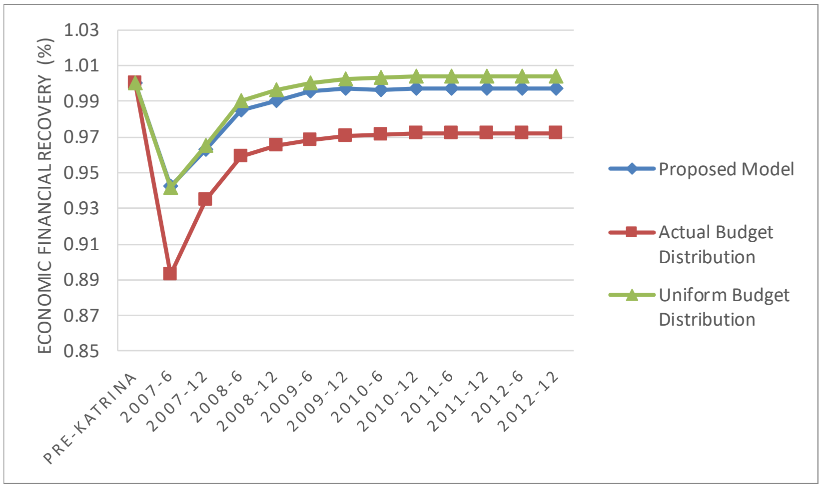

Figure 4.48: Harrison County Economic Recovery Progress (Environmental Version)

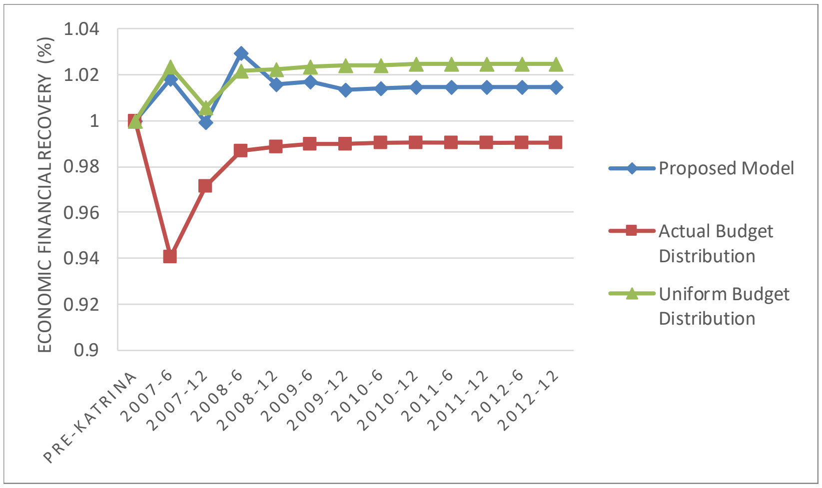

Figure 4.49: Jackson County Economic Recovery Progress (Environmental Version)

4.3.3.6. Residents Choices over the Different Insurance Companies – Environmental Vulnerability

Figure 4.50 presents the insurance policy choices of the residential sector utilizing the evolutionary game theory and Particle Swarm as a social learning model. Through the utilization of Particle Swarm, the residents changed their choices to attain the highest possible utility function. It can be observed that the residents tend to converge to the lowest cost insurer. This is due to the initial domination in the utilization of the Homeowner Assistance plan. The plan impacted the residents' recovery rate. As such, the residents with the lowest insurance premium costs, yet received the same government financial support, had better utility functions than the other residents. Moreover, all the residents who had insurance coverage were better off than the none-insured residents.

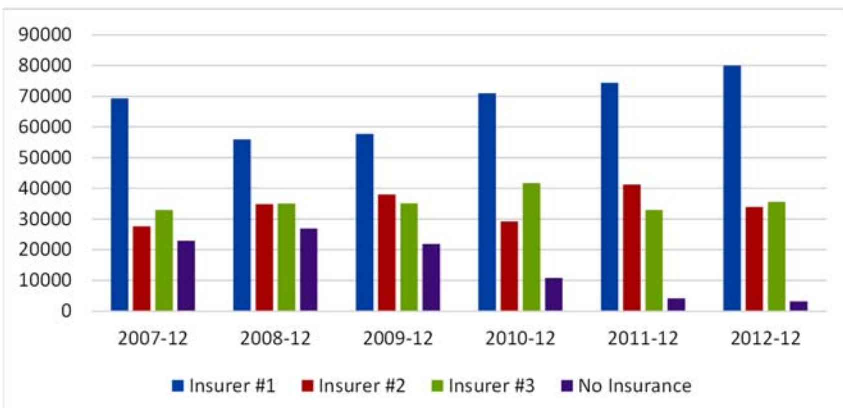

Figure 4.50: Residents' Choices over Different Insurance Options (Environmental Version)

4.3.4. Model's Results – Simultaneous Three-Dimensional Vulnerability

This section illustrates the full scale multi-objective optimization of the stakeholders' decision actions. Each implemented recovery plan had different effects on the residential and economic financial recovery in addition to the three-dimensional vulnerability of the host community. As discussed in the previous section, different results are obtained when attempting to optimize only one vulnerability dimension. This section illustrates simultaneous optimization of the three vulnerability dimensions. To this effect, the proposed model utilized Pareto Front sorting for the SDRC multi-objective optimization in redistributing the redevelopment funds across the different plans. This approach aims to equally meet the various complex objectives without subjective weighting criterion. Such solution can be considered as a compromise optimal solution that meets the stakeholders-driven objectives through gaining the most out of each recovery plan.

4.3.4.1. Proposed Model's SDRC Budget Distribution – Three-Dimensional Vulnerability

The framework was initiated with uniform budget distribution across the four recovery plans; 25% each. Through the model simulation, the budget distribution evolved to meet the needs of the stakeholders and simultaneously decrease the three-dimensional vulnerability of the host community. Figure 4.51 illustrates the SDRC's budget when attempting to simultaneously optimize for the three-dimensional vulnerability and meeting the needs of the different stakeholders.

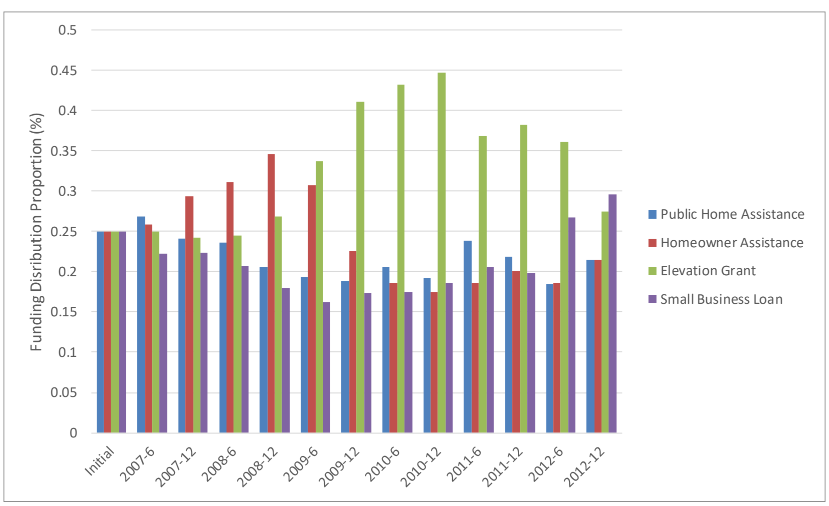

Figure 4.51: Proposed Funding Distribution (Three-Dimensional Vulnerability Version)

Through the first two years, the Homeowner Assistance plan share increased to 35% of the total budget distribution. The redevelopment plan aimed to increase the objective functions of the residential sector through financial aid to rebuild and recover from the disastrous event. Moreover, the SDRC attempted to increase the Public Home Assistance in the first year to meet the needs of the poor income residents. Nevertheless, as this plan has some adverse effect on the environmental vulnerability of the host community through building houses on existing vegetation covers, the SDRC decreased it share in the following years. Meanwhile, other plans (i.e., Elevation Grant), did not has such negative effect). Accordingly, the SDRC kept the Public Home Assistance plan budget to 20% of the total budget throughout the simulation run.

As the residents tend to recover, the SDRC's decreased the Homeowner Assistance plan share significantly as it increased the Elevation Grant to 45%. The Elevation Grant increases the utility functions of the residents through increasing the value of the households, decreased their social vulnerability, and decreased the economic vulnerability with no impact on the host community's environmental vulnerability. Finally, unlike the other aforementioned cases, the framework committed more than 20% of the budget to the Small Business Loan in the first two years to incentivize the retail sector to stay in the impacted region.

4.3.4.2. Proposed Model's Three-Dimensional Vulnerability

4.3.4.2.1. Social Vulnerability

The proposed framework aimed to reduce the social vulnerability of the most populated census tracts, which are mostly contained in Harrison county. Accordingly, the framework decreased the Harrison County's social vulnerability drastically to 1.902 in contrast to 2.755, 4.049, and 3.212, for the simulated budget distribution, uniform budget distribution, and existing conditions, respectively, as shown in Figure 4.52. Meanwhile, Figure 4.53 provides better vitalization on the proposed model's outcome per county. As such, a significant decrease in social vulnerability can be observed across the three counties. But most importantly, such decrease can be observed in the densely populated regions; east Hancock, southern Harrison, and west and east Jackson counties.

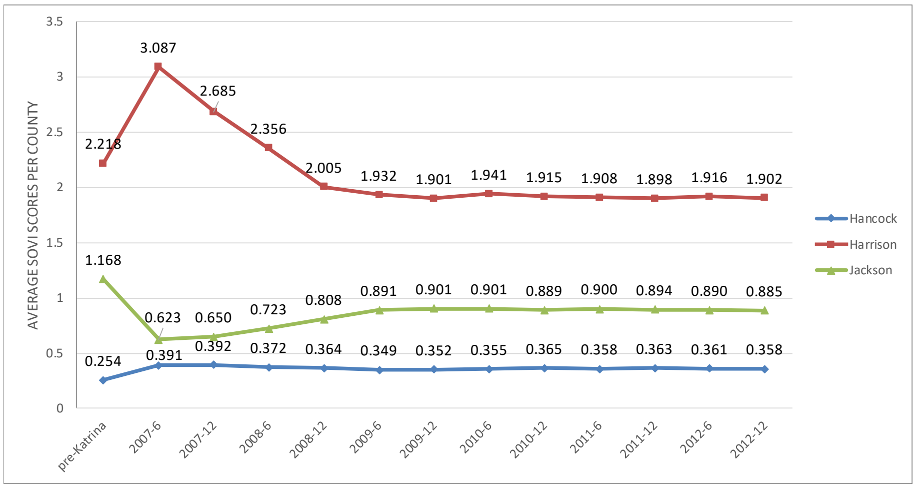

Figure 4.52: ABM Projected SoVI Scores (Three-Dimensional Vulnerability Version)

This significant decrease in social vulnerability is due to the extensive utilization of the Elevation Grant, that increases the resilience and value of the households in south Harrison. As such, the residents in these areas rapidly bounced back from the disaster impact due to the Homeowner assistance plan.

Figures 4.54-4.56 illustrate a boxplot for the three counties social vulnerability changes throughout the simulations. Such representation provides better understanding on the upper and lower bounds of the SDRC's budget distribution impact on the social vulnerability of the host community. It can be noticed that Jackson County, the least affected by the hurricane, showed the least amount of variation, in regard to the SoVI scores.

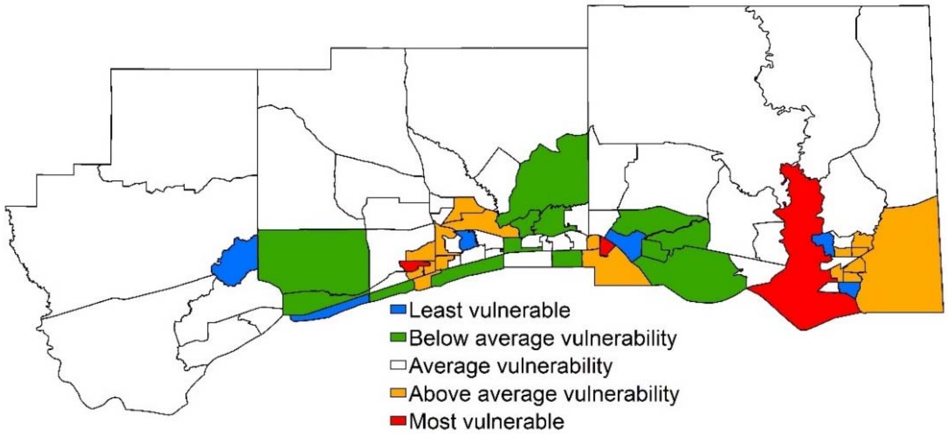

Figure 4.53: Projected Social Vulnerability (Three-Dimensional Vulnerability Version)

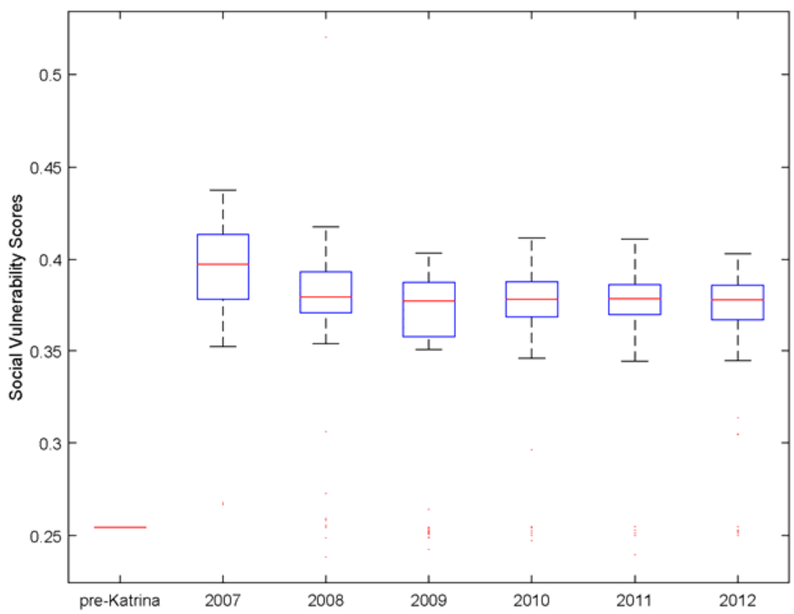

Figure 4.54: Hancock County SoVI – Boxplot

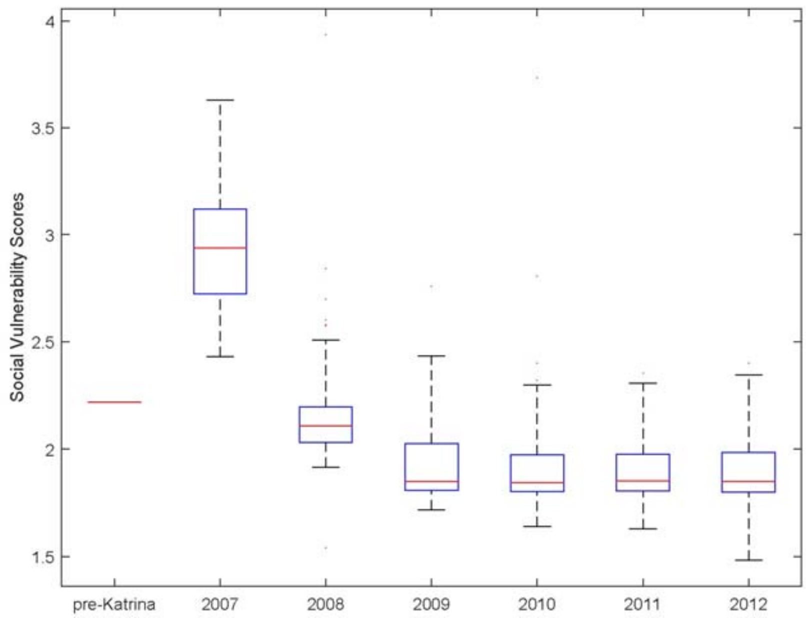

Figure 4.55: Harrison County SoVI – Boxplot

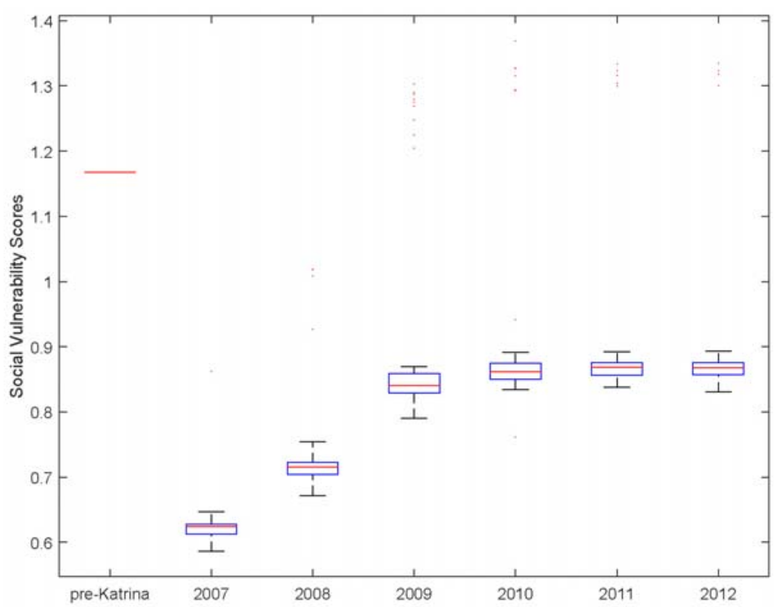

Figure 4.56: Jackson County SoVI – Boxplot

4.3.4.2.2. Economic Vulnerability

As shown in Figure 4.57, the proposed framework did not significantly reduce the economic vulnerability when attempting to simultaneously decrease the three vulnerability dimensions, in comparison to the simulated actual budget distribution and uniform budget distribution. However, the framework provided better results in comparison to the existing conditions. This is due to the compromise solution via Pareto Front Sorting embedded in the learning process of the modeled SDRC that attempted to optimize all the aforementioned contradicting objective functions. The impact of the Elevation Grant can be observed in Figure 4.57, where the rate in decreasing the economic vulnerability (2009-2010) was ramped up in 2010-2011 due to the increase in the Elevation Grant in the same year (as observed in Figure 4.50). As shown in Figure 4.58, the proposed model tackled the most populated regions to decrease their economic vulnerability. This can be observed in the east Hancock and west Jackson.

Figures 4.59-5.61 present the simulation results per year in regard to the EconVI scores per county through boxplots. It can be observed that the main change in the model's outcome in regard to the EconVI is around year 2010, where the Elevation Grant budget starts to increase.

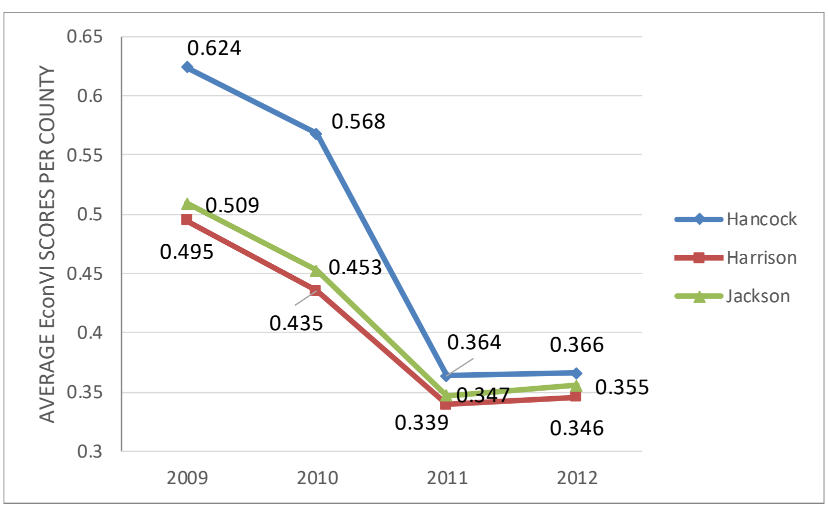

Figure 4.57: ABM Projected EconVI Scores (Three-Dimensional Vulnerability Version)

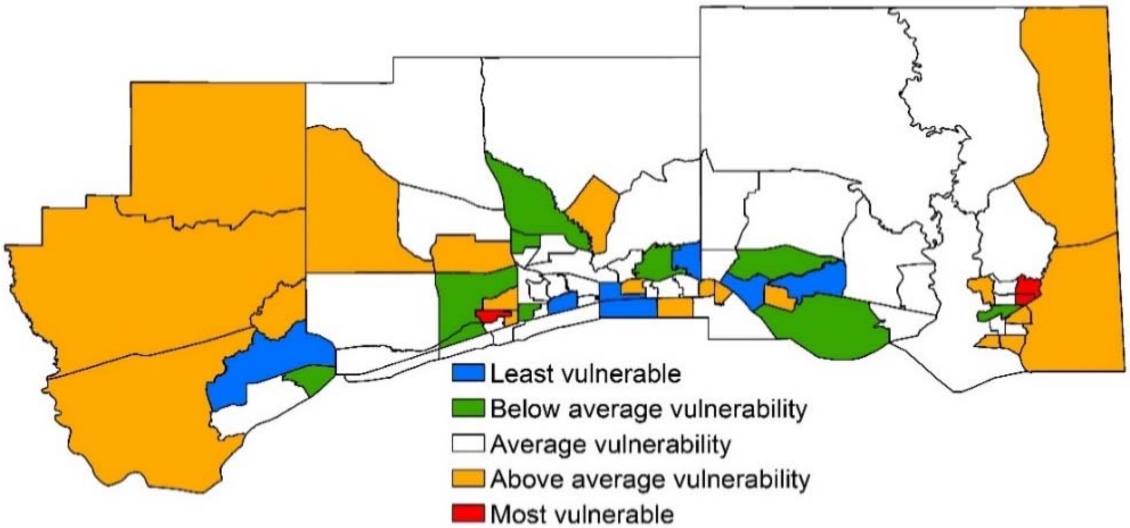

Figure 4.58: Projected Economic Vulnerability (Three-Dimensional Version)

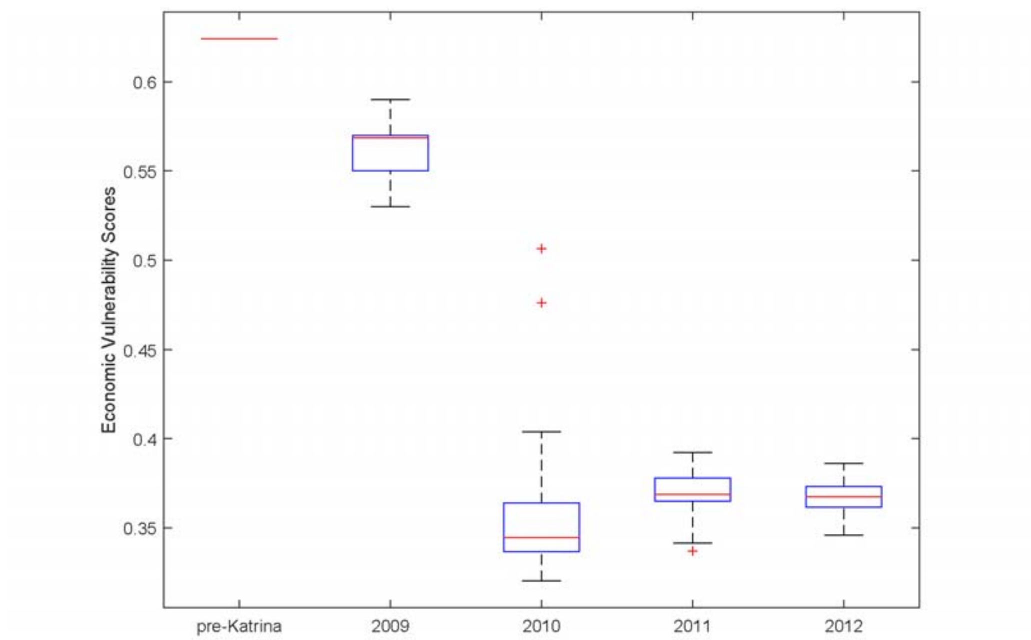

Figure 4.59: Hancock County EconVI – Boxplot

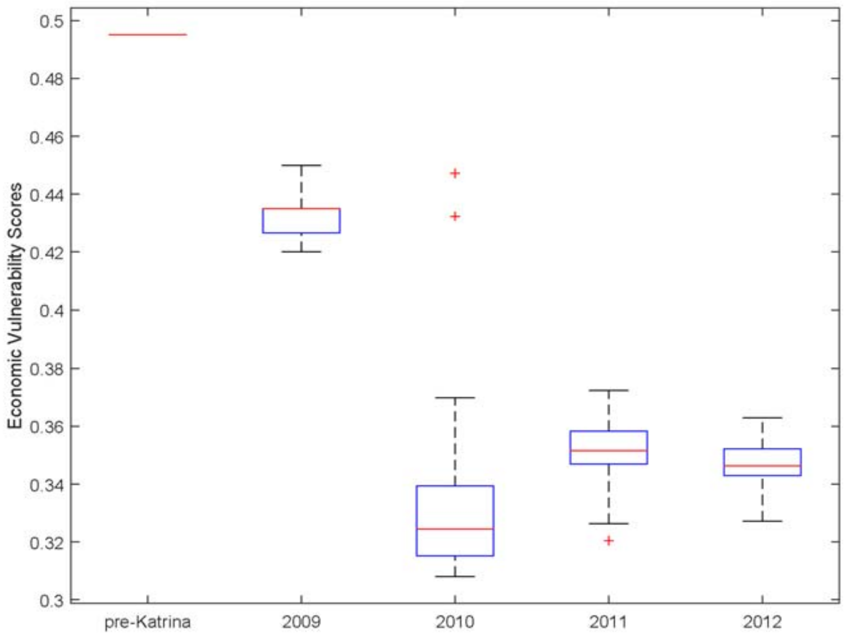

Figure 4.60: Harrison County EconVI – Boxplot

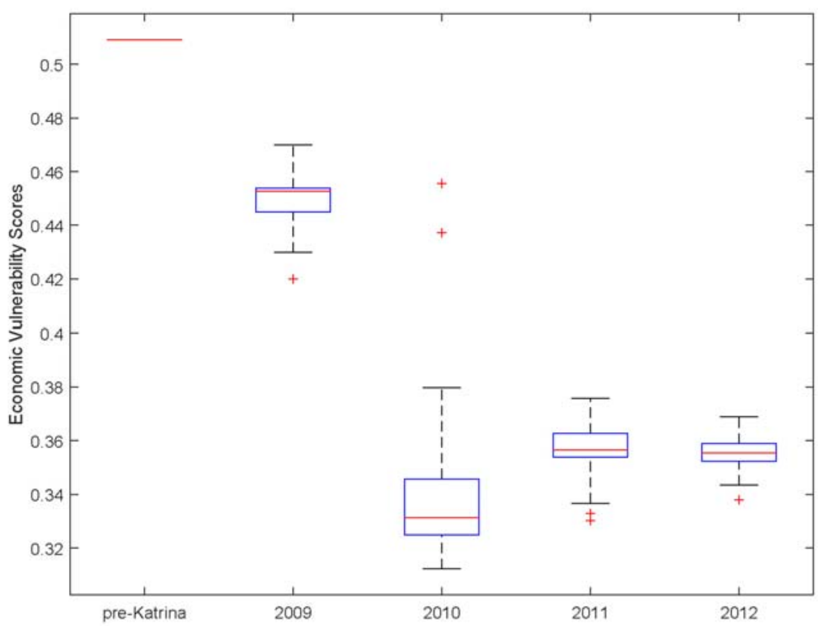

Figure 4.61: Jackson County EconVI – Boxplot

4.3.4.2.3. Environmental Vulnerability

Figure 4.62 illustrates the average EVI score per county for the proposed framework. It can be observed that the proposed framework decreased the average environmental vulnerability per county, in comparison to the simulated actual and uniform budget distributions. The framework also outperformed the existing conditions based on the MDA utilized strategies and budget distribution. This is due to the integration of the environmental vulnerability into the objective function of the SDRC in both the infrastructure development (WWTFs) and the budget redistribution (Eid and El-adaway 2016a). Figure 4.63 presented the framework's projected environmental vulnerability across the different census tract through color coding.

It should be noted that the EVI scores did not show any significant changes between the standalone reduction of environmental vulnerability and the three-dimensional vulnerability version. When testing the model utilizing economic or social vulnerability indicators, it was clearly noticed the increase in environmental vulnerability, but not through the three-dimensional vulnerability reduction. This is due to the rapid decrease in the Public Home Assistance plan that would negatively affect the environmental vulnerability and the optimal utilization of the WWTFs.

Figures 4.64-4.66 illustrate the EVI scores per county provided throughout the simulation via boxplots. It can be observed through these figures that as the EVI methodology is scalar, the EVI scores are not as sensitive to the SDRC's actions as the SoVI and EconVI, as they require significant changes to reach the next scalar threshold. This is also why no significant changes can be observed in the EVI map.

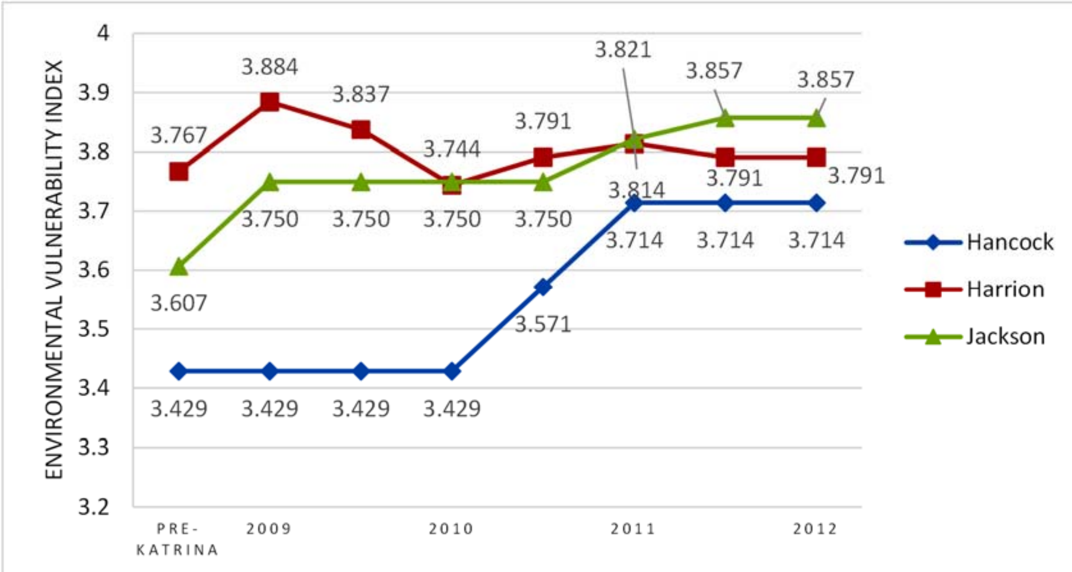

Figure 4.62: ABM Projected EVI per County (Three-Dimensional Version)

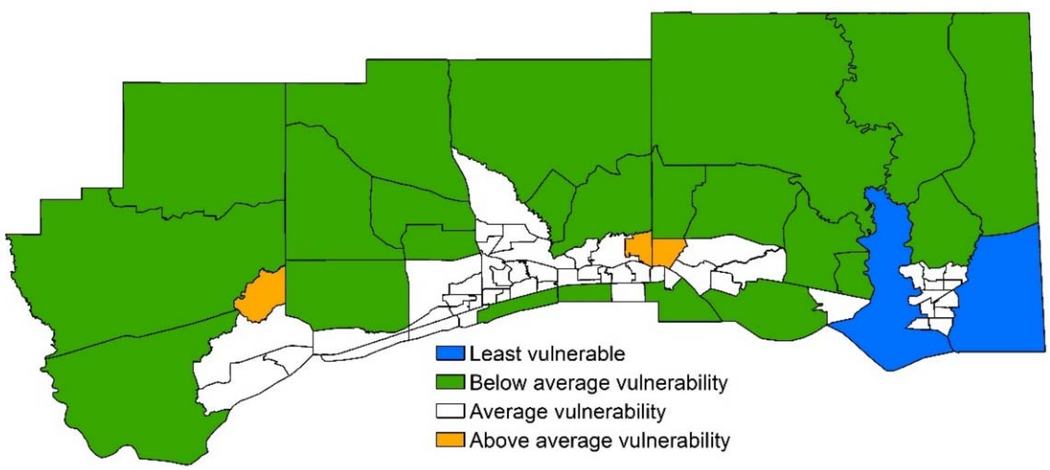

Figure 4.63: Projected EVI Per Census Tract (Three-Dimensional Version)

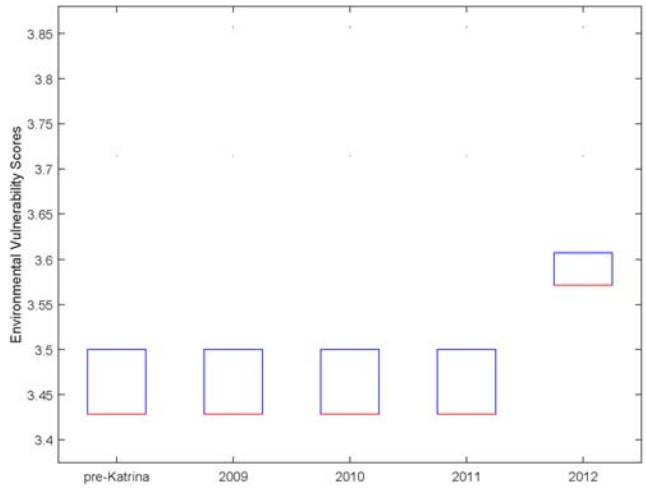

Figure 4.64: Hancock County EVI – Boxplot

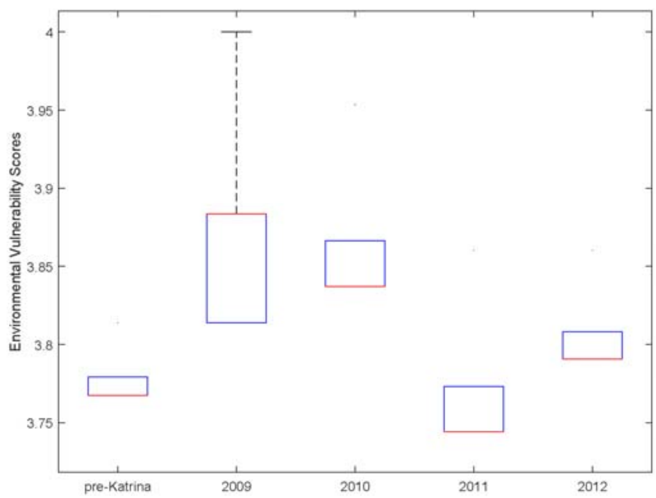

Figure 4.65: Harrison County EVI – Boxplot

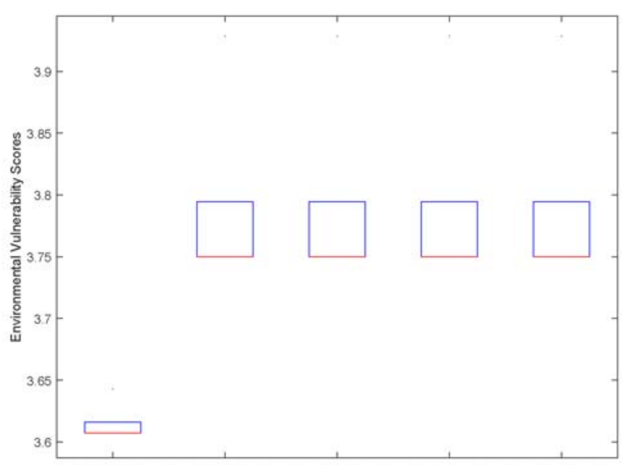

Figure 4.66: Jackson County EVI – Boxplot

4.3.4.3. Proposed Model's Residential Recovery – Three-Dimensional Vulnerability

This section illustrates the effect of the SDRC's optimized budget distribution on the residential sector recovery that is presented throughout Figures 4.67-4.69. The SDRC's objective function aimed to increase the welfare of the residents through meeting their needs. Accordingly, the dynamic evolution of the SDRC's budget met the needs of the residents (as shown below) and increased their recovery rate, in contrast to the actual budget distribution utilized by the MDA.

First, the proposed framework's residential redevelopment rate is significantly higher and did not slowdown at years 2008-2009, in contrast to the actual and uniform budget distribution scenarios. The actual budget distribution depleted all the financial resources on the Homeowner Assistance plan. As residents are different, not all the residents require the same type of redevelopment plan all throughout the recovery period. As such, this approach failed to meet the needs of the poor income households or increase the households' resilience. On the other hand, the uniform budget distribution did not address the dynamic needs of the residential sector.

In addition to utilizing Homeowner Assistance plan to help the residential sector to rebound from the perturbation, the optimized SDRC's budget met the needs of double the number of the poor income families across the three counties by offering the Public Home Assistance plan with a steady 20% of the total budget share, in comparison to the other budgets. The impact of this plan can be observed in Hancock and Jackson counties that had a significantly high recovery rates in the first years of the simulations. The residents of those counties utilized the Public Home Assistance plan the most. Moreover, the three counties residential recovery reached more than 100% due to the extensive utilization of the Elevation Grant, which peeked to 45% by year 2010,

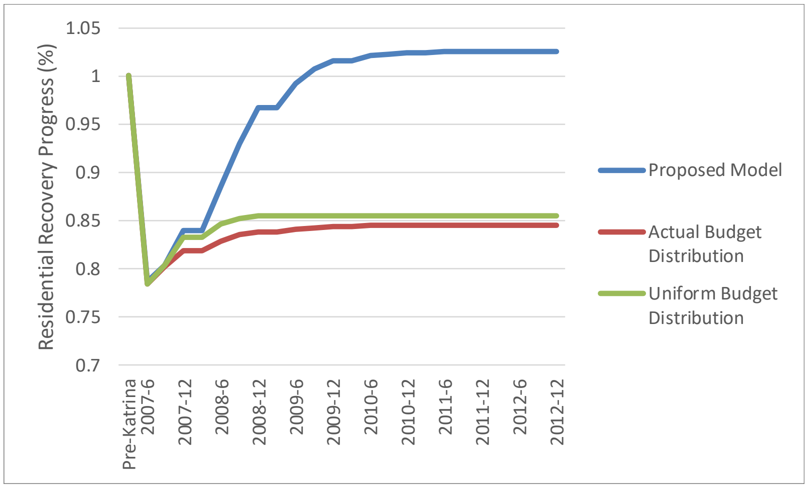

Figure 4.67: Hancock Residential Recovery (Three-Dimensional Version)

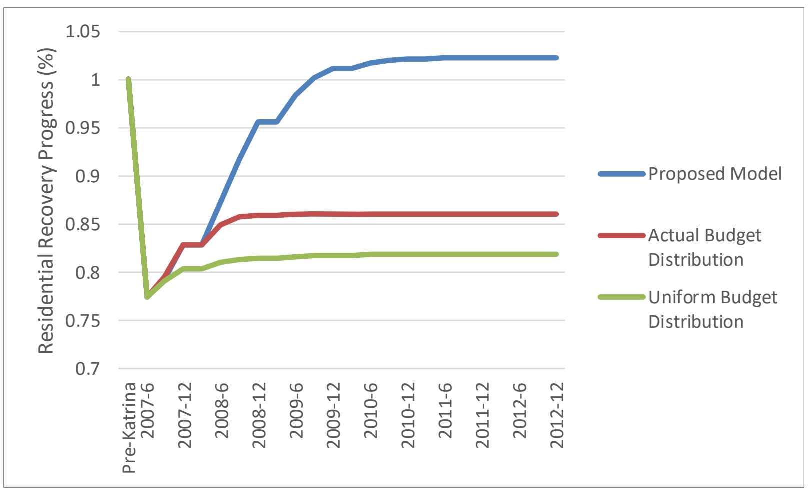

Figure 4.68: Harrison Residential Recovery (Three-Dimensional Version)

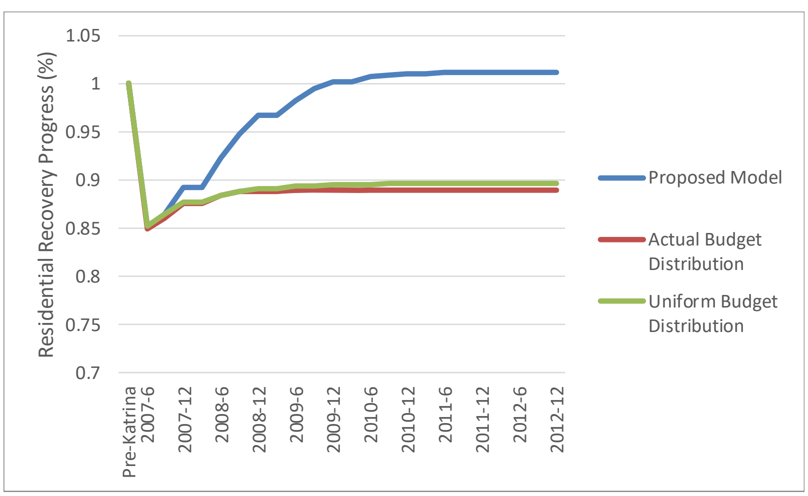

Figure 4.69: Jackson Residential Recovery (Three-Dimensional Version)

and increased the number of benefactors up to four folds. The Elevation Grant increases value of the households through increasing the resilience of households to floods (Eid and El-adaway 2016a). Thus, this plan utilizes extra resources for retrofitting the structures, which increases the household value in comparison to the pre-event condition.

Figures 4.70-4.72 present the lower and upper the residential recovery per county as an impact of the SDRC's budget distribution via boxplots. At the end of the simulation, Harrison county provided the least variation in regard to the residential recovery. This is due to (1) the number of residents within the county, and (2) the residents utilized Homeowners Assistance plan the most, that did not have any adverse effect on the SoVI, EconVI, or EVI.

4.3.4.4. Proposed Model's Economic Financial Recovery – Three-Dimensional Vulnerability

This section compares the framework's output to the actual and uniform budget distribution scenarios in regard to the economic financial recovery when the SDRC attempt to optimize all of the three vulnerability dimensions. Figures 4.73-4.75 present such comparison where the proposed model was not able to provide better outcome than of the uniform budget distribution but provided a significant advancement and recovery in comparison to the actual budget distribution.

As previously discussed in the SDRC's budget, the proposed framework maintained 20% of the budget to the Small Business Loan. Such plan incentivized the retail sector to stay in the impacted counties and those provide better financial recovery. As such, no dramatic decrease in revenue was observed across the three counties in comparison to the actual budget distribution scenario. In Jackson County, the economic recovery rate oscillated around 100% in the first year. This is due to: (1) the presence of the retail agents post the disastrous event due to the Small

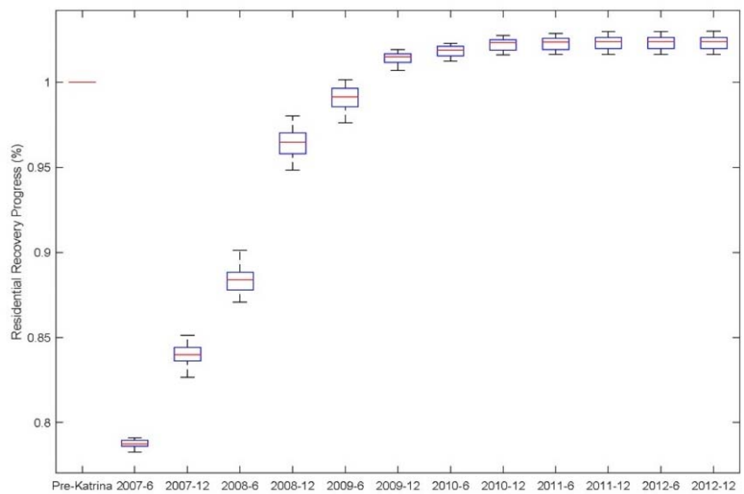

Figure 4.70: Hancock County Residential Recovery – Boxplot

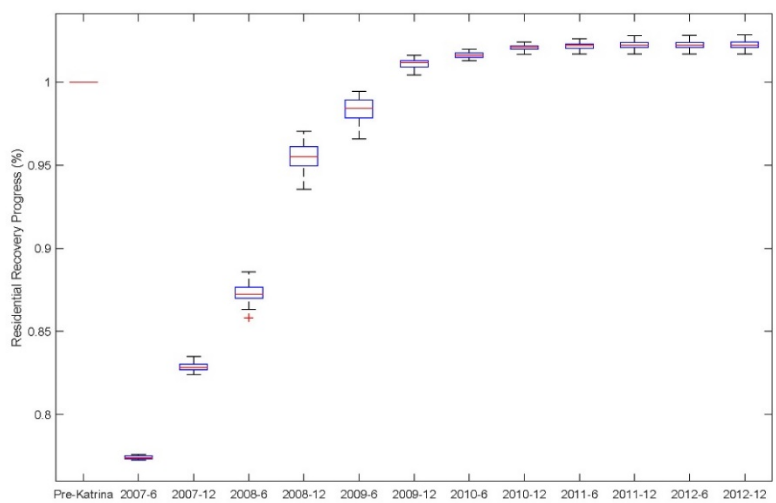

Figure 4.71: Harrison County Residential Recovery – Boxplot

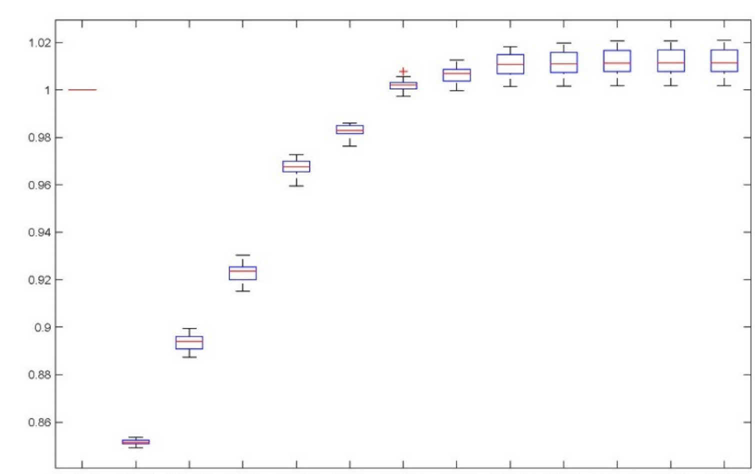

Figure 4.72: Jackson County Residential Recovery – Boxplot

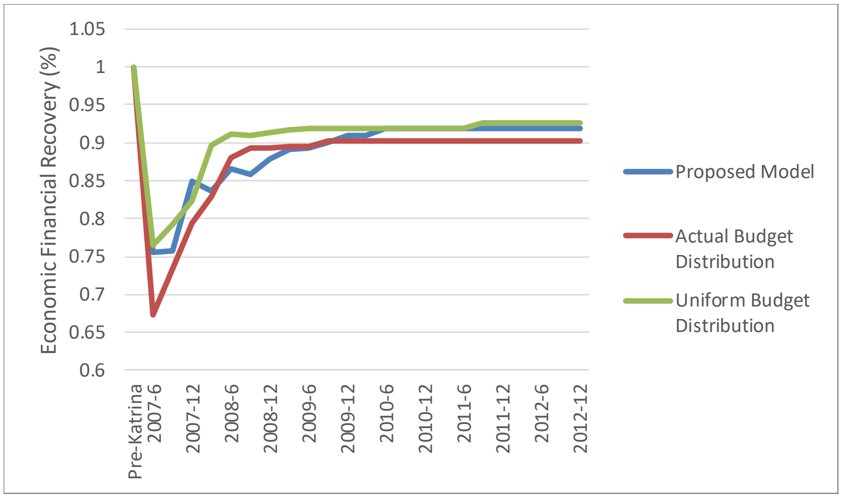

Figure 4.73: Hancock County Economic Recovery Progress (Three-Dimensional Version)

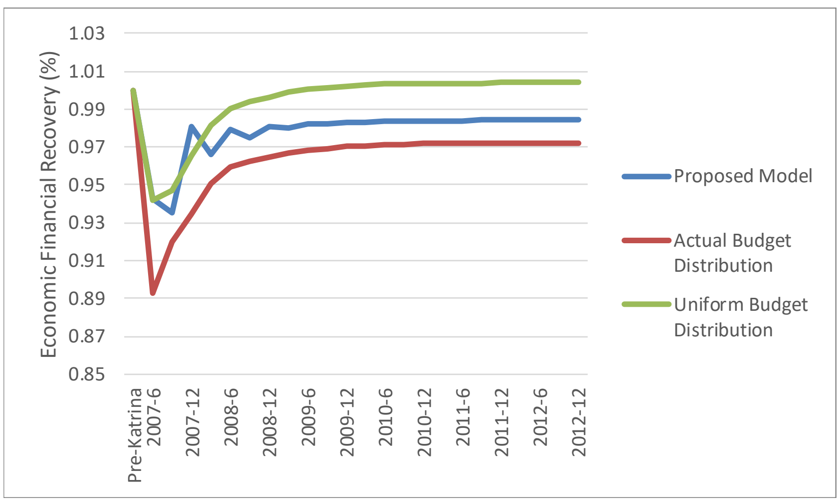

Figure 4.74: Harrison County Economic Recovery Progress (Three-Dimensional Version)

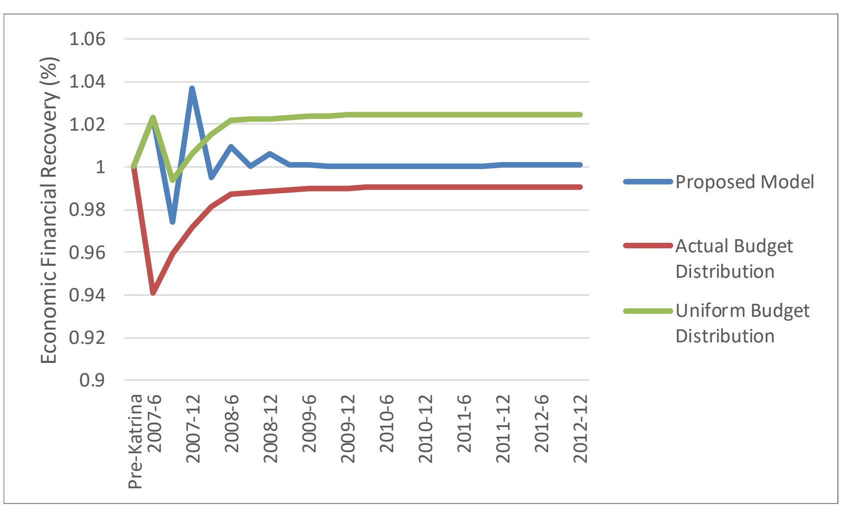

Figure 4.75: Jackson County Economic Recovery Progress (Three-Dimensional Version)

Business Loan incentive, and (2) the utilization of the Public Home Assistance plan and Elevation Grant by the residents that increases the retail sector revenue.

The upper and lower bound of the economic financial recovery can be observed through figures 4.76-4.78 via box plots. It can be observed that the shock itself creates the most disturbance in the market's equilibrium.

4.3.4.5. Residents Choices over the Different Insurance Companies – Three-Dimensional Vulnerability

Figure 4.79 illustrates the insurance policies choices of the residents, utilizing evolutionary game theory and Particle Swarm as social learning. Through the utilization of Particle Swarms as a social learning technique, residents changed their choices to increase their utility functions. It can be noticed from the previous analyses that in social standalone version the residents were a little indifference between the three insurance companies, as the SDRC's met all their needs, thus they are almost all equally the same. Meanwhile, through the economic standalone version, the residents tend to seek the second insurance company that provide great value for the premium paid. Finally, through the environmental standalone version, as the SDRC's budget did not meet the poor income families by not providing the Public Home Assistance, residents converged to the least premium insurance to decrease their losses.

It can be observed from Figure 4.64 that the residents tend to converge to the lowest cost insurer as in the environmental standalone version. This is due to the initial domination in the utilization of the Homeowner Assistance plan by the SDRC in the proposed model. That impacted

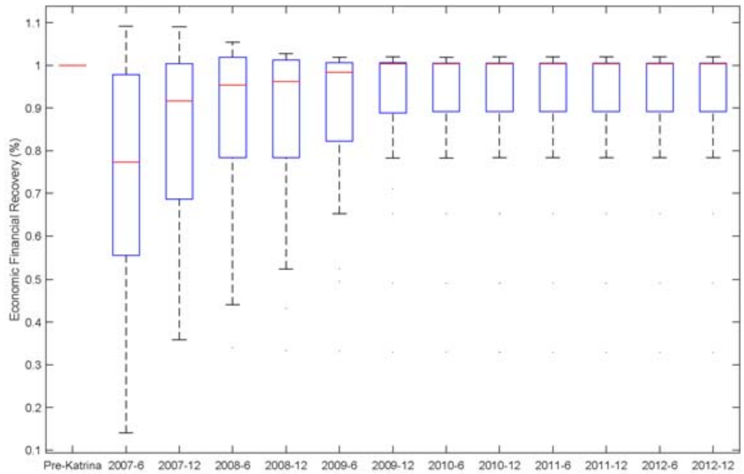

Figure 4.76: Hancock County Economic Recovery – Boxplot

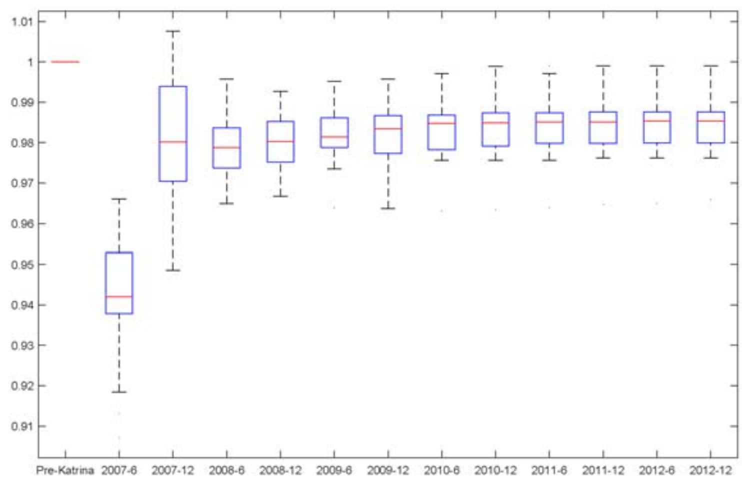

Figure 4.77: Harrison County Economic Recovery – Boxplot

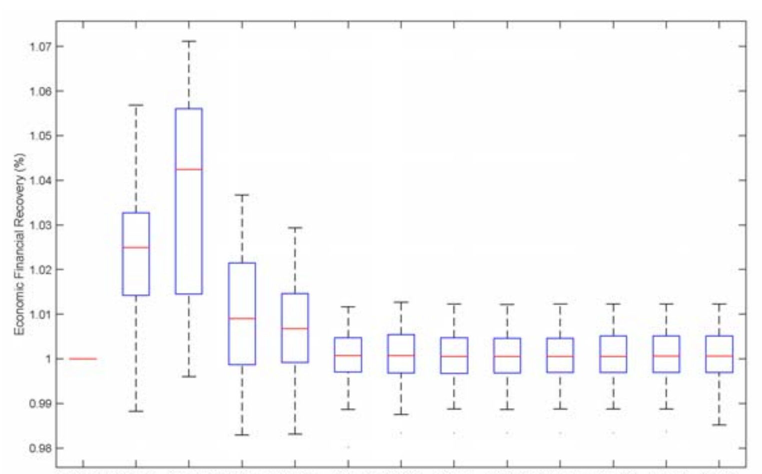

Figure 4.78: Jackson County Economic Recovery – Boxplot

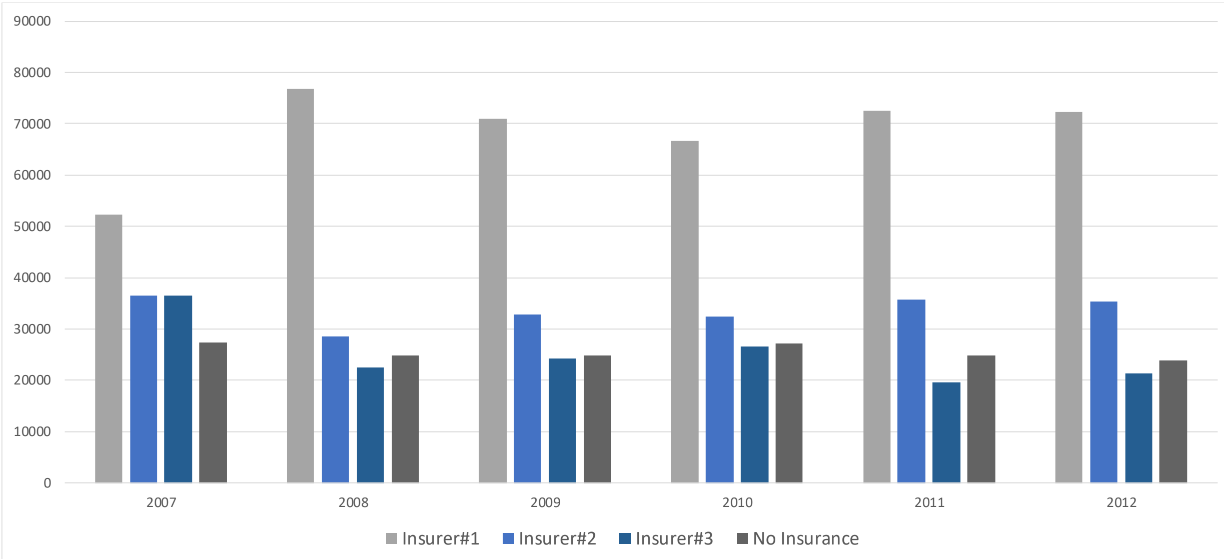

Figure 4.79: Residents' Choices over Different Insurance Options (Three-Dimensional Version)

the residents' recovery rate. As such, the residents with the lowest insurance premium costs, yet received the same government financial support, had better utility functions than the other residents. Moreover, all the residents who had insurance coverage were better off than the none-insured residents.

4.3.5. Model's Results with Different Budget Distribution Initial Conditions

The results discussed above assumed an initial uniform budget distribution for the SDRC. This assumption was made to provide the SDRC with equal and unbiased opportunity to learn the impact of each redevelopment plan (Eid and El-adaway 2016a). Such uniform initial condition does not always hold true. The initial budget of the SDRC may be dominated with one plan due either prior beliefs through the SDRC's past experiences, or due to current needs of the local community. Accordingly, multiple simulation scenarios were performed to investigate the impact of different initial conditions on the budget evolution of the SDRC, the recovery processes of the community and the vulnerability of the built environment.

Four initial conditions for the SDRC's budget were simulated. Each of them had one redevelopment plan dominating the other three. Table 4.18 presents the different initial conditions.

Table 4.18: Initial Conditions of the SDRC's Budget

Initial Condition	% Homeowner Assistance	% Public Home Assistance	% Elevation Grant	% Small Business Loan
Homeowner Assistance Dominated	80%	4%	4%	12%
Public Home Assistance Dominated	10%	60%	15%	15%
Elevation Grant Dominated	20%	5%	70%	5%
Small Business Loan Dominate	5%	15%	15%	65%

4.3.5.1. Budget Evolution of the SDRC

Figures 4.80-4.483 illustrate the budget distribution of the SDRC when utilizing each of initial condition. It can be noticed that regardless of the initial conditions, the SDRC converged to the same pattern in budget distribution, with the same final budget distribution across the different plans at the end of the simulation runs. This is due to the utilized individual learning module that enabled the SDRC to learn the impact of the different recovery plans and find the optimal distribution accordingly. Nevertheless, the budget distributions for the first two years were significantly different across the four scenarios. This is due to the different initial conditions of the budgets and the learning process of the SDRC. Such differences impacted the vulnerability of the built environment and the recovery processes of the residential and economic sectors, as discussed below.

4.3.5.2. Social Vulnerability

Figure 4.84-4.86 present a comparison between the different SDRC's initial conditions regarding the changes in the SoVI scores per county throughout the simulation runs. Each of the SDRC's initial conditions provided different outcomes for each of the three counties. The Small Business Loan Dominated initial conditions provided the best SoVI scores for Hancock County, while the Uniform Initial Conditions provided far better results for the populated county; Harrison County. Meanwhile, all the other three initial conditions provided better results for Jackson County regarding the SoVI final scores.

It can be also noticed the rate of change in SoVI scores. For the most populated county (Harrison), the community's SoVI rapidly decreased after the disastrous event when utilizing the

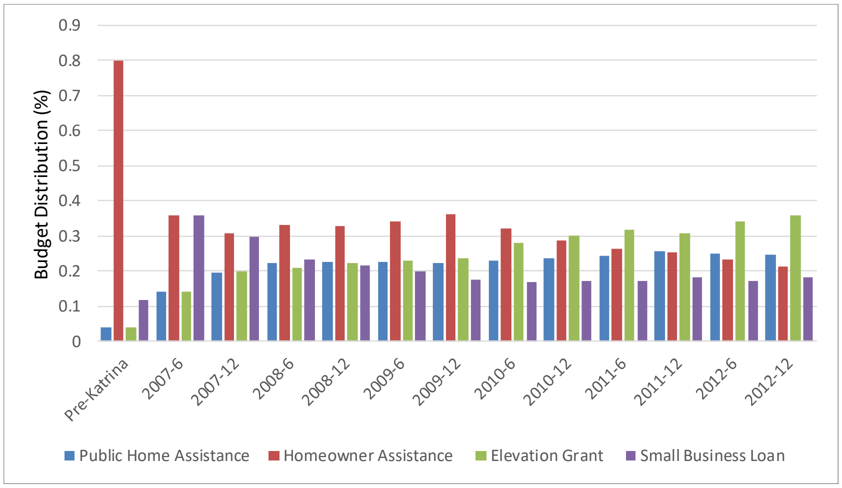

Figure 4.80: Homeowner Assistance Dominated as Initial Conditions

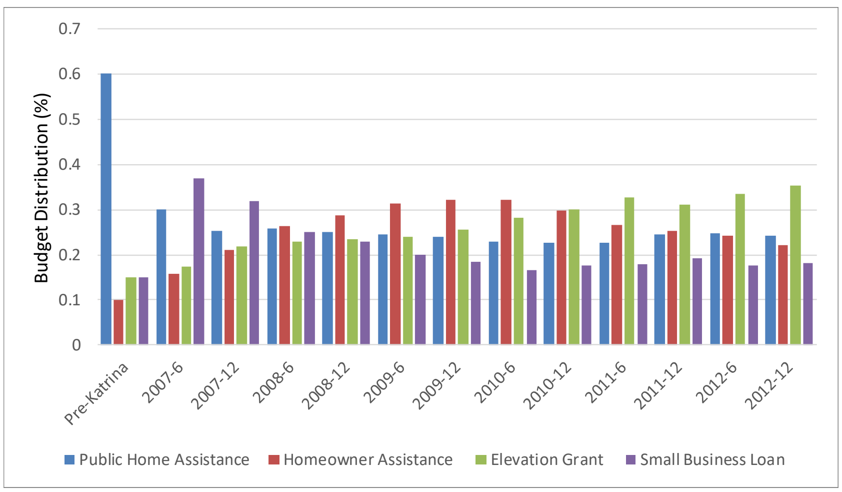

Figure 4.81: Public Home Assistance Dominated as Initial Conditions

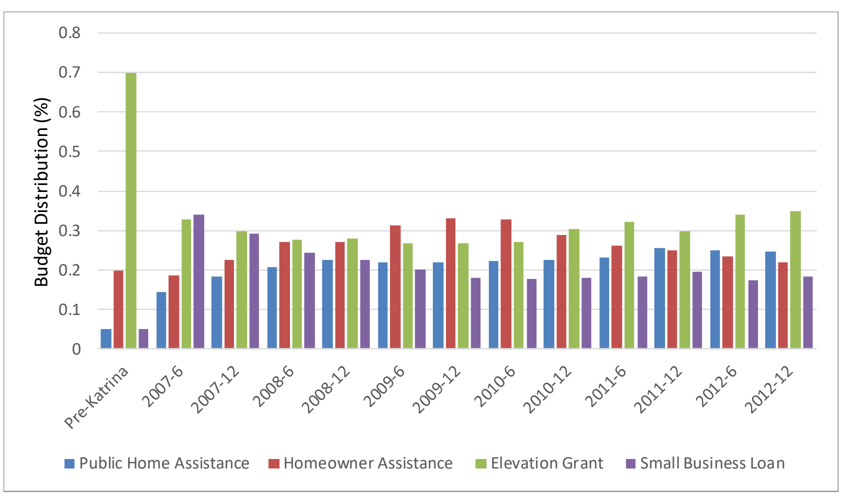

Figure 4.82: Elevation Grant Dominated as Initial Conditions

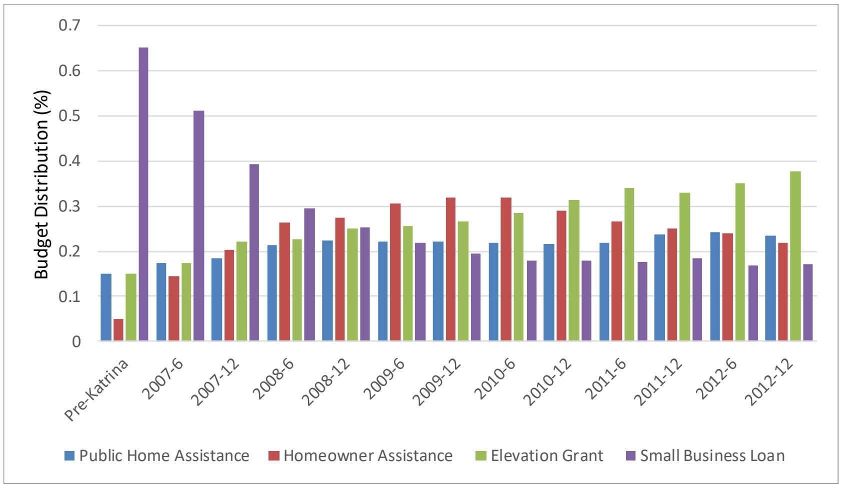

Figure 4.83: Small Business Loan Dominated as Initial Conditions

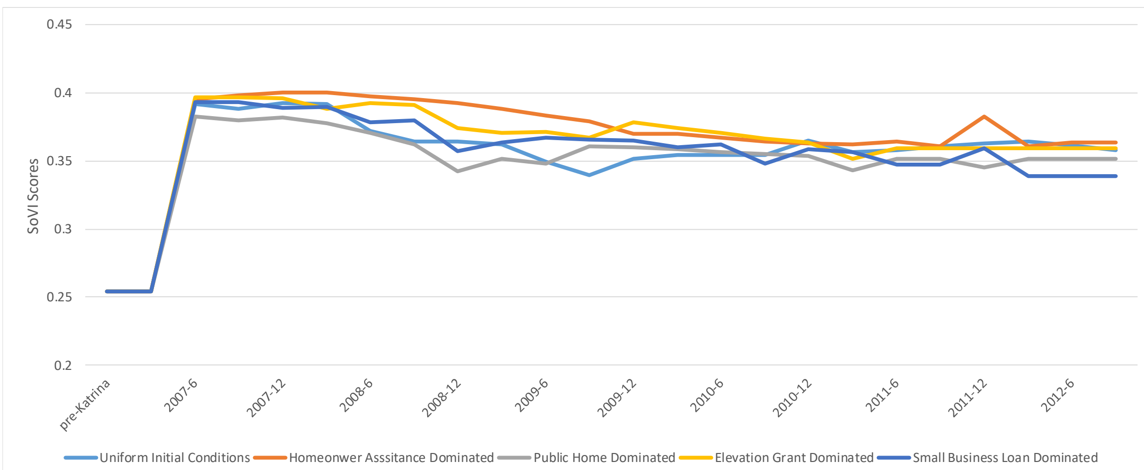

Figure 4.84: SoVI Scores Comparison for SDRC's Initial Conditions – Hancock County

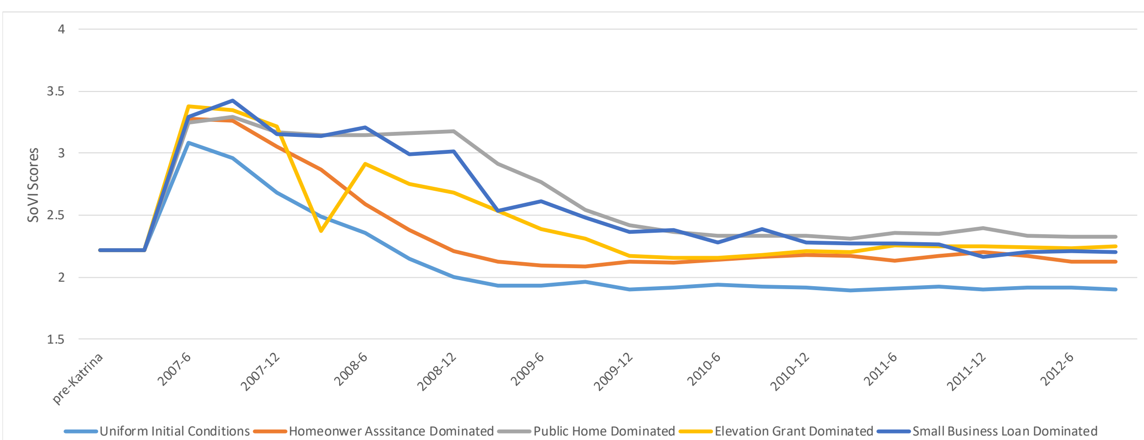

Figure 4.85: SoVI Scores Comparison for SDRC's Initial Conditions – Harrison County

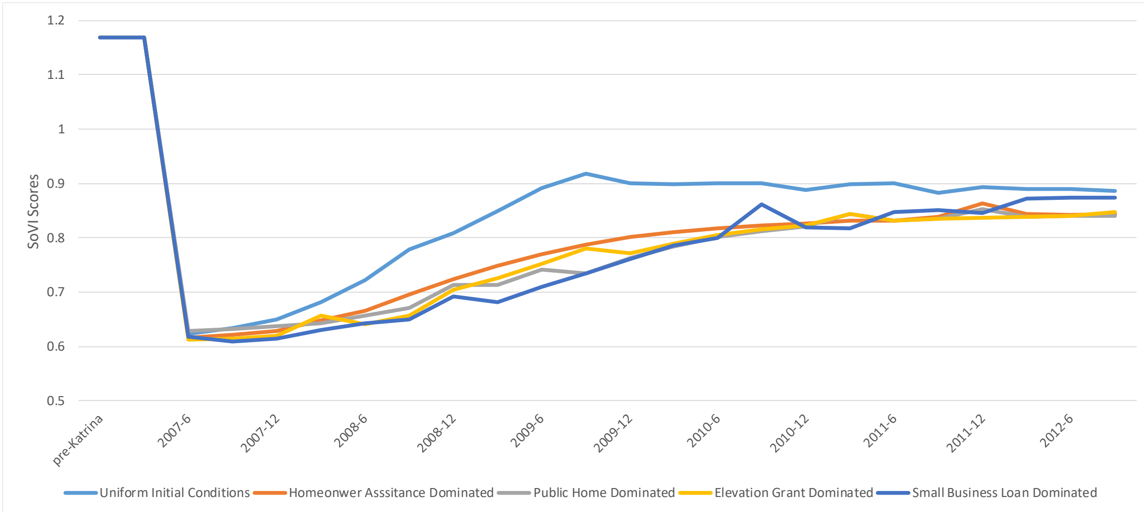

Figure 4.86: SoVI Scores Comparison for SDRC's Initial Conditions – Jackson County

Uniform initial conditions. This in contrast to Jackson county that increased their social vulnerability rapidly in comparison to the other initial conditions.

4.3.5.3. Economic Vulnerability

Figure 4.87-4.89 show a comparison between the different SDRC's initial conditions regarding the changes in the EconVI scores per county throughout the multiple simulation runs. Even though all the of the initial conditions of the SDRC's budget provided the similar outcome in Hancock county, the Uniform initial conditions provided significantly lower economic vulnerability for both Harrison and Jackson counties. Even though the Small Business Loan Dominated initial condition provided incentive to the economic agent to remain in the impacted region, it did not provide enough resources for the residential sector to recover, that ultimately negatively impacted the economic sector's revenue and financial recovery. This in return negatively impacted the economic vulnerability of the built environment.

4.3.5.4. Environmental Vulnerability

Figures 4.90-4.92 present a comparison between the different initial conditions regarding the changes in the EVI score per county. As this indicator is the least sensitive, in comparison to the other vulnerability indicators, the EVI scores did not change significantly across the different scenarios. However, a slight increase can be seen for the Public Home Dominated initial condition as it intensely utilized the Public Home Assistance plan in the first year, and thus created negative impact on the environmental vulnerability indicators through building new households on the existing vegetation cover.

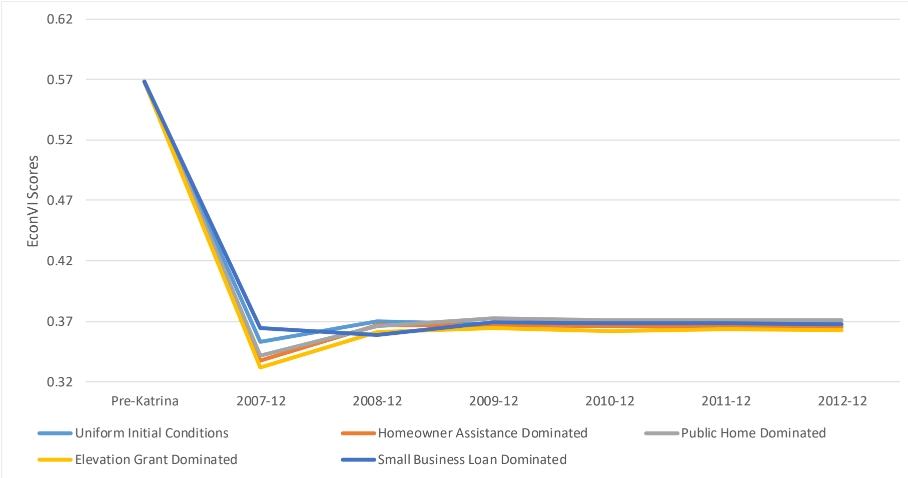

Figure 4.87: EconVI Scores Comparison for SDRC's Initial Conditions – Hancock County

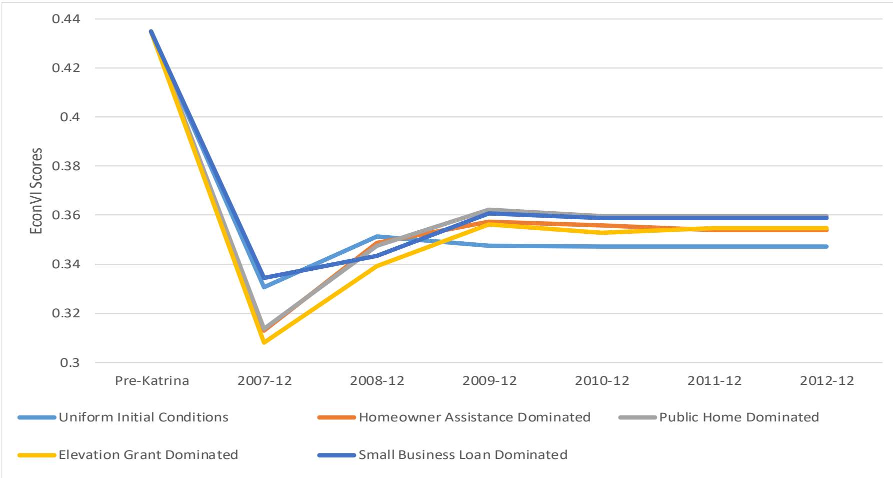

Figure 4.88: EconVI Scores Comparison for SDRC's Initial Conditions – Harrison County

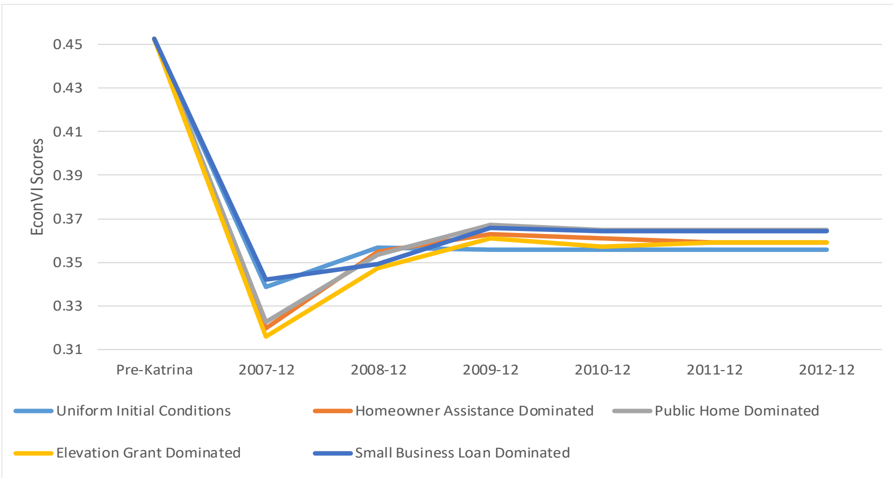

Figure 4.89: EconVI Scores Comparison for SDRC's Initial Conditions – Jackson County

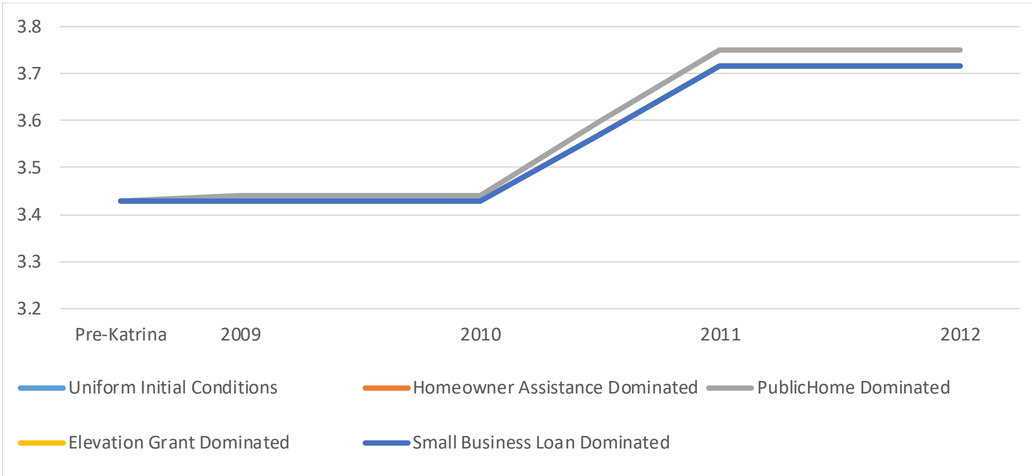

Figure 4.90: EVI Scores Comparison for SDRC's Initial Conditions – Hancock County

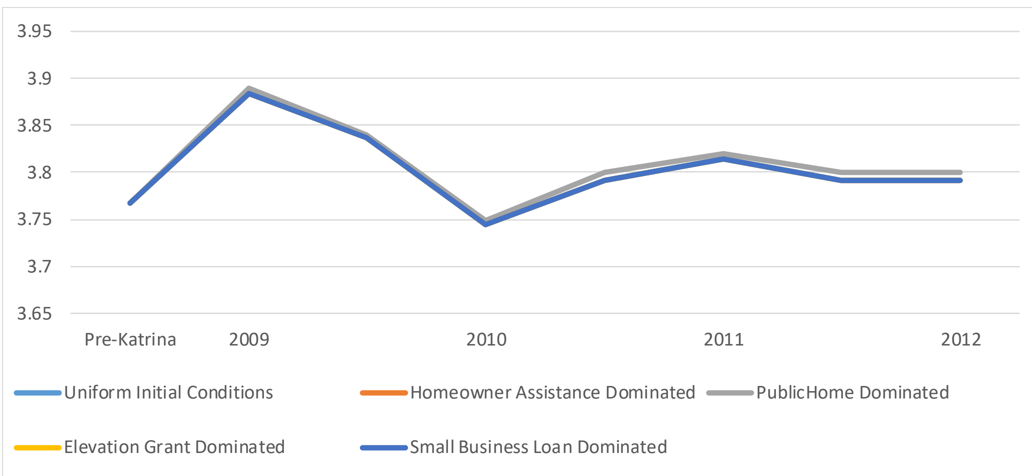

Figure 4.91: EVI Scores Comparison for SDRC's Initial Conditions – Harrison County

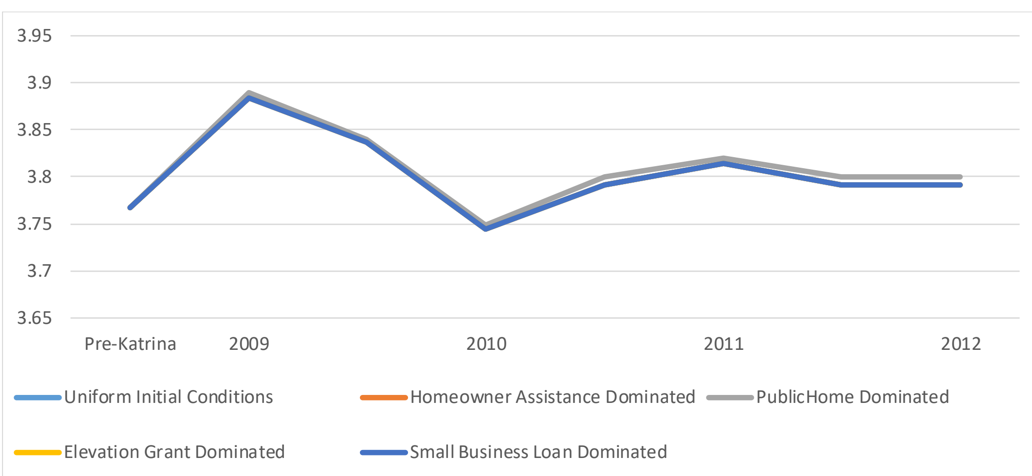

Figure 4.92: EVI Scores Comparison for SDRC's Initial Conditions – Jackson County

4.3.5.5. Residential Recovery

The impact of each of the initial conditions on the residential recovery per county is illustrated in Figures 4.93-4.95. All the initial conditions achieved the same final results regarding the residential recovery. This is due to integrating the residential utility functions within the SDRC's objective function, and allowing the SDRC to learn the optimal budget distribution to meet the residents' needs. However, the impact of the initial conditions can be observed regarding the rate of the residential recovery. The uniform initial condition achieved the highest rate in residential recovery. This is due to the unbiased distribution of the budget and allowing each strategy to be tested against its impact on the residential recovery. Meanwhile, as the model took time to learn and change the budget from the initial conditions to what meets the needs of the residents, the residential recovery rates for the other four initial conditions were not as high. It can also be observed that the Small Business Loan Dominated initial condition achieved the lowest rate in residential recovery across the three counties, even though the final recovery progress was similar to all the other initial conditions.

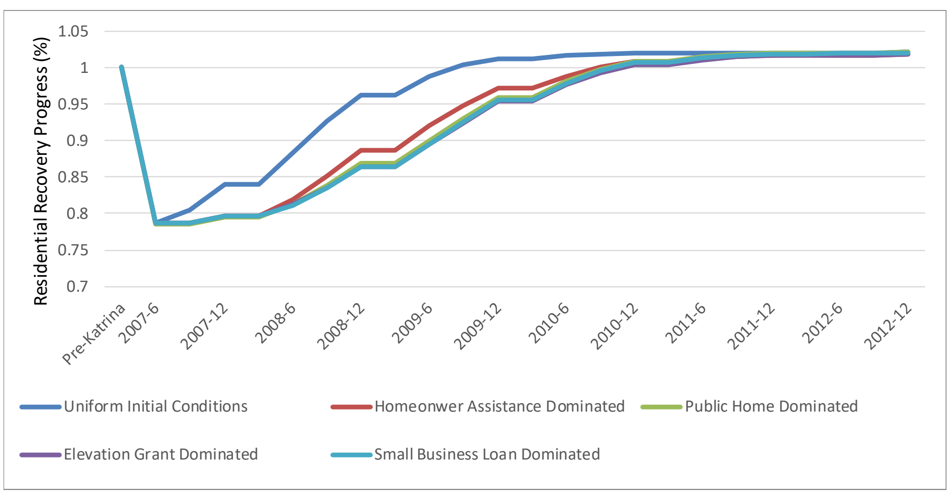

Figure 4.93: Residential Recovery Comparison for SDRC's Initial Conditions – Hancock County

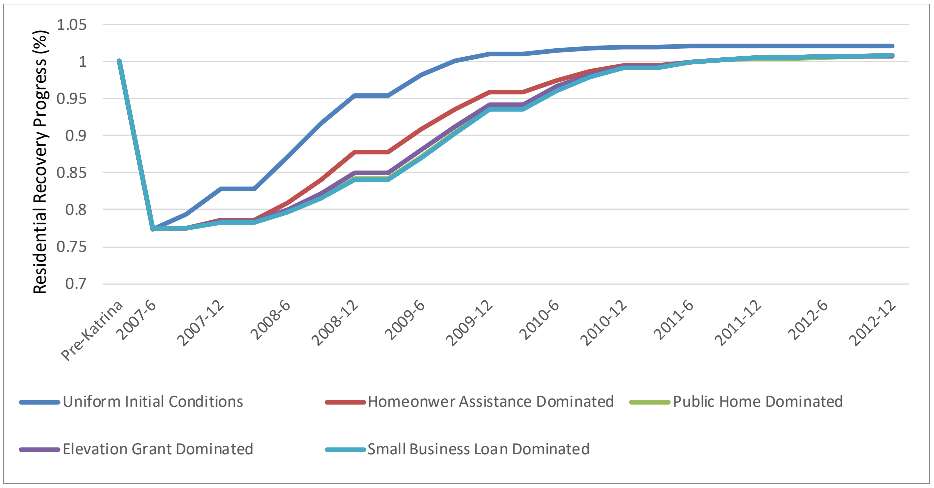

Figure 4.94: Residential Recovery Comparison for SDRC's Initial Conditions – Harrison County

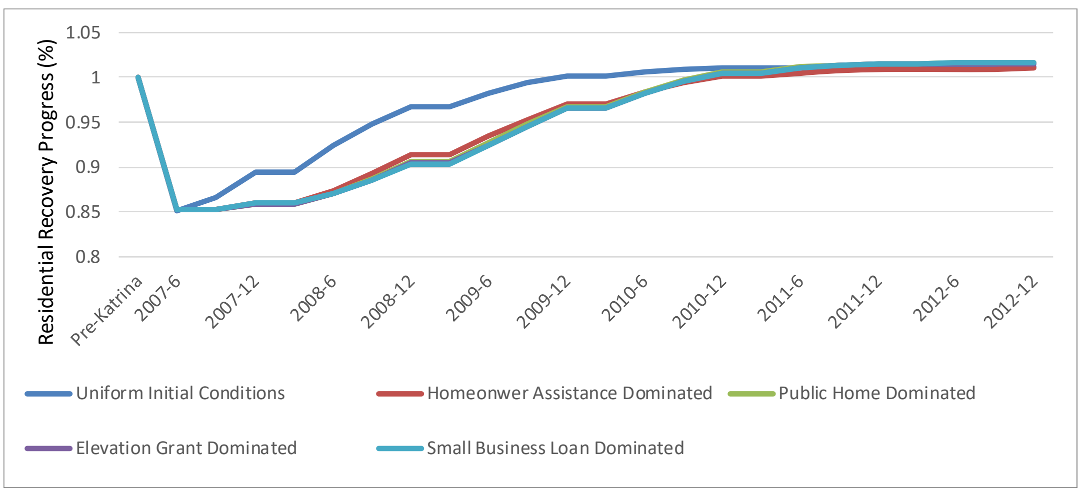

Figure 4.95: Residential Recovery Comparison for SDRC's Initial Conditions – Jackson County

4.3.5.6. Economic Recovery

Figures 4.96-4.98 compare the economic financial recovery per county for the different initial conditions. Through the comparison, the impact of the initial conditions can be observed on the rate of economic financial recovery as well as the final recovery progress. As the revenue of the economic agent is dependent on the net income of the residents, the economic financial recovery is highly impacted by the residential sector recovery.

The Small Business Loan Dominated initial condition incentivized more economic agents (+10% than the uniform initial condition) to remain in the impacted region. However, such initial condition did not provide better outcome for the residential sector recovery, as seen in the previous section (Figures 4.93-4.95). This low residential recovery rate decreased the rate of economic financial recovery, as the residents were not able to purchase enough goods/services from the economic agent due to the low recovery process. Meanwhile, the other initial conditions, and specifically the uniform initial condition, provided higher economic recovery rate within the first two years. Nevertheless, all the initial conditions reached similar final recovery progress across the three counties as the budget converged to the same final distribution.

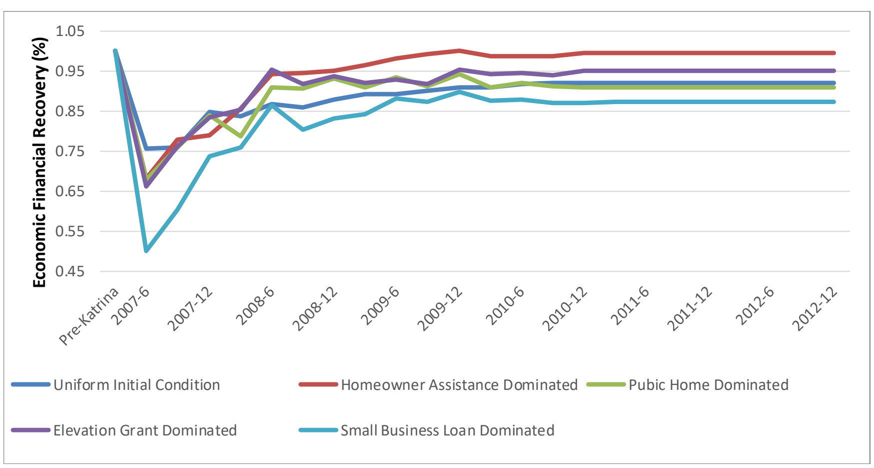

Figure 4.96: Financial Recovery Comparison for SDRC's Initial Conditions – Hancock County

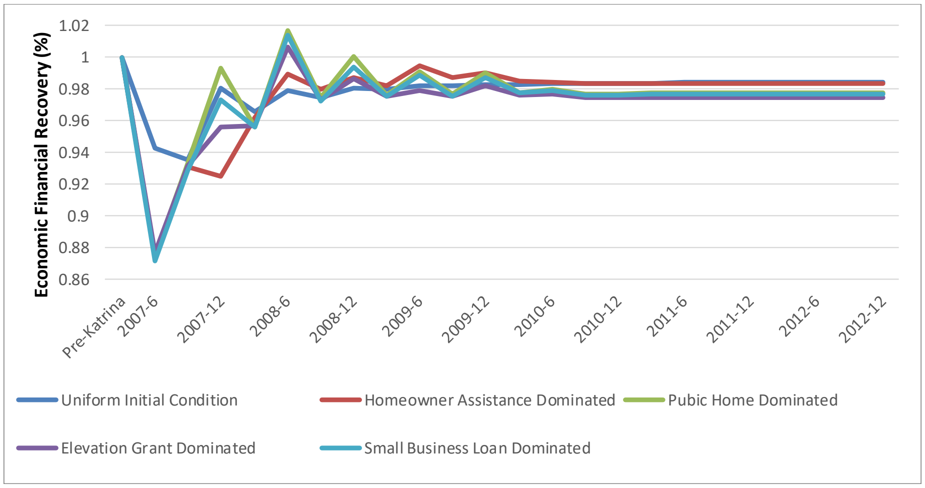

Figure 4.97: Financial Recovery Comparison for SDRC's Initial Conditions – Harrison County

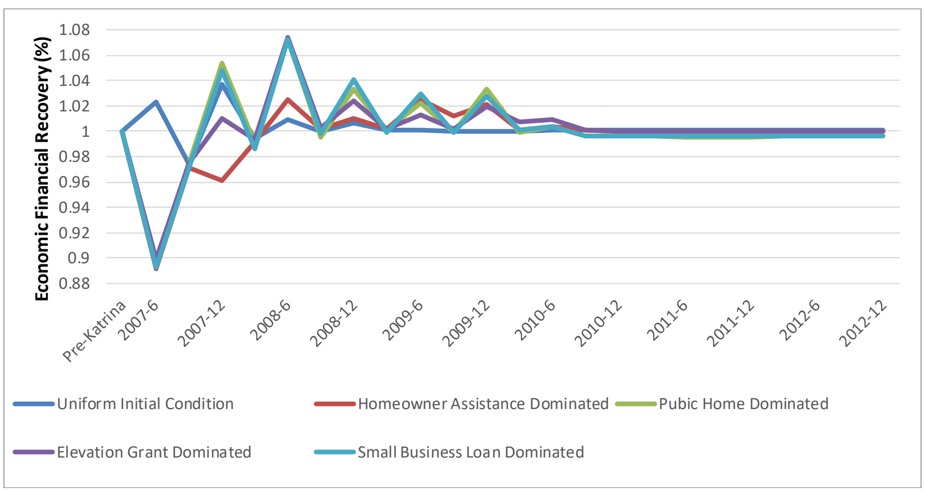

Figure 4.98: Financial Recovery Comparison for SDRC's Initial Conditions – Jackson County

4.4. General Discussion and Summary

Each disaster recovery and redevelopment plan have different effects on the residential and economic financial recovery and can provide positive and negative impact on the three-dimensional vulnerability of the host community. The effect and impact of the actions on the vulnerability and redevelopment of the community are discussed below.

The Homeowner Assistance plan has a significant impact on the residential recovery as it provides residents with the financial means to recover. Consequently, this plan impacts the social vulnerability of the community as it helps the residents to rebound to the pre-disaster conditions. This points out the importance of resourcefulness and adaptive capacity of the community to rebound back from shocks. Moreover, this plan does not have negative impact on the environmental vulnerability. However, the Homeowner Assistance plan does not contribute to the economic financial recovery and the economic vulnerability. In addition, it is unable to decrease the community's social vulnerability to future shocks.

On the other hand, Public Home Assistance plan aims to meet the needs of the low-income residents. As such, this plan increases the residential recovery rate through addressing a wider range of residents. Moreover, through meeting the needs of the poor income residents, the Public Home Assistance plan decreases the social vulnerability of the host community. In addition, this plan positively impacts the economic vulnerability indicator through increasing the retail sector revenue by building new households. However, this plan negatively impacts the environmental vulnerability by decreasing the vegetation cover.

The Elevation Grant increases the flood resilience of the households by elevating the households up to 6 feet and four inches (Eid and El-adaway 2016a). As such, additional resources will be used and would increase the household value in comparison to the pre-event conditions. Eventually, this will increase the overall residential recovery. More importantly, this will decrease the social vulnerability of the communities by increasing the households' value. Furthermore, the Elevation Grant does not have negative impact on the environmental vulnerability, however, it provides minimal positive impact on the economic vulnerability indicator.

Finally, the Small Business Loan only contributes to the economic financial recovery of the retail sector through incentivizing them to remain in the impacted region. Consequently, such plan contributes to the economic vulnerability of the host community through allowing the economic sector to rebound from the disaster economic shock.

From an infrastructure perspective, the WWTFs optimal utilization decreased the environmental vulnerability of the host community while meeting the population needs. Nevertheless, the proposed model did not account for the WWTFs' impact on the other vulnerability indicators. This is due to the lack of literature that backs up any claim of such sort. To this effect, it is believed that if such data on the impact of WWTFs (or any other infrastructure project) on the social and economic vulnerability indicators exists, their implementation will significantly change the model's outcome to meet the three-dimensional vulnerability. As can be observed from the existing conditions, a severally degraded environment, does not necessary means that it is socially vulnerable as well.

Table 4.19 summarizes the impact of each redevelopment plan on the different vulnerability indicators. The impact is color coded, where Red = high negative impact, Yellow = moderate negative impact, White = no impact, Green = moderate positive impact, and Blue = high positive impact.

Table 4.19: The Impact of the Redevelopment Plans on the Vulnerability Indicators

Vulnerability Dimension	Variables	Homeowner Assistance	Public Home Assistance	Elevation Grant	Small Business Loan	WWTFs
Social Vulnerability	Income					
	Median_House_Value					
	% High_Income					
	% With_Vehichles					
	%Phone					
	%Mobile_Home					
	%Home_Owneship					
	%Speak_English					
	%HighSchool					
	%Elderly					
	Median Age					
	%Female					
Economic Vulnerability	Percentage of Homeownership					
	Percentage of working age population that is employed					
	Percentage of female labor force participation					
	Per capita household income					
	Percentage of population not employed in primary industries					
	Mean sales volume of business					
	Ratio of large to small businesses					
	Retail center per 1,000 population					
	Commercial establishments per 1,000 population					
	Lending institutions per 1,000 population					
	Doctors and medical professionals per 1,000 population					
Environmental Vulnerability	Loss of cover					
	Terrestrial reserves					
	Vegetation Cover					
	Renewable water					
	Waste production					
	Waste treatment					
	Volcanos					
	Earthquakes					
	Tsunamis					
	Slides					

Table 4.19: The Impact of the Redevelopment Plans on the Vulnerability Indicators - Continued

Vulnerability Dimension	Variables	Homeowner Assistance	Public Home Assistance	Elevation Grant	Small Business Loan	WWTFs
Environmental Vulnerability	Sanitation					
	Vehicles					
	Population					
	Population growth					
	Environmental agreements					
	Land area					
	County dispersion					
	Isolation					
	Relief					
	Borders					
	Habitat fragmentation					-
	Coastal settlements					
	Conflicts					
	Biotechnology					

Through examining the results, it was found out that when accounting for only one vulnerability indicator, the model outcome significantly changes across the SDRC's decision actions, recovery outcome, and vulnerability indicators. For example, when accounting for only the social vulnerability indicator, the SDRC's budget was steered towards the Public Home Assistance plan and Elevation Grant. Those plans have compounded effect through increasing the recovery rate of the residential sector and decreasing the social vulnerability of the host community.

Meanwhile, when considering only the environmental vulnerability indicator, a significant and sudden decrease in the Public Home Assistance plan's share by the SDRC can be observed. This is due its adverse effect on the environmental vulnerability indicator through degrading the vegetation cover.

To this effect, the proposed model utilized Pareto Front sorting for the SDRC multi-objective optimization in redistributing the funds across the different plans. This approach aimed to equally meet the various complex objectives without subjective weighting criterion. As such, the proposed model provided a dynamically evolved Pareto optimal budget distribution that did not prioritize one objective over the others. Such solution can be considered as a compromise optimal solution that meets the stakeholders-driven objectives through gaining the most out of each recovery plan.

The effects of the utilized SDRC actions did not merely impact the residential and economic sector recovery and the three-dimensional vulnerability, but also significantly changed the residents' choice on insurers and insurance policies. It can be seen in the social vulnerability standalone version; the residents were indifferent when it came to selecting the insurance company, even though they avoided the "no insurance" strategy. The SDRC utilized actions drastically increased the recovery rates as such no significant relative fitness can be observed across the population. As such, no major learning happened at the social level.

Meanwhile, the economic and environmental vulnerability standalone versions presented different patterns. The utilized SDRC's then did not achieve the same level of recovery for the residential sector in the social vulnerability version, as such, the population attempted to mimic the fittest among them. To this end, the low premiums insurance policies achieved a bigger share at the end of the simulation runs.

The initial conditions of the SDRC's budget also impact the recovery progress (residential and economic sectors) and the vulnerability of the host community. A uniform initial budget distribution would provide the SDRC with the ability to learn the optimal budget distribution to be utilized to balance between the redevelopment of the community and their vulnerabilities to future events. Nevertheless, other initial conditions can be utilized depending on the SDRC's past experiences and prior knowledge.

It was observed through the results that even though a uniform initial condition provided better residential recovery rate, it did not provide better social or economic vulnerability in comparison to the other initial conditions across the three counties. As such, in order to define the optimal budget distribution, several initial conditions need to be utilized and evaluated, and then choose the one that best meet the needs of the community and their social, economic, and environmental vulnerability status.

This clearly points out the complexity and interdependency of the infrastructure redevelopment processes and how the different stakeholders are affected by it and in return impact the vulnerability of the built environment. As such, utilizing a decision action or strategy that does not holistically address the needs of the stakeholders and aims to achieve a more sustainable and less vulnerable built environment will only provide sub-optimal and unfavorable outcomes.

More importantly, it can be observed that integrating the vulnerability indicators into the stakeholders' objective functions create more effective decision making processes that dominates the other approaches.

To this effect, the presented research hypothesis provided a dominating holistic approach to maximize the welfare of the community through capitalizing the infrastructure redevelopment opportunities in order to elevate the society to a more sustainable and less vulnerable status.

CHAPTER FIVE

SUMMARY AND CONCLUSION

5.1. Research Summary

There is a dire need for a sustainable infrastructure development decision making framework that achieves holistic sustainability to the host communities. Such framework should aim to decrease the three-dimensional vulnerabilities of the built environment; social, economic, and environmental (Ingram et al. 2006, Pratt et al. 2004). Moreover, the involvement of the participating entities, in the infrastructure development planning phase, increases the individual utility of the associated stakeholders, thus increases the welfare generated from the infrastructure projects (Eid and El-adaway 2016a, Boz and El-adaway 2014, and Boz et. al 2014). However, the current development approaches rely on the available infrastructure sustainability rating tools that: (1) lack the comprehensive integration of vulnerability measurements, (2) neglect the interactions and preferences of the associated stakeholders,(3) focus on design alternatives and evaluations rather than the community sustainability and vulnerability, and (4) lack the holistic consideration of the sustainability and the important system details (Boz and El-adaway 2014, Haimes 2012, Guikema 2011; Guhnemann 2007; Hueting and Reijnders 2004).

As such, decision makers often fail to take into account the preferences and needs of the stakeholders in the decision-making processes of the infrastructure development. Moreover, the utilized infrastructure development strategies at the various government levels often lack the consideration for the sustainability and vulnerability of the communities to future shocks and perturbations. This left the infrastructure vulnerable and less sustainable to future events (Haimes 2012, Ingram et al. 2006).

To this effect, this research aimed to decrease the vulnerability of the built environment and increase its sustainability through an innovative holistic approach. The following research hypothesis was developed: integrating the interdependent relationships between the different vulnerability indicators and the objective functions of the associated stakeholders will result in more effective decision-making processes, increase the overall community welfare, and consequently, achieve a more sustainable civil infrastructure system.

In order to test the research hypothesis and develop a holistic decision making framework, this research tackled three objectives:

1. Measure the built environment social, economic, and environmental vulnerability based on the community-specific data
2. Capture the broad community relationship using the interdependency between the different vulnerability indicators and the objective functions of the associated stakeholders.
3. Create a holistic system approach to assess the infrastructure sustainability through the built environment and host community vulnerability.

The proposed framework utilized an agent based model (a bottom-up approach) to capture the objectives, decision actions, learning behaviors, and different attributes of the various stakeholders. Individual and social learning models were used to illustrate and mimic the learning behavior of the stakeholders of the host community. To model the complex interactions between the residential sector and the insurance companies, an evolutionary game theory was utilized. Furthermore, well-established community-specific vulnerability indicators were integrated into the objective functions of the stakeholders to better guide their decision-making processes to achieve sustainable infrastructure development. Finally, a multi-dimensional evaluation module was utilized to balance between the short-term community development objectives and the built environment vulnerability reduction goals.

This research adopted the post-Katrina infrastructure redevelopment activities for three Mississippi coastal counties, namely; Hancock, Harrison and Jackson. The utilization post-Katrina recovery as a problem domain is due to the accessibility of the required data to develop the associated stakeholders, their strategies and decision actions, in addition to measure the three-dimensional vulnerability assessments.

To test the research hypothesis, the outcome of the proposed framework was compared to null hypothesis tests. Through the tests, a simulation scenario (uniform budget distribution) was used where decision makers do not learn how to meet the needs of the stakeholders or decrease the vulnerability indicators. In addition, an actual budget distribution was also presented that shows the difference between the framework's outcome and the actual actions utilized by the government agencies.

The proposed framework outcome dominated both of the test scenarios (uniform and actual budget distribution) as well as the actual existing conditions, in regard to the redevelopment progress and vulnerability status of the host community.

5.2. Conclusion

It was observed through investigating the results obtained from the developed model that indeed each strategy has its different impacts on the welfare of the associated stakeholders and the vulnerability and sustainability of the community. Moreover, integrating the vulnerability indicators into the agents' decision making processes impacted the equilibria of the host community, and the vulnerability of the built environment. When accounting for only one vulnerability indicator (social, economic, or environmental), the stakeholders' decision actions significantly changed. For example, when utilizing only the social vulnerability indicator, the residents did not show any preference of one insurance company over the others. Meanwhile, when accounting for other indicators, drastic shift to the cheaper insurances was observed. This is contributed to the compounded effect of the Public Home Assistance and Elevation Grant on both the redevelopment of the residential sector and the social vulnerability indicator. This incentivized the SDRC to increase the share of those plans, which left the resident agents indifferent to the insurance policies, as the utilized government plans increased their recovery resources. This emphasizes that a strategy or a decision action that does not holistically address the needs of the stakeholders and aims to achieve a more sustainable and less vulnerable built environment will only provide sub-optimal and unfavorable outcomes.

Meanwhile, the proposed model was implemented on the infrastructure (Wastewater Treatment Facilities-WWTFs) redevelopment projects carried out by the Mississippi Development Authority after Hurricane Katrina. Due to the lack of reliable literature on the effects of such projects on the social and economic vulnerability indicators, it was found best to account for only the environmental vulnerability indicator. The proposed model provided an optimal WWTFs service allocations that would meet the needs of the residents while decreasing the environmental vulnerability of the host community. Nevertheless, it is believed that if data on the impact of WWTFs (or any other infrastructure project) on the social and economic vulnerability indicators exists, the vulnerability indicators implementation will significantly change the outcome of the model to meet the three-dimensional vulnerabilities and achieve a global optimal solution.

A comparison between the outcome of the framework (with the proposed decision making framework) and the actual and uniform budget distribution scenarios was carried out to test the research hypothesis. The outcome of the proposed model dominated the uniform budget distribution (null hypothesis) and the actual budget distribution. This is clearly observed in decreasing the social, environmental, and economic vulnerability of the three Mississippi coastal counties. Moreover, the proposed framework met the needs of the stakeholders and outperformed the other scenarios (with no integration of stakeholders needs and vulnerability indicators) regarding the redevelopment progresses.

To this effect, it can be concluded that the presented framework was able to prove the research hypothesis that integrating the interdependent relationships between the different vulnerability indicators and the objective functions of the associated stakeholders will result in more effective decision-making processes, increase the overall community welfare, and consequently, achieve a more sustainable civil infrastructure system.

5.3. Research Contribution

This research is distinctive from prior related research with respect to focus, purpose, and methods. A more advanced and comprehensive interdisciplinary framework is developed that integrated research methods from engineering, computer and social sciences. First, this project measured social, economic, and environmental vulnerability indicators as a function of community-specific data inputs. This enabled for a comprehensive understanding of the human-built environment vulnerability to shocks and perturbations. Second, this research employed game theory and learning algorithms within an agent-based modeling framework to capture the broad community relationships using the interdependency between the different vulnerability indicators and the objective functions of the associated stakeholders. This allowed for the development of a systems-based infrastructure decision-making processes that mutually satisfy short-term development objectives and long-term resilience goals. Thus, the proposed framework is able to determine the optimal sets of infrastructure development strategies that increase sustainability of the built environment and decrease the vulnerability of the associated host communities. Even though this research is applied using collected post-Katrina regional data related to three coastal counties in Mississippi; the research methodology is scalable and transferable for other applications both nationally and internationally.

Finally, the proposed research points out the dire need for implementing holistic decision making processes that do not compromise one objective over the others. Focusing on the development short-term objectives and keeping the long-term vulnerabilities of the communities out of focus creates an unsustainable built environment that is at risk to future perturbation. To this effect, utilizing the proposed decision making framework helps in balancing between our short-term objectives of development and long-term goals in resiliency and sustainability

5.4. Future Research Opportunities

The presented research was implemented on the post-Katrina infrastructure redevelopment of three counties in Mississippi. This opens the door for further implementation of the framework on other case studies across the nation (i.e. Hurricane Sandy, Hurricane Ike etc.). Such approach will furtherly validate the developed framework and research hypothesis. Apart from disaster related cases, the proposed model can be implemented on major infrastructure projects that impact the welfare and sustainability of the host community (i.e. dams, highways, airports, etc.). Further implementation of the model on private sector projects will be a major advancement, however this requires the availability of the data to initialize the model and evaluate the outcomes.

Moreover, for future work, the researcher aims to integrate other key stakeholders into the proposed model. Such stakeholders will include; reinsurance companies, different economic sectors, construction companies, contractors, etc. The aforementioned stakeholders affect the redevelopment progress in addition to the sustainability of the community. In addition, further development will be carried on the relationship between the different government agencies and the economic and residential sectors to capture the different negotiation processes. Future research will be carried out to investigate the impact of further decentralization of the decision-making processes on the welfare and vulnerability of the communities.

Future work will also account for the different limitation in the model in regard to the agents' assumptions and dynamics of built environment. The proposed model assumed the residential sector to have complete information when it comes to social learning, such assumption needs to be relaxed. Meanwhile, the economic sector and insurance companies were considered myopic agents and do not account for risk factors, which does not fully capture the dynamics of the host community. In regard to the built environment, the model does not account for vegetation cover growth, sudden change in population, etc. Such assumptions and limitations will be addressed in future work.

This research can also be extended through utilizing a top-down modeling approach (i.e., System Dynamics) to cross validate the research results. In addition, different hierarchy of the agents can be investigated to define the optimal government/social structure that effectively achieve sustainable infrastructure at the community level.

LIST OF REFERENCES

Ahmed, M., El-adaway, I.H., Coatney, K.T., and Eid, M.S. (2016). Construction Bidding and the Winner's Curse: Game Theory Approach. Journal of Construction Engineering and Management 142, 04015076.

Appadurai, A. (1984). How Moral is South Asia's Economy? A Review Article, Journal of Asian Studies, 43, 3, 481-497.

Arcand, J., Guillaumont, P. And Guillaumont Jeanneney, S. (2002). Ethnicity, communication and growth. In: CERDI Etudes et Documents (Clermont-Ferrand: CERDI).

Asgari, M. S., and Afshar, A. (2008). Modeling Subcontractors Cooperation in Time; Cooperative Game Theory Approach. First International Conference on Construction in Developing Countries (ICCIDC-I) "Advancing and Integrating Construction Education, Research & Practice", Karachi, Pakistan.

Axelrod, R. (1986). An Evolutionary Approach to Norms. American Political Science Review, 80(04), 1095–1111. doi:10.2307/1960858

Azar, E., & Menassa, C. C. (2011). Agent-Based Modeling of Occupants and Their Impact on Energy Use in Commercial Buildings. Journal of Computing in Civil Engineering, 26(4), 506–518. doi:10.1061/(ASCE)CP.1943-5487.0000158.

BREEAM. (2012). Retrieved March 16, 2012, from http://www.breeam.org/

Barnett, J., Lambert, S., & Fry, I. (2008). The Hazards of Indicators: Insights from the Environmental Vulnerability Index. Annals of the Association of American Geographers, 98(1), 102–119. doi:10.1080/00045600701734315

Becker, Gary S. (1962) "Irrational Behavior and Economic Theory". J.P.E. 70:1-13.

Blackburn, J. M. (1936). Acquisition of Skill: An Analysis of Learning Curves. IHRB Report No 73.

Blaikie, P., T. Cannon, I. Davis, and B. Wisner. 1994. At Risk: Natural Hazards, People's Vulnerability, and Disasters. London: Routledge.

Boz, M., and El-adaway, I. (2014) "Managing Sustainability Assessment of Civil Infrastructure Projects Using Work, Nature and Flow" Journal of Management in Engineering. Vol. 30 (5). 04014019.

Boz, M., El-adaway, I., and Eid, M. (2014) "A Systems Approach for Sustainability Assessment of Civil Infrastructure Projects Construction" Research Congress. May 2014, 444-453.

Breuer, M. (2005). "Multiple losses, ex ante moral hazard, and the implications for umbrella policies." Journal of Risk Insurance, 72(4), 525-538

Briguglio, L. (1997). Small island developing states and their economic vulnerabilities. SCOPE-SCIENTIFIC COMMITTEE ON PROBLEMS OF THE ENVIRONMENT INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS 58, 210–215.

Briguglio, L., Cordina, G., Farrugia, N., and Vella, S. (2009). Economic Vulnerability and Resilience: Concepts and Measurements. Oxford Development Studies 37, 229–247.

Brooks, N., Neil Adger, W., and Mick Kelly, P. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change 15, 151–163.

Bureau of Labor Statistics. (2014). "Consumer expenditures in 2012." ⟨http://www.bls.gov/cex/csxann12.pdf⟩ (Oct. 20, 2014).

Burton, C. G. (2010). Social vulnerability and hurricane impact modeling. Natural Hazards Review, 11(2), 58–68.

Burton, C.G. (2012). The Development of Metrics for community Resilience to Natural Disasters. University of South Carolina.

Burton, C.G. (2015). A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study. Annals of the Association of American Geographers 105, 67–86.

Carson, R. (2002). Silent Spring (Houghton Mifflin Harcourt).

CASBEE. (2012, February 8). Retrieved March 14, 2012, from http://www.ibec.or.jp/CASBEE/english/index.htm

Chandra, A., and Thompson, E. (2000). Does public infrastructure affect economic activity? Evidence from the rural interstate highway system. Regional Science and Urban Economics 30, 457–490.

Chang, S.E., & Miles, S. B. (2004). The dynamics of recovery: A framework. In Y. Okuyama & S. E. Chang (Eds.), Modeling spatial and economic impacts of disasters (pp. 181–204). Berlin: Springer-Verlag.

Cheng, R., and Jin, Y. (2015). A social learning particle swarm optimization algorithm for scalable optimization. Information Sciences 291, 43–60.

Cohen, I., Freiling, T., & Robinson, E. (2012). The economic impact and financing of infrastructure spending. Associated Equipment Distributors: Washington DC.

Consumer Expenditure Survey (2014). http://www.bls.gov/cex/

Cressman, R. (1996). Frequency-dependent stability for two-species interactions. Theoretical Population Biology 49, 189–210.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards*. Social Science Quarterly, 84(2), 242–261.

Cutter, S.L. (1993). Living with Risk: The Geography of Technological Hazards (E. Arnold).

Cutter, S. L., Emrich, C. T., Mitchell, J. T., Boruff, B. J., Gall, M., Schmidtlein, M. C., Melton, G. (2006). The long road home: Race, class, and recovery from Hurricane Katrina. Environment: Science and Policy for Sustainable Development, 48(2), 8–20.

Cutter, S.L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., and Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global Environmental Change 18, 598–606.

Daniell, KA, Kingsborough, AB, Malovka, DJ, Sommerville, HC, Foley, BA, & Maier, HR 2004, A Review of Sustainability Assessment for Housing Developments, Departmental Report No. R175, School of Civil and Environmental Engineering, The University of Adelaide, Adelaide, Australia, 30p. http://www.ecms.adelaide.edu.au/civeng/research/reports/docs/R175.pdf

Dawkins, R. (1976). The Selfish Gene (Oxford University Press), Oxford.

DeCoster, J. (1998). Overview of factor analysis.

De Waal, A. (1989). “Famine that Kills: Darfur, Sudan”. Clarendon, Oxford.

Doherty, N., and Smetters, K. (2005). “Moral hazard in reinsurance markets.” Journal of Risk and Insurance, 72(3), 375–391.

Dow, K. (1992) Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. Geoforum 23, 417-436.

Drew, D.S., and Skitmore, M. (2006). Testing Vickery's Revenue Equivalence Theory in Construction Auctions. Journal of Construction Engineering and Management 132, 425–428.

Dreze J., Sen, A. (1989) "Hunger and Public Action" Clarendon, London.

Du, J. and El-Gafy, M. (2012). " Virtual Organizational Imitation for Construction Enterprises: Agent-Based Simulation Framework for Exploring Human and Organizational Implications in Construction Management." J. Comput. Civ. Eng., 26(3), 282–297.

Economics of Climate Adaptation Working Group. (2009). "Shaping climate resilient development." A Rep. of the Economics of Climate Adaptation Working Group, Climate Works Foundation, Global Environment Facility, European Commission, McKinsey and Company, The Rockefeller Foundation, Standard Chartered Bank, and Swiss Re., Zurich, Switzerland.

El-adaway, I., and Kandil, A. (2009). "Multiagent System for Construction Dispute Resolution (MAS-COR)."J. Constr. Eng. Manage., 136(3), 303–315.

El-Anwar, O., Ye, J., and Orabi, W. (2015). Efficient Optimization of Post-Disaster Reconstruction of Transportation Networks. Journal of Computing in Civil Engineering 04015047.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2010). Maximizing the Sustainability of Integrated Housing Recovery Efforts. Journal of Construction Engineering and Management 136, 794–802.

Elbeltagi, E. Hegazy, T. and Grierson, D. (2005), "Comparison among five evolutionary-based optimization algorithms", Advanced Engineering Informatics, 19, 43-53.

Elbeltagi, E., Hegazy, T., and Grierson, D. (2010). "A New Evolutionary Strategy for Pareto Multi- Objective Optimization." Proceedings of the Seventh International Conference on Engineering Computational Technology, B.H.V. Topping, J.M. Adam, F.J. Pallares, R. Bru and M.L. Romero, (Editors), Civil-Comp Press, Stirlingshire, Scotland, Paper Ref. 19, Sep. 14-17

Elbeltagi, E.E. (2013). 20 - Swarm Intelligence for Large-Scale Optimization in Construction Management A2 - Alavi, Amir Hossein Gandomi Xin-She Yang Siamak TalatahariAmir Hossein. In Metaheuristic Applications in Structures and Infrastructures, (Oxford: Elsevier), pp. 479–495.

Eid, M., Abdelrazek, M., and Elbeltagi, E. (2012). Multi-objective repetitive activities projects scheduling using Genetic Algorithms. In Advances in Civil Engineering and Building Materials, S.-Y. Chang, S. Bahar, and J. Zhao, eds. (CRC Press), pp. 331–335.

Eid, M., El-adaway, I., Coatney, K. (2015). "Evolutionary stable strategy for post-disaster insurance: a game theory approach" Journal of Management in Engineering.

Eid, M., and El-adaway, I. (2016a) "Sustainable Disaster Recovery: Multi-Agent Based Model for Integrating Environmental Vulnerability into Decision Making Processes of the Associated Stakeholders", Journal of Urban Planning and Development, American Society of Civil Engineers, 10.1061/(ASCE)UP.1943-5444.0000349 , 04016022.

Eid, M., and El-adaway, I. (2016b) "Sustainable Disaster Recovery Decision-Making Support Tool: Integrating Economic Vulnerability into the Objective Functions of the Associated

Stakeholders", Journal of Management in Engineering, American Society of Civil Engineers, 10.1061/(ASCE)ME.1943-5479.0000487 , 04016041.

Engineering is Elementary® (EiE), http://www.mos.org/eie/, accessed: March 10, 2012.

Environment Waikato, (2003). Regional Ecological Footprint. Waikato Regional Council, Hamilton East, New Zealand.

ENVISION Sustainability Rating System. (2012). Retrieved 11 11, 2012, from Institute for Sustainable Infrastructure: http://www.sustainableinfrastructure.org/rating/index.cfm

Environmental Sustainability Index (2005): Benchmarking National Environmental Stewardship. Appendix A: Methodology

EPA Victoria, (2003). EPA Victoria and Eco-footprint. Environment Protection Authority, Victoria.

Epstein, J. M. (2001). Learning to be thoughtless: Social norms and individual computation. Computational Economics, 18(1), 9–24.

Epstein, J. M. (2002). Modeling civil violence: An agent-based computational approach. Proceedings of the National Academy of Sciences, 99(suppl 3), 7243–7250.

Erev, I., & Roth, A. E. (1998). "Predicting How People Play Games: Reinforcement Learning in Experimental Games with Unique, Mixed Strategy Equilibria". The American Economic Review, 88(4), 848–881.

Esty, D., Levy, M., Srebotnjak, T. Sherbinin, A., (2005). 2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship. New Haven: Yale Center for Environmental Law and Policy.

European Commission, DG Environment. (2012). “Assessment of resource efficiency indicators and targets: Final report. A report by BIO Intelligence Service (BIO), Institute for Social Ecology (SEC) and Sustainable Europe Research Institute (SERI).

Farmer, J. D., Patelli, P., & Zovko, I. I. (2005). The predictive power of zero intelligence in financial markets. Proceedings of the National Academy of Sciences of the United States of America, 102(6), 2254–2259.

Federal Highway Administration (2014). “Transpiration and Housing Costs: Combined Transpiration and Housing Decisions Saves Money and Build Wealth”. http://www.fhwa.dot.gov/livability/fact_sheets/transandhousing.cfm

Ferdinand, A. and Yu, D. (2014). "Sustainable Urban Redevelopment: Assessing the Impact of Third-Party Rating Systems." J. Urban Plann. Dev., 10.1061/(ASCE)UP.1943-5444.0000271, 05014033.

Ferng, J.J., 2002. Toward a scenario analysis framework for energy footprints. Ecological Economics 40, 159-172.

Fiedrich, F., and Burghardt, P. (2007). Agent-based Systems for Disaster Management. Commun. ACM 50, 41–42.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., and Walker, B. (2002). Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. AMBIO: A Journal of the Human Environment 31, 437–440.

Friedman, D. (1998). On economic applications of evolutionary game theory. Journal of Evolutionary Economics, 8(1), 15–43.

Georg, S. (1999). The social shaping of household consumption. Ecological Economics 28, 455–466.

Gibbons, R. (1992). Game Theory for Applied Economists (Princeton University Press).

Gilman, R., (1992), Sustainability, from the 1992 UIA/AIA "Call for Sustainable Community Solutions". Available at: http://www.context.org/ICLIB/DEFS/AIADef.html, 04/02/03.

Glumac, B., Han, Q., and Schaefer, W. (2015). Actors' Preferences in the Redevelopment of Brownfield: Latent Class Model. Journal of Urban Planning and Development 141, 04014017.

Gode, D.K., and Sunder, S. (1993). Allocative efficiency of markets with zero-intelligence traders: Market as a partial substitute for individual rationality. Journal of Political Economy 119–137.

Goffe, W.L., Ferrier, G.D., and Rogers, J. (1994). Global optimization of statistical functions with simulated annealing. Journal of Econometrics 60, 65–99.

Godschalk, D.R. (2003). Urban Hazard Mitigation: Creating Resilient Cities. Natural Hazards Review 4, 136–143.

Granovetter, Mark (1978) Thereshold Models of Collective Behavior. The American Journal of Sociology. Vol. 83, No.6,1420-1443.

Greenberg, M.R., and Issa, L. (2005). Measuring the success of the federal government's Brownfields Program. Remediation 15, 83–94.

Greene, D., (1997), Towards Sustainable Engineering Practice, Engineering Frameworks for Sustainability, The Institution of Engineers, Australia.

Greenwald, A.R., and Kephart, J.O. (1999). Shopbots and pricebots. In International Workshop on Agent-Mediated Electronic Commerce, (Springer Berlin Heidelberg), pp. 1–23.

Guikema, S. (2011), Integrated Modeling of Sustainability and Reliability for Interdependent Infrastructure Systems, John Hopkins University.

Guillaumont, P. (2009). An Economic Vulnerability Index: Its Design and Use for International Development Policy. Oxford Development Studies 37, 193–228.

Haimes, Yacov. Y. (2012). Systems-Based Approach to Preparedness for, Response to, and Recovery from Natural and Human-Made Disasters. Leadership and Management in Engineering, 12(4), 288–298.

HAZUS-MH [Computer software]. Washington, DC, Federal Emergency Management Agency.

Hegazy, T., and Ayed, A. (1999) “Simplified spreadsheet solutions: Models for critical path method and time-cost trade-off analyses.” Cost Eng. J. 41(7), 26-33.

Heijungs, R., Huppes, G., & Guinee, J. B. (2010). Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis. Polymer Degradation and Stability, 422-428.

Herendeen, R.A., 2000. Ecological footprint is a vivid indicator of indirect effects. Ecological Economics. 32, 357-358.

Ho, S. P., and Hsu, Y. (2014). Bid Compensation Theory and Strategies for Projects with Heterogeneous Bidders: A Game Theoretic Analysis. Journal of Management in Engineering, 30(5), 04014022.

Ho, S. P. (2005) Bid Compensation Decision Model for Projects with Costly Bid Preparation. Journal of Construction Engineering and Management, ASCE, 131(2), 151-159.

Ho, S. P. (2001). Real Options and Game Theoretic Valuation, Financing, and Tendering for Investments on Build-Operate-Transfer Projects. PhD thesis, Dept. Of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Ill.

Hofbauer, Josef and Sigmund, Karl. (2003), "Evolutionary Game Dynamics", Bulletin of the American Mathematical Society. Volume 40, pages 479-519.

Holland, J. H. (1975), "Adaptation in natural and artificial systems", University of Michigan Press, Ann Arbor, Mich.

Holling, C.S. (1973). Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics 4, 1–23.

Hueting, R., and Reijnders, L. Borad sustainability contra sustainability: the proper construction of sustainability indicators. Ecological Economics 50, 249–260.

Hyari, K. and El-Rayes, K. 2006, Optimal Planning and Scheduling for Repetitive Construction Projects. Journal of Management in Engineering. 22: 11-19.

Ingram, J.C., Franco, G., Rio, C.R., and Khazai, B. (2006). Post-disaster recovery dilemmas: challenges in balancing short-term and long-term needs for vulnerability reduction. Environmental Science & Policy 9, 607–613.

Janssen, M., and Karamychev, V. (2005), "Dynamic insurance contracts and adverse selection." Journal of Risk and Insurance, 72(1) 45–59.

Johnson, R., and Wichern, D. (1998). Applied Multivariate Statistical Analysis, 6th Edition (Pearson).

Kennedy J, Eberhart R. (1995) Particle Swarm Optimization. Proceedings of the IEEE International Conference on Neural Networks (Perth, Australia), 1942-1948. Piscataway, NJ: IEEE Service Center.

Kweku-Muata (Noel) Bryson, Harvey Millar, Anito Joseph, Ayodele Mobolurin, Using formal MS/OR modeling to support disaster recovery planning, European Journal of Operational Research, Volume 141, Issue 3, 16 September 2002, Pages 679-688, ISSN 0377-2217, http://dx.doi.org/10.1016/S0377-2217(01)00275-2. (http://www.sciencedirect.com/science/article/pii/S0377221701002752).

Lee, J.-S., Filatova, T., Ligmann-Zielinska, A., Hassani-Mahmooei, B., Stonedahl, F., Lorscheid, I., Voinov, A., Polhill, J.G., Sun, Z., and Parker, D.C. (2015). The Complexities of Agent-Based Modeling Output Analysis. Journal of Artificial Societies and Social Simulation 18(4), 4.

Lee, R. (2011). "The outlook for population growth." Science, 333 (6042), 569-573.

Lee, W., and Ligon J. A., (2001). "Moral hazard in risk pooling arrangements." Journal of Risk and Insurance, 68(1), 175–190

Li, H., and Love, P. (1997) "Using improved genetic algorithms to facilitate time-cost optimization", Journal of Construction Engineering and Management, 123(3), 233–237.

Li, Xia and Liu, Xiaoping, (2008). "Embedding sustainable development strategies in agent-based models for use as a planning tool". International Journal of Geographical Information Science. 22:1, 21-45.

Lim, G., Zangeneh, S., and Kim, S.J. Clustering Approach for Defining Hurricane Evacuation Zones. Journal of Urban Planning and Development 0, 04016008.

Lorscheid, I., Heine, B.-O. & Meyer, M. (2012). Opening the 'black box of simulations: Increased transparency and effective communication through the systematic design of experiments. Computational and Mathematical Organization Theory, 18(1), 22–62. [doi:10.1007/s10588-011-9097-3]

Macy, M. W., & Willer, R. (2002). F ROM F ACTORS TO A CTORS : Computational Sociology and Agent-Based Modeling. Annual Review of Sociology, 28(1), 143–166. doi:10.1146/annurev.soc.28.110601.141117

Manson, S. M., & Evans, T. (2007). Agent-based modeling of deforestation in southern Yucatán, Mexico, and reforestation in the Midwest United States. Proceedings of the National Academy of Sciences, 104(52), 20678–20683.

McGregor, P.G., Swales, J.K., Turner, K.R., (2004). The impact of Scottish consumption on the local environment: an alternative to the Ecological Footprint? Quarterly Economic Commentary – Economic perspectives. Vol. 29. Fraser of Allander Institute, University of Strathclyde, Glasgow. 29-34.

Mileti, D. (1999). Disasters by design: A reassessment of natural hazards in the United States. Washington, DC: Joseph Henry Press.

Miles, Scott B. and Chang, Stephanie E. (2003). Urban Disaster Recovery: A Framework and Simulation Model, MCEER Technical Report 03-0005, Multidisciplinary Center for Earthquake Engineering Research, Buffalo, NY.

Miles, Scott B. and Chang, Stephanie E. (2004). Foundations for modeling community recovery from earthquake disasters, proceedings, 13th World Conference on Earthquake Engineering, Vancouver, Canada, paper No. 567

Miles, Scott B. and Chang, Stephanie E. (2006) Modeling Community Recovery from Earthquakes. Earthquake Spectra: May 2006, Vol. 22, No. 2, pp. 439-458.

Miles, Scott B., and Chang, Stephanie E. (2011). ResilUS: a community based disaster resilience model. Cartography and Geographic Information Science 38, 36–51.

Miller, J. H., & Page, S. E. (2004). The standing ovation problem. Complexity, 9(5), 8–16.

Mills, E. (2007). "From Risk to Opportunity: 2007 – Insurers Responses to Climate Change". Ceres Report, October. Ceres, Boston,MA.

Mississippi Automated Resource Information System (2015) < http://www.maris.state.ms.us/>

Mississippi Development Authority (2015). Mississippi Disaster Recovery Division website, http://www.msdisasterrecovery.com/federal-reporting

Mitchell, J.K. (1989). Hazards Research. In Gaile, G.L. and Willmott, C.J., editors, Geography in America, Columbus, OH. Merrill, 410-24.

Moffatt, I., (2000) Ecological footprints and sustainable development. Ecological Economics 32, 359-362.

Moon, H., Kim, H., Kamat, V.R., and Kang, L. (2013). BIM-Based Construction Scheduling Method Using Optimization Theory for Reducing Activity Overlaps. Journal of Computing in Civil Engineering.

Mostafavi, A., Abraham, D., DeLaurentis, D., Sinfield, J., Kandil, A., and Queiroz, C. (2015). "Agent-Based Simulation Model for Assessment of Financing Scenarios in Highway Transportation Infrastructure Systems." J. Comput. Civ. Eng.10.1061/(ASCE)CP.1943-5487.0000482, 04015012.

Myerson, R.B. (1991). Game Theory (Harvard University Press).

National Agricultural Statistics Service (2015). U.S. Department of Agriculture. < https://www.nass.usda.gov/>

National Disaster Recovery Framework, (2011). “National Disaster Recovery Framework, Strengthening Disaster Recovery for the Nation”. Federal Emergency Management Agency (FEMA)

National Land Cover Database (2015). Multi-Resolution Land Characteristics Consortium, U.S. Department of the Interior <http://www.mrlc.gov/>

National Research Council (U.S.), Committee on Disaster Research in the Social Sciences: Future Challenges and Opportunities, National Research Council (U.S.), and Division on Earth and Life Studies (2006). Facing hazards and disasters understanding human dimensions (Washington, D.C.: National Academies Press).

Nelson, D.R., Adger, W.N., and Brown, K. (2007). Adaptation to Environmental Change: Contributions of a Resilience Framework. Annual Review of Environment and Resources 32, 395–419.

NetBeans IDE 7.4, Sun Microsystems, Santa Clara, California, USA, accessed: October 15, 2013.

NRG4SD (2004). International Seminar on Sustainable Development Indicators – Bases for developing common indicators at a regional level. Network of Regional Governments for Sustainable Development (NRG4SD), ENCORE, Basque Government; Carlton Hotel, Bilbao, Basque Country, November 9-10 2004.

NYSDOT. (2012). 2012 GreenLITES Draft Operations Certification Program. New York State Department of Transportation.

Oca, M.A.M. de, Stutzle, T., Enden, K.V. den, and Dorigo, M. (2011). Incremental Social Learning in Particle Swarms. IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) 41, 368–384.

Olshansky, Rober B., Johnson, Laurie A and Topping, Kenneth C (2006). Rebuilding Communities Following Disaster: Lessons from Kober and Los Angeles. Built Environment, Vol. 32, No. 4, December 29, 2006, pp. 354-474.

Olshansky (2006). Planning After Hurricane Katrina. Journal or the American Planning Association. Vol. 72, No. 2, 2006, pp. 147-153.

Olshansky, R. B., Hopkins, L. D., & Johnson, L. A. (2012). Disaster and Recovery: Processes Compressed in Time. Natural Hazards Review, 13(3), 173–178.

Orabi, W., Senouci, A.B., El-Rayes, K., and Al-Derham, H. (2010). Optimizing Resource Utilization during the Recovery of Civil Infrastructure Systems. Journal of Management in Engineering 26, 237–246.

Othman, A. (2008). Zero-intelligence agents in prediction markets. In Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems-Volume 2 (pp.

879–886). International Foundation for Autonomous Agents and Multiagent Systems. Retrieved from http://dl.acm.org/citation.cfm?id=1402346

Padgham, L. and Winikoff, M. (2004). "Developing Intelligent Agent Systems", John Wiley & Sons, UK.

Peña-Mora, F., and Chun-Yi, W. (1998). "Computer supported collaborative negotiation methodology." J. Comput. Civ. Eng., 12 (2), 64–81.

Pradhan, A., Laefer, D., and Rasdorf, W. (2007). "Infrastructure Management Information System Framework Requirements for Disasters." J. Comput. Civ. Eng., 10.1061/(ASCE)0887-3801(2007)21:2(90), 90-101.

Pratt, C.R., Kaly, U.L., and Mitchell, J. 2004. Manual: How to Use the Environmental Vulnerability Index (EVI). SOPAC Technical Report 383, United Nations Environment Programme (UNEP). South Pacific Applied Geoscience Commission (SOPAC).

Radhakrishnan, B.M., Srinivasan, D., Lau, Y.F.A., Parasumanna, B.G., Rathore, A.K., Panda, S.K., and Khambadkone, A. (2015). A reinforcement learning algorithm for Agent-based Computational Economics (ACE) model of electricity markets. In 2015 IEEE Congress on Evolutionary Computation (CEC), pp. 297–303.

Railsback, S.F., Lytinen, S.L., and Jackson, S.K. (2006). Agent-based Simulation Platforms: Review and Development Recommendations. SIMULATION 82, 609–623.

Riechmann, T. (2001). "Genetic algorithm learning and evolutionary games". Journal of Economic Dynamics and Control, 25(6), 1019–1037.

Ribot, Jesse, C. (1995). "The Causal Structure of Vulnerability: It's Application to Climate Impact Analysis". GeoJournal, 35.2 119-122.

Robinson, S., S. Van Zhandt, W. Peacock, and J. Grifith (2011), Charting Community Resilience in Rural Texas Border Communities, Texas A&M University.

Rodrik, D. (1999). Where did all the growth go? External shocks, social conflict and growth collapses, Journal of Economic Growth. 4(4), pp. 385-412.

Röhn, O., Caldera Sánchez, A., Hermansen, M., and Rasmussen, M. (2015). Economic resilience: A new set of vulnerability indicators for OECD countries.

Rose, A., and Liao, S.-Y. (2005). Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions*. Journal of Regional Science 45, 75–112.

Rose, A. (2007). Economic resilience to natural and man-made disasters: Multidisciplinary origins and contextual dimensions. Environmental Hazards, 7(4), 383–398. doi:10.1016/j.envhaz.2007.10.001

Rose, A.Z. (2009). Economic resilience to disasters. Community and Regional Resilience Institute Report No. 8.

Russell, S. J., and Norvig, P. (1995). "Artificial Intelligence: A modern Approach" Prentice Hall, Englewood, Cliffs, NJ.

Samuelson, L. (1997). Evolutionary Games and Equilibrium Selection. Cambridge, MA: MIT Press.

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. Nature, 413(6856), 591–596.

Schelling, T.C. (2006). “Micromotives and Macrobehavior”. W. W. Norton & Company, NY, U.S.A.

Scheuer, C. W., & Keoleian, G. A. (2002). Evaluation of LEED™ Using Life Cycle Assessment Methods. Ann Arbor, MI: Center for Sustainable Systems, University of Michigan.

Schwab, J. (1998). “Planning for post disaster recovery and reconstruction” PAS Rep. No. 483/484, American Planning Association, Chicago

Siche, J.R., Agostinho, F., Ortega, E., and Romeiro, A. (2008). Sustainability of nations by indices: Comparative study between environmental sustainability index, ecological footprint and the emergy performance indices. Ecological Economics 66, 628–637.

Simmie, J., & Martin, R. (2010). The economic resilience of regions: towards an evolutionary approach. Cambridge Journal of Regions, Economy and Society, 3(1), 27–43. doi:10.1093/cjres/rsp029

Shephered, A. (1988) “A Famine and Control of Assets”. In: Curtis, D. et al. (eds.): op. cit., pp. 192-214.

Smith, J.M., and Price, G.R. (1973). The Logic of Animal Conflict. Nature 246, 15–18.

Smith, G. and D. Wenger (2007), “Sustainable Disaster Recovery: Operationalizing An Existing Agenda”, Chapter 14 of Handbook of Disaster Research, Rodriguez, H., E. Quarentelli, and R. Dynes (editors), Springer, New York.

Son, J. and Rojas, Eddy M. (2011). “Evolution of Collaboration in Temporary Project Teams: An Agent-Based Modeling and Simulation Approach”. Journal of Construction Engineering and Management. Vol. 137, No. 8. 619- 628.

Sterman, J. (2000), Business Dynamics: Systems Thinking and Modeling for a Complex World, McGraw-Hill.

Sullivan, K., Coletti, M., & Luke, S. (2010). GeoMason: geospatial support for MASON. Fairfax, VA: Department of Computer Science, George Mason University. Technical Report Series.

Sun, Junjie, and Tesfatsion, Leigh, (2007) “An Agent-Based Computational Laboratory for Wholesale Power Market Design”. IEEE proceedings, Power and Energy Society, Piscataway, New Jersey, (2007).

Susman, P., O’Keefe, P. and Wisner, B. (1984). Global disaster: a radical interpretations of calamity, Boston, MA: Allen & Unwin, 264-83

Taylor, J., Levitt, R., and Villarroel, J. (2009). “Simulating Learning Dynamics in Project Networks” J. Constr. Eng. Manage., 135(10), 1009–1015.

Thorndike, E. (1898). Animal Intelligence: An Experimental Study of the Associative Processes in Animal.” Psychological Monographs, 2(8).

Tierney, K.J. and M. Bruneau, M. (2007), Conceptualizing and measuring resilience: A key to disaster loss reduction. TR News. 250 (May-June): 14-17.

Tobin, G. A., and J. C. Ollenburger. 1993. Natural Hazards and the Elderly. Boulder, Colo.: University of Colorado, Natural Hazards Research and Applications Information Center.

Trinh, Q.C., Saguan, M., and Meeus, L. (2013). Experience With Electricity Market Test Suite: Students Versus Computational Agents. IEEE Transactions on Power Systems 28, 112–120.

Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., et al. (2003). A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences 100, 8074–8079.

Turocy, T. L., and Stengel, B. V. (2001). Game Theory. CDAM Research Report LSE-CDAM-2001-09. Draft of an introductory survey of game theory, prepared for the Encyclopedia of Information Systems, Academic Press, http://www.cdam.lse.ac.uk/Reports/Files/cdam-2001-09.pdf. Accessed August 25, 2014.

United Nations, (1992). Conference on Environment and Development. Rio de Janeiro, Brazil.

University of Washington & CH2MHILL, Inc. (2011). Greenroads Manual v1.5. University of Washington.

Unsal, H., and Taylor, J. (2011). Modeling Interfirm Dependency: Game Theoretic Simulation to Examine the Holdup Problem in Project Networks. Journal of Construction Engineering and Management, 137(4), 284-294.

UrbanSim. (2012). Retrieved March 16, 2012, from http://www.urbansim.org

Van den Bergh, J.C.J.M., Verbruggen, H., (1999) Spatial Sustainability, trade and indicators: an evaluation of the Ecological Footprint. Ecological Economics 29, 61-72.

Vickery, P. J., Skerlj, P. F., Lin, J., Twisdale Jr, L. A., Young, M. A., & Lavelle, F. M. (2006). HAZUS-MH hurricane model methodology. II: Damage and loss estimation. Natural Hazards Review, 7(2), 94–103.

Vidal, J. M. (2007), Fundamentals of Multi-Agent Systems, Department of Computer Science and Engineering, University of South Carolina, Columbia, USA.

Villa, F., & McLEOD, H. (2002). Environmental Vulnerability Indicators for Environmental Planning and Decision-Making: Guidelines and Applications. Environmental Management, 29(3), 335–348. doi:10.1007/s00267-001-0030-2

Vlassis, N. (2003), A Concise Introduction to Multi-Agent Systems and Distributed AI, Intelligent Autonomous Systems, Informatics Institute, University of Amsterdam, Holland.

Von Neumann, J., and Morgenstern, O. (1944). Theory of Games and Economic Behavior (Princeton University Press).

Vriend, N.J. (2000). An illustration of the essential difference between individual and social learning, and its consequences for computational analyses. Journal of Economic Dynamics and Control 24(1), 1–19.

Wackernagel, M., and Rees, W.E. (1997). Perceptual and structural barriers to investing in natural capital: Economics from an ecological footprint perspective. Ecological Economics 20, 3–24.

Watkins, C.J.C.H. (1989). Learning from delayed rewards. King's College, Cambridge.

Watkins, C.J.C.H., and Dayan, P. (1992). Technical Note: Q-Learning. Machine Learning 8, 279–292.

Watts, Michael J. and Hans G Bohle (1993). Hunger, Famine and the Space of Vulnerability. GeoJournal, Vol. 30, No. 2, pp. 117-125.

Weibull, J. W. (1995). Evolutionary game theory, MIT Press, Cambridge,

MA.Wiedmann, T., Minx, J., Barrett, J., and Wackernagel, M. (2006). Allocating ecological footprints to final consumption categories with input–output analysis. Ecological Economics 56, 28–48.

WSP Environmental and Natural Strategies, (2003). Towards a sustainable London – Reducing the capital's Ecological Footprint. Phase 2 Report: Proposals to reduce London's Ecological Footprint. WSP Environmental Ltd, London and Natural Strategies LLC, Oakland CA.

Yang, H.Y., and Bozdogan, H. (2011). Learning factor patterns in exploratory factor analysis using the genetic algorithm and information complexity as the fitness function. Journal of Pattern Recognition Research 2, 307–326.

Zhu, W. (2015). Agent-Based Simulation and Modeling of Retail Center Systems. Journal of Urban Planning and Development 142, 04015004.

APPENDICES

Appendix A- Vulnerability Scores

SoVI Scores

2012		2011		2010		2007	
Census Tract	**Score**	**Census Tract**	**Score**	**Census Tract**	**Score**	**Census Tract**	**Score**
301	4.509156035	301	7.04938282	301	4.059375333	301	1.526457
302	-0.474626662	302	2.10027251	302	1.450221362	302	1.867177
303	-1.490320006	303	-1.52026113	303	-0.887295925	303	0.691705
304	-0.392174559	304	0.893034177	304	-2.404587521	304	-0.88846
305	11.42309546	305	14.32868006	305	14.210164	305	15.53781
306.01	-4.017717987	306.01	0.893564784	306.01	1.147997662	306.01	0.589969
306.02	-3.533057933	306.02	-1.35728451	306.02	-0.871352619	306.02	0.589969
1	2.150579211	1	-6.55139948	1	-8.281598347	1	-11.5809
3	-16.52407019	3	-18.6480208	3	-9.834217537	3	-7.12531
6	6.00344834	6	9.672956662	6	8.061927024	6	7.39824
12.01	0.952165561	12.01	-0.29423211	12.01	3.04111666	12.01	-2.04942
12.02	-0.490582348	12.02	-2.8932047	12.02	0.457621544	12.02	3.296689
13	-6.338856529	13	-8.54603905	13	-4.418522981	13	-3.38624
14	1.124884015	14	-0.95480063	14	1.520168573	14	5.259015
15.01	3.931571065	15.01	0.965683459	15.01	2.586528388	15.01	3.328721
15.02	5.575740665	15.02	7.025523714	15.02	5.082736562	15.02	3.328721
16	13.37806149	16	13.51215484	16	12.91814912	16	17.28851
17	-3.244104549	17	-4.6660251	17	-2.758704295	17	-0.81666
18	-4.952011123	18	-11.4068791	18	-9.964005514	18	-5.58721
19	-1.085508368	19	-3.19994032	19	-1.804106496	19	0.947052
20	-7.048060047	20	-8.67722576	20	-11.39715262	20	-6.05999
23	-5.764018177	23	-9.74590851	23	-7.356035957	23	-5.95716
24	-7.036206371	24	-7.66769048	24	-6.461223916	24	-6.35577
25	-11.2871695	25	-11.5004201	25	-15.25776669	25	-23.1879
26	-8.862137245	26	-16.1466762	26	-13.18994223	26	-3.43727
27	4.55001769	27	2.91245866	27	2.899853806	27	1.0178
28	7.796009872	28	7.007709079	28	3.64225016	28	4.430287
29	15.68780508	29	22.72335776	29	18.78222279	29	15.55951
30	3.446821569	30	2.930007872	30	-2.422623097	30	5.155619
31.01	4.286773925	31.01	2.15983151	31.01	2.270911711	31.01	0.343077
31.02	5.248920665	31.02	6.216919093	31.02	7.087215288	31.02	3.64543
32.04	-4.395197435	32.04	-7.54958798	32.04	-5.723634251	32.04	-2.78408
32.05	-0.32604648	32.05	-2.04991674	32.05	-1.068746297	32.05	1.305264
32.06	3.17761538	32.06	4.463895236	32.06	5.385733123	32.06	2.162695
32.07	-3.306578242	32.07	-6.05214913	32.07	-4.568131282	32.07	-4.81736
32.08	-2.707148956	32.08	-4.88562507	32.08	-5.613340153	32.08	-4.81736
33.01	-4.636382085	33.01	-7.18760771	33.01	-6.500259652	33.01	-2.13752
33.03	0.703922963	33.03	0.44333067	33.03	1.473691186	33.03	5.602325

2012		2011		2010		2007	
Census Tract	**Score**	**Census Tract**	**Score**	**Census Tract**	**Score**	**Census Tract**	**Score**
33.04	8.983342529	33.04	12.97705605	33.04	12.51985351	33.04	5.602325
34.02	3.887188317	34.02	3.931731376	34.02	6.366152716	34.02	4.183296
34.03	7.461950524	34.03	10.13133363	34.03	7.40395529	34.03	1.384043
34.04	0.165028071	34.04	1.661309596	34.04	-0.905755813	34.04	1.384043
35.01	-0.671458808	35.01	0.43672804	35.01	0.791182764	35.01	0.7077
35.02	2.340607632	35.02	1.322953994	35.02	1.373850227	35.02	-2.06029
35.04	1.81091077	35.04	2.889932443	35.04	2.511295055	35.04	3.818438
35.05	4.846333554	35.05	4.342526378	35.05	3.767729946	35.05	3.774848
36	-10.85948269	36	-14.0611265	36	-12.2191071	36	-17.1075
37	-7.896686281	37	-8.43137531	37	-1.94162196	37	-1.64708
38	-2.684614481	38	0.561976216	38	2.016966204	38	-2.31792
39	-4.555300773	39	-2.98816425	39	-0.070714119	39	-12.8912
401.01	2.471900462	401.01	5.286947179	401.01	2.119232925	401.01	1.446715
401.02	-0.858762814	401.02	3.350643279	401.02	1.691309256	401.02	0.355455
402.01	-0.740201622	402.01	2.223756553	402.01	3.005872455	402.01	0.576506
402.03	0.315147986	402.03	3.966896647	402.03	2.077666666	402.03	0.386693
402.04	-2.256498012	402.04	0.189034861	402.04	1.215750337	402.04	0.386693
403	-3.357473037	403	-5.1070338	403	-4.744852401	403	-0.20893
404	2.215861	404	2.394246593	404	0.561085485	404	4.406651
405	14.2189784	405	16.57457881	405	14.06074519	405	10.74585
406	5.984099665	406	7.80220393	406	5.927769352	406	3.702866
407	2.88987565	407	3.893867508	407	9.145154648	407	4.828193
408	-3.773131572	408	-3.42324132	408	-1.840394657	408	1.016419
409	1.596277614	409	4.038602796	409	5.04710908	409	4.117303
410	-3.585527562	410	0.419777284	410	1.049923725	410	0.92777
411	-3.708360828	411	-3.71396769	411	-4.871725915	411	-0.70343
413	0.128785517	413	0.652439469	413	0.383080859	413	-1.01139
414	5.10886797	414	5.021859915	414	5.722886035	414	6.319093
415	4.78063953	415	3.861102868	415	-0.167932279	415	0.576124
416	-5.753864667	416	-6.769775	416	-6.433967625	416	-3.89982
417	-6.26808699	417	-4.8312805	417	-3.879163145	417	-5.35154
418	1.049324129	418	1.416552891	418	-3.449907919	418	-1.45848
419	0.222767973	419	-3.10015236	419	-0.322823551	419	1.489526
420	-6.760690889	420	-7.08596277	420	-7.842921739	420	-5.78842
421	-7.505542596	421	-8.96271393	421	-7.236307885	421	-7.74485
422	-8.009212573	422	-7.1662514	422	-9.863276588	422	-6.94647
425	2.739306437	425	1.266010776	425	-1.89235672	425	2.301913
426	11.58839221	426	15.51515076	426	15.44815905	426	10.49796
427	1.299845726	427	-1.098254	427	-8.688616149	427	-2.63888
429	-2.895149658	429	-3.18778928	429	-3.129922126	429	-13.0437

EconVI Score

2012		2011		2010		2009	
Census Tract	Score	Census Tract	Score	Census Tract	Score	Census Tract	Score
301	0.330536	301	0.349443	301	0.375752	301	0.451468
302	0.391695	302	0.38572	302	0.444713	302	0.480465
303	0.301941	303	0.314702	303	0.314092	303	0.391802
304	0.487681	304	0.514437	304	0.724477	304	0.908369
305	0.33401	305	0.319851	305	0.358256	305	0.487517
306.01	0.528069	306.01	0.508061	306.01	0.724332	306.01	0.886521
306.02	0.601553	306.02	0.542215	306.02	0.744084	306.02	0.87606
1	0.502865	1	0.466855	1	0.52625	1	0.586297
3	0.71344	3	0.728303	3	0.795151	3	0.730705
6	0.428884	6	0.392964	6	0.451259	6	0.643269
12.01	0.35667	12.01	0.412436	12.01	0.434508	12.01	0.507578
12.02	0.364036	12.02	0.267938	12.02	0.280444	12.02	0.287267
13	0.256463	13	0.274701	13	0.287707	13	0.310829
14	0.411954	14	0.432341	14	0.437862	14	0.44649
15.01	0.422974	15.01	0.453297	15.01	0.554892	15.01	0.543831
15.02	0.355948	15.02	0.32296	15.02	0.399483	15.02	0.569263
16	0.371442	16	0.369573	16	0.435481	16	0.640884
17	0.236725	17	0.229595	17	0.238625	17	0.224591
18	0.312401	18	0.301023	18	0.341758	18	0.36933
19	0.386389	19	0.353087	19	0.439809	19	0.439794
20	0.312255	20	0.296949	20	0.345011	20	0.323664
23	0.443999	23	0.443043	23	0.57521	23	0.633697
24	0.583066	24	0.563215	24	0.676155	24	0.837338
25	2.971272	25	3.488534	25	3.34123	25	4.073906
26	0.438022	26	0.475815	26	0.534525	26	0.591582
27	0.365129	27	0.338562	27	0.419902	27	0.424084
28	0.371159	28	0.351944	28	0.457681	28	0.486215
29	0.373531	29	0.357662	29	0.325806	29	0.473477
30	0.469643	30	0.43502	30	0.59707	30	0.555899
31.01	0.279143	31.01	0.258444	31.01	0.283319	31.01	0.320741
31.02	0.342724	31.02	0.336733	31.02	0.388568	31.02	0.510141
32.04	0.31535	32.04	0.304797	32.04	0.327531	32.04	0.414003
32.05	0.237835	32.05	0.234052	32.05	0.253732	32.05	0.25552
32.06	0.3442	32.06	0.349112	32.06	0.385814	32.06	0.430694
32.07	0.430852	32.07	0.419151	32.07	0.400963	32.07	0.565768
32.08	0.532466	32.08	0.479691	32.08	0.560983	32.08	0.557909
33.01	0.217621	33.01	0.22154	33.01	0.235148	33.01	0.245027
33.03	0.345775	33.03	0.312102	33.03	0.372872	33.03	0.479291
33.04	0.295375	33.04	0.286502	33.04	0.339932	33.04	0.480434

2012		2011		2010		2009	
Census Tract	**Score**	**Census Tract**	**Score**	**Census Tract**	**Score**	**Census Tract**	**Score**
34.02	0.305898	34.02	0.30279	34.02	0.358511	34.02	0.440881
34.03	0.365472	34.03	0.350349	34.03	0.46414	34.03	0.675772
34.04	0.448949	34.04	0.410358	34.04	0.522481	34.04	0.675772
35.01	0.41821	35.01	0.407011	35.01	0.530525	35.01	0.607924
35.02	0.466664	35.02	0.49605	35.02	0.604686	35.02	0.742739
35.04	0.468846	35.04	0.466918	35.04	0.571503	35.04	0.552866
35.05	0.431507	35.05	0.415037	35.05	0.476677	35.05	0.609632
36	0.430415	36	0.426329	36	0.425582	36	0.481681
37	0.54875	37	0.460555	37	0.450714	37	0.433246
38	0.482079	38	0.481869	38	0.513854	38	0.575399
39	0.376212	39	0.323406	39	0.409544	39	0.437186
401.01	0.336248	401.01	0.344757	401.01	0.405497	401.01	0.458801
401.02	0.53069	401.02	0.515498	401.02	0.68786	401.02	0.821263
402.01	0.449283	402.01	0.445228	402.01	0.484454	402.01	0.549225
402.03	0.455811	402.03	0.464894	402.03	0.651115	402.03	0.601014
402.04	0.43351	402.04	0.416083	402.04	0.534641	402.04	0.598166
403	0.402442	403	0.38734	403	0.521855	403	0.532188
404	0.332806	404	0.321022	404	0.396867	404	0.433089
405	0.218731	405	0.20442	405	0.212643	405	0.218429
406	0.381389	406	0.37509	406	0.515205	406	0.619688
407	0.232622	407	0.222483	407	0.227671	407	0.233279
408	0.351881	408	0.363739	408	0.383453	408	0.385492
409	0.417674	409	0.385071	409	0.464723	409	0.603398
410	0.32198	410	0.308021	410	0.383206	410	0.379302
411	0.484045	411	0.453358	411	0.593168	411	0.740192
413	0.427315	413	0.404102	413	0.443193	413	0.468849
414	0.407848	414	0.395169	414	0.519954	414	0.594868
415	0.360255	415	0.398201	415	0.487467	415	0.538334
416	0.582026	416	0.56293	416	0.649345	416	0.921962
417	0.800761	417	0.917634	417	0.90184	417	1.551511
418	0.430838	418	0.427177	418	0.480448	418	0.471986
419	0.29485	419	0.270085	419	0.309852	419	0.346086
420	0.537238	420	0.506331	420	0.642296	420	0.670672
421	0.655875	421	0.578793	421	0.675421	421	0.575568
422	0.334913	422	0.292978	422	0.381841	422	0.338603
425	0.382179	425	0.402836	425	0.598475	425	0.640216
426	0.367325	426	0.32518	426	0.35985	426	0.442649
427	0.508892	427	0.617212	427	0.828074	427	0.908582
429	0.281729	429	0.282855	429	0.336576	429	0.321031

EVI Scores 2000

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
1	4	7	5	6	1	4	5	7	7	3	1
3	4	7	5	6	1	4	6	5	7	3	1
6	4	7	5	6	1	4	4	5	7	3	1
12.01	4	7	4	6	1	4	6	5	7	3	1
12.02	4	7	4	6	1	4	5	5	7	3	1
13	3	7	6	1	1	4	3	5	7	3	1
14	3	7	4	1	1	4	3	5	7	3	1
15.01	4	7	4	6	1	4	7	5	7	3	1
15.02	4	7	4	6	1	4	5	5	7	3	1
16	4	7	4	6	1	4	5	5	7	3	1
17	4	7	4	6	1	4	5	5	7	3	1
18	4	7	3	6	1	4	4	5	7	3	1
19	4	7	6	6	1	4	7	5	7	3	1
20	4	7	5	6	1	4	6	5	7	3	1
23	4	7	5	6	1	4	7	5	7	3	1
24	4	7	3	6	2	4	5	5	7	3	1
25	4	7	4	6	7	4	5	2	7	3	1
26	4	7	5	6	1	4	7	5	7	3	1
27	4	7	4	6	1	4	5	5	7	3	1
28	4	7	4	6	1	4	5	5	7	3	1
29	4	7	2	6	4	4	3	5	6	3	1
30	4	7	2	6	7	1	3	5	6	3	1
31.01	4	7	2	6	7	4	2	5	6	3	1
31.02	3	6	2	1	7	1	1	5	4	3	6
32.04	4	7	4	6	1	4	6	5	7	3	1
32.05	4	7	4	6	1	4	5	5	7	3	6
32.06	4	7	2	6	4	4	2	5	5	3	4
32.07	4	7	3	6	1	4	4	5	7	3	1
32.08	4	7	4	6	1	1	3	5	6	3	4
33.01	5	7	4	6	7	4	5	5	7	3	4
33.03	4	7	3	6	1	4	4	5	7	3	1
33.04	4	7	4	1	1	4	5	5	7	3	5
34.02	3	6	2	1	7	4	1	5	5	3	3
34.03	3	7	2	1	7	4	2	4	4	3	3
34.04	3	6	1	1	7	4	1	5	1	3	3
35.01	3	6	1	1	7	4	1	5	3	3	6
35.02	3	6	1	1	7	4	1	5	3	3	6
35.04	3	6	1	1	7	4	1	5	4	3	6
35.05	3	7	2	1	7	4	2	5	6	3	1
36	3	7	6	6	1	4	2	4	4	3	1
37	4	7	4	6	1	4	7	5	7	3	1
38	4	7	5	6	1	4	5	4	7	3	6
39	4	7	6	6	1	4	5	5	7	3	1
301	4	7	2	6	1	4	4	7	7	3	6
302	4	7	1	6	7	2	2	5	6	3	6
303	4	6	2	6	7	1	2	5	6	3	6
304	3	6	1	6	5	1	1	3	1	3	6
305	5	7	2	6	7	4	3	5	7	3	6
306.01	3	6	1	1	7	4	1	4	2	3	6
306.02	3	6	1	1	7	4	1	3	1	3	6
401.01	3	6	1	1	7	4	1	4	2	3	6
401.02	3	6	1	1	7	4	1	4	3	3	6
402.01	3	5	1	1	6	4	1	3	1	3	5

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
402.03	3	6	1	1	7	4	1	5	3	3	4
402.04	3	7	1	1	7	4	2	5	5	3	4
403	5	7	4	6	7	4	4	7	7	3	5
404	4	7	2	1	7	1	3	5	7	3	5
405	4	7	4	6	1	4	4	7	7	3	5
406	4	7	4	1	1	4	5	7	7	3	5
407	4	7	3	6	6	4	3	5	7	3	5
408	3	6	2	1	2	1	1	5	4	3	5
409	3	6	3	1	7	1	1	5	5	3	5
410	3	7	4	1	1	1	3	5	7	3	1
411	4	7	4	6	1	4	4	5	7	3	1
413	3	6	2	1	7	1	1	5	5	3	6
414	4	7	5	1	1	4	5	7	7	3	1
415	4	7	4	6	1	4	5	5	7	3	1
416	4	7	4	6	1	4	5	7	7	3	1
417	4	7	5	6	1	4	7	7	7	3	1
418	4	7	4	6	1	4	6	7	7	3	1
419	4	7	4	6	1	4	5	7	7	3	1
420	4	7	4	6	1	4	6	7	7	3	1
421	4	7	4	6	1	4	6	7	7	3	1
422	4	7	6	6	1	4	7	7	7	3	1
425	4	7	5	6	1	4	6	7	7	3	1
426	4	7	5	6	1	4	5	7	7	3	1
427	2	6	3	1	4	1	1	3	1	3	6
429	2	6	4	1	1	1	1	3	1	3	6

EVI Score 2009

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
1	4	7	6	6	1	4	4	5	6	3	1
3	4	7	6	6	1	4	6	5	7	3	1
6	4	7	5	6	1	4	3	5	6	3	1
12.01	4	7	5	6	1	4	6	5	7	3	1
12.02	4	7	5	6	1	4	6	5	7	3	1
13	3	7	5	1	1	4	3	5	7	3	1
14	3	7	4	1	1	4	2	5	4	3	1
15.01	4	7	6	6	1	4	7	5	7	3	1
15.02	4	7	3	6	1	4	5	5	7	3	1
16	4	7	6	6	1	4	5	5	7	3	1
17	4	7	6	6	1	4	5	5	7	3	1
18	4	7	4	6	1	4	4	5	7	3	1
19	4	7	6	6	1	4	7	5	7	3	1
20	4	7	6	6	1	4	6	5	7	3	1
23	4	7	6	6	1	4	7	5	7	3	1
24	4	7	3	6	2	4	5	5	7	3	1
25	4	7	5	6	7	4	6	3	7	3	1
26	4	7	6	6	1	4	7	5	7	3	1
27	4	7	4	6	1	4	5	5	7	3	1
28	4	7	4	6	1	4	4	5	7	3	1
29	4	7	4	6	4	4	3	4	5	3	1
30	4	7	4	6	7	1	2	5	5	3	1
31.01	4	7	2	6	7	4	2	5	6	3	1
31.02	3	6	1	1	7	1	1	5	3	3	6
32.04	4	7	6	6	1	4	6	5	7	3	1
32.05	4	7	4	6	1	4	6	5	7	3	6
32.06	4	7	2	6	4	4	2	5	6	3	4
32.07	4	7	3	6	1	4	4	5	7	3	1
32.08	4	7	4	6	1	1	3	5	7	3	4
33.01	5	7	5	6	7	4	5	5	7	3	4
33.03	4	7	3	6	1	4	4	5	7	3	2
33.04	4	7	4	1	1	4	5	5	7	3	5
34.02	3	6	1	1	7	4	1	5	5	3	3
34.03	3	7	1	1	7	4	2	4	4	3	3
34.04	3	6	1	1	7	4	1	5	1	3	3
35.01	3	6	1	1	7	4	1	5	3	3	6
35.02	3	6	1	1	7	4	1	5	3	3	6
35.04	3	6	1	1	7	4	1	5	5	3	6
35.05	3	7	2	1	7	4	2	5	6	3	1

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
36	3	7	6	6	1	4	1	2	2	3	1
37	4	7	6	6	1	4	7	5	7	3	1
38	4	7	6	6	1	4	4	3	6	3	6
39	4	7	6	6	1	4	5	5	7	3	1
301	5	7	5	6	1	4	4	7	7	3	6
302	4	7	3	6	7	2	2	5	5	3	6
303	4	6	3	6	7	1	1	5	5	3	6
304	3	6	1	6	5	1	1	2	1	3	6
305	5	7	3	6	7	4	3	5	7	3	6
306.01	3	6	1	1	7	4	1	4	2	3	6
306.02	3	6	1	1	7	4	1	3	1	3	6
401.01	3	6	1	1	7	4	1	5	2	3	6
401.02	3	6	1	1	7	4	1	5	3	3	6
402.01	3	5	1	1	6	4	1	4	1	3	5
402.03	3	6	1	1	7	4	1	5	3	3	4
402.04	4	7	1	1	7	4	2	5	6	3	4
403	5	7	4	6	7	4	4	7	7	3	5
404	4	7	2	1	7	1	3	5	7	3	5
405	4	7	4	6	1	4	3	5	7	3	4
406	4	7	4	1	1	4	5	7	7	3	5
407	5	7	3	6	6	4	3	7	7	3	5
408	2	6	1	1	2	1	1	5	4	3	5
409	3	6	2	1	7	1	1	5	6	3	5
410	3	7	3	1	1	1	3	5	7	3	1
411	4	7	4	6	1	4	4	7	7	3	1
413	3	6	2	1	7	1	1	5	5	3	6
414	4	7	4	1	1	4	5	7	7	3	1
415	4	7	4	6	1	4	5	7	7	3	1
416	4	7	4	6	1	4	5	7	7	3	1
417	4	7	6	6	1	4	6	7	7	3	1
418	4	7	6	6	1	4	6	7	7	3	1
419	4	7	6	6	1	4	5	7	7	3	1
420	4	7	4	6	1	4	6	7	7	3	1
421	4	7	5	6	1	4	6	7	7	3	1
422	4	7	6	6	1	4	7	7	7	3	1
425	4	7	6	6	1	4	6	7	7	3	1
426	4	7	6	6	1	4	5	7	7	3	1
427	2	6	2	1	4	1	1	2	1	3	6
429	2	6	2	1	1	1	1	3	1	3	6

EVI Score 2010

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
1	4	7	6	6	1	4	4	5	5	3	1
3	4	7	6	6	1	4	6	5	7	3	1
6	4	7	5	6	1	4	3	5	6	3	1
12.01	4	7	5	6	1	4	6	5	7	3	1
12.02	4	7	5	6	1	4	6	5	7	3	1
13	3	7	5	1	1	4	3	5	6	3	1
14	3	7	4	1	1	4	2	5	4	3	1
15.01	4	7	6	6	1	4	7	5	7	3	1
15.02	4	7	3	6	1	4	5	5	7	3	1
16	4	7	6	6	1	4	5	5	7	3	1
17	4	7	5	6	1	4	5	5	7	3	1
18	4	7	4	6	1	4	4	5	7	3	1
19	4	7	6	6	1	4	7	5	7	3	1
20	4	7	6	6	1	4	6	5	7	3	1
23	4	7	6	6	1	4	7	5	7	3	1
24	4	7	3	6	2	4	5	5	7	3	1
25	4	7	5	6	7	4	5	3	7	3	1
26	4	7	6	6	1	4	6	5	7	3	1
27	4	7	4	6	1	4	5	5	7	3	1
28	4	7	4	6	1	4	4	5	6	3	1
29	4	7	3	6	4	4	3	4	5	3	1
30	4	7	3	6	7	1	2	5	6	3	1
31.01	4	7	2	6	7	4	2	5	6	3	1
31.02	3	6	1	1	7	1	1	5	4	3	6
32.04	4	7	6	6	1	4	6	5	7	3	1
32.05	4	7	4	6	1	4	6	5	7	3	6
32.06	4	7	2	6	4	4	2	5	6	3	5
32.07	4	7	3	6	1	4	4	5	7	3	1
32.08	4	7	4	6	1	1	3	5	7	3	4
33.01	5	7	5	6	7	4	5	5	7	3	5
33.03	4	7	3	6	1	4	4	5	7	3	3
33.04	4	7	4	1	1	4	5	5	7	3	5
34.02	3	6	1	1	7	4	1	5	5	3	4
34.03	3	7	1	1	7	4	2	4	4	3	1
34.04	3	6	1	1	7	4	1	5	1	3	4
35.01	3	6	1	1	7	4	1	5	3	3	6
35.02	3	6	1	1	7	4	1	5	3	3	6
35.04	3	6	1	1	7	4	1	5	5	3	6
35.05	3	7	1	1	7	4	2	5	6	3	1

36	3	7	6	6	1	4	1	2	2	3	1
37	4	7	6	6	1	4	7	5	7	3	1
38	4	7	6	6	1	4	4	3	6	3	6
39	4	7	6	6	1	4	5	5	7	3	1
301	4	7	4	6	1	4	4	7	7	3	6
302	4	7	3	6	7	2	2	5	6	3	6
303	4	6	4	6	7	1	1	5	5	3	6
304	3	6	1	6	5	1	1	2	1	3	6
305	5	7	3	6	7	4	3	5	7	3	6
306.01	3	6	1	1	7	4	1	4	2	3	6
306.02	3	6	1	1	7	4	1	3	1	3	6
401.01	3	6	1	1	7	4	1	5	2	3	6
401.02	3	6	1	1	7	4	1	5	3	3	6
402.01	3	5	1	1	6	4	1	4	1	3	5
402.03	3	6	1	1	7	4	1	5	3	3	4
402.04	4	7	1	1	7	4	2	5	6	3	5
403	5	7	4	6	7	4	4	7	7	3	5
404	4	7	2	1	7	1	3	5	7	3	5
405	4	7	4	6	1	4	3	5	7	3	4
406	4	7	3	1	1	4	5	7	7	3	5
407	5	7	3	6	6	4	3	7	7	3	5
408	3	6	1	1	2	1	1	5	5	3	5
409	3	6	2	1	7	1	2	5	6	3	5
410	3	7	2	1	1	1	3	5	7	3	1
411	4	7	3	6	1	4	4	7	7	3	1
413	3	6	2	1	7	1	1	5	5	3	6
414	4	7	4	1	1	4	5	7	7	3	1
415	4	7	4	6	1	4	5	7	7	3	1
416	4	7	4	6	1	4	5	7	7	3	1
417	4	7	5	6	1	4	6	7	7	3	1
418	4	7	6	6	1	4	6	7	7	3	1
419	4	7	5	6	1	4	5	7	7	3	1
420	4	7	4	6	1	4	6	7	7	3	1
421	4	7	5	6	1	4	6	7	7	3	1
422	4	7	6	6	1	4	7	7	7	3	1
425	4	7	6	6	1	4	6	7	7	3	1
426	4	7	6	6	1	4	5	7	7	3	1
427	2	6	1	1	4	1	1	2	1	3	6
429	2	6	2	1	1	1	1	4	1	3	6

EVI Score 2011

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
1	4	7	6	6	1	4	4	5	5	3	1
3	4	7	6	6	1	4	5	5	7	3	1
6	4	7	5	6	1	4	3	5	6	3	1
12.01	4	7	6	6	1	4	6	5	7	3	1
12.02	4	7	5	6	1	4	6	5	7	3	1
13	3	7	5	1	1	4	3	5	6	3	1
14	3	7	4	1	1	4	2	5	4	3	1
15.01	4	7	6	6	1	4	7	5	7	3	1
15.02	4	7	4	6	1	4	5	5	7	3	1
16	4	7	6	6	1	4	5	5	7	3	1
17	4	7	6	6	1	4	5	5	7	3	1
18	4	7	4	6	1	4	4	5	7	3	1
19	4	7	6	6	1	4	7	5	7	3	1
20	4	7	6	6	1	4	6	5	7	3	1
23	4	7	6	6	1	4	7	5	7	3	1
24	4	7	3	6	2	4	5	5	7	3	1
25	5	7	6	6	7	4	5	4	7	3	1
26	4	7	6	6	1	4	7	5	7	3	1
27	4	7	4	6	1	4	5	5	7	3	1
28	4	7	4	6	1	4	4	5	7	3	1
29	4	7	4	6	4	4	3	3	5	3	1
30	4	7	4	6	7	1	2	5	6	3	1
31.01	4	7	2	6	7	4	2	5	6	3	1
31.02	3	6	1	1	7	1	1	5	4	3	6
32.04	4	7	6	6	1	4	6	5	7	3	1
32.05	4	7	4	6	1	4	6	5	7	3	6
32.06	4	7	2	6	4	4	2	5	6	3	5
32.07	4	7	3	6	1	4	4	5	7	3	1
32.08	4	7	4	6	1	1	3	5	7	3	4
33.01	5	7	5	6	7	4	5	5	7	3	5
33.03	4	7	4	6	1	4	4	5	7	3	3
33.04	4	7	4	1	1	4	5	5	7	3	5
34.02	3	6	1	1	7	4	1	5	6	3	4
34.03	3	7	1	1	7	4	2	5	4	3	1
34.04	3	6	1	1	7	4	1	5	1	3	4
35.01	3	6	1	1	7	4	1	5	3	3	6
35.02	3	6	1	1	7	4	1	5	3	3	6
35.04	3	6	1	1	7	4	1	5	5	3	6
35.05	3	7	2	1	7	4	2	5	6	3	1

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
36	3	7	6	6	1	4	1	3	3	3	1
37	4	7	6	6	1	4	7	5	7	3	1
38	4	7	6	6	1	4	4	3	6	3	6
39	4	7	6	6	1	4	5	5	7	3	1
301	5	7	5	6	1	4	4	7	7	3	6
302	4	7	3	6	7	2	2	5	6	3	6
303	4	6	3	6	7	1	2	5	6	3	6
304	3	6	1	6	5	1	1	2	1	3	6
305	5	7	3	6	7	4	3	7	7	3	6
306.01	3	6	1	1	7	4	1	4	2	3	6
306.02	3	6	1	1	7	4	1	4	1	3	6
401.01	3	6	1	1	7	4	1	5	2	3	6
401.02	3	6	1	1	7	4	1	5	3	3	6
402.01	3	5	1	1	6	4	1	4	2	3	5
402.03	3	6	1	1	7	4	1	5	3	3	4
402.04	4	7	1	1	7	4	2	5	6	3	5
403	5	7	4	6	7	4	4	7	7	3	5
404	4	7	2	1	7	1	3	5	7	3	5
405	4	7	4	6	1	4	3	5	7	3	4
406	4	7	3	1	1	4	5	7	7	3	5
407	5	7	3	6	6	4	3	7	7	3	5
408	3	6	1	1	2	1	1	5	5	3	5
409	3	6	2	1	7	1	2	5	6	3	5
410	3	7	3	1	1	1	3	5	7	3	1
411	4	7	4	6	1	4	4	7	7	3	1
413	3	6	2	1	7	1	1	5	5	3	6
414	4	7	4	1	1	4	5	7	7	3	1
415	4	7	5	6	1	4	5	7	7	3	1
416	4	7	4	6	1	4	5	7	7	3	1
417	4	7	6	6	1	4	6	7	7	3	1
418	4	7	6	6	1	4	6	7	7	3	1
419	4	7	6	6	1	4	5	7	7	3	1
420	4	7	4	6	1	4	6	7	7	3	1
421	4	7	6	6	1	4	6	7	7	3	1
422	4	7	6	6	1	4	7	7	7	3	1
425	4	7	6	6	1	4	6	7	7	3	1
426	4	7	6	6	1	4	5	7	7	3	1
427	2	6	2	1	4	1	1	2	1	3	6
429	2	6	2	1	1	1	1	4	1	3	6

EVI Score 2012

Census Tract	EVI	Land	Vegetation Cover	Loss of Cover	Habitat Fragmentation	Terrestrial Reserve	Waste Production	Vehicles	Population	Population Growth	Renewable Water
1	4	7	6	6	1	4	4	5	5	3	1
3	4	7	6	6	1	4	6	5	7	3	1
6	4	7	5	6	1	4	3	5	6	3	1
12.01	4	7	6	6	1	4	6	5	7	3	1
12.02	4	7	5	6	1	4	5	5	7	3	1
13	3	7	5	1	1	4	3	5	6	3	1
14	3	7	4	1	1	4	2	5	5	3	1
15.01	4	7	6	6	1	4	7	5	7	3	1
15.02	4	7	4	6	1	4	5	5	7	3	1
16	4	7	6	6	1	4	5	5	7	3	1
17	4	7	6	6	1	4	5	5	7	3	1
18	4	7	4	6	1	4	4	5	7	3	1
19	4	7	6	6	1	4	7	5	7	3	1
20	4	7	6	6	1	4	6	5	7	3	1
23	4	7	6	6	1	4	7	5	7	3	1
24	4	7	3	6	2	4	5	5	7	3	1
25	4	7	5	6	7	4	5	4	7	3	1
26	4	7	6	6	1	4	7	5	7	3	1
27	4	7	4	6	1	4	5	5	7	3	1
28	4	7	4	6	1	4	4	5	7	3	1
29	4	7	4	6	4	4	3	4	5	3	1
30	4	7	4	6	7	1	2	5	6	3	1
31.01	4	7	2	6	7	4	2	5	6	3	1
31.02	3	6	1	1	7	1	1	5	4	3	6
32.04	4	7	6	6	1	4	6	5	7	3	1
32.05	4	7	4	6	1	4	6	5	7	3	6
32.06	4	7	2	6	4	4	2	5	6	3	5
32.07	4	7	3	6	1	4	4	5	7	3	1
32.08	4	7	4	6	1	1	3	5	7	3	5
33.01	5	7	5	6	7	4	5	5	7	3	2
33.03	4	7	4	6	1	4	4	5	7	3	4
33.04	4	7	4	1	1	4	5	5	7	3	6
34.02	3	6	1	1	7	4	1	5	6	3	1
34.03	3	7	1	1	7	4	2	5	4	3	5
34.04	3	6	1	1	7	4	1	5	1	3	1
35.01	3	6	1	1	7	4	1	5	3	3	6
35.02	3	6	1	1	7	4	1	5	3	3	6
35.04	3	6	1	1	7	4	1	5	5	3	6
35.05	3	7	1	1	7	4	2	5	7	3	1

Census Tract	EVI	Land	Veget-ation Cover	Loss of Cover	Habit-at Fragm entati-on	Terres-trial Reser-ve	Waste Produ-ction	Vehicl-es	Popul-ation	Popul-ation Grow-th	Renew able Water
36	3	7	6	6	1	4	1	3	3	3	1
37	4	7	6	6	1	4	7	4	7	3	1
38	4	7	6	6	1	4	4	3	6	3	6
39	4	7	6	6	1	4	5	5	7	3	1
301	5	7	5	6	1	4	4	7	7	3	6
302	4	7	3	6	7	2	2	5	6	3	6
303	4	6	3	6	7	1	2	5	6	3	6
304	3	6	1	6	5	1	1	5	1	3	6
305	5	7	3	6	7	4	3	7	7	3	6
306.01	3	6	1	1	7	4	1	5	2	3	6
306.02	3	6	1	1	7	4	1	5	1	3	6
401.01	3	6	1	1	7	4	1	5	2	3	6
401.02	3	6	1	1	7	4	1	5	3	3	6
402.01	3	5	1	1	6	4	1	4	2	3	5
402.03	3	6	1	1	7	4	1	5	3	3	4
402.04	4	7	1	1	7	4	2	5	6	3	5
403	5	7	4	6	7	4	4	7	7	3	5
404	4	7	2	1	7	1	3	5	7	3	5
405	4	7	4	6	1	4	3	5	7	3	4
406	4	7	3	1	1	4	5	7	7	3	5
407	5	7	3	6	6	4	3	7	7	3	5
408	3	6	1	1	2	1	1	5	5	3	5
409	3	6	2	1	7	1	2	5	6	3	6
410	3	7	2	1	1	1	3	5	7	3	1
411	4	7	4	6	1	4	4	7	7	3	1
413	3	6	2	1	7	1	1	5	5	3	6
414	4	7	4	1	1	4	5	7	7	3	1
415	4	7	5	6	1	4	5	7	7	3	1
416	4	7	4	6	1	4	5	7	7	3	1
417	4	7	6	6	1	4	7	7	7	3	1
418	4	7	6	6	1	4	6	7	7	3	1
419	4	7	6	6	1	4	5	7	7	3	1
420	4	7	4	6	1	4	6	7	7	3	1
421	4	7	6	6	1	4	6	7	7	3	1
422	4	7	6	6	1	4	6	7	7	3	1
425	4	7	6	6	1	4	6	7	7	3	1
426	4	7	6	6	1	4	5	7	7	3	1
427	2	6	2	1	4	1	1	2	1	3	6
429	2	6	2	1	1	1	1	4	1	3	6

Appendix B – Source Code

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (FieldSimWithUI) Controls the initialization  and visualization of
 * the model
 */


package DSOAMB;
import sim.engine.*;
import sim.display.*;
import sim.portrayal.grid.*;
import java.awt.*;
import javax.swing.*;
import sim.portrayal.geo.GeomVectorFieldPortrayal;
import sim.util.gui.SimpleColorMap;
import java.awt.BorderLayout;
import java.awt.Color;
import javax.swing.JFrame;
import org.jfree.data.xy.XYSeries;
import sim.display.Console;
import sim.display.Controller;
import sim.display.Display2D;
import sim.display.GUIState;
import sim.engine.Schedule;
```

```
import sim.engine.SimState;
import sim.engine.Steppable;
import sim.portrayal.geo.GeomVectorFieldPortrayal;
import sim.portrayal.simple.OvalPortrayal2D;
import sim.portrayal.simple.HexagonalPortrayal2D;
import sim.util.gui.SimpleColorMap;
import sim.util.media.chart.ChartGenerator;
import sim.util.media.chart.TimeSeriesChartGenerator;
import com.vividsolutions.jts.geom.*;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
//import masontrail.CatchmentPortrayal;
import sim.portrayal.DrawInfo2D;
import sim.portrayal.Inspector;
//import sim.portrayal.Inspector;
import sim.portrayal.geo.GeomPortrayal;

/**
 *
 * @author MSaeid
 */
public class FieldSimWithUI extends GUIState {
   public FieldSim FSmodel;
   public Display2D display; //create a display
   public JFrame displayFrame;

   public int run;
```

```
//overall portryal
GeomVectorFieldPortrayal  mapPortrayal = new GeomVectorFieldPortrayal();
//portrayals for residence
GeomVectorFieldPortrayal ResidencePortrayal = new GeomVectorFieldPortrayal();
//Portrayal for Hazard
GeomVectorFieldPortrayal HazardPortrayal = new GeomVectorFieldPortrayal();

GeomVectorFieldPortrayal EconPortrayal = new GeomVectorFieldPortrayal();

public FieldSimWithUI (){
   super(new FieldSim(System.currentTimeMillis()));
}
public void start (){
   super.start();  // startup method
   setupPortrayals();
}

public void load(){
   super.load(state); //load a state
   setupPortrayals();
}

 public void init (Controller c){
   super.init(c); // screen where agents interact
   display = new Display2D(1000,800,this);
   display.setClipping(false);
   display.attach(mapPortrayal, "3counties");
   display.attach(ResidencePortrayal, "residence");
```

```
        display.attach(HazardPortrayal, "windstorm");
        //display.attach(EconPortrayal, "econAgent");
        displayFrame = display.createFrame();
        controller.registerFrame(displayFrame);
        displayFrame.setVisible(true);
        displayFrame.setTitle("Mississippi Coastal Counties");
        display.setBackdrop(Color.WHITE)
    }

    public void setupPortrayals(){ //setting up portrayals
        //setup GIS Portrayals
        FieldSim FS = (FieldSim)state;

        //setup Residence Portrayal
        ResidencePortrayal.setField(FS.ResidenceMap);
        ResidencePortrayal.setPortrayalForAll(new OvalPortrayal2D(Color.LIGHT_GRAY,2.0));
        //ResidencePortrayal.setPortrayalForAll(new OvalPortrayal2D(Color.BLUE,2.0));
        //setup Econ Agent Portrayal
       EconPortrayal.setField(FS.EconVImap);
       EconPortrayal.setPortrayalForAll(new OvalPortrayal2D(Color.GRAY,4));
       //EconPortrayal.setPortrayalForAll(new OvalPortrayal2D(Color.GREEN,4));
       //setup Hazard Portrayal
       HazardPortrayal.setField(FS.HazardMap);
       HazardPortrayal.setPortrayalForAll(new
HexagonalPortrayal2D(Color.DARK_GRAY,15.0));
       //HazardPortrayal.setPortrayalForAll(new HexagonalPortrayal2D(Color.RED,15.0));
       //setup map portrayal (left it to the end to keep boarder clear
       mapPortrayal.setField(FS.map);
       mapPortrayal.setPortrayalForAll(new GeomPortrayal(Color.BLACK, false));
```

```
    display.reset();
    display.setBackdrop(Color.WHITE);
    display.repaint();
   }


  //quit
   public void quit(){
     super.quit(); //quiting method
     if (displayFrame!=null) displayFrame.dispose();
     displayFrame= null;
     display = null;
  }

   public static void main(String[] args){
      //new FieldSimWithUI().createController();
     FieldSimWithUI SIM = new FieldSimWithUI();
     Console c = new Console (SIM);
     c.setSize(650, 300);
     c.setVisible(true);
     c.setTitle("Disaster Strategies Optimization Agent Based Model");
     c.setAlwaysOnTop(true);
      System.out.println("#################");
     System.out.println("start Simulation");
     System.out.println("#################");
  }
}
```

```
class NewThread implements Runnable {
    int Num;
    Thread t;
    FieldSim FSmodel;
    NewThread (FieldSim model){
        FSmodel = model;
        Num = 1;
        t = new Thread(this);
        t.start();
    }
    public void run(){
        //the public static void
        FieldSimWithUI SIM = new FieldSimWithUI();
    Console c = new Console (SIM);
    c.setSize(650, 300);
    c.setVisible(true);
    c.setTitle("Disaster Strategies Optimization Agent Based Model");

    FSmodel.Run = Num;
    System.out.println("#################");
    System.out.println("start Simulation");
    System.out.println("#################");
    }
  }
```

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (FieldSim) serves as the domain (Field) for the agents to interact
 */

package DSOAMB;
import com.numericalmethod.suanshu.stats.descriptive.correlation.CorrelationMatrix;
import java.io.FileInputStream;
import java.io.FileNotFoundException;
import java.io.InputStream;
import java.util.ArrayList;
import java.util.zip.GZIPInputStream;
import sim.engine.SimState;
import static sim.engine.SimState.doLoop;
import sim.engine.Steppable;
import sim.engine.Stoppable;
import sim.field.geo.GeomGridField;
import sim.field.geo.GeomGridField.GridDataType;
import sim.field.geo.GeomVectorField;
import sim.field.grid.IntGrid2D;
import sim.field.grid.ObjectGrid2D;
import sim.io.geo.ArcInfoASCGridImporter;
import sim.io.geo.ShapeFileImporter;
import java.util.Collections;
```

```
import java.util.Comparator;
import java.util.HashMap;
import sim.engine.SimState;
import static sim.engine.SimState.doLoop;
import sim.engine.Steppable;
import sim.field.geo.GeomVectorField;
import sim.io.geo.ShapeFileImporter;
import sim.util.Bag;
import sim.util.Interval;
import sim.util.geo.MasonGeometry;
import com.vividsolutions.jts.geom.*;
import java.lang.Object;
import com.numericalmethod.suanshu.stats.factoranalysis.*;
import static
com.numericalmethod.suanshu.stats.factoranalysis.FactorAnalysis.ScoringRule.THOMSON;
import com.numericalmethod.suanshu.stats.pca.PCAbyEigen;
import com.numericalmethod.suanshu.stats.pca.PCAbySVD;
import Jama.Matrix;
import com.mkobos.pca_transform.PCA;
import
com.numericalmethod.suanshu.algebra.linear.matrix.doubles.matrixtype.dense.DenseMatrix;
import java.applet.Applet;
import java.awt.event.KeyEvent;
import java.awt.event.KeyListener;
import java.io.BufferedReader;
import java.io.FileReader;
import java.util.Random;
import java.util.Scanner;
import java.security.SecureRandom;
```

```
import java.util.Arrays;
import javax.swing.JFrame;
import javax.swing.JRootPane;
import java.awt.*;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import java.util.logging.Level;
import java.util.logging.Logger;
import javax.swing.JButton;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.SwingConstants;

/**
 *
 * @author MSaeid
 */
/*===========================================================================
===========================================================================
General Discussion
This is the main simulation module, FieldSimWithUI is the graphical representation.
Several classes are created, one for residence agents. please check them.
There's also a Hazard class that includes a normal distribution so far (can be
adjusted) that determine the amount of damage. PS: you can add more than one
hazard type in the same simulation with their different frequency.
============================================================================
=========================================================================*/
public class FieldSim extends SimState {
```

```
public int Run;
/*transforming into a GIS model*/
public int gridWidth = 1000;
public int gridHeight = 800;
public int CT_number = 78;
public int ResNum =CT_number;
public int eAgentNum = 0; //just a counter and will be incremented later on

//Census Tracts
public Census[] Census = new Census[80];

//residence agents public = total households
public Residence[] R = new Residence[153000];

//business sector agents
public EconomicAgent[] eAgent = new EconomicAgent[10000]; //

//Insurance agents
public Insurance[] Ins = new Insurance[3];

// Local agents
public LDRM  LDRM_Hancock = new LDRM(this);
public LDRM LDRM_Harrison = new LDRM(this);
public LDRM LDRM_Jackson = new LDRM(this);

// State agent
public SDRC SDRC = new SDRC(this);
```

```
// Fedral Agent
public FDRC FDRC = new FDRC(this);

//Hazards
//windstorm event
public Hazard WindStorm = new Hazard(this);

//Hurricane
public Hazard Hurricane = new Hazard(this);

public Katrina Katrina = new Katrina(this);

//the agents' scheduling sequence.
int scheduleSeq =1;

//the map we are working on
public GeomVectorField map = new GeomVectorField(gridWidth, gridHeight);

//the map for EVI data
public GeomVectorField EVImap = new GeomVectorField(gridWidth,gridHeight);

//the map for EconVI data
public GeomVectorField EconVImap = new GeomVectorField(gridWidth, gridHeight);

//residence map which is empty in the beginning
public GeomVectorField ResidenceMap = new GeomVectorField(gridWidth, gridHeight);

 // can be used as grid, later experimentGeomGridField RMAP = new GeomGridField();
```

```
   public GeomVectorField HazardMap = new GeomVectorField(gridWidth, gridHeight);

   public DataOut file;

   public double[][] trackAssignments = new double [10][78]; //this is tracking variable for all
the WWTF assignments
   public double[][] nextTrackAssignments = new double [10][78];


public FieldSim (long seed){
   super(seed); // creating the random number generator
}

//Read data
public void readData(){
   try{

ShapeFileImporter.read(FieldSim.class.getResource("Data/3CountiesShapeSocial.shp"),map);

ShapeFileImporter.read(FieldSim.class.getResource("Data/EVI_GIS/3CountiesShapeEVI.shp"),
EVImap);

ShapeFileImporter.read(FieldSim.class.getResource("Data/Economic/3CountiesShapeEconVI.sh
p"), EconVImap);
      Envelope MBR = map.getMBR();

      //this will allow the GIS maps to be overlayed perfectly
      ResidenceMap.setMBR(map.getMBR());
      HazardMap.setMBR(map.getMBR());
```

```
    // can be used as grid, later experiment RMAP.setMBR(map.getMBR());
   } catch (FileNotFoundException ex)
      {
         System.out.println("Error opening shapefile!" + ex);
         System.exit(-1);
      }
}

 public void redrawEconMap(){
     // EconVImap.clear();
      //EconVImap.getGeometries().clear();
      EconVImap.setMBR(map.MBR);
      Envelope MBR =map.MBR;
      for (int i =0; i < eAgentNum; i++)
      {
         if (!eAgent[i].soldOut)
         {
          //EconVImap.addGeometry(new MasonGeometry(eAgent[i].location));
         }
      }EVImap.setMBR(MBR);
   }

public void scheduleall(){
for (int i =0; i <getResNum();i++)
   {
      schedule.scheduleRepeating(R[i], scheduleSeq, 1);
   }
   scheduleSeq ++;
```

```
    schedule.scheduleOnce(3, Katrina);
    WindStorm.rate = 1; //every three intervals there's a WindStorm
    //schedule.scheduleRepeating(WindStorm.rate, WindStorm);// mostly tornado hazard
    //schedule.scheduleRepeating(Hurricane, 15);

    schedule.scheduleRepeating(LDRM_Harrison,scheduleSeq,1);
    schedule.scheduleRepeating(LDRM_Hancock,scheduleSeq,1);
    schedule.scheduleRepeating(LDRM_Jackson,scheduleSeq,1);
    scheduleSeq++;
    schedule.scheduleRepeating(SDRC, scheduleSeq, 1);
    scheduleSeq++;
    for (int i = 0; i <eAgentNum; i++)
    {
      schedule.scheduleRepeating(eAgent[i],scheduleSeq,1);
    }
    scheduleSeq++;
    schedule.scheduleRepeating(FDRC,scheduleSeq,1);
}

public void start(){
    super.start();
    readData();
    file = new DataOut(this);
    file.CreateFile(getResNum());
    file.HazCreate(getResNum());
    file.EVICreate();
    file.EconVICreate();
    file.EconAgentCreate();
```

```
    GUI gui = new GUI(this);
    gui.optimization();

    CreateInsurance();
    createResidence();
    CreateEAgent();
    CreateCensus();
    createLDRMs();
    createHazard();
    scheduleall();
}

public int getResNum(){
    return ResNum;
}

public int getCTnumber(){
    return map.getGeometries().numObjs;
}

public void createResidence(){ //create public residence and place them on Residence map
    Bag geoms = map.getGeometries(); //an array containing the CTs
    CT_number = geoms.numObjs;
    int j = 0;
    for (int i = 0; i < geoms.numObjs ;i ++)
    {
        // depending on the index (or number) in array
        // mg is a controller to get attributes (and probably more)
```

```
        // mg also have the coordinates and can assign them to variables
        MasonGeometry mg = (MasonGeometry) geoms.get(i);

        // delcare a new resident with attributes from GIS

          /*FOR TESTING USE ONLY 1 K, FOR REAL WORLD USE FIRST "FOR
FUNCTION" */

        for (int k = 0; k <= mg.getIntegerAttribute("HouseHold");k++)
        //for (int k =0; k <5; k++)
        {
           R[j] = new Residence (this);
           R[j].DataIn(R[j], mg); //get data
           R[j].setTax();
           //set location on map
          ResidenceMap.addGeometry(new MasonGeometry(R[j].location));
          j++;
        }
    System.out.println("done with ct # " + (i+1));
    }R[0].x = 1;  // OK, this is stupid, but a work around to have only one learning iteration
    ResNum = j;
    System.out.print("number of residence = ");
    System.out.println(ResNum);

    //initial SoVI
    factAnalysisScoring(R);
}

class NewThread implements Runnable {
```

```
    Residence[] Res;
    Thread t;
    int from;
    int to;
    FieldSim FSmodel;
    MasonGeometry mg;

    NewThread( int x, int y, MasonGeometry d, Residence[] R){
        from = x;
        to = y;
        Res = R;
        mg = d;
        t = new Thread(this);
        t.start();
    }

    public void run(){
        for (int i =from; i <=to; i ++)
        {
            Res[i].addToMap(Res[i], mg);

            ResidenceMap.addGeometry(new MasonGeometry(Res[i].location));
        }
    }
}
public void CreateEAgent(){
    eAgentNum =-1;
```

```
  Bag geoms = EconVImap.getGeometries(); //an array containing the CTs
 for (int i = 0; i <CT_number ; i ++)
 {
    MasonGeometry mg =(MasonGeometry) geoms.get(i);
    for (int j = 0; j <mg.getIntegerAttribute("RetailNum"); j++)
    { eAgentNum++;

        eAgent[eAgentNum] = new EconomicAgent(this);
        eAgent[eAgentNum].type="Retail";
        eAgent[eAgentNum].gamma = 0.1; //Consumer Expernditure Survey (2014)
        eAgent[eAgentNum].freq = 1; //residents buy food and services every month
        eAgent[eAgentNum].DataIN(mg);
        EconVImap.addGeometry(new MasonGeometry(eAgent[j].location));
    }
 } System.out.println("number of economic agents = " + eAgentNum);
}

public void createLDRMs(){
  LDRM_Harrison.County= "Harrison";
  LDRM_Jackson.County = "Jackson";
  LDRM_Hancock.County = "Hancock";

  LDRM_Harrison.inti();
  LDRM_Jackson.inti();
  LDRM_Hancock.inti();
}
public void CreateInsurance()
{
```

```
/*=============================================================================
   this step allows to copy the premiums and compensation from the excel file
   in the data folder to the insurance companies.
   =========================================================================== */
   Scanner getPrem =null;
   Scanner getComp = null;
   Scanner getRecoveryRate = null;
   String getPremLOC;
      getPremLOC = "C:\\Saeid\\UTK\\Data\\DSOAMB\\Insurance\\Prem.csv";
   String getCompLOC;
      getCompLOC = "C:\\Saeid\\UTK\\Data\\DSOAMB\\Insurance\\Comp.csv";
   String getRecoveryRateLOC;
      getRecoveryRateLOC = "C:\\Saeid\\UTK\\Data\\DSOAMB\\Insurance\\RecoveryRate.csv";
      try{
         getPrem = new Scanner (new BufferedReader (new FileReader (getPremLOC)));
         getComp = new Scanner (new BufferedReader (new FileReader (getCompLOC)));
         getRecoveryRate = new Scanner (new BufferedReader (new FileReader
(getRecoveryRateLOC)));
            for(int i = 0; i< 3; i ++)
            {
               Ins[i] = new Insurance(this);
               for (int j= 0; j < 3 ; j ++)
               {
                  Ins[i].prem[j] = getPrem.nextDouble();
                  Ins[i].comp[j] = getComp.nextDouble();
                  Ins[i].recoveryRate[j] = getRecoveryRate.nextDouble();
               }
            }
```

```
        }catch(Exception e)
            {System.out.println(e);}
    }

    public void CreateCensus (){
        Bag geoms = EVImap.getGeometries(); //an array containing the CTs
        Bag EconGeoms = EconVImap.getGeometries();
        CT_number = geoms.numObjs;

        for (int i = 0; i <CT_number; i++)
        {
            MasonGeometry Emg = (MasonGeometry) geoms.get(i);
            MasonGeometry EconMg = (MasonGeometry) EconGeoms.get(i);
            Census[i] = new Census(this);
            Census[i].DataIn(Emg, EconMg); //read Environmental and Econmic data
            Census[i].averageEVI();
        }
        EconVulnerabilityIndex();
        // this following part is great for initial values, if for a full run please remove it
        //EVIOutPerYear();
    }

    public void EVIOutPerYear(){
         for (int i=0; i <CT_number; i++)
        {
            file.EVIOut(Census[i]);
        }file.EVIClose();
        System.out.println("Finished EVI Calculations");
```

```
}

public void createHazard(){
    int loc = random.nextInt(CT_number);
    //WindStorm
    MasonGeometry mg = (MasonGeometry) map.getGeometries().get(loc);
    WindStorm.location = mg.getGeometry().getInteriorPoint();

    HazardMap.addGeometry(new MasonGeometry(WindStorm.location));
}

public void factAnalysisScoring(Residence[] R){
    /*===========================================================================

===========================================================================
    This module Calculates the factor analysis using Mostlikelyhood principal
    component.
    The module at each step calculates the average attributes' values for each
    CT. Then it calles the standardizing module to get the variables Z-score
    values. Next it goes through the factor analysis calculations and get the
    loading values, and calculate the SoVI for each CT. Finally, it assign the
    SoVI from each CT to the corresponding Residence in it. (note, we use code
    instead for CT or county).

===========================================================================

==========================================================================*/
    double[][] CTractsValues = new double [getCTnumber()][12];
    double[] num = new double [getCTnumber()];
```

```
DenseMatrix CT  ;//(13,CT_number);

 for (int x = 0; x < CT_number ; x++)
 {
    for (int y = 0; y < 12; y ++) //intiate them with zero value
    {
       CTractsValues[x][y] = 0;
       num[x] = 0;
    }
 }

   for (int x = 0; x <getCTnumber(); x ++)
 {  int counter = 0;
    for (int i =0 ; i < getResNum(); i ++)
    {
       if (R[i].Code == x)
       {
          CTractsValues[x][0] += R[i].Elderly;
           CTractsValues[x][1] += R[i].Vehicle;
           CTractsValues[x][2] += R[i].English;
           CTractsValues[x][3] += R[i].HighSchool;
           CTractsValues[x][4] += R[i].HomeOwnership;
           CTractsValues[x][5] += R[i].income;
           CTractsValues[x][6] += R[i].Age;
           CTractsValues[x][7] += R[i].MobileHome;
           CTractsValues[x][8] += R[i].Females;
           CTractsValues[x][9] += R[i].Phones;
           CTractsValues[x][10]+= R[i].houseValue;
```

```
            CTractsValues[x][11]+= R[i].HighIncome;
            num[x] ++; //count the residence in eact CT
            counter++;
        } if (counter> 150) i = getResNum();
    }
}

//get average
 for (int x = 0; x < getCTnumber() ; x++)
{
    for (int y = 0; y < 12; y ++)
    {
        CTractsValues[x][y] = CTractsValues[x][y]/num[x];
    }
}

 // standrdize the values
Standardize(CTractsValues);

CT = new DenseMatrix(CTractsValues);
FactorAnalysis F1 = new FactorAnalysis(CT,5);
// I am using PCA matrix as it matches the FactorAnalysis more than Dense Matrix
PCAbyEigen PCA = new PCAbyEigen(CT);

DenseMatrix tempF = new DenseMatrix(F1.getEstimators(50).loadings());
//System.out.println("FactorLoadings = " +tempF);
// DenseMatrix tempFF = new DenseMatrix(F1.getEstimators(50).scores());
    double[] tempSOVI = new double[CT_number+1];
```

```
int k = 0;
for (int x = 1; x <= F1.nObs(); x ++)
{
   for (int i = 1; i <= F1.nFactors() ; i ++)
   {
    //  tempSOVI[k] += (PCA.X().get(x, 1) * tempF.get(1, i))-(PCA.X().get(x, 2) * tempF.get(2, i)) -(PCA.X().get(x, 3) * tempF.get(3,i))-(PCA.X().get(x, 4) * tempF.get(4, i))-(PCA.X().get(x,5) * tempF.get(5, i))-(PCA.X().get(x,6) * tempF.get(6, i)) +(PCA.X().get(x, 7) * tempF.get(7, i))+(PCA.X().get(x, 8) * tempF.get(8, i))+(PCA.X().get(x, 9) * tempF.get(9, i)) -(PCA.X().get(x, 10) * tempF.get(10, i)) + (PCA.X().get(x, 11) * tempF.get(11, i))-(PCA.X().get(x, 12) * tempF.get(12, i));
   //the following is after bozdogan advice
      tempSOVI[k] += (PCA.X().get(x, 1) * tempF.get(1, i))+(PCA.X().get(x, 2) * tempF.get(2, i)) +(PCA.X().get(x, 3) * tempF.get(3,i))+(PCA.X().get(x, 4) * tempF.get(4, i))+(PCA.X().get(x,5) * tempF.get(5, i))+(PCA.X().get(x,6) * tempF.get(6, i)) +(PCA.X().get(x, 7) * tempF.get(7, i))+(PCA.X().get(x, 8) * tempF.get(8, i))+(PCA.X().get(x, 9) * tempF.get(9, i)) +(PCA.X().get(x, 10) * tempF.get(10, i)) + (PCA.X().get(x, 11) * tempF.get(11, i))+(PCA.X().get(x, 12) * tempF.get(12, i));
   } //  System.out.println("CT =" + x + " = "+tempSOVI[k]);
 file.CTSOVIOUT(x, tempSOVI[k]);
   k++;
}
// System.out.println(tempFF);


//send back to residence


  for (int j = 0; j <getCTnumber(); j ++)
  {
     for (int i = 0; i < getResNum(); i ++)
     {
        if (R[i].Code == j)
        {
```

```
            R[i].SOVI = tempSOVI[j];
           // System.out.println("Resident # "+i + "SOVI = " +R[i].SOVI);
         }
       }

   }
}

public void Standardize ( double[][] CT){
    double total= 0;
    for (int j =0 ; j < 12 ; j++ )
    {
            for (int i= 0; i < getCTnumber(); i ++)
            {
                total += CT[i][j];
            }
        double mean = total/getCTnumber();
        double var = 0;
            for (int i=0; i < getCTnumber(); i++)
            {
                var += Math.pow((CT[i][j] - mean), 2);
            }
        double std = Math.sqrt(var);
            // z-score
            for (int i= 0; i < getCTnumber(); i ++)
            {
                CT[i][j] = (CT[i][j] - mean)/std;
            }
```

```
    }
}

public void SocialRates (){
    double elderly = 0.032;
    double vehicle = -0.0013;
    double english = 0.0027;
    double highschool = 0.121;
    double homeowner = -0.013;
    double income = 0.025;
    double age = 0.0082;
    double mobilehome = -0.076;
    double pFemale = -0.0006;
    double phone = 0.017;
    double housevalue = 0.0106;
    double highincome = 0.0247;

    for (int i = 0; i < getResNum(); i ++)
    {
        R[i].Age = R[i].Age * (1+age);
        R[i].Elderly = R[i].Elderly * (1+elderly);
        R[i].English = R[i].English * (1+english);
        R[i].Females = R[i].Females * (1+pFemale);
        R[i].HighIncome = R[i].HighIncome * (1 + highincome);
        R[i].HighSchool = R[i].HighSchool * (1 + highschool);
        R[i].HomeOwnership = R[i].HomeOwnership * (1 +homeowner);
        R[i].MobileHome = R[i].MobileHome * (1+mobilehome);
        R[i].Vehicle = R[i].Vehicle * (1+vehicle);
```

```
        R[i].Phones = R[i].Phones * (1 +phone);
        R[i].income = R[i].income * (1+income);
        R[i].houseValue = R[i].houseValue * (1 +housevalue);
    }
}

/*=================================================================
=================================================================
                  Simulated Annealing Modules
=================================================================
=================================================================*/
public void simulatedAnnealingForEVI(){

/*=================================================================
=================================================================
    This step is used to determine the optimal WWTFs distribution in each county
=================================================================
=================================================================*/
int WWTFnum =10;
//Create and declare new WWTF
WWTF[] WWTF = new WWTF[WWTFnum];
    for (int i = 0; i < WWTFnum; i ++)
    {
        WWTF[i] = new WWTF();
    }
createWWTF(WWTF);

System.out.println("WWTF INITIAL VALUES");
```

```
for (int i=0; i<WWTF.length; i++)
{
 System.out.println("WWTF#" +i+ " capacity = " +WWTF[i].capacity);
}
System.out.println("####################");


//Create and declare new locations to be servcied
ServiceLocations[] Service = new ServiceLocations[CT_number];
    for (int i =0; i < CT_number; i++)
    {
        Service[i] = new ServiceLocations();
        Service[i].feasible=Census[i].wwtfFeasibility;
        Service[i].water = Census[i].water;
        Service[i].Land = Census[i].Land;
        Service[i].VegCover = Census[i].VegCover;
        Service[i].need =Census[i].wwNeeds;
        Service[i].wwNeeds = Census[i].wwNeeds;
        Service[i].treatedWasteWater = Census[i].treatedWasteWater;
        Service[i].county = Census[i].County;
        Service[i].HabFragIndex = Census[i].HabFragIndex;
        Service[i].WasteIndex = Census[i].WasteIndex;
        Service[i].LandIndex = Census[i].LandIndex;
        Service[i].LossCoverIndex = Census[i].LossCoverIndex;
        Service[i].PopGrowthIndex = Census[i].PopGrowthIndex;
        Service[i].PopIndex = Census[i].PopIndex;
        Service[i].ReserveIndex= Census[i].ReserveIndex;
        Service[i].TotalVehIndex = Census[i].TotalVehIndex;
```

```
        Service[i].VegCoverIndex= Census[i].VegCoverIndex;
        Service[i].wasteWaterIndex = Census[i].wasteWaterIndex;
        Service[i].EVI = Census[i].EVI;
    }

    //assignment of each WWTF to the location
int[][] assignment = new int[WWTFnum][CT_number];
Random rand = new Random();
//initial solution
for (int i= 0; i < WWTFnum; i++)
{
    for (int j=0; j < CT_number; j ++)

        {//make sure it is in the desired region
            if ((feasibleService(Service[j]))&&(sameCounty(WWTF[i],Service[j])))
            {
                assignment[i][j] = rand.nextInt(2);
                if (assignment[i][j]==1){addLocation(WWTF[i],i,Service[j],j);}
            }else
            {
                assignment[i][j]=0;
            }
        }
}

copyDoubleAssignments(trackAssignments,nextTrackAssignments,WWTF.length,CT_number);

   //offspring service locations for finiding neighbor  (currently just a copy)
```

```
ServiceLocations[] nextService = new ServiceLocations[CT_number];
   for (int i= 0; i < CT_number; i++)
   {
      nextService[i] = new ServiceLocations();
      nextService[i].feasible=Service[i].feasible;
      nextService[i].water = Service[i].water;
      nextService[i].Land = Service[i].Land;
      nextService[i].VegCover = Service[i].VegCover;
      nextService[i].need =Service[i].need;
      nextService[i].wwNeeds = Service[i].wwNeeds;
      nextService[i].treatedWasteWater = Service[i].treatedWasteWater;
      nextService[i].county = Service[i].county;
      nextService[i].HabFragIndex = Service[i].HabFragIndex;
      nextService[i].WasteIndex = Service[i].WasteIndex;
      nextService[i].LandIndex = Service[i].LandIndex;
      nextService[i].LossCoverIndex = Service[i].LossCoverIndex;
      nextService[i].PopGrowthIndex = Service[i].PopGrowthIndex;
      nextService[i].PopIndex = Service[i].PopIndex;
      nextService[i].ReserveIndex= Service[i].ReserveIndex;
      nextService[i].TotalVehIndex = Service[i].TotalVehIndex;
      nextService[i].VegCoverIndex= Service[i].VegCoverIndex;
      nextService[i].wasteWaterIndex =Service[i].wasteWaterIndex;
      nextService[i].EVI = Service[i].EVI;
   }

//create dummy wwtf for offspring (nextWWTF)
WWTF[] nextWWTF = new WWTF[WWTFnum];
   for (int i = 0; i <WWTF.length; i ++)
```

```
    {
        nextWWTF[i] = new WWTF();
        nextWWTF[i].County = WWTF[i].County;
        nextWWTF[i].capacity = WWTF[i].capacity;
        nextWWTF[i].cost = WWTF[i].cost;
        nextWWTF[i].seq = WWTF[i].seq;
        nextWWTF[i].size = WWTF[i].size;
        nextWWTF[i].location = WWTF[i].location;
        nextWWTF[i].value = WWTF[i].value;
        nextWWTF[i].seqCounter = WWTF[i].seqCounter;
    }

System.out.println("########################");
System.out.println("BEING SIMULATED ANNEALING");
System.out.println("########################");

//start the optimization module
    int maxrun =2000000000;
    double T=maxrun;
    double muT=1.00003;
    double minT = 2.0e-9;

for (int t = 0; t < maxrun ; t++)
{
    //System.out.println("Time step "+t);
    //System.out.println("parent evi = " +evaluateEVI(assignment, Service));
    //check schedule
   T = T/muT;
```

```
  if (T<=minT)
  {
     t=maxrun;
     System.out.println("finishing simulated annealing");
  }

   //get next assignment (offsprings)
   //int[][] next =getNextAssignment(WWTF,Service,nextService,assignment);
   int[][] next = nextRandomAssignment(nextWWTF,nextService,assignment);

   //evaluate offsprings and parent then Choose
   double evi1= evaluateEVI(assignment,Service);
   System.out.println("evi1 = " +evi1);
   double evi2= evaluateEVI(next,nextService);
   System.out.println("evi2 = " +evi2);
   if (evi2<evi1) {

copyDoubleAssignments(nextTrackAssignments,trackAssignments,WWTF.length,CT_number);
       copyAssignments(next,assignment,WWTF.length,CT_number);
       copyServiceTo(nextService,Service);
       copyWWTF(nextWWTF,WWTF);
     // System.out.print("accept next from 1st if");
      // System.out.println(" next evi = "+evaluateEVI(next,nextService) + " current evi = " +
evaluateEVI(assignment, Service));
   }else
       {if (Math.exp((evi1-evi2)/T)> Math.random()){ //acceptance probability

copyDoubleAssignments(nextTrackAssignments,trackAssignments,WWTF.length,CT_number);
           copyAssignments(next,assignment,WWTF.length,CT_number);
```

```
            copyServiceTo(nextService,Service);
            copyWWTF(nextWWTF,WWTF);
        //     System.out.println("accept next from 2nd ");
        // System.out.println(" next evi = "+evaluateEVI(next,nextService) + " current evi = " +
evaluateEVI(assignment, Service));
         }
            else{
copyDoubleAssignments(trackAssignments,nextTrackAssignments,WWTF.length,CT_number);
                  copyAssignments(assignment,next,WWTF.length,CT_number);
                  copyServiceTo(Service,nextService);
                  copyWWTF(WWTF,nextWWTF);
                 // System.out.println("reject next");
               }
         }

}
DataOut newFile = new DataOut(this);

newFile.createSimulatedAnnealingWWTFOutcome();
newFile.createSimulatedAnnealingServicesOutcome();
newFile.createSimulatedAnnealingAssignmentsOutcome();
newFile.SimulatedAnnealingOutcome(WWTF, Service, assignment);
newFile.closeSimulatedAnnealingOutcome();

}

public int[][] getNextAssignment(WWTF[] WWTF, ServiceLocations[]
Services,ServiceLocations[]nextServices, int[][] current){
```

```
/*=======================================================================
===========================================================================
finding a new neighbor is simply through:
for every WWTF, if capacity is less than max (!=0)
   find Max EVI for every service location and add it
else
   find max and min EVI for every service location and switch

==========================================================================
==========================================================================*/
int[][]next = new int[WWTF.length][Services.length];
next = current;//copy
for (int x =0; x < WWTF.length ; x ++)
{
   if (WWTF[x].capacity!=0)
   {int check=0; double checkvalue=0;
      for (int y=0; y<Services.length; y++)
      {

if((Services[y].EVI>checkvalue)&&(feasibleService(Services[y]))&&(sameCounty(WWTF[x],S
ervices[y]))) {checkvalue =Services[y].EVI; check=y;}
      }
      next[x][check]=1;
      addNextLocation(WWTF[x],x,nextServices[check],check);
   }else
   {
      int checkmax=0;int checkmin=0; double checkmaxvalue=0; double checkminvalue=
99999;
      for (int y=0; y<Services.length; y++)
      {
```

```
if((Services[y].EVI<=checkminvalue)&&(feasibleService(Services[y]))&&(sameCounty(WWT
F[x],Services[y]))) {checkminvalue =Services[y].EVI; checkmin=y;}
         }
         next[x][checkmin]=0;
         removeNextLocation(WWTF[x],x,nextServices[checkmin],checkmin);
         for (int y=0; y<Services.length; y++)
         {

if((Services[y].EVI>checkmaxvalue)&&(feasibleService(Services[y]))&&(sameCounty(WWTF
[x],Services[y]))) {checkmaxvalue =Services[y].EVI; checkmax=y;}
         }
         next[x][checkmax]=1;
         addNextLocation(WWTF[x],x,nextServices[checkmax],checkmax);
      }
   }
   return next;
}

public int[][] nextRandomAssignment(WWTF[] nextWWTF, ServiceLocations[] nextServices,
int[][] current){
   int[][] next= new int[nextWWTF.length][nextServices.length];


   for (int x = 0; x < nextWWTF.length; x++)
   {
      for (int y = 0; y <nextServices.length; y++)
      {
         int i = random.nextInt(2);


         int check = current[x][y];
```

```
        if (check!=i)
        {
          if (i==1)
          {
if((feasibleService(nextServices[y]))&&(sameCounty(nextWWTF[x],nextServices[y])))
            {
              addNextLocation(nextWWTF[x],x,nextServices[y],y);
              next[x][y]=1;
            } else{
              next[x][y]=0; //not feasible or not same county
            }
          }
          else{
if((feasibleService(nextServices[y]))&&(sameCounty(nextWWTF[x],nextServices[y])))
            {
              removeNextLocation(nextWWTF[x],x,nextServices[y],y);
/*System.out.println("removed location")*/;
              next[x][y]=0;
            }else {
                next[x][y]=0;
               }
          }
        }else
        { //do nothing          System.out.println("did nothing");
          next[x][y]=i;//cause its just the same as current
        }
```

```
        }
    }
    return next;
}

public double evaluateEVI(int[][] current,ServiceLocations[] Service){
    double evi=0;
    for (int i =0; i<CT_number; i++)
    {
        Service[i].averageEVI();
        evi += Service[i].EVI;
    }evi = evi/CT_number;
    return evi;
}

public boolean sameCounty(WWTF WWTF, ServiceLocations Service)
{
    if (Service.county.equals(WWTF.County))
    return true;
    else return false;
}

public boolean feasibleService(ServiceLocations Service){
    if (Service.feasible==1)return true;
    else return false;
}

public void removeLocation(WWTF WWTF, int i,ServiceLocations Service, int j){
```

```
 /*System.out.println("before removing, WWTF#"+i+ " capacity = " + WWTF.capacity + " and service#" +j+ " need = " + Service.need);*/
WWTF.capacity += trackAssignments[i][j];
Service.need +=trackAssignments[i][j];
//  System.out.println("removed " +trackAssignments[i][j] + " from WWTF#"+i);
Service.adjustNeedNeg(trackAssignments[i][j]);
trackAssignments[i][j]=0;
WWTF.removeLocation(j, Service, CT_number);
 /*System.out.println("after removing, WWTF#"+i+ " capacity = " +WWTF.capacity + " and service#" +j+ " need = " +Service.need);*/
}

public void addLocation (WWTF WWTF, int i, ServiceLocations Service, int j){
   /* System.out.println("before adding, WWTF#"+i+ " capacity = " +WWTF.capacity + " and service#" +j+ " need = " +Service.need);*/
   if (WWTF.capacity>=Service.need)
   {
      WWTF.capacity-=Service.need;
      double value = Service.need;
      trackAssignments[i][j]= value;
      Service.need = 0;
   }
   else
   {
      Service.need -= WWTF.capacity;
      double value = WWTF.capacity;
      trackAssignments[i][j]=value;
      WWTF.capacity = 0;
   }
```

```
    Service.adjustNeedPos(trackAssignments[i][j]);
    WWTF.addLocation(j, Service);
  // System.out.println("added " +trackAssignments[i][j] + " to WWTF#"+i);
     /* System.out.println("after adding, WWTF#"+i+ " capacity = " +WWTF.capacity + " and
service#" +j+ " need = " +Service.need);*/
}

public void removeNextLocation(WWTF nextWWTF, int i,ServiceLocations nextService, int j){
   /* System.out.println("before removing, WWTF#"+i+ " capacity = " +nextWWTF.capacity + "
and service#" +j+ " need = " +nextService.need);*/
    nextWWTF.capacity += nextTrackAssignments[i][j];
    nextService.need += nextTrackAssignments[i][j];
  // System.out.println("removed " + nextTrackAssignments[i][j] + " from nextWWTF#"+i);
    nextService.adjustNeedNeg(nextTrackAssignments[i][j]);
    nextTrackAssignments[i][j] =0;
    nextWWTF.removeLocation(j, nextService, CT_number);
    /*System.out.println("after removing, WWTF#"+i+ " capacity = " +nextWWTF.capacity + "
and service#" +j+ " need = " +nextService.need);*/
}

public void addNextLocation (WWTF nextWWTF, int i, ServiceLocations nextService, int j){
    /* System.out.println("before adding, WWTF#"+i+ " capacity = " +nextWWTF.capacity + "
and service#" +j+ " need = " +nextService.need);*/
    if (nextWWTF.capacity>=nextService.need)
    {
        nextWWTF.capacity-=nextService.need;
        double value = nextService.need;
        nextTrackAssignments[i][j]=value;
        nextService.need = 0;
    }
```

```
    else
    {
        nextService.need -= nextWWTF.capacity;
        double value = nextWWTF.capacity;
        nextTrackAssignments[i][j]=value;
        nextWWTF.capacity = 0;

    }
   double x = nextTrackAssignments[i][j];
    nextService.adjustNeedPos(x);
    nextWWTF.addLocation(j, nextService);
   // System.out.println("added " +nextTrackAssignments[i][j] + " to nextWWTF#"+i);
      /*System.out.println("after adding, WWTF#"+i+ " capacity = " +nextWWTF.capacity + "
and service#" +j+ " need = " +nextService.need);*/
}

public void copyServiceTo(ServiceLocations[] Src, ServiceLocations[] Dist)//SRC then Dist
{
    for (int i= 0; i < CT_number; i++)
    {
        Dist[i].feasible=Src[i].feasible;
        Dist[i].water = Src[i].water;
        Dist[i].need =Src[i].need;
        Dist[i].Land = Src[i].Land;
        Dist[i].VegCover = Src[i].VegCover;
        Dist[i].wwNeeds = Src[i].wwNeeds;
        Dist[i].treatedWasteWater = Src[i].treatedWasteWater;
        Dist[i].county = Src[i].county;
        Dist[i].HabFragIndex = Src[i].HabFragIndex;
```

```
        Dist[i].WasteIndex = Src[i].WasteIndex;
        Dist[i].LandIndex = Src[i].LandIndex;
        Dist[i].LossCoverIndex = Src[i].LossCoverIndex;
        Dist[i].PopGrowthIndex = Src[i].PopGrowthIndex;
        Dist[i].PopIndex = Src[i].PopIndex;
        Dist[i].ReserveIndex= Src[i].ReserveIndex;
        Dist[i].TotalVehIndex = Src[i].TotalVehIndex;
        Dist[i].VegCoverIndex= Src[i].VegCoverIndex;
        Dist[i].wasteWaterIndex =Src[i].wasteWaterIndex;
        Dist[i].EVI = Src[i].EVI;
    }
}

public void copyAssignments(int[][] Src, int[][] Dist, int X, int Y)//Source then dist, x and y)
{
    for (int x =0; x <X ; x ++)
    {
        for (int y =0; y< Y; y++)
        {
            Dist[x][y] = Src[x][y];
        }
    }
}

public void copyDoubleAssignments(double[][] Src, double[][] Dist, int X, int Y)//Source then
dist, x and y)
{
    for (int x =0; x <X ; x ++)
    {
```

```
        for (int y =0; y< Y; y++)
        {
            Dist[x][y] = Src[x][y];
        }
    }
}

public void copyWWTF(WWTF[] Src, WWTF[] Dist)
{
    for (int i = 0; i <Src.length; i ++)
    {
        Dist[i].County = Src[i].County;
        Dist[i].capacity = Src[i].capacity;
        Dist[i].cost = Src[i].cost;
        Dist[i].seq = Src[i].seq;
        Dist[i].size = Src[i].size;
        Dist[i].location = Src[i].location;
        Dist[i].value = Src[i].value;
        Dist[i].seqCounter = Src[i].seqCounter;
    }
}

public void createWWTF(WWTF[] WWTF){
    Scanner getWWTF =null;
    String getWWTFLOC;
        getWWTFLOC =
"C:\\Saeid\\UTK\\MASON\\Trial\\MasonTrail\\src\\DSOAMB\\Data\\WWTF\\WWTF.csv";
    try{
        getWWTF = new Scanner (new BufferedReader (new FileReader (getWWTFLOC)));
```

```
   for (int i =0; i<WWTF.length; i++)
   {
      WWTF[i].capacity= getWWTF.nextDouble();
      WWTF[i].cost = getWWTF.nextDouble();
      WWTF[i].size =getWWTF.nextDouble();
      WWTF[i].County = getWWTF.next();
   }
   }catch(Exception e)
         {System.out.println(e);}
}

/*=====================================================================
======================================================================
              Modules for the Economic Vulenrability
======================================================================
=====================================================================*/
public void StandardizeEconData(){
   double maxHomeOwnerShip=0, maxEmployment=0, maxFemaleLabor=0, maxIncome=0,
maxNonPrimary = 0;
   double maxLarge2Small=0, maxRetail=0, maxCommerical=0, maxLending=0, maxDoc=0,
maxMeanSales = 0;


   double minHomeOwnerShip=99999999, minEmployment=99999999,
minFemaleLabor=99999999, minIncome=99999999, minNonPrimary = 99999999;
   double minLarge2Small=99999999, minRetail=99999999, minCommerical=99999999,
minLending=99999999, minDoc=99999999, minMeanSales = 99999999;
   //get Max and Min
   for (int i=0; i<CT_number; i++)
   {
```

```
if (Census[i].HomeOwnership > maxHomeOwnerShip ) maxHomeOwnerShip =
Census[i].HomeOwnership;
if (Census[i].HomeOwnership < minHomeOwnerShip ) minHomeOwnerShip =
Census[i].HomeOwnership;

if (Census[i].employment > maxEmployment) maxEmployment = Census[i].employment;
if (Census[i].employment < minEmployment) minEmployment = Census[i].employment;

if (Census[i].femalLabor > maxFemaleLabor) maxFemaleLabor = Census[i].femalLabor;
if (Census[i].femalLabor < minFemaleLabor) minFemaleLabor = Census[i].femalLabor;

if (Census[i].income  > maxIncome) maxIncome = Census[i].income;
if (Census[i].income  < minIncome) minIncome = Census[i].income;

if (Census[i].nonPrimary > maxNonPrimary) maxNonPrimary = Census[i].nonPrimary;
if (Census[i].nonPrimary < minNonPrimary) minNonPrimary = Census[i].nonPrimary;

if (Census[i].small2Large > maxLarge2Small) maxLarge2Small = Census[i].small2Large;
if (Census[i].small2Large < minLarge2Small) minLarge2Small = Census[i].small2Large;

if (Census[i].retail > maxRetail) maxRetail = Census[i].retail;
if (Census[i].retail < minRetail) minRetail = Census[i].retail;

if(Census[i].commerical > maxCommerical ) maxCommerical = Census[i].commerical;
if(Census[i].commerical < minCommerical ) minCommerical = Census[i].commerical;

if(Census[i].lending > maxLending) maxLending = Census[i].lending;
if(Census[i].lending < minLending) minLending = Census[i].lending;
```

```
        if (Census[i].doctors > maxDoc) maxDoc = Census[i].doctors;
        if (Census[i].doctors < minDoc) minDoc = Census[i].doctors;

        if (Census[i].meanSales > maxMeanSales) maxMeanSales = Census[i].meanSales;
        if (Census[i].meanSales < minMeanSales) minMeanSales = Census[i].meanSales;

    }
   //Standardize
    for (int i=0; i<CT_number; i++)
    {
        Census[i].standardizeHomeOwnership(maxHomeOwnerShip, minHomeOwnerShip);
        Census[i].standardizeEmployment(maxEmployment, minEmployment);
        Census[i].standardizeFemaleLabor(maxFemaleLabor, minFemaleLabor);
        Census[i].standardizeIncome(maxIncome, minIncome);
        Census[i].standadizeNonPrimary(maxNonPrimary, minNonPrimary);
        Census[i].standardizeSmall2Large(maxLarge2Small, minLarge2Small);
        Census[i].standrdizeRetail(maxRetail, minRetail);
        Census[i].standrdizeCommerical(maxCommerical, minCommerical);
        Census[i].standardizeLedning(maxLending, minLending);
        Census[i].standardizeDoc(maxDoc, minDoc);
        Census[i].stanardizeMeanSales(maxMeanSales, minMeanSales);

    }
}

public void EconVulnerabilityIndex(){
/*=====================================================================
======================================================================
```

Economic Vulenrability

```
================================================================================
=============================================================================*/
   //First Standaridze data
  StandardizeEconData();
   //Create a matrix to hold all the data

  double[][] CensusEcon = new double [CT_number][11];
  for (int i = 0; i<CT_number; i++)
  {
       CensusEcon[i][0] = Census[i].StHomeOwnership;
       CensusEcon[i][1] = Census[i].StEmployment;
       CensusEcon[i][2] = Census[i].StFemalLabor;
       CensusEcon[i][3] = Census[i].StIncome;
       CensusEcon[i][4] = Census[i].StNonPrimary;
       CensusEcon[i][5] = Census[i].StSmall2Large;
       CensusEcon[i][6] = Census[i].StRetail;
       CensusEcon[i][7] = Census[i].StCommerical;
       CensusEcon[i][8] = Census[i].StLending;
       CensusEcon[i][9] = Census[i].StDoctors;
       CensusEcon[i][10] = Census[i].StMeanSales;

  }
  //Factor Analysis using 3 factors
    DenseMatrix CT ;
  CT = new DenseMatrix(CensusEcon);
  //System.out.println(CT);
  FactorAnalysis F1 = new FactorAnalysis(CT,3);
```

```
    DenseMatrix tempF = new DenseMatrix(F1.getEstimators(50).loadings());


    //resting the CT EconVI values
    for (int i = 0; i < CT_number; i ++)
    {
      Census[i].EconVI = 0;
    }
    int k = 0;
    for (int i = 1; i<= F1.nObs(); i ++)
    {
      for (int j=1; j<= F1.nFactors(); j ++)
      {
        Census[k].EconVI += (CT.get(i,1)*tempF.get(1, j)) + (CT.get(i, 2) * tempF.get(2,j)) +
(CT.get(i, 3)*tempF.get(3, j))+ (CT.get(i, 4)*tempF.get(4, j)) + (CT.get(i, 5)*tempF.get(5,j)) +
(CT.get(i,6)*tempF.get(6, j))+ (CT.get(i, 7)*tempF.get(7, j)) + (CT.get(i, 8)*tempF.get(8, j))+
(CT.get(i,9)*tempF.get(9, j))+ (CT.get(i, 10)*tempF.get(10, j)) + (CT.get(i, 11)*tempF.get(11,
j)) ;
      }
    k++;
    }
}


}
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (FDRC) is the Federal Disaster Recovery Coordinator
 */

package DSOAMB;
import sim.engine.*;
/**
 *
 * @author MSaeid
 */
public class FDRC implements Steppable {
    int stepCounter = 0;
    int fundCounter =0;
    double funds = 2000000000;
    FieldSim FSmodel;

    public FDRC (FieldSim FSmodel){
        this.FSmodel= FSmodel;
    }

    public void step(SimState state){
      stepCounter ++;
       if (stepCounter == 12){ funds = 2000000000; stepCounter = 0;} // new cycle
```

```
    if (FSmodel.WindStorm.damage > 0.85){ // in case of catstrphy
        fundRaise();
    }
  }

  public void fundRaise (){

   if ((FSmodel.SDRC.funds <1000000000) && (fundCounter<2))
   {
       FSmodel.SDRC.funds += 1000000000;
       fundCounter++;
   }
  }
}
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (SDRC) is the State Disater Recovery Coordinator agent
 */
package DSOAMB;
import com.vividsolutions.jts.geom.Envelope;
import java.awt.Toolkit;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import java.util.ArrayList;
import sim.engine.*;
import java.util.Collections;
import java.util.List;
import javax.swing.JComboBox;
import javax.swing.JFrame;
import sim.util.Bag;
import sim.util.geo.MasonGeometry;
/**
 *
 * @author MSaeid
 */
/*=========================================================================
=========================================================================

                State Disaster Recovery Coordinator (SDRC)
SDRC, as refered by FEMA's NDRF, is the coordinator for recovery in the state
```

and, as noticed in the State of Mississippi through the Katrina Recovery, is considered the main agent in the managing the recovery process.

In this module, the SDRC agent will be represnеted along with his actions and learning module.

objective: Increase the individual's utility (further more in the research we should tie increase in resilience and more factors to be increase.

Actions: 1- Repair and Rebuild homes for low income family (public homes) [PubHome]

2- Repair and Rebuild homes for renters [Repair]

3- Elevation of houses (houses upgrades) [Upgrade]

4- Small Business Loan (SBL) [SmallEconAgentAid]

Constriants: The amount of funding SDRC has plus the amount funded by FEMA in case of catastrophy or sever need of fund.

```
====================================================================
==================================================================*/
public class SDRC implements Steppable {

    /*======================================
    =======================================
        What to Optimize!
    =======================================
    ======================================*/

    public boolean social = false;
    public boolean enviro = false;
    public boolean econom = true;
```

```
FieldSim FSmodel;
FieldSimWithUI GUI;
double Utility=1;
double DeltaUtility=1;
public double AvgSOVI =0;
public double MaxSOVI;
public double MinSOVI;

//SOVI
double PubHomeSOVI; double p=1;
double UpgradeSOVI; double u= 1;
double RepairSOVI; double r = 1;
double SmallEconAgentAidSOVI; double s =1;
double ExemptionsSOVI;

double PubHomeSOVIRank;
double UpgradeSOVIRank;
double RepairSOVIRank;
double SmallEconAgentAidSOVIRank;
double ExemptionsSOVIRank;

//EVI
double PubHomeEVI;
double UpgradeEVI;
double RepairEVI;
double SmallEconAgentAidEVI;
double ExemptionsEVI;
```

```
double PubHomeEVIRank;
double UpgradeEVIRank;
double RepairEVIRank;
double SmallEconAgentAidEVIRank;
double ExemptionsEVIRank;

//EconVI
double PubHomeEconVI;
double UpgradeEconVI;
double RepairEconVI;
double SmallEconAgentAidEconVI;
double ExemptionsEconVI;

double PubHomeEconVIRank;
double UpgradeEconVIRank;
double RepairEconVIRank;
double SmallEconAgentAidEconVIRank;
double ExemptionsEconVIRank;

//strategies propesnity
double QPubHome=1;
double QRepair=1;
double QUpgrade=1;
double QSmallEconAgentAid = 1;
double QExemptions=1;

/*
```

```
double QPubHome=1/25;
double QRepair=21/25;
double QUpgrade=2.5/25;
*/
double UpgradeRank;
double RepairRank;
double PubHomeRank;
double SmallEconAgentAidRank;
double ExemptionsRank;
//strategies probabilities

double probPubHome=.04; //values used by government
double probRepair=.8;
double probUpgrade=.04;
double probSmallEconAgentAid = 0.12;
double probExemptions =0;

double PubHomeReward = 0; // roth e'rve learning rewards
double RepairReward = 0;
double UpgradeReward = 0;
double SmallEconAgentAidReward = 0;
double ExemptionsReward=0;

//grants and awards
double RepairAward = 150000; //maximum
double PubHomeAward = 50000;  // from fedral review
double UpgradeAward = 30000; // maximum
double SmallEconAgentAidAward = 275000; //average of small business award
```

```
double funds = 1000000000;

double RepairFunds = 0;
double PubHomeFunds = 0;
double UpgradeFunds = 0;
double SmallEconAgentAidFunds = 0;
double ExemptionsFunds = 0;

double RepairCost  = 0;
double UpgradeCost = 0;
double PubHomeCost = 0;
double SmallEconAgentAidCost = 0;
double ExemptionsCost =0;

int[] upgradeControl;

double damage;

int MaxStep = 72;

int stepCounter= 0;
int taxcounter=0;
int OverallCounter;
int threeStepCounter = 0;
int sixStepCounter =0;

long totalFund=0;
```

```
 // Q LEARNING PARAMETERS
 double alpha = 0.2;
 double gamma = 0.2;

 double Qup=.25;
 double QR= .25;
 double Qp=.25;
 double Qse = .25;

//learning moduels swtich
 boolean RV=false ;
 boolean Qlearning=false;

 //list of all Qs for bar char output
 public List<Double> PubHomelist = new ArrayList<Double>();
 public List<Double> Repairlist = new ArrayList<Double>();
 public List<Double> Upgradelist = new ArrayList<Double>();
 public List<Double> SmallEconAgentAidlist = new ArrayList<Double>();

 public SDRC(FieldSim FSmodel){
    this.FSmodel = FSmodel;

 }
    public void step (SimState state){
```

```
if (stepCounter == 0) //change stepcounter
{   redistributeFund();
   //initail Vulnerability Assessment
   EVIOut();
   EconVIOut();


}
  //SOVI
   FSmodel.LDRM_Hancock.getResSOVI(); // assign the AvgSoVI for each county
   FSmodel.LDRM_Harrison.getResSOVI();
   FSmodel.LDRM_Jackson.getResSOVI();

   /* this is made to calculate the SoVI per year
   FSmodel.file.OutGOV(this,0); //remove when done
   FSmodel.file.CloseGOV();//remove when done
   */

   FSmodel.file.OutRes(FSmodel.R);// file out residents
   FSmodel.file.fundOut();//print out fund expindeture

   //reset costs
   RepairCost  = 0;
   UpgradeCost = 0;
   PubHomeCost = 0;
   SmallEconAgentAidCost=0;
   ExemptionsCost =0;

taxcounter ++;
```

```
//annaual
if (taxcounter ==12)
{
    FSmodel.SocialRates();
    taxcounter =0;
     for (int i = 0; i <FSmodel.CT_number; i++)
        {
            FSmodel.Census[i].addEconAgent();
        }
     FSmodel.redrawEconMap();
    EVIOut();
    EconVIOut();
}

//biannual
sixStepCounter++;
if (sixStepCounter==6)
{// funds are assest every six month
    getFund(); sixStepCounter = 0;
}

//Quarter Annual
threeStepCounter++;
if (threeStepCounter==3)
{  threeStepCounter=0;
//Vulnerability assessments
    //Sovi
    getSOVI();
```

```
    //EVI
    getEVI();
    //EconVI
    getEconVI();

    //only if you want to do it every three month
    if ((RV) || (Qlearning)){redistributeFund();}

    //file output
    FSmodel.file.OutGOV(this, OverallCounter); //file out government
    FSmodel.file.EconAgentAverage(FSmodel.eAgent);
}
//fund redistribution every step
// if ((RV) || (Qlearning)){redistributeFund();}

stepCounter++;
System.out.println("Counter = " +stepCounter);

getUtility(); //calculate over all utility (NOT REALLY USED NOW AT ALL)

//EconAgent output
if (stepCounter != MaxStep)
{
    for (int i = 0; i <FSmodel.eAgentNum; i ++)
    {
   FSmodel.file.EconAgentOut(FSmodel.eAgent[i]);
    }FSmodel.file.EconAgentLine();
}
```

```
    OverallCounter++;
    if (OverallCounter == MaxStep) //closing the model
    {
        //GUI gui = new GUI(FSmodel);
        //gui.BarChart();
        FSmodel.file.CloseGOV();
        FSmodel.file.EconVIClose();
        FSmodel.schedule.clear();

        //  FSmodel.simulatedAnnealingForEVI();
        System.out.println("#################");
        System.out.println("End of Simulation");
        System.out.println("#################");
        Toolkit.getDefaultToolkit().beep();
    }

    //this is for the residents and econ agent through the census tract
    //I used SDRC as it is the last to play
    //this will determine if we will add a new retail center (eAgent)
}


public double setDamage(){
    return FSmodel.WindStorm.damage;
}

public void getDamage(){
```

```
    damage = setDamage();
  }

  public void getUtility(){
    /* ==============================================================
==============================================================
                *******NOT REALLY USED NOW AT ALL********
    setting the utility as a function of all the residence relative increase
    in utility. Then calculate its relative increase or decrease in overall
    utility.
    1 = no change
    < 1 decrease
    > 1 increase

=============================================================
==============================================================*/
  double OldUtility = Utility;
    Utility = 0;
    double low = 0;
    double Wlow=0.5;
    double moderate =0;
    double Wmoderate = 0.3;
    double high = 0;
    double Whigh = 0.2;
    AvgSOVI =0;
    MaxSOVI = -999;
    MinSOVI = 999;
    for (int i = 0; i < FSmodel.getResNum(); i ++)
    { if(FSmodel.R[i].SOVI > MaxSOVI)  MaxSOVI = FSmodel.R[i].SOVI;
```

```
      if(FSmodel.R[i].SOVI<MinSOVI) MinSOVI = FSmodel.R[i].SOVI;
      if (FSmodel.R[i].SOVI<-1){
        low = low+ FSmodel.R[i].Utility;
      }else
        if(FSmodel.R[i].SOVI<1){
          moderate += FSmodel.R[i].Utility;
        }else
        {
          high+=FSmodel.R[i].Utility;
        }
      AvgSOVI += FSmodel.R[i].SOVI;
    }
    AvgSOVI = AvgSOVI/FSmodel.getResNum();

    Utility = (low*Wlow) + (moderate*Wmoderate) + (high*Whigh) +AvgSOVI;
    if (stepCounter==0){
      OldUtility = Utility;
    }
    // NaN and Infinity check....
    if (Math.abs(OldUtility) < 0.001) {OldUtility = 0.001;}
    DeltaUtility = (Utility-OldUtility)/OldUtility;
    if (Double.isNaN(DeltaUtility)){DeltaUtility =1;}
  }


/*=====================================================================
======================================================================

                Er've and Roth Learning Module
  The learning module used is the Er've and Roth Reinforced learning (1998).
```

```
==============================================================================
=============================================================================*/
  public void getRelativeFitness(){
    //First choose the vulnerability evaluation dimension
    if (social && econom && enviro)
    {//all
      SOVI_EVI_EconVI();
    }else {
      if (social && !econom && enviro)
      {
         //EVI and SOVI
         SOVI_EVI();
      }
        else {
              if(social && econom && !enviro)
              {
              SOVI_EconVI();
              }else {
                 if(social && !econom && ! enviro)
                 {
                  //This is for the SOVI Only
                   socialOnly();
                 }else
                 {
                    if(!social && !econom && enviro)
                    {
                       //This is for the EVI only
                       enviOnly();
```

```
                    }else {
                        if(!social &&econom && enviro)
                        { //economic and environmental
                            EVI_EconVI();
                        }else{
                            if (!social && econom && !enviro)
                            {//economic only
                                econOnly();
                            }
                        }
                    }
                }
            }
        }
    }

    //now, get the actions relative fitness (relative fitness = 1/rank)
    RepairReward = 1/RepairRank;
    UpgradeReward = 1/UpgradeRank;
    PubHomeReward = 1/PubHomeRank;
    SmallEconAgentAidReward = 1/SmallEconAgentAidRank;
    ExemptionsReward= 1/ExemptionsRank;
}

public void socialOnly(){
    RepairRank = (RepairRank + RepairSOVIRank)/2;
    UpgradeRank = (UpgradeRank + UpgradeSOVIRank)/2;
    PubHomeRank = (PubHomeRank + PubHomeSOVIRank)/2;
```

```
    SmallEconAgentAidRank = SmallEconAgentAidRank;
}

public void enviOnly(){
    RepairRank = (RepairRank + RepairEVIRank)/2;
    UpgradeRank = (UpgradeRank + UpgradeEVIRank)/2;
    PubHomeRank = (PubHomeRank + PubHomeEVIRank)/2;
    SmallEconAgentAidRank = (SmallEconAgentAidRank + SmallEconAgentAidEVIRank)/2;
    ExemptionsRank = (ExemptionsRank + ExemptionsEVIRank)/2;

    double han=0; int han1=0;
    double har=0; int har1=0;
    double jak=0; int jak1=0;
        for (int i =0;i <FSmodel.CT_number ;i ++ )
        {
            if (FSmodel.Census[i].County.equals("Hancock"))
            {
                han+= FSmodel.Census[i].EVI;
                han1++;
            }
            if (FSmodel.Census[i].County.equals("Harrison"))
            {
                har+= FSmodel.Census[i].EVI;
                har1++;
            }
            if (FSmodel.Census[i].County.equals("Jackson"))
            {
                jak+= FSmodel.Census[i].EVI;
```

```
                jak1++;
            }
        }
        han = han/han1;
        har = har/har1;
        jak = jak/jak1;
    }


    public void econOnly(){
        RepairRank = (RepairRank + RepairEconVIRank)/2;
        UpgradeRank = (UpgradeRank + UpgradeEconVIRank)/2;
        PubHomeRank = (PubHomeRank + PubHomeEconVIRank)/2;
        SmallEconAgentAidRank = (SmallEconAgentAidRank +
SmallEconAgentAidEconVIRank)/2;
        ExemptionsRank = (ExemptionsRank + ExemptionsEconVIRank)/2;


        double han=0; int han1=0;
            double har=0; int har1=0;
            double jak=0; int jak1=0;
            for (int i =0;i <FSmodel.CT_number ;i ++ )
            {
                if (FSmodel.Census[i].County.equals("Hancock"))
                {
                    han+= FSmodel.Census[i].EconVI;
                    han1++;
                }
                if (FSmodel.Census[i].County.equals("Harrison"))
                {
                    har+= FSmodel.Census[i].EconVI;
```

```
                har1++;
            }
            if (FSmodel.Census[i].County.equals("Jackson"))
            {
                jak+= FSmodel.Census[i].EconVI;
                jak1++;
            }
        }
        han = han/han1;
        har = har/har1;
        jak = jak/jak1;


    }
    public void SOVI_EconVI()
    {
     System.out.println("YOU DID NOT ADD THIS  MODULE YET!");
    }

    public void EVI_EconVI(){
      System.out.println("YOU DID NOT ADD THIS  MODULE YET!");
    }

    public void SOVI_EVI(){
        RepairRank = (RepairRank + RepairSOVIRank + RepairEVIRank)/3;
        UpgradeRank = (UpgradeRank + UpgradeSOVIRank + UpgradeEVIRank)/3;
        PubHomeRank = (PubHomeRank + PubHomeSOVIRank + PubHomeEVIRank)/3;
    }
```

```
public void SOVI_EVI_EconVI(){
    RepairRank = (RepairRank + RepairSOVIRank + RepairEVIRank + RepairEconVIRank)/4;
    UpgradeRank = (UpgradeRank + UpgradeSOVIRank + UpgradeEVIRank +
UpgradeEconVIRank)/4;
    PubHomeRank = (PubHomeRank + PubHomeSOVIRank + PubHomeEVIRank +
PubHomeEconVIRank)/4;
    SmallEconAgentAidRank = (SmallEconAgentAidRank + SmallEconAgentAidEVIRank +
SmallEconAgentAidEconVIRank)/3;
}



public void getRank(){
    rankReward();
    rankSOVI();
    rankEVI();
    rankEconVI();
    getRelativeFitness();
}

public void rankReward(){

    List<Double> list = new ArrayList<Double>();

    list.add(UpgradeReward);
    list.add(RepairReward);
    list.add(PubHomeReward);
    list.add(SmallEconAgentAidReward);
    Collections.sort(list);
```

```
 Collections.reverse(list); //maximize
double sum =0;

 for (int i =0; i <list.size();i++)
 {
      sum += list.get(i);
 }

 if (sum==0)
 {
    UpgradeRank = 1;
    RepairRank = 1;
    PubHomeRank =1;
    //ExemptionsRank=1;
    SmallEconAgentAidRank =1;
 }
 else{

    for (int i = 0; i <list.size(); i ++)
    {
      if (list.get(i) == UpgradeReward) UpgradeRank = i+1;
      if (list.get(i) == RepairReward) RepairRank = i+1;
      if (list.get(i) == PubHomeReward) PubHomeRank =i+1;
      //if (list.get(i) == ExemptionsReward) ExemptionsRank=i+1;
      if (list.get(i) == SmallEconAgentAidReward) SmallEconAgentAidRank =i+1;
    }
 }
/*  System.out.println();
```

```
System.out.println("Upgrade Reward Rank = " +UpgradeRank);
System.out.println("Repair Reward Rank = " +RepairRank);
System.out.println("PubHome Reward Rank = " +PubHomeRank);
System.out.println("SBL Reward Rank = " +SmallEconAgentAidRank);
System.out.println();*/

/*
        ******************
        ******************
         an old approach
        ******************
        ******************
//first rank rewards from utility
if ((UpgradeReward == RepairReward)&&(UpgradeReward == PubHomeReward))
{
  UpgradeRank= 1; RepairRank=1; PubHomeRank = 1;
}
else
{
  if ((UpgradeReward>= RepairReward) && (UpgradeReward>=PubHomeReward ))
  {
    UpgradeRank =1;
    if (RepairReward>= PubHomeReward)
    {RepairRank = 2; PubHomeRank =3;}
    else
    {PubHomeRank = 2; RepairRank =3;}
  }else
  {
```

```
        if((RepairReward >= UpgradeReward)&&(RepairReward>= PubHomeReward))
        {
          RepairRank = 1;
          if (UpgradeReward >= PubHomeReward)
          {UpgradeRank = 2; PubHomeRank =3;}
          else
          {PubHomeRank = 2; UpgradeRank =3;}
        }else
        {
          PubHomeRank =1;
          if (UpgradeReward>= RepairReward)
          {UpgradeRank =2; RepairRank =3;}
          else{RepairRank =2; UpgradeRank=3;}
        }
      }
    }*/
  }

  public void rankSOVI(){
     //rank average SOVI (Max SOVI which acually decrease vulnerabiity, signs are invertead)
    /*if ((UpgradeSOVI == RepairSOVI)&&(UpgradeSOVI == PubHomeSOVI))
    {
      UpgradeSOVIRank =1; RepairSOVIRank =1; PubHomeSOVIRank=1;
    }
    else
    {
      if ((UpgradeSOVI>= RepairSOVI) && (UpgradeSOVI >=PubHomeSOVI ))
      {
```

```
    UpgradeSOVIRank =1;
    if (RepairSOVI >= PubHomeSOVI)
    {RepairSOVIRank = 2; PubHomeSOVIRank =3;}
    else
    {PubHomeSOVIRank = 2; RepairSOVIRank =1;}
  }else
  {
    if((RepairSOVI >= UpgradeSOVI)&&(RepairSOVI>= PubHomeSOVI))
    {
      RepairSOVIRank = 1;
      if (UpgradeSOVI >= PubHomeSOVI)
      {UpgradeSOVIRank = 2; PubHomeSOVIRank =3;}
      else
      {PubHomeSOVIRank = 2; UpgradeSOVIRank =3;}
    }else
    {
      PubHomeSOVIRank =1;
      if (UpgradeSOVI>= RepairSOVI)
      {UpgradeSOVIRank =2; RepairSOVIRank =3;}
      else{RepairSOVIRank =2; UpgradeSOVIRank=3;}
    }
  }
}*/

ArrayList<Double> list = new ArrayList<Double>();
list.add(UpgradeSOVI);
list.add(RepairSOVI);
list.add(PubHomeSOVI);
```

```
    Collections.sort(list);
    Collections.reverse(list);

    if((UpgradeSOVI == RepairSOVI) && (UpgradeSOVI==PubHomeSOVI))
    {
      UpgradeSOVIRank=1; RepairSOVIRank=1; PubHomeSOVIRank =1;
    }else{
    for (int i =0; i <list.size(); i++)
    {
      if(list.get(i) == UpgradeSOVI) UpgradeSOVIRank = i+1;
      if(list.get(i) == RepairSOVI) RepairSOVIRank = i+1;
      if(list.get(i) == PubHomeSOVI) PubHomeSOVIRank = i+1;
    }
    }

    /*System.out.println("PubHome SoVI = " + PubHomeSOVI);
    System.out.println("Repair SoVI = " + RepairSOVI);
    System.out.println("Upgrade SoVI = " + UpgradeSOVI);
    System.out.println("PubHome SoVI Rank = " +PubHomeSOVIRank);
    System.out.println("Repair SoVI Rank = " +RepairSOVIRank);
    System.out.println("Upgrade SoVI Rank = " +UpgradeSOVIRank);*/

  }

  public void rankEVI(){
    //rank EVI depending on the change in delta of EVI - is most resilient + is least resilient

    List<Double> list = new ArrayList<Double>();
```

```
list.add(UpgradeEVI);
list.add(RepairEVI);
list.add(PubHomeEVI);
// list.add(ExemptionsEVI);
list.add(SmallEconAgentAidEVI);

Collections.sort(list);

double sum =0;

for (int i =0; i <list.size();i++)
{
     sum += list.get(i);
}

if (sum==0)
{
    UpgradeEVIRank = 1;
    RepairEVIRank = 1;
    PubHomeEVIRank =1;
  //  ExemptionsEVIRank=1;
    SmallEconAgentAidEVIRank =1;
}
else{

    for (int i = 0; i <list.size(); i ++)
    {
```

```
            if (list.get(i) == UpgradeEVI) UpgradeEVIRank = i+1;
            if (list.get(i) == RepairEVI) RepairEVIRank = i+1;
            if (list.get(i) == PubHomeEVI) PubHomeEVIRank =i+1;
           // if (list.get(i) == ExemptionsEVI) ExemptionsEVIRank=i+1;
            if (list.get(i) == SmallEconAgentAidEVI) SmallEconAgentAidEVIRank =i+1;
          }
        }
    }

    public void rankEconVI(){
      List<Double> list = new ArrayList<Double>();

      list.add(UpgradeEconVI);
      list.add(RepairEconVI);
      list.add(PubHomeEconVI);
      list.add(SmallEconAgentAidEconVI);

      Collections.sort(list);
      Collections.reverse(list); //values here for resilience, so max resilience which will decrease
vulnerability

      double sum =0;

      for (int i =0; i <list.size();i++)
      {
          sum += list.get(i);
      }

      if (sum==0)
```

```
        {
          UpgradeEconVIRank = 1;
          RepairEconVIRank = 1;
          PubHomeEconVIRank =1;
          SmallEconAgentAidEconVIRank =1;
        }
        else{
          for (int i = 0; i <list.size(); i ++)
          {
            if (list.get(i) == UpgradeEconVI) UpgradeEconVIRank = i+1;
            if (list.get(i) == RepairEconVI) RepairEconVIRank = i+1;
            if (list.get(i) == PubHomeEconVI) PubHomeEconVIRank =i+1;
            if (list.get(i) == SmallEconAgentAidEconVI) SmallEconAgentAidEconVIRank =i+1;
          }
        }

    }

    public void getReward(){
        p = r = u = s= 1;
        UpgradeSOVI = RepairSOVI = PubHomeSOVI = SmallEconAgentAidSOVI=
ExemptionsSOVI=0;
        UpgradeEVI = RepairEVI = PubHomeEVI = SmallEconAgentAidEVI= ExemptionsEVI=0
;
        UpgradeEconVI = RepairEconVI = PubHomeEconVI= SmallEconAgentAidEconVI =
ExemptionsEconVI=0;
        UpgradeReward = RepairReward = PubHomeReward = SmallEconAgentAidReward =
ExemptionsReward=0;
```

```
/*=====================================================================
======================================================================
  Rewards depends on the action taken to a resident and how much the delta-
  utility (Adjusted to delta Recovery is chaning as awhole. and the average SOVI
  or the total change in EVI    or the total change in EconVI

======================================================================
=====================================================================*/
    for (int i = 0; i < FSmodel.getResNum(); i ++)
    { FSmodel.R[i].deltaSOVI();
      if (FSmodel.R[i].GovPlan == 'U')
      {UpgradeReward += FSmodel.R[i].DeltaUtility;
      u++;
      UpgradeSOVI += FSmodel.R[i].deltaSOVI;
      UpgradeEVI += FSmodel.Census[FSmodel.R[i].Code].deltaEVI;
      UpgradeEconVI += FSmodel.Census[FSmodel.R[i].Code].deltaEconVI;
      }
      else {
        if (FSmodel.R[i].GovPlan == 'R')
        {RepairReward += FSmodel.R[i].DeltaUtility;
        r ++;
        RepairSOVI += FSmodel.R[i].deltaSOVI;
        RepairEVI += FSmodel.Census[FSmodel.R[i].Code].deltaEVI;
        RepairEconVI += FSmodel.Census[FSmodel.R[i].Code].deltaEconVI;
        }

        else
        {
```

```
            if (FSmodel.R[i].GovPlan== 'P')
            {PubHomeReward +=FSmodel.R[i].DeltaUtility;
            p ++;
            PubHomeSOVI += FSmodel.R[i].deltaSOVI;
            PubHomeEVI += FSmodel.Census[FSmodel.R[i].Code].deltaEVI;
            PubHomeEconVI += FSmodel.Census[FSmodel.R[i].Code].deltaEconVI;
            }
          }
        }
      }


/*=======================================================================
=========================================================================
   Rewards depends on the action taken by the economic sector and how much the
   recovery is chaning as awhole and the average EconVI

=========================================================================
=======================================================================*/


      for (int i =0; i <FSmodel.eAgentNum; i ++)
      {
        if (FSmodel.eAgent[i].gov_Fund)
        {
          if(FSmodel.eAgent[i].govFund!=0) //thus small business load applied
          {s++;
            //Reward
            if (FSmodel.eAgent[i].oldRevenue != 0){SmallEconAgentAidReward +=
FSmodel.eAgent[i].revenue/FSmodel.eAgent[i].oldRevenue;} else
SmallEconAgentAidReward+=1;
```

```
                //EconVI
                SmallEconAgentAidEconVI +=
FSmodel.Census[FSmodel.eAgent[i].code].deltaEconVI;
                //EVI
                SmallEconAgentAidEVI += FSmodel.Census[FSmodel.eAgent[i].code].deltaEVI;
                //SOVI
                //it doesnt affect SoVI
            }


        }
    }
                SmallEconAgentAidReward= SmallEconAgentAidReward/s;
                SmallEconAgentAidEconVI = SmallEconAgentAidEconVI /s;
                SmallEconAgentAidEVI = SmallEconAgentAidEVI/s;
        getRank();
    }


    public void getQ(){
        getReward();
        double Forgetting = .85;  //please refere to modified Erve and Roth 1998
        double Experimenting = 0.15;
        QPubHome = (QPubHome * (1 - Forgetting)) + (PubHomeReward * (1- Experimenting));


        QRepair = (QRepair * (1 - Forgetting)) + (RepairReward * (1- Experimenting));


        QUpgrade = (QUpgrade * (1 - Forgetting)) + (UpgradeReward * (1- Experimenting));


        QSmallEconAgentAid = (QSmallEconAgentAid * (1 -Forgetting)) +
(SmallEconAgentAidReward * (1 - Experimenting));
```

```
}
 public void redistributeFund(){
  if (RV) RothErve();
  else if (Qlearning)QLearning();
  //AHC();
  //DFA();
  RepairFunds = probRepair * funds;
  UpgradeFunds = probUpgrade *funds;
  PubHomeFunds = probPubHome *funds;
  SmallEconAgentAidFunds =probSmallEconAgentAid * funds;

  //add them to the list for bar char
  PubHomelist.add(probPubHome);
  Repairlist.add(probRepair);
  Upgradelist.add(probUpgrade);
  SmallEconAgentAidlist.add(probSmallEconAgentAid);
}

 public void RothErve(){
  getQ();
  double totalQ = QPubHome+ QRepair + QUpgrade + QSmallEconAgentAid ;//+
QExemptions;

  probPubHome= QPubHome/totalQ;
  probRepair = QRepair/totalQ;
  probUpgrade = QUpgrade/totalQ;
  probSmallEconAgentAid = QSmallEconAgentAid/totalQ;
}
```

```
/*==========================================================================
============================================================================
                         Q LEARNING
============================================================================
==========================================================================*/
   public void QLearning(){ //SARSA
      // NOTE: the state are infinite.. .thus having a Q(s,a) and Q(s',a') is
      // practically impossible and incorrect. Thus, I generate a new Q at
      // each state... there's no path here after all... just budget.

      double oldQup = Qup;
      double oldQp = Qp;
      double oldQR = QR;
      double oldQse=Qse;
      getReward();
      Qup = Qup + (alpha *(UpgradeReward + (gamma *oldQup) -Qup));
      Qp  = Qp + (alpha *(PubHomeReward + (gamma *oldQp)-Qp));
      QR  = QR + (alpha *(RepairReward + (gamma *oldQR)-QR));
      Qse = Qse + (alpha *(SmallEconAgentAidReward + (gamma *oldQse)-Qse));

      double total = Qup + Qp + QR + Qse;
      //insure that the total is equal to 1
      probUpgrade = Qup/total;
      probPubHome = Qp/total;
      probRepair = QR/total;
      probSmallEconAgentAid = Qse/total;
```

```
}
//Adaptive Heuristic Critic algorithm
public void AHC(){
    double oldPubHomeReward = PubHomeReward;
    double oldRepairReward = RepairReward;
    double oldUpgradeReward = UpgradeReward;

    getReward();

    Qp = oldPubHomeReward + gamma*PubHomeReward;
    QR = oldRepairReward + gamma*RepairReward;
    Qup = oldUpgradeReward + gamma*UpgradeReward;

    double total = Qp+QR+Qup;

    probUpgrade = Qup/total;
    probPubHome = Qp/total;
    probRepair = QR/total;

}
// Derivitave Follower Algorithm
public void DFA(){
    double[] deltaA = {0.01,0.02,0.03,0.04,0.05,0.06,0.07,0.08,0.09,0.1};

    getReward();
    //increasing the best fiting strategy
    char checkMax = getMaxRewardIndex();
```

```
        if (checkMax =='p') probPubHome += deltaA[FSmodel.random.nextInt(deltaA.length)];
        if (checkMax == 'u') probUpgrade += deltaA[FSmodel.random.nextInt(deltaA.length)];
        if (checkMax == 'r') probRepair += deltaA[FSmodel.random.nextInt(deltaA.length)];

        //decreasing the lowest fitting strategy
        char checkMin = getMinRewardIndex();
        if (checkMin =='p') probPubHome -= deltaA[FSmodel.random.nextInt(deltaA.length)];
        if (checkMin == 'u') probUpgrade -= deltaA[FSmodel.random.nextInt(deltaA.length)];
        if (checkMin == 'r') probRepair -= deltaA[FSmodel.random.nextInt(deltaA.length)];

        //make sure it adds up to 1.0 and non is negative
        if (probPubHome <0) probPubHome =0;
        if (probRepair<0) probRepair =0;
        if (probUpgrade<0) probUpgrade =0;
        double total = probPubHome + probRepair + probUpgrade;

        probPubHome = probPubHome/total;
        probRepair = probRepair/total;
        probUpgrade = probUpgrade/total;

    }

/*=================================================================
==================================================================

                    Action Modules

 ================================================================

=================================================================*/

    public void PubHome(Residence R){
```

```
        if (PubHomeFunds >= PubHomeAward) //Sufficient fundings
        {
          R.GovFund+= PubHomeAward;
          PubHomeCost += PubHomeAward;
          R.Reward = 1; // the reward function for Roth Erve
          R.Repair =0; //these values are to check what plan is given to an agent
          R.Upgrade =0; //might change those boolean, not crucial
          R.PubHome = 1;
          R.none = 0;
          R.GovPlan = 'P';
          R.govFund = true;
          totalFund+= PubHomeAward;
          funds -= PubHomeAward; //decrease the total fund available by this amount
          PubHomeFunds -= PubHomeAward;
          //update the land vegitation cover due to building new public home
          FSmodel.Census[R.Code].updateVegCoverAndLoss(1600);//average public household
size in mississippi is 1600 sqft
          economicImpact('p', FSmodel.Census[R.Code]);
        }else
        {
         R.GovFund += 0;
         R.Reward = -1;
         R.Repair = 0;
         R.Upgrade = 0;
         R.PubHome = 1;
         R.none = 0;
         R.govFund = false;
        }
  }
```

```
public void Repair(Residence R){
        if (RepairFunds>= Math.min(RepairAward, (R.initialHouseValue-R.houseValue)))
//sufficient funds
        {
            if (FSmodel.random.nextDouble()< 0.96) //probability of accepting (MDA Federal
Reporting)
            {
            if((R.initialHouseValue-R.houseValue)>RepairAward) //not more than the maximum
            {
                R.GovFund += RepairAward ;
                RepairCost+=RepairAward;
                totalFund += RepairAward;
                funds -= RepairAward;
                RepairFunds -= RepairAward;
                R.govFund =true;
            }
            else
            {
            R.GovFund += R.initialHouseValue-R.houseValue;
            RepairCost+=R.initialHouseValue -R.houseValue;
            totalFund+=R.initialHouseValue-R.houseValue;
            funds-= R.initialHouseValue - R.houseValue;
            RepairFunds-= R.initialHouseValue - R.houseValue;
            R.govFund = true;
            }
        R.Reward = 1;
        R.Repair =1;
```

```
    R.Upgrade =0;
    R.PubHome = 0;
    R.none = 0;
    R.GovPlan = 'R';
    R.govFund = true;
    economicImpact('r', FSmodel.Census[R.Code]);
    }else {
            R.GovFund += 0;
        R.Reward = -1;
        R.Repair = 1;
        R.Upgrade = 0;
        R.PubHome = 0;
        R.none =0;
        R.govFund = false;
        }
    }else
    {
        R.GovFund += 0;
        R.Reward = -1;
        R.Repair = 1;
        R.Upgrade = 0;
        R.PubHome = 0;
        R.none = 0;
        R.govFund = false;
    }
}

public void Upgrade(Residence R){
```

```
/*=================================================================
==================================================================

    Uprgrading (Elevation Grant) increases the house value. doesn't have to
    be damaged
==================================================================
==================================================================
*/
    if (UpgradeEligible(R)) // if he's eligible (R.upgradeCheck = false) AND BELOW I-10
    {
      if (UpgradeFunds>=UpgradeReward) //sufficient funding
      {
        if (FSmodel.random.nextDouble()<0.52) // probability of accepting
        {
      R.GovFund+= UpgradeAward;
      R.initialHouseValue += UpgradeAward; // houseValue now increases too
      UpgradeCost+= UpgradeAward;
      R.Reward = 1; //to calculate propesnaty
      R.Repair =0;
      R.Upgrade =1;
      R.PubHome = 0;
      R.none = 0;
      R.govFund = true;
      R.upgrade = true;
      R.GovPlan = 'U'; //to calculate recovery
      totalFund += UpgradeAward;
      funds-= UpgradeAward;
      UpgradeFunds -=UpgradeAward;
      economicImpact('u', FSmodel.Census[R.Code]);
```

```
        }
          else
          {
          R.GovFund += 0;
          R.Reward = -1;
          R.Repair = 0;
          R.Upgrade = 1;
          R.PubHome = 0;
          R.none =0;
          }
        }else
        {
          R.GovFund += 0;
          R.Reward = -1;
          R.Repair = 0;
          R.Upgrade = 1;
          R.PubHome = 0;
          R.none = 0;
        }
    }
      else
      { // in case he applied for upgrade before.
         R.GovFund += 0;
          R.Reward = -10;
          R.Repair = 0;
          R.Upgrade = 1;
          R.PubHome = 0;
```

```
            R.none = 0;
        }
    }

    public void EconAgentAid(EconomicAgent eAgent){
        if (SmallEconAgentAidFunds >= SmallEconAgentAidAward *
eAgent.size*eAgent.damage)
        {
            eAgent.gov_Fund =true;
            eAgent.govFund = 0.1;
            SmallEconAgentAidCost += SmallEconAgentAidAward *eAgent.size*eAgent.damage;
            funds -= SmallEconAgentAidAward * eAgent.initialSize*eAgent.damage;
            SmallEconAgentAidFunds -= SmallEconAgentAidAward * eAgent.size*eAgent.damage;
        economicImpact('e', FSmodel.Census[eAgent.code]);
        }
    }

    public void EconAgentExemption(EconomicAgent eAgent){
        eAgent.gov_Fund =true;
        eAgent.ex = true; // this will increase the econ agent revenue as shown in the class
         funds-= eAgent.meanRevenue*.035;  //losses in gov tax that will take from the funds.
    }

    public void economicImpact(char x, Census census){
        //these values are taken from Cohen et al. 2012
        // the assumption is that when any work is done, a generated extra
        //revenue for the retail sector will increase.

        if (x == 'r')
```

```
    {
        census.retailMultiplier = (census.retailMultiplier + 1.000)/2;
    }
    if (x== 'p')
    {
        census.retailMultiplier = (census.retailMultiplier + 1.0912)/2;
        census.income = census.income*1.002;
    }
    if (x=='u')
    {
        census.retailMultiplier = (census.retailMultiplier + 1.005)/2;
        census.income = census.income * 1.003;
    }
    if (x=='e')
    {
        census.retailMultiplier = (census.retailMultiplier + 1.00)/2;
        census.employment = census.employment*1.001;
    }
}

public Boolean UpgradeEligible(Residence R){
    if ((!R.upgrade) &&(R.I10==1) &&(R.Recovery>0))
        return true;
    else return false;
}

public char getMaxRewardIndex(){
   if ((PubHomeReward> RepairReward) && (PubHomeReward>UpgradeReward))
```

```
    return 'p';
    else if((RepairReward>UpgradeReward)) return 'r';
    else return 'u';
}

public char getMinRewardIndex(){
    if ((PubHomeReward< RepairReward) && (PubHomeReward<UpgradeReward))
    return 'p';
    else if((RepairReward<UpgradeReward)) return 'r';
    else return 'u';
}

public void getFund(){
    if (funds <= 1000000000)
    {
      if ((RV)||(Qlearning)){FSmodel.FDRC.fundRaise();System.out.println("new funds");}
    }
}

public void EVIOut(){
    for (int i = 0; i<FSmodel.CT_number;i++)
          {
            FSmodel.file.EVIOut(FSmodel.Census[i]); //file out EVI per census tract
          }
    FSmodel.file.EVIOutLine();
}

public void EconVIOut(){
```

```
    for (int i = 0; i<FSmodel.CT_number;i++)
          {
            FSmodel.file.EconVIOut(FSmodel.Census[i]); //file out EVI per census tract
          }
    FSmodel.file.EconVIOutLine();
  }

/*=====================================================================
Optimization Parameters
  ====================================================================*/
   public void getSOVI(){
    if (social)
    {
    FSmodel.factAnalysisScoring(FSmodel.R);
    }
  }

  public void getEVI(){
    if (enviro)
    {
    for (int i = 0; i < FSmodel.CT_number; i++)
         {
           FSmodel.Census[i].averageEVI();
         }
    }
  }

  public void getEconVI(){
    if (econom)
```

```
        {
          for (int i = 0; i <FSmodel.CT_number; i ++)
          {
            FSmodel.Census[i].oldEconVI = FSmodel.Census[i].EconVI;
            FSmodel.Census[i].meanSalesAdjust();//calculate and adjust revenue
          }

          FSmodel.EconVulnerabilityIndex();

          for (int i = 0; i <FSmodel.CT_number; i ++)
          {
            FSmodel.Census[i].deltaEconVI();
          }
        }
    }
}
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (LDRM) is the Local Disaster Recovery Management agent
 */
package DSOAMB;
import sim.engine.*;
/**
 *
 * @author MSaeid
 */
public class LDRM implements Steppable {
    FieldSim FSmodel;

    public int population =0;
    public String County;
    public double MaxSOVI;
    public double MinSOVI;
    public double AvgSOVI;
    public double initialValue =0;
    public double recoveryProgress=0;
    public double recoveryReport=0;

    public double repairSignal = 0.96; //acceptance signal to residents (can be dynamic later on)
    public double pubHomeSignal = 1; //thes values comes from the MDA federal reporting
```

```
public double upgradeSignal = 0.57;

int counter = 0;

int handelingRate =10000; //case handeling per month (average taken from 2007 progress)

public LDRM (FieldSim FSmodel){
   this.FSmodel= FSmodel;
}

public void step (SimState state){
   if (counter ==3) {getRecoveryProgress();} //quarter annual recovery assessment
   counter ++;
   if(counter>3) {counter =0;}
   getResidence();
   getEconAgent();
}
public int getMaxHandeling(){
   int x = (int) (.05*population);
  //return handelingRate;
  //if (x < 6000) x = 6000;
   return x;
}

public void inti(){
   for (int i=0; i< FSmodel.getResNum(); i++)
   {   if(FSmodel.R[i].County.equals(County))
         population++;
```

```
        }
        getInitialValue();
            }
 public void getResidence2(){
     int counter = 0;

/*=================================================================
    Determine residence depending on their SOVI (can be changed later)
=================================================================*/


    for (int i = 0; i < FSmodel.getResNum(); i ++)
     {
        if (FSmodel.R[i].County.equals(County))
            {
            if ((FSmodel.R[i].Recovery == 0)||(FSmodel.R[i].GovPlan == 'P') ||
(FSmodel.R[i].GovPlan =='R'))
                {System.out.println("Residence 1 Reocery = "+ FSmodel.R[1].Recovery);
                    FSmodel.R[i].Reward=-10; //penelty for cheating
                }
                    else
                    {//eligable
                        if (FSmodel.R[i].SOVI < -1) //recovery < 100 just incase the amount didn't add up
to the initial value
                        {
                            getAction(FSmodel.R[i]);
                            counter++;
                        }
                    }
                            if (counter == handelingRate) {i = FSmodel.getResNum(); } //maximum
handeling
```

```
          }
    } //what if no low or moderate vulenrability
     if (counter != handelingRate)
     {
     for (int i = 0; i < FSmodel.getResNum(); i ++)
        {
          if (FSmodel.R[i].County.equals(County))
              {
                if ((FSmodel.R[i].Recovery == 0)||(FSmodel.R[i].GovPlan == 'P') ||
(FSmodel.R[i].GovPlan =='R'))
               {
                 System.out.println("Residence 1 Reocery = "+ FSmodel.R[1].Recovery);
                  FSmodel.R[i].Reward=-10; //penelty for cheating
               }

                else
                {
                   getAction(FSmodel.R[i]);
                   counter++;
                }
             if (counter == handelingRate){i = FSmodel.getResNum(); }
              }
        }
    }
 }
```

```
/*=====================================================================
======================================================================

 Residence agents choices over the different plans

 in future work we may need to apply a negotiation module here.

 =====================================================================

=====================================================================*/

   public void getAction(Residence R){

       R.getProb();

       double tempRepairUtil = (R.houseValue+ R.income/12 - R.tax/12 - R.InsPrem/12 +
R.InsComp - R.RepairCost + ((Math.min(FSmodel.SDRC.RepairAward,R.initialHouseValue-
R.houseValue))*repairSignal)) * R.probRepair;  ;

       double tempUpgradeUtil = (R.houseValue+ R.income/12 - R.tax/12 - R.InsPrem/12 +
R.InsComp - R.RepairCost + (FSmodel.SDRC.UpgradeAward)*upgradeSignal) *
R.probUpgrade;

       double tempPubHomeUtil = (R.houseValue+ R.income/12 -  - R.tax/12 - R.InsPrem/12 +
R.InsComp - R.RepairCost+ FSmodel.SDRC.PubHomeAward) *pubHomeSignal*
R.probPubHome;

       double tempNoneUtil = (R.houseValue+ R.income/12 -  - R.tax/12 - R.InsPrem/12 +
R.InsComp - R.RepairCost ) * R.probnone;

       if ((tempRepairUtil > tempUpgradeUtil) && (tempRepairUtil>tempPubHomeUtil)&&
(tempRepairUtil > tempNoneUtil))

           {//do repair;

              FSmodel.SDRC.Repair(R);

           }

       else

       if ((tempUpgradeUtil > tempRepairUtil) && (tempUpgradeUtil>tempPubHomeUtil) &&
(tempUpgradeUtil > tempNoneUtil))

           {//do upgrade

              FSmodel.SDRC.Upgrade(R);

           }

       else
```

```
        if ((tempPubHomeUtil > tempRepairUtil) && (tempPubHomeUtil> tempUpgradeUtil)
&& (tempPubHomeUtil > tempNoneUtil))
                {
        //do pubHome
           FSmodel.SDRC.PubHome(R);
        }
        else
        { //don't apply for assisstance
          // R.Qnone ++;
           R.Repair=0;
           R.Upgrade=0;
           R.PubHome= 0;
           R.none = 1;
           R.Reward = 0;


        }


  }

  // get the average SoVI for this population in the County
  public void getResSOVI(){
      MaxSOVI= -999;
      MinSOVI= 999;
      AvgSOVI=0;
     int x= 0;
     for (int i = 0; i <FSmodel.getResNum(); i ++)
     {
        if (FSmodel.R[i].County.equals(County))
```

```
        {
          x++;
          AvgSOVI+= FSmodel.R[i].SOVI;
          if (FSmodel.R[i].SOVI > MaxSOVI ) MaxSOVI = FSmodel.R[i].SOVI;
          if (FSmodel.R[i].SOVI < MinSOVI) MinSOVI = FSmodel.R[i].SOVI;
        }
      }
      AvgSOVI = AvgSOVI/x;
    }

 public void getResidence(){

/*=====================================================================
Determine residence No SoVI refernce here yet.
=====================================================================*/
     int counter =0;
    for (int i =0; i < FSmodel.getResNum() ; i ++) //for every resident
    {
            int x = FSmodel.random.nextInt(FSmodel.getResNum()); //so as not to visit the same
residents each time... making it more random
      // might be a smarter way of doing it, like making some kind of list, and the LDRM visit it
        if (FSmodel.R[x].County.equals(County)) // in this county
        {
          if (FSmodel.R[x].applyCheck) // if he applied for a recovery plan
          {
            if (!FSmodel.R[x].govFund) //and no plan has been assigend to him yet
            {
              getAction(FSmodel.R[x]); //approve him to the SDRC
              counter++; if (counter> getMaxHandeling()){i = FSmodel.getResNum();}
```

```
                }else
                {
                   if (!FSmodel.R[i].upgrade) // if he gov fund but not an upgrade
                   {
                      FSmodel.SDRC.Upgrade(FSmodel.R[i]); //send him for upgrade if eligible
                      counter++; if (counter> getMaxHandeling()){i = FSmodel.getResNum();}
                   }
                   else
                   {
                   }
                }
             }
          }
       }
   }

public void getInitialValue(){
   for (int i =0; i < FSmodel.getResNum() ; i ++) //for every resident
   {
      if (FSmodel.R[i].County.equals(County)) // in this county
          {initialValue += FSmodel.R[i].initialHouseValue;}
   }
}

public void getRecoveryProgress(){
    recoveryProgress = 0;
     for (int i =0; i < FSmodel.getResNum() ; i ++) //for every resident
   {
```

```
      if (FSmodel.R[i].County.equals(County)) // in this county
          {recoveryProgress += FSmodel.R[i].houseValue;}
   }
recoveryReport= recoveryProgress/initialValue;
}


public void getEconAgent(){
    for (int i = 0; i <FSmodel.eAgentNum; i ++)
    {
        if (FSmodel.eAgent[i].county.equals(County))
        {
            if (!FSmodel.eAgent[i].gov_Fund)
            {
                if ((FSmodel.eAgent[i].size<0.5)&&
(FSmodel.eAgent[i].size<FSmodel.eAgent[i].initialSize))
                {
                    EconAgentAid(FSmodel.eAgent[i]);
                }else
                {
                    if((FSmodel.eAgent[i].size >=0.5) &&
(FSmodel.eAgent[i].size<FSmodel.eAgent[i].initialSize))
                    {
                        // EconAgentExemption(FSmodel.eAgent[i]);
                    }
                }
            }
        }
    }
}
```

```
 public void EconAgentAid(EconomicAgent eAgent){
    FSmodel.SDRC.EconAgentAid(eAgent);
 }

 public void EconAgentExemption(EconomicAgent eAgent){
    FSmodel.SDRC.EconAgentExemption(eAgent);
 }
}
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (Residence) represents the residents on a household level
 */
package DSOAMB;
import com.vividsolutions.jts.geom.Point;
import com.vividsolutions.jts.geom.Coordinate;
import com.vividsolutions.jts.geom.CoordinateFilter;
import java.util.ArrayList;
import java.util.Random;
import sim.engine.*;
import sim.field.geo.GeomVectorField;
import sim.util.geo.MasonGeometry;
/**
 *
 * @author MSaeid
 */
public class Residence implements Steppable{
  boolean applyCheck = false;
  boolean govFund = false;
  boolean upgrade = false;

  int x; //agents
  Point location;
```

```
String County;
double CT;
// resident properties from GIS
double Elderly;
double Vehicle;
double English;
double HighSchool;
double HomeOwnership;
double income;
double Age;
double MobileHome;
double Females;
double Phones;
double houseValue;
double initialHouseValue;
double HighIncome;
int Code;
int I10; //if below I-10;

double tax;
double damage;

//INSURANCE
int InsCompIndex; //Inurance Company Index
int InsPlanIndex;
double InsPrem;
double InsComp;
```

```
double InsRecoveryRate;
boolean usedInsCompensation = false;

double compensation= 0;
double SOVI;
double oldSOVI=0;
double deltaSOVI=0;

//SoVi calculation variables (z-scores)
double Z_Elderly;
double Z_Vehicle;
double Z_PerEngli;
double Z_HighSch;
double Z_PerHomeO;
double Z_Income;
double Z_Age;
double Z_MobileHo;
double Z_PFemale;
double Z_PPhone;
double Z_HouseVal;
double Z_HighInc;

double Utility;
double DeltaUtility;

char Ins;

char Repair_Relocate;
```

```
double RepairCost ;
double RepairRate = 0.9; //need to be verified

double fit;
double relFit;
int fitCheck;

char GovPlan;
double GovFund=0;
double UsedFund=0;

double Recovery=1; //Reocvery process
double oldRecovery;
double DeltaRecovery;
double RecoveryRate = 0;

 // strategies indicators
 int PubHome = 0;
 int Repair = 0;
 int Upgrade = 0;
 int none = 0;

 //strategies propesnity
 double QPubHome=1;
 double QRepair=1;
 double QUpgrade=1;
 double Qnone = 1;
```

```
  double oldQPubhome=1;
  double oldQRepair=1;
  double oldQUpgrade =1;
  double oldQnone =1;
  //strategies probabilities  (VALUES HERE IS TOO STATIC)
  double probPubHome=1/4;
  double probRepair=1/4;
  double probUpgrade=1/4;
  double probnone = 1/4;
  int Reward; //reward 0,1 or -1

  //social learning
  int rank;

  //residents and econ agent interaction
  double expenditure;

  private FieldSim FSmodel;
  DataOut file = new DataOut(FSmodel);

  int stepCounter =0;
public Residence(FieldSim FSmodel){
   this.FSmodel = FSmodel;
}

 public void step(SimState state){

     getExpenditure(); //get the expenditure value
```

```
oldSOVI = SOVI;

//if (stepCounter >12) //after one year from Katrina
// {
getDamage();// won't have damage by tornado except after one year
// }
stepCounter++;
needRecovery();
actions();
getInsurance();
getUtility();
getRecovery();

if (stepCounter % 6==0) //learning every 6 month
{
if(this.x==1)// the learning thing in FeldSim I talked about
{
   learning(); //Social Learning
}
}
damage = 0;// damage equal zero as the damage changed the housevalue already, no need for more changes

}

public void DataIn(Residence R, MasonGeometry mg){ //set agent data and location on map

R.CT = mg.getDoubleAttribute("CT");
R.Code = mg.getIntegerAttribute("Code");
```

```
R.County = mg.getStringAttribute("County");

R.SOVI = mg.getDoubleAttribute("SOVI");

R.income = mg.getIntegerAttribute("Income");
R.houseValue =mg.getIntegerAttribute("HouseValue");
R.initialHouseValue= mg.getIntegerAttribute("HouseValue");
R.Elderly = mg.getDoubleAttribute("PerElderly");
R.Age = mg.getDoubleAttribute("MedianAge");
R.HighSchool = mg.getDoubleAttribute("PerHighSch");
R.Vehicle = mg.getDoubleAttribute("PerVehicle");
R.English = mg.getDoubleAttribute("PerEnglish");
R.HomeOwnership = mg.getDoubleAttribute("PerHomeOwn");
R.Females = mg.getDoubleAttribute("PerFemale");
R.Phones = mg.getDoubleAttribute("PerPhone");
R.HighIncome = mg.getDoubleAttribute("PerHighInc");
R.MobileHome = mg.getDoubleAttribute("PerMobile");
R.I10 = mg.getIntegerAttribute("I10");
// get SoVI attributes

R.Z_Elderly = mg.getDoubleAttribute("Z_Elderly");
R.Z_Vehicle = mg.getDoubleAttribute("Z_Vehicle");
R.Z_PerEngli = mg.getDoubleAttribute("Z_PerEngli");
R.Z_HighSch = mg.getDoubleAttribute("Z_HighSch");
R.Z_PerHomeO = mg.getDoubleAttribute("Z_PerHomeO");
R.Z_Income = mg.getDoubleAttribute("Z_Income");
R.Z_Age = mg.getDoubleAttribute("Z_Age");
R.Z_MobileHo = mg.getDoubleAttribute("Z_MobileHo");
```

```
        R.Z_PFemale = mg.getDoubleAttribute("Z_PFemale");
        R.Z_PPhone = mg.getDoubleAttribute("Z_PPhone");
        R.Z_HouseVal = mg.getDoubleAttribute("Z_HouseVal");
        R.Z_HighInc = mg.getDoubleAttribute("Z_HighInc");

       // set its location from MasonGeometry
       //find the location within the given area with a random number from the centroid
       //four times for the four directions... stupid but works
        addToMap(R,mg);

        //initital values
        R.DeltaUtility = R.houseValue;
        R.Utility = R.houseValue;
        R.InitActions();
    }

public void addToMap(Residence R, MasonGeometry mg){

  getRandomPoint(R,mg);

}

public void getCentroid(Residence R, MasonGeometry mg){
     R.location = mg.getGeometry().getCentroid();
    int numGeo = mg.geometry.getNumPoints();

    do{
        ArrayList<Double> pointX = new ArrayList();
```

```
        ArrayList<Double> pointY = new ArrayList();
        for (int i = 0; i < 3; i ++)
            {// make a triangle
            int random = FSmodel.random.nextInt(numGeo);
            pointX.add(mg.geometry.getCoordinates()[random].x);
            pointY.add(mg.geometry.getCoordinates()[random].y);
            }
        R.location.getCoordinate().x = (pointX.get(0) + pointX.get(1) +
pointX.get(2))/pointX.size();
        R.location.getCoordinate().y =(pointY.get(0) + pointY.get(1) +
pointY.get(2))/pointY.size();
    }while (!mg.getGeometry().covers(location));
}


public void getRandomPoint(Residence R, MasonGeometry mg){


     R.location = mg.getGeometry().getCentroid();
    int numGeo = mg.geometry.getNumPoints();
    int counter = 0;


    do{
        counter++;
        ArrayList<Double> pointX = new ArrayList();
        ArrayList<Double> pointY = new ArrayList();
       for (int i = 0; i < 3; i ++)
             {// make a triangle
             int random = FSmodel.random.nextInt(numGeo);
             pointX.add(mg.geometry.getCoordinates()[random].x);
             pointY.add(mg.geometry.getCoordinates()[random].y);
```

```
            }

        double distanceX1 = pointX.get(0) - pointX.get(1);//normalize to orign
        double distanceY1 = pointY.get(0) - pointY.get(1);
        double distanceX2 = pointX.get(0) - pointX.get(2);
        double distanceY2 = pointY.get(0) - pointY.get(2);
        double r1 = FSmodel.random.nextDouble();//random variables
        double r2 = FSmodel.random.nextDouble();

        R.location.getCoordinate().x =  pointX.get(0)-((r1*distanceX1) + (r2*distanceX2));
        R.location.getCoordinate().y = pointY.get(0)- ((r1*distanceY1) + (r2*distanceY2));
        if (counter>200){getCentroid(R,mg); break;} //give it to 200 trial before going to another
methoth, this method can take too long

    }while (!mg.getGeometry().covers(location));

}

public void getAngles(ArrayList<Double> pointX, ArrayList<Double> pointY){

     double lineA = Math.sqrt(Math.pow(pointX.get(0) - pointX.get(1),2) +
Math.pow(pointY.get(0) - pointY.get(1),2));
     double lineB = Math.sqrt(Math.pow(pointX.get(0) - pointX.get(2),2) +
Math.pow(pointY.get(0) - pointY.get(2),2));
      double lineC = Math.sqrt(Math.pow(pointX.get(1) - pointX.get(2),2) +
Math.pow(pointY.get(1) - pointY.get(2),2));

      double angle0 = Math.acos((Math.pow(lineC, 2)- Math.pow(lineA, 2) -
Math.pow(lineB,2))/(2*lineA *lineB *-1));
```

```
    double angle1 =Math.acos((Math.pow(lineB, 2)- Math.pow(lineA, 2) -
Math.pow(lineC,2))/(2*lineA *lineC *-1));

    double angle2 =Math.acos((Math.pow(lineA, 2)- Math.pow(lineB, 2) -
Math.pow(lineC,2))/(2*lineB *lineC *-1));

}


public void getExpenditure(){

  expenditure = 0.55 * income/12; //Highway report (2014)

}


public double setDamage(){

  return FSmodel.WindStorm.damage;

}


public void getDamage(){

  if ((FSmodel.WindStorm.County==(County))&&(FSmodel.WindStorm.damage>0)){ //if the
hazard is at your location

  damage = FSmodel.random.nextDouble()*setDamage(); //percentage of damage to the
structure.

  initialHouseValue = houseValue;

  houseValue = houseValue * (1-damage);

  Recovery = initialHouseValue -houseValue;

  }

}

public void getInsurance(){

  if (damage != 0){

    compensation = InsComp*initialHouseValue*damage;

  }else {

    compensation = 0;

  }
```

```
}

 public void setInsPrem(){
        // InsPrem = houseValue *InsPrem;
    }
    public void setInsComp(){
      /* if (damage>0){
            InsComp = InsComp *initialHouseValue*damage;
       }else {InsComp = 0;}*/
    }

public void setTax (){

    /*calculated based on Harrison (only) available Data
    http://mscoast.org/taxes-incentives/local-state-taxes/*/
    double IncomeTax ;
    if (income <= 5000)
        IncomeTax = 0.03;
    else {
        if(income <=10000){IncomeTax = 0.04;}
        else{IncomeTax = 0.05;}
    }
    double PropertyTax = 0.1;
    tax = income*IncomeTax + houseValue*PropertyTax;
}

public void getUtility (){// REMEMBER step =1 month
        double OldUtility= Utility; //utility at time -1
```

```
    Utility =houseValue+ income/12  - tax/12 - InsPrem*initialHouseValue/12 +
InsComp*initialHouseValue*damage - RepairCost ;
    DeltaUtility = (Utility -OldUtility)/OldUtility;  // % change in Utility
}

public void learning(){ //Social Learning
    /*============================
    =======GA Learning ===========
    this done by finding the parent that has a relative fittness greater
    than the crossover probability, then determine a residence with a
    relative fitnesss less than 1-crossover (i.e; he's in the low percentile)
    then, the child will copy the parent's actions and propesnity.
    Convergence happens when the counter reaches the percentage of popluation
    that leanrs (this vaule can be adjusted)
    ===============================
    ===============================*/

    //setFitnes(); //first calculate fitness
    //GAs();

    /*============================
    =======PS Learning ===========
    ===============================
    ===============================*/
    PS(FSmodel.R); // TIME CONSUMING
}

public void setFitnes(){
    /*Calculate the relative fitness for a set of residence
```

```
NOTE: this is not based on socioeconomic standard or porximity,
they are all learning together*/
double TFitness= 0;

for (int i =0; i < FSmodel.getResNum(); i ++)
{
   TFitness += FSmodel.R[i].DeltaUtility;
}
// if Total Fitness = 0 then this mean there no change to learn from.
// thus skip fitness

if ((TFitness !=0) && !(Double.isNaN(TFitness))){

for (int i = 0; i< FSmodel.getResNum();i++)
{
  FSmodel.R[i].fit = FSmodel.R[i].DeltaUtility/TFitness;
  FSmodel.R[i].fitCheck = 0;
}
double SumFit=0;
int Counter = 0;
do {
   int i = FSmodel.random.nextInt(FSmodel.getResNum());
   if(FSmodel.R[i].fitCheck ==0)
      {
         SumFit= SumFit + FSmodel.R[i].fit;
         FSmodel.R[i].relFit = SumFit;
         Counter++;
      }
```

```
        }while (Counter<=FSmodel.getResNum());
    }
}


public  void GAs(){
/*===========================================================================
========================================Discussion===========================
This is not conventional GAs. Its is a mimicry GAs.
The Child (AKA the lowest fit Residence) copy Parent1 (which is the best parent).
Later on, we can adjust.
============================================================================
==========================================================================*/
        Residence Parent1 = new Residence (FSmodel);

        int LearnPop = 100000;
        double Crossover = 0.8;
        //find parent1 from the most fit

        for (int i = 0; i <FSmodel.getResNum(); i++)
        {
            int x = FSmodel.random.nextInt(FSmodel.getResNum());
            if (FSmodel.R[x].relFit > Crossover)
            {
                Parent1 = FSmodel.R[x];
                i = FSmodel.getResNum();
            }
                if (i == FSmodel.getResNum())
```

```
        {
            if (Parent1 ==null)
                {i=0;}
        }
  }

Residence Parent2 = new Residence (FSmodel);
 //Find parent2
 Parent2 = null;
 for (int i = 0; i <FSmodel.getResNum(); i++)
 {
    int x = FSmodel.random.nextInt(FSmodel.getResNum());
    if (FSmodel.R[x].relFit > Crossover)
    {
        Parent2 = FSmodel.R[x];
        i = FSmodel.getResNum();
    }
        if (i== FSmodel.getResNum())
        {
            if(Parent2 == null)
            {i=0;}
        }
 }
 int OverflowCheck =0;
 int counter = 0;
 do {OverflowCheck++;

    int x = FSmodel.random.nextInt(FSmodel.getResNum());
```

```
    if (FSmodel.R[x].relFit < 1-Crossover){
        FSmodel.R[x].Ins= Parent1.Ins;
        FSmodel.R[x].InsCompIndex = Parent1.InsCompIndex;
        FSmodel.R[x].InsComp= Parent1.InsComp;
        FSmodel.R[x].InsPlanIndex = Parent1.InsPlanIndex;
        FSmodel.R[x].InsPrem = Parent1.InsPrem;
        FSmodel.R[x].InsRecoveryRate = Parent1.InsRecoveryRate;
        FSmodel.R[x].Repair_Relocate = Parent1.Repair_Relocate;

        counter++;

    }
  }while ((counter < LearnPop) && (OverflowCheck < LearnPop));
}


public void actions(){

/*=================================================================
=================================================================
    Actions so far thought of are:
    1- Purchasing or cont. purchasing Insurance policies
    2- Repair household
    3- relocate
    NOTE: Repairing and relocation will depend on the government funding and
    amount residence will pay.
    This is CRUCIAL cause it will control the learning and many more.

    KEYS: I = Insurance
```

```
        N = No Insurance
        R = Repair
        L = Relocate (Leave)

================================================================================
=============================================================================*/
    if (Ins==  'I')
    {
    setInsPrem();
    setInsComp();
    }

    else {
      InsPrem = 0;
      InsComp = 0;
    } // no insurance no prem cost or compansation

    RepairCost=0;
  if(damage>0){ //repair iff damage occurs
    if (Repair_Relocate== 'R')
    {
    getRepair(); //repair cost
    houseValue += RepairCost; //value added to home
    }
    else { //leave or relocate
      //AT THE MOMENT RESIDENTS ARE CONSTRAINTED FROM LEAVING THE
SYSTEM
    getRepair();
   // Ins = 'N';
```

```
        // InsPrem = 0;
        // InsComp = 0;
         }
    }
}


public void getRepair(){
        RepairCost = initialHouseValue*damage;
        //constrainted by the income (25% of monthly income will go to repairing
        double repair = income*.25/12;
        if (repair<RepairCost) RepairCost = repair;
}

public void InitActions(){
/*=======================================================================
Initial Randomized actions
=======================================================================*/

         double i = FSmodel.random.nextDouble();
         if (i < (1/FSmodel.Ins.length+1))
         {
             Ins ='N'; InsPrem= 0;
             InsCompIndex = 4;
         }
         else
         {
             Ins = 'I'; getInitialInsComp();
```

```
        }

        double r = FSmodel.random.nextDouble();
        if(r < 0.9) //small percentage will choose to leave from day one :)
        {
            Repair_Relocate = 'R';
        }
        else
        {
            Repair_Relocate = 'L';
            Ins = 'N';
        }
    }

    public void getInitialInsComp(){
        int i = FSmodel.random.nextInt(3); // company
        InsCompIndex = i;

        int j = FSmodel.random.nextInt(3); //plan
        InsPlanIndex = j;
        InsPrem = FSmodel.Ins[i].prem[j];
        InsComp = FSmodel.Ins[i].comp[j];
        InsRecoveryRate = FSmodel.Ins[i].recoveryRate[j];
    }


    public void getRecovery(){
        /*
```

```
   First check if it have a pre-defined recovery rate
   then determine the current goverment fund plan and determine the new recovery
   rate
   then check which is greate, and follows it.
    */

   oldRecovery = Recovery;
   double tempRecovery =0;
   if (RecoveryRate!=0 )
   {
     tempRecovery = RecoveryRate;
   }
      if (initialHouseValue > houseValue) // resident need recovery
      {
         if (govFund) // if gov fund is avaialble
         {
             if (GovPlan== 'U') {RecoveryRate = 0.044;} //these rates are based on the data
collected from the Fedral review
             else if (GovPlan== 'R') {RecoveryRate = 0.075;}
             else if (GovPlan== 'P') {RecoveryRate = 0.025;}
             else RecoveryRate= 0.05; //just use avegage in case on an error

             // add the recovery rate from the insurance
             if (InsCompIndex !=4) {getInsRecovery();} //if there is an insurance company, add the
insurance recovery Rate

              if (RecoveryRate < tempRecovery ){RecoveryRate = tempRecovery;}// for future
steps
```

```
            houseValue += GovFund *RecoveryRate; //increase house value by the rate
           // System.out.println("houseValue after" + houseValue);
            Recovery = houseValue/initialHouseValue;

        }
    }else // if the house value is restored or no damage
    {
        govFund = false; // no gov fund anymore
        GovFund = 0; // zero gov fund
        RecoveryRate =0;
    }
    UsedFund += GovFund *RecoveryRate; // if agent consumed all gov fund.
    if (UsedFund >= GovFund) {GovFund = 0; govFund =false; UsedFund=0;}

    DeltaRecovery = Recovery/oldRecovery;
}


public void getQ(){
    double Forgetting = 0.5;  //please refere to modified Erve and Roth 1998
    double Experimenting = 0.5;
    Reward = Reward - (-1); //R(x) = x - xmin where xmin = -1 (Roth and Erev 1998)
    if (PubHome== 1)

        QPubHome = (QPubHome * (1 - Forgetting)) + (Reward * (1- Experimenting));
        else{
        QPubHome = (QPubHome *(1 - Forgetting)) + (Reward * Experimenting/3);
    }
```

```
    if (Repair== 1)
       QRepair = (QRepair * (1 - Forgetting)) + (Reward * (1- Experimenting));
       else{
       QRepair = (QRepair *(1 - Forgetting)) + (Reward * Experimenting/3);
    }
    if (Upgrade== 1)
    QUpgrade = (QUpgrade * (1 - Forgetting)) + (Reward * (1- Experimenting));
       else{
       QUpgrade = (QUpgrade *(1 - Forgetting)) + (Reward * Experimenting/3);
    }
    if (none == 1)
       Qnone = (Qnone * (1 - Forgetting )) + (Reward * 1- Experimenting);
    else {
         Qnone = (Qnone *(1 - Forgetting)) + (Reward * Experimenting/3);
        }
}

  public void Q_Learning(){
     double alpha =0.8; double gamma =0.8;
     if(PubHome==1){
        QPubHome = QPubHome + alpha * (Reward + gamma *(QPubHome -oldQPubhome ));
     }else
     if (Repair ==1) {
        QRepair = QRepair + alpha * (Reward + gamma *(QRepair -oldQRepair ));
     }else
     if(Upgrade ==1){
        QUpgrade = QUpgrade + alpha * (Reward + gamma *(QUpgrade -oldQUpgrade ));
```

```
    }else
      Qnone = Qnone + alpha * (Reward + gamma * (Qnone-oldQnone));
  }
public void getProb(){
    getQ();
    //Q_Learning();
    double totalQ = QPubHome + QRepair + QUpgrade + Qnone;
    if (totalQ!=0){
    probPubHome= QPubHome/totalQ;
    probRepair = QRepair/totalQ;
    probUpgrade = QUpgrade/totalQ;
    probnone = Qnone/totalQ;
    }else {probPubHome=0.25; probRepair=0.25; probUpgrade = 0.25; probnone = 0.25;}
    //if(Reward ==-1){System.out.println("" + probPubHome +", " +  probRepair + ", " +
probUpgrade+ ", "+ probnone);}
}


public void getInsRecovery(){


  RecoveryRate+= InsRecoveryRate;
  if(!usedInsCompensation)
  {
  double TempCompensation = InsComp*initialHouseValue*(1-
(houseValue/initialHouseValue));
  GovFund += TempCompensation;
  usedInsCompensation =true;
 // System.out.println("compensation = " + TempCompensation);
 // System.out.println("Recovery Rate = " + RecoveryRate);
  }
```

```
}

public void needRecovery(){
        if (((initialHouseValue - houseValue) > 30000)&& (!applyCheck)) //least government plan
            applyCheck = true;
        else applyCheck = false;
    }

public void deltaSOVI(){
    deltaSOVI = (SOVI - oldSOVI);


}
/*===========================================================================
===========================================================================
                        PS as Social Learning
                Particle Swarm Cheng and Jin 2014
============================================================================
==========================================================================*/
public void PS(Residence[] R){
    sort_rank(R);
    for (int i=0; i < FSmodel.ResNum; i++)
    {
        if (R[i].rank!=1){
            R[i].probL(FSmodel.ResNum);

            if (FSmodel.random.nextDouble()>=R[i].pL)
            {
                int deomonstrator = R[i].demonstrator(R[i].rank);
```

```
                R[i].Ins = R[deomonstrator].Ins;
                R[i].InsComp = R[deomonstrator].InsComp;
                R[i].InsCompIndex = R[deomonstrator].InsCompIndex;
                R[i].InsPlanIndex = R[deomonstrator].InsPlanIndex;
                R[i].InsPrem = R[deomonstrator].InsPrem;
            }
        }
    }
}

public void sort_rank(Residence[] R){

    int NumThread =50;
    ArrayList<NewPSThread> ThreadArray = new ArrayList();

    for (int i = 0; i <NumThread; i++)
    {

        ThreadArray.add(new
NewPSThread(i*FSmodel.ResNum/NumThread,FSmodel.ResNum*(i+1)/NumThread,R));

    }

       try{
           for (int i= 0; i <NumThread; i++)
           {
               ThreadArray.get(i).t.join();
```

```
        }
    }catch(Exception e) {System.out.println("Error at joinning PS LEARNING");}
}

public double pL;
public void probL(int m){
    pL = 1- ((double)(rank-1)/(double)m);

  }
public int demonstrator (int rank){

    return FSmodel.random.nextInt(rank-1)+1;
}
}


class NewPSThread implements Runnable{
Thread t;
int from;
int to;
Residence[] R;
  NewPSThread(int i, int j, Residence[] Rin){
    t = new Thread(this);
    from = i;
    to = j;
    R = Rin;
    t.start();
  }
```

```
public void run(){

    ArrayList<Integer> sorted = new ArrayList();
    int counter =0;
    do{
            double max = -99999999;
            int index =0;
      for (int i=from; i<to;i++)
        {
            if ((R[i].Utility>=max)&&(!(sorted.contains(i))))
            {
            max= R[i].Utility;
            index = i;
            }
        }
      sorted.add(index);
       counter++;
    }while(counter<(to-from-1));

    //assign each agent its rank
    for( int i=0; i <sorted.size(); i++)
    {
       R[sorted.get(i)].rank = i+1;
    }

    }
}
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (Economic Agent) represents the retail economic agent
 */
package DSOAMB;

import com.vividsolutions.jts.geom.Point;
import java.util.ArrayList;
import sim.engine.*;
import sim.field.geo.GeomVectorField;
import sim.util.geo.MasonGeometry;
/**
 *
 * @author MSaeid
 */
public class EconomicAgent implements Steppable {

FieldSim FSmodel;
    //revenue variables
    public double gamma; //expenditure share of resident income
    public double freq; //frequency
    public double revenue=0; //economic agent revenue
    public double meanRevenue=0; //average monthly revenue
    public double oldRevenue;
```

```
//economic agent properties
public int index;
public double size;
public double initialSize;
public double damage;
public double thresholdRecovery=.9;
public double physical; //physical structure
public double savings;
public boolean soldOut = false; // if its gonna leave the area
public boolean normalCondition = true; //to collect revenues
public boolean onHold = false; // for residents to observe (might not be used)
Point location;
public String type; //type of agent (retail, financial, medical).

//economic sector location
public String county;
public int code;
public double ct;

//recovery
public double recoveryRate;
public double recoveryCostRate;

//disaster assistance
public double govFund = 0.0; //just initial value
public boolean gov_Fund = false;
```

```
    public double exempt = 0;
    public boolean ex =false;

    public double InsuranceComp = 0.0; // just initial value
    public double InsurancePrem = 0.0;
    public int Insurance;
    public int Plan;

    int counter =0;

    public EconomicAgent (FieldSim FSmodel){
        this.FSmodel = FSmodel;
    }

    public void step(SimState state){
/*=====================================================================
=====================================================================
        At each time step, check if the business is sold out or not
        then, if it is running at normal conditions or not,
        if it is, just collect revenues,
        if not, thus there was a disaster and in recovery.

        In case of recovery, the business is on hold until meeting the threshold

        When fully recovered, move back to normal conditions.
 =====================================================================
=====================================================================*/
        counter++;
```

```
 meanRevenue = (meanRevenue + revenue)/counter;
 revenue = 0;

  if (!soldOut)
  {
     if(normalCondition)
     {
        //get reveunues
        getRevenue();
     }else// sell out opiton or recovery process
     {
      if (!sellout())
      {
        //get recovery
         recovery();
         if (recovered())
         {
            //get reveune
            getRevenue();
         }
      }else
      {
         //do nothing and move to next time step
      }
     }
  }else{}
}
```

```
public void initial(){ // data in and initial values

}

public boolean recovered(){
    if (size>=thresholdRecovery * initialSize)
    {
        normalCondition=true;
        return true;
            }
    else
    {
        normalCondition=false;
        return false;
    }
}

public void recovery(){
    if (initialSize > size)// still there is recovery to be made
    {
        size = size * (1+ getRecoveryRate());// this takes an average of 7 month for 4% damage
    }
    if (initialSize <= size) {normalCondition
=true;FSmodel.Census[code].addEconAgentBack(this);}

    if (initialSize< size) size =initialSize; //make sure it will never be too big
}

public double getRecoveryRate(){
```

```
    if (gov_Fund)
    {
       recoveryRate = 0.075; //gov boost
    }
    else recoveryRate  = 0.025; //average rate
       return recoveryRate;
 }


 public boolean sellout(){
 /*
==============================================================================
==============================================================================
    decision on selling out or remaining in the impacted area
==============================================================================
============================================================================*/
    double recoveryCost = initialSize*damage - initialSize*damage*govFund -
initialSize*damage*InsuranceComp;
    double sellout = initialSize - (initialSize*damage);
    if (recoveryCost >sellout)
    {
          //sellout
          soldOut = true;
          //FSmodel.Census[code].removeEconAgent(this); already removed with Katrina
          return true;
       }else
       {
          //start recovering
```

```
            return false;
        }
    }

    public void getRevenue(){
/*==========================================================================
==========================================================================
        Revenue calculations depending on the resident expenditure, gamma and
        income, as in Chapter 4 (Model Development).
==========================================================================
=========================================================================*/
        oldRevenue = revenue;
        revenue =0;
        for (int i= 0; i < FSmodel.getResNum(); i ++)
        {
          if (FSmodel.R[i].Code == code)//if in the same service area
          { double x = FSmodel.random.nextDouble();
            if (x <= freq) //double check on this vaule
            {
                if (FSmodel.R[i].expenditure>0)
                {
                    revenue += gamma * (FSmodel.R[i].expenditure);
                    FSmodel.R[i].expenditure-= gamma*FSmodel.R[i].expenditure;
                }
            }
          }
        }
        if (ex)
```

```
    {
        revenue = revenue * 1.035;
    }
}
public void DataIN(MasonGeometry mg){

     //some location attributes
    index = FSmodel.eAgentNum;
    code = mg.getIntegerAttribute("Code");
    county = mg.getStringAttribute("County");
    ct = mg.getDoubleAttribute("CT");
    addToMap(mg);
    size = getSize(mg);
    initialSize = size;
    insurance();
}

public void insurance(){

    Insurance = FSmodel.random.nextInt(4);
    if (Insurance!=3){
    Plan = FSmodel.random.nextInt(3);
    InsuranceComp = FSmodel.Ins[Insurance].comp[Plan];
    InsurancePrem = FSmodel.Ins[Insurance].prem[Plan];
    }else {InsuranceComp = 0; InsurancePrem = 0; Plan = 0;}
}

public double getSize(MasonGeometry mg){
```

```
    double tempSize = 0;

    if(FSmodel.random.nextDouble()<mg.getDoubleAttribute("RBig2Small"))
    {
       //big size
       tempSize =0.5 + 0.5* FSmodel.random.nextDouble();
    }
    else{
       //small
       tempSize = 0.5*FSmodel.random.nextDouble();
    }
    return tempSize;
}

public void addToMap(MasonGeometry mg){

    //visulizing location
getRandomPoint(mg);
//getRandomPointPoly(mg);

}

public void getCentrioid(MasonGeometry mg){
   location = mg.getGeometry().getCentroid();
int numGeo = mg.geometry.getNumPoints();



do{
```

```
    ArrayList<Double> pointX = new ArrayList();
    ArrayList<Double> pointY = new ArrayList();
    for (int i = 0; i < 3; i ++)
        {// make a triangle
        int random = FSmodel.random.nextInt(numGeo);
        pointX.add(mg.geometry.getCoordinates()[random].x);
        pointY.add(mg.geometry.getCoordinates()[random].y);
        }
    location.getCoordinate().x = (pointX.get(0) + pointX.get(1) + pointX.get(2))/pointX.size();
    location.getCoordinate().y =(pointY.get(0) + pointY.get(1) + pointY.get(2))/pointY.size();
}while (!mg.getGeometry().covers(location));
}

public void getRandomPointPoly(MasonGeometry mg){
     location = mg.getGeometry().getCentroid();
int numGeo = mg.geometry.getNumPoints();


do{
    ArrayList<Double> pointX = new ArrayList();
    ArrayList<Double> pointY = new ArrayList();
    ArrayList<Double> randomVector = new ArrayList();
    for (int i =0 ; i< numGeo; i++)//get Polygons and random Vector
    {int random =FSmodel.random.nextInt(numGeo);
        pointX.add(mg.geometry.getCoordinates()[random].x);
        pointY.add(mg.geometry.getCoordinates()[random].y);
        randomVector.add(FSmodel.random.nextDouble(false,false));
    }
    double x = 0;
```

```
    double y =0;

    for (int i = 1; i <numGeo; i++) //normalize to origin
    {
       x +=(randomVector.get(i)*(pointX.get(i) - pointX.get(0)));
       y+= (randomVector.get(i)*(pointY.get(i) - pointY.get(0)));
    }

    location.getCoordinate().x=x;
    location.getCoordinate().y=y;

}while(!mg.geometry.covers(location));System.out.println("done");
}

public void getRandomPoint(MasonGeometry mg){
    location = mg.getGeometry().getCentroid();
int numGeo = mg.geometry.getNumPoints();
int counter = 0;

do{
    counter++;
    ArrayList<Double> pointX = new ArrayList();
    ArrayList<Double> pointY = new ArrayList();
   for (int i = 0; i < 3; i ++)
        {// make a triangle
        int random = FSmodel.random.nextInt(numGeo);
        pointX.add(mg.geometry.getCoordinates()[random].x);
        pointY.add(mg.geometry.getCoordinates()[random].y);
```

```
        }
      double distanceX1 = pointX.get(0) - pointX.get(1);//normalize to orign
      double distanceY1 = pointY.get(0) - pointY.get(1);
      double distanceX2 = pointX.get(0) - pointX.get(2);
      double distanceY2 = pointY.get(0) - pointY.get(2);
      double r1 = FSmodel.random.nextDouble();//random variables
      double r2 = FSmodel.random.nextDouble();

      location.getCoordinate().x =  pointX.get(0)-((r1*distanceX1) + (r2*distanceX2));
      location.getCoordinate().y = pointY.get(0)- ((r1*distanceY1) + (r2*distanceY2));
      if (counter>200){getCentrioid(mg); break;}

    }while (!mg.getGeometry().covers(location));
    }

    public void projectedRevenue(){
      //this is a work around the issue of who comes before who,
      //wokrs best for the meansales reveune function in the census tract coming before the econ
agent calculations
     revenue = 0;
      for (int i= 0; i < FSmodel.getResNum(); i ++)
      {
        if (FSmodel.R[i].Code == code)//if in the same service area
        { double x = FSmodel.random.nextDouble();
          if (x <= freq) //double check on this vaule
          {
              if (FSmodel.R[i].expenditure>0)
              {
                revenue += gamma * (FSmodel.R[i].expenditure);
```

```
                //doesn't take out income from residents
                }
            }
          }
        }
      }
    }
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (Insurance) represents the insurance companies
 */
package DSOAMB;
import sim.engine.*;
/**
 *
 * @author MSaeid
 */

/*=================================================================
==================================================================
This is the insurance agent class... so far it does nothing more than offering a
set of predetirmined premiums and compensations that are found in excel files in
the data section of this model.
next move is to apply different insurance stategies for determining the best fit
premium and compensation values.
==================================================================
================================================================*/
public class Insurance implements Steppable{

    public double[] prem = new double[3];
    public double[] comp = new double[3];
    public double[] recoveryRate = new double[3];
```

```
    FieldSim FSmodel;

    public Insurance (FieldSim FSmodel){
    this.FSmodel = FSmodel;
    }

public void step(SimState State){

}

}
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (Katrina) replicates the Hurricane Katrina Event based on
 * HAZUS-MH data
 */
package DSOAMB;
import sim.engine.*;
/**
 @author MSaeid
 */
public class Katrina implements Steppable{
FieldSim FSmodel;

    public Katrina(FieldSim FSmodel) {
    this.FSmodel = FSmodel;
    }
public void step(SimState State){
    //Residents
    getDamage();
    setDamage();

    //ecocnomic agent
    getEAgentDamage();
    setEAgentDamage();
```

```
}
public void getDamage(){
   for (int i = 0; i <FSmodel.getResNum(); i++)
   {
      if (FSmodel.R[i].County.equals("Hancock"))
         getHancock(FSmodel.R[i]);
      else
         if (FSmodel.R[i].County.equals("Harrison"))
            getHarrison(FSmodel.R[i]);
         else
            if (FSmodel.R[i].County.equals("Jackson"))
               getJackson(FSmodel.R[i]);
            else{ System.out.println("ERROR: Couldn't find County for Katrina");
System.out.println(FSmodel.R[i].County);}


   }
}
public void getHancock(Residence R){
   double random = FSmodel.random.nextDouble();
   double damage ;
   if (random >=.4856) //None
      damage = FSmodel.random.nextDouble()*0.02 + 0;
   else if (random >= 0.34747) //Minor
      damage = FSmodel.random.nextDouble()*0.15 + 0.02;
   else if (random >= 0.13290) // Moderate
      damage = FSmodel.random.nextDouble()*0.5 + 0.15;
   else if (random >= 0.02189) // Severe
      damage = FSmodel.random.nextDouble()*0.7 + 0.5;
```

```
    else // Destruction
        damage = FSmodel.random.nextDouble()+ 0.7;

    if (damage >1 ) damage = 1;
    R.damage = damage;
}
public void getHarrison(Residence R){
    double random = FSmodel.random.nextDouble();
    double damage;
    if (random >=0.4374) //None
        damage = FSmodel.random.nextDouble()*0.02 + 0;
    else if (random >= 0.354606) //Minor
        damage = FSmodel.random.nextDouble()*0.15 + 0.02;
    else if (random >= 0.16470) // Moderate
        damage = FSmodel.random.nextDouble()*0.5 + 0.15;
    else if (random >= 0.0294) // Severe
        damage = FSmodel.random.nextDouble()*0.7 + 0.5;
    else // Destruction
        damage = FSmodel.random.nextDouble()+ 0.7;

    if (damage >1) damage = 1;
    R.damage = damage;
}
public void getJackson(Residence R){
    double random = FSmodel.random.nextDouble();
    double damage;
    if (random >=.7589) //None
        damage = FSmodel.random.nextDouble()*0.02 + 0;
```

```
    else if (random >= 0.1994) //Minor
        damage = FSmodel.random.nextDouble()*0.15 + 0.02;
    else if (random >= 0.03771) // Moderate
        damage = FSmodel.random.nextDouble()*0.5 + 0.15;
    else if (random >= 0.0025) // Severe
        damage = FSmodel.random.nextDouble()*0.7 + 0.5;
    else // Destruction
        damage = FSmodel.random.nextDouble()+ 0.7;

    if (damage >1) damage = 1;
    R.damage = damage;
}
public void setDamage(){
    for (int i = 0; i< FSmodel.getResNum(); i ++)
    {
        FSmodel.R[i].houseValue =FSmodel.R[i].initialHouseValue -
(FSmodel.R[i].initialHouseValue *FSmodel.R[i].damage);
        FSmodel.R[i].Recovery = FSmodel.R[i].houseValue/FSmodel.R[i].initialHouseValue;
        //System.out.println("Reovery = " +FSmodel.R[i].Recovery);
    }
}

public void getEAgentDamage(){
     for (int i = 0; i <FSmodel.eAgentNum; i++)
    {
        if (FSmodel.eAgent[i].county.equals("Hancock"))
            getEAgentHancock(FSmodel.eAgent[i]);

        else
```

```
        if (FSmodel.eAgent[i].county.equals("Harrison"))
          getEAgentHarrison(FSmodel.eAgent[i]);


        else
            if (FSmodel.eAgent[i].county.equals("Jackson"))
            getEAgentJackson(FSmodel.eAgent[i]);
    }
}

public void getEAgentHancock(EconomicAgent E){
    double random = FSmodel.random.nextDouble();
     double damage =0;
    if (random >=.4856) //None
        damage = FSmodel.random.nextDouble()*0.02 + 0;
    else if (random >= 0.34747) //Minor
        damage = FSmodel.random.nextDouble()*0.15 + 0.02;
    else if (random >= 0.13290) // Moderate
        damage = FSmodel.random.nextDouble()*0.5 + 0.15;
    else if (random >= 0.02189) // Severe
        damage = FSmodel.random.nextDouble()*0.7 + 0.5;
    else // Destruction
        damage = FSmodel.random.nextDouble()+ 0.7;
    if (damage > 1) damage =1;
    E.damage = damage;
    E.normalCondition = false;
}

public void getEAgentHarrison(EconomicAgent E){
```

```
    double random = FSmodel.random.nextDouble();
    double damage =0;
    if (random >=0.4374) //None
        damage = FSmodel.random.nextDouble()*0.02 + 0;
    else if (random >= 0.354606) //Minor
        damage = FSmodel.random.nextDouble()*0.15 + 0.02;
    else if (random >= 0.16470) // Moderate
        damage = FSmodel.random.nextDouble()*0.5 + 0.15;
    else if (random >= 0.0294) // Severe
        damage = FSmodel.random.nextDouble()*0.7 + 0.5;
    else // Destruction
        damage = FSmodel.random.nextDouble()+ 0.7;
    if (damage > 1) damage =1;
    E.damage = damage;
    E.normalCondition = false;
}

public void getEAgentJackson(EconomicAgent E){
    double random = FSmodel.random.nextDouble();
     double damage =0;
    if (random >=.7589) //None
        damage = FSmodel.random.nextDouble()*0.02 + 0;
    else if (random >= 0.1994) //Minor
       damage = FSmodel.random.nextDouble()*0.15 + 0.02;
    else if (random >= 0.03771) // Moderate
        damage = FSmodel.random.nextDouble()*0.5 + 0.15;
    else if (random >= 0.0025) // Severe
        damage = FSmodel.random.nextDouble()*0.7 + 0.5;
```

```
   else // Destruction
      damage = FSmodel.random.nextDouble()+ 0.7;


   if (damage >1) damage = 1;
   E.damage = damage;
   E.normalCondition = false;
}
public void setEAgentDamage(){
   for (int i = 0; i <FSmodel.eAgentNum; i++)
   {
      FSmodel.eAgent[i].size = FSmodel.eAgent[i].initialSize-
(FSmodel.eAgent[i].initialSize*FSmodel.eAgent[i].damage);
      if
(!FSmodel.eAgent[i].normalCondition){FSmodel.Census[FSmodel.eAgent[i].code].removeEcon
Agent(FSmodel.eAgent[i]);}
   }
}
}
                                    /* END OF CLASS*/
```

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (Hazard) is used to simulate the repeated Hazardous Events
 */
package DSOAMB;
import com.vividsolutions.jts.geom.CoordinateSequenceFilter;
import com.vividsolutions.jts.geom.Point;
import sim.engine.*;
import sim.field.geo.GeomVectorField;
import sim.util.Bag;
import sim.util.geo.MasonGeometry;
import java.lang.Object;
/**
<Hazard>
Input
no input (based on Random Distribution)
Output
no output, but the damage value would change from zero to a value depending on a probability
distribution and change its county as well


@author MSaeid
 */
public class Hazard implements Steppable {
    Point location;
    double damage=0;
```

```
double rate;
FieldSim FSmodel;

String County;

public Hazard (FieldSim FSmodel){
    this.FSmodel = FSmodel;
}



public void step(SimState State){
    GeomVectorField HazardField = FSmodel.HazardMap;

    double R =FSmodel.random.nextGaussian() +1;

    if (rate == 15)

    {
        //Hurricane
      //  getHurricane();
     }else if(R< 0.0061)
   {
        //Tornado
        getTornado();
    }else damage =0;

}
```

```
public void Create(MasonGeometry mg){
   location = mg.getGeometry().getInteriorPoint();


}
   public void Move(MasonGeometry mg){
       location = mg.getGeometry().getInteriorPoint();


   }
  public void getHurricane(){
      damage = 0.86;
  }
  public void getTornado(){
      getLocation();
      double R = FSmodel.random.nextGaussian();
      if (R>0.4306)
      {
          //f0
          damage = 0.01;  //might be arbitrary at this point
      }
      else if (R>0.363)
      {
          //f1
          damage = 0.05;
      }
      else if (R>0.1623)
```

```
        {//f2
            damage = 0.1;
        }
        else {
                //f3
            damage = 0.25;
                }
    }

    public void getLocation(){
        MasonGeometry mg = (MasonGeometry)
FSmodel.map.getGeometries().get(FSmodel.random.nextInt(FSmodel.CT_number));
        location = mg.getGeometry().getCentroid();
        Bag temp =  FSmodel.HazardMap.getGeometries();

        MasonGeometry tempmg = (MasonGeometry) temp.get(0);

        tempmg.geometry.getCoordinate().x= location.getCoordinate().x;
        tempmg.geometry.getCoordinate().y= location.getCoordinate().y;
        location = mg.getGeometry().getCentroid();
        County= mg.getStringAttribute("County");
    }

}
```

/* END OF CLASS*/

```
/*
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 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (ServiceLocations) is used to faciltate the EVI calculations
 * and Wastewater treatment facilities optimization
 */
package DSOAMB;
/**
 *
 * @author MSaeid
 */
//WWTF Service locations for EVI
public class ServiceLocations {
    double need;
    double EVI,oldEVI;
    int feasible;
    String county;
    public double wwNeeds;
    public double water;
    public double treatedWasteWater;
    public double VegCover;
    public double Land;

    public int LandIndex, VegCoverIndex, LossCoverIndex,HabFragIndex, ReserveIndex;
    public int WasteIndex, TotalVehIndex, PopIndex, PopGrowthIndex, wasteWaterIndex;
```

```
public void getVegIndex(){
   if (VegCover >=0.8) VegCoverIndex =1;
   else{
      if(VegCover >= 0.6) VegCoverIndex =2;
      else {
         if(VegCover >= 0.4) VegCoverIndex =3;
         else{
            if(VegCover >=0.2) VegCoverIndex =4;
            else{
               if(VegCover>=0.1) VegCoverIndex = 5;
               else VegCoverIndex = 6;
            }
         }
      }
   }
}

public void getWasteWaterIndex(){ //which is actually renewable water

   double ratio = (water -treatedWasteWater)/water;
   if (ratio <=0.10) wasteWaterIndex =1;
   else{
       if (ratio <=0.20) wasteWaterIndex =2;
       else{
          if(ratio<=0.40) wasteWaterIndex=3;
          else{
             if(ratio<=0.60) wasteWaterIndex=4;
```

```
                else{
                    if(ratio<=0.80) wasteWaterIndex = 5;
                    else{
                        if(ratio<=1.00) wasteWaterIndex =6;
                        else wasteWaterIndex=7;
                    }
                }
            }
        }
    }
}

public void adjustNeedPos(double value){
    treatedWasteWater += value;
}

public void adjustNeedNeg(double value){
    treatedWasteWater -=value;
}

public void updateVegCoverAndLoss(double areaKM2){
    //only used by actions that affect the vegitation cover
    double vegOld = VegCover;
    VegCover = (Land * VegCover) - (areaKM2);
    VegCover = VegCover/Land;
}

public void updateVegCoverGain(double areaKM2){
```

```
        VegCover = (Land * VegCover) + (areaKM2);
        VegCover = VegCover/Land;
    }

    public void averageEVI(){
        oldEVI = EVI;
        getWasteWaterIndex();
        EVI = (LandIndex + VegCoverIndex + LossCoverIndex + HabFragIndex + ReserveIndex +
WasteIndex + PopIndex + PopGrowthIndex + TotalVehIndex+ wasteWaterIndex)/10;

    }
}
                                        /* END OF CLASS*/
```

```
/*
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 * DSOAMB is developed to test the research hypothesis utilizing the
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 *
 * This class (Census) holds the data on the census tract level needed to
 * evaluate the vulnerability of the community
 */
package DSOAMB;
import sim.engine.*;
import sim.util.Bag;
import sim.util.geo.MasonGeometry;
/**
 this class is for the census tracts.
 It is practically useful (and designed) for the EVI and EconVI data gathering and calculation
 * @author MSaeid
 */
public class Census implements Steppable {
    private FieldSim FSmodel;


    // General Data
    public String County;
    public double CT;
    public int code;
    // Environmental Data
    public double Land;
    public double VegCover;
```

```
public double LossCover;
public double HabFrag;
public double Reserve;
public double Waste;
public double TotalVeh;
public double Pop;
public double PopGrowth;
public int wwtfFeasibility;
public double wwNeeds;
public double water;
public double treatedWasteWater;

//Sub EVI
public int LandIndex, VegCoverIndex, LossCoverIndex,HabFragIndex, ReserveIndex;
public int WasteIndex, TotalVehIndex, PopIndex, PopGrowthIndex, wasteWaterIndex;

//EVI
public double EVI = 0;
public double deltaEVI=0;
public double oldEVI = 0;


//Economic Data
public double HomeOwnership;
public double employment;
public double femalLabor;
public double income;
public double nonPrimary;
```

```
public double small2Large;
public double retail;
public double commerical;
public double lending;
public double doctors;
public double meanSales;

public double retailMultiplier = 1;



//standaridzed Economic data
public double StHomeOwnership;
public double StEmployment;
public double StFemalLabor;
public double StIncome;
public double StNonPrimary;
public double StSmall2Large;
public double StRetail;
public double StCommerical;
public double StLending;
public double StDoctors;
public double StMeanSales;

//EconVI
public double EconVI;
public double deltaEconVI;
public double oldEconVI;
```

```
    public Census (FieldSim FSmodel){
        this.FSmodel = FSmodel;
    }

    public void step (SimState state){


    }

    public void DataIn(MasonGeometry Emg, MasonGeometry EconMg){


/*==========================================================================
==========================================================================
General Data
==========================================================================
=========================================================================*/
        County = Emg.getStringAttribute("County");
        CT = Emg.getDoubleAttribute("CT");
        code = Emg.getIntegerAttribute("Code");
/*=========================================================================
=========================================================================
                        Environmental Data
==========================================================================
=========================================================================*/
        Land= Emg.getDoubleAttribute("LandArea");
        VegCover = Emg.getDoubleAttribute("VegCover");
        LossCover = Emg.getDoubleAttribute("LossCover");
        HabFrag = Emg.getDoubleAttribute("HabFrag");
```

```
        Reserve = Emg.getDoubleAttribute("Reserve");
        Waste = Emg.getDoubleAttribute("Waste");
        Pop = Emg.getDoubleAttribute("Pop");
        PopGrowth = Emg.getDoubleAttribute("PopGrowth");
        TotalVeh = Emg.getDoubleAttribute("TotalV");
        water = Emg.getDoubleAttribute("water");
        wwtfFeasibility = Emg.getIntegerAttribute("WWTF");
        wwNeeds = Emg.getDoubleAttribute("wwNeeds");
        treatedWasteWater = Emg.getDoubleAttribute("wwTreated");//which is actually affecting
the renewable water
/*=====================================================================
======================================================================
                    Economic Data
======================================================================
=====================================================================*/
        HomeOwnership = EconMg.getDoubleAttribute("PerHomeOwn");
        employment = EconMg.getDoubleAttribute("Employment");
        femalLabor = EconMg.getDoubleAttribute("FLabor");
        income = EconMg.getIntegerAttribute("Income");
        nonPrimary = EconMg.getDoubleAttribute("nonPrimary");
        small2Large = EconMg.getDoubleAttribute("RBig2Small");
        retail = EconMg.getDoubleAttribute("Retail");
        commerical = EconMg.getDoubleAttribute("Commerical");
        lending = EconMg.getDoubleAttribute("Lending");
        doctors = EconMg.getDoubleAttribute("Doc");
        meanSales = EconMg.getDoubleAttribute("MeanSales");
    }

    public void getLandIndex(){
```

```
    if (Land >= 12000000) LandIndex = 1;
    else {
        if (Land >= 163000) LandIndex = 2;
        else {
            if(Land >=22000) LandIndex = 3;
            else {
                if(Land >=3000) LandIndex =4;
                else {
                    if (Land >=403) LandIndex =5;
                    else{
                        if (Land >=55) LandIndex =6;
                        else LandIndex =7;
                    }
                }
            }
        }
    }
}

public void getVegIndex(){
    if (VegCover >=0.8) VegCoverIndex =1;
    else{
        if(VegCover >= 0.6) VegCoverIndex =2;
        else {
            if(VegCover >= 0.4) VegCoverIndex =3;
            else{
                if(VegCover >=0.2) VegCoverIndex =4;
                else{
```

```
                if(VegCover>=0.1) VegCoverIndex = 5;
                else VegCoverIndex = 6;
            }
        }
    }
  }
}

public void getLossCoverIndex(){
  if (LossCover > 0) LossCoverIndex = 1;
  else {
    if (LossCover == 0) LossCoverIndex = 3;
    else{
      if (LossCover <= -2) LossCoverIndex = 7;
      else LossCoverIndex = 6;
    }
  }
}

public void getHabFragIndex(){
  if (HabFrag <= 0.2) HabFragIndex = 1;
  else {
    if (HabFrag <= 0.4) HabFragIndex = 2;
    else {
      if (HabFrag <= 0.6) HabFragIndex =3;
      else {
        if (HabFrag <=0.8) HabFragIndex = 4;
        else {
```

```
                    if (HabFrag <=1) HabFragIndex = 5;
                    else {
                        if (HabFrag <=1.2 ) HabFragIndex =6;
                        else HabFragIndex = 7;
                    }
                }
            }
        }
    }
}

public void getReserveIndex(){
    if (Reserve >= 0.2) ReserveIndex = 1;
    else {
        if (Reserve >= 0.15) ReserveIndex = 2;
        else{
            if (Reserve >= 0.1) ReserveIndex = 3;
            else {
                if (Reserve >=0) ReserveIndex = 4;
                else ReserveIndex = 7;
            }
        }
    }
}

public void getTotalVehIndex(){
    if (TotalVeh <=1.7 ) TotalVehIndex = 1;
    else {
```

```
        if (TotalVeh <= 3.5) TotalVehIndex = 2;
        else {
          if (TotalVeh <= 6.4) TotalVehIndex = 3;
          else {
            if (TotalVeh <= 11.2) TotalVehIndex = 4;
            else {
              if (TotalVeh <=147.4) TotalVehIndex = 5;
              else {
                if (TotalVeh <=19.1) TotalVehIndex =6;
                else TotalVehIndex = 7;
              }
            }
          }
        }
      }
    }

    public void getWasteIndex(){
      if(Waste <=1.7) WasteIndex = 1;
      else {
        if(Waste<=6.4) WasteIndex = 2;
        else {
          if (Waste <=19.1) WasteIndex = 3;
          else {
            if (Waste <=53.6) WasteIndex =4;
            else {
              if (Waste <=147.4) WasteIndex =5;
              else {
```

```
                if (Waste <=402.4) WasteIndex =6;
                else WasteIndex = 7;
              }
            }
          }
        }
      }
    }

    public void getPopIndex(){
      if (Pop <=19.1) PopIndex = 1;
      else {
        if (Pop<=32.1) PopIndex = 2;
        else {
          if (Pop<=53.6) PopIndex =3;
          else {
            if (Pop<=89) PopIndex =4;
            else {
              if (Pop <=147.4) PopIndex = 5;
              else {
                if (Pop<=243.7) PopIndex =6;
                else PopIndex =7;
              }
            }
          }
        }
      }
```

```
}

public void getPopGrowthIndex(){
   if (PopGrowth ==0) PopGrowthIndex = 1;
   else {
      if (PopGrowth <= 0.5) PopGrowthIndex = 3;
      else {
         if (PopGrowth <= 1) PopGrowthIndex =4;
         else {
            if (PopGrowth <=1.5) PopGrowthIndex =5;
            else {
               if( PopGrowth <=2) PopGrowthIndex = 6;
               else PopGrowthIndex =7;
            }
         }
      }
   }
}

public void getWasteWaterIndex(){ //which is actually renewable water
   double ratio = (water -treatedWasteWater)/water;

   if (ratio <=0.10) wasteWaterIndex =1;
   else{
       if (ratio <=0.20) wasteWaterIndex =2;
       else{
          if(ratio<=0.40) wasteWaterIndex=3;
          else{
```

```
                if(ratio<=0.60) wasteWaterIndex=4;
                else{
                    if(ratio<=0.80) wasteWaterIndex = 5;
                    else{
                        if(ratio<=1.00) wasteWaterIndex =6;
                        else wasteWaterIndex=7;
                    }
                }
            }
        }
    }
}

public void averageEVI(){
    oldEVI = EVI;
    updateAll();
    getLandIndex();
    getVegIndex();
    getLossCoverIndex();
    getHabFragIndex();
    getReserveIndex();
    getWasteIndex();
    getTotalVehIndex();
    getPopIndex();
    getPopGrowthIndex();
    getWasteWaterIndex();
    EVI = (LandIndex + VegCoverIndex + LossCoverIndex + HabFragIndex + ReserveIndex +
WasteIndex + PopIndex + PopGrowthIndex + TotalVehIndex+ wasteWaterIndex)/10;
```

```
    deltaEVI = EVI - oldEVI; //the less the better
}

public void updateVegCoverAndLoss(double size){
    //only used by actions that affect the vegitation cover
    double vegOld = VegCover;
    VegCover = (Land * VegCover) - (size*9.290304e-8);
    VegCover = VegCover/Land;
    LossCover = (VegCover - vegOld) /2 ;
}

public void updateWaste(){
    //changes every year with the change in population and change in consumption rate
    //waste generation is fixed at this time... can be changed later on (value of 1.986 kg a day)
Waste = (Pop * 1.986 * 356) /  (Land *1000);
}

public void updatePopandGrowth(){
//linear change to the actual change in population growth in the last 10 years
Pop = Pop * (1 +PopGrowth);


}

public void updateAll(){
    // the perioidical change (annual)
    updatePopandGrowth();
    updateWaste();
}
```

```
public void standardizeHomeOwnership(double max, double min){
    double diff = max-min;
    StHomeOwnership = (HomeOwnership-min)/diff;
}

public void standardizeEmployment (double max, double min){
    double diff = max-min;
    StEmployment = (employment-min)/diff;
}

public void standardizeFemaleLabor (double max, double min){
    double diff = max-min;
    StFemalLabor = (femalLabor-min)/diff;


}

public void standardizeIncome (double max, double min){
    double diff = max-min;
    StIncome = (income-min)/diff;
}

public void standadizeNonPrimary (double max, double min){
    double diff = max-min;
    StNonPrimary = (nonPrimary -min)/diff;
}

public void standardizeSmall2Large (double max, double min){
```

```
    double diff = max-min;
    StSmall2Large = (small2Large- min)/diff;
}
public void standrdizeRetail (double max, double min){
    double diff = max-min;
    StRetail = (retail-min)/diff;
}

public void standrdizeCommerical( double max, double min){
    double diff = max-min;
    StCommerical = (commerical-min)/diff;
}

public void standardizeLedning (double max, double min){
    double diff = max-min;
    StLending = (lending-min)/diff;
}

public void standardizeDoc (double max, double min){
    double diff = max-min;
    StDoctors = (doctors-min)/diff;
}

public void stanardizeMeanSales (double max,double min){
    double diff = max-min;
    StMeanSales = (meanSales-min)/diff;
}
```

```
public void getEconRev(){
   for (int i =0; i <FSmodel.eAgentNum; i++)
   {
      if (FSmodel.eAgent[i].code == code)
      {
         FSmodel.eAgent[i].getRevenue();


      }
   }
}

public void meanSalesAdjust(){
   meanSales=0;
   int counter =1;
   for (int i=0; i<FSmodel.eAgentNum; i++)
   {
      if(FSmodel.eAgent[i].code == code)
      {counter ++;
      //FSmodel.eAgent[i].projectedRevenue();
      meanSales += FSmodel.eAgent[i].revenue * retailMultiplier;
      }
   }
   meanSales = meanSales/counter;
}



public void deltaEconVI(){
   deltaEconVI = EconVI - oldEconVI;
```

```
    }
/*=============================================================================
==============================================================================
                Residents and Econ Agent Interactions
==============================================================================
============================================================================*/
    public boolean checkRetailGrowth(){
        double residentsBudget=0;
        for (int i = 0; i <FSmodel.ResNum; i ++)
        {
            if (FSmodel.R[i].CT == CT)
            {
             residentsBudget += FSmodel.R[i].expenditure;
            }
        }
        if (residentsBudget>0)
        {
            return true;
        }
        else return false;
    }

    public void addEconAgent(){

    }

    public void addEconAgentBack(EconomicAgent eAgent){
        retail = ((retail*1000)+1)/1000;
            commerical = ((commerical*1000)+1)/1000;
```

```
    }

    public void removeEconAgent(EconomicAgent eAgent){
        //decrease the retail by one
        //won't affect the vegetaion cover.
        retail = ((retail*1000)-1)/1000;
        commerical = ((commerical*1000)-1)/1000;

    }

}
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (GUI) controls some of the needed GUI interfaces
 */

package DSOAMB;
import com.lowagie.text.Font;
import com.lowagie.text.Graphic;
import java.awt.Color;
import java.awt.FlowLayout;
import java.awt.Graphics;
import java.awt.Graphics2D;
import java.awt.Rectangle;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import javax.swing.JButton;
import javax.swing.JComponent;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;

/**
 *
 * @author MSaeid
```

```
 */
public class GUI {
   FieldSim FSmodel;
   public GUI(FieldSim FSmodel){
      this.FSmodel = FSmodel;
   }
   public void optimization (){

/*=====================================================================
======================================================================
This method is creaated to choose which vulnerability indicator to be optimized
   Consult the following links
   http://stackoverflow.com/questions/15392699/how-to-get-the-input-from-a-jframe-form
   https://docs.oracle.com/javase/tutorial/uiswing/layout/using.html

======================================================================
===================================================================*/
   final JFrame frame = new JFrame("Step 1: Vulnerability Optimization Parameters"); //create a
frame to hold the panel
   frame.setLocation(700,350);
   final JPanel p; //first create a panel that holds all buttons and labels


   final String[] msg = {"Social" , "Enviromental", "Economic", "Social and Enviromental",
"Social and Economic", "Enviromental and Economic", "ALL"};
   JButton[] button = new JButton[msg.length];//create buttons with label on them
     p = new JPanel(new FlowLayout());
   for (int i = 0; i<msg.length; i ++)
   {
       button[i] = new JButton (msg[i]);
      p.add(button[i]);
```

```
}

JLabel l = new JLabel("Select the vulnerability indicator(s) for optimization");
p.add(l);



final JPanel p2= new JPanel (new FlowLayout());
 final String[] msg2 = {"Roth Erev Model", "Q-learning", "None"};
 JButton[] button2 = new JButton[msg2.length];

 for (int i = 0; i <msg2.length; i++ )
 {
    button2[i] = new JButton (msg2[i]);
    p2.add(button2[i]);
 }

JLabel l2 = new JLabel ("Select Learning Module");
p2.add(l2);

//SDRC buget distribution
final JPanel p3= new JPanel(new FlowLayout());
final String[] msg3 = {"Uniform", "Actual"};
JButton[] button3= new JButton[msg3.length];

for (int i= 0; i<msg3.length; i++)
{
   button3[i] = new JButton(msg3[i]);
```

```
    p3.add(button3[i]);
  }
  JLabel l3= new JLabel ("Select SDRC's Initial Budget Distribution");
  p3.add(l3);


  //set all panels opaqu =true
  frame.setDefaultCloseOperation(JFrame.HIDE_ON_CLOSE);
    p.setOpaque(true);
    p2.setOpaque(true);
    p2.setOpaque(true);


   for (int i =0; i <msg.length; i++) //for each button
   {
    button[i].addActionListener(new ActionListener(){ //listen to the action
      @Override
      public void actionPerformed (ActionEvent e)
      {
        JButton b = (JButton)e.getSource();//transfer the action to string

      String text = (String) b.getText();
      switch (text){// check the string value and correlate
        case "Social": {FSmodel.SDRC.social=true; FSmodel.SDRC.econom =false;
FSmodel.SDRC.enviro=false; break;}

        case "Enviromental": {FSmodel.SDRC.social=false; FSmodel.SDRC.econom =false;
FSmodel.SDRC.enviro=true;break;}
```

```
            case "Economic": {FSmodel.SDRC.social=false; FSmodel.SDRC.econom =true;
FSmodel.SDRC.enviro=false;break;}

            case "Social and Enviromental": {FSmodel.SDRC.social=true;
FSmodel.SDRC.econom =false; FSmodel.SDRC.enviro=true;break;}

            case "Social and Economic": {FSmodel.SDRC.social=true; FSmodel.SDRC.econom
=true; FSmodel.SDRC.enviro=false;break;}

            case "Enviromental and Economic": {FSmodel.SDRC.social=false;
FSmodel.SDRC.econom =true; FSmodel.SDRC.enviro=true;break;}

            case "ALL": {FSmodel.SDRC.social=true; FSmodel.SDRC.econom =true;
FSmodel.SDRC.enviro=true;break;}
          }
        System.out.println("Social vulnerability = " + FSmodel.SDRC.social);
        System.out.println("Economic vulnerability = " + FSmodel.SDRC.econom);
        System.out.println("Environmental vulnerability = " + FSmodel.SDRC.enviro);
          frame.remove(p);
          frame.add(p2);
          frame.setTitle("Step 2: SDRC's Learning Module");
          frame.setSize(500,200);
          frame.revalidate();
          frame.repaint();



          }
        });
    }
```

```
for (int i =0; i<msg2.length; i++)
{
    button2[i].addActionListener(new ActionListener(){ //listen to the action
        public void actionPerformed (ActionEvent e)
        {
            JButton b2 = (JButton)e.getSource();
            String text2 = (String)b2.getText();
            switch (text2){
                case "Roth Erev Model": {FSmodel.SDRC.RV = true; FSmodel.SDRC.Qlearning =
false;break;}
                case "Q-learning": {FSmodel.SDRC.RV = false; FSmodel.SDRC.Qlearning =true;
break;}
                case "None": {FSmodel.SDRC.RV = false; FSmodel.SDRC.Qlearning =
false;break;}
            }
        System.out.println("Roth Erve = " + FSmodel.SDRC.RV);
        System.out.println("Q-learning = " + FSmodel.SDRC.Qlearning);
            frame.remove(p2);
            frame.add(p3);
            frame.setTitle("Step 3: SDRC's Initial Budget");
            frame.revalidate();
            frame.repaint();
        }
    });
}
```

```
    for (int i=0; i<msg3.length; i++)
    {
       button3[i].addActionListener(new ActionListener(){
        public void actionPerformed (ActionEvent e)
        {
           JButton b2 = (JButton)e.getSource();
           String text3= (String)b2.getText();
           switch (text3){
              case "Uniform":
{FSmodel.SDRC.probPubHome=0.25;FSmodel.SDRC.probRepair=0.25;
FSmodel.SDRC.probSmallEconAgentAid=0.25;FSmodel.SDRC.probUpgrade=0.25; break;}
              case "Actual": {FSmodel.SDRC.probPubHome =0.04; FSmodel.SDRC.probRepair
=0.8; FSmodel.SDRC.probSmallEconAgentAid = 0.12; FSmodel.SDRC.probUpgrade
=0.04;break;}
           }
         frame.setVisible(false);
        }
       });
    }

    frame.add(p);
    frame.pack();
    frame.setSize(600, 300);
    frame.setVisible(true);
}


   public void BarChart(){
    JFrame frame = new JFrame();
```

```
        frame.setSize(400,400);
          frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);


          BarChartComponent c  = new BarChartComponent();
          frame.add(c);
          frame.setVisible(true);
      }


}
```

/* END OF CLASS*/

```java
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (WWTF) represents the WWTFs projects
 */
package DSOAMB;

/**
 *
 * @author MSaeid
 */

//WWTF for EVI calculation
public class WWTF {
    double capacity;
    double value;
    double location;
    double cost;
    String County;
    double size;
    int[] seq =new int[78];
    int seqCounter =1;

    public int findFirst(ServiceLocations[] Service)
    {
```

```
    int check =0;
    for (int x =0; x < Service.length ; x++)
    {
    if (seq[x]==1)
        check = x;
    x = Service.length;
    }
    return check;
}

public void addLocation(int i, ServiceLocations Service){
    if (seqCounter==1)
    {//adjust associated service location vegatition cover loss
        Service.updateVegCoverAndLoss(size);
    }
    seq[i]=seqCounter+1;
    seqCounter ++;
}

public void removeLocation(int i, ServiceLocations Service, int length){
    int check = seq[i];
    if (check == 1)
    {
        //adjust associated service location vegation cover gain
        Service.updateVegCoverGain(size);
    }
    for (int x=0; x < length; x++)
    {
```

```
            if(seq[x]==check) seq[x]=0;
            else {
               if (seq[x]>check) seq[x]--;
            }
         }seqCounter--;
      }

   }
```

/* END OF CLASS*/

```
/*
 * Disaster Recovery Strategy Optimization using Agent Based Modeling (DSOAMB)
 * Developed by Mohamed S. Eid for his Doctoral Dissertation
 * DSOAMB is developed to test the research hypothesis utilizing the
 * Post-Katrina redevelopment in three Mississippi coastal counties
 *
 * This class (DataOut) controls where all the data will be printed on the
 * Secondary storage
 */
package DSOAMB;
import java.util.Formatter;
import static java.lang.System.out;
import javax.swing.JFrame;
import java.io.*;
import java.util.*;
import java.util.logging.Level;
import java.util.logging.Logger;
/**
 *
 * @author MSaeid
 */
public class DataOut {
    private Formatter RES;
    private Formatter GOV;

    private Formatter EconAgentHancock;
    private Formatter EconAgentHarrison;
    private Formatter EconAgentJackson;
```

```
private Formatter EconAgentAverage;

private Formatter LGOV_Hancock;
private Formatter LGOV_Harrison;
private Formatter LGOV_Jackson;

private Formatter SoVI;

private Formatter EVIHancock;
private Formatter EVIHarrison;
private Formatter EVIJackson;


private Formatter EconVIHancock;
private Formatter EconVIHarrison;
private Formatter EconVIJackson;

private Formatter HAZ;

private Formatter Fund;

private Formatter WWTF;
private Formatter assignments;
private Formatter services;

FieldSim FSmodel;

private Formatter CTSOVI;
```

```
   public  DataOut(FieldSim FSmodel){
       this.FSmodel = FSmodel;
   }


   public void CreateFile (int n){ //residents, gov, social and funds
       try {
       RES = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\Residence\\" + n + ".csv");
           RES.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s",
"Average Utility", ",", "Co1 plan A", ",", "Co1 plan B", ",", "Co1 plan C", ",", "Co2 plan
D",",","Co2 plan E",",","Co2 plan F",",","Co3 plan G",",","Co3 plan H",",","Co3 plan I",",","No
Inusrance", '\n');


       GOV = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\GOV\\"+"SRDC.csv");
           GOV.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", "number",
",", "PubHome" , ",", "Repair", ",", "Upgrade", "," , "SmallLoan", "," , "TaxExemption" , ",",
"Utility", ",", "AvgSOVI ",",","Min",",","Max", '\n');
      CTSOVI = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\CTSOVI.csv");


      Fund = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\GOV\\Fund.csv");
           Fund.format("%s%s%s%s%s%s%s%s",
"Upgrade",",","Repair",",","PubHome",",","SBL",'\n');


           SoVI = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\SoVI.csv");
           SoVI.format("%s%s%s%s%s%s", "County",",","code",",","SoVI",'\n');
   } catch (Exception e ){
         System.out.println("Error");
   }
}
//envirionmental output
```

```
    public void EVICreate(){
        try {
        RES.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s",
"Average Utility", ",", "Co1 plan A", ",", "Co1 plan B", ",", "Co1 plan C", ",", "Co2 plan
D",",","Co2 plan E",",","Co2 plan F",",","Co3 plan G",",","Co3 plan H",",","Co3 plan I",",","No
Inusrance", '\n');


        EVIHancock = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\EVIHancock.csv");

EVIHancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s
%s", "CT",",","County",",","EVI",",","Land",",","Vegitation Cover",",","Loss of
Cover",",","Habitat Fragmination",",","Terrastrial Reserve",",","Waste
Production",",","Vehicles",",","Population",",","Population Growth",",",'\n');


        EVIHarrison = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\EVIHarrison.csv");

EVIHarrison.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%
s", "CT",",","County",",","EVI",",","Land",",","Vegitation Cover",",","Loss of
Cover",",","Habitat Fragmination",",","Terrastrial Reserve",",","Waste
Production",",","Vehicles",",","Population",",","Population Growth",",",'\n');


        EVIJackson = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\EVIJackson.csv");

EVIJackson.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%
s", "CT",",","County",",","EVI",",","Land",",","Vegitation Cover",",","Loss of
Cover",",","Habitat Fragmination",",","Terrastrial Reserve",",","Waste
Production",",","Vehicles",",","Population",",","Population Growth",",",'\n');


    } catch (Exception e ){
          System.out.println("Error");
    }
 }
```

```
    public void EVIOut(Census Census){
        if (Census.County.equals("Hancock"))
        {

EVIHancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s
%s%s%s",
Census.CT,",",Census.County,",",Census.EVI,",",Census.LandIndex,",",Census.VegCoverIndex,
",",Census.LossCoverIndex,",",Census.HabFragIndex,",",Census.ReserveIndex
,",",Census.WasteIndex,",",Census.TotalVehIndex,",",Census.PopIndex,",",Census.PopGrowthIn
dex,",",Census.wasteWaterIndex,",",'\n');
        }

    if (Census.County.equals("Harrison"))
        {

EVIHarrison.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%
s%s%s",
Census.CT,",",Census.County,",",Census.EVI,",",Census.LandIndex,",",Census.VegCoverIndex,
",",Census.LossCoverIndex,",",Census.HabFragIndex,",",Census.ReserveIndex
,",",Census.WasteIndex,",",Census.TotalVehIndex,",",Census.PopIndex,",",Census.PopGrowthIn
dex,",",Census.wasteWaterIndex,",",'\n');
        }

    if (Census.County.equals("Jackson"))
        {

EVIJackson.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%
s%s%s",
Census.CT,",",Census.County,",",Census.EVI,",",Census.LandIndex,",",Census.VegCoverIndex,
",",Census.LossCoverIndex,",",Census.HabFragIndex,",",Census.ReserveIndex
```

```
,",",Census.WasteIndex,",",Census.TotalVehIndex,",",Census.PopIndex,",",Census.PopGrowthIn
dex,",",Census.wasteWaterIndex,",",'\n');
        }
    }
    public void EVIOutLine(){
        EVIHancock.format("%s", '\n');
        EVIHarrison.format("%s", '\n');
        EVIJackson.format("%s", '\n');
    }

    public void EVIClose(){
        EVIHancock.close();
        EVIHarrison.close();
        EVIJackson.close();
    }

//EconVI Output
    public void EconVICreate(){
        try{
            EconVIHancock = new Formatter
("C:\\Saeid\\UTK\\Data\\DSOAMB\\EconVI\\EconVIHancock.csv");
             EconVIHarrison= new Formatter
("C:\\Saeid\\UTK\\Data\\DSOAMB\\EconVI\\EconVIHarrison.csv");
              EconVIJackson = new Formatter
("C:\\Saeid\\UTK\\Data\\DSOAMB\\EconVI\\EconVIJackson.csv");


EconVIHancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s
%s%s%s%s%s%s",
"CT",",","County",",","EconVI",",","HomeOwnership",",","Employement",",","Female
```

```
Labor",",","Income",",","non primary",",","big to
small",",","retail",",","commerical",",","lending",",","Doc", "," , "meanSales",",",'\n');

EconVIHarrison.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s
%s%s%s%s%s%s",
"CT",",","County",",","EconVI",",","HomeOwnership",",","Employement",",","Female
Labor",",","Income",",","non primary",",","big to
small",",","retail",",","commerical",",","lending",",","Doc", "," , "meanSales",",",'\n');

EconVIJackson.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%
s%s%s%s%s%s",
"CT",",","County",",","EconVI",",","HomeOwnership",",","Employement",",","Female
Labor",",","Income",",","non primary",",","big to
small",",","retail",",","commerical",",","lending",",","Doc", "," , "meanSales",",",'\n');
        }catch (Exception e){
            System.out.println("Error are EconVI Create");
        }
    }

    public void EconVIOut (Census Census){
        if (Census.County.equals("Hancock"))
        {

EconVIHancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s
%s%s%s%s%s%s",
Census.CT,",",Census.County,",",Census.EconVI,",",Census.HomeOwnership,",",Census.emplo
yment,",",Census.femalLabor,",",Census.income,",",Census.nonPrimary,",",Census.small2Large,
",",Census.retail,",",Census.commerical,",",Census.lending,",",Census.doctors, "," ,
Census.meanSales,",",'\n');
        }
        if (Census.County.equals("Harrison"))
        {

EconVIHarrison.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s
%s%s%s%s%s%s",
```

```
Census.CT,",",Census.County,",",Census.EconVI,",",Census.HomeOwnership,",",Census.emplo
yment,",",Census.femalLabor,",",Census.income,",",Census.nonPrimary,",",Census.small2Large,
",",Census.retail,",",Census.commerical,",",Census.lending,",",Census.doctors, "," ,
Census.meanSales,",",'\n');

        }


        if (Census.County.equals("Jackson"))

        {

EconVIJackson.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%
s%s%s%s%s%s",
Census.CT,",",Census.County,",",Census.EconVI,",",Census.HomeOwnership,",",Census.emplo
yment,",",Census.femalLabor,",",Census.income,",",Census.nonPrimary,",",Census.small2Large,
",",Census.retail,",",Census.commerical,",",Census.lending,",",Census.doctors, "," ,
Census.meanSales,",",'\n');

        }

    }


    public void EconVIOutLine(){


        EconVIHancock.format("%s", '\n');

        EconVIHarrison.format("%s", '\n');

        EconVIJackson.format("%s", '\n');

    }


    public void EconVIClose()

    {

        EconVIHarrison.close();

        EconVIHancock.close();

        EconVIJackson.close();

    }
```

```
    public void HazCreate(int n){
        try{
            HAZ = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\HAZ\\" + "WindStorm.csv");
                HAZ.format("%s%s%s%s%s","number", ",", "Damage",",", '\n');
            LGOV_Hancock = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\GOV\\" +
"LRDM_Hancock.csv");
                LGOV_Hancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s",
"number", ",", "MinSOVI" , ",", "AvgSOVI", ",", "MaxSOVI", "," , "Recovery Report", ",", "
",",",","",",",","", '\n');
            LGOV_Harrison = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\GOV\\" +
"LRDM_Harrison.csv");
                LGOV_Harrison.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s",
"number", ",", "MinSOVI" , ",", "AvgSOVI", ",", "MaxSOVI", "," , "Recovery Report", ",", "
",",",","",",",","", '\n');
            LGOV_Jackson = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\GOV\\" +
"LRDM_Jackson.csv");
                LGOV_Jackson.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", "number",
",", "MinSOVI" , ",", "AvgSOVI", ",", "MaxSOVI", "," , "Recovery Report", ",", " ",",",","",",",","",
'\n');
        }catch (Exception e){
            System.out.println("Error");
        }
    }


    public void OutRes(Residence[] R){ //counts the insurance per resident
        double utl=0;
        int A=0,B=0,C=0,D=0,E=0,F=0,G=0,H=0,I=0,J = 0;
        for (int i =0; i < FSmodel.getResNum() ; i++)
        {
            utl += R[i].DeltaUtility;
```

```
if (R[i].InsCompIndex ==0)
{
   switch (R[i].InsPlanIndex)
   {
    case 0: A++;
          break;
    case 1: B++;
          break;
    case 2: C++;
          break;
    }
}else if(R[i].InsCompIndex == 1)
{
   switch (R[i].InsPlanIndex)
   {
    case 0: D++;
          break;
    case 1: E++;
          break;
    case 2: F++;
          break;
   }
}else if (R[i].InsCompIndex == 2)
{
   switch (R[i].InsPlanIndex)
   {
    case 0: G++;
          break;
```

```
            case 1: H++;
                  break;
            case 2: I++;
                  break;
            }

        }else J++;
      }
      utl = utl/FSmodel.getResNum();
       RES.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", utl, ",", A, ",", B, ",", C, ",", D,",",E,",",F,",",G,",",H,",",I,",",J, '\n');
      /*
      for(int i = 0; i < FSmodel.getResNum(); i++)
      {
        RES.format("%s%s%s%s%s%s%s%s%s%s", i, ",", R[i].Ins, ",", R[i].Repair_Relocate, ",", R[i].SOVI, ",", R[i].Utility, '\n');
      }*/
  }

  //economic agent
  public void EconAgentCreate(){
       try {
        EconAgentHancock = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\EconAgent\\EconAgentHancock.csv");

EconAgentHancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s","index", ",","county", ",", "CT", ",", "Size", "," ,"Condition", ",", "damage", ",", "Revenue",",","Initial Size",'\n');
        EconAgentHarrison = new Formatter ("C:\\Saeid\\UTK\\Data\\DSOAMB\\EconAgent\\EconAgentHarrison.csv");
```

```
EconAgentHarrison.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s","index",
",","county", ",", "CT", ",", "Size", "," ,"Condition", ",", "damage", ",", "Revenue",",","Initial
Size",'\n');

            EconAgentJackson= new Formatter
("C:\\Saeid\\UTK\\Data\\DSOAMB\\EconAgent\\EconAgentJackson.csv");

              EconAgentJackson.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s","index",
",","county", ",", "CT", ",", "Size", "," ,"Condition", ",", "damage", ",", "Revenue",",","Initial
Size",'\n');


            EconAgentAverage = new
Formatter("C:\\Saeid\\UTK\\Data\\DSOAMB\\EconAgent\\EconAgentAverage.csv");

              EconAgentAverage.format("%s%s%s%s%s%s","county",  ",", "Delata Size", ","
,"Mean Revenue",'\n');

     } catch (Exception e ){

         System.out.println("Error");

    }

   }

   public void EconAgentOut(EconomicAgent eAgent){

     if (eAgent.county.equals("Hancock"))
EconAgentHancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", eAgent.index,
",",eAgent.county, ",", eAgent.ct, ",",eAgent.size, "," ,eAgent.normalCondition, ",",
eAgent.damage, ",", eAgent.revenue,",",eAgent.initialSize,'\n');

       if
(eAgent.county.equals("Harrison"))EconAgentHarrison.format("%s%s%s%s%s%s%s%s%s%s
%s%s%s%s%s%s", eAgent.index, ",",eAgent.county, ",", eAgent.ct, ",",eAgent.size, ","
,eAgent.normalCondition, ",", eAgent.damage, ",", eAgent.revenue,",",eAgent.initialSize,'\n');

        if
(eAgent.county.equals("Jackson"))EconAgentJackson.format("%s%s%s%s%s%s%s%s%s%s
%s%s%s%s%s%s", eAgent.index, ",",eAgent.county, ",", eAgent.ct, ",",eAgent.size, ","
,eAgent.normalCondition, ",", eAgent.damage, ",", eAgent.revenue,",",eAgent.initialSize,'\n');

    }

   public void EconAgentLine(){

       EconAgentHancock.format("%s", '\n');
```

```
            EconAgentHarrison.format("%s", '\n');
                  EconAgentJackson.format("%s", '\n');
    }

    public void EconAgentAverage(EconomicAgent[] eAgent){
        double harrisonAverageSize=0;
        double hancockAverageSize=0;
        double jacksonAverageSize =0;

        double harrisonSales=0;
        double hancockSales=0;
        double jacksonSales =0;
        for (int i = 0; i<FSmodel.eAgentNum; i++)
        {
            if ((eAgent[i].county.equals("Hancock"))&&(!eAgent[i].soldOut))
            {
                hancockSales+= eAgent[i].revenue *
FSmodel.Census[eAgent[i].code].retailMultiplier;
                double delta = eAgent[i].size / eAgent[i].initialSize;
                hancockAverageSize += delta;
            }
            if ((eAgent[i].county.equals("Harrison"))&&(!eAgent[i].soldOut))
            {
                harrisonSales+= eAgent[i].revenue* FSmodel.Census[eAgent[i].code].retailMultiplier;
                double delta = eAgent[i].size / eAgent[i].initialSize;
                harrisonAverageSize += delta;
            }
            if ((eAgent[i].county.equals("Jackson"))&&(!eAgent[i].soldOut))
            {
```

```
            jacksonSales+= eAgent[i].revenue* FSmodel.Census[eAgent[i].code].retailMultiplier;
            double delta = eAgent[i].size / eAgent[i].initialSize;
            jacksonAverageSize += delta;
          }


        }
        EconAgentAverage.format("%s%s%s%s%s%s","Hancock",  ",", hancockAverageSize, ","
,hancockSales,'\n');
        EconAgentAverage.format("%s%s%s%s%s%s","Harrison",  ",", harrisonAverageSize, ","
,harrisonSales,'\n');
        EconAgentAverage.format("%s%s%s%s%s%s","Jackson",  ",", jacksonAverageSize, ","
,jacksonSales,'\n');
        EconAgentAverage.format("%s",'\n');
    }


    public void OutGOV (SDRC SDRC, int i){


        int hanP=0, hanU=0,hanR=0;
        int harP=0, harU=0,harR=0;
        int jacP=0, jacU=0,jacR=0;


        for (int x =0; x<FSmodel.ResNum; x ++)
        {
          if (FSmodel.R[x].County.equals("Hancock"))
          {
           if(FSmodel.R[x].GovPlan=='P') hanP++;
           if (FSmodel.R[x].GovPlan=='R') hanR++;
           if (FSmodel.R[x].GovPlan=='U') hanU++;
          }
```

```
if (FSmodel.R[x].County.equals("Harrison"))
{
 if(FSmodel.R[x].GovPlan=='P') harP++;
 if (FSmodel.R[x].GovPlan=='R') harR++;
 if (FSmodel.R[x].GovPlan=='U') harU++;
}
if (FSmodel.R[x].County.equals("Jackson"))
{
  if(FSmodel.R[x].GovPlan=='P') jacP++;
 if (FSmodel.R[x].GovPlan=='R') jacR++;
 if (FSmodel.R[x].GovPlan=='U') jacU++;
}
}
GOV.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", i , ",", SDRC.probPubHome , ",", SDRC.probRepair, ",", SDRC.probUpgrade, "," , SDRC.probSmallEconAgentAid, ",", SDRC.probExemptions, ",", SDRC.DeltaUtility, ",", SDRC.AvgSOVI,",",SDRC.MinSOVI,",",SDRC.MaxSOVI, '\n');

 LGOV_Hancock.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", i, ",", FSmodel.LDRM_Hancock.MinSOVI , ",", FSmodel.LDRM_Hancock.AvgSOVI, ",", FSmodel.LDRM_Hancock.MaxSOVI, "," , FSmodel.LDRM_Hancock.recoveryReport, ",",hanP,",",hanR,",",hanU, '\n');

 LGOV_Harrison.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", i, ",", FSmodel.LDRM_Harrison.MinSOVI , ",", FSmodel.LDRM_Harrison.AvgSOVI, ",", FSmodel.LDRM_Harrison.MaxSOVI, "," , FSmodel.LDRM_Harrison.recoveryReport, ",", harP,",",harR,",",harU, '\n');

 LGOV_Jackson.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s", i, ",", FSmodel.LDRM_Jackson.MinSOVI , ",", FSmodel.LDRM_Jackson.AvgSOVI, ",", FSmodel.LDRM_Jackson.MaxSOVI, "," , FSmodel.LDRM_Jackson.recoveryReport, ",", jacP,",",jacR,",",jacU, '\n');

HAZ.format("%s%s%s%s%s",i, ",", FSmodel.WindStorm.damage,",", '\n');


for (int y = 0; y < FSmodel.CT_number; y ++)
```

```
    {
        for (int x= 0; x <FSmodel.ResNum; x ++)
        {
        if (FSmodel.R[x].Code == y)
        {
            SoVI.format("%s%s%s%s%s%s",
FSmodel.R[x].County,",",FSmodel.R[x].Code,",",FSmodel.R[x].SOVI,'\n');
            x = FSmodel.ResNum;}
        }
    }
  }

  public void fundOut(){
    Fund.format("%s%s%s%s%s%s%s%s",
FSmodel.SDRC.UpgradeCost,",",FSmodel.SDRC.RepairCost,",",FSmodel.SDRC.PubHomeCost
,",",FSmodel.SDRC.SmallEconAgentAidCost,'\n');
  }

  public void CTSOVIOUT(int CT, double SOVI){
    CTSOVI.format("%s%s%s%s",CT,",",SOVI,'\n');



  }

  public void CloseGOV(){
    GOV.close();
    HAZ.close();
    RES.close();
    LGOV_Hancock.close();
```

```
        LGOV_Harrison.close();
        LGOV_Jackson.close();
        CTSOVI.close();
        EVIHancock.close();
        EVIHarrison.close();
        EVIJackson.close();
        Fund.close();
        EconAgentHancock.close();
        EconAgentHarrison.close();
        EconAgentJackson.close();
        EconAgentAverage.close();
    }

    public void OpenGOV(){


    }


    public void createSimulatedAnnealingWWTFOutcome(){
        try{
            WWTF = new Formatter("C:\\Saeid\\UTK\\Data\\DSOAMB\\EVI\\WWTF\\" +
"WWTF.csv");
            WWTF.format("%s%s%s%s%s", "county", ",","Capacity",",",'\n');
        }catch (Exception e){
            System.out.println("Error in WWTF");
        }
    }
    public void createSimulatedAnnealingServicesOutcome(){
        try{
```

```
        services = new Formatter("C:\\Saeid\\UTK\\Data\\DSOAMB\\EVI\\Service\\"
+"Service.csv");
        services.format("%s%s%s%s%s","need",",","treated waste water",",",'\n');
      }catch (Exception e){
        System.out.println("Error in Services");
      }
   }
   public void createSimulatedAnnealingAssignmentsOutcome(){
      try{
        assignments = new Formatter("C:\\Saeid\\UTK\\Data\\DSOAMB\\EVI\\WWTF\\" +
"assignments.csv");
      }catch (Exception e){
        System.out.println("Error in assignments");
      }
   }


   public void SimulatedAnnealingOutcome(WWTF[] wwtf, ServiceLocations[] service, int[][]
assignment){
      for (int i =0; i <wwtf.length; i++)
      {
        WWTF.format("%s%s%s%s%s", wwtf[i].County,",",wwtf[i].capacity,",",'\n');


        for (int j =0; j<service.length;j++)
        {
          assignments.format("%s%s", assignment[i][j],",");
        }assignments.format("%s",'\n');
      }


      for (int j =0; j<service.length;j++)
```

```
        {
            if(service[j].feasible==1) services.format("%s%s%s%s",
service[j].need,",",service[j].treatedWasteWater,'\n');
        }
    }
    public void closeSimulatedAnnealingOutcome(){
        WWTF.close();
        services.close();
        assignments.close();
}


}
```

/* END OF CLASS*/

Appendix C – Raw Data

Part I – Data Input

A- Social

Gathered Social Data 2000 - a

Census Tract	% Elderly	% pop w/ vehicle	% pop speaking English	% pop w/ Disability	% w/ high school education or higher	% pop un infirmed	% homeownership	Income / Capita	Median Age	% Mobile Homes
301	0.158	0.886108714	0.925	0	0.808158508	0	0.605263158	18688	38.5	0.040148699
302	0.141	0.057	0.945	0	0.74891096	0	0.722838137	16967	38	0.062178703
303	0.122	0.046	0.954	0	0.72070714	0	0.801310616	15948	38.5	0.217313788
304	0.119	0.055	0.974	0	0.683591913	0	0.844011142	14822	38.6	0.310367454
305	0.249	0.016	0.958	0	0.917274432	0	0.911684252	26631	48.4	0.021400778
306.01	0.093	0.033	0.975	0	0.748164092	0	0.872072526	15382	34.1	0.421245421
306.02	0.093	0.033	0.975	0	0.748164092	0	0.872072526	15382	34.1	0.421245421
1	0.160316319	0.851405622	0.646	0	0.551794872	0	0.537	14440	32.9	0.014
3	0.17698496	0.799635701	0.822	0	0.611645813	0	0.529	11933	36.4	0.024
6	0.311520376	0.903248588	0.924	0	0.885341727	0	0.381	23889	45.2	0
12.01	0.167225951	0.939361702	0.879	0	0.861538462	0	0.413	17293	31.2	0.03
12.02	0.15916955	0.920330703	0.922	0	0.849172148	0	0.366	20836	32.9	0.048
13	0.140105541	0.963045913	0.906	0	0.845019659	0	0.247	18668	32.7	0.023
14	0.229181495	0.94227923	0.935	0	0.849072279	0	0.409	24561	38.8	0.018
15.01	0.168824376	0.944581281	0.939	0	0.866297194	0	0.543	22662	36.4	0.085
15.02	0.168824376	0.944581281	0.939	0	0.866297194	0	0.543	22662	36.4	0.085
16	0.272270685	0.992763158	0.973	0	0.942098093	0	0.912	35170	44.3	0.003
17	0.172580645	0.900978916	0.948	0	0.786951872	0	0.488	15636	34.1	0.031
18	0.184345282	0.770072993	0.969	0	0.572310859	0	0.464	11895	34.3	0.117
19	0.188960379	0.911764706	0.971	0	0.758113371	0	0.643	17583	37.5	0.015
20	0.142765273	0.886947023	0.943	0	0.728098447	0	0.42	12484	33	0.068
23	0.164465786	0.862886598	0.95	0	0.650306748	0	0.549	13882	31.9	0.031
24	0.129851111	0.895400593	0.98	0	0.609059764	0	0.612	10365	30.3	0.099
25	0.001917546	1	0.908	0	0.966476913	0	0.014	11863	21.6	0
26	0.209756098	0.82991453	0.981	0	0.575487013	0	0.559	14786	34.6	0.047
27	0.146100846	0.929565217	0.931	0	0.827715356	0	0.695	16968	34.5	0.01
28	0.194415719	0.960784314	0.953	0	0.868545838	0	0.547	22792	37.6	0
29	0.317448943	0.951678952	0.93	0	0.899007337	0	0.758	30680	47.3	0
30	0.203798883	0.938053097	0.908	0	0.806140879	0	0.725	25056	38	0.033
31.01	0.125452664	0.960121534	0.932	0	0.809934396	0	0.74	16509	33.3	0.13
31.02	0.150105366	0.945958017	0.942	0	0.792610512	0	0.824	17636	37	0.217
32.04	0.113609184	0.98582996	0.949	0	0.783543872	0	0.624	16076	31.2	0.036
32.05	0.116349946	0.957477305	0.953	0	0.860756324	0	0.655	18962	32.9	0.039
32.06	0.109258071	0.953828171	0.936	0	0.810874704	0	0.811	19096	33.8	0.321
32.07	0.083844818	0.969809914	0.926	0	0.769996788	0	0.695	14177	30.8	0.095

Census Tract	% Elderly	% pop w/ vehicle	% pop speaking English	% pop w/ Disability	% w/ high school education or higher	% pop un infirmed	% homeownership	Income / Capita	Median Age	% Mobile Homes
32.08	0.083844818	0.969809914	0.926	0	0.769996788	0	0.695	14177	30.8	0.095
33.01	0.128663619	0.956915279	0.903	0	0.775756451	0	0.72	15564	33.3	0.202
33.03	0.172867343	0.978689054	0.921	0	0.877727803	0	0.767	21459	37.2	0.158
33.04	0.172867343	0.978689054	0.921	0	0.877727803	0	0.767	21459	37.2	0.158
34.02	0.122055675	0.970108696	0.954	0	0.755825338	0	0.863	18907	35.7	0.337
34.03	0.107938321	0.976598412	0.974	0	0.743880235	0	0.877	15618	33.4	0.45
34.04	0.107938321	0.976598412	0.974	0	0.743880235	0	0.877	15618	33.4	0.45
35.01	0.10519802	0.95851272	0.963	0	0.727058824	0	0.87	16648	32.8	0.414
35.02	0.101128291	0.950388524	0.958	0	0.731306991	0	0.85	14699	31.8	0.397
35.04	0.135968471	0.977924945	0.959	0	0.778269809	0	0.833	19657	35.4	0.278
35.05	0.135968471	0.977924945	0.956	0	0.778269809	0	0.833	19657	35.4	0.278
36	0.254911499	0.806896552	0.83	0	0.599777035	0	0.426	15258	0.178019895	0.02
37	0.17	0.916172735	0.936	0	0.83411215	0	0.477	15390	35.5	0.05
38	0.209829868	0.8647343	0.929	0	0.52173913	0	0.504	18351	39.7	0.02
39	0.172237791	0.860509655	0.936666667	0	0.73788356	0	0.456333333	16695.333	0.189647199	0.029
401.01	0.141792309	0.968	0.983	0	0.738106565	0	0.887269193	17318	34.5	0.31
401.02	0.123969562	0.974	0.979	0	0.796960073	0	0.889207259	15589	33	0.308
402.01	0.128515859	0.97	0.97	0	0.753450839	0	0.911725368	15481	34	0.36
402.03	0.104149715	0.968	0.968	0	0.784009347	0	0.910987483	16019	32.4	0.426
402.04	0.104149715	0.968	0.968	0	0.784009347	0	0.910987483	16019	32.4	0.426
403	0.164194757	0.983	0.903	0	0.799545361	0	0.760687343	16439	35.6	0.035
404	0.171661672	0.976	0.913	0	0.864156759	0	0.827077748	21707	36.9	0.032
405	0.277528885	0.878	0.953	0	0.834830484	0	0.581265823	27244	44.3	0.015
406	0.158195021	0.961	0.937	0	0.881351981	0	0.79577788	20124	37.9	0.01
407	0.115287588	0.962	0.92	0	0.88260713	0	0.769397329	22846	35	0.102
408	0.120154209	0.95	0.941	0	0.778306092	0	0.723292469	19017	33.3	0.225
409	0.102002918	0.976	0.956	0	0.894973743	0	0.84193073	19796	34.1	0.129
410	0.131920954	0.947	0.963	0	0.821454458	0	0.692857143	17743	34.4	0.171
411	0.118582264	0.935	0.931	0	0.824535157	0	0.75375626	16557	30.9	0.13
413	0.142622706	0.961	0.972	0	0.761402797	0	0.790621144	16029	35.7	0.152
414	0.236719478	0.973	0.97	0	0.869109948	0	0.849960723	21944	42.5	0
415	0.146938776	0.85	0.976	0	0.76459144	0	0.651315789	18124	37.9	0.063
416	0.156730769	0.89	0.974	0	0.717763751	0	0.695156695	12368	31.6	0.022
417	0.133129304	0.932	0.98	0	0.704038257	0	0.715765247	11870	31.1	0.061
418	0.216073006	0.857	0.986	0	0.599763407	0	0.727272727	13521	38.4	0.003
419	0.194010417	0.907	0.969	0	0.756909193	0	0.645195354	17781	40.9	0.063
420	0.085878548	0.91	0.888	0	0.811330839	0	0.495939086	14645	28.7	0.033
421	0.118467852	0.935	0.909	0	0.705766967	0	0.494497432	11879	29.3	0.019
422	0.162533384	0.832	0.926	0	0.679647906	0	0.418276762	13692	31.1	0.005
425	0.228356336	0.918	0.966	0	0.823842687	0	0.606591865	19482	38	0
426	0.190021558	0.946	0.957	0	0.910423453	0	0.859691809	29726	40.5	0.038

Census Tract	% Elderly	% pop w/ vehicle	% pop speaking English	% pop w/ Disability	% w/ high school education or higher	% pop un infirmed	% homeownership	Income / Capita	Median Age	% Mobile Homes
427	0.16530484	0.955	0.982	0	0.714904679	0	0.797319933	13509	37.5	0.277
429	0.169765772	0.834333333	0.949	0	0.788012917	0	0.614263877	16287.333	32.6	0.041

Gathered Social Data 2000 - b

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
301	0	0	0	0	0	0	0	0.519728	0.962036	83300	0.11346
302	0	0	0	0	0	0	0	0.521011	0.949636	89000	0.102255
303	0	0	0	0	0	0	0	0.491445	0.953342	82300	0.109861
304	0	0	0	0	0	0	0	0.489046	0.941504	60400	0.089498
305	0	0	0	0	0	0	0	0.515731	0.990621	135000	0.300585
306.01	0	0	0	0	0	0	0	0.493612	0.947872	87400	0.124049
306.02	0	0	0	0	0	0	0	0.493612	0.947872	87400	0.124049
1	0	0	0	0	0	0	0	0.488138	0.931727	53700	0.077821
3	0	0	0	0	0	0	0	0.526758	0.90255	53100	0.042885
6	0	0	0	0	0	0	0	0.516066	0.991525	91700	0.047619
12.01	0	0	0	0	0	0	0	0.514728	0.974468	85800	0.039076
12.02	0	0	0	0	0	0	0	0.522145	0.96693	140300	0.029011
13	0	0	0	0	0	0	0	0.492084	0.961366	84700	0.078313
14	0	0	0	0	0	0	0	0.472361	0.959053	130000	0.040732
15.01	0	0	0	0	0	0	0	0.514581	0.964901	92300	0.044715
15.02	0	0	0	0	0	0	0	0.514581	0.964901	92300	0.044715
16	0	0	0	0	0	0	0	0.520751	1	129300	0.30303
17	0	0	0	0	0	0	0	0.533226	0.935617	84800	0.031664
18	0	0	0	0	0	0	0	0.538405	0.875912	59000	0.013468
19	0	0	0	0	0	0	0	0.536065	0.939628	65400	0
20	0	0	0	0	0	0	0	0.518114	0.88367	62100	0.037523
23	0	0	0	0	0	0	0	0.497799	0.936082	56400	0.056769
24	0	0	0	0	0	0	0	0.527947	0.951039	57200	0.03012
25	0	0	0	0	0	0	0	0.266539	1	0	0
26	0	0	0	0	0	0	0	0.552654	0.893162	50300	0.017408
27	0	0	0	0	0	0	0	0.524115	0.984783	85600	0.014085
28	0	0	0	0	0	0	0	0.506929	0.995798	95400	0.049281
29	0	0	0	0	0	0	0	0.539592	0.989353	123400	0.106529
30	0	0	0	0	0	0	0	0.526257	0.965155	87800	0.108216
31.01	0	0	0	0	0	0	0	0.523151	0.951386	88500	0.035036
31.02	0	0	0	0	0	0	0	0.503809	0.979455	108200	0.088083
32.04	0	0	0	0	0	0	0	0.504903	0.977733	73200	0.07078
32.05	0	0	0	0	0	0	0	0.518645	0.988533	89900	0.090153
32.06	0	0	0	0	0	0	0	0.506949	0.969024	97700	0.11041

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
32.07	0	0	0	0	0	0	0	0.4696	0.96981	77200	0.034356
32.08	0	0	0	0	0	0	0	0.4696	0.96981	77200	0.034356
33.01	0	0	0	0	0	0	0	0.501344	0.965243	74400	0.082687
33.03	0	0	0	0	0	0	0	0.509708	0.98999	108000	0.144244
33.04	0	0	0	0	0	0	0	0.509708	0.98999	108000	0.144244
34.02	0	0	0	0	0	0	0	0.489079	0.978261	125600	0.046921
34.03	0	0	0	0	0	0	0	0.48301	0.967823	109700	0.099315
34.04	0	0	0	0	0	0	0	0.48301	0.967823	109700	0.099315
35.01	0	0	0	0	0	0	0	0.491062	0.937769	103300	0
35.02	0	0	0	0	0	0	0	0.484747	0.952779	78400	0
35.04	0	0	0	0	0	0	0	0.508288	0.956165	107400	0.019724
35.05	0	0	0	0	0	0	0	0.508288	0.956165	107400	0.019724
36	0	0	0	0	0	0	0	0.467921	0.921182	55900	0.14
37	0	0	0	0	0	0	0	0.510951	0.948349	72900	0.053485
38	0	0	0	0	0	0	0	0.497637	0.947826	73400	0.028
39	0	0	0	0	0	0	0	0.510836	0.911516	74166.67	0.955671
401.01	0	0	0	0	0	0	0	0.50703	0.947522	81900	0.134
401.02	0	0	0	0	0	0	0	0.488427	0.964661	82900	0.136
402.01	0	0	0	0	0	0	0	0.486385	0.954525	89500	0.153
402.03	0	0	0	0	0	0	0	0.490294	0.952364	88000	0.1
402.04	0	0	0	0	0	0	0	0.490294	0.952364	88000	0.1
403	0	0	0	0	0	0	0	0.506667	0.982397	74100	0.109
404	0	0	0	0	0	0	0	0.506993	0.996425	92300	0.253
405	0	0	0	0	0	0	0	0.538552	0.956456	116000	0.227
406	0	0	0	0	0	0	0	0.516425	0.987609	79600	0.195
407	0	0	0	0	0	0	0	0.512866	0.987008	112900	0.296
408	0	0	0	0	0	0	0	0.495395	0.953298	104500	0.195
409	0	0	0	0	0	0	0	0.513596	0.980472	106400	0.208
410	0	0	0	0	0	0	0	0.512551	0.957619	85000	0.163
411	0	0	0	0	0	0	0	0.513127	0.978297	82000	0.159
413	0	0	0	0	0	0	0	0.499329	0.938297	62900	0.153
414	0	0	0	0	0	0	0	0.496738	0.958366	77000	0.199
415	0	0	0	0	0	0	0	0.538776	0.886513	68100	0.086
416	0	0	0	0	0	0	0	0.526923	0.940171	54700	0.076
417	0	0	0	0	0	0	0	0.498087	0.973533	49300	0.083
418	0	0	0	0	0	0	0	0.545481	0.929482	48400	0.08
419	0	0	0	0	0	0	0	0.498264	0.913411	81400	0.167
420	0	0	0	0	0	0	0	0.52138	0.963452	66500	0.093
421	0	0	0	0	0	0	0	0.519289	0.933969	57500	0.047
422	0	0	0	0	0	0	0	0.50496	0.87624	67100	0.118
425	0	0	0	0	0	0	0	0.52729	0.981066	59300	0.126

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
426	0	0	0	0	0	0	0	0.499538	0.987835	112400	0.4
427	0	0	0	0	0	0	0	0.494029	0.850921	54000	0.091
429	0	0	0	0	0	0	0	0.339193	0.339193	78533.33	0.049333

Gathered Social Data 2010-a

Census Tract	% Elderly	% pop w/ vehicle	% pop speaking English	% pop w/ Disability	% w/ high school education or higher	% pop un infirmed	% homeownership	Income / Capita	Median Age	% Mobile Homes
301	0.223	1	0.949746104		0.675378658	0.097067039	0.68	22790	41.9	0.11
302	0.209	0.975698663	0.932756445		0.657641473	0.159036145	0.622	21284	43.1	0.075
303	0.186	0.986679662	0.965287822		0.561125942	0.176561058	0.569	21133	41.3	0.111
304	0.182	0.98600311	0.984500574		0.606759847	0.026277372	0.838	16567	41.2	0.278
305	0.274	1	0.89957939		0.768104587	0.188441439	0.864	30675	49.2	0.015
306.01	0.302	0.997157937	0.931632319		0.5732911	0.096735669	0.937	18054	36	0.485
306.02	0.149	0.981186094	0.99274219		0.549560839	0.089855072	0.795	17667	32.3	0.343
1	0.029	1	0.794050343		0.534268293	0.357843137	0.233	20760	29.6	0.29
3	0.206	0.952440551	0.639850826		0.430306945	0.095410628	0.563	16409	40.2	0.12
6	0.259	1	0.912314636		0.746201579	0.280653951	0.649	33080	41.5	0.07
9	0.2	1	0.901381149		0.684163165	0.105793451	0.506	28538	34.1	0.008
12.01	0.17	0.983149171	0.901938239		0.675942778	0.133559706	0.407	27799	33.9	0.071
12.02	0.128	0.958031088	0.743669788		0.733614849	0.091412742	0.243	24980	36.6	0
13	0.161	1	1		0.643544538	0.18338558	0.43	26503	41.7	0.04
14	0.247	1	0.929230769		0.63579884	0.210638298	0.751	18814	42	0.01
15.01	0.144	0.996194101	0.82394027		0.659805739	0.311675623	0.516	35278	34	0.067
15.02	0.241	1	0.933124019		0.69091798	0.265544989	0.88	36580	45.3	0
16	0.189	0.975473322	0.854370958		0.665251478	0.118232484	0.529	20153	37	0.05
17	0.185	0.963010204	0.996785858		0.53922335	0.091557669	0.44	12381	36.8	0.168
18	0.203	0.991158267	0.961434978		0.626576687	0.142241379	0.605	18184	43.7	0.047
19	0.109	0.995305164	0.948524985		0.48349414	0.055483029	0.483	13662	27.6	0.074
20	0.193	0.988888889	0.954429302		0.566571713	0.100671141	0.475	13841	34.6	0.032
23	0.149	0.984752224	0.980016653		0.541601124	0.0608914	0.576	12768	37.8	0.049
24	0.02	1	0.898637602		0.645387387	0.090909091	0.029	13051	20.1	0.029
25	0.225	0.921460177	0.970674487		0.40835762	0.046002191	0.549	12504	34.9	0.03
26	0.199	0.983231084	0.930506058		0.641383534	0.176294395	0.793	22325	37.6	0.025
27	0.201	1	0.920725389		0.663997527	0.093933464	0.481	26198	39.5	0.024
28	0.303	1	0.946402349		0.808209711	0.221494102	0.819	47298	53.6	0
29	0.141	0.990024938	0.92166549		0.518420972	0.073614557	0.742	19620	25.6	0.054
30	0.153	1	0.948841153		0.632732489	0.215099338	0.694	24033	38.6	0.108
31.01	0.208	0.977511788	0.949188057		0.692736717	0.087782157	0.778	26550	43.6	0.185
31.02	0.133	0.968388246	0.829180581		0.611311691	0.081761006	0.564	17825	32	0.072
32.04	0.15	0.942068547	0.919198664		0.609350954	0.139324487	0.703	23081	31.5	0.016

32.05	0.134	0.991735537	0.933546326		0.647871274	0.133729569	0.816	26335	37.4	0.147
32.06	0.117	0.964705882	0.892110763		0.601935596	0.088765603	0.598	22889	30.1	0.094
32.07	0.072	1	0.925411165		0.589968629	0.139520202	0.682	14855	33.6	0.012
32.08	0.132	0.950649351	0.880317041		0.582994103	0.137881405	0.604	17394	31.9	0.178
33.01	0.114	0.996472663	0.907931571		0.623195572	0.118326118	0.619	27789	35.2	0.176
33.03	0.248	1	0.953567839		0.709058812	0.140116764	0.814	36135	41.3	0.043
33.04	0.136	0.997156206	0.928656233		0.661768453	0.150526944	0.896	25513	37.6	0.211
34.02	0.233	1	0.961502347		0.613472517	0.069230769	0.837	27411	37.6	0.244
34.03	0.121	1	0.972288374		0.592184295	0.150992235	0.89	18539	35.3	0.456
34.04	0.146	1	0.964827243		0.551703172	0.135495224	0.867	19448	34.4	0.328
35.01	0.145	1	0.959167493		0.576276715	0.157175399	0.827	20661	39.7	0.388
35.02	0.161	1	0.971570311		0.583441325	0.189586115	0.807	20575	36.4	0.263
35.04	0.151	0.990691013	0.920544023		0.61781946	0.169259962	0.872	26925	37	0.195
35.05	0.191	0.913580247	0.886010363		0.516331019	0.234567901	0.552	13971	29.3	0
36	0.184	0.971384377	0.83246493		0.633340525	0.102880658	0.591	21267	42.6	0.05
37	0.233	0.966836735	0.816831683		0.700459172	0.204481793	0.613	23900	45.2	0.012
38	0.228	0.967459324	0.754770318		0.690757712	0.09883364	0.543	22095	43.6	0.053
39	0.184	0.992903008	0.986308232		0.611223121	0.134943639	0.836	21601	36.9	0.269
401.01	0.193	0.994235334	0.975550122		0.594058379	0.121351263	0.869	21076	36.5	0.262
401.02	0.162	1	0.976953498		0.609762714	0.162225476	0.926	21263	38.7	0.291
402.01	0.162	1	0.962945808		0.578537828	0.125988142	0.85	19766	41.8	0.494
402.03	0.125	1	0.922774457		0.629537349	0.101503759	0.835	21040	36.9	0.291
402.04	0.194	0.982932776	0.825776398		0.582811985	0.116655196	0.722	17190	33.7	0.028
403	0.164	0.97973158	0.911129454		0.647576602	0.126546682	0.723	25562	32.7	0.046
404	0.333	0.971147541	0.935008375		0.729111318	0.263500325	0.658	37905	52.4	0.024
405	0.186	0.995519044	0.937788018		0.744055738	0.098995162	0.723	27160	41.8	0
406	0.161	0.997509622	0.927702626		0.661715499	0.176417642	0.76	35215	41.3	0.11
407	0.163	0.983000425	0.926168394		0.649196121	0.096929825	0.548	20067	34.4	0.222
408	0.115	1	0.935396308		0.634406423	0.190077178	0.865	27428	33.5	0.033
409	0.171	0.986607143	0.979643184		0.678973924	0.07970297	0.656	21709	36.3	0.134
410	0.127	0.958204865	0.97029997		0.550146138	0.15431888	0.645	18240	29.3	0.083
411	0.199	1	0.979340117		0.620554153	0.044833625	0.814	18728	37.5	0.177
413	0.229	0.976709241	0.967398536		0.696860406	0.145149526	0.877	24841	43.1	0
414	0.201	1	0.976616231		0.689072084	0.060137457	0.658	14707	40.6	0.071
415	0.148	0.984939759	0.97188418		0.520975328	0.119922631	0.573	15537	36.8	0.106
416	0.208	1	0.994634146		0.56474123	0.075630252	0.717	12998	43	0.054
417	0.228	0.884615385	0.9876		0.650935957	0.03554724	0.725	20119	42.8	0.034
418	0.195	0.946454414	0.974141116		0.650365602	0.120085776	0.507	24906	43.1	0.107
419	0.124	0.982175503	0.751819676		0.578875556	0.030932391	0.398	17452	31.2	0.028
420	0.151	0.988344988	0.836266499		0.56425792	0.133644134	0.53	16263	35.3	0.034
421	0.175	0.925465839	0.881554209		0.53088204	0.12999323	0.47	15464	33.4	0
422	0.175	0.965517241	0.984736583		0.616208278	0.17352614	0.635	20816	40.6	0.036
425	0.237	0.965357968	0.964816263		0.718253968	0.254531722	0.882	44169	44.1	0.021

426	0.215	0.919117647	0.823115578		0.428205607	0.120098039	0.816	15265	41.6	0.235
427	0.149	0.988071571	0.871603623		0.678750965	0.204238921	0.638	18946	32.2	0.065
429	0.223	1	0.949746104		0.675378658	0.097067039	0.68	22790	41.9	0.11

Gathered Social Data 2010 – b

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
301	0.211	0	0.023	0.007	0	0.258030726	0.167598	0.535679	0.890671	156800	0.284
302	0.142	0	0.009	0.047	0	0.172690763	0.135743	0.536394	0.890742	154900	0.251
303	0.007	0.006	0	0.06	0	0.257459243	0.085205	0.443196	0.900501	152700	0.213
304	0.207	0	0	0.01	0	0.096350365	0.227737	0.516958	0.812162	93300	0.121
305	0.009	0.002	0.016	0.03	0	0.195819244	0.083	0.505796	0.982309	192200	0.425
306.01	0.003	0	0.02	0.056	0	0.175159236	0.186306	0.485364	0.921836	90000	0.197
306.02	0.049	0.002	0	0.002	0	0.19047619	0.099793	0.52407	0.951536	120300	0.348
1	0	0	0.15077605	0.050997783	0	0.284313725	0.343137	0.512195	1	215900	0.145
3	0.427391938	0	0.29140359	0.113161729	0.04468599	0.324879227	0.115942	0.508014	0.930518	117000	0.177
6	0.018822101	0	0	0	0	0.09400545	0.053134	0.434123	0.966292	134800	0.263
12.01	0.196915512	0.003353	0.03240948	0.066830577	0.004030227	0.262972292	0.036776	0.443004	0.994064	151500	0.269
12.02	0.185061153	0.005387	0.05125218	0.056057076	0.011318619	0.282965478	0.079513	0.534362	0.95797	182300	0.246
13	0.233012927	0	0.08054359	0.146503149	0	0.350692521	0.038781	0.429897	0.958763	131600	0.149
14	0.197478992	0	0	0.009243697	0	0.053291536	0.18652	0.5	0.911708	161000	0.227
15.01	0.276027225	0.003277	0.00277288	0.023695488	0	0.24751773	0.048227	0.535669	0.97409	138900	0.206
15.02	0.092917331	0.017536	0.05989524	0.105215213	0	0.0913532	0.057645	0.502619	0.963006	299500	0.302
16	0.010799766	0	0.01576182	0.016929364	0	0.067300658	0.054133	0.514302	0.992647	182100	0.429
17	0.278675601	0	0.02128498	0.086125345	0.006767516	0.199840764	0.178742	0.491131	0.945487	129600	0.132
18	0.833212473	0	0	0	0	0.355529132	0.200951	0.537708	0.885135	87300	0.014
19	0.350920245	0	0	0.071574642	0	0.251724138	0.12931	0.51411	0.921731	89300	0.111
20	0.331646244	0.007192	0	0.018646777	0.006527415	0.24151436	0.101828	0.483218	0.902699	83400	0.093
23	0.609960159	0	0	0.031474104	0	0.342281879	0.142058	0.535857	0.921765	94500	0.078
24	0.878192033	0	0	0.005617978	0	0.397363465	0.153798	0.543156	0.959431	104300	0.097
25	0.153603604	0	0.01351351	0.161261261	0	0.220779221	0	0.328378	1	0	0.029
26	0.798796791	0.003342	0.00501337	0.023729947	0	0.480832421	0.184009	0.605615	0.860075	71400	0.107
27	0.045400644	0.001016	0.03218702	0.022700322	0.007274283	0.149336757	0.08558	0.519058	0.97683	141300	0.295
28	0	0	0.04401583	0.028684471	0	0.143835616	0.05773	0.549456	0.921412	185300	0.35
29	0.18156228	0	0.00492611	0	0	0.163826999	0.070773	0.608023	0.955519	243400	0.332
30	0.459717097	0	0.14175892	0	0	0.306865178	0.015715	0.483087	0.906977	219500	0.307
31.01	0.184671336	0.004041	0.02007004	0.028825431	0	0.285827815	0.085033	0.559806	0.916604	149900	0.313
31.02	0.148730964	0	0.03874788	0.010998308	0.006807596	0.144392691	0.122178	0.481557	0.94513	160800	0.352
32.04	0.333493052	0.012218	0.02060374	0.122424533	0.010332435	0.245732255	0.192273	0.480115	0.961942	113200	0.186
32.05	0.322177041	0.013294	0	0.045511417	0.006332931	0.13238842	0.151387	0.504848	0.964513	140700	0.354
32.06	0.094389246	0.004822	0.01548802	0.035797779	0	0.193759287	0.082318	0.49547	0.985507	169600	0.382
32.07	0.239843029	0	0.02562327	0.022622345	0	0.251040222	0.141008	0.539935	0.972603	127100	0.194

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
32.08	0.509454233	0.004512	0.01482596	0.069832402	0	0.330808081	0.102904	0.454663	0.914191	116700	0.131
33.01	0.122864019	0.004934	0.06630566	0.038507822	0.014392631	0.377662637	0.10852	0.519254	0.917358	115900	0.211
33.03	0.157785978	0	0.0301107	0.054464945	0.005194805	0.318037518	0.053968	0.437343	0.934579	171500	0.285
33.04	0.166283525	0	0.0362069	0.050957854	0.015846539	0.280650542	0.04754	0.501724	0.972035	184600	0.456
34.02	0.05237366	0.001429	0.02756508	0.033690658	0	0.173792006	0.10698	0.514752	0.913788	187900	0.422
34.03	0	0	0	0.036951501	0.020192308	0.178846154	0.132692	0.482679	1	185100	0.356
34.04	0.079727564	0	0.0078125	0.003205128	0.012079379	0.205349439	0.112597	0.525641	0.927802	95400	0.212
35.01	0.05985876	0.001121	0.00650151	0.036094608	0.017596782	0.16314731	0.111614	0.497029	0.960545	139500	0.299
35.02	0.050431196	0	0.02062242	0.01856018	0.014123007	0.173120729	0.143964	0.472253	0.916209	151500	0.241
35.04	0.116270698	0	0	0.024478042	0	0.186915888	0.153983	0.49478	0.951104	163700	0.321
35.05	0.165494685	0.014718	0.01847915	0.061651676	0.003795066	0.160910816	0.032258	0.5426	0.956211	167800	0.305
36	0.388888889	0.136574	0.07407407	0.101851852	0	0.391975309	0	0.571759	0.840116	134300	0.102
37	0.137360662	0.012226	0.03092413	0.080546566	0.019753086	0.217283951	0.060082	0.574254	0.932407	92100	0.24
38	0.072189349	0	0	0.186982249	0	0.19047619	0.081232	0.471006	0.888312	119900	0.275
39	0.2152513	0	0.01941075	0.193067591	0.021485574	0.403928791	0.080417	0.44922	0.945743	115400	0.215
401.01	0.092889373	0.005913	0	0.003578653	0.007085346	0.196457327	0.190982	0.524195	0.91006	125800	0.294
401.02	0.020628286	0	0.00647162	0	0.038045261	0.090849459	0.197442	0.497506	0.943617	98000	0.282
402.01	0.036417071	0.003322	0	0.024405827	0.002342606	0.155490483	0.22694	0.466522	0.920993	123100	0.277
402.03	0.004227859	0	0	0.025589675	0.064229249	0.243577075	0.110672	0.473298	0.960338	116900	0.246
402.04	0.006475904	0.013554	0.02650602	0.020933735	0.013157895	0.247807018	0.118108	0.505723	0.941667	138300	0.243
403	0.162846442	0.000449	0.162397	0.021573034	0.033723331	0.327253957	0.062285	0.540225	0.915876	109600	0.166
404	0.094327678	0.003798	0.03342618	0.033679413	0.003093363	0.174353206	0.079584	0.50709	0.893853	141800	0.294
405	0.038449612	0	0.00930233	0.023255814	0	0.119713728	0.03123	0.48	0.951668	224700	0.384
406	0.140255009	0	0.00765027	0.034790528	0.020468924	0.224786007	0.07741	0.51439	0.917734	139000	0.297
407	0.095980224	0	0.05814703	0.011392949	0	0.187893789	0.087984	0.506986	0.96572	179100	0.45
408	0.207991975	0	0.00250794	0.082594884	0.021929825	0.121491228	0.169298	0.530179	0.925264	136400	0.222
409	0.050889328	0.000988	0.01333992	0.050889328	0.018963616	0.194928335	0.084454	0.492194	0.936403	164200	0.446
410	0.367448935	0	0.00738809	0.03563668	0.01980198	0.152475248	0.136634	0.513907	0.913116	115400	0.27
411	0.487253912	0.000631	0	0.029909137	0	0.164902697	0.070673	0.541141	0.913738	129800	0.309
413	0.196360434	0	0	0.011593778	0.006654991	0.169176883	0.246935	0.532286	0.92502	87900	0.218
414	0.486992386	0	0.02093909	0.010152284	0.003646973	0.150255288	0.155361	0.508566	0.942643	131400	0.258
415	0.773263434	0	0	0.005897772	0	0.403780069	0.168385	0.498689	1	87900	0.104
416	0.855551134	0	0.00119379	0	0	0.356866538	0.168279	0.52885	0.987692	69300	0.13
417	0.961275626	0	0	0	0.014005602	0.277310924	0.359944	0.468793	0.86692	82500	0.065
418	0.934027778	0	0	0	0	0.308699719	0.231057	0.469136	0.996832	74400	0.056
419	0.468932372	0	0	0	0.007147963	0.278055754	0.069335	0.559904	0.947967	94900	0.25
420	0.405978376	0	0.03582786	0.225991096	0.062306673	0.192222713	0.202828	0.451558	0.994259	103700	0.19
421	0.297668858	0	0	0.173341303	0.012432012	0.192696193	0.175602	0.563658	0.941686	95000	0.136
422	0.343987823	0.007801	0.02853881	0.119482496	0.018957346	0.169939066	0.148274	0.490677	0.905848	102900	0.171
425	0.081441923	0	0	0	0.035595106	0.125695217	0.098999	0.461949	0.816441	151300	0.173
426	0.078231293	0	0	0.017384732	0	0.099697885	0.09139	0.472789	0.980311	232600	0.474

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
427	0.03364486	0	0	0.127102804	0	0	0.262255	0.609346	0.979885	76800	0.126
429	0.159749035	0	0	0.120173745	0.026011561	0.151252408	0.163776	0.553571	0.931507	104900	0.181

Gathered Social Data 2011 – a

Census Tract	% Elderly	% pop w/ vehicle	% pop speaking English	% pop w/ Disability	% w/ high school education or higher	% pop un infirmed	% homeownership	Income / Capita	Median Age	% Mobile Homes
301	0.267	1	0.94087174		0.730085425	0.114816218	0.691	23023	46.6	0.07
302	0.174	0.985018727	0.939156402		0.699416968	0.13507982	0.67	22366	43	0.051
303	0.178	0.99189463	0.959507273		0.528254576	0.208545918	0.669	18729	37.5	0.066
304	0.233	0.97443609	0.947191011		0.610881877	0.024566474	0.898	18445	42.3	0.319
305	0.304	1	0.892041872		0.772722489	0.166759003	0.844	32471	47.8	0.007
306.01	0.184	0.99709664	0.944736396		0.6014824	0.2090946	0.913	20318	38.7	0.481
306.02	0.125	0.979575805	0.996318454		0.562840086	0.130312751	0.797	18470	36.4	0.358
1	0.181	1	0.909090909		0.610650754	0.19266055	0.077	19004	31.9	26.50%
3	0.177	0.898573693	0.714654616		0.424789773	0.083591331	0.463	13823	34.7	5.90%
6	0.291	1	0.927096774		0.776742945	0.276902887	0.643	32653	46.1	5.80%
9	0.197	0.975956284	0.93437877		0.685433773	0.064109903	0.444	25205	33.8	0.50%
12.01	0.159	0.96391455	0.921176662		0.656501716	0.147380882	0.4	25141	28.8	5.00%
12.02	0.144	0.899000526	0.794598436		0.741840328	0.074971165	0.234	23858	36.3	0.00%
13	0.176	0.973357016	1		0.731641975	0.230407524	0.371	25017	37.2	0.80%
14	0.249	1	0.926808016		0.617846772	0.285508291	0.737	18588	39.8	1.70%
15.01	0.155	0.99564839	0.809988109		0.666557474	0.249887438	0.486	37018	37.1	9.30%
15.02	0.251	1	0.948369565		0.707659085	0.26121372	0.864	38356	44.8	0.50%
16	0.183	0.973181633	0.862547289		0.667040739	0.098835024	0.475	19760	33.7	3.40%
17	0.153	0.973572939	1		0.488457293	0.074565884	0.428	12091	36	13.20%
18	0.205	1	0.988677536		0.585586655	0.186528497	0.578	18840	42.8	1.60%
19	0.154	0.984496124	0.920482783		0.569338832	0.061934586	0.427	16680	33.5	7.70%
20	0.134	0.988960442	0.960136674		0.548003829	0.08974359	0.442	13173	28.4	1.80%
23	0.16	0.980697385	0.964392498		0.531377609	0.063393412	0.505	13366	36.9	5.50%
24	0.033	1	0.865108869		0.682485307	0.063348416	0.117	15709	21.4	1.80%
25	0.183	0.924568966	0.977731385		0.412744135	0.071	0.5	11431	34	0.80%
26	0.205	0.986881083	0.925660377		0.654171229	0.134948097	0.79	23358	37.5	2.50%
27	0.226	1	0.904179409		0.733057999	0.141952984	0.5	30125	44.7	1.60%
28	0.465	1	0.952188006		0.835116189	0.27991453	0.829	41751	57.9	0.00%
29	0.198	0.979865772	0.950236967		0.612917336	0.073454545	0.731	25474	36.2	4.70%
30	0.152	1	0.946587537		0.630082008	0.195732156	0.654	25892	38.1	7.80%
31.01	0.227	0.977202073	0.94268272		0.674472331	0.109760333	0.78	26183	43.8	19.20%
31.02	0.123	0.958713394	0.865261473		0.59475432	0.095458758	0.501	17887	32.6	7.40%
32.04	0.175	0.935101404	0.937447734		0.605170016	0.179179811	0.737	23366	34.5	1.30%
32.05	0.122	0.992690469	0.936582318		0.655345595	0.17534569	0.773	26887	35.9	10.70%

32.06	0.116	0.962724344	0.951734875		0.591675972	0.052378664	0.603	18776	31.3	8.60%
32.07	0.103	1	0.928915969		0.582083731	0.080296896	0.661	15997	34.4	0.00%
32.08	0.122	0.971428571	0.877958296		0.597763486	0.113568924	0.544	19006	31.2	15.50%
33.01	0.105	0.986042693	0.890999042		0.61163817	0.107290234	0.609	27188	34.5	18.80%
33.03	0.258	1	0.940128154		0.716749903	0.130077965	0.784	38315	43.8	1.20%
33.04	0.12	0.997019929	0.899627889		0.617699291	0.116387337	0.845	25957	36.5	16.00%
34.02	0.236	1	0.954088953		0.640967472	0.051258155	0.862	29941	42.6	16.20%
34.03	0.129	1	0.989163416		0.642858847	0.149548069	0.909	21297	35.9	36.60%
34.04	0.155	0.990405117	0.973658537		0.561244668	0.128672746	0.881	19307	32.8	31.90%
35.01	0.139	1	0.960946985		0.591337479	0.158604651	0.845	19915	39.5	34.40%
35.02	0.165	1	0.970741097		0.623546355	0.154148472	0.805	20949	38.8	27.00%
35.04	0.147	0.992432432	0.931167016		0.635240691	0.114728682	0.865	27329	37.5	15.50%
35.05	0.171	0.970731707	0.780979827		0.474568297	0.121359223	0.398	13401	28.5	0.00%
36	0.23	0.907441016	0.807955002		0.573443481	0.118811881	0.568	17898	42.6	5.10%
37	0.235	0.976987448	0.821627648		0.709215707	0.206741573	0.588	25690	45.3	2.50%
38	0.216	0.967223253	0.715576437		0.652184422	0.123971798	0.567	21623	42.8	3.00%
39	0.205	0.994448073	0.987932677		0.640336299	0.133417244	0.824	25756	39.2	0.257
401.01	0.199	0.994542974	0.98268017		0.635795554	0.107865914	0.82	21983	37.8	0.25
401.02	0.159	1	0.975936524		0.614291516	0.145033695	0.916	20467	38.9	0.284
402.01	0.238	0.9839513	0.953071253		0.569250469	0.121925134	0.874	22076	42.5	0.409
402.03	0.096	1	0.952795208		0.598624423	0.140249203	0.853	19848	36.4	0.294
402.04	0.146	0.985620506	0.817831754		0.60853513	0.137399877	0.685	18336	32.4	0.038
403	0.183	0.994668911	0.901370235		0.641345607	0.136452242	0.745	29013	34.1	0.01
404	0.362	0.984752224	0.934938191		0.748002446	0.304955527	0.631	42270	53.4	0.016
405	0.212	0.995642702	0.927744511		0.76440189	0.13905857	0.753	31289	43.4	0
406	0.145	1	0.901195579		0.631104321	0.125269978	0.694	28042	36.6	0.121
407	0.162	0.974525043	0.926374819		0.667549263	0.12865242	0.558	19242	34.5	0.231
408	0.108	1	0.949958036		0.647637394	0.16616509	0.818	28467	33.3	0.036
409	0.191	0.98976268	0.827311018		0.659881331	0.096003675	0.696	23472	39.1	0.174
410	0.142	0.970163934	0.937044203		0.577937854	0.147794602	0.699	19531	32.6	0.111
411	0.241	1	0.964677804		0.613084741	0.077777778	0.771	19504	38.7	0.157
413	0.224	0.991959064	0.970976253		0.657854991	0.117812062	0.881	25109	41.3	0
414	0.191	1	1		0.766711246	0.066225166	0.695	18236	41.8	0.048
415	0.12	0.990375361	0.98059455		0.558524772	0.125708885	0.51	15266	36.8	0.154
416	0.22	0.991511036	1		0.525032202	0.071428571	0.691	12204	47.2	0.031
417	0.262	0.990243902	0.976106541		0.634779406	0.037001898	0.758	20931	44	0.03
418	0.19	0.947063689	0.969439728		0.592725851	0.090322581	0.516	25941	40.8	0.1
419	0.137	0.982086879	0.782832618		0.586380652	0.027385537	0.406	19042	32.1	0.022
420	0.101	0.985022026	0.871314496		0.49522565	0.054625551	0.538	15373	33.2	0.041
421	0.201	0.936926606	0.911875589		0.598546379	0.136155606	0.564	19393	35.3	0.031
422	0.199	0.982311321	0.974594595		0.641722108	0.16745283	0.626	24579	42.1	0.052
425	0.237	0.984996249	0.952501813		0.723709417	0.239940387	0.839	43673	43.2	0.013
426	0.232	0.948805461	0.937716263		0.551273349	0.232081911	0.756	21607	49.4	0.295

427	0.126	0.991635688	0.888580675		0.704388601	0.189045936	0.645	23002	29.3	0.015
429	0.267	1	0.94087174		0.730085425	0.114816218	0.691	23023	46.6	0.07

Gathered Social Data 2011 – b

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
301	0.166	0	0.023	0.007	0.002	0.225464191	0.148541114	0.513063	0.984843	156700	0.227
302	0.198	0	0.008	0.051	0.009005321	0.146541138	0.107654523	0.509588	0.951303	142200	0.227
303	0.012	0	0.011	0.055	0.008928571	0.279655612	0.119260204	0.49145	0.97124	156400	0.212
304	0.2	0	0	0.045	0	0.079479769	0.189306358	0.554477	0.978523	89200	0.21
305	0.006	0.013	0.019	0.045	0.006648199	0.216620499	0.066204986	0.486665	0.984472	190200	0.441
306.01	0.002	0	0.006	0.032	0.021518473	0.174177832	0.119772635	0.507805	0.940117	87000	0.241
306.02	0.065	0	0	0.003	0.020449078	0.123496391	0.123496391	0.526293	0.942977	130600	0.295
1	0.007537688	0	0.077889	0.04522613	0	0.174311927	0.19266055	0.515075	1	114400	0.107
3	0.459090909	0	0.177273	0.19431818	0.049535604	0.284829721	0.072755418	0.540909	0.88	109500	0.113
6	0.024539877	0.000613497	0	0.00429448	0	0.1167979	0.062992126	0.445399	0.985795	125800	0.255
12.01	0.179790624	0.030496131	0.033682	0.03686846	0.005724098	0.317115054	0.089295936	0.473373	0.982249	144600	0.233
12.02	0.258009153	0.003861556	0.039045	0.04476545	0.009470257	0.275525303	0.065403966	0.528032	0.972222	197700	0.229
13	0.19037871	0	0.077107	0.14056636	0.000576701	0.341983852	0.029411765	0.443876	0.95398	143000	0.158
14	0.22875817	0	0	0.00580973	0	0.078369906	0.172413793	0.49528	0.884354	175000	0.182
15.01	0.309307752	0.004407571	0.002852	0.02177858	0	0.226387888	0.033886085	0.580503	0.964714	138900	0.195
15.02	0.085188551	0.023625625	0.053158	0.13493866	0	0.090049527	0.048626745	0.478646	0.980682	322300	0.349
16	0.00870542	0	0.014603	0.01151362	0	0.083113456	0.05474934	0.508846	0.982505	190600	0.438
17	0.278219396	0	0.010533	0.09777424	0.007140173	0.229612927	0.140924464	0.492448	0.971069	126900	0.132
18	0.901581722	0	0	0	0	0.290091931	0.20020429	0.507557	0.910931	90900	0.011
19	0.34410407	0	0	0.00797314	0	0.232297064	0.141623489	0.489719	0.886429	100400	0.084
20	0.331218274	0.001903553	0	0.03521574	0.009046625	0.288796103	0.100904662	0.495876	0.915279	88900	0.112
23	0.596240863	0	0	0.02540898	0	0.345238095	0.148351648	0.514793	0.956969	102400	0.085
24	0.811441198	0	0	0.05057697	0	0.389061529	0.159105034	0.534004	0.958942	95600	0.107
25	0.124666073	0	0.020036	0.19857524	0	0.180995475	0.090497738	0.322351	1	64800	0.097
26	0.755395683	0	0.003128	0.02189553	0	0.541	0.164	0.613075	0.87904	68400	0.095
27	0.050635176	0.001073537	0.050277	0.02451244	0	0.163062284	0.083044983	0.541242	0.988046	142600	0.294
28	0	0	0.034316	0.05413243	0	0.158227848	0.070524412	0.59594	0.946058	177900	0.395
29	0.041053447	0	0.006971	0.01936483	0	0.091880342	0.076923077	0.579396	0.992138	256800	0.341
30	0.406482307	0	0.056497	0	0	0.153454545	0.104727273	0.505501	0.963115	197300	0.316
31.01	0.215208748	0.004348907	0.027709	0.04100398	0	0.263428992	0.088790778	0.546968	0.943084	157100	0.322
31.02	0.142763589	0.002946955	0.048461	0.01015062	0.012851685	0.126432789	0.130948246	0.494106	0.966785	163100	0.341
32.04	0.371650388	0.006761833	0.004007	0.10969196	0.008341057	0.287303058	0.227988879	0.485349	1	113800	0.151
32.05	0.317268446	0.016483516	0	0.04521193	0.006624606	0.14637224	0.14637224	0.524804	0.963579	143700	0.335
32.06	0.152814272	0.004287097	0.011893	0.03153091	0	0.202412474	0.07884672	0.478634	0.982646	170600	0.398
32.07	0.384047856	0	0.012562	0.02053838	0.007208073	0.313791446	0.084094185	0.485743	0.970716	132100	0.151
32.08	0.489265267	0.002385496	0.015744	0.05796756	0	0.259784076	0.110661269	0.479723	0.949503	124500	0.151

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
33.01	0.122850412	0.004004711	0.059482	0.05936396	0.018883194	0.359859725	0.100620448	0.519906	0.936672	119900	0.187
33.03	0.149307646	0	0.072848	0.04560506	0.035763411	0.300412655	0.091609354	0.454545	0.994048	167300	0.301
33.04	0.123691353	0	0.054672	0.0411012	0.011079196	0.277390234	0.054575297	0.476347	0.973246	182600	0.456
34.02	0.06850198	0.001196943	0.060308	0.04520762	0	0.201675978	0.090130354	0.508425	0.946018	196800	0.414
34.03	0	0	0	0.05390335	0.018639329	0.152842498	0.122087605	0.491171	0.987966	211900	0.379
34.04	0.045328032	0	0	0.00457256	0.021774856	0.189400164	0.13599014	0.544135	0.937208	107300	0.294
35.01	0.052936673	0.001203106	0.007547	0.02449962	0.009625127	0.186676798	0.102077001	0.507711	0.972251	144100	0.306
35.02	0.025438101	0	0.024119	0.02204635	0.005581395	0.184186047	0.166046512	0.487281	0.936937	155800	0.242
35.04	0.086408641	0	0.012421	0.03060306	0	0.264628821	0.137554585	0.516652	0.942421	160500	0.3
35.05	0.193947077	0.005545872	0.014578	0.04436698	0.003875969	0.165891473	0.073643411	0.526541	0.971893	164600	0.346
36	0.305227656	0.13153457	0.102024	0.14586847	0.019417476	0.470873786	0.162621359	0.488196	0.902844	119600	0.113
37	0.160346696	0.011195377	0.026002	0.12748285	0.00990099	0.163366337	0.10990099	0.546768	0.952421	107900	0.16
38	0.09947644	0	0.013613	0.21361257	0	0.186516854	0.116853933	0.441885	0.911647	107500	0.205
39	0.195249738	0	0.035627	0.200489	0.047591069	0.387191539	0.08813161	0.458959	0.957532	141300	0.164
401.01	0.005041518	0	0	0.00192764	0.006922593	0.182819383	0.142227816	0.525208	0.933663	138000	0.39
401.02	0.001500273	0	0.005865	0	0.034185197	0.085960836	0.217391304	0.511184	0.983177	110300	0.303
402.01	0.003625816	0	0	0.01401982	0.002929974	0.213595078	0.205098154	0.485376	0.912197	123300	0.311
402.03	0	0	0.011726	0.02462477	0.059893048	0.213903743	0.079144385	0.508912	1	158700	0.226
402.04	0.012618725	0	0.021438	0.01411126	0.011880614	0.247754274	0.118226601	0.49118	0.959812	141300	0.252
403	0.001577287	0	0.164611	0.02552337	0.019408503	0.359519409	0.067159581	0.533266	0.966569	113500	0.203
404	0.004077598	0	0.036081	0.04040529	0.003898635	0.169033695	0.079086605	0.518102	0.954266	152000	0.306
405	0	0	0.00581	0.0146789	0	0.137229987	0.034942821	0.482875	0.97377	232100	0.398
406	0.007939509	0	0.007183	0.05387524	0.028027309	0.200862379	0.088753144	0.527788	0.928064	137200	0.374
407	0	0	0.037564	0.04310976	0	0.233909287	0.074514039	0.491786	0.959685	181200	0.389
408	0	0.003146216	0.00977	0.0582878	0.012647187	0.118185783	0.124727431	0.514158	0.940195	122600	0.188
409	0.003362798	0	0.012202	0.03718294	0.023430782	0.220980224	0.08061049	0.490968	0.945796	161500	0.432
410	0	0	0.038567	0.15384615	0.036747818	0.159393661	0.107487368	0.528078	0.963203	118300	0.264
411	0	0	0.001317	0.07847268	0	0.178406847	0.053982883	0.511126	0.936086	132900	0.288
413	0	0	0.007772	0.02884472	0.021863799	0.18781362	0.251612903	0.514273	0.952973	90200	0.198
414	0	0	0.019146	0.00910232	0.025946704	0.116409537	0.218092567	0.519774	0.960034	133700	0.28
415	0	0	0	0.00607903	0	0.34602649	0.135761589	0.525076	1	97500	0.208
416	0	0	0	0	0	0.375236295	0.241020794	0.533492	0.990807	71600	0.081
417	0	0	0	0	0.024350649	0.292207792	0.331168831	0.433856	0.859433	85600	0.067
418	0	0.011725907	0.006596	0	0	0.275142315	0.226755218	0.478197	0.996633	74200	0.08
419	0	0	0	0	0.008064516	0.262096774	0.062096774	0.567462	0.955128	96300	0.229
420	0	0	0.027443	0.19427443	0.059905862	0.171587505	0.225074882	0.469497	0.988859	104700	0.234
421	0	0	0	0.14395887	0.011453744	0.207929515	0.17092511	0.561268	1	96300	0.164
422	0.014824227	0	0.04892	0.04997882	0.020594966	0.168764302	0.135583524	0.521177	0.916185	110900	0.18
425	0	0	0	0.02661208	0.029481132	0.142688679	0.120283019	0.4652	0.910539	158200	0.206
426	0	0	0	0.03127196	0	0.06557377	0.109538003	0.462755	0.980257	231200	0.526
427	0	0	0	0	0	0.030716724	0.092150171	0.587699	1	90700	0.136

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
429	0	0	0	0.11139896	0.011484099	0.143992933	0.148409894	0.478411	0.921875	108700	0.209

Gathered Social Data 2012 – a

Census Tract	% Elderly	% pop w/ vehicle	% pop speaking English	% pop w/ Disability	% w/ high school education or higher	% pop un infirmed	% homeownership	Income / Capita	Median Age	% Mobile Homes
301	0.306	0.995251286	0.95324481	0.664232244	0.707046011	0.052583531	0.697	23973	48.1	0.046
302	0.163	0.99279661	0.96771112	0.650145243	0.686498911	0.054829339	0.666	21062	38.5	0.048
303	0.176	0.981846154	0.955771837	0.681547619	0.574640453	0.07657967	0.621	18986	37.5	0.054
304	0.233	0.970068027	0.949006978	0.581874356	0.652812564	0.03707518	0.89	20184	44.7	0.349
305	0.326	1	0.95611324	0.762320867	0.782041477	0.076546662	0.842	32335	47.9	0.016
306.01	0.177	0.997479294	0.951704111	0.730731707	0.586550244	0.081393728	0.902	20226	38.3	0.476
306.02	0.151	0.973052632	0.94585125	0.667975238	0.603194172	0.048618451	0.836	20155	37.7	0.362
1	0.197	1	0.945	0.282	0.734043956	0.25	0.179	18617	35	0.146
3	0.169	0.860703812	0.744788732	0.166	0.707241935	0.074498567	0.442	12635	31.8	0.015
6	0.298	1	0.971755212	0.117	0.950837516	0.205645161	0.614	28726	43.6	0.034
9	0.164	0.985120575	0.904203324	0.152	0.93309553	0.065280185	0.481	29789	34.8	0.002
12.01	0.159	0.961111111	0.929507918	0.113	0.940914533	0.133162612	0.399	24031	31.9	0.044
12.02	0.214	0.910094637	0.842342342	0.115	0.865547505	0.083856246	0.269	26844	36.8	0
13	0.251	0.976157083	0.996635262	0.109	0.912022959	0.181575434	0.311	26789	35.9	0.018
14	0.161	0.987820513	0.94381061	0.194	0.905120619	0.176806084	0.719	23893	39.8	0.003
15.01	0.301	1	0.804000953	0.085	0.900243728	0.257279236	0.517	39767	37.5	0.082
15.02	0.191	1	0.950819672	0.169	0.9245	0.214435879	0.874	43142	47.4	0.005
16	0.159	0.975231054	0.901875617	0.185	0.888426223	0.106878307	0.451	20854	35.5	0.023
17	0.202	0.981613892	0.993024963	0.213	0.794627725	0.090643275	0.457	11834	37.1	0.105
18	0.159	0.994296578	0.995406523	0.196	0.920538226	0.200570342	0.626	19906	41.1	0.033
19	0.131	0.979534227	0.908042077	0.129	0.856453657	0.079002079	0.438	16852	34.6	0.063
20	0.145	0.989382239	0.940298507	0.179	0.824170063	0.071705426	0.408	13349	32.3	0.02
23	0.044	0.972513089	0.955647383	0.198	0.806741996	0.036666667	0.483	12242	30	0.069
24	0.192	1	0.873325893	0.021	0.976706848	0	0.127	16706	21.9	0.029
25	0.218	0.906642729	0.985947712	0.149	0.739912026	0.075938567	0.498	11659	33.9	0
26	0.27	0.973977695	0.932174245	0.154	0.912842646	0.138111058	0.77	23065	37.6	0.008
27	0.447	1	0.846075433	0.096	0.881570313	0.195266272	0.501	30060	46.1	0.017
28	0.18	0.983673469	0.969775475	0.19	0.93113206	0.298804781	0.8	40292	57.7	0
29	0.167	0.981510015	0.956691631	0.132	0.906360942	0.116295765	0.717	23037	30.9	0.019
30	0.192	0.989539749	0.949628844	0.158	0.905360777	0.210447388	0.655	26767	40.2	0.08
31.01	0.15	0.988807163	0.962083143	0.177	0.881814587	0.155430712	0.777	26079	40.4	0.22
31.02	0.17	0.960950764	0.884335155	0.144	0.841611507	0.155742297	0.478	18741	35.1	0.062
32.04	0.128	0.925840759	0.957841207	0.145	0.899385551	0.126674432	0.656	21768	32.3	0.022
32.05	0.144	0.991316147	0.929031355	0.131	0.914686926	0.176800224	0.724	25628	34.2	0.112
32.06	0.104	0.949975716	0.941632467	0.138	0.904159328	0.06676485	0.544	19388	33.1	0.084

32.07	0.133	1	0.89968652	0.196	0.825650959	0.131975867	0.643	16513	33.1	0
32.08	0.102	0.98001998	0.880301719	0.141	0.869394145	0.092690279	0.572	20975	32.9	0.162
33.01	0.238	0.979239687	0.889393702	0.147	0.869317106	0.095146167	0.533	26039	34.4	0.178
33.03	0.121	1	0.931233933	0.116	0.959867753	0.117413725	0.793	36775	43.7	0
33.04	0.199	0.991842788	0.902414688	0.1	0.921161618	0.132264151	0.836	26978	35.8	0.152
34.02	0.14	1	0.93977591	0.126	0.902996357	0.089673913	0.848	29678	42.4	0.187
34.03	0.187	1	0.993096447	0.113	0.922830289	0.138176076	0.894	20705	35.4	0.379
34.04	0.16	0.987352213	0.966357584	0.16	0.870372732	0.159079016	0.867	19582	34.4	0.371
35.01	0.173	1	0.964912281	0.178	0.870897272	0.146983857	0.892	20974	39.5	0.312
35.02	0.145	0.959175258	0.974326059	0.151	0.871497709	0.178495538	0.82	21811	38.3	0.202
35.04	0.145	0.995585739	0.956159005	0.14	0.933649241	0.114633247	0.851	26289	32.5	0.155
35.05	0.214	0.965292842	0.770083102	0.119	0.789992647	0.082251082	0.36	13818	29.4	0
36	0.242	0.919354839	0.790518639	0.194	0.777264376	0.097674419	0.496	16975	36.4	0.064
37	0.206	0.972911964	0.844262295	0.198	0.842565556	0.160465116	0.582	21874	53.5	0.023
38	0.206	0.966575716	0.785487848	0.166	0.871963815	0.153740563	0.484	19742	41.2	0.031
39	0.207	1	0.988	0.81337	0.639000599	0.09789	0.79	25705	37.7	0.241
401.01	0.179	0.995741893	0.989240885	0.822457214	0.669282733	0.135626217	0.828	21732	36.7	0.256
401.02	0.16	1	0.972586569	0.818040621	0.618276703	0.131944444	0.884	19928	37.3	0.294
402.01	0.227	0.973377704	0.9375	0.863416988	0.586963158	0.107563025	0.904	24378	41.8	0.37
402.03	0.098	0.989422527	0.960624385	0.863976483	0.599535054	0.139367816	0.766	20450	32.5	0.27
402.04	0.157	0.987891959	0.858632504	0.856833598	0.634244365	0.120073892	0.611	20401	36.1	0.044
403	0.195	0.9914056	0.890386343	0.865368634	0.630708997	0.149499865	0.75	29840	35.2	0.009
404	0.361	0.985552764	0.922845992	0.816681147	0.733748919	0.256965944	0.607	48164	53.1	0.007
405	0.213	0.99086116	0.9550664	0.803623814	0.745752917	0.151716889	0.754	34564	41.1	0
406	0.17	1	0.904486785	0.836909368	0.670782221	0.115189568	0.699	29232	38.9	0.107
407	0.157	0.975950349	0.889257063	0.827371185	0.692500649	0.151185387	0.59	23231	36.4	0.229
408	0.112	1	0.940332252	0.92077481	0.60938007	0.162007624	0.815	26501	32.1	0.046
409	0.168	0.988616462	0.806170083	0.89393644	0.620759543	0.057876414	0.698	21660	35.3	0.14
410	0.151	1	0.931470496	0.801389854	0.550657789	0.114146707	0.687	18342	32.5	0.094
411	0.269	1	0.961398878	0.7725	0.624310938	0.08930008	0.76	20293	40.4	0.176
413	0.226	0.993852459	0.971821966	0.768809016	0.684662808	0.132985658	0.819	25278	43.7	0
414	0.296	0.9578125	1	0.737366003	0.802043413	0.082934609	0.692	27585	51.5	0.06
415	0.127	0.980327869	0.977421704	0.769585253	0.597382673	0.087520259	0.525	14678	37	0.12
416	0.196	0.968695652	0.991631799	0.724865536	0.536324369	0.070146819	0.725	12856	44.7	0.01
417	0.257	1	0.978574372	0.735438884	0.651690318	0.044790652	0.742	21081	44.1	0
418	0.208	0.953767123	0.960702341	0.770331018	0.686188341	0.100164204	0.559	28187	44.6	0.08
419	0.142	0.978851964	0.876306249	0.859182476	0.553134947	0.031669866	0.457	17872	30.8	0.008
420	0.106	0.983651226	0.850211657	0.795069795	0.481612415	0.039055404	0.573	15045	33.5	0.052
421	0.209	0.949494949	0.847972132	0.857026807	0.567370872	0.149655172	0.467	18129	35.5	0.031
422	0.191	0.969726563	0.928970066	0.837837838	0.707631941	0.181640625	0.695	27835	40.8	0.048
425	0.252	0.956785444	0.959806476	0.882102273	0.735951705	0.249625187	0.827	38376	44.8	0.022
426	0.206	0.96969697	0.938709677	0.809677419	0.685647312	0.177156177	0.861	26972	49.7	0.212
427	0.13	0.978456014	0.885558583	0.823688969	0.723766012	0.141166526	0.681	24827	34.8	0.014

429	0.306	0.995251286	0.95324481	0.664232244	0.707046011	0.052583531	0.697	23973	48.1	0.046

Gathered Social Data 2012 – b

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
301	0.174	0	0.02	0.006	0.0151	0.2665	0.1576	0.518897	0.983193	147800	0.205
302	0.195	0	0.005	0.035	0.00585	0.1523	0.1389	0.506718	0.943989	141600	0.209
303	0.062	0	0.009	0.027	0.01354	0.2992	0.1136	0.500458	0.971019	150100	0.214
304	0.21	0	0	0.043	0.0051	0.1382	0.1357	0.568486	0.990719	87000	0.237
305	0.005	0.002	0.017	0.037	0.01455	0.1959	0.0629	0.499243	1	179400	0.454
306.01	0.002	0	0.019	0.02	0.07084	0.1483	0.1653	0.48446	0.961625	93100	0.259
306.02	0.051	0.004	0	0.069	0.029424	0.083155	0.1381	0.533142	0.939694	109000	0.35
1	0.075	0	0.101	0	0	0.453389831	0	0.516484	1	329200	0.213
3	0.532746823	0	0.147605	0.1627566	0.041547278	0.318051576	0.06017192	0.542522	0.902864	87800	0.088
6	0.063989962	0.000627353	0	0.00627353	0.008064516	0.165322581	0.072580645	0.451694	0.982734	142000	0.307
12.01	0.069888813	0.017472203	0.045609	0.05763558	0.005777008	0.312536106	0.09994223	0.503517	0.971292	135400	0.265
12.02	0.256710892	0.003548288	0.040574	0.0759025	0.009603073	0.288412292	0.054417414	0.554767	0.962126	179700	0.218
13	0.201640465	0	0.054682	0.12235133	0.00912721	0.337706788	0.063320023	0.436774	0.972789	130700	0.175
14	0.222576531	0	0	0.02678571	0	0.08811749	0.17222964	0.537628	0.913333	192400	0.204
15.01	0.26443299	0.003092784	0	0.05128866	0	0.18504436	0.036755387	0.543299	0.974755	138200	0.305
15.02	0.130376344	0.017697133	0.058468	0.13642473	0	0.126491647	0.046778043	0.468638	0.984154	228300	0.344
16	0.013149847	0	0	0.02293578	0	0.120532586	0.063069376	0.504587	0.993122	184700	0.461
17	0.298094882	0.007284273	0.008965	0.07844602	0.008818342	0.186948854	0.143915344	0.502802	0.96741	119900	0.155
18	0.924046322	0	0	0	0	0.31871345	0.158869396	0.502044	0.983819	93600	0.01
19	0.368283093	0	0	0.01485365	0	0.329847909	0.103612167	0.49716	0.955577	79600	0.07
20	0.327868852	0.001891551	0	0.07534678	0.006930007	0.293139293	0.133056133	0.516078	0.900774	123300	0.109
23	0.647647277	0	0	0.0389033	0.005813953	0.373062016	0.151162791	0.498703	0.967532	105500	0.08
24	0.787900188	0	0	0.05743879	0	0.443333333	0.143333333	0.512006	0.983199	89700	0.104
25	0.11163227	0	0.023452	0.17542214	0	0.151960784	0.117647059	0.305816	1	64600	0.051
26	0.71978673	0	0.002073	0.0207346	0	0.505119454	0.186006826	0.592121	0.890861	74100	0.093
27	0.097332372	0.001441961	0.042898	0.02649603	0	0.179876602	0.08258187	0.572999	0.983691	140800	0.264
28	0	0	0.023438	0.12988281	0.010848126	0.055226824	0.079881657	0.614258	0.975207	174500	0.361
29	0.056478405	0	0.006645	0.04152824	0.007968127	0.137450199	0.079681275	0.577243	0.993538	260600	0.324
30	0.480964836	0	0.034874	0	0.002153625	0.131371141	0.114860014	0.498402	0.992201	170800	0.32
31.01	0.195602148	0.001534134	0.025697	0.03247251	0	0.292926768	0.095226193	0.53912	0.960668	159000	0.343
31.02	0.108050243	0.002426492	0.018127	0.02940337	0.003121099	0.109550562	0.112047441	0.511704	0.995058	166900	0.433
32.04	0.330105383	0.003702649	0.002563	0.11848476	0.011204482	0.302521008	0.237535014	0.496155	0.993684	106600	0.167
32.05	0.371583058	0.00570742	0	0.02748573	0.006988934	0.154047758	0.127548049	0.516972	0.995451	140100	0.259
32.06	0.183329199	0.002728851	0.008311	0.04304143	0	0.209302326	0.086578874	0.463533	0.989015	173500	0.369
32.07	0.369240221	0	0.025189	0.02293672	0.005891016	0.313696613	0.073146784	0.48802	0.992051	119000	0.194
32.08	0.449599223	0.003157639	0.024047	0.09084285	0	0.180995475	0.088235294	0.467088	0.97954	120200	0.17
33.01	0.163766279	0	0.08171	0.04990204	0.013313238	0.340366742	0.128108515	0.506627	0.959455	119500	0.206

Census Tract	% African American	% Native American	% Asian American	% Hispanic	% Employed in Extraction	% Employed in Service	% Employed Transportation	% Female	% pop w/ phones	Median House Value	% pop w/ High Income
33.03	0.164397751	0	0.067032	0.04483575	0.028681743	0.314396029	0.095697739	0.483871	1	163600	0.316
33.04	0.092634619	0	0.066433	0.06767072	0.007140024	0.276477588	0.061483538	0.478853	0.971987	178900	0.45
34.02	0.055227189	0	0.062893	0.03463243	0.003207547	0.236415094	0.084528302	0.506372	0.952282	181500	0.387
34.03	0	0	0	0.05236794	0.013586957	0.150362319	0.113224638	0.46949	1	213200	0.385
34.04	0.042047184	0	0	0.00532725	0.050927754	0.170548756	0.142913541	0.521309	0.949746	113200	0.248
35.01	0.048927982	0.001209456	0.011325	0.02078065	0.009157509	0.195185767	0.091836735	0.501924	0.97354	136000	0.251
35.02	0.023622047	0	0.016297	0.0230727	0.003398471	0.168224299	0.186915888	0.50412	0.977854	152800	0.272
35.04	0.121330392	0	0.009333	0.02290854	0.007649809	0.236294093	0.160220994	0.526557	0.964811	161400	0.318
35.05	0.192903037	0.003504673	0.015479	0.01839953	0.004423148	0.131588647	0.089568743	0.510368	0.984202	167700	0.382
36	0.337418301	0.093954248	0.124183	0.11846405	0.023809524	0.493506494	0.140692641	0.469771	0.937901	121600	0.101
37	0.16636528	0.003616637	0.022785	0.1761302	0.010465116	0.226744186	0.086046512	0.542134	0.968076	103700	0.154
38	0.123333333	0	0.013333	0.20111111	0	0.213953488	0.127906977	0.47	0.939655	102700	0.141
39	0.203246534	0	0.093676	0.08488333	0.04186685	0.250514756	0.077556623	0.514711	0.954135	139700	0.15
401.01	0.096	0.004493709	0	0.00284602	0.007015306	0.187818878	0.183035714	0.541941	0.94536	143500	0.403
401.02	0.016418533	0.001391401	0.005983	0	0.047047372	0.085009734	0.225178456	0.49033	0.961871	102600	0.278
402.01	0.045878136	0	0.008722	0.0130227	0.009259259	0.216724537	0.19994213	0.503823	0.957989	121600	0.326
402.03	0.026076555	0	0.013158	0.03062201	0.063305322	0.201680672	0.082352941	0.466986	0.985553	160100	0.3
402.04	0.0518824	0.015963815	0.021152	0.01263802	0.01091954	0.267528736	0.085344828	0.493814	0.994519	139400	0.25
403	0.138262742	0	0.109835	0.02785355	0.022475369	0.299568966	0.073891626	0.543575	0.972973	114100	0.206
404	0.122980781	0.007428369	0.037378	0.03961797	0.00405515	0.206812652	0.076507164	0.507605	0.981419	148900	0.303
405	0.047852407	0	0.007783	0.03574517	0	0.136842105	0.020433437	0.492649	0.976834	284400	0.401
406	0.120624571	0.007892931	0.001716	0.03946465	0.013665032	0.250875964	0.080939033	0.550103	0.941204	132300	0.419
407	0.123171846	0.002170932	0.043304	0.03484918	0	0.214199469	0.089591886	0.503656	0.972948	169200	0.376
408	0.248214286	0	0.037013	0.06444805	0.029148853	0.146910222	0.141080451	0.512338	0.980242	117700	0.234
409	0.08622079	0.003312741	0.012982	0.05407825	0.018847946	0.191232529	0.099322321	0.492524	0.953013	156600	0.407
410	0.337725247	0	0.038752	0.14783957	0.028720627	0.152741514	0.128372498	0.565782	0.983051	111200	0.243
411	0.379386878	0	0.001665	0.08808434	0	0.221182635	0.086077844	0.497156	0.964626	116200	0.21
413	0.13515625	0	0.010625	0.02609375	0.020917136	0.17699115	0.267497989	0.515	0.977162	93200	0.257
414	0.464209564	0	0.018581	0.01583917	0.022164276	0.117340287	0.125162973	0.504721	0.99584	135500	0.256
415	0.761976048	0	0	0.00823353	0	0.311004785	0.119617225	0.437126	1	113800	0.286
416	0.889863206	0	0	0	0	0.316855754	0.167747164	0.528236	0.985479	76900	0.089
417	0.962763757	0	0	0.00041374	0	0.295269168	0.256117455	0.453041	0.897698	81300	0.11
418	0.90121521	0	0.004704	0	0	0.264849075	0.241480039	0.506076	0.988399	81400	0.081
419	0.379942927	0	0.004077	0.0101916	0.006568144	0.328407225	0.057471264	0.497758	0.988517	98400	0.261
420	0.435430784	0	0.036012	0.09699903	0.070537428	0.169865643	0.253358925	0.487512	0.976418	103900	0.227
421	0.392931393	0	0	0.16424116	0.040871935	0.124432334	0.264305177	0.510544	0.990204	94400	0.179
422	0.28440367	0.000229358	0.047936	0.13463303	0.017931034	0.17862069	0.146896552	0.509862	0.952553	110900	0.143
425	0.092383292	0	0	0.08501229	0.041992188	0.163085938	0.112304688	0.536609	0.987283	145800	0.281
426	0.154119318	0	0	0.03728693	0	0.095952024	0.094452774	0.474787	0.988934	253800	0.522
427	0.050537634	0	0	0	0	0.10955711	0.118881119	0.472043	1	79700	0.268
429	0.176345004	0	0.003843	0.10717336	0.009298394	0.174978867	0.165680473	0.497011	0.94509	108800	0.238

B- Economic
Gathered Economic Data - 2009

Census Tract	% Homeownership	% employed	% Female Labor	Per Capital Income	% pop employed in primary industry	Ratio large to small	Retail center per 1000	commercial est. / 1000	Lending est. / 1000	number of doctors per 1000
1	0.438298	0.611	0.716	17312	0.924303	0.046512	0.015	0.016	0.001	0
3	0.589459	0.528	0.605	16925	0.956425	0.018868	0.008	0.012	0.001	0.001
6	0.583514	0.491	0.486	21457	0.990111	0.023077	0.02	0.024	0.005	0.008
12.01	0.522843	0.536	0.664	28494	0.994302	0.034483	0.016	0.017	0.003	0.026
12.02	0.380684	0.643	0.777	27193	0.991796	0.011494	0.069	0.076	0.016	0.037
13	0.258178	0.632	0.69	25938	1	0.01626	0.104	0.106	0.003	0.046
14	0.533575	0.733	0.73	29567	1	0.010526	0.009	0.011	0.002	0.007
15.01	0.564646	0.504	0.472	24177	1	0.043478	0.036	0.041	0.005	0.018
15.02	0.564646	0.504	0.472	19169.5	1	0.018182	0.036	0.041	0.005	0.018
16	0.890049	0.474	0.535	38339	1	0	0.009	0.015	0.001	0.001
17	0.518444	0.54	0.6	19483	0.992271	0.006098	0.114	0.137	0.037	0.09
18	0.461538	0.368	0.463	11738	1	0.024064	0.123	0.152	0.007	0.039
19	0.592892	0.568	0.652	17071	0.991071	0.007519	0.035	0.043	0.01	0.002
20	0.459933	0.564	0.535	13348	0.99398	0.005249	0.089	0.132	0.016	0.01
23	0.492322	0.433	0.443	13890	1	0.004405	0.028	0.043	0.007	0.024
24	0.622252	0.454	0.542	11462	1	0.125	0.006	0.01	0.001	0
25	0.050119	0.191	0.31	13816	1	0	0	0	0	0
26	0.614126	0.35	0.515	13085	1	0.027523	0.015	0.023	0.003	0.188
27	0.800676	0.504	0.652	22772	0.993664	0.011494	0.04	0.048	0.01	0.019
28	0.512017	0.588	0.701	28090	1	0.015385	0.017	0.018	0.003	0.001
29	0.81182	0.575	0.688	37895	1	0.015625	0.014	0.016	0.003	0.003
30	0.694365	0.591	0.706	23446	1	0.040816	0.007	0.012	0	0
31.01	0.687343	0.632	0.682	24584	1	0.00339	0.09	0.106	0.006	0.02
31.02	0.818525	0.498	0.544	27192	0.991972	0.015267	0.038	0.066	0.002	0.006
32.04	0.602588	0.571	0.581	17674	0.986315	0.02649	0.065	0.076	0.001	0.089
32.05	0.676228	0.668	0.696	23491	0.997899	0.010135	0.075	0.09	0.024	0.098
32.06	0.826684	0.627	0.72	26034	0.994914	0	0.025	0.044	0.004	0.002
32.07	0.655509	0.533	0.624	9075	1	0	0.015	0.04	0.005	0.009
32.08	0.655509	0.533	0.624	9075	1	0.050691	0.015	0.04	0.005	0.009
33.01	0.630618	0.524	0.519	17029	0.99646	0.009877	0.141	0.167	0.029	0.021
33.03	0.713008	0.583	0.672	14327	0.998922	0.010101	0.017	0.025	0.004	0.079
33.04	0.713008	0.583	0.672	14327	0.998922	0	0.017	0.025	0.004	0.079
34.02	0.86279	0.65	0.714	25283	0.97744	0	0.027	0.056	0.001	0.006
34.03	0.830254	0.583	0.672	9855	0.974152	0	0.01	0.014	0	0.001
34.04	0.830254	0.583	0.672	9855	0.974152	0	0.01	0.014	0	0.001
35.01	0.853267	0.595	0.563	19536	0.979121	0	0.019	0.026	0.002	0.001
35.02	0.772051	0.522	0.514	19396	0.990918	0	0.012	0.021	0	0.007

35.04	0.832671	0.587	0.633	25918	0.99703	0	0.012	0.023	0.001	0.006
35.05	0.832671	0.587	0.633	12959	0.99703	0.024476	0.012	0.023	0.001	0.006
36	0.830065	0.365	0.529	23802.5	1	0.014286	0.038	0.043	0.01	0.077
37	0.637971	0.552	0.616	28998	0.986842	0	0.041	0.044	0.006	0.033
38	0.671171	0.499	0.627	29761	1	0.018987	0.008	0.009	0.003	0.014
39	0.568776	0.608333	0.704333	18923.67	0.988899	0.017045	0.036	0.046	0.004	0.016
301	0.681839	0.563	0.71	24690	1	0.003906	0.000022	0.054	0.005	0.022
302	0.591846	0.555	0.634	20225	0.989805	0.005348	0.000011	0.045	0.01	0.006
303	0.59307	0.571	0.453	20923	0.99197	0.016667	0.000011	0.13	0.014	0.047
304	0.726264	0.481	0.443	17012	1	0.038462	0.00002	0.018	0.001	0.001
305	0.898387	0.479	0.553	30767	0.995892	0.00905	0.00003	0.058	0.008	0.037
306.01	0.84	0.493	0.459	17596	0.960985	0	0.000163	0.019	0.003	0.003
306.02	0.84	0.493	0.459	17596	0.960985	0.029268	0.000007	0.019	0.003	0.003
401.01	0.849652	0.624	0.602	22017	1	0	0.04	0.047	0.004	0.014
401.02	0.875317	0.536	0.508	20982	0.94939	0.018519	0.007	0.011	0.001	0
402.01	0.910954	0.597	0.612	20816	0.998256	0	0.022	0.034	0.001	0.001
402.03	0.828013	0.601	0.637	19156	0.994563	0	0.011	0.014	0.001	0
402.04	0.828013	0.601	0.637	19156	0.994563	0.016129	0.011	0.014	0.001	0
403	0.779059	0.537	0.675	18520	0.979385	0	0.02	0.031	0.003	0.022
404	0.673688	0.577	0.722	27723	0.994519	0.007692	0.03	0.042	0.004	0.005
405	0.64872	0.561	0.793	31026	1	0.003431	0.163	0.177	0.016	0.044
406	0.754246	0.578	0.624	26378	0.982589	0.028986	0.007	0.008	0	0.005
407	0.777481	0.607	0.73	32762	1	0.005376	0.092	0.11	0.017	0.218
408	0.57549	0.51	0.508	22546	0.993007	0.011152	0.084	0.101	0.008	0.019
409	0.858183	0.593	0.637	26864	0.987921	0	0.007	0.009	0	0.002
410	0.683411	0.542	0.592	21373	0.981026	0.006472	0.072	0.087	0.009	0.021
411	0.700043	0.532	0.589	17806	1	0	0.004	0.006	0	0.001
413	0.794	0.548	0.571	19136	0.992772	0.018868	0.053	0.062	0.004	0.011
414	0.886173	0.527	0.723	24417	1	0	0.005	0.006	0	0.004
415	0.643939	0.415	0.635	15379	1	0.005236	0.029	0.036	0.008	0.004
416	0.633517	0.444	0.471	17543	1	0	0.012	0.012	0	0.001
417	0.681701	0.394	0.36	11851	0.980983	0	0.006	0.012	0	0
418	0.676824	0.586	0.712	15444	1	0.048544	0.02	0.021	0.007	0.01
419	0.47612	0.585	0.659	21727	0.99384	0.015209	0.058	0.075	0.007	0.108
420	0.452308	0.63	0.577	18242	0.949068	0.008772	0.008	0.014	0.001	0.002
421	0.483967	0.567	0.638	17800	0.988506	0	0.015	0.021	0.003	0
422	0.63104	0.383	0.462	16088	1	0.008895	0.085	0.103	0.02	0.103
425	0.672431	0.517	0.643	21731	0.945529	0	0.017	0.019	0.001	0.009
426	0.812434	0.661	0.76	41056	1	0.25	0.002	0.002	0	0
427	0.710027	0.472	0.438	15183	1	0.12766	0.005	0.014	0.001	0
429	0.663825	0.5235	0.544	18416	0.974552	0.4	0.067	0.08	0.023	0.016

Gathered Economic Data 2010

Census Tract	% Homeownership	% employed	% Female Labor	Per Capital Income	% pop employed in primary industry	Ratio large to small	Retail center per 1000	commercial est. / 1000	lending est. / 1000	number of doctors per 1000
1	0.233161	0.664	0.608	20760	1	0.054054	0.013	0.014	0	0
3	0.56267	0.489	0.559	16409	0.955314	0.017544	0.007	0.011	0.001	0.001
6	0.648876	0.513	0.514	33080	1	0.025	0.019	0.021	0.006	0.01
12.01	0.505666	0.571	0.668	28538	0.99597	0.01087	0.015	0.015	0.003	0.023
12.02	0.407048	0.666	0.821	27799	0.988681	0.011976	0.068	0.074	0.012	0.042
13	0.242912	0.658	0.694	24980	1	0.02	0.106	0.108	0.002	0.05
14	0.429942	0.668	0.679	26503	1	0.009346	0.01	0.012	0.001	0.01
15.01	0.7507	0.435	0.542	18814	1	0.048193	0.031	0.034	0.003	0.019
15.02	0.516148	0.605	0.512	35278	1	0.020408	0.031	0.034	0.003	0.019
16	0.880147	0.497	0.6	36580	1	0	0.012	0.016	0.001	0.001
17	0.529044	0.597	0.665	20153	0.993232	0.007366	0.112	0.132	0.033	0.093
18	0.440034	0.385	0.516	12381	1	0.025714	0.135	0.151	0.008	0.046
19	0.604972	0.577	0.609	18184	1	0	0.037	0.042	0.008	0.003
20	0.482955	0.563	0.554	13662	0.993473	0.007082	0.091	0.122	0.014	0.008
23	0.475426	0.453	0.524	13841	1	0	0.028	0.04	0.007	0.027
24	0.575801	0.534	0.643	12768	1	0.09375	0.006	0.009	0	0
25	0.029333	0.153	0.373	13051	1	0	0.001	0.001	0	0.001
26	0.548507	0.409	0.584	12504	1	0.022305	0.014	0.022	0.002	0.211
27	0.793327	0.513	0.579	22325	0.992726	0.005495	0.047	0.051	0.007	0.019
28	0.480638	0.618	0.604	26198	1	0.016129	0.018	0.019	0.003	0.001
29	0.818781	0.615	0.715	47298	1	0.014925	0.016	0.018	0.002	0.003
30	0.742248	0.556	0.553	19620	1	0.040816	0.011	0.013	0	0
31.01	0.693585	0.658	0.741	24033	1	0.003436	0.092	0.105	0.006	0.021
31.02	0.777778	0.55	0.645	26550	0.993192	0.016878	0.048	0.06	0.001	0.007
32.04	0.564304	0.648	0.697	17825	0.989668	0.023569	0.073	0.08	0.003	0.113
32.05	0.702912	0.692	0.761	23081	0.993667	0.006849	0.077	0.084	0.023	0.106
32.06	0.816149	0.641	0.669	26335	1	0	0.028	0.041	0.003	0.002
32.07	0.597975	0.672	0.699	22889	1	0	0.018	0.039	0.004	0.002
32.08	0.682343	0.436	0.652	14855	1	0.063348	0.018	0.039	0.004	0.002
33.01	0.60408	0.544	0.51	17394	0.985607	0.017857	0.172	0.192	0.031	0.034
33.03	0.618854	0.637	0.673	27789	0.994805	0.009709	0.02	0.024	0.005	0.087
33.04	0.814086	0.582	0.722	36135	0.984153	0	0.02	0.024	0.005	0.087
34.02	0.895791	0.67	0.762	25513	1	0	0.027	0.053	0	0.006
34.03	0.836784	0.641	0.625	27411	0.979808	0	0.012	0.016	0	0.002
34.04	0.890086	0.63	0.633	18539	0.987921	0	0.012	0.016	0	0.002
35.01	0.867318	0.594	0.59	19448	0.982403	0	0.018	0.024	0.001	0
35.02	0.827431	0.539	0.537	20661	0.985877	0	0.01	0.016	0	0.008
35.04	0.807045	0.528	0.526	20575	1	0	0.014	0.023	0.001	0.004
35.05	0.871761	0.546	0.603	26925	0.996205	0.030303	0.014	0.023	0.001	0.004
36	0.552326	0.484	0.709	13971	1	0.015528	0.036	0.039	0.01	0.073

37	0.590741	0.521	0.543	21267	0.980247	0	0.043	0.047	0.005	0.062
38	0.612987	0.513	0.548	23900	1	0.019802	0.022	0.022	0.003	0.014
39	0.542571	0.629	0.669	22095	0.978514	0.017857	0.038	0.044	0.004	0.021
301	0.679612	0.582	0.723	22790	1	0	0.042	0.045	0.004	0.029
302	0.621764	0.535	0.605	21284	0.997189	0.005988	0.035	0.039	0.007	0.008
303	0.569225	0.547	0.525	21133	0.984313	0.015748	0.104	0.113	0.014	0.058
304	0.837838	0.456	0.482	16567	1	0.040541	0.012	0.019	0.001	0.001
305	0.863868	0.499	0.585	30675	0.993544	0.009217	0.05	0.057	0.009	0.037
306.01	0.936725	0.477	0.431	18054	0.978503	0	0.015	0.019	0.003	0.003
306.02	0.795106	0.504	0.454	17667	0.963561	0.043478	0.015	0.019	0.003	0.003
401.01	0.836317	0.615	0.62	21601	1	0	0.041	0.048	0.004	0.016
401.02	0.86911	0.524	0.511	21076	0.961955	0.017241	0.01	0.012	0	0
402.01	0.92626	0.578	0.614	21263	0.997657	0	0.02	0.025	0.001	0.004
402.03	0.849805	0.566	0.579	19766	0.935771	0	0.012	0.014	0.001	0
402.04	0.835088	0.601	0.596	21040	0.986842	0.014706	0.012	0.014	0.001	0
403	0.721743	0.543	0.665	17190	0.966277	0	0.021	0.03	0.003	0.018
404	0.722659	0.579	0.707	25562	0.996907	0.016129	0.028	0.035	0.005	0.003
405	0.658271	0.575	0.714	37905	1	0.00349	0.154	0.164	0.011	0.052
406	0.72266	0.594	0.614	27160	0.979531	0.029851	0.006	0.007	0	0.005
407	0.759728	0.599	0.68	35215	1	0.005545	0.088	0.101	0.016	0.237
408	0.547914	0.495	0.537	20067	0.97807	0.011111	0.085	0.094	0.008	0.02
409	0.865324	0.608	0.669	27428	0.981036	0	0.01	0.01	0	0.004
410	0.655783	0.545	0.626	21709	0.980198	0.006024	0.058	0.065	0.008	0.028
411	0.644569	0.563	0.641	18240	1	0	0.002	0.003	0	0
413	0.814354	0.53	0.561	18728	0.993345	0.018519	0.052	0.061	0.004	0.009
414	0.876974	0.521	0.672	24841	0.996353	0.027778	0.003	0.005	0	0.003
415	0.657986	0.454	0.699	14707	1	0	0.03	0.037	0.007	0.004
416	0.573333	0.522	0.604	15537	1	0	0.009	0.009	0	0.001
417	0.717364	0.422	0.495	12998	0.985994	0	0.01	0.014	0	0
418	0.725449	0.515	0.653	20119	1	0.041237	0.019	0.021	0.007	0.009
419	0.507317	0.606	0.735	24906	0.992852	0.016393	0.053	0.072	0.007	0.121
420	0.398393	0.657	0.605	17452	0.937693	0.009009	0.01	0.015	0	0.005
421	0.530339	0.499	0.518	16263	0.987568	0	0.017	0.021	0.002	0.002
422	0.470175	0.363	0.47	15464	0.981043	0.009358	0.084	0.097	0.019	0.11
425	0.635135	0.532	0.606	20816	0.964405	0	0.014	0.015	0	0.01
426	0.881865	0.627	0.741	44169	1	0.166667	0.004	0.005	0	0
427	0.816092	0.49	0.454	15265	1	0.170213	0.005	0.014	0.001	0
429	0.638128	0.623	0.728	18946	0.973988	0.333333	0.062	0.069	0.021	0.015

Gathered Economic Data 2011

Census Tract	% Homeownership	% employed	% Female Labor	Per Capital Income	% pop employed in primary industry	Ratio large to small	Retail center per 1000	commercial est. / 1000	Lending est. / 1000	number of doctors per 1000
1	0.076531	0.675	0.588	19004	1	0.060606	0.013	0.014	0	0
3	0.463448	0.465	0.49	13823	0.950464	0.018182	0.007	0.011	0	0.001
6	0.643466	0.53	0.53	32653	1	0.016393	0.017	0.019	0.005	0.008
12.01	0.443787	0.524	0.618	25205	0.994276	0.019802	0.018	0.019	0.004	0.029
12.02	0.399802	0.655	0.78	25141	0.99053	0.011765	0.069	0.075	0.012	0.048
13	0.234453	0.665	0.718	23858	0.999423	0.016529	0.099	0.1	0.003	0.049
14	0.370748	0.55	0.612	25017	1	0	0.009	0.011	0.003	0.01
15.01	0.737474	0.455	0.554	18588	1	0.0625	0.035	0.039	0.004	0.018
15.02	0.485795	0.627	0.576	37018	1	0.019231	0.035	0.039	0.004	0.018
16	0.864241	0.514	0.579	38356	1	0	0.01	0.014	0.001	0.001
17	0.475035	0.628	0.716	19760	0.99286	0.007326	0.11	0.125	0.031	0.082
18	0.42753	0.447	0.634	12091	1	0.023669	0.137	0.155	0.008	0.049
19	0.578441	0.603	0.702	18840	1	0	0.035	0.039	0.008	0
20	0.427227	0.59	0.678	16680	0.990953	0.007184	0.085	0.112	0.013	0.012
23	0.441534	0.499	0.63	13173	1	0	0.025	0.04	0.008	0.019
24	0.504523	0.524	0.61	13366	1	0.068966	0.005	0.007	0	0
25	0.116625	0.137	0.27	15709	1	0	0	0	0	0.003
26	0.500462	0.425	0.574	11431	1	0.021127	0.016	0.024	0.002	0.224
27	0.789885	0.533	0.616	23358	1	0.005495	0.053	0.055	0.009	0.015
28	0.5	0.624	0.645	30125	1	0.015152	0.024	0.025	0.003	0.001
29	0.828616	0.406	0.633	41751	1	0	0.018	0.02	0.002	0.003
30	0.731148	0.57	0.58	25474	1	0.022222	0.007	0.009	0	0
31.01	0.653674	0.662	0.769	25892	1	0.003636	0.09	0.102	0.004	0.021
31.02	0.779894	0.553	0.668	26183	0.987148	0.018018	0.048	0.064	0.001	0.007
32.04	0.501321	0.655	0.675	17887	0.991659	0.016722	0.069	0.073	0.004	0.116
32.05	0.736511	0.673	0.706	23366	0.993375	0.006897	0.084	0.09	0.028	0.095
32.06	0.77285	0.633	0.617	26887	1	0	0.027	0.035	0.003	0.002
32.07	0.603037	0.549	0.61	18776	0.992792	0	0.02	0.044	0.003	0.009
32.08	0.661424	0.436	0.609	15997	1	0.051064	0.02	0.044	0.003	0.009
33.01	0.544426	0.549	0.538	19006	0.981117	0.014768	0.181	0.199	0.033	0.041
33.03	0.609127	0.684	0.739	27188	0.964237	0.006369	0.021	0.025	0.005	0.085
33.04	0.784452	0.586	0.747	38315	0.988921	0	0.021	0.025	0.005	0.085
34.02	0.845003	0.667	0.748	25957	1	0	0.036	0.057	0.001	0.006
34.03	0.861613	0.639	0.667	29941	0.981361	0	0.014	0.016	0.001	0.003
34.04	0.908666	0.621	0.605	21297	0.978225	0	0.014	0.016	0.001	0.003
35.01	0.881027	0.589	0.628	19307	0.990375	0	0.02	0.027	0.001	0
35.02	0.845345	0.533	0.514	19915	0.994419	0	0.009	0.015	0	0.008
35.04	0.805118	0.526	0.543	20949	1	0	0.013	0.018	0.001	0.004
35.05	0.865173	0.521	0.585	27329	0.996124	0.023256	0.013	0.018	0.001	0.004
36	0.398104	0.49	0.589	13401	0.980583	0.011976	0.038	0.043	0.011	0.068

37	0.568394	0.449	0.489	17898	0.990099	0	0.041	0.043	0.005	0.066
38	0.588353	0.535	0.483	25690	1	0.024735	0.009	0.009	0.002	0.012
39	0.566506	0.681	0.724	21623	0.952409	0.018868	0.05	0.054	0.004	0.019
301	0.691022	0.53	0.682	23023	0.998105	0	0.045	0.046	0.004	0.025
302	0.670226	0.54	0.618	22366	0.990995	0.005882	0.029	0.033	0.007	0.009
303	0.66876	0.495	0.48	18729	0.991071	0.010638	0.111	0.118	0.013	0.053
304	0.897987	0.455	0.552	18445	1	0.049383	0.012	0.02	0.001	0.001
305	0.843874	0.53	0.584	32471	0.993352	0.009259	0.046	0.054	0.007	0.039
306.01	0.913112	0.483	0.485	20318	0.978482	0	0.015	0.019	0.003	0.004
306.02	0.797484	0.488	0.477	18470	0.979551	0.044118	0.015	0.019	0.003	0.004
401.01	0.824062	0.603	0.61	25756	0.993077	0	0.04	0.044	0.003	0.017
401.02	0.81964	0.52	0.505	21983	0.965815	0.018519	0.009	0.011	0.001	0
402.01	0.915503	0.547	0.54	20467	0.99707	0	0.019	0.023	0.001	0.004
402.03	0.873542	0.551	0.576	22076	0.940107	0	0.012	0.015	0.001	0.001
402.04	0.852501	0.611	0.632	19848	0.988119	0.014085	0.012	0.015	0.001	0.001
403	0.685332	0.587	0.73	18336	0.980591	0	0.02	0.028	0.001	0.018
404	0.745051	0.581	0.729	29013	0.996101	0.015152	0.033	0.039	0.004	0.01
405	0.63082	0.563	0.671	42270	1	0.003478	0.156	0.166	0.013	0.049
406	0.752958	0.634	0.633	31289	0.971973	0.014493	0.007	0.01	0	0.003
407	0.694453	0.618	0.693	28042	1	0.00369	0.1	0.112	0.016	0.236
408	0.558183	0.492	0.507	19242	0.987353	0.010989	0.086	0.093	0.007	0.02
409	0.817754	0.608	0.646	28467	0.976569	0	0.008	0.009	0	0.004
410	0.695887	0.575	0.664	23472	0.963252	0.00565	0.068	0.079	0.009	0.031
411	0.69869	0.574	0.648	19531	1	0	0.002	0.003	0	0
413	0.770696	0.518	0.542	19504	0.978136	0.009174	0.049	0.058	0.004	0.01
414	0.880952	0.545	0.739	25109	0.974053	0.027027	0.005	0.008	0	0.002
415	0.694853	0.507	0.653	18236	1	0	0.028	0.033	0.008	0.005
416	0.509704	0.519	0.553	15266	1	0	0.008	0.008	0	0.001
417	0.690506	0.347	0.395	12204	0.975649	0	0.011	0.016	0	0
418	0.757576	0.489	0.616	20931	1	0.03125	0.019	0.019	0.006	0.011
419	0.516484	0.615	0.793	25941	0.991935	0.007752	0.059	0.072	0.006	0.126
420	0.405836	0.616	0.569	19042	0.940094	0.017544	0.01	0.013	0	0.005
421	0.537577	0.472	0.508	15373	0.988546	0	0.016	0.02	0.002	0.002
422	0.564162	0.468	0.651	19393	0.979405	0.006402	0.078	0.09	0.021	0.115
425	0.626225	0.544	0.721	24579	0.970519	0.013514	0.01	0.012	0.001	0.012
426	0.839092	0.587	0.685	43673	1	0.076923	0.005	0.005	0	0
427	0.756219	0.396	0.498	21607	1	0.170213	0.004	0.012	0.001	0
429	0.645089	0.594	0.794	23002	0.988516	0.333333	0.065	0.073	0.02	0.014

Gathered Economic Data 2012

Census Tract	% Homeownership	% employed	% Female Labor	Per Capital Income	% pop employed in primary industry	Ratio large to small	Retail center per 1000	commercial est. / 1000	Lending est. / 1000	number of doctors per 1000
1	0.1792	0.616	0.559	18617	1	0.044444	0.017	0.018	0	0
3	0.442092	0.464	0.516	12,635	0.958453	0.017857	0.009	0.012	0.001	0.001
6	0.614388	0.541	0.55	28,726	0.991935	0.021739	0.018	0.019	0.006	0.011
12.01	0.481127	0.486	0.615	29,789	0.994223	0.020408	0.072	0.073	0.004	0.029
12.02	0.398888	0.633	0.724	24,031	0.990397	0.00838	0.002	0.008	0.014	0.051
13	0.269017	0.657	0.824	26,844	0.990873	0.018182	0.114	0.115	0.01	0.061
14	0.310667	0.573	0.684	26,789	1	0.008696	0.01	0.012	0.003	0.015
15.01	0.719495	0.5	0.591	23,893	1	0.050633	0.034	0.039	0.003	0.021
15.02	0.516695	0.587	0.548	39,767	1	0.017467	0.034	0.039	0.003	0.021
16	0.87414	0.511	0.604	43,142	1	0	0.011	0.014	0.001	0
17	0.450686	0.646	0.741	20,854	0.991182	0.008489	0.116	0.13	0.036	0.104
18	0.45712	0.459	0.669	11,834	1	0.025568	0.143	0.162	0.008	0.051
19	0.625864	0.59	0.64	19,906	1	0	0.038	0.04	0.007	0
20	0.438424	0.57	0.677	16,852	0.99307	0.007958	0.093	0.118	0.016	0.012
23	0.408163	0.511	0.604	13,349	0.994186	0	0.033	0.046	0.013	0.014
24	0.482527	0.503	0.621	12,242	1	0.0625	0.004	0.006	0.001	0
25	0.127473	0.13	0.265	16,706	1	0	0.001	0.001	0	0.005
26	0.497782	0.471	0.609	11,659	1	0.02	0.018	0.026	0.004	0.246
27	0.77027	0.5	0.597	23,065	1	0.005025	0.056	0.057	0.012	0.028
28	0.501033	0.6	0.704	30,060	0.989152	0.015152	0.022	0.023	0.003	0.001
29	0.799677	0.465	0.662	40,292	0.992032	0	0.019	0.02	0.002	0.002
30	0.716638	0.555	0.577	23,037	0.997846	0.019231	0.01	0.012	0	0
31.01	0.654716	0.64	0.68	26,767	1	0.003521	0.095	0.108	0.011	0.024
31.02	0.776771	0.564	0.645	26,079	0.996879	0.016129	0.052	0.073	0.006	0.006
32.04	0.477895	0.623	0.681	18,741	0.988796	0.02	0.078	0.084	0.003	0.151
32.05	0.656328	0.675	0.725	21,768	0.993011	0.006192	0.09	0.097	0.041	0.121
32.06	0.723955	0.59	0.604	25,628	1	0	0.057	0.066	0.008	0.002
32.07	0.54372	0.553	0.622	19,388	0.994109	0	0.021	0.044	0.003	0.012
32.08	0.642796	0.402	0.573	16,513	1	0.053061	0.021	0.044	0.003	0.012
33.01	0.57165	0.573	0.624	20,975	0.986687	0.017613	0.198	0.22	0.04	0.05
33.03	0.533406	0.643	0.685	26,039	0.971318	0.008152	0.024	0.03	0.007	0.103
33.04	0.792812	0.633	0.739	36,775	0.99286	0	0.024	0.03	0.007	0.103
34.02	0.835581	0.668	0.763	26,978	0.996792	0.006309	0.042	0.067	0.003	0.009
34.03	0.848193	0.643	0.679	29,678	0.986413	0	0.015	0.017	0.001	0.001
34.04	0.894416	0.613	0.607	20,705	0.949072	0	0.015	0.017	0.001	0.001
35.01	0.866731	0.564	0.633	19,582	0.990842	0	0.021	0.029	0.004	0.001
35.02	0.892224	0.563	0.526	20,974	0.996602	0	0.012	0.018	0.002	0.009
35.04	0.820045	0.524	0.563	21,811	0.99235	0	0.015	0.019	0.002	0.004
35.05	0.850555	0.532	0.592	26,289	0.995577	0.022876	0.015	0.019	0.002	0.004
36	0.359743	0.523	0.562	13,818	0.97619	0.011173	0.045	0.05	0.014	0.07

37	0.496117	0.388	0.428	16,975	0.989535	0	0.042	0.044	0.007	0.071
38	0.581897	0.558	0.544	21,874	1	0.025397	0.01	0.01	0.003	0.014
39	0.484211	0.607	0.692	19,742	0.958133	0.016667	0.047	0.051	0.006	0.027
301	0.697479	0.556	0.749	23973	0.984	0	0.055	0.057	0.008	0.033
302	0.666211	0.539	0.619	21062	0.994142	0.005587	0.037	0.041	0.011	0.008
303	0.62111	0.506	0.53	18986	0.986451	0.011962	0.125	0.131	0.023	0.07
304	0.889791	0.478	0.562	20184	0.994878	0.046512	0.018	0.025	0.003	0.002
305	0.842077	0.568	0.615	32335	0.985445	0.008734	0.046	0.053	0.007	0.044
306.01	0.902182	0.514	0.52	20226	0.929151	0	0.017	0.022	0.004	0.004
306.02	0.836018	0.46	0.415	20155	0.970576	0.042056	0.017	0.022	0.004	0.004
401.01	0.79011	0.601	0.633	25,705	0.992985	0	0.052	0.055	0.01	0.016
401.02	0.828223	0.532	0.507	21,732	0.952953	0.016393	0.012	0.015	0.002	0
402.01	0.884096	0.551	0.589	19,928	0.990741	0	0.022	0.027	0	0.001
402.03	0.903894	0.549	0.635	24,378	0.936695	0	0.012	0.015	0.001	0.001
402.04	0.765599	0.611	0.631	20,450	0.98908	0.013699	0.012	0.015	0.001	0.001
403	0.611288	0.584	0.711	20,401	0.977525	0	0.022	0.03	0.002	0.017
404	0.749662	0.576	0.73	29,840	0.995945	0.013793	0.036	0.044	0.006	0.012
405	0.606821	0.547	0.639	48,164	1	0.003215	0.165	0.177	0.015	0.057
406	0.754083	0.607	0.629	34,564	0.986335	0.027027	0.009	0.011	0.002	0.005
407	0.699005	0.59	0.612	29,232	1	0.006483	0.117	0.134	0.024	0.271
408	0.589582	0.531	0.534	23,231	0.970851	0.010676	0.087	0.094	0.013	0.022
409	0.815238	0.6	0.633	26,501	0.981152	0	0.009	0.01	0	0.003
410	0.697997	0.576	0.666	21,660	0.971279	0.005391	0.076	0.087	0.012	0.038
411	0.686804	0.542	0.653	18,342	1	0	0.002	0.003	0	0
413	0.760196	0.48	0.514	20,293	0.979083	0.017094	0.053	0.061	0.01	0.009
414	0.818636	0.564	0.745	25,278	0.977836	0.022727	0.005	0.008	0	0.002
415	0.691525	0.512	0.697	27,585	1	0	0.03	0.035	0.011	0.005
416	0.524685	0.508	0.541	14,678	1	0	0.01	0.01	0	0.001
417	0.725064	0.337	0.437	12,856	1	0	0.013	0.017	0	0
418	0.742459	0.494	0.631	21,081	1	0.039216	0.02	0.021	0.009	0.012
419	0.558852	0.56	0.723	28,187	0.993432	0.01049	0.068	0.078	0.007	0.143
420	0.457047	0.569	0.595	17,872	0.929463	0.015748	0.012	0.016	0.002	0.006
421	0.573061	0.464	0.454	15,045	0.959128	0	0.019	0.023	0.003	0.002
422	0.466667	0.397	0.547	18,129	0.982069	0.007238	0.085	0.097	0.033	0.114
425	0.694798	0.619	0.755	27,835	0.958008	0.012821	0.009	0.01	0.001	0.013
426	0.826962	0.575	0.678	38,376	1	0.058824	0.007	0.008	0	0
427	0.861314	0.529	0.508	26,972	1	0.186047	0.003	0.01	0.001	0
429	0.681098	0.604	0.766	24,827	0.990702	0.333333	0.1	0.108	0.02	0.015

C- Environmental
Gathered Environmental Data 2000

Census Tract	Land Area (Sq Mile)	Vegetation cover (%)	Loss of Cover (average Percentage in the last five years)	Habitat fragmentation	Terrestrial Reserves	Waste Production 4.38 lbs per person per day	Vehicles	Population (Per km2)	Population Growth
1	3.110023	0.135438	-0.03361	0	0	330.044	192.3523	455.3021	-0.20129
3	2.853611	0.176599	-0.03988	0	0	726.2589	141.3673	1001.888	-0.06821
6	7.973569	0.183936	-0.01482	0	0	231.9155	91.15489	319.932	-0.10421
12.01	3.8379	0.264558	-0.04942	0	0	1015.401	60.46204	1400.766	-0.04221
12.02	5.740308	0.22916	-0.02209	0	0	729.9023	85.50832	1006.915	0.033441
13	11.8611	0.046939	0.031306	0	0	231.6255	53.06474	319.532	-0.06144
14	15.18618	0.23608	0.00047	0	0	201.1969	55.92341	277.5551	-0.10237
15.01	2.125734	0.249444	-0.04875	0	0	1212.28	33.42692	1672.364	0.026694
15.02	6.335844	0.366502	-0.00617	0	0	468.0552	50.11986	645.6914	0.027342
16	4.896632	0.23424	-0.04268	0	0	560.0296	36.6937	772.5719	-0.03474
17	5.392912	0.258565	-0.04064	0	0	833.375	60.34581	1149.657	-0.03344
18	7.179521	0.418519	-0.03818	0	0	276.042	23.5183	380.8054	0.019781
19	1.761795	0.081013	-0.01941	0	0	1215.011	26.26497	1676.132	-0.06097
20	3.258907	0.115454	-0.02555	0	0	1040.321	35.36114	1435.144	-0.08791
23	1.960307	0.137738	-0.03089	0	0	932.2253	16.28965	1286.023	0.020599
24	6.459914	0.576287	-0.03469	0.335927	0	460.6367	21.69435	635.4573	0.009459
25	3.490504	0.356085	-0.06355	1.401333	0	426.9795	3.167246	589.0266	0.017559
26	2.29116	0.182629	-0.03556	0	0	1102.604	17.38123	1521.063	-0.00554
27	5.674137	0.374922	-0.03138	0	0	820.5597	32.90274	1131.978	-0.01986
28	7.088536	0.247488	-0.00745	0	0	494.4382	29.54809	682.0872	-0.15372
29	9.95869	0.688978	-0.07412	0.673413	0	203.156	16.26244	280.2577	-0.17276
30	19.35493	0.762758	-0.09399	1.296848	0.615503	167.5998	23.27797	231.2073	-0.03787
31.01	37.40299	0.748244	-0.00226	1.884617	0	149.8503	32.79571	206.7215	0.007577
31.02	107.089	0.781078	0.014367	2.679989	0.237361	41.75822	27.8792	57.60629	0.050067
32.04	3.333349	0.226079	-0.04475	0	0	909.2253	17.86585	1254.294	-0.04142
32.05	5.500439	0.364023	-0.03339	0	0	735.1116	25.22372	1014.101	0.049515
32.06	44.12758	0.796037	-0.00326	0.723415	0	76.82973	20.61363	105.9881	0.151271
32.07	8.445035	0.562586	-0.03138	0	0	402.0569	19.39076	554.6454	0.017751
32.08	16.98106	0.314008	-0.00289	0	2.480422	168.6182	12.91913	232.6122	0.013461
33.01	8.982672	0.332578	-0.05132	1.228781	0	600.237	32.31812	828.0387	0.039466
33.03	13.38302	0.462437	-0.0186	0	0	251.7584	21.59863	347.3057	0.113574
33.04	6.852326	0.310767	0.010686	0	0	430.978	23.17029	594.5426	0.057965
34.02	77.35355	0.794346	0.007541	1.51782	0	65.64475	29.24688	90.55823	0.117867
34.03	25.42609	0.783834	0.03158	1.986405	0	58.75847	8.14949	81.05847	0.015957
34.04	291.0849	0.902581	0.013803	1.451105	0	12.30957	19.00611	16.9813	0.016409
35.01	202.015	0.903517	0.012641	2.148971	0	26.0941	28.18816	35.99733	0.058722

35.02	138.8923	0.889167	0.014762	2.401586	0	24.97852	18.45218	34.45836	0.035822
35.04	55.93078	0.836456	0.015969	3.753897	0	51.71233	15.72997	71.33818	0.105443
35.05	29.83471	0.773936	0.031599	3.905644	0	112.6403	19.21881	155.3895	0.104464
36	27.08863	0.090086	-0.02061	0	0	64.75905	10.89009	89.33638	-0.05881
37	2.076106	0.245445	-0.04296	0	0	1094.263	12.32867	1509.557	-0.02544
38	4.193568	0.105303	-0.00444	0	0	359.3709	10.52022	495.7592	-0.14055
39	4.904903	0.06661	-0.01043	0.028867	0	730.077	20.9268	1007.156	-0.10904
301	10.64521	0.675251	-0.12115	0	0	390.0505	217.7505	538.0823	-0.00891
302	34.27642	0.834195	-0.08834	2.082812	0.172706	164.069	92.10413	226.3363	-0.06909
303	55.7819	0.782574	-0.09396	2.673018	1.206411	126.0782	68.39136	173.9274	-0.00971
304	227.0565	0.90754	-0.00276	0.875567	0.694375	9.034927	4.743313	12.46386	-0.07836
305	23.39134	0.76355	-0.05449	7.455041	0	183.2109	109.3995	252.7431	0.115943
306.01	267.6605	0.86496	0.019593	1.757898	0	14.94409	7.416112	20.61567	0.070571
306.02	393.4758	0.902	0.002659	1.266302	0	10.16567	5.044783	14.02373	0.049696
401.01	225.9729	0.846453	0.014576	1.266064	0	18.93601	8.81964	26.1226	0.032105
401.02	202.7387	0.824566	0.022593	1.513139	0	22.55418	10.06221	31.11393	0.034367
402.01	456.1063	0.866621	0.018518	1.085046	0	10.62288	4.770817	14.65448	0.060868
402.03	91.55543	0.826685	0.019551	2.10256	0	24.33839	12.16749	33.57529	0.087508
402.04	42.91997	0.801136	0.0185	4.01463	0	93.36428	38.93293	128.7979	0.081171
403	10.25646	0.38158	-0.03555	6.910422	0	471.7653	228.7339	650.8095	0.012257
404	26.69988	0.661129	0.010341	4.191856	0.57254	163.0603	81.83558	224.9449	0.091993
405	11.11668	0.322248	-0.01049	0	0	276.5447	156.0718	381.4989	-0.0413
406	6.749411	0.3207	0.020474	0	0	621.2044	310.2493	856.9636	0.003445
407	19.28049	0.58019	-0.00583	1.198374	0	298.0696	138.2745	411.1929	0.027748
408	63.42461	0.741384	0.020654	0.379008	2.671677	53.36274	25.6525	73.61495	0.075267
409	65.16987	0.47318	0.060082	2.925191	0.812507	83.85694	40.66297	115.6823	0.105592
410	18.44508	0.369087	0.058206	0	1.621188	220.7476	107.7794	304.5256	-0.01507
411	15.49221	0.399107	-0.00331	0.17926	0	320.7963	144.6533	442.5449	0.01445
413	62.55612	0.694322	0.017769	1.822069	0.4733	77.67325	37.34247	107.1518	-0.01048
414	5.434269	0.186698	0.025782	0	0	429.3901	227.8135	592.352	0.00515
415	3.8379	0.212689	-0.00516	0	0	277.6488	134.7091	383.0219	-0.01195
416	4.51615	0.297392	-0.01437	0.024939	0	500.7931	207.4776	690.8539	-0.01405
417	2.034749	0.186571	-0.02866	0	0	931.2512	398.0835	1284.679	-0.01582
418	2.456587	0.223657	-0.03838	0	0	1002.387	410.7324	1382.813	-0.06552
419	4.582321	0.203256	-0.03169	0	0	364.4761	187.4596	502.802	0.037291
420	3.705559	0.287902	-0.00337	0.030395	0	1088.834	483.8676	1502.068	-0.01624
421	2.572386	0.212344	-0.03343	0	0	1029.967	495.6488	1420.86	-0.01837
422	2.787441	0.065824	-0.01646	0	0	1363.212	571.492	1880.578	-0.04387
425	2.679913	0.149246	-0.02697	0	0	862.3224	488.4486	1189.591	-0.10161
426	4.168754	0.195785	-0.02814	0	0	564.6094	279.9398	778.8898	-0.02514
427	125.1122	0.527991	0.067576	0.633506	2.252768	9.218122	4.555909	12.71658	-0.09193
429	164.0951	0.314853	0.114446	0	0.711878	10.78312	5.435874	14.87552	-0.00708

Gathered Environmental Data 2009

Census Tract	Land Area (Sq Mile)	Vegetation cover (%)	Loss of Cover (average Percentage in the last five years)	Habitat fragmentation	Terrestrial Reserves	Waste Production 4.38 lbs per person per day	Vehicles	Population (Per km2)	Population Growth
1	3.110023	0.001883	-0.03361	0	0	142.6461	89.60989	196.7831	-0.20129
3	2.853611	0.040847	-0.03988	0	0	545.6467	110.2099	752.7304	-0.06821
6	7.973569	0.117788	-0.01482	0	0	168.0956	52.20806	231.8911	-0.10421
12.01	3.8379	0.137037	-0.04942	0	0	794.4154	63.42082	1095.912	-0.04221
12.02	5.740308	0.144497	-0.02209	0	0	869.1899	113.9468	1199.065	0.033441
13	11.8611	0.168586	0.031306	0	0	208.1574	57.99685	287.1572	-0.06144
14	15.18618	0.218118	0.00047	0	0	55.84825	18.87105	77.04376	-0.10237
15.01	2.125734	0.05973	-0.04875	0	0	1447.234	36.77219	1996.487	0.026694
15.02	6.335844	0.410341	-0.00617	0	0	558.5543	55.13442	770.5366	0.027342
16	4.896632	0.077305	-0.04268	0	0	537.0837	33.77269	740.9175	-0.03474
17	5.392912	0.099046	-0.04064	0	0	726.5148	46.37266	1002.241	-0.03344
18	7.179521	0.281856	-0.03818	0	0	301.0817	17.23102	415.3481	0.019781
19	1.761795	0.005917	-0.01941	0	0	1144.242	24.41504	1578.504	-0.06097
20	3.258907	0.011321	-0.02555	0	0	836.1275	28.00309	1153.454	-0.08791
23	1.960307	0.014323	-0.03089	0	0	979.9274	15.76906	1351.829	0.020599
24	6.459914	0.462292	-0.03469	0.335927	0	467.0328	22.94966	644.281	0.009459
25	3.490504	0.121424	-0.06355	1.401333	0	527.2865	6.303592	727.4021	0.017559
26	2.29116	0.05082	-0.03556	0	0	1007.055	12.76109	1389.252	-0.00554
27	5.674137	0.254545	-0.03138	0	0	608.2337	27.16622	839.0703	-0.01986
28	7.088536	0.20453	-0.00745	0	0	225.9997	14.99476	311.771	-0.15372
29	9.95869	0.332355	-0.07412	0.673413	0	114.207	8.257748	157.5508	-0.17276
30	19.35493	0.388879	-0.09399	1.296848	0.615503	104.0804	13.35136	143.581	-0.03787
31.01	37.40299	0.748899	-0.00226	1.884617	0	129.9853	39.31001	179.3172	0.007577
31.02	107.089	0.829846	0.014367	2.679989	0.237361	31.78742	25.2519	43.85137	0.050067
32.04	3.333349	0.05299	-0.04475	0	0	916.4017	23.72469	1264.194	-0.04142
32.05	5.500439	0.249469	-0.03339	0	0	886.9309	39.32394	1223.539	0.049515
32.06	44.12758	0.782204	-0.00326	0.723415	0	103.5895	38.54062	142.9038	0.151271
32.07	8.445035	0.498073	-0.03138	0	0	440.3399	28.72482	607.4575	0.017751
32.08	16.98106	0.370853	-0.00289	0	2.480422	184.6263	19.14391	254.6956	0.013461
33.01	8.982672	0.144493	-0.05132	1.228781	0	625.9798	36.26135	863.5515	0.039466
33.03	13.38302	0.428216	-0.0186	0	0	366.0463	39.27981	504.9681	0.113574
33.04	6.852326	0.376705	0.010686	0	0	404.2138	26.17472	557.6208	0.057965
34.02	77.35355	0.875023	0.007541	1.51782	0	79.52339	47.85543	109.7041	0.117867
34.03	25.42609	0.900914	0.03158	1.986405	0	62.49324	9.897431	86.21066	0.015957
34.04	291.0849	0.954398	0.013803	1.451105	0	13.08904	23.091	18.05659	0.016409
35.01	202.015	0.946004	0.012641	2.148971	0	29.13339	37.73132	40.19008	0.058722
35.02	138.8923	0.934473	0.014762	2.401586	0	28.75713	22.886	39.67103	0.035822

35.04	55.93078	0.886678	0.015969	3.753897	0	62.85835	23.76581	86.71432	0.105443
35.05	29.83471	0.788139	0.031599	3.905644	0	136.9614	29.03759	188.941	0.104464
36	27.08863	0.007825	-0.02061	0	0	23.01355	2.253122	31.74764	-0.05881
37	2.076106	0.071518	-0.04296	0	0	1192.376	15.22032	1644.907	-0.02544
38	4.193568	0.07874	-0.00444	0	0	157.6461	4.634994	217.4759	-0.14055
39	4.904903	0.022472	-0.01043	0.028867	0	497.0139	17.51988	685.6405	-0.10904
301	10.64521	0.169802	-0.12115	0	0	363.0847	224.4202	500.8825	-0.00891
302	34.27642	0.46337	-0.08834	2.082812	0.172706	112.5939	68.23933	155.3254	-0.06909
303	55.7819	0.430463	-0.09396	2.673018	1.206411	89.05526	54.46211	122.8535	-0.00971
304	227.0565	0.890813	-0.00276	0.875567	0.694375	6.266983	3.360397	8.645426	-0.07836
305	23.39134	0.544016	-0.05449	7.455041	0	269.6101	143.3436	371.9325	0.115943
306.01	267.6605	0.933133	0.019593	1.757898	0	17.55213	8.764835	24.21351	0.070571
306.02	393.4758	0.902	0.002659	1.266302	0	11.94162	5.962248	16.47369	0.049696
401.01	225.9729	0.898014	0.014576	1.266064	0	18.85261	12.2404	26.00754	0.032105
401.02	202.7387	0.908324	0.022593	1.513139	0	24.52785	13.21405	33.83665	0.034367
402.01	456.1063	0.935692	0.018518	1.085046	0	12.68421	7.292159	17.49811	0.060868
402.03	91.55543	0.92215	0.019551	2.10256	0	28.07018	20.11896	38.72337	0.087508
402.04	42.91997	0.862192	0.0185	4.01463	0	107.6808	64.39893	148.5478	0.081171
403	10.25646	0.30761	-0.03555	6.910422	0	437.9819	269.3912	604.2047	0.012257
404	26.69988	0.707433	0.010341	4.191856	0.57254	194.6624	127.6036	268.5406	0.091993
405	11.11668	0.288405	-0.01049	0	0	210.6852	137.2712	290.6444	-0.0413
406	6.749411	0.383112	0.020474	0	0	604.6647	392.6268	834.1468	0.003445
407	19.28049	0.555661	-0.00583	1.198374	0	334.7644	220.0671	461.8141	0.027748
408	63.42461	0.816646	0.020654	0.379008	2.671677	55.61429	32.03804	76.721	0.075267
409	65.16987	0.698979	0.060082	2.925191	0.812507	102.7217	64.2168	141.7066	0.105592
410	18.44508	0.59861	0.058206	0	1.621188	179.5613	106.6409	247.7083	-0.01507
411	15.49221	0.387566	-0.00331	0.17926	0	344.8935	172.0219	475.7874	0.01445
413	62.55612	0.765002	0.017769	1.822069	0.4733	74.05785	42.63372	102.1643	-0.01048
414	5.434269	0.314298	0.025782	0	0	417.6515	250.6317	576.1585	0.00515
415	3.8379	0.213075	-0.00516	0	0	342.0557	156.3355	471.8726	-0.01195
416	4.51615	0.244242	-0.01437	0.024939	0	395.1771	189.7634	545.1546	-0.01405
417	2.034749	0.06729	-0.02866	0	0	790.8867	296.8425	1091.044	-0.01582
418	2.456587	0.073583	-0.03838	0	0	823.5686	492.9603	1136.129	-0.06552
419	4.582321	0.092965	-0.03169	0	0	519.1887	304.8673	716.231	0.037291
420	3.705559	0.26738	-0.00337	0.030395	0	1022.322	646.3262	1410.314	-0.01624
421	2.572386	0.112158	-0.03343	0	0	917.5302	541.1319	1265.751	-0.01837
422	2.787441	0.00274	-0.01646	0	0	1349.949	537.7693	1862.282	-0.04387
425	2.679913	0.035487	-0.02697	0	0	679.2006	363.0715	936.9706	-0.10161
426	4.168754	0.071618	-0.02814	0	0	426.1958	280.1796	587.9455	-0.02514
427	125.1122	0.796987	0.067576	0.633506	2.252768	5.231907	2.685588	7.217519	-0.09193
429	164.0951	0.782918	0.114446	0	0.711878	10.01006	5.996524	13.80907	-0.00708

Gathered Environmental Data 2010

Census Tract	Land Area (Sq Mile)	Vegetation cover (%)	Loss of Cover (average Percentage in the last five years)	Habitat fragmentation	Terrestrial Reserves	Waste Production 4.38 lbs per person per day	Vehicles	Population (Per km2)	Population Growth
1	3.110023	0.006589	-0.03361	0	0	105.1199	78.7949	145.015	-0.20129
3	2.853611	0.047702	-0.03988	0	0	523.0385	102.8711	721.5418	-0.06821
6	7.973569	0.135331	-0.01482	0	0	149.7314	45.77057	206.5574	-0.10421
12.01	3.8379	0.1578	-0.04942	0	0	845.0344	69.37054	1165.742	-0.04221
12.02	5.740308	0.17332	-0.02209	0	0	867.2957	116.3247	1196.451	0.033441
13	11.8611	0.187	0.031306	0	0	184.3837	57.3432	254.3609	-0.06144
14	15.18618	0.239968	0.00047	0	0	56.80292	16.44319	78.36075	-0.10237
15.01	2.125734	0.080556	-0.04875	0	0	1352.775	37.51844	1866.179	0.026694
15.02	6.335844	0.419145	-0.00617	0	0	502.3785	54.05436	693.041	0.027342
16	4.896632	0.094741	-0.04268	0	0	507.1799	33.19332	699.6646	-0.03474
17	5.392912	0.122574	-0.04064	0	0	682.0234	52.80258	940.8646	-0.03344
18	7.179521	0.306967	-0.03818	0	0	278.4652	16.82331	384.1482	0.019781
19	1.761795	0.016878	-0.01941	0	0	1005.995	22.99201	1387.789	-0.06097
20	3.258907	0.023664	-0.02555	0	0	835.0153	28.7949	1151.92	-0.08791
23	1.960307	0.012318	-0.03089	0	0	928.1577	15.11411	1280.412	0.020599
24	6.459914	0.482995	-0.03469	0.335927	0	439.4283	25.33153	606.2	0.009459
25	3.490504	0.149119	-0.06355	1.401333	0	461.0382	5.592893	636.0112	0.017559
26	2.29116	0.055869	-0.03556	0	0	946.6255	13.4296	1305.888	-0.00554
27	5.674137	0.292489	-0.03138	0	0	754.128	34.97704	1040.334	-0.01986
28	7.088536	0.235893	-0.00745	0	0	206.7744	13.76704	285.2493	-0.15372
29	9.95869	0.412414	-0.07412	0.673413	0	103.4342	8.550765	142.6895	-0.17276
30	19.35493	0.418638	-0.09399	1.296848	0.615503	121.7954	15.48861	168.0192	-0.03787
31.01	37.40299	0.773941	-0.00226	1.884617	0	143.8811	45.4631	198.4868	0.007577
31.02	107.089	0.850729	0.014367	2.679989	0.237361	40.00504	34.32914	55.18774	0.050067
32.04	3.333349	0.066175	-0.04475	0	0	907.703	27.07604	1252.194	-0.04142
32.05	5.500439	0.287299	-0.03339	0	0	842.6503	39.73369	1162.453	0.049515
32.06	44.12758	0.795087	-0.00326	0.723415	0	112.4273	42.27541	155.0957	0.151271
32.07	8.445035	0.518513	-0.03138	0	0	371.8426	26.61713	512.9641	0.017751
32.08	16.98106	0.3765	-0.00289	0	2.480422	198.6707	18.87903	274.0701	0.013461
33.01	8.982672	0.179513	-0.05132	1.228781	0	670.6062	40.54391	925.1145	0.039466
33.03	13.38302	0.45398	-0.0186	0	0	366.9671	39.78265	506.2384	0.113574
33.04	6.852326	0.394913	0.010686	0	0	552.2104	28.22053	761.7851	0.057965
34.02	77.35355	0.897636	0.007541	1.51782	0	91.7902	55.89378	126.6264	0.117867
34.03	25.42609	0.931612	0.03158	1.986405	0	61.72348	10.57845	85.14876	0.015957
34.04	291.0849	0.960479	0.013803	1.451105	0	12.4316	25.46251	17.14964	0.016409
35.01	202.015	0.9551	0.012641	2.148971	0	32.0112	42.06711	44.16009	0.058722
35.02	138.8923	0.946928	0.014762	2.401586	0	27.83857	24.34188	38.40386	0.035822

35.04	55.93078	0.905427	0.015969	3.753897	0	72.00845	25.26495	99.33707	0.105443
35.05	29.83471	0.80831	0.031599	3.905644	0	148.5753	30.77874	204.9626	0.104464
36	27.08863	0.012118	-0.02061	0	0	23.12059	3.476246	31.8953	-0.05881
37	2.076106	0.094319	-0.04296	0	0	971.0099	13.49785	1339.527	-0.02544
38	4.193568	0.081509	-0.00444	0	0	146.0647	3.984469	201.4991	-0.14055
39	4.904903	0.026981	-0.01043	0.028867	0	426.3709	15.82633	588.187	-0.10904
301	10.64521	0.219631	-0.12115	0	0	414.1563	263.5927	571.3367	-0.00891
302	34.27642	0.506208	-0.08834	2.082812	0.172706	121.1589	72.03202	167.1411	-0.06909
303	55.7819	0.39973	-0.09396	2.673018	1.206411	94.82507	55.17919	130.813	-0.00971
304	227.0565	0.900968	-0.00276	0.875567	0.694375	5.835988	2.831895	8.05086	-0.07836
305	23.39134	0.576514	-0.05449	7.455041	0	245.934	139.7953	339.2708	0.115943
306.01	267.6605	0.940683	0.019593	1.757898	0	18.31857	9.201956	25.27082	0.070571
306.02	393.4758	0.910539	0.002659	1.266302	0	12.47588	6.213851	17.21072	0.049696
401.01	225.9729	0.906905	0.014576	1.266064	0	20.61693	13.09449	28.44146	0.032105
401.02	202.7387	0.915365	0.022593	1.513139	0	26.5194	14.54581	36.58403	0.034367
402.01	456.1063	0.940203	0.018518	1.085046	0	12.43786	7.259272	17.15828	0.060868
402.03	91.55543	0.926669	0.019551	2.10256	0	35.58124	21.44056	49.08502	0.087508
402.04	42.91997	0.881269	0.0185	4.01463	0	112.1452	74.37098	154.7065	0.081171
403	10.25646	0.345789	-0.03555	6.910422	0	471.7653	279.9212	650.8095	0.012257
404	26.69988	0.727715	0.010341	4.191856	0.57254	214.4273	136.7422	295.8066	0.091993
405	11.11668	0.334653	-0.01049	0	0	210.294	137.1813	290.1047	-0.0413
406	6.749411	0.422207	0.020474	0	0	589.6286	396.7754	813.4043	0.003445
407	19.28049	0.579221	-0.00583	1.198374	0	349.8032	229.0917	482.5604	0.027748
408	63.42461	0.837405	0.020654	0.379008	2.671677	68.3578	37.09916	94.30093	0.075267
409	65.16987	0.724491	0.060082	2.925191	0.812507	112.5656	72.99386	155.2865	0.105592
410	18.44508	0.620056	0.058206	0	1.621188	180.8582	109.2974	249.4974	-0.01507
411	15.49221	0.422357	-0.00331	0.17926	0	370.7687	188.4172	511.4827	0.01445
413	62.55612	0.784867	0.017769	1.822069	0.4733	78.9595	44.58396	108.9262	-0.01048
414	5.434269	0.327687	0.025782	0	0	420.4528	244.9272	580.0229	0.00515
415	3.8379	0.204195	-0.00516	0	0	288.2259	154.7721	397.6132	-0.01195
416	4.51615	0.25591	-0.01437	0.024939	0	403.3632	220.5418	556.4474	-0.01405
417	2.034749	0.106157	-0.02866	0	0	781.9803	337.1423	1078.757	-0.01582
418	2.456587	0.081298	-0.03838	0	0	764.8476	423.3516	1055.122	-0.06552
419	4.582321	0.108902	-0.03169	0	0	460.8155	301.5939	635.7041	0.037291
420	3.705559	0.298009	-0.00337	0.030395	0	922.7504	590.4642	1272.952	-0.01624
421	2.572386	0.129072	-0.03343	0	0	942.892	500.3137	1300.738	-0.01837
422	2.787441	0.005266	-0.01646	0	0	1366.853	519.8317	1885.601	-0.04387
425	2.679913	0.052754	-0.02697	0	0	607.7913	335.4586	838.46	-0.10161
426	4.168754	0.094821	-0.02814	0	0	460.1037	311.6039	634.722	-0.02514
427	125.1122	0.8043	0.067576	0.633506	2.252768	6.199491	3.261072	8.55232	-0.09193
429	164.0951	0.782247	0.114446	0	0.711878	9.153061	6.496235	12.62683	-0.00708

Gathered Environmental Data 2011

Census Tract	Land Area (Sq Mile)	Vegetation cover (%)	Loss of Cover (average Percentage in the last five years)	Habitat fragmentation	Terrestrial Reserves	Waste Production 4.38 lbs per person per day	Vehicles	Population (Per km2)	Population Growth
1	3.110023	0.001014	-0.03361	0	0	92.76659	83.81615	127.9733	-0.20129
3	2.853611	0.017505	-0.03988	0	0	447.0849	81.24115	616.7623	-0.06821
6	7.973569	0.125344	-0.01482	0	0	148.1859	47.95932	204.4254	-0.10421
12.01	3.8379	0.067577	-0.04942	0	0	829.9242	58.85401	1144.897	-0.04221
12.02	5.740308	0.138974	-0.02209	0	0	882.9545	111.3118	1218.053	0.033441
13	11.8611	0.166274	0.031306	0	0	179.1278	56.48156	247.1104	-0.06144
14	15.18618	0.23736	0.00047	0	0	65.72909	15.53275	90.67458	-0.10237
15.01	2.125734	0.055556	-0.04875	0	0	1315.264	36.05167	1814.432	0.026694
15.02	6.335844	0.340023	-0.00617	0	0	503.637	59.09463	694.7772	0.027342
16	4.896632	0.060667	-0.04268	0	0	527.1651	37.36964	727.2346	-0.03474
17	5.392912	0.094698	-0.04064	0	0	676.3779	55.9153	933.0766	-0.03344
18	7.179521	0.26578	-0.03818	0	0	287.2493	20.29956	396.266	0.019781
19	1.761795	0.003376	-0.01941	0	0	980.4847	22.58543	1352.598	-0.06097
20	3.258907	0.013266	-0.02555	0	0	701.1103	27.4044	967.1955	-0.08791
23	1.960307	0.008585	-0.03089	0	0	1062.389	18.25449	1465.587	0.020599
24	6.459914	0.437962	-0.03469	0.335927	0	457.0458	25.84653	630.5037	0.009459
25	3.490504	0.092674	-0.06355	1.401333	0	466.4377	6.628042	643.46	0.017559
26	2.29116	0.040376	-0.03556	0	0	1011.485	13.78614	1395.363	-0.00554
27	5.674137	0.249659	-0.03138	0	0	714.0134	33.80399	984.9955	-0.01986
28	7.088536	0.217476	-0.00745	0	0	211.5807	14.95337	291.8797	-0.15372
29	9.95869	0.393204	-0.07412	0.673413	0	93.9715	6.060122	129.6355	-0.17276
30	19.35493	0.390579	-0.09399	1.296848	0.615503	125.9527	17.26535	173.7542	-0.03787
31.01	37.40299	0.739196	-0.00226	1.884617	0	155.9746	49.06278	215.17	0.007577
31.02	107.089	0.8394	0.014367	2.679989	0.237361	41.34531	36.04746	57.03667	0.050067
32.04	3.333349	0.046431	-0.04475	0	0	868.3417	25.11104	1197.894	-0.04142
32.05	5.500439	0.231389	-0.03339	0	0	839.4874	38.62495	1158.089	0.049515
32.06	44.12758	0.783279	-0.00326	0.723415	0	118.7846	42.8537	163.8658	0.151271
32.07	8.445035	0.437414	-0.03138	0	0	430.4687	26.17151	593.84	0.017751
32.08	16.98106	0.303023	-0.00289	0	2.480422	178.9488	17.47033	246.8633	0.013461
33.01	8.982672	0.122082	-0.05132	1.228781	0	685.132	43.00112	945.153	0.039466
33.03	13.38302	0.386819	-0.0186	0	0	359.8715	42.72951	496.4498	0.113574
33.04	6.852326	0.348346	0.010686	0	0	545.6516	28.55955	752.7371	0.057965
34.02	77.35355	0.824257	0.007541	1.51782	0	101.7798	60.95749	140.4073	0.117867
34.03	25.42609	0.913057	0.03158	1.986405	0	61.35286	11.29351	84.63747	0.015957
34.04	291.0849	0.956282	0.013803	1.451105	0	12.52623	27.19859	17.28018	0.016409
35.01	202.015	0.953721	0.012641	2.148971	0	32.80781	41.39412	45.25901	0.058722
35.02	138.8923	0.947893	0.014762	2.401586	0	27.69766	23.93379	38.20946	0.035822

35.04	55.93078	0.895846	0.015969	3.753897	0	71.99549	26.01452	99.31919	0.105443
35.05	29.83471	0.767151	0.031599	3.905644	0	153.3375	30.58038	211.5321	0.104464
36	27.08863	0.007181	-0.02061	0	0	31.73728	4.398953	43.78221	-0.05881
37	2.076106	0.072169	-0.04296	0	0	966.82	11.50397	1333.747	-0.02544
38	4.193568	0.087547	-0.00444	0	0	165.079	4.858612	227.7297	-0.14055
39	4.904903	0.025506	-0.01043	0.028867	0	423.1195	16.0145	583.7017	-0.10904
301	10.64521	0.189182	-0.12115	0	0	396.1791	239.7322	546.5368	-0.00891
302	34.27642	0.48405	-0.08834	2.082812	0.172706	116.9081	70.1065	161.277	-0.06909
303	55.7819	0.405887	-0.09396	2.673018	1.206411	107.9111	53.08174	148.8655	-0.00971
304	227.0565	0.89899	-0.00276	0.875567	0.694375	5.918995	2.928787	8.165369	-0.07836
305	23.39134	0.551063	-0.05449	7.455041	0	257.958	154.7581	355.8582	0.115943
306.01	267.6605	0.937998	0.019593	1.757898	0	17.69567	9.00768	24.41152	0.070571
306.02	393.4758	0.913087	0.002659	1.266302	0	12.82222	6.470538	17.68851	0.049696
401.01	225.9729	0.908604	0.014576	1.266064	0	21.63382	13.5503	29.84428	0.032105
401.02	202.7387	0.921942	0.022593	1.513139	0	26.21548	14.46196	36.16477	0.034367
402.01	456.1063	0.940741	0.018518	1.085046	0	13.14987	7.224192	18.14051	0.060868
402.03	91.55543	0.905657	0.019551	2.10256	0	33.76021	19.73668	46.57288	0.087508
402.04	42.91997	0.875947	0.0185	4.01463	0	124.4744	80.03268	171.7149	0.081171
403	10.25646	0.235843	-0.03555	6.910422	0	492.8975	311.901	679.9618	0.012257
404	26.69988	0.701372	0.010341	4.191856	0.57254	219.7214	133.4838	303.11	0.091993
405	11.11668	0.277918	-0.01049	0	0	213.2283	141.5891	294.1526	-0.0413
406	6.749411	0.401938	0.020474	0	0	568.1485	408.0356	783.7721	0.003445
407	19.28049	0.556697	-0.00583	1.198374	0	359.3153	241.0727	495.6825	0.027748
408	63.42461	0.821727	0.020654	0.379008	2.671677	69.02069	36.51579	95.2154	0.075267
409	65.16987	0.70912	0.060082	2.925191	0.812507	115.7691	74.37487	159.7057	0.105592
410	18.44508	0.594583	0.058206	0	1.621188	185.4563	116.508	255.8406	-0.01507
411	15.49221	0.384014	-0.00331	0.17926	0	355.3746	196.8731	490.2462	0.01445
413	62.55612	0.766518	0.017769	1.822069	0.4733	77.5342	43.72074	106.96	-0.01048
414	5.434269	0.295055	0.025782	0	0	424.9881	251.7358	586.2795	0.00515
415	3.8379	0.194661	-0.00516	0	0	248.5617	164.9339	342.8958	-0.01195
416	4.51615	0.232576	-0.01437	0.024939	0	404.9683	230.0632	558.6617	-0.01405
417	2.034749	0.071656	-0.02866	0	0	818.6746	289.4706	1129.378	-0.01582
418	2.456587	0.069086	-0.03838	0	0	805.2736	417.2455	1110.891	-0.06552
419	4.582321	0.074042	-0.03169	0	0	404.4989	263.8401	558.0142	0.037291
420	3.705559	0.274119	-0.00337	0.030395	0	990.827	602.6081	1366.865	-0.01624
421	2.572386	0.076659	-0.03343	0	0	986.5705	441.2246	1360.993	-0.01837
422	2.787441	0	-0.01646	0	0	1227.983	625.6635	1694.027	-0.04387
425	2.679913	0.039307	-0.02697	0	0	528.5377	316.4282	729.1281	-0.10161
426	4.168754	0.077304	-0.02814	0	0	494.881	319.7598	682.698	-0.02514
427	125.1122	0.795657	0.067576	0.633506	2.252768	5.087059	2.341897	7.017698	-0.09193
429	164.0951	0.77116	0.114446	0	0.711878	10.23093	6.557175	14.11377	-0.00708

Gathered Environmental Data 2012

Census Tract	Land Area (Sq Mile)	Vegetation cover (%)	Loss of Cover (average Percentage in the last five years)	Habitat fragmentation	Terrestrial Reserves	Waste Production 4.38 lbs per person per day	Vehicles	Population (Per km2)	Population Growth
1	3.110023	0.001014	-0.03361	0	0	106.0523	90.76864	146.3012	-0.20129
3	2.853611	0.017068	-0.03988	0	0	519.7361	87.80739	716.9862	-0.06821
6	7.973569	0.124656	-0.01482	0	0	144.9131	47.37994	199.9105	-0.10421
12.01	3.8379	0.066858	-0.04942	0	0	832.3796	62.68112	1148.284	-0.04221
12.02	5.740308	0.140794	-0.02209	0	0	818.5514	104.1138	1129.208	0.033441
13	11.8611	0.172162	0.031306	0	0	178.8222	56.51128	246.6888	-0.06144
14	15.18618	0.237961	0.00047	0	0	74.8462	19.67114	103.2518	-0.10237
15.01	2.125734	0.054444	-0.04875	0	0	1323.107	40.14319	1825.252	0.026694
15.02	6.335844	0.341809	-0.00617	0	0	510.7305	55.85446	704.5628	0.027342
16	4.896632	0.063517	-0.04268	0	0	484.0859	34.69003	667.806	-0.03474
17	5.392912	0.096001	-0.04064	0	0	719.6597	61.45911	992.7846	-0.03344
18	7.179521	0.26578	-0.03818	0	0	296.4372	21.00768	408.9409	0.019781
19	1.761795	0.003376	-0.01941	0	0	941.8084	21.38603	1299.243	-0.06097
20	3.258907	0.013266	-0.02555	0	0	705.559	27.36578	973.3325	-0.08791
23	1.960307	0.014184	-0.03089	0	0	998.0468	17.39802	1376.825	0.020599
24	6.459914	0.437546	-0.03469	0.335927	0	476.6832	24.59122	657.5939	0.009459
25	3.490504	0.101882	-0.06355	1.401333	0	442.7628	7.64774	610.8	0.017559
26	2.29116	0.040376	-0.03556	0	0	1068.118	16.54931	1473.489	-0.00554
27	5.674137	0.24941	-0.03138	0	0	708.7755	30.78552	977.7698	-0.01986
28	7.088536	0.217672	-0.00745	0	0	209.4332	13.90498	288.9172	-0.15372
29	9.95869	0.392484	-0.07412	0.673413	0	87.63879	6.526285	120.8994	-0.17276
30	19.35493	0.38679	-0.09399	1.296848	0.615503	128.874	16.71173	177.7842	-0.03787
31.01	37.40299	0.739214	-0.00226	1.884617	0	151.5946	47.63038	209.1277	0.007577
31.02	107.089	0.838545	0.014367	2.679989	0.237361	47.42391	38.93624	65.42222	0.050067
32.04	3.333349	0.047082	-0.04475	0	0	763.5231	21.30159	1053.295	-0.04142
32.05	5.500439	0.230477	-0.03339	0	0	877.4422	41.92705	1210.449	0.049515
32.06	44.12758	0.782977	-0.00326	0.723415	0	132.4356	44.3958	182.6975	0.151271
32.07	8.445035	0.437068	-0.03138	0	0	419.1383	24.7985	578.2095	0.017751
32.08	16.98106	0.302453	-0.00289	0	2.480422	175.7472	15.53185	242.4467	0.013461
33.01	8.982672	0.127288	-0.05132	1.228781	0	700.2226	46.85074	965.9709	0.039466
33.03	13.38302	0.388019	-0.0186	0	0	366.0463	43.37268	504.9681	0.113574
33.04	6.852326	0.353509	0.010686	0	0	512.7517	29.23759	707.351	0.057965
34.02	77.35355	0.824509	0.007541	1.51782	0	101.4706	61.24133	139.9807	0.117867
34.03	25.42609	0.910153	0.03158	1.986405	0	62.49324	11.80428	86.21066	0.015957
34.04	291.0849	0.957792	0.013803	1.451105	0	13.08904	28.88929	18.05659	0.016409
35.01	202.015	0.954081	0.012641	2.148971	0	32.63557	40.12538	45.02141	0.058722
35.02	138.8923	0.948215	0.014762	2.401586	0	28.5014	26.61394	39.31824	0.035822

35.04	55.93078	0.900331	0.015969	3.753897	0	76.37613	26.73102	105.3624	0.105443
35.05	29.83471	0.900331	0.031599	3.905644	0	166.3849	32.45378	229.5313	0.104464
36	27.08863	0.00763	-0.02061	0	0	32.75416	4.94614	45.18501	-0.05881
37	2.076106	0.073598	-0.04296	0	0	965.4233	10.35566	1331.82	-0.02544
38	4.193568	0.087547	-0.00444	0	0	155.5718	4.502856	214.6144	-0.14055
39	4.904903	0.024874	-0.01043	0.028867	0	437.0116	14.51902	602.8662	-0.10904
301	10.64521	0.1906	-0.12115	0	0	370.9157	237.3837	511.6855	-0.00891
302	34.27642	0.48085	-0.08834	2.082812	0.172706	116.4852	68.852	160.6936	-0.06909
303	55.7819	0.4067	-0.09396	2.673018	1.206411	113.525	58.26263	156.6099	-0.00971
304	227.0565	0.8927	-0.00276	0.875567	0.694375	6.199939	17.33049	8.552938	-0.07836
305	23.39134	0.543762	-0.05449	7.455041	0	265.9844	345.8117	366.9306	0.115943
306.01	267.6605	0.9433	0.019593	1.757898	0	19.43165	24.44515	26.80635	0.070571
306.02	393.4758	0.912635	0.002659	1.266302	0	12.20138	15.95778	16.83204	0.049696
401.01	225.9729	0.904759	0.014576	1.266064	0	21.41569	13.55915	29.54336	0.032105
401.02	202.7387	0.914937	0.022593	1.513139	0	25.69703	15.05879	35.44956	0.034367
402.01	456.1063	0.940694	0.018518	1.085046	0	13.30244	7.215422	18.35098	0.060868
402.03	91.55543	0.904889	0.019551	2.10256	0	33.09514	19.69299	45.6554	0.087508
402.04	42.91997	0.875136	0.0185	4.01463	0	126.9572	81.50053	175.1399	0.081171
403	10.25646	0.239387	-0.03555	6.910422	0	492.2614	314.046	679.0843	0.012257
404	26.69988	0.702493	0.010341	4.191856	0.57254	230.2555	135.0943	317.6419	0.091993
405	11.11668	0.280298	-0.01049	0	0	226.2046	143.2083	312.0537	-0.0413
406	6.749411	0.402594	0.020474	0	0	625.93	421.5183	863.4827	0.003445
407	19.28049	0.556873	-0.00583	1.198374	0	329.0496	212.5465	453.9304	0.027748
408	63.42461	0.824	0.020654	0.379008	2.671677	70.40362	40.64668	97.12318	0.075267
409	65.16987	0.713509	0.060082	2.925191	0.812507	124.2337	74.94261	171.3829	0.105592
410	18.44508	0.60191	0.058206	0	1.621188	202.8268	123.827	279.8036	-0.01507
411	15.49221	0.385867	-0.00331	0.17926	0	337.3134	172.2801	465.3305	0.01445
413	62.55612	0.765399	0.017769	1.822069	0.4733	74.16214	39.00497	102.3081	-0.01048
414	5.434269	0.289824	0.025782	0	0	437.9272	269.4015	604.1291	0.00515
415	3.8379	0.192061	-0.00516	0	0	252.3393	166.7578	348.107	-0.01195
416	4.51615	0.239896	-0.01437	0.024939	0	457.6157	270.1416	631.2899	-0.01405
417	2.034749	0.071921	-0.02866	0	0	861.0689	282.5901	1187.862	-0.01582
418	2.456587	0.070133	-0.03838	0	0	752.7494	409.5112	1038.433	-0.06552
419	4.582321	0.076491	-0.03169	0	0	388.0469	254.8927	535.3183	0.037291
420	3.705559	0.274426	-0.00337	0.030395	0	1010.389	535.9515	1393.852	-0.01624
421	2.572386	0.078619	-0.03343	0	0	948.8097	428.0073	1308.902	-0.01837
422	2.787441	0	-0.01646	0	0	1133.843	532.7468	1564.159	-0.04387
425	2.679913	0.041376	-0.02697	0	0	550.4474	382.1019	759.3529	-0.10161
426	4.168754	0.083206	-0.02814	0	0	489.6644	316.4015	675.5016	-0.02514
427	125.1122	0.798295	0.067576	0.633506	2.252768	5.388343	3.428921	7.433325	-0.09193
429	164.0951	0.772636	0.114446	0	0.711878	10.34579	6.788748	14.27222	-0.00708

Part II – Data Output

A- Residential Recovery
Hancock County

Time Step	Actual Budget	Uniform Budget	Social Only	Economic Only	Environmental Only	3 vulnerabilities
Pre-Katrina	1	1	1	1	1	1
2007-6	0.784794	0.784159	0.789955	0.788882	0.786354	0.787437
	0.803723	0.801847	0.807443	0.869446	0.80546	0.804314
2007-12	0.832345	0.818461	0.843389	0.945825	0.842338	0.840378
	0.832345	0.818461	0.843389	0.945825	0.842338	0.840378
2008-6	0.846614	0.829209	0.890738	0.981955	0.892042	0.88512
	0.852868	0.835305	0.935605	0.995836	0.931262	0.929639
2008-12	0.854577	0.838799	0.971674	1.000606	0.950456	0.966681
	0.854577	0.838799	0.971674	1.000606	0.950456	0.966681
2009-6	0.8551	0.841513	0.996314	1.003455	0.958621	0.992453
	0.855337	0.843218	1.010902	1.005251	0.961975	1.007864
2009-12	0.855368	0.844158	1.018415	1.006342	0.963679	1.016324
	0.855368	0.844158	1.018415	1.006342	0.963679	1.016324
2010-6	0.855368	0.84474	1.022415	1.006883	0.964486	1.020826
	0.855368	0.845123	1.024448	1.007174	0.964904	1.023228
2010-12	0.855368	0.845346	1.0255	1.007245	0.965118	1.024551
	0.855368	0.845346	1.0255	1.007245	0.965118	1.024551
2011-6	0.855368	0.845443	1.025991	1.007255	0.965214	1.025261
	0.855368	0.845502	1.026225	1.007255	0.965251	1.025603
2011-12	0.855368	0.845545	1.026328	1.007255	0.965256	1.025748
	0.855368	0.845545	1.026328	1.007255	0.965256	1.025748
2012-6	0.855368	0.845593	1.026372	1.007255	0.965257	1.025805
	0.855368	0.845623	1.026385	1.007255	0.965257	1.025829
2012-12	0.855368	0.845642	1.026387	1.007255	0.965257	1.02584

Harrison County

Time Step	Actual Budget	Uniform Budget	Social Only	Economic Only	Environmental Only	3 vulnerabilities
Pre-Katrina	1	1	1	1	1	1
2007-6	0.774514	0.774614	0.774179	0.775735	0.773841	0.774173
	0.795771	0.791673	0.791912	0.785755	0.792515	0.793054
2007-12	0.829076	0.804195	0.826773	0.851896	0.828152	0.82866
	0.829076	0.804195	0.826773	0.851896	0.828152	0.82866
2008-6	0.848814	0.810582	0.873018	0.905351	0.876309	0.873025
	0.857172	0.81374	0.918685	0.928166	0.912289	0.917555
2008-12	0.859847	0.815292	0.957541	0.937233	0.926701	0.955971
	0.859847	0.815292	0.957541	0.937233	0.926701	0.955971
2009-6	0.860072	0.816501	0.985922	0.940695	0.932195	0.984533
	0.860227	0.817374	1.003736	0.942574	0.93425	1.002101
2009-12	0.860333	0.817959	1.013347	0.943404	0.935446	1.011717
	0.860333	0.817959	1.013347	0.943404	0.935446	1.011717
2010-6	0.860377	0.818311	1.018018	0.94387	0.936099	1.016844
	0.860394	0.818501	1.02042	0.944223	0.93646	1.019682
2010-12	0.860394	0.818562	1.021666	0.944378	0.93663	1.02132
	0.860394	0.818562	1.021666	0.944378	0.93663	1.02132
2011-6	0.860394	0.818593	1.022296	0.944404	0.936692	1.022179
	0.860394	0.81862	1.022544	0.944407	0.936705	1.022589
2011-12	0.860394	0.818642	1.022653	0.944407	0.936705	1.022777
	0.860394	0.818642	1.022653	0.944407	0.936705	1.022777
2012-6	0.860394	0.818654	1.0227	0.944407	0.936705	1.022856
	0.860394	0.81866	1.022712	0.944407	0.936705	1.022888
2012-12	0.860394	0.818664	1.022717	0.944407	0.936705	1.0229

Jackson County

Time Step	Actual Budget	Uniform Budget	Social Only	Economic Only	Environmental Only	3 vulnerabilities
Pre-Katrina	1	1	1	1	1	1
2007-6	0.850152	0.852621	0.851399	0.853458	0.851765	0.851617
	0.860652	0.865331	0.864651	0.88787	0.866721	0.86537
2007-12	0.875569	0.876719	0.893358	0.932815	0.894956	0.892795
	0.875569	0.876719	0.893358	0.932815	0.894956	0.892795
2008-6	0.884139	0.88381	0.924398	0.961922	0.926178	0.922341
	0.887757	0.888337	0.949083	0.973123	0.947578	0.947545
2008-12	0.888826	0.891109	0.969011	0.977647	0.957312	0.967538
	0.888826	0.891109	0.969011	0.977647	0.957312	0.967538
2009-6	0.889108	0.89323	0.984072	0.980597	0.961617	0.98319
	0.88922	0.894537	0.994996	0.982371	0.964004	0.994735
2009-12	0.889223	0.895289	1.002106	0.983187	0.965366	1.002305
	0.889223	0.895289	1.002106	0.983187	0.965366	1.002305
2010-6	0.889223	0.895706	1.006077	0.98349	0.965922	1.006866
	0.889223	0.895963	1.008178	0.983663	0.966141	1.009411
2010-12	0.889223	0.896075	1.009142	0.983702	0.966225	1.010726
	0.889223	0.896075	1.009142	0.983702	0.966225	1.010726
2011-6	0.889223	0.89614	1.009599	0.983703	0.966242	1.011372
	0.889223	0.896184	1.009794	0.983703	0.966244	1.01167
2011-12	0.889223	0.896216	1.009882	0.983703	0.966244	1.011805
	0.889223	0.896216	1.009882	0.983703	0.966244	1.011805
2012-6	0.889223	0.896245	1.009919	0.983703	0.966244	1.011867
	0.889223	0.896274	1.009933	0.983703	0.966244	1.011895
2012-12	0.889223	0.896295	1.009938	0.983703	0.966244	1.011909

B- Economic Financial Recovery
Hancock County

Time Step	Actual Budget	Uniform Budget	Social Only	Economic Only	Environmental Only	3 vulnerabilities
Pre-Katrina	1	1	1	1	1	1
2007-6	0.672807	0.765631	0.823408	0.765631	0.810667	0.755068
	0.732754	0.792309	0.766283	0.748072	0.779799	0.757866
2007-12	0.794278	0.82394	0.809243	0.810043	0.880027	0.848291
	0.829399	0.897218	0.806573	0.812163	0.877009	0.835886
2008-6	0.879653	0.910605	0.825985	0.868538	0.947211	0.866394
	0.892985	0.910471	0.802666	0.859099	0.928835	0.858314
2008-12	0.892985	0.912496	0.8117	0.87138	0.928657	0.87808
	0.894098	0.917169	0.805523	0.874235	0.935655	0.892058
2009-6	0.894098	0.919273	0.858956	0.903866	0.947169	0.892579
	0.901463	0.919266	0.858419	0.90698	0.943774	0.899629
2009-12	0.901463	0.919263	0.858382	0.914094	0.943846	0.909532
	0.9029	0.919263	0.858453	0.912218	0.943196	0.909294
2010-6	0.9029	0.919263	0.858434	0.919014	0.943502	0.918928
	0.9029	0.919263	0.858438	0.916298	0.943405	0.919051
2010-12	0.9029	0.919263	0.858383	0.921473	0.943399	0.919001
	0.9029	0.919263	0.858383	0.920419	0.94439	0.919059
2011-6	0.9029	0.919263	0.858383	0.923138	0.944412	0.91907
	0.9029	0.926633	0.858383	0.922956	0.944403	0.91908
2011-12	0.9029	0.926633	0.858383	0.925941	0.944403	0.91908
	0.9029	0.926633	0.858383	0.924124	0.944402	0.91908
2012-6	0.9029	0.926633	0.858383	0.924495	0.944403	0.91908
	0.9029	0.926633	0.858383	0.924013	0.944403	0.91908
2012-12	0.9029	0.926633	0.858383	0.925004	0.944403	0.91908

Harrison County

Time Step	Actual Budget	Uniform Budget	Social Only	Economic Only	Environmental Only	3 vulnerabilities
Pre-Katrina	1	1	1	1	1	1
2007-6	0.892561	0.941893	0.950719	0.941893	0.942306	0.942557
	0.919653	0.946894	0.942776	0.937018	0.932889	0.935358
2007-12	0.934874	0.965322	0.969645	0.978196	0.962954	0.980871
	0.950746	0.981504	0.966434	0.968228	0.964711	0.965859
2008-6	0.959205	0.990284	0.978457	0.98558	0.984945	0.978962
	0.962236	0.993608	0.979137	0.980852	0.986004	0.974821
2008-12	0.96492	0.996224	0.984875	0.985696	0.989872	0.980542
	0.966785	0.998766	0.982514	0.98407	0.990838	0.979946
2009-6	0.968168	1.000439	0.983187	0.989456	0.995218	0.981989
	0.969387	1.001412	0.982955	0.989597	0.99405	0.982177
2009-12	0.970236	1.002357	0.98236	0.992951	0.997147	0.982856
	0.970779	1.002852	0.982616	0.993668	0.996191	0.983071
2010-6	0.971207	1.003301	0.982712	0.995983	0.996078	0.983441
	0.971579	1.003451	0.983146	0.996387	0.996443	0.983784
2010-12	0.971687	1.003554	0.983149	0.99887	0.997141	0.983854
	0.971764	1.00371	0.98315	0.998533	0.997	0.983891
2011-6	0.97192	1.003781	0.983153	1.000591	0.996763	0.984031
	0.971988	1.003868	0.983153	1.000106	0.996665	0.984196
2011-12	0.972086	1.004012	0.983153	0.999871	0.996997	0.984281
	0.972129	1.004052	0.983154	0.99945	0.99697	0.984322
2012-6	0.972131	1.004075	0.983154	0.999277	0.997096	0.984354
	0.972153	1.004114	0.983155	0.99892	0.997167	0.984395
2012-12	0.972166	1.004122	0.983155	0.998723	0.997168	0.984405

Jackson County

Time Step	Actual Budget	Uniform Budget	Social Only	Economic Only	Environmental Only	3 vulnerabilities
Pre-Katrina	1	1	1	1	1	1
2007-6	0.94089	1.023332	1.025741	1.023332	1.017947	1.023322
	0.959436	0.993528	0.975981	0.975187	0.971006	0.973962
2007-12	0.971633	1.005952	1.004186	1.019874	0.999098	1.036903
	0.981496	1.015134	0.99717	0.998635	0.992741	0.994866
2008-6	0.987147	1.02146	1.017719	1.017283	1.029376	1.009377
	0.987963	1.022105	1.005028	1.004201	1.013909	1.000186
2008-12	0.988477	1.022501	1.011231	1.01534	1.016039	1.006412
	0.989264	1.02314	1.003059	1.007439	1.015366	1.001035
2009-6	0.989598	1.02346	1.004183	1.01244	1.017014	1.000599
	0.989968	1.02394	1.002441	1.010546	1.013067	0.999986
2009-12	0.990075	1.024204	1.003621	1.013643	1.013287	1.000285
	0.990238	1.024217	1.00296	1.013803	1.013311	1.000194
2010-6	0.990452	1.024266	1.003006	1.01667	1.014119	1.000437
	0.99049	1.024573	1.002964	1.016125	1.013639	1.000468
2010-12	0.990519	1.024571	1.002948	1.01938	1.014559	1.000442
	0.990605	1.024594	1.00295	1.018937	1.014181	1.000472
2011-6	0.990649	1.024601	1.00295	1.021887	1.014632	1.000483
	0.990665	1.024602	1.00295	1.021256	1.014586	1.000574
2011-12	0.990665	1.024611	1.00295	1.022126	1.014553	1.000579
	0.990665	1.024611	1.00295	1.021959	1.014545	1.000588
2012-6	0.990665	1.024611	1.00295	1.021844	1.01453	1.00074
	0.990684	1.024611	1.00295	1.021502	1.014532	1.000792
2012-12	0.990692	1.024628	1.00295	1.020893	1.014505	1.000792

C- State Disaster Recovery Coordinator Budget
Social Vulnerability Dimension

	Public Home Assistance	Homeowner Assistance	Elevation Grant	Small Business Loan
Initial	0.25	0.25	0.25	0.25
2007-6	0.248835	0.262489	0.253955	0.234721
	0.252759	0.289727	0.24007	0.217444
2007-12	0.248411	0.320033	0.229322	0.202234
	0.244771	0.345397	0.220328	0.189504
2008-6	0.239427	0.36698	0.21462	0.178973
	0.23697	0.37559	0.215876	0.171564
2008-12	0.239069	0.373671	0.220854	0.166406
	0.256948	0.352216	0.228454	0.162382
2009-6	0.271079	0.328431	0.242421	0.158069
	0.282477	0.305483	0.258075	0.153965
2009-12	0.288239	0.285045	0.271759	0.154957
	0.288239	0.285045	0.271759	0.154957
2010-6	0.337199	0.245351	0.256823	0.160627
	0.357223	0.229204	0.241639	0.171934
2010-12	0.364492	0.223882	0.228772	0.182855
	0.357504	0.211807	0.217127	0.213561
2011-6	0.333342	0.203646	0.211695	0.251317
	0.322387	0.195955	0.212845	0.268813
2011-12	0.299601	0.193553	0.210388	0.296458
	0.282427	0.186645	0.211285	0.319643
2012-6	0.265739	0.180293	0.216066	0.337903
	0.249275	0.189968	0.207555	0.353203
2012-12	0.24067	0.192615	0.213409	0.353306

Economic Vulnerability Dimension

	Public Home Assistance	Homeowner Assistance	Elevation Grant	Small Business Loan
Initial	0.25	0.25	0.25	0.25
2007-6	0.295679	0.313492	0.206536	0.184293
	0.282993	0.306983	0.229201	0.180823
2007-12	0.244108	0.307069	0.24347	0.205353
	0.27036	0.31426	0.223085	0.192294
2008-6	0.261513	0.309968	0.223032	0.205486
	0.26112	0.307699	0.225589	0.205592
2008-12	0.283957	0.295665	0.2436	0.176779
	0.260036	0.35736	0.221409	0.161194
2009-6	0.230082	0.337965	0.279812	0.152141
	0.25937	0.245478	0.324788	0.170363
2009-12	0.235635	0.22792	0.369316	0.167129
	0.241179	0.208797	0.401492	0.148532
2010-6	0.244939	0.224756	0.345272	0.185033
	0.246567	0.193384	0.406644	0.153405
2010-12	0.235474	0.200423	0.35232	0.211784
	0.242335	0.187657	0.376999	0.193009
2011-6	0.234484	0.179189	0.367665	0.218662
	0.244541	0.175974	0.371479	0.208007
2011-12	0.242875	0.178446	0.359708	0.218971
	0.24824	0.166856	0.384136	0.200768
2012-6	0.252118	0.167573	0.37207	0.208239
	0.254078	0.169587	0.36451	0.211825
2012-12	0.242403	0.18386	0.306213	0.267524

Environmental Vulnerability Dimension

	Public Home Assistance	Homeowner Assistance	Elevation Grant	Small Business Loan
Initial	0.25	0.25	0.25	0.25
2007-6	0.217938	0.289187	0.246438	0.246438
	0.254713	0.377533	0.201015	0.166739
2007-12	0.259008	0.387851	0.19571	0.157431
	0.24338	0.463612	0.166351	0.126657
2008-6	0.25763	0.399156	0.191135	0.152079
	0.25943	0.391013	0.194266	0.155291
2008-12	0.259694	0.38982	0.194725	0.155761
	0.330987	0.35585	0.177889	0.135274
2009-6	0.38248	0.214393	0.249785	0.153342
	0.405045	0.233565	0.219735	0.141654
2009-12	0.257851	0.174497	0.353743	0.21391
	0.375209	0.157879	0.270017	0.196894
2010-6	0.276163	0.166128	0.311845	0.245864
	0.282626	0.169191	0.295297	0.252885
2010-12	0.25448	0.178456	0.280291	0.286774
	0.23531	0.166389	0.288038	0.310263
2011-6	0.23531	0.166389	0.288038	0.310263
	0.23531	0.166389	0.288038	0.310263
2011-12	0.23531	0.166389	0.288038	0.310263
	0.23531	0.166389	0.288038	0.310263
2012-6	0.23531	0.166389	0.288038	0.310263
	0.23531	0.166389	0.288038	0.310263
2012-12	0.23531	0.166389	0.288038	0.310263

Three Vulnerability Dimensions

	Public Home Assistance	Homeowner Assistance	Elevation Grant	Small Business Loan
Initial	0.25	0.25	0.25	0.25
2007-6	0.259689	0.256291	0.253596	0.230424
	0.255188	0.308626	0.230989	0.205197
2007-12	0.235467	0.29906	0.250181	0.215292
	0.244107	0.372727	0.220413	0.162752
2008-6	0.239463	0.31811	0.231738	0.210689
	0.251966	0.321721	0.223948	0.202365
2008-12	0.231819	0.321733	0.233163	0.213284
	0.19598	0.360088	0.295769	0.148163
2009-6	0.202358	0.315038	0.314309	0.168294
	0.206661	0.278954	0.353633	0.160752
2009-12	0.213964	0.226074	0.391932	0.16803
	0.247016	0.212533	0.346941	0.19351
2010-6	0.235098	0.203514	0.396657	0.16473
	0.241547	0.204896	0.368458	0.185099
2010-12	0.247328	0.204995	0.357666	0.19001
	0.233633	0.179997	0.373513	0.212856
2011-6	0.238761	0.20935	0.349528	0.202361
	0.241445	0.201052	0.323917	0.233586
2011-12	0.238785	0.211652	0.361389	0.188175
	0.238117	0.20361	0.350318	0.207954
2012-6	0.225284	0.210139	0.272541	0.292036
	0.208601	0.189663	0.331206	0.27053
2012-12	0.21959	0.217572	0.281394	0.281444

VITA

Mohamed S. Eid was born in Egypt in 1985. He earned his BS and MS degrees in Construction Engineering and Management in 2008 and 2012, respectively, from The Arab Academy for Science and Technology (AAST), Cairo, Egypt. Eid worked as a part time and full time engineer at Trading and Contracting Group, Egypt from 2003 to 2012. Eid also worked as a Graduate Research Assistant at AAST (2008-2013), Mississippi State University (2013-2014), and The University of Tennessee, Knoxville (2014-2017).

To this date, Eid has fourteen peer-reviewed journal and conference publications and gave twelve conference presentation and invited talks.