A FRAMEWORK TO INTEGRATE SOCIAL VULNERABILITY INTO CATASTROPHIC NATURAL DISASTER PREPAREDNESS PLANNING

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Abstract

Social vulnerability is typically not fully understood due to complex relationships between the components that contribute to it. The Social Vulnerability Index (Cutter et al., 2003) is an important tool that combines the contributions of known social factors to vulnerability into one relative index. In preparedness planning projects for large scale natural disasters it is typically necessary to consider contributions of multiple individual social vulnerability factors as some of those may better relate to the selection among available preparedness actions. In this research-in-progress paper we discuss social vulnerability and its use by disaster planners. We provide a conceptual framework to show how social factors along with vulnerability principals and vulnerability criteria may influence the selection of preparedness actions. We argue that vulnerability criteria selected may be used as an indicator of preparedness actions and discuss a methodology to statistically test the relationship.

Introduction

Why is vulnerability to natural disasters increasing?

The world has faced an increase in the frequency and magnitude of disasters which devastated the impacted regions and communities. Disasters manifest pre-existing conditions within the

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social, economic, physical, and environmental fabrics of a society (Villagran de Leon, 2006). Social factors are related to issues of social equity, social class, gender, education, literacy, race and ethnicity, traditional values, and beliefs. Physical factors encompass susceptibilities of location and the built environment. Economic factors are related to issues of poverty, economic reserves, levels of debt, and economic diversity. Finally, environmental factors include natural resource depletion, degradation and climate change (See Figure 1).

As demonstrated in Figure 1, all these factors contribute to people's vulnerability to hazards. City expansion, uncontrolled, unplanned growth due to migration to urban areas, densification of vulnerable areas in particular geographic regions, trends in land occupancy, lack of building codes, population growth, use of inappropriate technology, increases in poverty levels, resource and power differences, lack of education, lack of planning regulations, employment of inadequate organizational systems and pressure on natural resources have increased the vulnerability of populations (Cardona, 2003; Villagran de Leon, 2006; Comfort et al., 1999; NAS, 2006; Mileti, 1999).

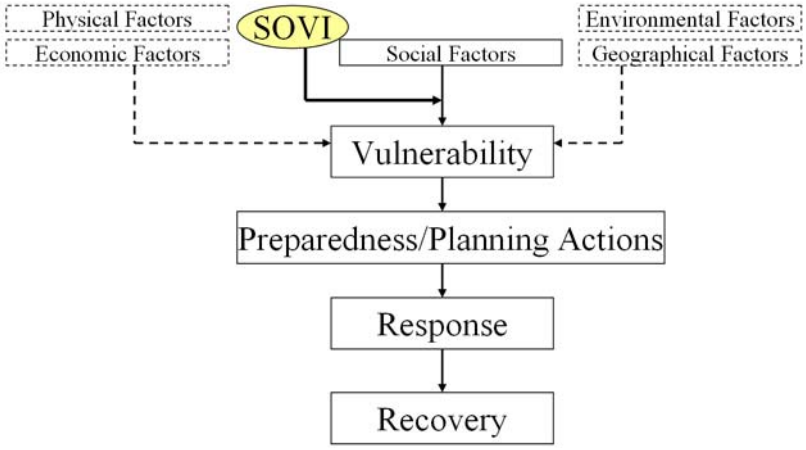

Figure 1. Relationship between Vulnerability Factors and Phases of Emergency Management

Emergency management begins with the identification of hazard risks and vulnerabilities. Environmental, political, social and economic forces that influence the frequency, nature and location of disasters are within the scope of emergency management (Buckle, 1998). As our understanding of those social, physical, economic and environmental forces improves, so does our chance of developing more robust strategies for preparedness/planning, response and recovery. Therefore, a comprehensive vulnerability assessment is a critical component of an effective emergency management framework.

This study is primarily motivated by our work and observations in a large scale disaster preparedness project with the Federal Emergency Management Agency (FEMA) currently conducted by the University of Illinois Mid American Earthquake Center, the George Washington University Institute for Crisis Disaster and Risk Management and Virginia Tech Center for Technology, Security, and Policy. The objective of the project is to facilitate the planning and preparation for potential large scale earthquake disasters within the New Madrid Seismic Zone (NMSZ). NMSZ is located in the central United States and is an active fault line which has generated large earthquakes in the past. Our work in this project consisted of providing the state and regional planners (1) a set of analytical data products to help them better understand and compare social vulnerability at different levels of aggregation (i.e. state versus region) for the states within the NMSZ, (2) to further reinforce the data products with output from modelling and simulation tools (such as HAZUS), (3) to create GIS maps of various social vulnerability factors and of other relevant phenomenon with known spatial

distributions in an effort to ease data comparison for the planners through improved geo-visualization.

Importance of social vulnerability analysis

In the actual planning for emergencies, historically, little attention has been paid to social vulnerability. Cutter (2006a) argues that among all factors that contribute to vulnerability, the factors that we know least about are social factors that decrease resilience and impede recovery. However, as social factors significantly influence the needs of communities in the aftermath of large scale disasters, from a planning perspective, taking into account only the physical or economic vulnerabilities gives us an incomplete picture for our needs assessment. The degree at which populations are vulnerable to hazards is neither solely a function of the proximity to the source of the hazard nor its physical nature (Cutter, 2006a; Cutter, 2000). Comprehensive disaster preparedness plans must take into consideration the impact of those social factors and disaster planners should use this critical piece of information as they identify relevant preparedness actions.

Social vulnerability is a by-product of social inequalities. It is defined as the susceptibility of social groups to the impacts of hazards, as well as their resiliency, or ability to adequately recover from them (Cutter and Emrich, 2006). This susceptibility is not only a function of the demographic characteristics of the population. Social vulnerabilities typically exhibit more complex constructs (Cutter et al., 2003; Cutter et al., 2000; Cutter, 1996).

Social vulnerability to disaster is a social dynamic rooted in gender, class, race, culture, nationality, age, and other power relationships (Enarson et al., 2006). In addition to the sheer number of people at risk, emergency managers have the additional task of identifying those residents who may be the most vulnerable (Cutter, 2006b).

Factors Influencing Social Vulnerability

Social vulnerability is influenced by a variety of factors. Social class is one of the largest contributors to social vulnerability (Burton and Cutter, 2008). It includes employment (type and stability), income, savings, and education levels (Zahran et al., 2008; Burton and Cutter, 2008; Cutter, 2006a; Fothergill and Peek, 2004; Dwyer et al., 2004; Lindell and Perry; 2004; Cutter et al., 2003; Buckle et al., 2000; Mileti, 1999, Morrow, 1999; Bolin and Stanford, 1998; Dash, Peacock and Morrow, 1997; Blaikie et al., 1994). This is a central component of vulnerability, particularly in combination with other marginalization factors (Blaikie et al., 1994).

Race and ethnicity also contribute to social vulnerability through a lack of access to resources (based on language, culture, educational levels) and the economic marginalization that is often associated with racial and ethnic disparities (Burton and Cutter, 2008; Wisner et al., 2004; Cutter et al., 2003; Bolin and Stanford, 1998). Hurricane Katrina (August 2005) and Rita (September 2005) appear to substantiate the claim that disasters inflict unequal harm on minorities and communities with lower income (Zahran et al., 2008). Consideration must be given to how ethnicity is socially constructed, how it relates to social class and immigration status, and how those may translate into various risk factors (Bolin and Stanford, 1998).

Age, specifically the elderly, is identified as another contributing factor. Elderly are more dependent, have less resistance to disease, and may have mobility constraints (Burton and Cutter, 2008; Cutter, 2006a; Dwyer et al., 2004; Cutter et al., 2003; Buckle et al., 2000; Morrow, 1999; Bolin and Stanford, 1998; Blaikie et al., 1994). Age is indirectly related to social class as many older households with retired wage earners have reduced incomes, live on pensions and have limited access to other resources (Phillips, 1993).

Gender is also an important component of social vulnerability. Females are considered more vulnerable than males (Burton and Cutter, 2008; Dwyer et al., 2004; Wisner et al., 2004;

Buckle et al., 2000; Mileti, 1999; Morrow, 1999; Bolin and Stanford, 1998) often due to sector-specific employment, lower wages, and family care responsibilities (Cutter, 2006a; Cutter et al., 2003). Gender effects cannot be separated from class, ethnicity, and age, as multiple and combined factors may significantly disadvantage some households over others during disasters (Enarson and Morrow, 1998).

The quality of human settlements (housing type and construction, infrastructure and lifelines) (Dwyer et al., 2004; Cutter et al., 2003; Bolin and Stanford, 1998), tenure type (Dwyer et al., 2004; Cutter et al., 2003), built environment, family structure (Cutter et al., 2003; Buckle et al., 2000; Morrow, 1999), population growth (Cutter et al., 2003), commercial and industrial development (Cutter et al., 2003), medical services (Cutter et al., 2003), and special needs population (Cutter et al., 2003) are also important in understanding social vulnerability, especially since those characteristics have an influence on economic losses, injuries and fatalities from natural hazards (Cutter et al., 2003).

The Social Vulnerability Index (SOVI)

The Social Vulnerability Index (SOVI) was developed by Cutter et al. (2003) to identify differing levels of social vulnerability at the county level. The SOVI provides a county-level comparative metric of social vulnerability to natural hazards based on the underlying socioeconomic, demographic and built environment profile. SOVI can help determine which places may require special attention in terms of post-event needs planning based on their existing level of social vulnerability. It can also help assess where additional resources may be needed to facilitate longer term recovery after an event. As an objective quantitative metric, the SOVI allows emergency managers, planners, and individuals identify the relative social vulnerability of their places of interest which is a critical step towards actions to decrease overall vulnerability and to increase future resilience (Cutter et al., 2003; Cutter and Emrich; 2006; Cutter and Finch, 2008).

Problem Statement

The Social Vulnerability Index (Cutter et al., 2003) is a tool for summarizing social vulnerability information within a uniform geographical boundary (see Figure 2a). Its reductionist nature and standardized scoring allow for comparisons across multiple locations, thus making it very suitable for decision processes where a single standardized quantitative metric for social vulnerability may be necessary. An example of such decision process may be the high level distribution of funds for vulnerability reduction activities and projects across multiple locations (Cutter et al., 2003). However, based on our work with state and regional (i.e. planning area as illustrated in Figure 2b) disaster planners, the Social Vulnerability Index while very useful to get a general feel for the spatial distribution of social vulnerabilities, may not provide sufficient information to drive the selection of specific preparedness actions within a planning unit.

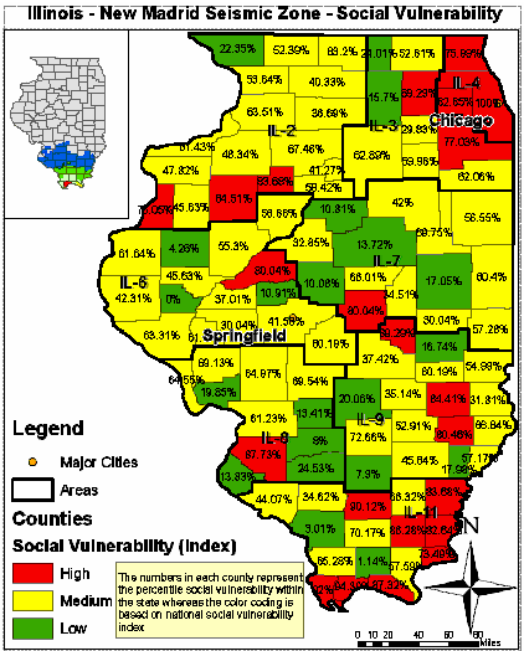

Figure 2a. Distribution of Social Vulnerability Index (county-level) and the percentile equivalent (within state)

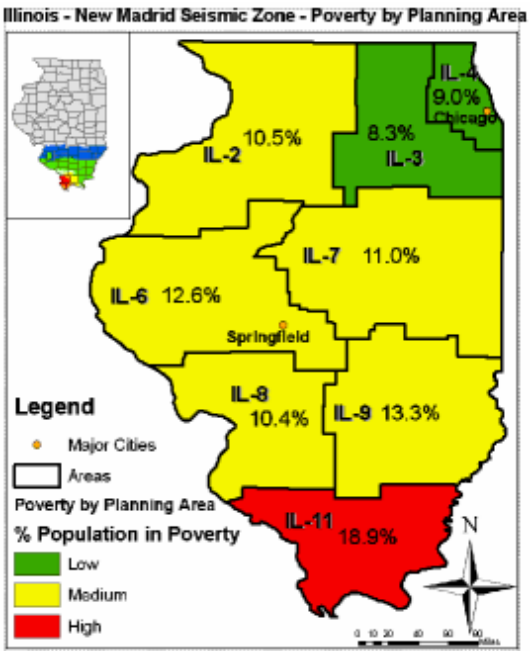

Figure 2b. Distribution of a Social Vulnerability Factor (i.e. Poverty) within the state of Illinois (regional-level)

As the main focus of planners is to establish planning priorities and to identify the most realistic, beneficial, and plausible set of preparedness activities, they seek for vulnerability criteria that they can easily translate into preparedness actions. Furthermore, while planning for preparedness, disaster planners need:

- An optimal number of informative social vulnerability criteria that can be measured quantitatively
- Information systems that enhance the geo-visualization/interpretation of the criteria (i.e. GIS and such)
- Information systems and methods to rank the criteria in terms of importance for planning purposes
- Methodology to bridge the gap between the interpretation of vulnerability criteria and the selection of preparedness actions
- And finally a well-defined process flow that systematically encapsulates all planning steps from the initial analysis of social factors until the identification of appropriate preparedness actions

The Theory and Method section will define in detail the individual steps involved in this planning effort. Furthermore, we will formally define the relationships and dependencies between individual planning steps and propose a methodology that can improve the linkage between vulnerability criteria and the selection of preparedness actions.

Theory and Method

The generic process of planning for major natural disasters that pose a significant social vulnerability is a chain of steps from the collection of relevant data on social factors to the selection of a number of preparedness actions. Every step in the process receives input from the previous step and then feeds its own output into the next in the chain. Figure 3 gives an overview of the steps and their relationships.

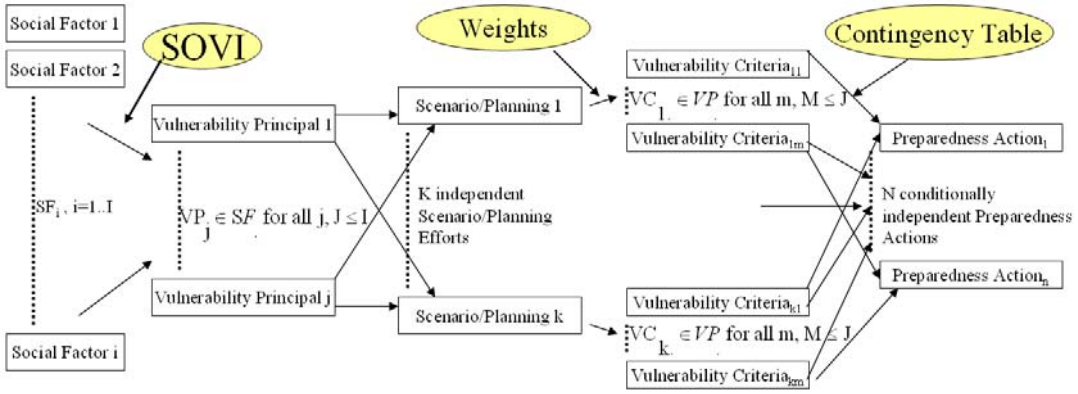

Figure 3. The steps in the planning life cycle from Social Factors to the selection of Preparedness Actions

The first step in the process is the identification of social factors (SF_i, for i=1..I) that will be considered as potential proxies for measuring social vulnerability. Cutter (2003) details those social factors and explains how they are reduced to j vulnerability principals (VP_j, for j=1..J, J < I) through principal component analysis. Those vulnerability principals each are column vectors that are aimed to encapsulate as much of the variability between different social factors as possible. Each vulnerability principal has one or more dominant social factor which is significantly correlated with the component itself. The Social Vulnerability Index (Cutter, 2003) can be calculated as an additive model of the 11 vulnerability principal scores which explain approximately 75% of the variance. However, for the purposes of preparedness planning, eliciting the relative importance of 11 components can be still daunting; therefore further reduction of the dimensionality of vulnerability sample space is typically necessary. This step can be performed in a variety of ways including the use of decision support software (Eisner, 2005), the analytical hierarchy process (Saaty, 1980; Rashed and Weeks, 2003), and multi-attribute utility theory (Keeney and Raiffa, 1993). All of those techniques mentioned are mature and well studied in literature; therefore we will provide the most influential references but won't go into the mechanics. We call the outcomes of the elicitation as the Vulnerability Criteria (VC_M, for M=1..m, m < j) as those elements will be the final subset of social factors that will influence the selection of preparedness actions. In this project, the vulnerability criteria were selected through the process of consensus building within the planner group. More specifically, the 4 final Vulnerability Criteria selected were:

- Poverty Level (measured by the percent of population living in poverty)
- Lack of Proficiency in English (measured by percent of population not proficient in English)
- Vulnerable Age Groups (measured as percent of population under 5 and above 65)
- Disabled Population (measured by the number of disable residents within the county or region)

We should note that only two of the above criteria (i.e. Poverty Level and Vulnerable Age Groups) have significant correlations with the initial vulnerability principals. This is yet another indicator that vulnerability criteria for preparedness planning may have unique partial correlations with the selection of Preparedness Actions (PA_n, for n=1..N, PA_n's conditionally independent given VC_m). Because both the independent variable VC and the dependent variable PA are column vectors of dichotomous [0 or 1] random variables, the formal approach for testing the significance of their correlation structure is through contingency tables and the use of goodness of fit procedures such as the Likelihood Ratio Chi-Squared test based on the G^2 statistic and the more commonly used Pierson Chi-Squared test based on the χ^2 statistic (SAS, 2003). An example contingency table in this context is available in Figure 4.

	PA_1	.	.	PA_N	Sum of Columns
VC_1	VC_1-PA_1	.	.	VC_1-PA_N	$\sum_{n=1}^{N} VC_1 * PA_n$
.	.	.		.	.
.	.	.	.	.	.
VC_M	VC_M-PA_1	.	.	VC_M-PA_N	$\sum_{n=1}^{N} VC_m * PA_n$
Sum of Rows	$\sum_{m=1}^{M} VC_m * PA_1$	.	.	$\sum_{m=1}^{M} VC_m * PA_N$	$\sum_{m=1}^{M}\sum_{n=1}^{N} VC_m * PA_n$

$$\chi^2 = \sum_{i=1}^{M*N} \frac{(\text{observed } (VC*PA)_i - \text{expected } (VC*PA)_i)^2}{\text{expected}(VC*PA)_i}$$

where

$$\text{expected}(VC*PA)_i = \left(\frac{\sum_{m=1}^{M}(VC_m * PA_n) * \sum_{n=1}^{N}(VC_m * PA_n)}{\sum_{m=1}^{M}\sum_{n=1}^{N} VC_m * PA_n} \right)$$

Figure 4. Calculation of the Pearson Chi-Squared statistic

The method above can serve as a starting point in addressing the dependencies between the vulnerability criteria and the chosen preparedness actions. Table 1 demonstrates the calculation of expected frequencies of our vulnerability criteria across a sample set of preparedness actions. The table also highlights significant positive deviations from the expected frequency, which indicates a positive correlation between the vulnerability criteria and preparedness action pair.

Expected / Observed Frequency	Invest into Evacuation Coordination	Invest into Short Term Housing	Invest into Long Term Housing	Improve Emergency Medical Services	Invest into Job Creation	Capacity Building - Search & Rescue	**Row Totals**
Social Dependence	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	*0*
Poverty Level	3.46 / 1	4.85 / 9	3.80 / 6	5.54 / 5	5.54 / 6	3.81 / 0	*27*
Lack of Proficiency in English	1.67 / 1	2.33 / 1	1.83 / 2	2.67 / 2	2.67 / 7	1.83 / 0	*13*
Vulnerable Age Groups	2.82 / 5	3.95 / 4	3.10 / 2	4.51 / 8	4.51 / 0	3.10 / 3	*22*
Disabled Population	2.05 / 3	2.87 / 0	2.26 / 1	3.28 / 1	3.28 / 3	2.26 / 8	*16*
Infrastructure and Lifelines	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	*0*
Health Insurance Coverage	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	*0*
Column Totals	*10*	*14*	*11*	*16*	*16*	*11*	***78***

Table 1. Contingency table of vulnerability criterion (rows) and preparedness actions (columns)

Preliminary Findings and Future Research

We proposed a conceptual framework that integrates the use of social vulnerability factors to the selection of preparedness actions for a catastrophic earthquake hazard planning and preparedness project. Starting from the Social Vulnerability Index (SOVI), we explained why further reduction in the dimensionality of social vulnerability factors and principals may be necessary in disaster planning projects and briefly mentioned relevant methodologies. We took the analysis one step further and explained how the selected vulnerability criteria may act as an indicator of potential preparedness actions and detailed one methodology that can be used to formally explore this relationship.

However, for this conceptual framework to be of any practical value there is more work to be done and several challenges to be met.

- First of all, the contingency table methodology mentioned in the discussion may require significant amounts of data to provide reliable results. For the test to be unbiased, the expected value in each cell should be greater than 5.
- The procedure requires use of standardized sets for vulnerability criteria and preparedness actions. While thanks to the work of Cutter and colleges the social vulnerability criteria are fairly standardized, the same is not true for preparedness actions and more research is necessary to get there.

- In our framework, we introduced the Scenario/Planning step (of independent planning groups) to facilitate the elicitation of vulnerability criteria from vulnerability principals. For data collection between those independent planning groups, some mechanism of coordination or the utilization of a collaborative information system is necessary.
- Assuming significant correlations between the vulnerability criteria and the preparedness actions is established per methodology described above, the next logical step would be to better understand the nature of this relationship, and not a mere proof of its existence. For the multivariate case of testing differences in mean preparedness action response given a unique vulnerability criterion, statistical methods like ANOVA (O'Brien, 1979) can be used.

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