SIMULATING MEDICAL TREATMENT AND EVACUATION OF COMBAT CASUALTIES

P. B. RICHARDS, Ph.D.; J. R. FLETCHER, M.D.; and C. DELFOSSE*

SUMMARY

The Navy Amphibious Medical Evacuation Simulation (NAMES II) Model simulates medical treatment and evacuation of casualties within a military combat zone. (The medical system which the model represents includes various levels of casualty receiving facilities, including the hospital corpsman or medic, battalion aid stations, clearing stations, and hospitals. Casualties entering the simulated system receive necessary medical treatment, provided appropriate medical personnel are assigned to these facilities; they die if this treatment is delayed too long; and they convalesce within the combat zone and return to duty if the evacuation policy and bed capacity within the combat zone allow this.) Otherwise, the casualties are evacuated out of the combat zone. The model computes, on a daily basis, patient dispositions as well as the requirements for various resources, including medical personnel and evacuation vehicles. It also computes the availability of such resources at the time they are required. The model concepts can also be applied to world-wide treatment and evacuation of military casualties, as well as to the treatment and evacuation of victims of mutual disasters, such as earthquakes.

GENERAL DESCRIPTION OF THE NAMES II MODEL

The NAMES II Model is capable of simulating various configurations of the basic medical treatment and evacuation chain illustrated in Figure 1. Casualty receiving facilities may be added or removed (completely, if desired) at any of the facility levels or echelons, and additional levels may also be inserted into the model. As each patient enters the system, he is classified according to the nature and severity of his wounds or illness by assigning him to one of a set of user-defined patient classes which encompass all types of anticipated casualties, including outpatients as well as inpatients. A patient may enter the system at any facility level. The distribution of entering patients over all levels is specified by the model user. The user also selects the second facility level to which a patient should go if he must be evacuated from his entry level. The class to which a patient is assigned determines to a large extent his flow through the evacuation chain and his processing at each facility that he enters. Each inpatient's class determines which of three priorities he will be assigned: Priority 1, "urgent," indicates that the patient is in critical condition and must receive the most expeditious attention in order to save his life; Priority 2, "immediate," indicates that the patient's condition is very serious and he must be treated without delay; Priority 3, "routine," indicates that the patient is serious enough to require admission to the medical system, but requires no special attention to treat his condition. Outpatients are assigned Priority 4, which indicates that those patients may

---

* P. B. Richards is Director, Fleet Medical Support Project, Naval Research Laboratory, Washington, D.C.

J.R. Fletcher is Head, Experimental Surgery and Physiology, Naval Medical Research Institute, Bethesda, Maryland

C. Deliosse is Senior Associate, C.A.C.I., Inc., Arlington, Virginia

wait for treatment until there are no other patients at a higher priority requiring commitment of treater resources. Each patient's class also indicates whether he occupies a litter or ambulatory status, and assigns to the patient in ordered sequence of medical treatments, called work units, which the patient must receive before he can convalesce and return to duty. For each patient, certain work units may be identified as critical work units in that any delay in completing them will cause death or prolonged convalescent time because of complications. Some patient classes, more serious than others, are assigned threshold times for initiating treatment at the entry level. If treatment is delayed beyond these specified times, the patient dies. These critical times associated with the various patient classes determine the mortality rate within the NAMES II Model, and allow the user of the model to observe the resources and parameters of the evacuation system which affect the mortality rate. The NAMES II Model was intended to demonstrate the impact of new medical techniques and advanced medical training in addition to technological improvements in transportation, health care facilities, logistics and command control. Tests conducted with the model indicate that the mortality rate is quite sensitive to the selection of a patient's sequence of required work units and the allowable delay times for the patient to receive his critical work units.

At the medic level, or Forward Edge of the Battle Area (FEBA), all patients undergo triage and receive first aid on a first-in, first-out basis. Inpatients who survive this initial treatment are then evacuated to the rear for further treatment; outpatients are returned to duty. At all facilities except at the medic level, patients are treated on a priority basis. After undergoing triage, each patient receives his sequence of work units, provided appropriate treaters are assigned. The NAMES II Model allows flexibility in designating treaters by identifying preferred and alternate treaters for each work unit. An expected treatment time is associated with each treater's performance of a particular work unit. If an appropriate treater is not assigned to the facility level, the patient is stabilized and evacuated to the rear. Otherwise the patient continues to receive his ordered sequence of work units. Each patient's convalescent time, which is specified on his admission and may be extended if certain work units are not received in time, is constantly compared to the evacuation policy at his particular facility, i.e., the period of time which a patient is allowed, by military consideration, to remain at a facility. If his convalescent time should exceed the evacuation policy at any time, he is stabilized and evacuated to the rear, provided he has received a user-specified work unit which indicates that the patient can be moved safely.

If a patient is able to receive all of his required work units and if his convalescent time does not exceed the evacuation policy at his facility, he will enter a convalescent ward and return to duty from that facility in the convalescent bed capacity is sufficient. Otherwise he will be stabilized and evacuated further to the rear. Two of the factors which cause a patient to be evacuated (treaters and bed capacity) are measures of the resources of the evacuation chain; the third (evacuation policy) is a command policy. The order in which these factors enter a patient's processing within the NAMES II Model is considered to be logical -- if necessary treaters are not assigned, the patient must go elsewhere for treatment; once his critical work units are received and he can be moved safely, he should be evacuated as soon as possible if it is known that he must be evacuated anyway; finally, if his facility has enough convalescent beds allocated, and if his convalescent time falls within the evacuation policy of the facility, he should be retained at this facility and returned to duty, and not evacuated further to the rear.

When a patient is evacuated from any facility, his destination is designated to be his user-selected second facility if his present facility is closer to the FEBA than his second facility. Otherwise, his destination is designated to be the next facility to the rear. Depending on the vehicle destination rules in force, the vehicle which is evacuating the patient may or may not stop next at the patient's designated destination, and, depending on the patient unloading rules in force, the patient may or may not be unloaded at the vehicle's next stop. Wherever the patient is unloaded next, he will remain until he dies, or returns to duty, or until one of the three conditions is met to force his stabilization and evacuation.

The vehicle destination rules and the patient unloading rules always prevail over the patient's designated destination. If the patient is unloaded at a facility closer to the FEBA than his designated destination, his next designated destination, if he has to be evacuated again, will be the same as it was before, that is, to his second facility if he hasn't already been there, or else to the next facility to the rear. If he is unloaded at his designated destination or at a facility further to the rear than his designated destination, then his next designated destination, if he has to be evacuated, will be the next facility to the rear.

In the NAMES II Model, it is assumed that patients who are evacuated from the facility level furthest from the FEBA will be transferred to staging facilities for air evacuation out of the combat zone. These staging facilities are not currently included in the evacuation chain simulated by the model; hence, evacuees from the last facility level are removed from the simulation once they enter the evacuation queue at that facility. They are never placed on board any of the evacuation vehicles which service the simulated evacuation chain.

The NAMES II Model is "driven" by various parameters, or inputs, which describe the resources and the operational environment of the medical evacuation system. These inputs consist of operational (tactical) inputs, such as the spacing of facilities, the number and arrival rate of casualties, and distribution of patients among patient classes; physical resources, including the numbers of casualty receiving facilities and evacuation vehicles, the numbers and types of medical personnel (treaters) assigned, the convalescent bed capacity, and the capacity and speed of evacuation vehicles; medical technology inputs, such as patient class descriptions, priorities, ambulatory or litter status, required work units, preferred and alternate treaters and treatment times, allowable delay times, convalescent times, stabilization times and evacuation threshold times; and command and control inputs, which include the evacuation policy for each facility, the patient's second facility following evacuation from his entry facility, the number of non-urgent casualties that trigger a request for an evacuation vehicle, and rules for the employment of evacuation vehicles. By properly selecting the rules for the employment of evacuation vehicles the user may (1) restrict the type of evacuation vehicle to be employed at each facility; (2) restrict the destinations that can be reached directly from each facility; (3) restrict the patients that can use each type of evacuation vehicle; and (4) specify that certain patients must be evacuated to specific facilities.

The NAMES II Model computes and prints daily and cumulative statistics at the end of each simulated day. This output data provides the model user with a quantitative method of observing various measures of the effectiveness of specific medical evacuation systems. This permits the relative comparison of different evacuation systems, and also shows the sensitivity of an evacuation system to the various design parameters or inputs. The output data includes measures of patient dispositions, such as the number who die, who return to duty, who are evacuated, and who remain at each facility, together with patient location at time of death -- in treatment, treatment queue or evacuation queue at a facility, or in transit from one facility to another facility; lost time due to injuries and illness, including time spent in the system by those who die, who are returned to duty, and who are evacuated, the number of patients whose convalescent time is increased, the number who enter convalescence, the number who are evacuated and the reason -- because required treaters are not assigned, because the patient's convalescent time exceeds the facility evacuation policy, or because of the shortage of convalascent beds, and the convalescent time associated with patients who enter convalescence or are evacuated. The output also includes measures of resource requirements, including medical treaters, convalescent beds and evacuation vehicles; and measures of resources utilization, which include medical treater availability, convalescent bed occupancy, and utilization of evacuation vehicles.

NAMES II BASELINE SIMULATION

The medical treatment and evacuation system simulation used as the baseline for comparative analysis was designed to represent a system which might support a U.S. Marine Corps combat division, and used the same number of battle casualties that were recorded during the Chosin Reservoir Campaign in Korea in 1950. Over 3600 inpatients were admitted to the system during the 15-day simulated combat period, and an additional 150 outpatients were admitted each day. Each patient was assigned to one of 75 classes, which were defined by the U.S. Army Academy of Health Sciences, and correspond to diagnostic codes defined in the U.S. Department of Defense Disease and Injury Codes. These patient classes encompass those wounded in action (WIA's) as well as diseased and non-battle injury (DNBI) patients, and also include outpatients as well as inpatients.

The configuration of the baseline system is illustrated in Figure 2. There are 360 medics supporting the combat forces at the FEBA; 10 medics are assigned to each of 36 evacuation terminals or landing zones (LZ). All of the inpatients and 50 percent of the outpatients enter the system at this level. All of these inpatients who survive their initial treatment are evacuated to the rear for additional treatment; the outpatients who enter the system at the FEBA return to duty after receiving first aid.

Three miles behind the FEBA are nine battalion aid stations (BAS). Each BAS, which services four landing zones, has one ambulance, and two physicians with supporting medical personnel. There are no convalescent beds at this level, however. Twenty percent of the outpatients enter the system at this level.

Nine miles further to the rear are three 60-bed clearing stations (CS), each with a 3-day evacuation policy. Twenty percent of all outpatients enter at this level. Each CS, which services three battalion aid stations, has three ambulances and 44 medical personnel, including two surgeons, two general practitioners, and supporting personnel.

Eighteen miles behind the clearing stations is a 200-bed hospital which has a 15-day evacuation policy. Ten percent of all outpatients enter the system at this level. The hospital has six ambulances and 131 medical personnel, including two surgeons, six general practitioners, four other physician specialists and supporting personnel.

Within the evacuation chain of the baseline simulation, ambulances (speed: 25 mph) are requested from the closest support facility that has any available, including the requesting facility itself. Helicopters are provided only be a central pool, adjacent to the hospital, which contains 16 helicopters (speed: 100 mph). In the NAMES II Model, helicopters are dispatched at any time, day or night to pick up a Priority 1 patient; for all other patients, helicopters respond only in daylight. Helicopters are also the model's preferred mode of travel in the evacuation chain for Priority 1 and Priority 2 patients; however, in the baseline simulation, all patients are evacuated from the FEBA, battalion aid stations and clearing stations by whichever kind of vehicle arrives first, whether it be helicopter or ambulance. Patients are put aboard the vehicle by priority, and it then proceeds to the closest facility to which any patient on board is designated to go, either by the user (patient class) or by the model (patient evacuated from the next lower level). At each stop, only those patients designated for evacuation to that facility are unloaded. The evacuation vehicle then takes on board, by priority, all who will fit and proceeds again to the closest facility to which any patient is designated to go. This procedure, together with the patient flow rules contained in the NAMES II Model, forces evacuation vehicles in the baseline simulation to proceed always in a direction away from the FEBA. Each vehicle returns home when it unloads its last patient and there are no further patients waiting to be evacuated.

Other inputs and details of the baseline simulation, including the patient classes, work units, preferred and alternate treaters, and allowable delay times, are described in the NAMES II Documentation.

RESULTS

Using the baseline simulation configuration, resources and procedures as a standard for comparison, various additional evacuation systems have been quantitatively analyzed and evaluated using output variables which are sensitive to changes in the input parameters that describe these systems. Some output variables, such as the mortality rate and the number of casualties returned to duty are sensitive to various input parameters. They are measures of the entire system's efficiency and afford the model user an opportunity to compare the model with historical results, which, in general, are not obtainable at the fine level of detail at which the model operates.

One logistic parameter which affects the mortality rate significantly is the number of available medical treaters, e.g., increasing the number of surgeons at the hospital from two to six cut the mortality rate from 3.4% to 1.7%. The speed and the quantity of evacuation vehicles, not their capacity, are also very important, e.g., replacing the pool helicopters by slower ambulances caused the mortality rate to increase from 3.4% in the baseline simulation to 11.6%. This was almost as high as when there were no vehicles at all in the pool adjacent to the hospital (12.8%).

The number of patients returned to duty is affected considerably by the convalescent bed capacity and the evacuation policies in force at each facility. The evacuation policy governs bed requirements, and both the bed requirements and the bed capacity govern bed occupancy, which is a measure of the number of casualties returned to duty. To determine convalescent bed requirements, the NAMES II Model records the number of patients who, upon receipt of all of their required work units, have convalescent times which do not exceed the evacuation policy at their facility. All of these patients will be allowed (by the evacuation policy) to recuperate at their facility and subsequently return to duty provided the bed capacity is sufficient. Consequently these patients establish the bed requirements at the facility. Clearly the convalescent bed occupancy cannot exceed either the convalescent bed capacity or the convalescent bed requirements. These last two factors are independant of each other. The upper curves of Figure 3 show that in the baseline simulation, the hospital convalescent bed requirements dictated by the 15-day evacuation policy overtake the 200 bed capacity prior to the second day of combat. The only way to increase the bed occupancy is to increase the bed capacity. Even if that cannot be done, however, a shorter evacuation policy would have the effect of returning more patients to duty, because it would result in a higher turnover rate in the convalescent ward. By contrast, the lower curves of Figure 3 show that the combined 180 bed capacity at the three clearing stations exceeds the requirements imposed by the 3-day evacuation policy. In this situation, a longer evacuation policy would make more efficient use of the bed capacity.

Several additional simulations were run to see the impact that changes in bed capacities and evacuation policies would have on bed requirements, bed occupancy and the number of casualties returned to duty. Space does not permit the display of curves similar to those of Figure 3, but the most significant results, the number returned to duty following convalescence, are as follows:

COMPARISON SIMULATIONS			TOTAL NUMBER WHO ENTERED CONVALESCENCE DURING 15-DAY COMBAT PERIOD. (WILL RETURN TO DUTY)		
BASELINE SIMULATION	CS	HOSP	CS LEVEL	HOSPITAL	TOTAL
EVAC POLICY (DAYS)	3	15			
BEDS	60	200	451	569	1020 (28% of all inpatients)
SIMULATION B					
EVAC POLICY	6	15			
BEDS	60	200	662	553	1215 (35% of all inpatients)
SIMULATION C					
EVAC POLICY	6	10			
BEDS	60	200	662	641	1303 (37% of all inpatients)
SIMULATION D					
EVAC POLICY	6	15			
BEDS	60	200	662	988	1650 (47% of all inpatients)

These simulations demonstrate the effect of the evacuation policy when a facility is filled to capacity and when it is not. When the hospital is filled to capacity, as it is most of the time in all four simulations, a decrease in the evacuation policy (Simulation C), which causes a higher turnover rate, allows more patients to be admitted, with a resulting increase in the number returned to duty. Conversely, a longer evacuation policy under the same crowded conditions would result in fewer patients returning to duty. Obviously this would not be the result if the facility were not crowded, as is seen in Simulations B, C, and D, where a longer evacuation policy at the clearing stations, which are not crowded, permits more patients to enter convalescence and subsequently return to duty from those facilities.

Additional research is required to determine the most "efficient" evacuation system configurations, resources and procedures. Preliminary results suggest, for example, that a medical facility with fixed resources (beds) has an optimum evacuation policy which maximizes the number of patients returned to duty or minimizes the number evacuated (Figure 4). The effect of other parameters, such as the mortality rate, has to be investigated. Other findings suggest that the mortality rate among surgical patients rises sharply as the ratio of surgeons to surgical patients drops below 1 to 10 (Figure 5). More research is required in this area to determine the effect of delays in arriving at treatment facilities, as well as the effect of other parameters that influence mortalities.

CONCLUSIONS

NAMES II presents to the user a research tool which can be used for combat medical contingency planning and for analyzing and evaluating combat medical treatment and evacuation systems, together with the requirements those systems impose on supporting medical, transportation and logistics facilities. The NAMES II Model is currently operational on a CDC 6600 computer system. The computer program is written in the SIMSCRIPT II.5 simulation language.

ACKNOWLEDGEMENT

The development of the NAMES II Model was supported in part by the Office of the Assistant Secretary of Defense for Health Affairs and the Office of Naval Research.

BASIC CHAIN OF EVACUATION

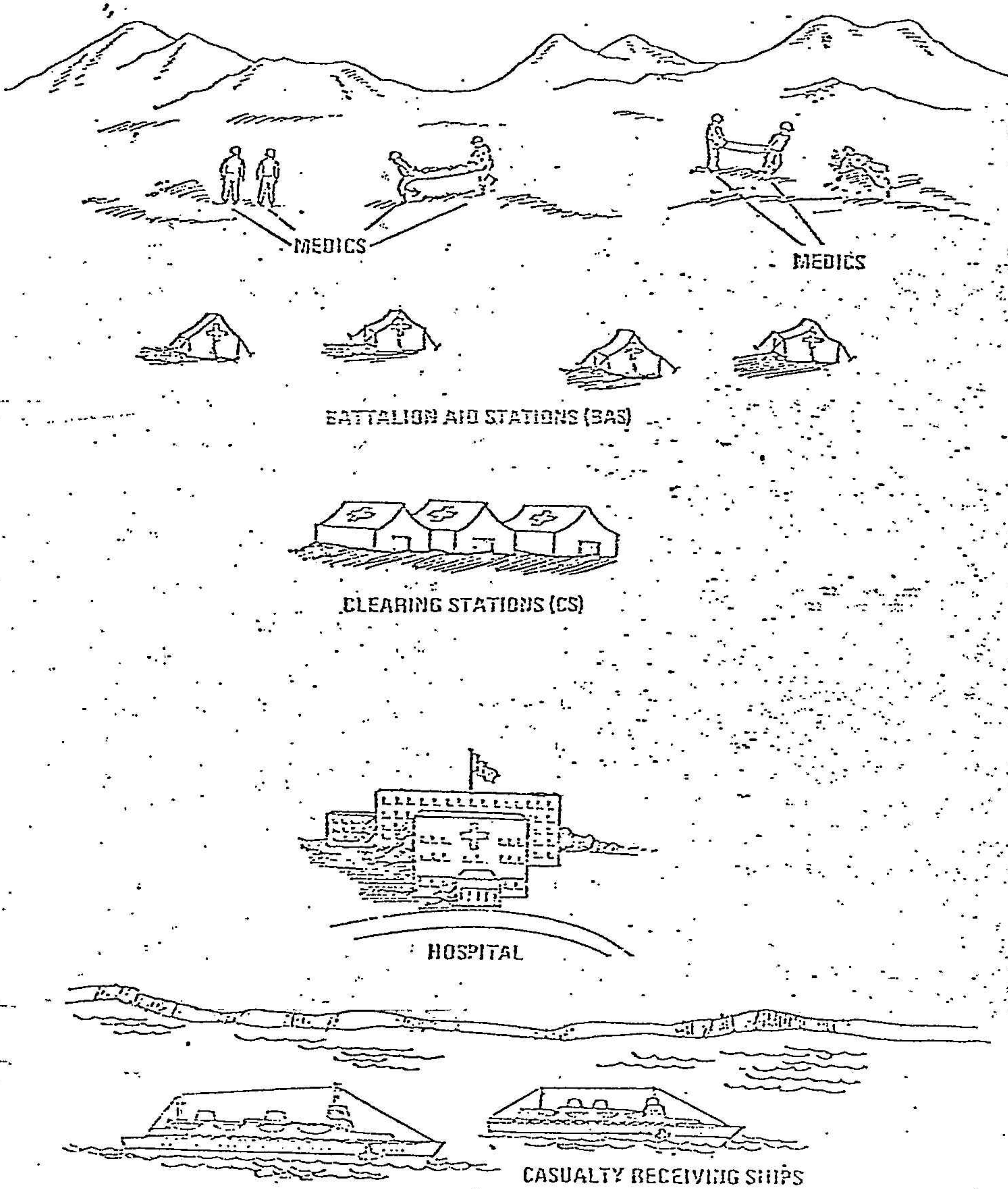
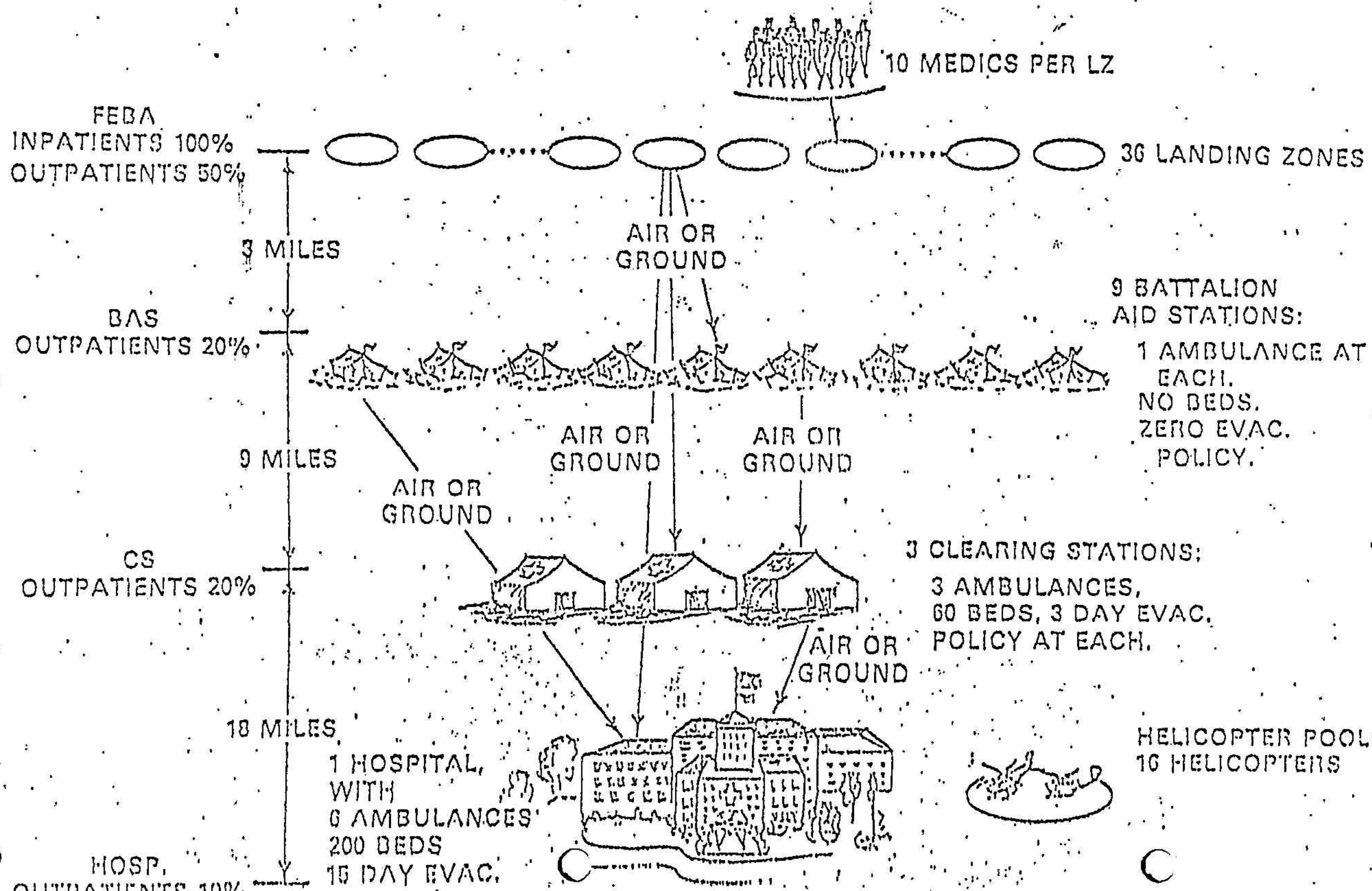


FIGURE 1

NAMES II

BASELINE SIMULATION OPERATIONAL AREA, SHOWING POSSIBLE EVACUATION ROUTES



BASELINE SIMULATION CONVALESCENT BED REQUIREMENTS, CAPACITY & OCCUPANCY

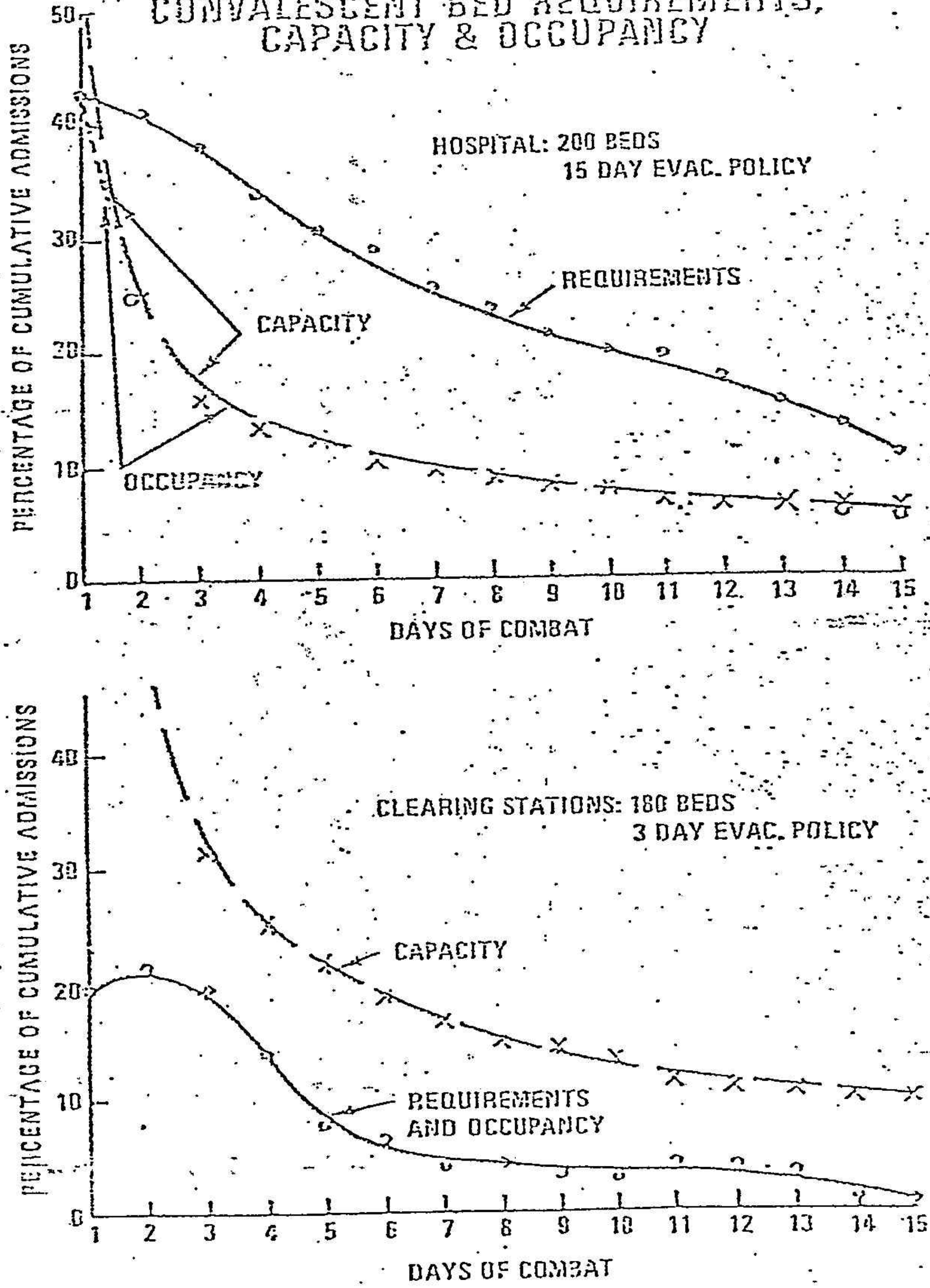
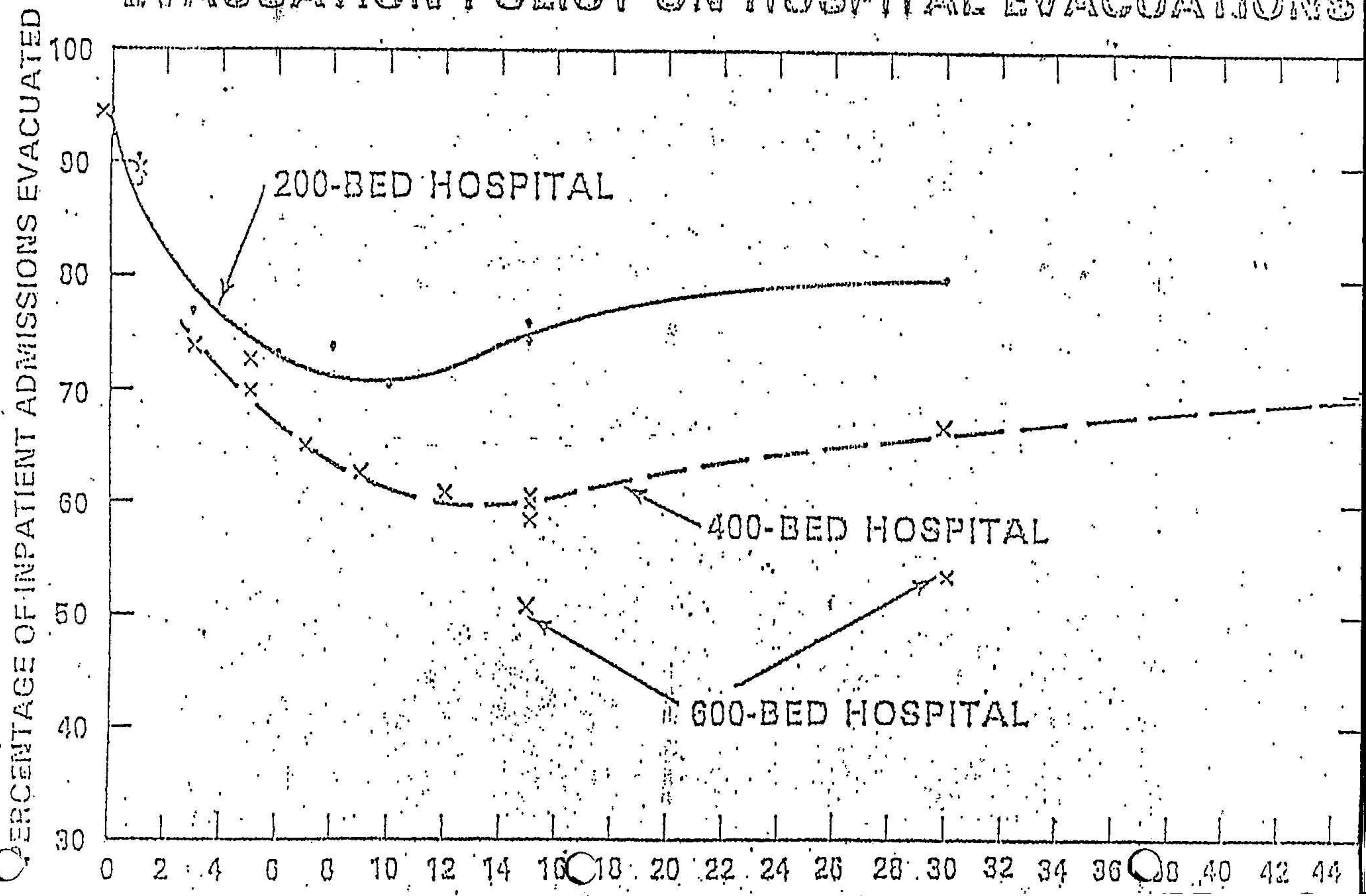


FIGURE 3

IMPACT OF EVACUATION POLICY ON HOSPITAL EVACUATIONS



VARIATION OF SURGICAL MORTALITIES AT HOSPITAL WITH THE NUMBER OF ASSIGNED SURGEONS

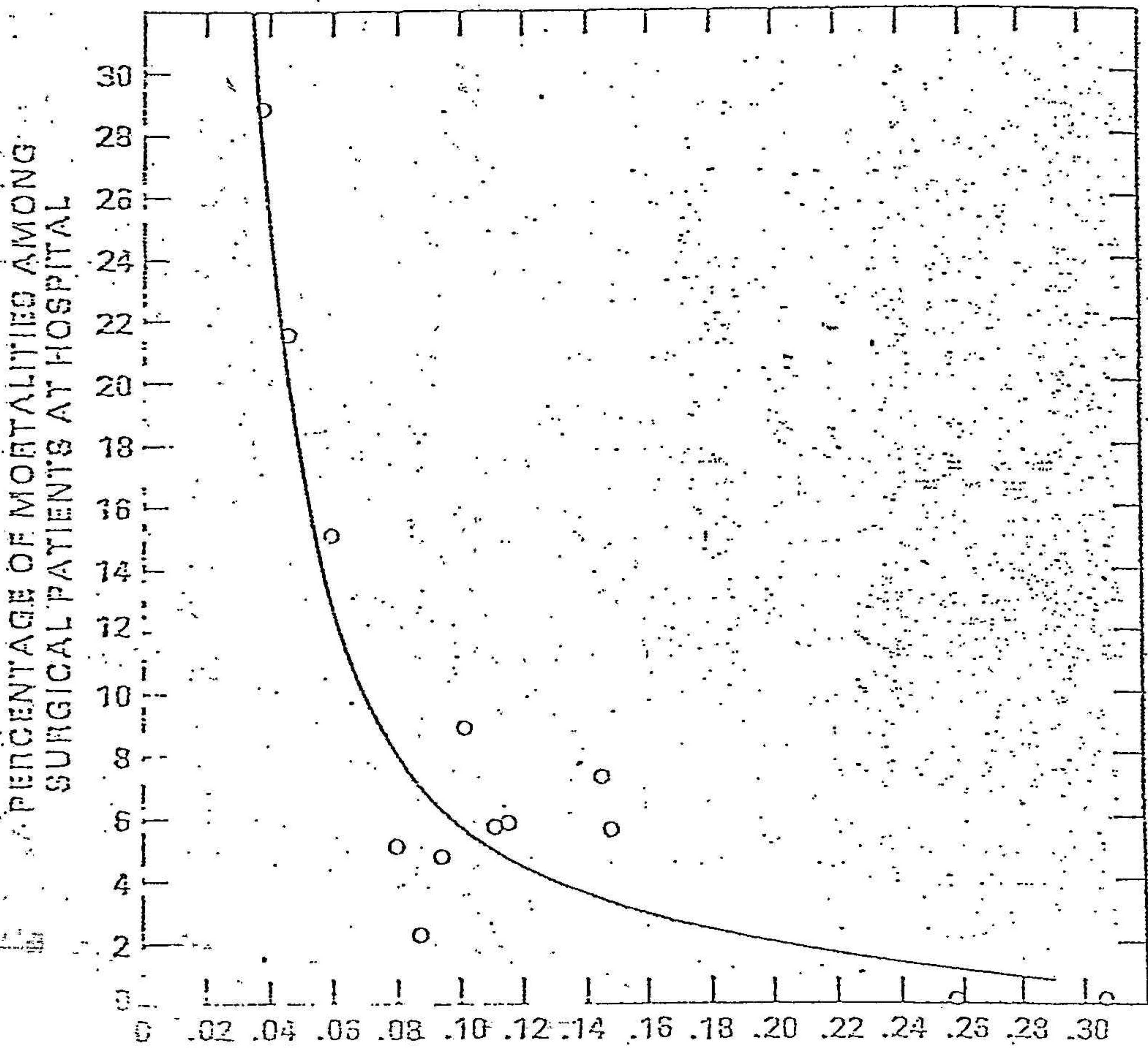


FIGURE 5