Holistic Sustainable Disaster Recovery Framework: Multi-Agent Based Modeling Approach

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1- Introduction

Problem Statement

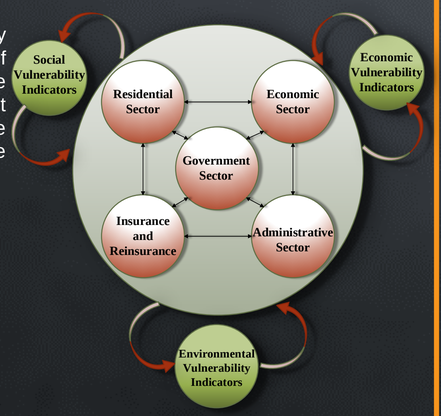
Our built environment is vulnerable to the increasing rate and magnitude of hazardous events that severely damage the existing infrastructure, and disrupt the welfare of the host communities. As such, a decision support tool is required to enable the societies highlight the post disaster recovery strategies that capitalize the redevelopment opportunities in order to achieve the recovery short-term objectives and long-term resiliency and sustainability goals.

Sustainable Disaster Recovery

Pre-event planning and post-event Participation of stakeholders to reshape and restore the social, economic, and natural environment (Smith and Wenger 2007).

2- Research Hypothesis

The integration of the vulnerability indicators into the objective functions of the stakeholders will result in a more effective decision making processes that meet the individuals' needs, decrease the built environment vulnerability and increase the overall community welfare.



3- Research Objectives

- ***Measure*** social, economic, and environmental *vulnerability* of the host communities.
- ***Capture*** community relationships using the interdependency between the *vulnerability indicators* and the *objective functions* of the stakeholders.

4- Methodology and Model Development

(i) Measure the Host Community Vulnerability

The proposed research utilizes well-established vulnerability indicators on the community specific data. This is carried out on the three vulnerability dimensions; *Social, Environmental, and Economic.*

- Social Vulnerability Index (Cutter et al. 2003).
  - Social Equity
  - Economic Standard
  - Adaptive Capacity
  - Occupation
- Environmental Vulnerability Index (SOPAC).
  - Exposure to Hazard
  - Internal and External Stressors
  - Human Systems
- Economic Vulnerability Index (Burton 2010).
  - Microeconomics
  - Mesoeconomics

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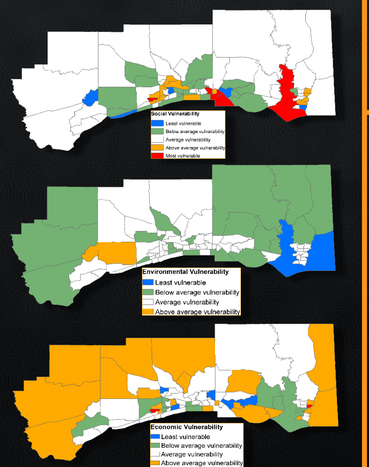


Pre-Katrina Vulnerability Assessment

(ii) Capture the Associated Stockholders Interactions

Agent Based Modeling

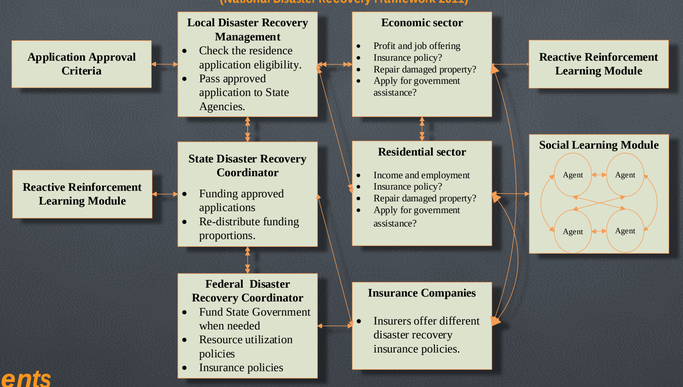
A computational approach to simulate systems as collections of autonomous, interdependent, and interacting agents.

Game Theory

The study of mathematical models of conflicts and cooperation between intelligent rational decision makers.

Associated Stakeholders

(National Disaster Recovery Framework 2011)



Residents

Objective: $Z_i = H_i + I_i - T_i - P_{i(n,m)} + C_{i(n.m)} - R_i$

i: Resident index
Z_i: Objective function
H_i: Household value
I_i: Monthly income
T_i: Monthly distributed tax amount
$P_{i(n,m)}$: Premium cost
n: Insurer index
m: Insurance Policy index
$C_{i(n,m)}$: Insurance compensation value,
$R_i$is the self-paid repair costs.

State Disaster Recovery Coordinator

Objective:

Max $\sum_i^I \Delta Z_{i_k}$ $\forall\, k = 1,2,\dots,K$
Max $\sum_e^E \Delta FR_{e_k}$ $\forall\, k = 1,2,\dots,K$
Min $\sum_i^I SoVI_{i_k}$ $\forall\, k = 1,2,\dots,K$
Min $\sum_i^I EVI_{i_k}$ $\forall\, k = 1,2,\dots,K$
Min $\sum_i^I EconVI_{i_k}$ $\forall\, k = 1,2,\dots,K$

SoVI, EVI, and EconVI: Social, Environmental, and Economic Vulnerability Indices, Respectively.
K: development plan index
FR: Economic financial recovery
e: Economic agent index

Agents' Learning Modules

- Individual

  Roth Erev Reinforced learning

  A game theory model based on observations of actual player.

  Decision action's propensity:

  $q_j(t+1) = q_j(t) \times (1-\phi) + E_j(k) \times (1-\varepsilon)$

  Decision action's probability:

  $pr_j(t) = q_j(t) / \sum_{j=1}^{J} q_j(t)$

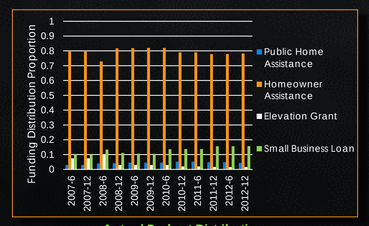
- Social

  Particle Swarm

  Inspired by the migration of flock of birds, each particle represents a solution. Particles do not evolve through creating new particles, but rather change their social behavior and consequently move to a better state.

5- Problem Domain - Post Katrina Recovery

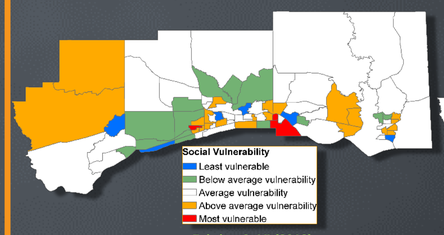
The proposed model is developed on the post-Katrina recovery for three Mississippi coastal counties, namely; Hancock, Harrison and Jackson. The model outcome is compared to the existing conditions as well as two simulation scenarios; actual and uniform budget distribution.



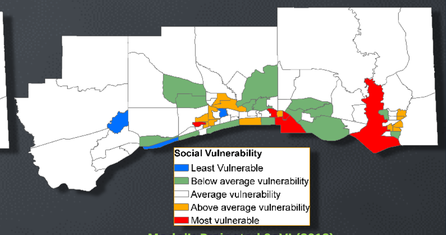
Actual Budget Distribution

6- Recovery and Vulnerability Results

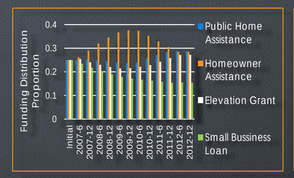
Social Dimension



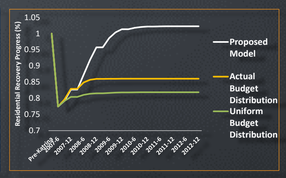
Existing SoVI (2012)



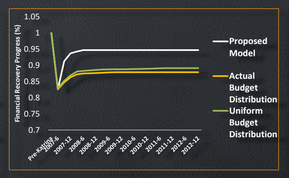
Model's Projected SoVI (2012)



Proposed Budget Distribution – Social

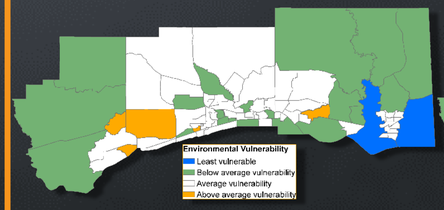


Residential Recovery - Social

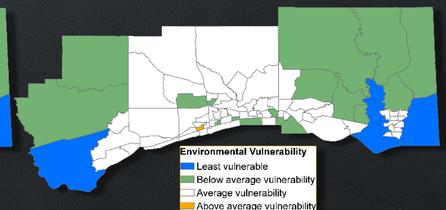


Economic Financial Recovery - Social

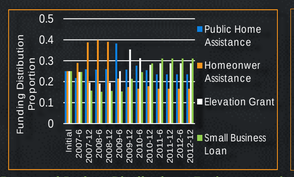
Environmental Dimension



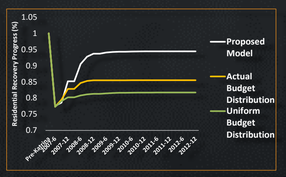
Existing EVI (2012)



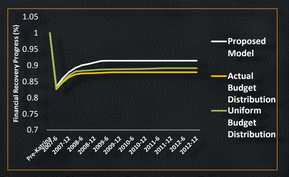
Model's Projected EVI (2012)



Proposed Budget Distribution – Environmental

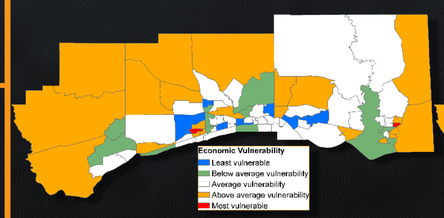


Residential Recovery – Environmental

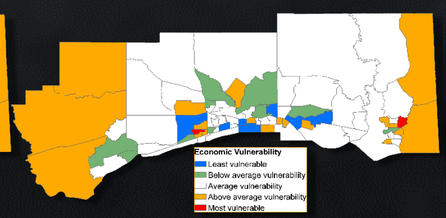


Economic Financial Recovery – Environmental

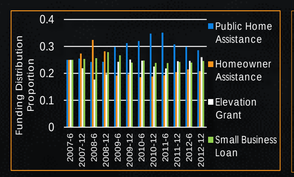
Economic Dimension



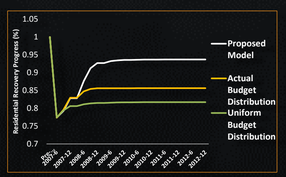
Existing EconVI (2012)



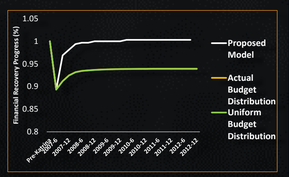
Model's Projected EconVI (2012)



Proposed Budget Distribution – Economic



Residential Recovery – Economic



Economic Financial Recovery – Economic