A Computer Simulation of a California Casualty Collection Point Used to Respond to a Major Earthquake

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I. The Casualty Collection Point

The California Emergency Medical Services Authority (EMSA) is charged with organizing and directing the State's medical response to major disasters. Detailed plans have been developed and tested for delivering large quantities of medical supplies, personnel, and equipment to counties. A critical part of the response is the establishment of Casualty Collection Points (CCP) in the disaster area. This paper reports on progress made to date to develop a computer simulation of a CCP's operational ability to care for large numbers of earthquake related victims.

The Casualty Collection Point Concept

CCPs "are sites predesignated by county officials for the congregation, triage, austere medical treatment, holding, and evacuation of casualties following a major disaster" (Freeman, and Haynes,1989). A casualty collection point would be established when: a local jurisdiction has confirmed or suspects that a sufficiently large number of casualties have occurred to overwhelm its medical transportation and treatment system; a significant number of hospitals have been seriously damaged or lost their ability to function; and the acute medical problems of the disaster require a protracted response lasting several weeks. A major deciding factor is the expectation that medical mutual aid to alleviate the acute medical problems will not arrive for two days (Freeman and Haynes, 1989).

It is assumed that initial life saving actions will be organized and performed by citizens and emergency responders. They will bring casualties to the CCP for care. From there the casualties will be moved by helicopter or surface transportation to either a hospital in the affected area or to an airport where they can be evacuated by fixed wing aircraft to unaffected areas.

The opinions presented in this paper are the authors and do not represent the position of the California Emergency Medical Services Authority or of California State University at Sacramento.

Table 1 identifies the factors that are involved in establishing a CCP. Many factors such as number and type of medical personnel available, availability and capability of air and ground transport, and number and distribution of injured are independent variables that effect a CCP's operational efficiency. They are included in the simulation and are more fully discussed below.

Operation of a Casualty Collection Point

A CCP is made up of a series of discrete interrelated steps that collectively result in medical care being provided to a casualty. Generally the stages are: triage, treatment, and evacuation. Each stage must be completed before the next can take place. Because of the large number of casualties anticipated they will often have to wait before they can complete any one of the steps. Generally, each patient has an injury. Each injury is triaged into one of four categories (Table 2). The rate of consumption of supplies and staff time is associated with the amount of care required to treat arriving casualties in each triage category. Stabilized patients are then transported to a hospital bed in the area or evacuated to another part of the state.

Medical care and services provided at a CCP are very limited. Such activities as casualty congregation and registration, triage, austere (life-saving) medical care, stabilization and preparation of casualties for transport, casualty holding, and casualty evacuation would be done. Table 3 summarizes the types of injuries that are expected for a major earthquake and the medical procedures that could be offered.

CCP operations are very labor intensive. EMTs, physicians, and nurses must be available to triage, treat, and monitor the condition of victims. Litter bearers are need to move casualties. Additional staff are needed for communications, administrative duties, and logistic support. Job descriptions, assumed staffing requirements, and team descriptions have been estimated based on expert opinion by the Authority (Freeman and Haynes, 1989).

The amount of medical supplies and equipment for treating 600 patients at a CCP for a twenty-four hour period has been estimated (Freeman and Haynes, 1989). Some medical supplies will be obtained early on in the area but the vast majority will have to be brought in. Generally both medical personnel and supplies are very limited.

Ground and air transportation are critical to the successful operation of a CCP. The Authority has published detailed requirements for CCP configuration to land helicopters, and for ground traffic management (Freeman and Haynes, 1989). The optimum number of ground and air vehicles required to evacuate the expected number of stabilized casualties from the CCP and to deliver the needed supplies over a twenty-four hour period is unknown.

Table 1

Factors Affecting Casualty Collection Point Establishment

1. Extent of damage of medical care system especially hospitals and other medical facilities.

2 The number and type of available medical and support personnel.

3. Availability of medical and support equipment and supplies.

4. Casualty number, location and injury severity.

5. Rate that casualties arrive at medical care sites (convergence at hospitals for example).

6. Rate at which surviving hospitals increase their capacity to care for disaster casualties by implementing discharge plans and expanding operations.

7. Availability of ground and air transport vehicles to move casualties to the CCP and from the CCP to care inside and outside of the disaster area.

8. Time it takes for the State to establish an effective casualty evacuation, and medical resupply system (personnel and supplies).

Adapted from: Freeman, and Haynes, 1989, p. 12-13.

Table 2

Definitions of Injury Categories

Priority 1 -- Urgent, the patient is critical and must receive immediate attention to save his/her life. Examples: head trauma or internal bleeding.

Priority 2 -- Very serious, the patient must be treated without delay. Example: compound fracture of the femur.

Priority 3 -- Serious enough to require hospitalization in many cases but requires no apparent special attention. Examples: simple fracture, missed diagnosis of a damaged spleen, every-day medical maintenance problems such as dialysis, or oxygen taken at home.

Priority 4 -- Out patients whose care can be delayed. Example: serious wound that is not life threatening.

Table 3

Types of Injuries and Medical Procedures to be Provided at a CCP for a Major Earthquake

1. Types of Injuries

Injuries/health problems which may be presented at CCPs include:

a. Lacerations
b. Fractures
c. Shock
d. Burns
e. Hazardous substance contamination/exposure.
f. Cardiac emergency care
g. Respiratory emergencies
h. Childbirth, emergency
i. Genital-urinary emergencies
j. Eye emergencies
k. Chest injuries
l. Spinal injuries
m. Penetrating body injuries
n. Crush injuries
o. Psychological emergencies

2. Medical Services

Specific medical procedures include:

a. Triage
b. Wound Care
c. Control of bleeding
d. Treatment of shock
e. Fluid replacement
f. Splinting of fractures
g. Pain relief
h. Initial care of burns
i. Mental health

Table 4
CCP Operational Assumptions

1. Uncontrollable Factors that Drive the Simulation for a major earthquake:

   - Magnitude of quake, building stock, and time of occurrence
   - Distribution and number of victim injuries from quake
   - Ability to rescue and move victims to CCP
   - Distribution and number of injuries upon arrival

2. Independent Variables that control the operation of the system:

   - Personnel (arrival time, level and assignment priorities)
   - Supplies (arrival time, use by priority)
   - Evacuation vehicle (type, carrying capacity and round trip time)
   - Capabilities and capacity of facilities receiving victims
   - Evacuation, triage and care priorities
   - Time to triage by injury, to provide care by injury, and before each priority patient dies
   - Amount of time that care extends life of casualty
   - Use of supplies by injury

3. Dependant Variables or measures of system effectiveness:

   - Mortality, morbidity, and number evacuated
   - Medical personnel utilization rate
   - Supplies utilization rate
   - Location of increase mortality or morbidity in the CCP care system
   - Vehicle requirements, utilization, and speed of evacuation

Field Demonstration of a Casualty Collection Point

The Authority and Sonoma County EMS Agency set up and ran a demonstration CCP in 1986 (Van Ness, Freeman, and Haynes, 1987). Early in the planning process it became clear that the undertaking was a massive and expensive one. Participant roles and responsibilities were defined for local law enforcement, fire service, hospital, American Red Cross, mental health and ambulance personnel. State agencies such as the California National Guard, Department of Forestry, Conservation Corps and Highway patrol were also involved. Eventually about 200 staff from various agencies filled direction and control, provider, and logistic support roles. An additional 80 local volunteers simulated casualties.

The primary objective of the demonstration was to produce a series of training video tapes, not to assess the operational characteristics and requirements of a functioning CCP. It also demonstrated that operational field testing of a CCP with a full complement of staff and a large enough pool of casualties to validate operational assumptions and efficiencies is extremely costly to undertake.

Questions to be Addressed by a CCP Simulation

We decided to simulate rather than model the operations of a CCP. A CCP model would demonstrate a strict correspondence between the elements of a CCP and the components of the model. It assumes that the relationship and interaction of operational components is well understood and can be mathematically defined. The model's predicted future states should closely mimic those that actually occur. In contrast, simulations allow experimentation where the relationship between variables is not known; the purpose of the simulation is to specify what these relationships might be (Casti, 1989). Each run of the simulation is an experiment to determine CCP performance characteristics under various conditions. It can not produce an all-or-nothing causal explanation (Rosen, 1978).

Such a simulation would be used by EMSA and local EMS agencies to:

1. Assist CCP administrators and other disaster response managers with response planning and real time disaster medical response decision making;

2. Determine the relationship between staffing and supply levels and delivery times, evacuation capabilities and casualty morbidity and mortality;

3. Determine and evaluate the medical staffing and supply needs, and costs of a CCP;

4. Evaluate triage, care, and evacuation policies; and

5. Identify possible bottle necks and other conditions that may increase the loss of life which could be prevented if detected by the CCP manager early on.

Existing EMS Disaster Computer Models and Simulations

Recently a great deal of effort was directed at improving casualty estimates for earthquakes and to apply these estimates to the prediction of the type and distribution of earthquake related injuries (Jones,1989). At least four computer models are being or have been developed and provisionally tested for predicting the recovery of trapped people in collapsed buildings (Shiono and Krimgold, 1989; Reavely, 1990; Durkin and Thiel, 1990; and Holmes, 1990). These models do not address medical care for casualties.

EMS disaster response software is capable of tracking inventories of personnel and supplies, and showing their geographic location. It is useful for assisting response management. However it is not designed for simulating complex and dynamic medical care operations and field response strategies.

Current day-to-day EMS system computer modeling has focused on optimizing response vehicle locations for transporting patients to hospitals (Valenzuela, and Criss, 1990 and bibliography). These models have been designed for mainframe computers and cost from $5,000 to $15,000 to run. Again, they do not address how an EMS system would respond to a medical disaster.

Medical models to care for battle field casualties have been developed by the military and are run on mainframe computers (Richards, 1983; and Fletcher and Richards, 1981; and Fletcher and Delfosse, 1979) but are not available for general use. Fletcher and Delfosse's work helped to clarify what our EMS disaster simulation might look like. However, the distribution and type of casualties, availability of medical aid and transport resources, etc., is not the same as those required to respond to an unpredictable natural disaster. For the most part military conflicts are well planned, natural disasters are not (Koehler, 1990).

As far as we know, neither dynamic EMS models nor simulations of medical disaster responses that can be run on a personal computer are available in the public sector.

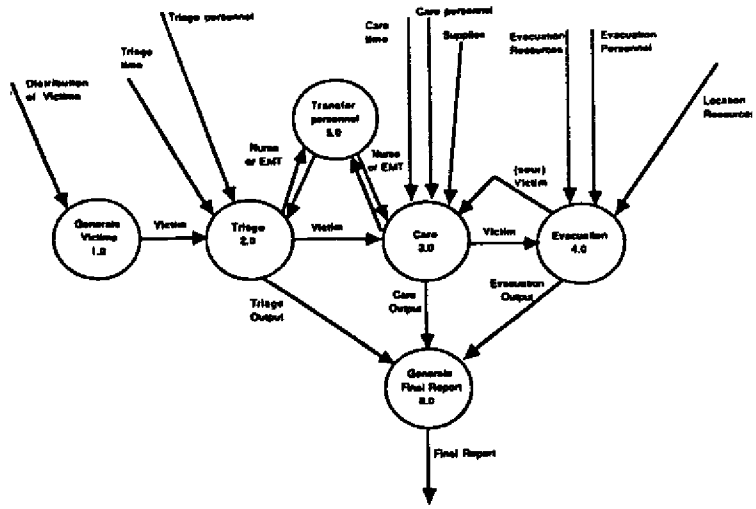
II. Simulation Development and Validation

CCP Simulation Operational Assumptions

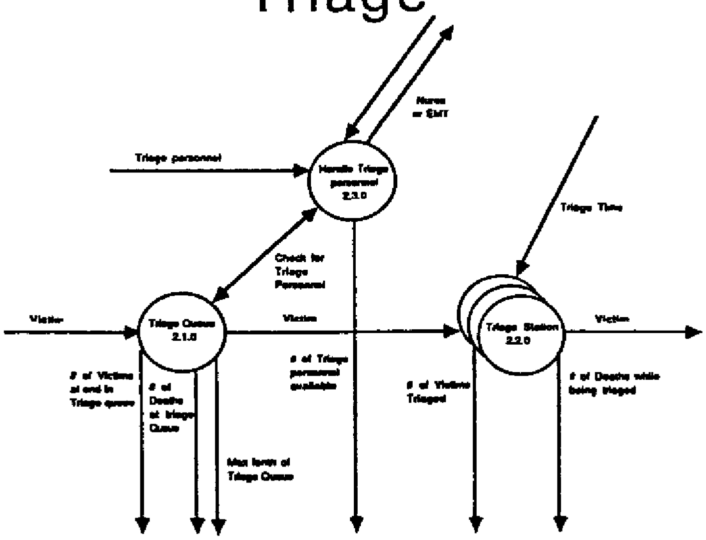
As noted, aside from the Sonoma field test showing that a CCP could be established, it is a theoretical concept that has not been operationally investigated. For example, staffing standards have been estimated but not established according to real time work load data. Medical supplies and equipment have been estimated but the rate that injured patients can be cared for and the use of supplies under such field conditions is unknown. Still these basic theoretical assumptions can serve as a basis for determining the CCP's organization and work flow (Diagram 1).

Diagram 1

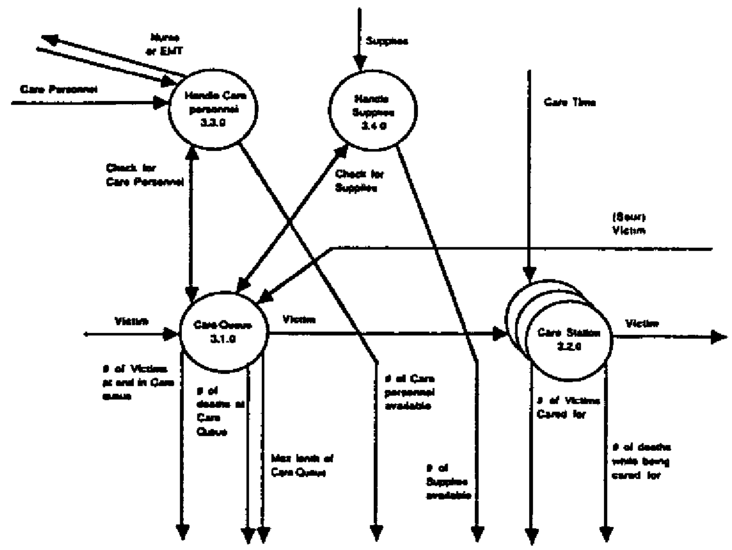
Simulation of a CCP



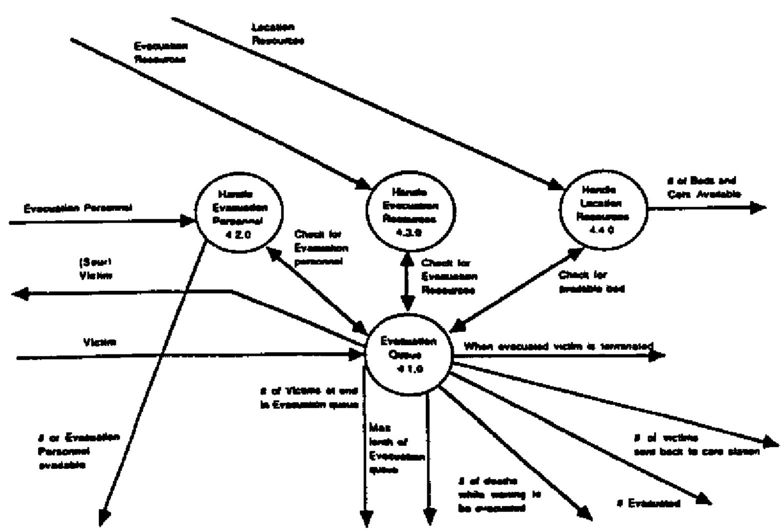
Triage



Care



Evacuation



Numerous theoretical assumptions about how victims will be cared for have been developed by EMSA based on hospital emergency department, EMS multi-casualty incident, and military field experience. Even though we don't know how a CCP works it is highly likely that medical care will be offered in a similar way.

Thus the basic organization and work flow of a CCP, the likely time it takes to care for a patient, how long before a patient dies based on the severity of their wounds ("golden hour"), the most probable distribution of casualties by injury (but not their distribution and arrival over time), among other important factors can be reasonably determined. It is how they dynamically interact that is unknown.

The distribution and arrival of injured casualties over time proved to one of the most difficult and yet important problems to be solved. Epidemiological data describes the shape of this curve for major earthquakes in developing and a few industrialized countries (Appendix). This distribution is highly dependent on building construction materials, time of day, work and movement patterns, and rescue capabilities, among other factors (EMS Authority, 1990; Jones, et.al., 1989). The shape, slope, relative distribution of injury type appears to be event specific to a large degree.

The approach decided upon for simulating casualty arrival at the CCP is not a perfect one. Casualties are divided into four injury categories (Table 3). Each injury category is assigned a level of injury, a mean arrival time and a standard deviation by the user. The last two values generate a time of arrival normal curve. The simulation program then randomly generates casualties according to these four normal distributions. Their arrival rate is tied directly to the slope of the curve or of interacting curves at any particular time. Because the distribution for each of the four priorities of casualties can be defined with either a relatively loose or tight standard deviation, the CCP simulation is able to accommodate varying distributions of injured patients over time resulting in varying mixes and arrival rates of casualties.

The simulation uses a four fold triage system. It does so because we are trying to determine who needs care first not who needs to be transported to get care. This triage method is similar to that used by many hospitals to triage patients that have been transported to them.

Variables not included in the CCP simulation that are relevant to its operation are: time it takes to establish a CCP, availability of personnel to warehouse and control supplies, availability of potable water and food, access to electricity, sanitation, casualties with an infectious disease (ie. public health problems), significant casualties exposed to hazardous material, rest period during a health care giver's shift, sex and age of victims, child birth, psychological or social emergencies, public convergence and disruption of the site, capability of a Regional Evacuation Point to receive victims, and variations in weather and seasonal conditions.

Operation of the Simulation

Environmental factors that are not controlled for in the simulation, and independent and dependant variables that affect the CCPs operation are identified in Table 4. The implications of the location of the CCP (far removed from a hospital vs. in its parking lot for example) in terms of its casualty mix, need for supplies, evacuation, etc., can be simulated.

Generally the simulation works as follows:

o Casualties: The user estimates the total number of earthquake casualties that will come to the CCP. The simulation software then apportions them among four injury categories according to the injury severity distribution assigned by the user. The computer places them in the triage queue according to this distribution.

o Triage: As each victim is generated and placed in a triage queue they are automatically assigned a user specified increment of time before they "die," and a beginning level of morbidity score (sicker casualties will accrue more "morbidity)." The time before death occurs starts when the victims arrives at the CCP, not at the time they received their injury. The mortality and morbidity of each injury category is tracked such that when their "life time" runs out they are counted as a death at a particular point in the simulation process. Morbidity is accrued up to the point of their death. It is possible for casualties to die in the triage queue. The time that it takes to triage each casualty priority is assigned by the user.

o Staffing: The user assigns the mix of health care providers for each of three skill levels (EMT, nurse, physician for example), including their arrival time, and work period. At the end of the work period the staff person is removed from the simulation unless they are busy triaging or providing care to a victim. When this is completed they are removed from the simulation.

It is assumed that all medical care providers have experience with caring for casualties in the field. The skill levels are broken down as follows:

o Lowest level care: least trained. Can stop bleeding and give CPR. Could be a First Aider or EMT-1.
o Midlevel care: equivalent to a licensed RN or paramedic.
o Highest level care: capable of providing the most advanced level of austere care. Must be available for maximum increment in care to be given.

Staff are assigned by the software as follows:

o Triage: requires one low level or midlevel person (EMT or nurse for example) to triage. If no one is available the casualty waits in the triage queue.

o Care Station: requires a team of two and supplies to care for a casualty. For example, in terms of specific training, the following combinations would be acceptable to provide care: MD + EMT-1, MD + Nurse, Nurse or Paramedic + EMT-1.

Assignment of personnel to the care station is given priority over assignment to triage. In other words if there are people waiting in the triage queue and the care queue, the staff will be automatically allocated to provide care, not to triage.

o Supplies: Supplies are defined as integers (arbitrary "amounts") rather than as specific quantities of bandages and the like. The user can define how many supplies are used by each injury priority, and the amount that will arrive at a particular time.

o Care: Once triaged the simulation moves the victim to a care queue and from their to the care station. The sickest casualties (priority 1) are given care first followed in order by priority 2, 3, and 4. Medical resources are consumed and care provided according to their injury priority. Provision of care results in a reduction in morbidity and an increase in the amount of "life time" they have available (defined as 50% of originally assigned "life time"). A casualty can die in the care line and at the care station. Care cannot be provided unless there are staff and supplies available.

o Evacuation: Victims who have received an increment of care are considered stabilized and are placed in the evacuation queue. The most seriously injured are evacuated first. Priority 4 victims are assumed to be able to walk away. The availability, carrying capacity, return time of helicopters and ambulances, and hospital bed availability are assigned by the user. If evacuation assets are not available and Priority 2 and 3 use up all but twenty minutes of their "life time," they are returned to the care queue and upon reaching the care station receive an increase in "life time" equal to 50% of their original assigned "life time." Priority 1 injured are assumed to benefit from the one increment of care they have already received and are not returned to the care queue for additional care after they are placed in the evacuation queue.

Victims can be evacuated either to a local hospital or to a Regional Evacuation Point such as a functioning airport where they will be moved to another part of the state for definitive care. Priority 1 victims are evacuated to the hospital first if beds are available. The number of hospital beds can be set by the user.

o Data: At each stage in the triage/medical care/evacuation chain the mortality and morbidity is calculated for each victim and summated. Generally, mortality and morbidity are increased when treatment is delayed either by queuing or depletion of critical care and supply resources. Those casualties with initially severe injuries are at greatest risk of dying in the simulation. Data on mortality, available personnel, supply use, and evacuation is reported out in six hour increments over a 72 hour period.

Computer Software

The software has two components: a user interface written in Turbo Pascal and GPSS (a proprietary general purpose simulation program). The programmers developed a user interface to make the program user friendly. GPSS is a discrete process-oriented simulation language allowing the simulator to define specific processes involved in the system such as queuing lines, providing services, and collecting statistics (Bronson, 1984). Both programs can be run on an IBM compatible machine with 640K of resident memory. The program simulation software is defined and discussed in D. Foley and M. Jones, "Disaster Recovery System Model of a Casualty Collection Point" (Foley and Jones, 1990).

Simulation tests and Validation

The CCP simulation software was tested to make certain that the user defined and other parameters were working properly (Brewer and Hall, 1972, provide general guidance for evaluating a simulation used for policy making). Generally test results indicated that the CCP model was acceptable and that the major drawbacks were not serious enough to invalidate the data.

The initial step was to assign extremely low values to all of the independent variables to determine the effect on casualties. For example, no personnel were assigned resulting in all of the casualties dying in the triage line. This test was conducted for personnel, supplies, evacuation vehicles, and hospital beds. In the first three cases all of the relevant casualties died. In the last an excess number of priority 1 casualties died. In summary the CCP simulation passed all of these tests.

Typically GPSS uses a random number seed to generate customers or other entities that are acted upon by the simulation. Each simulation run uses a different random number seed. A statistical test comparing run data must be performed to see if the results are significant. Random number seeds are not used in the casualty collection point simulation. As noted, what is provided is a normal distribution using a user defined mean and standard deviation. Casualties arrive in a random way within the peramters of this curve. Multiple runs with the same input results in identical outputs.

A second series of tests looked at how significant variables were numerically defined (range of values that could be assigned for example) compared to the expected range of values that would be assigned by the user. Problems identified are:

o Limitations on the size of the allowable casualty standard deviation relative to the mean (could not be any less than 1/3 the value of the mean) made it difficult to define victim distributions that rose steeply immediately following the event and then gradually tapered off with smaller periodic increases. Such a pattern could fit current expectations of how casualties will be generated in a major earthquake in California.

The data on earthquake casualties reported in the appendix indicates that this may not be a very serious problem since the time when the peak number of persons arrive at the CCP is very close to the peak reported by the simulation.

o Assignment of "life times" to the least injured casualties produced an excessive number of deaths since no one in this category would in fact die. The reported average morbidity for a particular CCP operational element was also too high for the same reason.

The first problem can be dealt with in three ways depending on whether this group is to be given medical care or not. If they are to be given medical care the overall mortality can be adjusted by by subtracting the priority 4 deaths from the rest. A second approach would be to set the amount of care time and supplies for this group to zero. This turns out to be the most effective approach since they can be triaged and are then evacuated from the simulation. The third approach is to assign a very large life time. This simply increases the run time of the simulation without changing the mortality rate. The problem with over estimating morbidity has not been resolved as of this writing.

o Priority 3 casualties are a very difficult group to predict outcomes for. Many of the individuals included in this group would not die but would experience serious morbidity if they did not receive care. After stabilization they would probably be directed to a Red Cross Shelter and not evacuated. On the other hand, this category also includes outpatients with serious illnesses that require technology dependant care such as dialysis, or continuous administration of oxygen. If this care is withheld for long they will die. In all likelihood the casualties in this category are probably overestimated by the simulation by from 70-90% even if this last group of outpatients are included. A hand calculation by the user can make this adjustment when reporting the data.

o The evacuation capacity of ambulances and helicopters acted more like an evacuation policy in that the injured would not be transported unless the transporting vehicle's capacity was full.

Apparently the simulation can not evaluate the use of different vehicles with different transport capabilities. However, the simulation does allow evaluation of ambulance and helicopter filling evacuation policies.

Two more software and hardware problems were identified:

o In some cases run time was very long. This seemed to depend on the number of casualties, how many arrived at one time, and their injuries.

o The typical PC resident memory of 640K was exceeded for large casualty runs.

III. Earthquake Response Planning Simulations

Perhaps the most important test of the CCP simulation is whether it offends common sense by failing to generate good enough data to assist with reasonable policy choices. Two scenarios were developed based on "best" and "worst" case state and local response capabilities of EMSA for a major earthquake. The "best" case simulates a situation where the local agency has done a great deal of operational planning, and is able to quickly mobilize personnel, supplies, and evacuation vehicles. The state is able to deliver staff and supplies within 12-24 hours. The "worst" case simulates the more or less ad hoc development of a CCP under the best of conditions. A few personnel can be located, there are some medical supplies in the general area, and some ambulances can be found. The EMSA begins to deliver personnel and supplies 36 hours after the event. In both cases the CCP is not located next to a hospital or airport.

A. Simulation Assumptions

1. Number and distribution of Casualties: 650 casualties were assigned to both simulations. The distribution of injuries and their arrival time (Table 5) is based on studies of California earthquakes (Van Ness, Freeman, and Moorhead, 1984; and National Oceanic and Atmospheric Administration, 1973), international experience, and recent efforts to improve casualty estimates (JHU, 1989; EMSA, 1990).

CCP arrival time by distribution of injuries (Table 5) is based on reports on "fade-away" times for trapped victims, effectiveness of rescue operations, and final death toll reported at the 1989 John Hopkins meeting, 1980 Italian earthquake data, and simulations and data on the 1985 Mexico City earthquake (Appendix). The estimates used here are comparable to injury data for the Loma Prieta earthquake.

Table 6 reports the assigned mortality value for each injury priority. This value in minutes is the life-time remaining that is assigned upon entry into the

Table 5

Injury Distribution and Arrival Times for Best and Worst Case

Priority	Percent of Injuries	Time of Arrival*: Mean	Standard Deviation
1.	.04	8 hrs.	2 hrs.
2.	.06	8 hrs.	2 hrs.
3.	.10	12 hrs.	4 hrs.
4.	.80	3 hrs.	1 hr.

*These values are limited by mean/standard deviation limitations built into the software.

Table 6

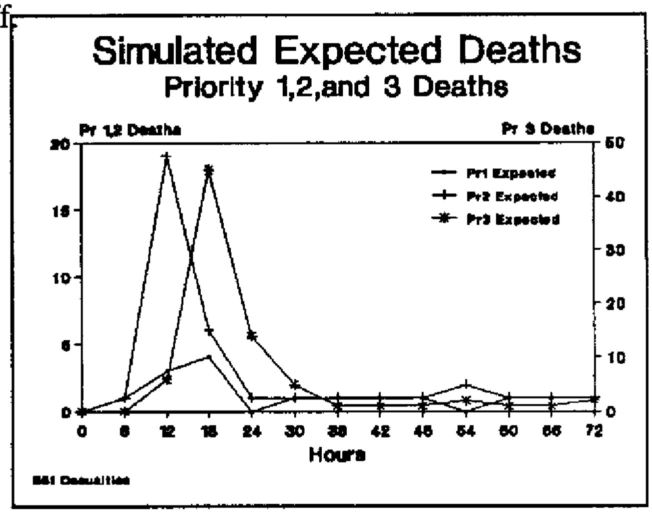
Life time Remaining for Each Priority Upon Entry into the Triage Queue

Priority 1	60 minutes
Priority 2	120 minutes
Priority 3	240 minutes
Priority 4	480 minutes

triage queue.

The simulated profile of the time of casualty deaths if no care is provided is shown by Graph 1 for priority 1-3 patients. This distribution also serves as a general proxy (it is skewed to the right) for how many and when casualties are assigned to the CCP since the time it takes by definition for Priority 1, and 2 victims to die is less than six hours.

2. Medical Personnel: The number of medical personnel are assigned by the user to a particular six hour increment provided by the software; a value of zero to 99 can be assigned to any particular increment. Table 7 shows the distribution for the "best" and "worst" case. It is assumed that an ambulance staffed with two EMTs will be able to begin providing care within six hours of the event in both cases. The remaining arrival times assume that staff is found locally and are being flown in from outside of the disaster area. In the "best" case outside help is able to augment staff by 12-24 hours into the event vs 36 hours for the "worst" case. Medical personnel are taken out of service after 18 hours have elapsed. Staffing estimates are based on the best "guess" of EMSA disaster staff.



3. Supplies: It is very difficult to determine how many supplies will be delivered at a particular time because of the arbitrary method chosen to represent quantity. Generally it was felt that relatively few supplies would be available early on in the area because the CCP is not located close to a hospital. Supplies would have to be transported to the CCP from within and outside of the area.

4. Triage and Medical Care: Table 8 reports the triage time and austere medical care time for each priority. Both times include basic record keeping such as filling out the triage tag. It is assumed that the care time is sufficient to stabilize the patient. Both are based on estimates by an emergency physician and surgeon experienced in treating medical injuries in the field. For the "best" case it is assumed that all casualties will be triaged but only priority 1, 2, and 3 will receive medical care and use supplies. Priority 4 casualties will be directed to a first aid station. This policy is not adopted

Table 7

Staff Arrival Time at the CCP

Hour	Staff: Best Case	Worst Case
0	2	2
6	4	3
12	2	0
18	1	4
24	8	2
30	3	1
36	7	7
42	5	5
48	17	17
54	8	8
60	5	5
66	10	10

Table 8

Triage and Care Time by Injury Priority

Priority	Time for Triage	Time for Care	Supplies
1.	4 minutes	10 minutes	1
2.	4 minutes	15 minutes	5
3.	3 minutes	3 minutes	3
4.	3 minutes	0 minutes ("best") 3 minutes ("worst")	1

for the "worst" case simulation. The relative proportions of supplies needed to care for each injury were estimated in the same way.

5. Evacuation: The evacuation policy adopted for the "worst" case simulation was that an ambulance or helicopter should leave when it has two patients. The "best" case assumed that large numbers of stabilzed patients would have to be evacuated and set the evaucation policy that ambulances should leave when they have four stabilized patients, helicopters when they have six. The round trip to the hospital or Regional Evacuation Point was set at one hour for both simulations and for both methods of evacuation. For the "best" case scenario, one ambulance arrives at hour zero, and three at hour eight for a total of four. For the "worst" case scenario, one ambulance arrives at hour zero, one at hour sixteen, and one at hour twenty-four for a total of three ambulances. No helicopters are available. Again, these estimates are based on best "guesses" provided by EMSA disaster staff. In both cases there are 75 local hospital beds available.

B. Simulation Results

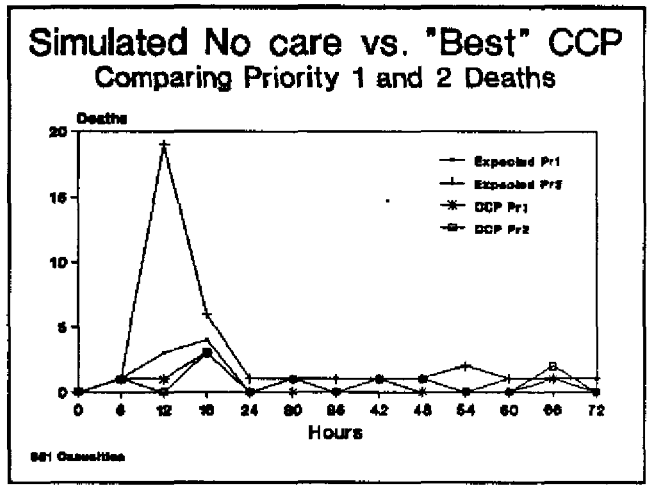
Distribution of Deaths: Table 9 reports the distribution of deaths by injury priority. The "best" case would see a 49% reduction in deaths or a savings of 32 lives compared to no care deaths vs. a 25% reduction in lives lost for the "worst" case. Note that we are assuming here that all of the priority 3 deaths will occur. If only 10% of this group died, the deaths would be as follows: then there would be: 72 (11%) for no care, 22 (3%) for "best" care, and 43 (7%) for "worst" care. The "best" level of care death rate compares favorably with the VietNam and Korean casulty death rate of 3% (Fletcher and Richards, 1981). This can probably be reduced even more.

Table 9

Distribution of "Worst" and "Best" Case Deaths by Injury Priority for 650 Casualties

Priority	No Care	Best Case	Worst Case	Difference
1.	26	7	10	3
2.	39	10	27	17
3.	65	49	61	12
Totals:	130 (20%)	66 (10%)	98 (15%)	32

Graphs 2 ("best" case) and 3 ("worst" case) show when in time priority 1 and 2 deaths occurred compared to when they would have occurred without care. A large number of priority 2 deaths occur between hours six and eighteen for the "worst" case scenario and between hours twelve and twenty-four for the "best" case. Graphs 4, 5, and 6 compare number of deaths over time by injury priority for each scenario.



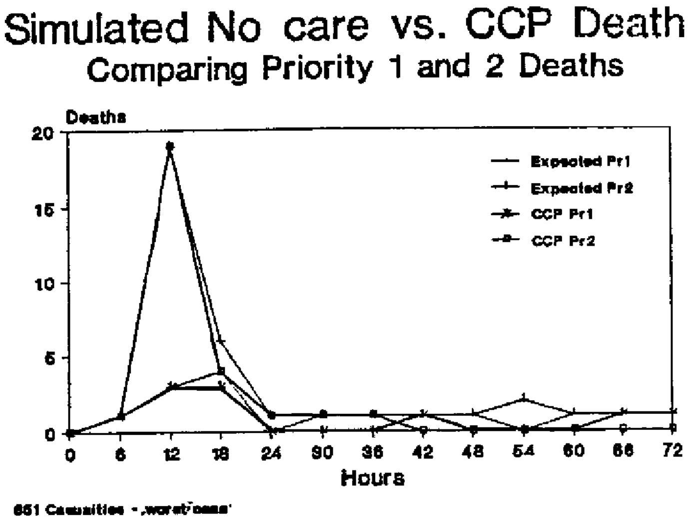
The CCP location where the deaths occurred are reported in Table 10. The largest number of deaths for both simulations occurred in the care queue (this was also true of battlefield simulation findings, Fletcher and Richards, 1981). The "best" case saw more deaths occurring in the evacuation queue.

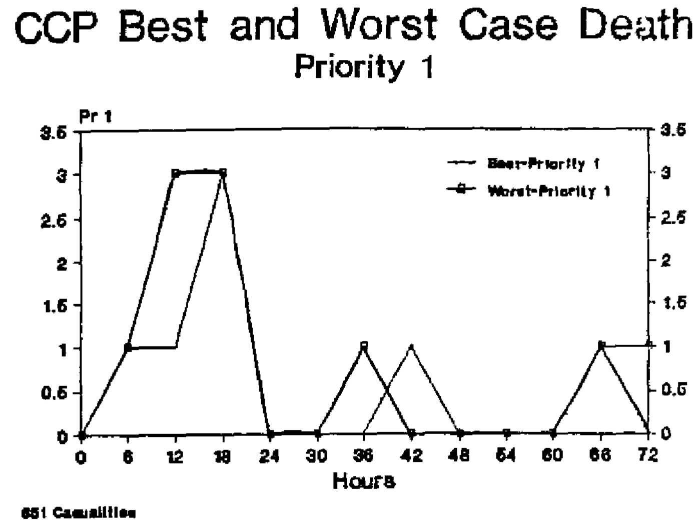
Operational Indicators: The simulation reports staff and supplies available every six hours. Graphs 7, 8, and 9 report this data.

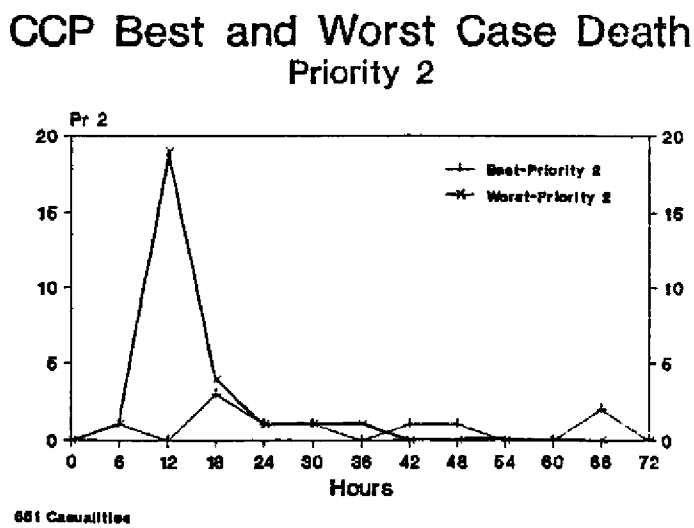
The CCP simulation records data on the maximum length of the triage, care and evacuation queues, the total number of victims triaged and given care, the number sent back for care from evacuation because they could not be evacuated before they died, and the number evacuated. This data is presented in Tables 11 and 12.

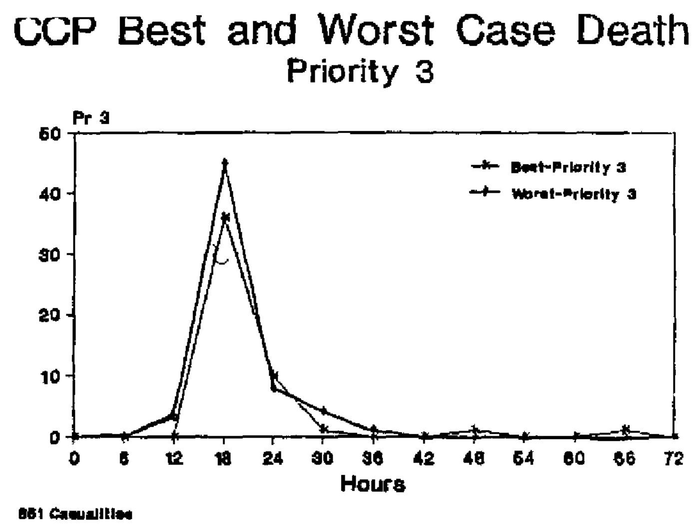
C. Discussion of Simulation Results

There is a substantial difference in estimated number of deaths between the "best" and "worst" case scenarios; ninety-eight deaths for the "worst" case, sixty-six for the "best" case. Most of the "best" case scenario deaths occur between twelve and twenty-four hours following the event. "Worst" case deaths occured between six and twenty-four hours following the event. The single factor that varies the most during this time period is staff providing care on site (a similar finding was made for military battlefield simulations, Fletcher and Richards, 1981). Table 13 reports the number providing care at a particular time (the staffing before the twenty-four hour increment determines what will be reported at that time).

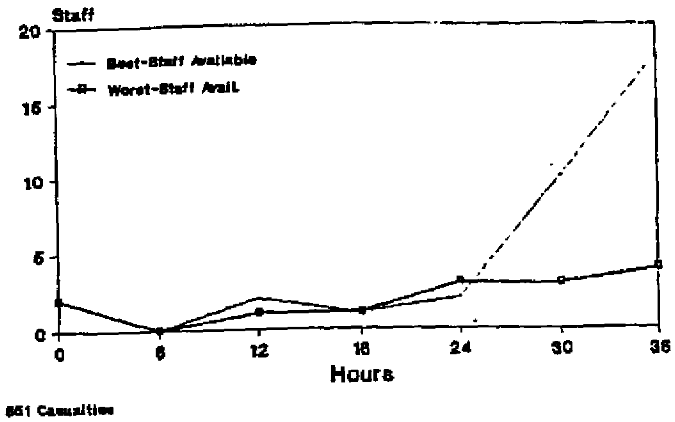

Simulated No care vs. CCP Death
Comparing Priority 1 and 2 Deaths
Deaths
Expected Pr1
Expected Pr2
CCP Pr1
CCP Pr2
Hours
651 Casualties - worst case


CCP Best and Worst Case Death
Priority 1
Pr 1
Best-Priority 1
Worst-Priority 1
Hours
651 Casualties

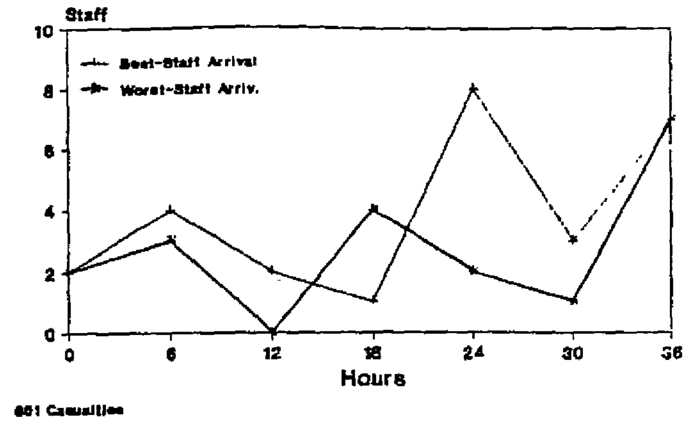

CCP Best and Worst Case Death
Priority 2
Pr 2
Best-Priority 2
Worst-Priority 2
Hours
651 Casualties


CCP Best and Worst Case Death
Priority 3
Pr 3
Best-Priority 3
Worst-Priority 3
Hours
651 Casualties

Staff Available
Best and Worst case Compared



Staff Arrival
Best and Worst case Compared



graph 9

Best vs. Worst CCP Stock
(6 & 30 Hrs. 50+ Units for best case)

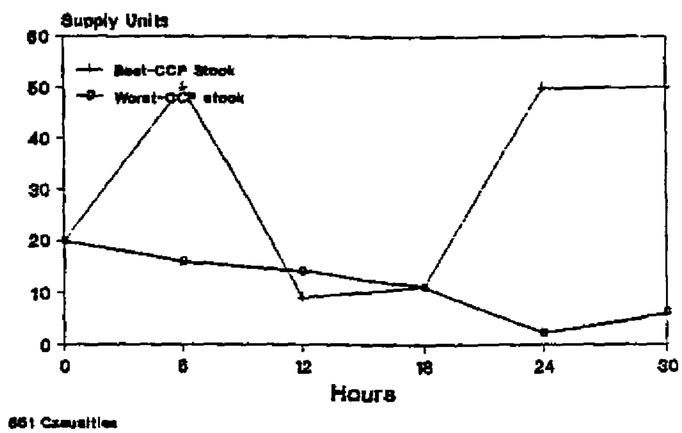


Table 10
Location of "Best" and "Worst" Case Deaths at the CCP

"B" = Best "W" = Worst

Priority	Triage		Care Queue		Care Station		Evac. Queue	
	B	W	B	W	B	W	B	W
1.	0	0	3	6	1	1	3	3
2.	0	0	5	27	0	0	5	0
3.	0	0	46	61	1	0	2	0
Totals:	0	0	53	94	2	1	10	3

Table 11

Maximum Length of Triage, Care, and Evacuation Queues and Number Given Care

Scenario	Triage Q	Care Q	Evacuation Q	# Given Care
Best	168	258	4	612
Worst	168	326	3	192

Table 12
Movement of Casualties inside of and from CCP

"B" = Best Case "W" = Worst Case

Priority	Sent Back for Care		Hospital Evac.		REP Evac.	
	B	W	B	W	B	W
1.	0	0	8	5	0	0
2.	6	2	8	9	0	0
3.	9	2	NA	NA	30	18

Table 13

Medical Staff Providing Care by Hour at CCP

Scenario	Hours after event: 0	6	12	18	Total Assigned
1. "Best"	2	6	8	7	23
2. "Worst"	2	5	5	7	19

By twelve hours after the event the "best" scenario has eight treatment personnel on site vs. five for the "worst" case. At about this time Priority 1, 2, and 3 casualties begin to arrive and die in mass (Graph 1). As pointed out above, care of victims is dependant upon the ability to form "care teams." In this case we are assuming that it is necessary to form a two person team with one member being either a doctor or a nurse. This relatively small difference in the number of staff (3) at this early time in the response hinders the number of medical care teams that can be formed (Table 14) resulting in a serious lag in the rate that care can be provided in the "worst" case scenario leading to a substantial build up in the care queue. This problem is made worse because priority 4 casualties must be given care thus increasing the "worst" case workload. By the time an additional increment in treatment staff occurs at eighteen and twenty-four hours, the priority 1, and 2 casualties have already died in the care queue or are about to. A very large and probably impossible increment in treatment care staff would be necessary to stop the snow ball effect that began at hour six.

Table 14

Formation of Care Teams

Hour	Number of Care Teams Formed: "Best"	"Worst"
0	0	0
6	2	2
12	4	2
18	4	2
24	4	2
30	4	2

Interestingly the "best" case was assigned only four more staff than the "worst" case. This data and that reported above seems to indicate that the mortality rate may be highly sensitive to workload (ie. not having to treat priority 4 casualties), to small increments in the number of staff, and to when the staff are delivered to the CCP.

Adopting the policy of triaging but not caring for priority 4 vicitms and refering them to a first aid provider apparently had an important effect on mortality. Additional simulation runs indicated that this policy resulted in an additional twelve lives being saved (two priority 1, two priority 2, and eight priority 3) when compared to a policy that would treat them. Again, military casualty care simulations findings are consistent with ours. A change in who gets what care or procedure, particularly those who probably don't require it, can significantly improve productivty (Fletcher and Richards, 1981).

Generally the simulation seems to show that mortality appears to be directly related to the arrival time and mix of staff on site, triage and care policies, and that the sudden massive arrival of casualties will result in a "snowballing" increasing in mortality if staff is two low or does not include the proper mix of training to form "care teams."

Six additional simulations with increased staffing and different times of arrival were run. Additional staff early on tended to reduce the number of priority 3 deaths but at the expense priority 2 deaths increased. It may be that priority 2 casualities arrive in large numbers very quickly. All of their life clocks start running and they quickly expire before they can be cared for leaving time to care for priority 3 casualties. However, large number of additional staff on site with adequate supplies should be able to save priority 2 lives. Apparently the "best" case care scenario is very close to the optimal number of staff required for a CCP if priority 1 and 2 deaths are to be reduced at this point. On the other hand it may be that the simulation software is biased in some unknown way to produce these results.

The values set for supplies for both scenarios were not small enough at any particular moment to delay the treatment of casualties. However such delays would probably create a similar problem to that identified above.

About three times as many people died waiting for evacuation in the "best" scenario compared to the worst. This was so even though the earlier had only 25% more evacuation resources. One explanation could be that the larger number of ambulances available early on (four) for the "best" scenario probably allowed them to transport a significant number of casualties but not enough to keep up with the number being stabilized for transport. This may have accounted for the larger number of deaths in the evacuation queue. A second "best" case simulation was run changing the evacuation policy to two for both ambulances and hospitals. This "load and go" policy saw one additional priority 1 patient die but saved an additional five priority 2, and two priority 3 lives. This approach is consistent with trauma system studies that recommend that patients be transported as quickly as possible (Eastman, et.al., 1987).

The relatively late arrival of the helicopters probably made little difference. Perhaps helicopters should be used for long range transport of personnel and supplies to make the CCP operational, rather than for long range hops to hospitals in the area that are about equal to the surface transport time of ambulances. On the other hand helicopters could quickly move large numbers of casualties to hospitals close by which could reduce mortality even further (Fletcher and Richards, 1979).

Fifteen casualties were sent back to the care queue for the "best" scenario in contrast to only four for the "worst" case. Given the relatively long length of the "best" care queue, many of the priority 2 casualties returning for care probably died there. Thus a higher care rate does not necessarily mean a higher survival rate particularly if it is combined with a poor evacuation policy. In fact this particular feed-back loop could result in even more sever problems for the care providers if few evacuation transport vehicles were available at the right time.

The "worst" case scenario tells a little different story. Two ambulances were available when the most casualties were being cared for. Because of care delays already noted, far fewer stabilized casualties were making their way to the evacuation queue. Thus the smaller number of ambulances, combined with the "scoop and run" policy were able to perform better than the larger number assigned to the "best" scenario. This finding suggests that casualty transportation assets should be carefully matched with available treatment staff at any one CCP. It also suggests that given the delay in casualty arrival and care, Other transportation resources such as buses and cars could be used to quickly deliver treatment personnel to CCPs during the first one to four hours following the event when the least injured are probably arriving. Later in the response it may be appropriate to use these transport assets to smooth the arrival time of treatment personnel so that the described snow ball effect does not start. This could also be done by transporting treatment personnel back from the hospital or Regional Evacuation Point after a stabilized casualty is delivered.

The long care, triage, and evacuation queues indicate that there is a need to comfort, monitor pulses, apply a pressure bandage, and assist casualties as they wait. This could be done by relatives or volunteers. Emotional support should be available to deal with grieving relatives and to reduce frustrations and stress caused by waiting in a queue for care.

Implications for Local and State Preparedness

The "Job Descriptions and Team Configuration" identified in the Authority's CCP guidelines call for twenty-one triage and treatment related personnel. Both simulations reach this level after eighteen hours. So it is not the number of staff that is important but when they are on site and their ability to form medical care teams. The "best" simulation suggests that a more modest staffing level may provide good outcomes early on if a significant number of care teams can be on-site within six hours and a relatively small number of care teams can be continuously delivered. An effective evacuation system that can keep up with casualty stabilization is also required. On the other hand the need for large infusions of staff and supplies by the state could be anticipated after twelve hours or so if the death snow-ball effect identified due to low staffing and\or level of supplies becomes established.

One approach to this problem would be to locally organize large numbers of medical care teams (only two medical care providers are need for each team) that are ready at a moments notice to staff preestablished CCP locations. Prepositioned supplies would also be required to jump start the response. For example caches used for day-to-day for multi-casualty trauma accidents in the disaster area could be gathered together in one place and easily moved to preidentified CCP locations. Transportation assets could be used to selectively adjust the level of readiness of CCPs as sketchy information comes in on the actual geographic distribution of casualties. Given the chaotic way in which a medical response to a disaster organizes itself, it may be necessary to hold some of the medical personnel and supplies in reserve so that they can be quickly assigned to unexpected casualty sites (Koehler, 1990). Obviously this would require a functioning CCP-emergency operations center communication system to accomplish.

A new acronym for this local effort might be "SHOVE." SHOVE would involve the immediate self dispatching of preorganized medical care teams and supply cashes, according to some predefined criteria (magnitude 7.5 earthquake for example) to preidentified CCPs within the area such that they arrive prior to the expected peak of casualty arrival. At least one team would bring the necessary radio communications with them. Consideration should also be given to preidentifying local heavy equipment assets that can be used to quickly open roads to CCPs so that medical personnel and supplies can be moved in and stable patients evacuated.

The institution of a care policy that could have short run detrimental effects on a large group of casualties such as not treating priority 4 victims, could have serious consequences. Law enforcement problems could be created if these people have to travel a long distance for first aid care. Also first aiders must be trained to treat serious lacerations that are not life threatening in a effective manner. This suggests that a first aid station should be set up close to a CCP and be prepared to handle large numbers of slightly injured casualties after CCP triage.

Clearly the Authority must be able to deliver a large numbers of staff and supplies very early on in the response. The EMSA's PUSH concept, which calls for the almost immediate mobilization of massive quantities of preidentified supplies and personnel, is validated. However, the overwhelming number of casualties that would arrive around four to six hours after the event suggests that a more rapid "front-end" support effort is necessary. Both the San Francisco Bay Area and the Los Angeles basin are surrounded by highly populated counties that may not be affected by the earthquake. Both regions are also linked by commercial airlines. While the surrounding counties will be used to receive casualties, care teams and mobile trauma medical supply kits could be self-dispatched (8.0 magnitude earthquake) or standby to be dispatched (7.5 magnitude earthquake), to preidentified air fields for transport by commercial aircraft to state managed staging areas close to or within the disaster area. (A plan similar to this has already been developed and is being implemented by San Bernardino, San Diego, Riverside, Mono, and Inyo Counties.) A similar effort could be mounted from the Los Angeles basin or San Francisco bay area depending on where the event occurs. In either case EMSA or the involved counties would have to precontract with airlines and other carriers to provide this service.

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Appendix

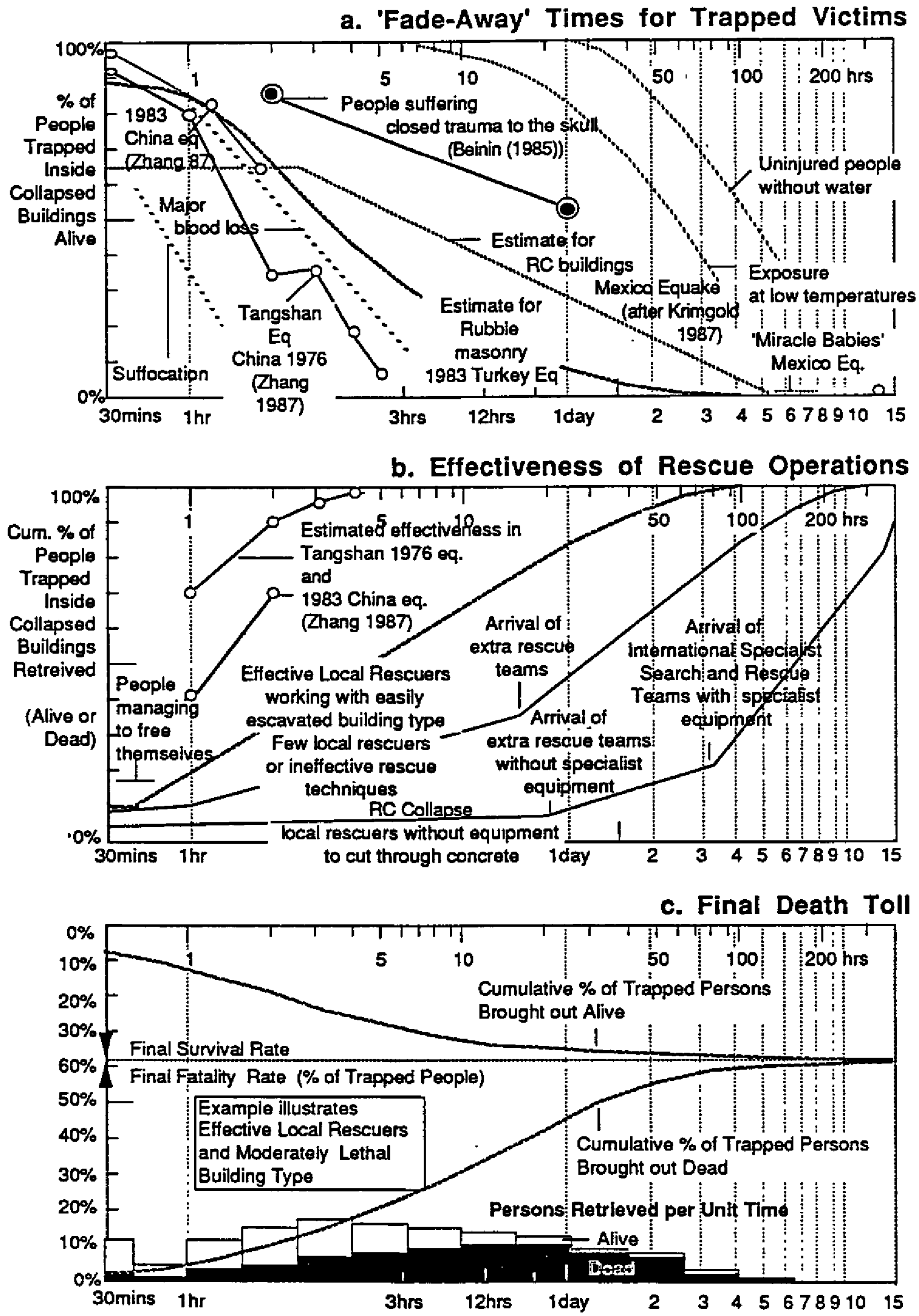

a. 'Fade-Away' Times for Trapped Victims
100%
% of People Trapped Inside Collapsed Buildings Alive
0%
1983 China eq (Zhang 87)
Major blood loss
Suffocation
Tangshan Eq China 1976 (Zhang 1987)
People suffering closed trauma to the skull (Beinin (1985))
Estimate for RC buildings
Estimate for Rubble masonry 1983 Turkey Eq
Mexico Equake (after Krimgold 1987)
Uninjured people without water
Exposure at low temperatures
'Miracle Babies' Mexico Eq.
1
5
10
50
100
200 hrs
30mins
1hr
3hrs
12hrs
1day
2
3
4
5
6
7
8
9
10
15
b. Effectiveness of Rescue Operations
100%
Cum. % of People Trapped Inside Collapsed Buildings Retreived (Alive or Dead)
0%
Estimated effectiveness in Tangshan 1976 eq. and 1983 China eq. (Zhang 1987)
People managing to free themselves
Effective Local Rescuers working with easily escavated building type
Few local rescuers or ineffective rescue techniques
Arrival of extra rescue teams
Arrival of extra rescue teams without specialist equipment
Arrival of International Specialist Search and Rescue Teams with specialist equipment
RC Collapse
local rescuers without equipment to cut through concrete
c. Final Death Toll
0%
10%
20%
30%
60%
50%
40%
Cumulative % of Trapped Persons Brought out Alive
Final Survival Rate
Final Fatality Rate (% of Trapped People)
Example illustrates Effective Local Rescuers and Moderately Lethal Building Type
Cumulative % of Trapped Persons Brought out Dead
Persons Retrieved per Unit Time
Alive
Dead

Figure 13

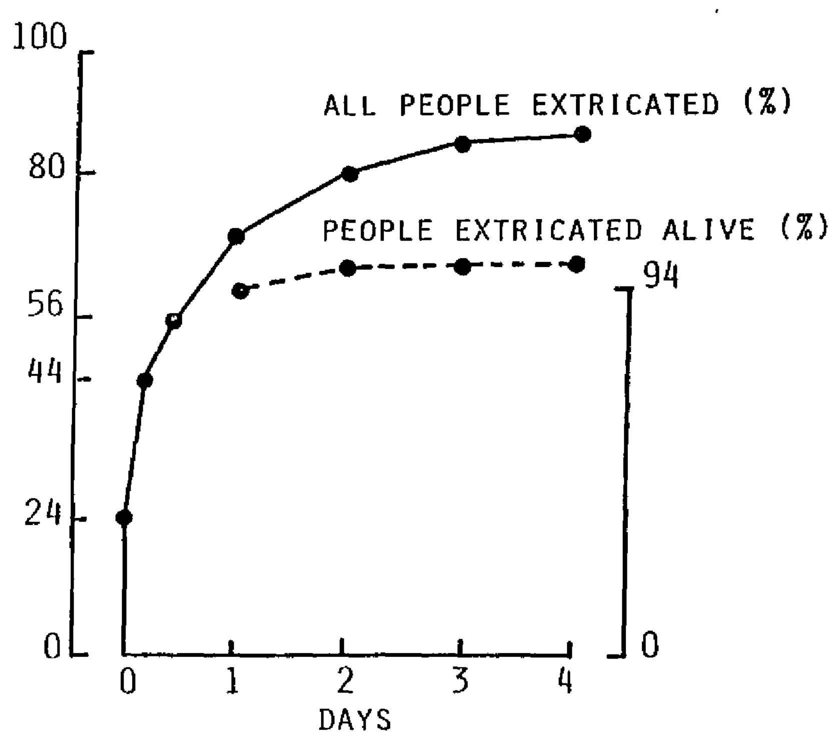
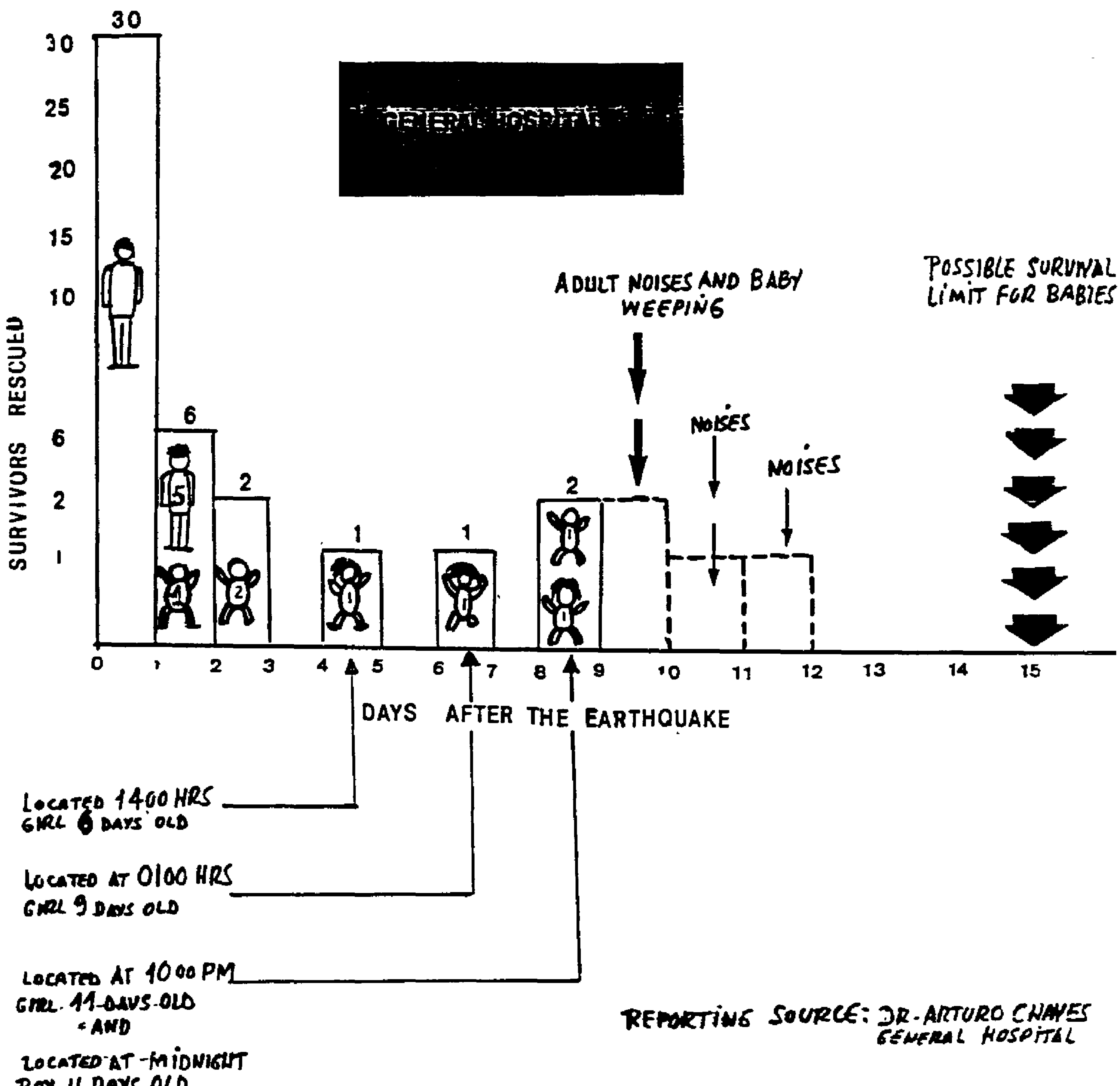


Fig. 2 : CUMULATIVE NUMBER OF PEOPLE EXTRICATED, TOTAL AND ALIVE, ACCORDING TO DELAY IN RESCUE, ITALY, 1980

TERREMOTO DE MEJICO

SURVIVORS RESCUED VS DAYS AFTER IMPACT



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