A Cost Estimate Model for Initial Mass Care Needs Following Major Earthquakes Affecting the San Francisco Bay Region

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Abstract
After a catastrophic earthquake, many victims are forced from uninhabitable homes, while others choose to leave other housing due to their fears of further damage. Although many of these victims are able to find alternative shelter, many seek shelter in Red Cross or other local mass care facilities. In addition, a catastrophic earthquake may disrupt power and water supplies, generating additional demand for feeding of people beyond those in the shelters. This paper describes a modeling effort that will support the planning efforts of the American Red Cross, the Federal Emergency Management Agency (FEMA), the State of California, and local governments by providing an estimate of the resources required to provide emergency sheltering and feeding for potential victims of a San Francisco Bay Area earthquake. The results show the need for developing response strategies that will allow people to sustain themselves in their homes, even if lifelines are seriously damaged. In addition, the results demonstrate the cost-benefit of retrofitting residential structures by providing an estimate of the high cost of the emergency mass care efforts that could be avoided by mitigation.

Introduction
The cost model developed in this study attempts to estimate the cost of the initial 60 days of providing mass care services (shelter, feeding, and bulk distribution of supplies) following a large-scale San Francisco Bay area earthquake. The scale of mass care services needed following a Hayward or San Andreas fault earthquake scenario could be more than ten times greater than the level of services provided following any historical disaster in the United States. Arriving at even approximate cost figures for any component of such an unprecedented response is a difficult and highly subjective process. This document draws heavily on current draft planning documents and guidelines of the American Red Cross, the agency that would be responsible for coordinating the delivery of mass care services. Since the Red Cross is still developing the organizational strategies and structures required by this challenge, this analysis does not attempt to provide a definitive answer to the problem of estimating the cost of responding to a catastrophic earthquake. It does, however, provide a conceptual structure and an analytic process for calculating these costs and for studying the consumption of resources during a response to a significant earthquake. Available data and operational concepts are used to demonstrate the utility of the model through the calculation of an initial cost estimate. This estimate is provided for illustrative purposes only, a reliable estimate will require resolution of some of the ambiguity of the modeling assumptions described below. Assumptions, described in detail in Harrald and Renda-Tanali (2000), were made to estimate modeling parameters in each of the following areas:

- The extent of housing damage
- The number of displaced families
- The peak shelter populations
- The time dependence of shelter demand
- The initial feeding demand
- The time dependence of the feeding demand
- The sheltering strategy
- The feeding strategy
- The bulk distribution strategy
- The warehousing and distribution strategy
- The mass care organizational and staffing structure
- Personnel cost factors
- Materiel cost factors
- Cost breakdown structure

These assumptions involve a high degree of uncertainty. In particular, the estimates of the demand for feeding and bulk distribution are highly dependent upon factors such as infrastructure (transportation, water, power) damage. The mass care organizational structure is dependent upon the still evolving service delivery strategy. Most significantly, there are no historical data on which to base accurate personnel cost assumptions. The uncertainty involved in the analysis is compounded at each step and the resulting estimates must be interpreted with caution.

Specific Assumptions

Population Behavior Pattern Assumption: Figure 1 shows the behavior pattern assumption followed in calculating the mass care needs of the affected population. The

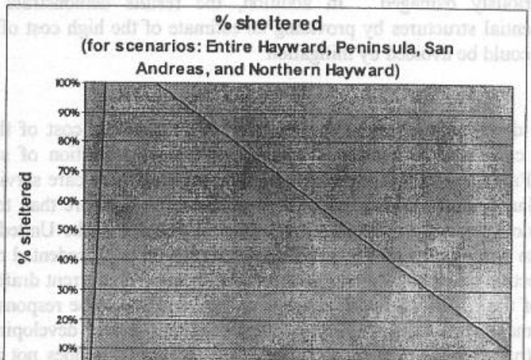

Figure 1- Population Behavior Assumption

assumption was based on patterns observed in the historical data from Northridge and Kobe earthquakes. The shelter population reaches its peak at day 3, remains at this peak level for a week, then declines at a constant rate, reaching a level equal to 10% of the peak population at day 60. The total population displaced from their homes is assumed to follow the same pattern when estimating the needs for feeding and distribution of supplies. However, this assumption is unsubstantiated by historical data, and reflects an underlying assumption concerning the availability of housing and the ability to restore/repair partially damaged housing.

Shelter Consolidation Assumption: The number of shelters will decline in a stepwise manner based on the assumption that the ARC and other shelter managers will consolidate shelters for cost efficiency and to revert shelters to their original use (schools, libraries, etc.) for communities. The gradual consolidation of shelters is assumed to follow the pattern described on figure 2a. It was assumed that 50% of the estimated peak shelter amount would be open during the first three days and that the remaining shelters would open to meet the peak demand, staying open for about 20 days. Then it was assumed that 20% of them would be closed on the 25th day, and, then, 20% of the remaining would be closed every two weeks to meet the diminishing demands of the population until 10% of the peak shelter population remains at the end of two months. This heuristic was used for to predict resource allocations and personnel requirements. The modeling result is a stepwise downsizing in personnel, whereas there is a continuous linear decrease in the demand for shelter.

Aggregate Shelter Capacity Assumption: Some shelters will be closed every two weeks since their occupancy will drop significantly as people leave shelters to seek other forms of shelters or go back to their homes. The model assumes that the residual shelter population will be evenly distributed across the shelters that remain open during the course of the 2-month mass care period. The number of shelters that are open, changes roughly every two weeks, therefore the peak points indicate the starting capacities of those certain number of shelters. The number of shelters was increased by 20% (heuristic assumption) where the 100% capacity was exceeded. This assumption provides some relaxation to the conservative assumption that the shelter population is evenly distributed across the number of open shelters.

Work Breakdown Structure Assumption: A hierarchical decomposition of the cost elements of a mass care response was developed using the traditional work break down structure methodology typical for project management. The cost elements needed to populate the work break down structure are taken from Red Cross plans and procedures. The structure provides a basis for modeling costs to whatever detail level is practical, for comparing estimate, targeted, and actual costs, and for identifying cost centers that have significant impacts on the overall cost. Detailed or unit costs are at the lowest level of the hierarchy, summations moving up the hierarchy produce segment costs and the overall project cost. The modeling assumptions contained in this technique are expressed in the way cost elements are grouped and assigned to branches of the model.

Unit Cost Assumptions: Unit costs were assigned for each of the cost centers at the lowest levels of the cost breakdown structure. For direct to client costs, including feeding, the unit costs for food, supplies, and items distributed to shelter residents were assumed based on Red Cross historical data and current supply cost rates. Indirect costs (utilities, repairs, transportation) were based on historical data and current bay area rates. The applicability of these cost rates to a large-scale earthquake event is an untested assumption. Unit cost estimates were based for bulk distribution items. Item descriptions and costs were taken from the current Red Cross Mass Care Budget Worksheet.

Assumptions for Mass Care Personnel Cost Computations

Labor costs were assumed as indirect costs, and they were allocated to each task category in the work breakdown structure (feeding, sheltering, bulk distribution, warehousing, or administration unit). The Red Cross mass care workforce consists of local and national volunteers (coordinators or specialists), and Red Cross paid staff (regular employees and reserves). Mass care staffing requirements and costs were computed only for the senior positions that require specific job skills. All other workers (corresponding to the American Red Cross Technician level staff) are assumed to be no cost local volunteers

The personnel needs for four different earthquake scenarios were modeled based upon American Red Cross Bay Area Chapter cost relationship assumptions. Relationships developed by Red Cross Mass Care specialists at Red Cross headquarters was used to develop staffing relationships so a consistent method could be applied across the different scenarios. While there were some differences between the two sets of relationships, they complemented each other and formed a basis to extrapolate the staffing needs for a single shelter or supporting site. This staffing estimate was then multiplied by the number of needed shelters and sites for the specific earthquake scenario to produce a total personnel requirement. The shelter and site staffing needs were calculated using as base a ratio of the number of staff positions required per shelter or site. The positions were broken down first into their functional areas (Shelter, Fixed/Mobile Feeding Sites, Distribution Sites, and Headquarters sites). Each functional area was further broken down into specific staffing positions. Each position was assigned a pay level equivalent to the going market rate for their services.

Estimating Staffing and Cost

The relationship used to determine the staffing needs was determined by four variables: number of shelters, number of community based feeding sites, number of distribution sites, and the number of serving areas for Northern Hayward, Combined Hayward, Peninsula, and San Andreas scenarios. These four scenarios were selected as providing two representative worst-case events for both the East Bay region and the Peninsula region. The number of persons displaced and the estimated peak shelter populations for each of these scenarios are shown in table 1.

scenario no.	*Scenario name*	*Displaced Persons*	*Sheltered Persons*
1	entire hayward	356,614	110,273
2	peninsula fault	238,289	70,308
3	san andreas fault	141,621	44,115
4	northern hayward fault	140,753	45,191

Table 1: Displaced Populations and Peak Shelter Populations for Four Scenarios

The number of shelters required to service the peak shelter population was determined by assuming an average shelter size of 600 persons. The decline in the number of shelters and required shelter staffing was determined using the assumptions described above. The number of community-based feeding sites required for each scenario was determined by first assuming that the number of people needing to be fed was roughly equal to the number of people displaced less the number of people seeking shelter. The model assumes that those individuals in shelters are being fed in the shelters and that community based feeding sites and mobile distribution units (e.g. Red Cross Emergency Response Vehicles) are used to feed the remaining population. The number of community feeding sites and the number of distribution centers were assumed to remain constant over the 60-day period. As stated above, the displaced population decreases over the period as people return to their homes or leave the area. The demand for feeding is assumed to decrease at the same rate. However, the demand for feeding is assumed to be sufficient to require the maintenance of the feeding operation for the full 60 days. This is clearly a worst-case assumption. The number and type of service delivery units may be derived from these assumptions. Using all the above assumptions, costs were calculated and aggregated for the 60 days of initial mass care operations, for four different earthquake scenarios. Direct to client costs (distributed items, food, etc.) follow the pattern shown in figure 1, whereas labor costs decrease following a step function, and the administration costs remain constant over the specified period. The senior personnel staffing requirements for each scenario are as follows:

- Hayward Combined Scenario 4,610 persons
- Peninsula Scenario 3,090 persons
- San Andreas Scenario 1,977 persons
- Northern Hayward Scenario 1,951 persons

These numbers do not include the large numbers of persons who will volunteer for lower skilled positions. The Red Cross and other nongovernmental organizations (NGOs) are prepared to train disaster victims to fill these needed roles. The number of senior people required for mass care significantly exceeds the current cadre of trained personnel.

The total estimated costs of the feeding, sheltering, and bulk distribution resources described above are summarized in table 2 below. These results should be used with caution for varied reasons: the staffing included in the modeling represents only the senior staff directly associated with mass care service delivery; the estimated costs of wages, supplies, and foodstuffs are subject to a very wide range of uncertainty; and additional uncertainty is introduced by the modeling assumptions described in the first section of this report. However, the model can and does provide a valid basis for performing and engineering analysis of the resource requirements and resource consumption during a mass care response. This comparative analysis is presented below.

Cost Element	**Entire Hayward Scenario**	**Peninsula Scenario**	**San Andreas Scenario**	**Northern Hayward**
Sheltering	$22,000,000	$14,000,000	$9,000,000	$9,000,000
Bulk Distribution	$18,000,000	$12,000,000	$7,000,000	$7,000,000
Fixed and Mobile Feeding	$153,000,000	$102,000,000	$61,000,000	$60,000,000
Administration	$3,000,000	$3,000,000	$3,000,000	$3,000,000
Total	$196,000,000	$131,000,000	$80,000,000	$79,000,000

Table 2: Total Cost by Scenario by Function

Sensitivity analysis

An extensive sensitivity analysis was performed on critical parameters, since the assumptions that established these parameters are highly subjective. The value assumed for the peak displaced was ranged between +20% and –10% of the base value; the residual shelter population after 60 days was ranged between 10% and 100%; the length of peak service demand was ranged between 3 and 10 days; and the allowable shelter vacancy rate was ranged between 20% and 50%. Parameters for feeding demand are linked to these parameters. The extreme results for the Hayward Combined Scenario were:

Base Case:	$ 196M
Minimum Case:	$ 166M
Maximum Case:	$ 342M

The analysis showed that the model was most sensitive to the assumed value of displaced persons and the assumed rate of decline of service delivery. Both of these assumptions are strongly affected by the ability of relief organizations to support the ability of families to remain in their partially damaged homes. As a point of comparison, the cost of all services provided by the American Red Cross after the 1989 Loma Prieta earthquake was under $30 million.

Analysis of Distribution of Total Mass Care Costs

The modeling methodology provides a basis for breaking down the composition of projected costs for each function and for the total mass care response. These breakdowns show which functions and cost factors dominate the cost structure. Figure 2 and figure 3 show that, contrary to current planning assumptions, the major response cost will be driven by the need to feed persons who are not at shelters. This food could be provided by fixed or mobile feeding sites. The need for feeding the population is driven by the damage to infrastructure (water, power, gas, roads) and the ability of relief agencies to distribute supplies that would enable people to sustain themselves in their moderately damaged homes.

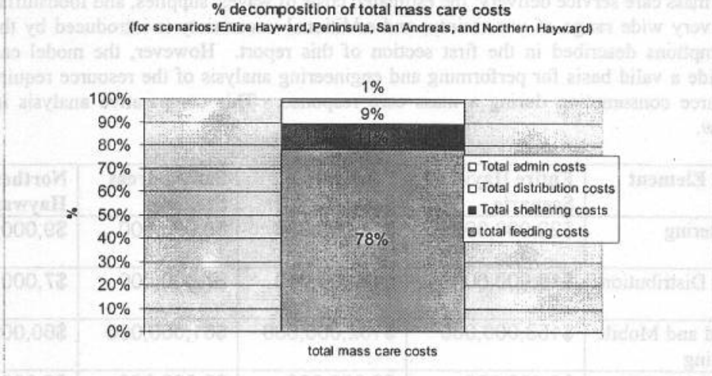

Figure 2 Percent Breakdown of Total Mass Care Costs

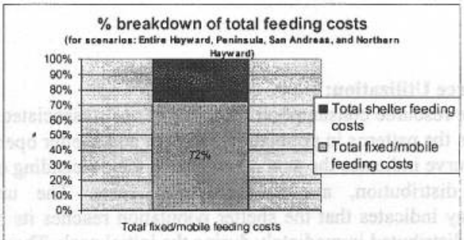

Figure 3- Percent Breakdown of Total Feeding Costs

Analysis of Daily Resource Utilization

A critical management issue is determining the consumption rate of resources. The analysis below shows that different functions consume resources at different rates and have peak resource usage at different times in the response. The analysis is common to all four scenarios.

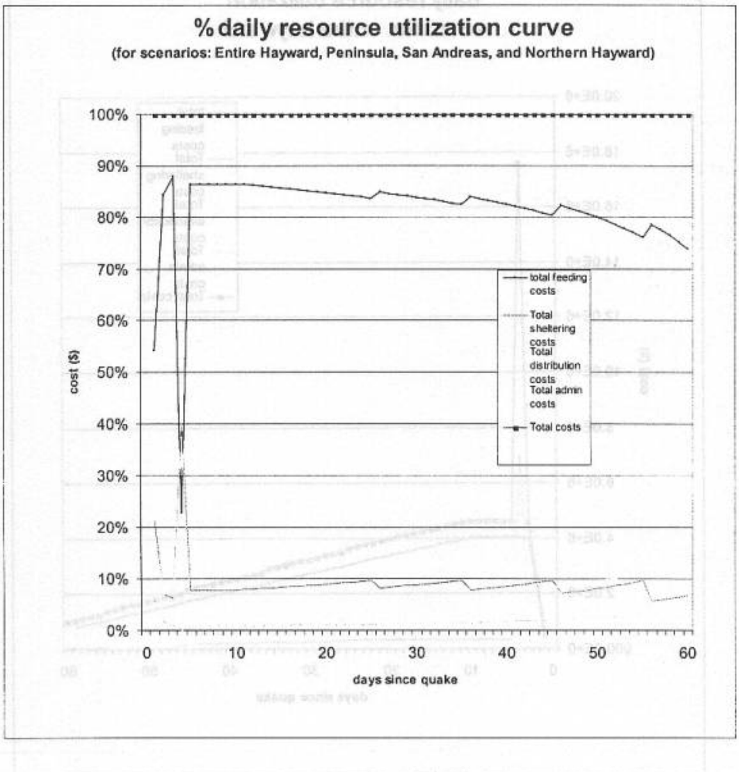

Figure 4- Percent Daily Resource Utilization

Percent Daily Resource Utilization:

Figure 4 illustrates the resource consumption (in terms of costs associated to them) as total daily percentages. It follows the patterns in population behavior and shelter operation assumptions (the zigzag pattern). The curve indicates the general pattern in the descending order of magnitude: the feeding, sheltering, distribution, and administration costs. The unusual spike on the (approximately) 3rd day indicates that the shelter population reaches its peak, and the one-time distribution items are distributed immediately during the initial peak. Therefore, for a short while, the balance in usual daily percentage cost consumption pattern changes and the feeding costs drop to 20% of the total daily resource consumption, which is usually around 80-90% during the course of 60-day operations. The administrative costs, on the other hand, stay under 5% in a stable manner, since no downsizing was assumed.

Daily Resource Utilization Hayward Combined Scenario

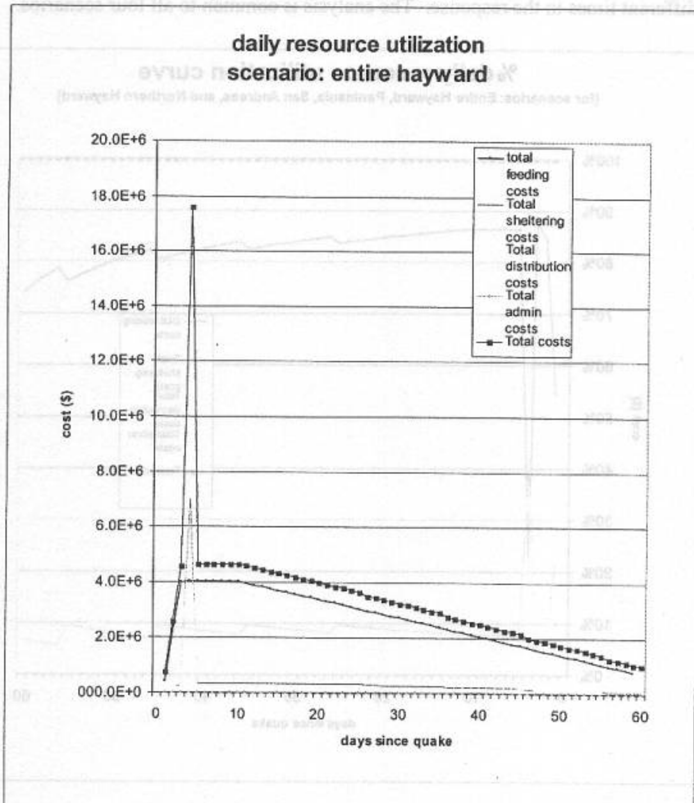

Figure 5- Daily Resource Utilization; Illustrative Example

Figure 5 shows the analysis of the daily resource consumption for the entire Hayward Fault Scenario. The other scenarios follow the same basic pattern. Figure 5 shows the patterns of resource consumption over 60-day period. It accelerates during the critical days initially, reaches its peak with the peak population, drops suddenly after the necessary items are distributed, and, then, follows a mild pattern of decrease for the rest of the time

Conclusions

Developing a model to predict the resource requirements and cost of the mass care response to a significant bay area earthquake is a difficult undertaking, which requires close coordination with the Red Cross and other responsible organizations. The results are a valuable planning tool in that they provide response planners some way to estimate the resource implications of their planning assumptions. The results presented in this report represent the current assumptions in a continuing and dynamic planning process. Alternative strategies will produce alternative resource requirements. And the value of this tool allows these resource demands to be calculated and to be part of the process of developing response strategies and tactics.

Modeling results reflect the ambiguity and uncertainty of the inputs used in the models. In this case, considerable ambiguity exists over which costs to include in the model and which cost values to assign to a resource. For example, should volunteers be assigned a salary cost equal to the value of their service? Should donated food supplies be assigned a value or treated as a free commodity? Two types of uncertainty affect all modeling efforts. The first type of uncertainty is model uncertainty--does the model adequately represent the real world? In this case, significant modeling uncertainty is produced by uncertainty over the organizational strategy and structure selected to represent the mass care response. The second type of uncertainty is the uncertainty in the model parameters. In this case, the major uncertainty is in the number of people demanding services. The demand for feeding and supplies is particularly poorly defined.

The uncertainty and ambiguity involved in the modeling process preclude using the numeric results as a basis for cost benefit decision-making. The results do, however, show that a significant cost can be avoided if persons can remain relatively self sufficient in their homes. Therefore, the degree of retrofitting of structures, protection of infrastructure, and individual and organizational stockpiling of emergency supplies required to achieve this goal should be investigated.

The results of the four scenarios examined show that large numbers of skilled mass care workers supported by a well-funded response organization will be required to mount a response that provides the minimum mass care needs to the impacted population. The analysis shows that the mass care challenge shifts from reacting to a peak shelter demand within the first week to establishing and maintaining an extensive feeding program.

The costs calculated in this study are a small fraction of the actual cost of the planned federal, state, and local response to a bay area earthquake. However, the mass care costs may be among the most avoidable of the response costs as the need for long-term sheltering and feeding can be minimized by preparation and mitigation. The cost models developed in this analysis can be used by the Red Cross and other emergency planners to project and to analyze the resource implications of planning strategies and tactics. The factors that most influence resource requirements can be identified and potential alternatives can be examined. The cost model will be refined and improved as the planning process in the Bay Area continues.

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