Sea Bright, NJ reconstructed for Hurricane Sandy

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1. Purpose

The model was developed for future evaluate of flood mitigation policies for coastal flood situations. The current instantiation was implemented to evaluate the quality of the agents' decision model, calibrate model parameters and validate performance against survey response data from historical events. The simulation is based upon flood responses to Hurricane Sandy in Sea Bright, NJ and implements an integrated Protective Action Decision Model (PADM) and Protection Motivation Theory (PAM) decision making process.

2. Entities, state variables, and scales

The model is comprised of property lots, housing units and property owners within the Borough of Sea Bright, NJ. It is structured on a continuous latitude/longitude grid from 40.3604N to 40.39435N and 72.0237W to 73.9773W with 1032 residential properties and homeowners, and 1018 dwellings initially.

Lots consist of locations, elevations, acreage, property values, purchase dates and prices, location benefit level, and the owner's location status. Residences consist of construction year, number of stories, construction type, housing style, value, square footage and flood proofing height. Owners are instilled with gender, ethnicity, age, income, and mortgage status.

3. Process overview and scheduling

The model process consists of establishing the initial laydown of homes and property owners from input files, then implementing flood events per an inputted schedule. For each flood, the flooded houses and flood depths are determined. These are converted into damage levels based upon the number of floors. Owner risk levels and expected future flood heights are calculated based upon owner demographics and previous flood experience. Repair, mitigation, rebuilding and relocation costs and benefits are determined as is the affordability of each option. See Figure 1 for a flow chart of owner decisions. The best value, affordable option is selected by the owner and implemented. The model uses an annual time step with historic floods of Hurricanes Irene (2011) and Sandy (2012).

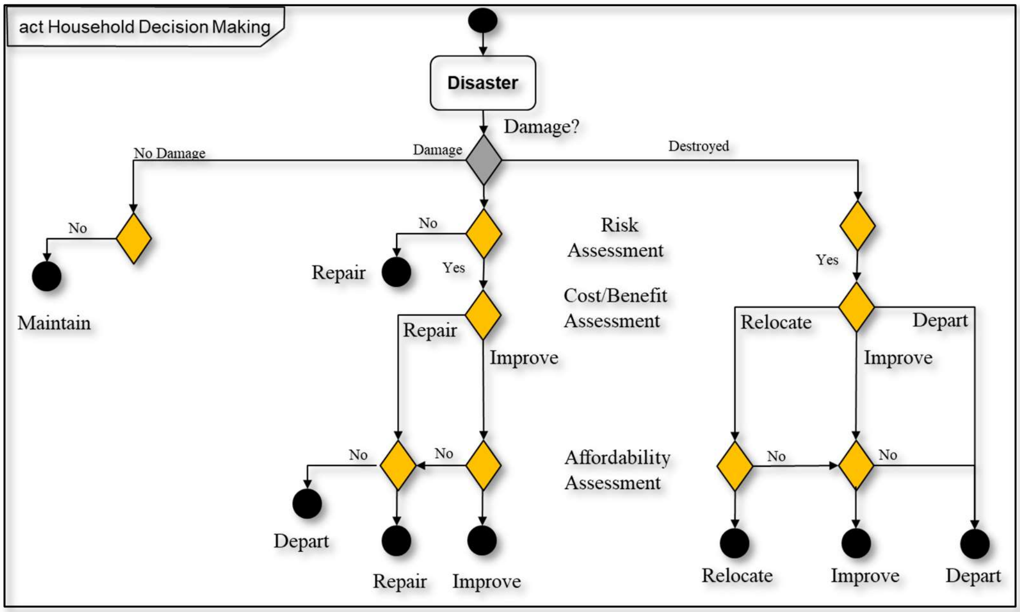

Figure 1: Homeowner Decision Model.

4. Design Concepts
   a. Basic Principles
      The model implements a flood response model based upon Protective Action Decision Model and Protection Motivation Theory. Lindell and Hwang's (2008) socio-economic risk perception factors of ethnicity, gender, income and flood experience are utilized to determine the perceived risk level, while Bubeck's et al. (2012) process is implemented. See figure 2 for an overview of the decision-making model.

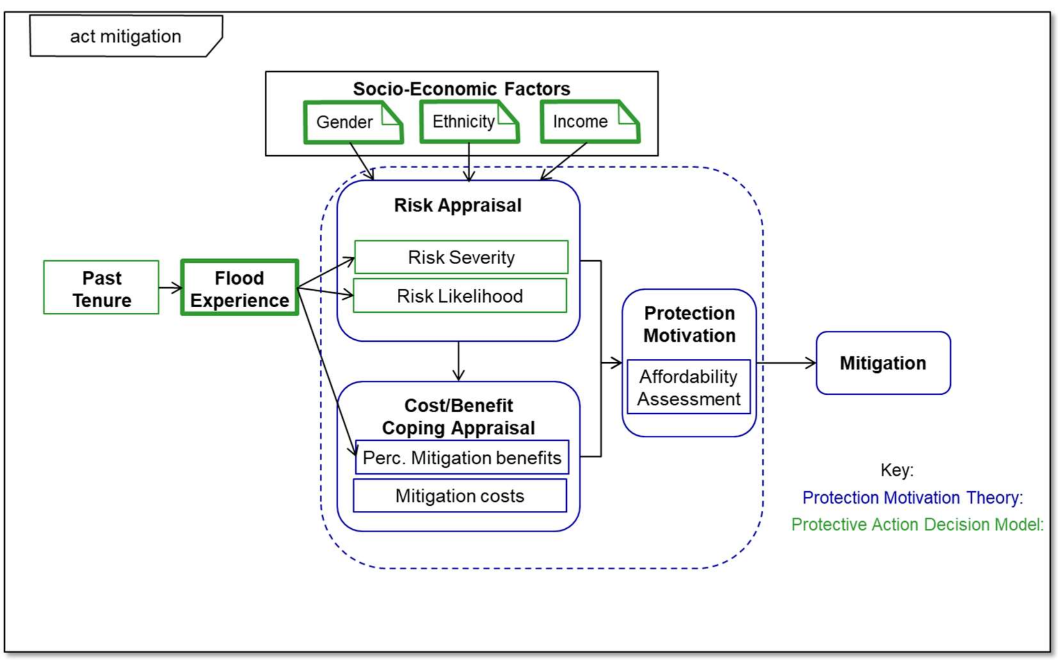

Figure 2: The risk mitigation decision making model.

b. Emergence

Population trends are derived from the individual housing unit flood level, homeowner risk assessments, and value decisions. Due to the high number of townhouses and duplexes, low risk mitigation thresholds were required for single family homes to attain the historical levels of flood-proofing (McNeil et al. 2017), regardless of homeowner socio-economic factors.

Although each of the homeowners made individual decisions on whether to mitigate against future storm damage or only repair to the pre-Sandy protection level, community trends emerged based upon housing types. 63.6% of the damaged households were townhouses or duplexes which precluded elevation, while 77% of the single-family homes were elevated. This outcome has potential ramifications in developing effective flood prevention policies, since townhouse flood mitigation must be built in during initial construction or be part of a larger community-wide mitigation project.

c. Adaption

Owners adapt to flood event by increasing the percentage of income they allot to housing and depending upon their decisions, they may relocate or improve their home's flood-proofing based upon perceived best value.

d. Objectives

The owners' overall objective is to minimize the cost of coastal flooding over time. This includes flood-proofing costs, relocation costs and any damage from unmitigated flooding.

e. Learning

Owners' risk level is based upon previous flood experience in addition to socio-economic factors. Risk levels are elevated if flooding has been experienced within the previous seven years.

f. Prediction

Owners' expected future flood height is based upon previous flood experience. The maximum height of the current and previous flood (within seven years) is taken as the expected future flood height. The expected number of future flooding events (i.e. 1.25) as determined during model calibration and was adjusted to replicate the percentage of houses which were floodproofed in post-storm survey responses.

g. Sensing

Owners sense the flood height and damage to their homes. In addition, they have awareness of their monetary situation, repair-rebuilding-floodproofing costs, property values and location benefit of waterfront/waterview lots.

h. Interaction

Owner interaction is limited to vacant lot construction. Based upon survey results post-Sandy, residents of Sea Bright did not generally consider the opinions of their neighbors in their relocation decisions (McNeil et al. 2015).

i. Stochasticity
30 stochastically generated property owner populations were developed as individual inputs to the model with varied ages, ethnicities, genders and incomes based upon US Census Bureau (American Community Survey 2007-2011) and survey response data (McNeil et al. 2017) demographics. Additionally, the percentage of each owner's income allotted to housing and the increase in the housing allotment post-Sandy were uniform randomly generated for each owner. See Table 1~~Table 1~~ for the associated stochastic variables, their distribution and source.

Table 1, Stochastic Variables with ranges or community averages.

Variable	Range	Reference
Lot Elevation	2 to 12 - 0.5 + U(0,1)	Google Earth/Landsat/Copernicus
Owner Ethnicity	White (92.6±0.6%)	2007-2011 ACS B01001x Tract 8121
Owner Gender	Female (22.5±1.0%)	2007-2011 ACS B11001x Tract 8121
Owner Age	19-99	2007-2011 ACS B25128 Tract 8121
Owner Income	5,000 to 200,000	2007-2011 ACS B25118 Tract 8121
Mortgage Status	Mortgage (61.1±1.4%)	2007-2011 ACS B25100 Tract 8121
Percentage of Income for Housing	15 – 40%	2007-2011 ACS B25091 Tract 8121
Post-Sandy Housing Increase	\$0 - \$2,000 5 – 10%	Author Estimate
Sea Level Rise	0	Not implemented for Validation

j. Collectives
Collectives were not established in this model; however, the results of homeowner decisions were collectively recorded by reconstruction decision (see paragraph k) in summary statistics. Future extensions of the model will include community level flood mitigations (e.g., sea walls, berms, etc.) which will require collective risk assessments and advocacy by the majority of homeowners to implement.

k. Observation
Two levels of statistics (summary and detailed) were output from the model. Summary statistics: undamaged homes, repaired, mitigated, destroyed/rebuilt, destroyed/moved, damaged/moved, dry and wet lots were recorded for each flood. Additionally, individual parameters were recorded for each flood, and each lot and owner. The flood height at each lot, the flood height above flood proofing for each building and the damage level was output. The repair cost, repair value, repair affordability, mitigation cost, mitigation benefit, mitigation value, mitigation affordability, relocation value, relocation cost and relocation affordability for each owner's damaged or destroyed

property. Average and standard deviation for each factor was calculated across the 30 replications and subsets evaluated as necessary.

5. Initialization

The model was initialized with property record derived lot and structural data (Monmouth County 2019). Elevations were randomized ±0.5 ft. to simulate a continuous distribution rather than the integer level available from Google Earth (2019) data. The homeowner population was statistically distributed for each replication to reflect U.S. Census Bureau, American Community Survey 2007-2011 demographics anchored to property value and owner name (2019). See Table 1~~Table 1~~ for a breakdown of demographic statistics for Sea Bright, NJ, and Table 3~~Table 3~~ for the initialization factors, their range and source of information.

Table 2, Sea Bright Demographics.

Factor	Value	Reference
Household Race: White	81.1%	US Census Bureau
Hispanic	8.9%	Monmouth County Property Records
Asian	3.1%	Monmouth County Property Records
Black	–2.2%	Monmouth County Property Records
Multi-racial	4.7%	Monmouth County Property Records
Year Built	1904-2012	Monmouth County Property Records
Number of Floors	1 - 3	Google Street View
1^{st} Floor Height	0.5 – 21.5	Monmouth County Property Records
Building Construction	Frame, others	Monmouth County Property Records
Building Type	Townhouse, others	Monmouth County Property Records
Square Footage	312-25,282	Monmouth County Property Records
Building Value	$2,900-1,658,300	Monmouth County Property Records
Location Premium	1.04 or 1.15 (Waterfront)	Zillow Rental Price Monmouth County Property Records

Table 3, Initialization Factors and range of values.

Factor	Value	Reference
Lot Location	40.3460 to 40.3944 N 73.9725 to 73.9773W	Monmouth County Property Records
Lot Value	$35,000-$2,025,900	Monmouth County Property Records
Lot Acreage	0.0098 – 1.5	Monmouth County Property Records
Lot Purchase Year	1958 - 2012	Monmouth County Property Records
Lot Owner Occupied	58%	Monmouth County Property Records
Year Built	1904-2012	Monmouth County Property Records
Number of Floors	1 - 3	Google Street View
1^{st} Floor Height	0.5 – 21.5	Monmouth County Property Records
Building Construction	Frame, others	Monmouth County Property Records
Building Type	Townhouse, others	Monmouth County Property Records

Square Footage	312-25,282	Monmouth County Property Records
Building Value	$2,900-1,658,300	Monmouth County Property Records
Location Premium	1.04 or 1.15 (Waterfront)	Zillow Rental Price Monmouth County Property Records
Sandy Flood Gauge Location	40.3460 to 40.3943 N 73.9726 to 73.9774W	FEMA MOTF Impact Analysis
Depth Damage Functions	3 to 53%	FEMA HAZUS-MH 2.2
Maximum Percentage Housing Shift	20%	Author Estimate
Masonry Building Elevation overhead	$57/sqft	Aerts 2017
Framed Building Elevation overhead	$26/sqft	Aerts 2017
Elevation cost	$1.5/sqft/ft elevated	Aerts 2017
Demolition cost	15%	Fixer.com
New Housing Elevation Cost	1.15%/ft elevated	Aerts 2017
Mortgage Interest Rate	5%	Freddie Mac
Construction Cost	$192.8/sqft	Monmouth County Property Records

6. Input Data

Flood levels were input into the model for Hurricane Irene (2011) based upon maximum storm surge levels for Sandy Point, NJ (Avila & Cangialosi 2011). Flood levels for Hurricane Sandy (2012) were referenced to FEMA damage assessments (FEMA 2015) with inundation measurements and the closest data point to each home was used. Table 4~~Table 3~~ provide the range of storm surge heights in Sea Bright for Hurricanes Irene and Sandy.

Table 4~~3~~, Range of Storm Surge Heights for Hurricanes Irene and Sandy

Input	Value	Reference
Hurricane Irene (2011) Storm Surge Height	3.35-7.86 ft	Avila & Cangialosi 2011
Hurricane Sandy (2012) Storm Surge Height	5.71-13.81 ft	FEMA MOTF Impact Analysis 2015

Model calibration was conducted to produce comparable results to post-Sandy resident survey responses for the percentage of undamaged, destroyed and floodproofed houses (McNeil et al. 2017). Socio-economic risk factors were also weighted to obtain correlation with homeowner risk perception equal to Lindell and Hwang (2008) determined levels. Table 5~~Table 4~~ values were identified for calibrating the model.

Table 5~~4~~, Calibrated Values for Flood and Perceived Risk.

Input	Value	Calibration Factor	Reference
Floodproof Height Bias	- 3 ft	Not extensive damage	McNeil et al. 2013
Damage scaling	40%	Destroyed Houses	McNeil et al. 2013

Risk Mitigation Threshold	- 0.175	Flood-proofed Houses	McNeil et al. 2013
Expected number of future hurricanes	1.25	Flood-proofed Houses	McNeil et al. 2013
Female risk weighting	0.14	Risk Perception correlation	Lindell & Hwang 2008
Experience risk weighting	0.21	Risk Perception correlation	Lindell & Hwang 2008
Income risk weighting	-0.21	Risk Perception correlation	Lindell & Hwang 2008
White risk weighting	-0.14	Risk Perception correlation	Lindell & Hwang 2008

7. Sub-models

The model implemented several sub-models in converting flood levels to reconstruction decisions. Damage levels, homeowner risk appraisals, and reconstruction decisions are described below.

a. Damage levels

Building flood levels in excess of their flood-proofed height were arithmetically determined based upon lot elevation, flood-proofing height and the nearest flood elevation datapoint. Flood damage was calculated from FEMA HAZUS©-MH (2003) depth damage functions based upon the building's number of floors (or split-level building type). Damage levels in excess of 50% constituted destruction of the residence, in accordance with FEMA statutory requirements (CFR 2002).

b. Owner Risk Assessment

Risk assessments were constructed as the combination of expected flood likelihood and expected flood consequence. Flood likelihood utilized the following formula with weighting factors tuned to replicate Lindell and Hwang (2008) correlation factors across the compilation of all homeowners from all 30 replications.

$$\theta = 0.14 * g - 0.14 * e + 0.21 * h - 0.21 * i + U(0,1)$$

where θ is the perceived risk level, gender *g* is 1 if female, ethnicity *e* is 1 if white, history *h* is 1 if the flood severity was greater than 0 (all 0 otherwise), and *i* is income/$200,000.

Flood consequence was projected as the maximum flood height experienced within the previous 7 years, given repeated flooding in the community. With two hurricanes on sequential years and the severity of the second, Hurricane Sandy inundation levels were taken as the expected future risk consequence.

The threshold for initiating flood mitigations was determined based upon sensitivity analysis to replicate post-Sandy survey levels of flood-proofing. A θ in excess of -0.1 triggered cost benefit analysis for mitigation options.

c. Reconstruction Decision

Selection of post-Sandy reconstruction options was based upon value and affordability analysis. The value of repairing, repairing and elevating, rebuilding with elevation, relocating with elevation and departing was calculated based upon the following equation:

$$V_{j,k} = \alpha_j * P_j + S_j + C_{j,k|E(f)} * F + I_c - B_{j,k} - D_{c|d} - P_{j|r} - M_c$$

where $V_{j,k}$ is the value of option k for lot j, α is the perceived location premium of lot j, P is the assessed property value of lot j, S is the structural value on lot j, $C_{j,k|E(f)}$ is the cost avoidance of option k on lot j given the expected future flood consequence, F is the expected number of future floods, I_c is the insurance payout of the current dwelling, B_j is the construction costs of option k for lot j, $D_{c|d}$is the demolition cost of the current residence if destroyed, $P_{j|r}$ is the purchase cost of lot j given relocation, and M_c is the current house's mortgage balance.

Annual affordability was also developed for each option per:

$$A_j = S * p + \left(\left(P_c + S_c + I_c - M_c - D_{c|d}\right) - \left(P_j + S_j\right)\right) * MR/30$$

where A_j is the annual affordability for lot j, subscript c denotes current housing, S is the household annual income, *p* is the percentage of income for housing, and MR is the mortgage ratio of total cost to initial outlay.

The highest valued option with a positive affordability was selected for each homeowner and appropriate updates to the homeowner location, building floodproofing and condition were completed.

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