ESTIMATING THE DEMAND FOR SHELTERING AND FEEDING IN FUTURE EARTHQUAKES AFFECTING THE SAN FRANCISCO BAY REGION

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ABSTRACT

The preparation for sheltering and feeding large numbers of people following a major earthquake is a critical social issue for the American Red Cross and San Francisco Bay area residents. Equivalent, simplified models were developed for Red Cross planners that integrated expert knowledge, damage estimates, and 1990 census socio-economic data. The assumptions and methodologies used in building the model and the results of using the model to analyze five scenario earthquakes in Northern California are discussed. The worst case scenario examined in the report is the Hayward combined (north and south) earthquake. The model predicts that approximately 120,000 people would require shelter and 260,000 would require mass care feeding in the nine county bay area based on this worst case scenario.

INTRODUCTION

This paper describes the results of a study designed to assist the American Red Cross Northern California Earthquake Relief and Preparedness Project (NCERPP), the Association of Bay Area Governments (ABAG), and the Bay Area Earthquake Preparedness Program (BAREPP) in establishing guidelines for risk area planning. The primary Red Cross function following a catastrophic earthquake or other major disaster will be to coordinate the delivery of mass care (sheltering and feeding) services. The ability to estimate service demands and mass care staffing requirements is, therefore, an essential first step for risk area planning. This paper develops a model and methodology for the estimation of the population requiring sheltering and feeding following an earthquake, and applies this model to five scenario earthquakes. The methodology uses as input data the results of the companion study completed by the Association of Bay Area Governments (ABAG) in April, 1992, *Estimates of Uninhabitable Dwelling Units in Future Earthquakes Affecting the San Francisco Bay Region* (Perkins, 1992). Sponsored by NCERPP and the Bay Area Earthquake Preparedness Project (BAREPP), ABAG modeled the damage for the five scenario earthquakes and estimated the number of uninhabitable dwelling units that would result from each scenario. The ABAG model was calibrated against the actual damage reports of the Loma Prieta earthquake. Feeding and sheltering demands are calculated based on the ABAG damage estimates.

BACKGROUND

The methodology described in this paper was developed by the George Washington University during two prior studies of Red Cross mass care service delivery for catastrophic events under the Federal Response Plan (Harrald et al., 1990, 1991). The modeling effort followed a three step process:

1. the estimation of the number of persons impacted by the disaster,
2. the estimation of the number of persons likely to seek public mass care assistance, and
3. the estimation of the number of service delivery units and mass care staff required to meet this demand.

The determination of the number of persons impacted by an earthquake requires the estimation of the damage done to structures and the calculation of the actual number of dwelling units contained by the impacted buildings. The estimation of structural damage is difficult since damage is dependent upon the intensity and duration of local ground shaking and the structural type of the building. The local ground shaking is a function of four parameters in addition to the magnitude of the earthquake: the underlying local geology, the depth of the epicenter, the duration of the earthquake and the distance from the fault. The predicted local intensity, given an epicenter and magnitude is, therefore, a stochastic variable. Differences in local geology will cause significant variation in local shaking intensity along iso-seismal lines. Precise information concerning building structural type is essential since most earthquake damage will be sustained by high risk structures such as unreinforced masonry buildings, pre-1940 wood homes, and mobile homes. The factors influencing the proportion of the population affected by earthquake damage are discussed in greater detail in Perkins (1992) and Harrald et al. (1992).

The San Francisco Bay area is unique in that excellent data on local geology and relatively complete structural inventories are available. . ABAG maintains ground shaking models as a component of its Bay Area Spatial Information System (BASIS) (Perkins, 1983, 1992). ABAG also maintains an inventory of existing building stock by construction type and number of stories. The ABAG report develops its damage estimates based on the intensity vs structural type damage matrices developed by Dunne and Sonnenfeld (1991). The availability of this data allowed ABAG to develop estimates of the number of uninhabitable (red tagged) dwelling units for each of the over 2000 census tracts in the nine county bay area for five scenario earthquakes as described in Perkins (1992), Steinbrugge et al., (1987) and Davis et al. (1982).

A MODEL FOR ESTIMATING MASS CARE SERVICE DEMAND

The ABAG estimates of damaged dwelling units for each census tract provided the essential initial data for the next step in the modeling process: the calculation of the population seeking shelter. When a family is made homeless by a disaster they may or may not seek public shelter or assistance. If they do require shelter, they may leave as soon as other alternatives become available. Prior studies have shown that the propensity to seek shelter is dependent upon damage levels, geographic area, and demographic variables such as income, age, and ethnicity. The U.S. Army Corps of Engineers and the U.S. Federal Emergency Management Agency (COE, FEMA 1990) found ethnicity and income to be good predictors of the likelihood of seeking public shelter following the evacuation of the North and South Carolina Coast during Hurricane Hugo. Milleti and Sorensen (1991) examined 23 incidents where public shelter was available and concluded that only the socio-economic status and age of the evacuees were predictors of shelter usage.

Models developed in studies prepared for the American Red Cross by the George Washington University in 1988 and 1989 used the expert opinion of Red Cross disaster managers to predict the likely behavior of affected populations. These models used the software package EXPERT CHOICE to integrate this expert judgement with demographic data and damage estimates in a hierarchical decision model. The integration of precise demographic data, approximate damage estimates, and subjective expert opinion into a useful predictive tool is a unique contribution of this methodology.

Several modifications were required to adapt the EXPERT CHOICE model for this project. First, the damage classifications were revised to reflect the classifications of ABAG. Three damage classifications were used: RED TAG--dwelling unit is uninhabitable; PARTIAL--dwelling unit sustains visible damage, but is habitable; NEGLIGIBLE--no visible damage. The number of red tagged dwelling units per census tract were calculated by ABAG based on the Dunne and Sonnenfeld damage matrices as described in the April, 1992 ABAG report. The damage threshold for producing homelessness is assumed to be approximately 20%.

The damage type variable formed the upper tier of the EXPERT CHOICE hierarchy shown in figure 1. The model was applied to each of the approximately 2000 census tracts in the bay area for all five scenarios. For each census tract, the percentage of dwelling units in each category (red tag, partial, negligible damage) as determined by ABAG was used as the weighting factor.

The next step in the modeling process was to use Red Cross experts familiar with the bay area population and bay area disaster to estimate the relative importance of each of the socio-economic variables (income, ethnicity, etc.) as predictors of the likelihood of seeking public shelter for each damage type. The estimates made by the experts were merged by eliminating extreme values and then calculating mean values. These estimates became the weights for the second tier of variables shown in Figure 1. The model provides a consistent method of integrating the weights for damage type that are based on data (ABAG calculations) and the weights for the relative importance of the socio-economic variables that are based on expert opinion.

The third tier of the hierarchical model represents the actual socio-economic description of each census tract. The variables used were: Income distribution (discrete increments), ethnic type (white, black, hispanic, Asian and other), age (% under/over 65) and type of residence (owned, rental, vacation). The values for these variables for each census tract were obtained from the Donnelly Marketing CONQUEST system and represent 1990 demographic projections.

This modeling technique assumes that the distribution of socio-economic groups across the eight building types within the target geographical area is uniform. This assumption is certainly not true for a large geographical area such as a city or a county and is the reason that the smallest possible geographic area (census tract) was used as the basis for the analysis. The use of geographical areas larger than census tracts would have required assumptions of uniformity that clearly are invalid. The average number of persons per dwelling unit for census tracts in Alameda county, for example, varied from 1.2 to 5.1 and the percentage of families with income less than $10,000 per year ranges from 0 % to 60%. The final level of the hierarchical model was supplied by expert judgement. Red Cross experts were asked to provide their estimate of the percentage of a population segment described by two variables: damage level (red tag, partial, or negligible) and Socio-economic (income level, ethnic type, age). The methodology implies two important assumptions: (1) the experts could consider the effect of the socio-economic variables independently, and (2) considering the variables independently would not introduce significant computational error. Variables such as income and ethnicity are clearly correlated in the urban areas under study. Experts had some trouble separating the variables, but were able to provide consistent and useful information interacting with the EXPERT CHOICE model. The expert judgements were again merged by eliminating outlying values and calculating mean values.

The EXPERT CHOICE model was very useful for structuring the problem and for interactively extracting expert judgements. It would, however, have been extremely difficult to solve since a separate model would have to be constructed for each of the 2000 census tracts. The problem was transformed into a reasonably straight forward, albeit cumbersome, form that enabled it to be solved using a micro computer based spreadsheet. The mathematical formulation of the problem is essentially a weighted Bayesian probability analysis.

The estimation of the proportion of the affected population that will seek public feeding was based on the estimates of the population requiring shelter as described in Harrald et al. (1991). The population that requires feeding services will consist of four groups. A description of these groups and a first approximation of the percentage of each group that would seek feeding services following a major earthquake, based on interviews with Red Cross disaster services personnel are as follows:

1. Persons in Shelters: 100%
2. Persons displaced from red tag dwellings, but not in shelters: 50%
3. Persons still in partially damaged homes, without the ability to obtain and prepare food: 10%
4. Disaster workers: 100%

The estimates of demand for sheltering and feeding were adjusted upward to account for two factors: the pre-disaster homeless, and seeking of public services by people in habitable dwellings due to interrupted water, electricity, and natural gas service. The method of making these adjustments is described in Harrald et al. (1992).

RESULTS OF MASS CARE DEMAND MODEL

Demand for sheltering was calculated for each of the five scenario earthquakes used in the ABAG study: the peninsula segment of the San Andreas Fault, Hayward Fault Combined, Hayward Fault North, Hayward Fault South, and the Healdsburg-Rogers Creek Fault. A summary of the results is shown in Table 1. The maximum projected shelter population is 120,153 resulting from the Hayward combined scenario; the minimum is 23,380 resulting from the Healdsburg--Rogers Creek scenario. The model projects that 68,695 victims will require shelter in Alameda County following a Hayward combined scenario earthquake. The shelter population estimates for Alameda following a Hayward North event (48,012) and Hayward south event (33,614) and projections for Contra Costa county for the Hayward combined and North scenarios ranges (13,029) show that the East Bay event will provide the worst case scenarios for the bay area. The shelter population anticipated in San Francisco County ranges between 10,000 to 15,000 for the Hayward scenarios. The San Andreas peninsula scenario is primarily a West Bay event, resulting in projected shelter populations of 11,253 in San Francisco county, 6,370 in San Mateo County, and 8,842 in Santa Clara county.

SOURCES OF ERROR AND UNCERTAINTY

The results of all modeling efforts should be interpreted with a degree of skepticism. The joint ABAG and GWU project has attempted to make a first approximation to some of the critical impacts of a northern California earthquake. The results are useful, but highly uncertain. Any model is a selective representation of reality. All models leave things out; and the validity of a model is limited by the modeler's ability to make simplifying assumptions while still capturing significant variables and relationships. A major simplifying assumption in most models is the treatment of uncertainty with deterministic variables or artificially constructed probability distributions. Sources of uncertainty and error include the following:

1. Parameters that describe the basic earthquake event are stochastic. The following factors will

influence the intensity of local ground shaking: e.g., the duration of the earthquake, the depth of the epicenter, and the location of the epicenter along the fault.

2. The intensity of the local ground shaking depends upon the local geology. Although the local geology in the Bay area is known and mapped with a higher degree of accuracy than most areas in the United States; in other areas, the precise type of local geology and its response to the earthquake are not known with certainty.

3. The estimated response of buildings to a given level and duration of shaking intensity is a stochastic variable. There is significant uncertainty in the relationship between damage, shaking, intensity, and structural type.

4. Significant potential sources of uncertainty and error are introduced in the GWU model through the use of expert judgement. The model treats highly correlated variables (e.g. income, ethnicity) as independent making it difficult for experts to provide valid input and introducing potential computational errors.

5. The behavior of the disaster victims is inherently a stochastic variable. The same population may react in very different ways to similar events depending upon external factors such as news coverage (or inability to get information), and political leadership (or lack thereof).

CALIBRATION AGAINST LOMA PRIETA

An attempt was made to calibrate the modeling technique used in this study by comparing the actual Loma Prieta earthquake shelter populations with the shelter populations calculated by the model. Loma Prieta peak shelter populations for San Francisco, Alameda, and Santa Clara counties were obtained from the Red Cross records and the actual number of Red Tag dwellings and the estimated number of dwellings sustaining partial damage was obtained from ABAG. The predicted number of persons seeking shelter from these damaged dwelling units was calculated using the ABAG damage model and the GWU demand model.

The actual experience in Loma Prieta was approximately 35% of the shelter population predicted by the ABAG-GWU model. Although the model may appear to severely overestimate, it should be noted that the Loma Prieta event was less severe than any of the scenario earthquakes and comparatively little infrastructure damage actually occurred. Population could in fact seek alternative shelter outside of area. In addition, the Loma Prieta event was of relatively short duration and partial damage estimates used to calculate expected shelter populations are probably high.

CONCLUSIONS

The preparation for sheltering and feeding large numbers of people following a bay area earthquake is a critical social issue. Based on USGS data, "The combined probability of one or more of these earthquakes occurring is 15% in 5 years, 33% in 10 years, 50% in 20 years and 67% in 30 years." (ABAG, 1992, p.6). The models constructed by ABAG and The George Washington University, provide an initial point for disaster relief planners and provide an insight into the factors that influence the demand for mass care services. In particular, the GWU model shows the importance of preparedness activities. Persons in partially and negligibly damaged dwelling units will not need to seek public shelter or feeding if they have stockpiled food and water in their home and are prepared to be self-sustaining for several days. In areas without adequate education and preparedness programs, these populations could quickly overwhelm relief facilities.

Data available in the bay area allowed ABAG and the GWU to make reasonable estimates of earthquake damage and mass care service demands. This information is critical to the development of Federal, State, and Red Cross disaster plans. The modeling efforts initiated by the Red Cross, the Bay Area of Governments and The George Washington University should be refined and applied to other risk areas. Critical work in other risk areas will be the creation of structural inventory and local geology data bases that correspond to the data maintained by ABAG.

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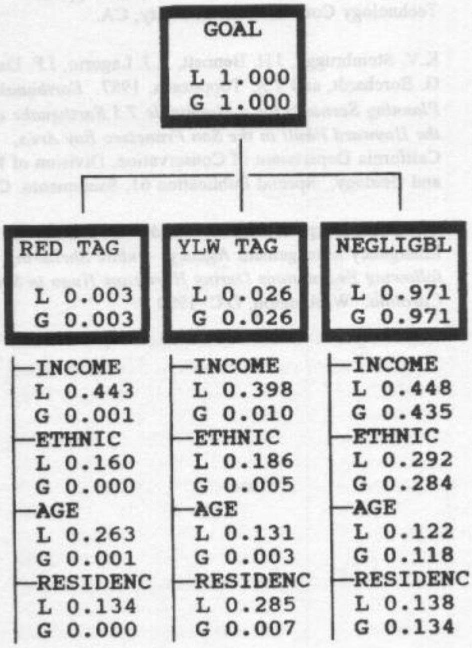
FIGURE 1: EXPERT CHOICE MODEL FOR PREDICTING THE PERCENTAGE OF HOUSEHOLDS THAT WOULD SEEK SHELTER FOLLOWING A BAY AREA EARTHQUAKE



RED TAG: % OF DWELLINGS UNHABITABLE
YELLOW TAG: % OF DWELLINGS PARTIALLY DAMAGED
NEGLIGIBLE: % OF DWELLINGS WITH NO OR MINOR DAMAGE
INCOME: INCOME DISTRIBUTION OF HOUSEHOLDS IN AFFECTED AREA
ETHNIC: ETHNIC DISTRIBUTION OF POPULATION IN AFFECTED AREA
AGE: AGE DISTRIBUTION OF POPULATION IN AFFECTED AREA
RESIDENCE: DISTRIBUTION OF RESIDENCE TYPE (OWN, RENT, VACATION) IN AFFECTED AREA

TABLE 1: SHELTER POPULATIONS FOR SELECTED EARTHQUAKE SCENARIOS BY COUNTY

COUNTY	SAN ANDREAS/ PENINSULA	HAYWARD COMBINED	HAYWARD NORTHERN SEGMENT	HAYWARD SOUTHERN SEGMENT	HEALSDBURG RODGERS CREEK
ALAMEDA	2,614	68,695	48,012	33,614	1,735
CONTRA COSTA	72	13,029	13,029	1,056	626
MARIN	614	1,150	1,150	620	984
NAPA	8	98	98	11	335
SAN FRANCISCO	11,253	14,904	14,904	10,316	5,656
SAN MATEO	6,370	896	493	896	50
SANTA CLARA	8,842	20,179	1,151	20,179	59
SOLANO	395	921	921	540	876
SONOMA	38	281	281	46	13,059
TOTAL	30,206	120,153	80,039	67,278	23,380