Proposal for the City of Houston

"Tools for household-level risk assessment and evaluation of evacuation policies under hurricane hazards"

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1 RESEARCH MOTIVATION

The Houston metropolitan area is home to over 5.5 million inhabitants; it is the sixth-largest in the United States. When Hurricane Rita bore down on Houston, 2.5 million Houston area residents were evacuated, making it the largest evacuation in the history of the United States. Critics of the evacuation process believe that authorities waited far too long (NPR, 2005) to permit outward-bound cars to use both sides of the Interstate highways. It is estimated (Stein, 2007), that residents who decided to leave Houston (and that did not need to evacuate) had a significant impact in the mobility of populations at true risk. Indeed, if a mere 15% of Harris county residents inside the loop had sheltered in place in their homes, the transportation system could have absorbed evacuees from the more vulnerable Galveston area. Instead, thousands of residents clogged major freeways and witnessed gasoline shortages, and difficult recovery. The need for good planning and information integration tools which can help regional authorities develop sound evacuation and sheltering policies has never been more critical.

Our goal is to develop tools ***at the household level*** for risk assessment and evaluation of evacuation policies under hurricane hazards for the City of Houston and its surrounding communities. The tools integrate engineering analyses of existing infrastructure at the level of individual households, and empirically gathered sociological data on human behaviors in response to threats and advisories, to drive detailed computational simulations of sheltering and evacuation plans at the level of individual streets. In contrast to coarse-grained models and tools used by FEMA and the FHWA (HAZUS, OREMS, ETIS) into which it is difficult to fold in detailed structural and behavioral information we already possess, our tools will provide emergency planning and management authorities with information and tools to study the impact of decisions at a much finer granularity. Examples are the evacuation of specific streets or neighborhoods, choice of evacuation or sheltering destinations at the level of zip codes, and the opening of contra-flow lanes at the level of specific exits on specific streets. Since the information and simulations

we generate will be directly comprehensible to the general public, emergency planners can use our tools and simulations to easily communicate the impact/value of their policies to the public. We envisage using weather stations to relay regional advisories to residents on individual streets showing them the status of the relevant roadways and providing a set of dynamically updated alternate routes with predictions on clearance times on each of them. Risk assessment data on households can also be made available to the public (through HCAD, e.g.,) to guide decision making at the level of individual households. By empowering people with reliable information on the hurricane-worthiness of their properties, we have the potential to significantly reduce pressure on evacuation routes.

In this proposal, we integrate three distinct kinds of information and analysis at a new, more useful level of granularity, for our city. The first is estimation of household risk level based on detailed engineering considerations. The second is careful characterization of likely behavior at the level of households (possibly aggregated by zip codes), in response to the threat of hurricane and the issuing of specific evacuation/sheltering guidelines. The third is the construction of scenario-driven, agent-based computational simulations of response to hurricane threats, taking detailed information on risks to structures and human behaviors into account. Our ultimate objective is to have reliable simulation-tested policies and plans in place to respond to hurricanes, so as to limit loss and displacement of human life.

2 RESEARCH GOALS AND OBJECTIVES

Goal 1: Estimation of household risk level. A new level of risk assessment refinement will be pursued in this goal. Risk information at the household level will equip family heads with the tools to either retrofit their property before disaster, or to assess whether or not evacuation is a necessary option. The objectives to achieve this goal include:

- Extensive data mining of the Harris County Appraisal District (HCAD) database.
- Field surveys for HCAD calibration and geospatial demographic characterization.
- Characterization of plausible hazard scenarios including storm surge and rainfall
- Estimation of household-level structural vulnerability to direct and induced damage.
- Assignment of safety tags to individual residential units and assess evacuation needs.
- Estimation of regional functionality and restoration times.

Goal 2: Behavioral characterization. Behavior addresses human response to emergency situations. Modeling of human behavior is one of the weakest components of transportation modeling tools like OREMS, DYNASMART-P and ETIS used now by FEMA and the FHWA (FHWA, 2007). Most of them adopt loading curves for the transportation network, which have little basis in actual human behavior. This limits the accuracy and utility of their predictions. Detailed information of the type gathered by sociological surveys, for example, (1) households with physically disabled are less likely to evacuate (Dow, 2002) ; (2) households living in rentals are more likely to evacuate with more than one car per household (Stein, 2007), cannot be added to such models. We plan to gather detailed behavioral information to incorporate into models of the type considered in Goal 3. The objectives to achieve this goal include analyzing existing survey data on Houston gathered by Professor Stein, as well as the design and administration of new surveys to:

- Determine demographics (age, gender , socio-economic status, household composition, transportation and sheltering choices) at the street /zip code level.
- Estimate exposure to risk and perception of risk at the level at individual households.
- Estimate likelihood of specific actions (sheltering in place, evacuation with multiple cars, etc.) per household to manage risk.
- Estimate likelihood of compliance to specific evacuation guidelines and policies.

Goal 3: Agent-based modeling tools for look-ahead scenarios and policy evaluation. Agent-based modeling is a powerful simulation technique that has been used in several real-world application problems. One of the most prominent ones is the simulation of traffic in Portland, Oregon with the TRANSIMS model (transims.tsasa.lanl.gov) developed at the Los Alamos National Laboratories. There are a few agent-based evacuation models in use including ARENA (Rockwell) and OREMS (Farahmand, 1997), which we shall evaluate for our purposes. The objectives to achieve this goal include:

- Accurate and detailed modeling of the transportation network in the greater Houston Metro area. Roadway details to be gathered include segment lengths, number of lanes, widths, signals, exits and entrance ramps, location of refueling stations and rest areas, probability of road availability under high wind and water conditions.
- Generating realistic traffic originations and destinations at the household level based on data gathered from Goals 1 and 2.
- Evaluating the suitability of existing tools for implementing an agent-based dynamical simulation of the transportation network in response to the generated traffic configurations and specific evacuation and sheltering policies.
- Route planning for evacuation and in-town sheltering.
- Running and evaluating scenarios under various threat levels.
- Designing visualizations of dynamic simulations for communication with the public.

3 RESEARCH APPROACH

The research activities of this proposal will mainly focus on *household-level risk assessment* for functional evacuation plans and effective intra-city sheltering strategies. The two other projects will be pursued at exploratory levels. These projects include initial characterization of human behavior according to their demographic signature, and a small scale development of agent-based models to predict the outcome of evacuation strategies as a function of likely household decisions. Figure 1 illustrates the conceptual representation of the proposed risk and evacuation support tools.

Project 1: Estimation of flood and wind risk at the household level. Will evacuation decision making at the household level change with added accuracy in hurricane risk and loss estimation? Evidence from the implementation plans to evacuate the city of Houston in response to Hurricane Rita suggests an affirmative answer. Current modeling tools to predict the impact of hurricane hazards in coastal cities are too coarse to reach household and street levels. Census tracts are the smallest aggregation levels in modern loss estimation tools such as HAZUZ-MH (Schneider and Schauer 2006; FEMA 2007), but their size is still too large to help individuals make decisions about evacuation. Census tracts are small, relatively permanent statistical subdivisions of a county, which usually have between 2,500 and 8,000 persons and are designed to be homogeneous with respect to population characteristics, economic status, and living conditions. This project will

bring a more detailed level of resolution in the risk assessment of residential housing—which comprises the majority of the built environment. Street and household level assessments of structural integrity under hurricane hazards will better inform the public about their choices in the event of hurricane-induced evacuation. This information could be used to justify *not* evacuating, and allowing the transportation network to cope with mandatory evacuation plans from counties east of Houston. Also, public officials will be able to explore novel evacuation and sheltering plans including reallocation *within* the city. In addition, evacuation routes can be established at the street level increasing the effectiveness of counter-flow measures.

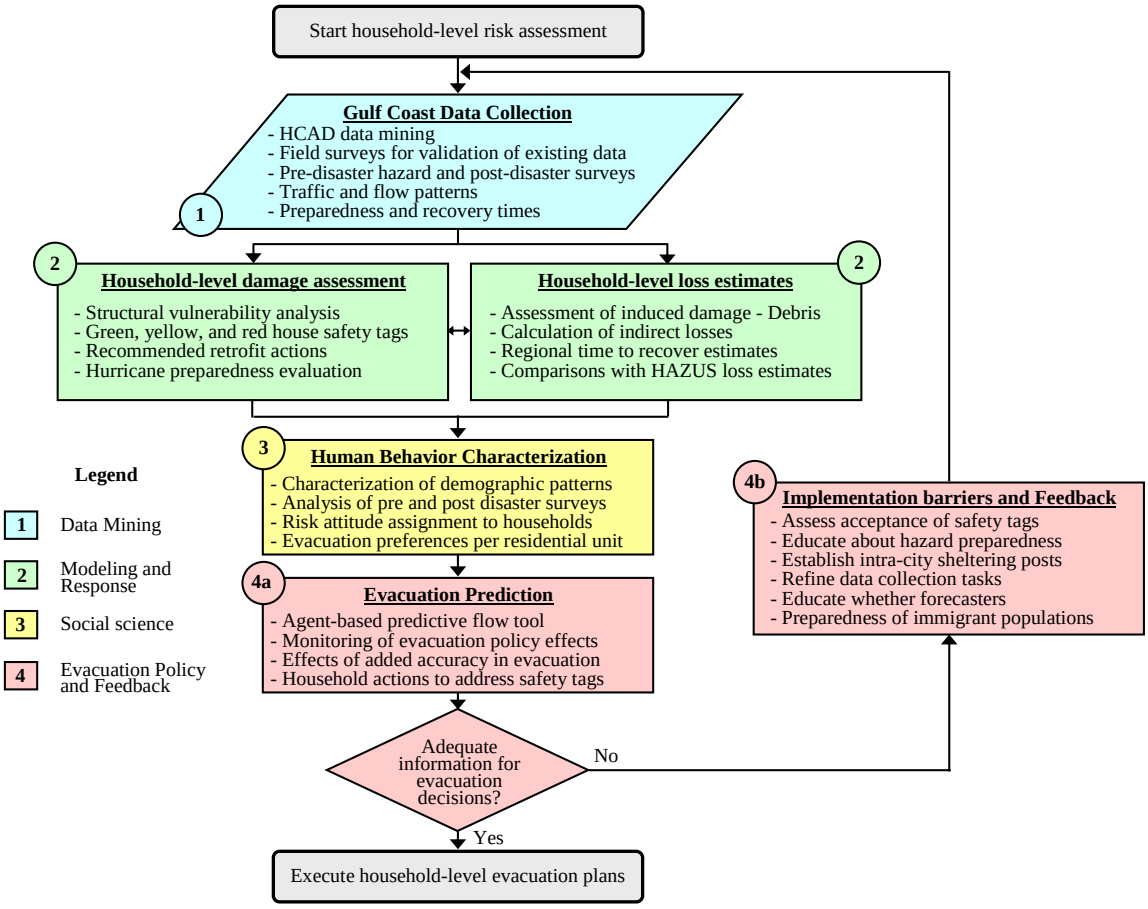

Figure 1. Framework for household risk assessment and evacuation support tools.

The risk assessment process at the household level will be initially tested and implemented in Harris County. The use of tax records, such as the Harris County Appraisal District (HCAD) database can provide initial information to assess the risk of individual households to flooding and wind-induced damage. Additional information will be collected in the field by engineering students at Rice University. Field data will include structural, nonstructural, geotechnical and debris potential characterization of selected neighborhoods. This data will help calibrating the final assessment of residential unit vulnerability (Jain and Davidson 2007). The results can be synthesized into simple informative evaluation levels for different hurricane scenarios: green for safe structures, yellow for structures with restricted use if a hurricane strikes, and red for unsafe structures. In addition, monetary estimates of direct damage, induced damage, and indirect losses

(correlated with time to recover functionality) will be calculated using a HAZUS aggregating approach (Scawthorn et al. 2006b). Figure 2 illustrates the concept of household level risk assessment versus aggregated evacuation strategies. The work of this project will provide households with unprecedented means to decide a course of action after their property is evaluated. They can retrofit (Steward 2003)), design contingency plans to stay, or adhere to city plans to evacuate in case of emergency.

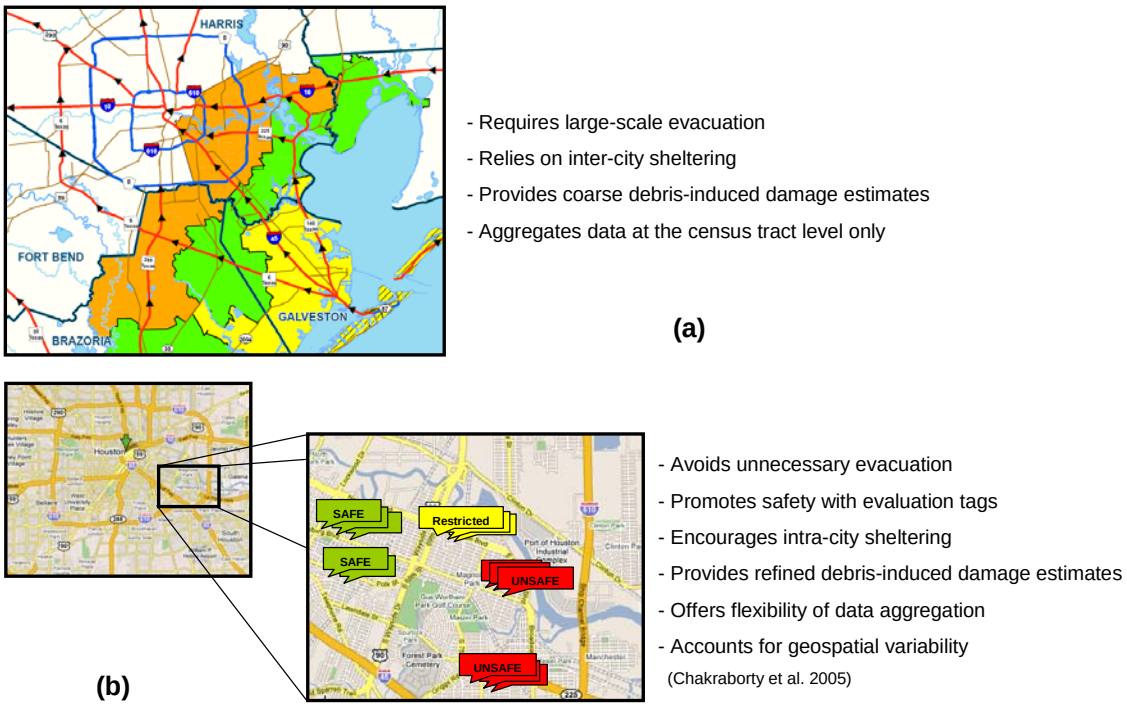

Figure 2. Risk assessment strategies: (a) census tract level damage estimation enabling zip code evacuation, and (b) household-level risk assessment enabling informed implementation of mitigation actions and individual evacuation decisions.

Project 2: Behavioral characterization of individual households.

In the context of this proposal, we will focus on analyzing existing survey results gathered by Professor Stein on the Rita evacuation to

- Determine demographics (age, gender , socio-economic status, household composition, transportation and sheltering choices) at the street /zip code level.
- Estimate likelihood of specific actions (sheltering in place, evacuation with multiple cars, etc.) per household to manage risk.
- Estimate likelihood of compliance to specific evacuation guidelines and policies.

We will seek external funding to administer new surveys to gather even more detailed behavioral information at the household level.

Project 3: Agent-based modeling tools for "what-if" policy evaluation and decision making. In the context of this proposal, we will produce a feasibility report that identifies the informational and computational resources we need to build urban-scale evacuation models at the household level for Houston. Our focus will be on

- Evaluating information sources from local and state authorities to build an accurate and detailed model of the transportation network for the greater Houston Metro area.
- Building a traffic generation prototype that constructs realistic traffic originations and destinations at the household level ,based on data gathered from Project 2.
- Evaluating the suitability of existing tools for implementing an agent-based dynamical simulation of the transportation network in response to the generated traffic configurations and specific evacuation and sheltering policies.
- Evaluating tools for visualizations of dynamic simulations for communication with the public.

The ground work proposed here will help us seek external funding to produce a full-fledged model for use by our city in the next two to three years.

4 RESEARCH PLAN

To execute the proposed tasks in Project 1, the P.I. and Co-P.I.'s will work with six undergraduate research assistants during one year as displayed in Figure 2. The results from this project are expected to be used in the 2008 hurricane season. Faculty members will also initiate exploratory work to establish the scope of Projects 2 and 3, as outlined above.

Task No.	Research Task Description	Personnel*	Time (months)	Year 1											
				M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
1	Statistical data mining tools for HCAD	DS, LD URA_{DS}, URA_{LD}	3												
2	Field sampling of Harris County for data validation	URA_{DS}, URA_{LD}, URA_{RS}	6												
3	Wheather forecasting and hazard scenarios	RS, URA_{RS}, URA_{DS}, URA_{LD}	6												
4	Household-level structural fragility characterization	All	6												
5	Residential unit informative tagging	All	9												
6	Restoration crew dispatching and scheduling of resources	All	4												
7	Human behavior characterization	RS, URA_{RS}, URA_{DS}, URA_{LD}	6												
8	Agent based modeling exploration	DS, LD URA_{DS}, URA_{LD}	8												
9	Participation on one major energy conference with papers and presentations.	All	1												
10	Submission of three research manuscripts on smart urban evacuation for peer-reviewed journal publication	All	3												
11	Final report, recommendations for future research, and joint pre-proposals for federal funding	All	1												

* DS: Devika Subramanian, LD: Leonardo Duenas-Osorio, RS: Robert Stein, and URA: Undergraduate Research Assistant.

Figure 2. Scheduling and planning of proposed research tasks.

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