Computer Model for Simulation of Emergency Medical Systems

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Contingency planning for emergency medical systems (EMS) is primarily based on the experience of individual physicians caring for trauma patients. To great extent, many of the factors involved with large numbers of casualties are omitted from the planning of emergency medical systems because of lack of money, personnel, and physician interest. At best, trauma patients receive excellent care in centers designed to manage major injuries. Unfortunately, these centers are widely distributed throughout the world and can only make a limited impact on the mortality of the multiple-injured patient.

The purpose of this report is to describe a computer model (NAMES II, Navy Amphibious Medical Evacuation Simulation) that includes in concept the many complexities of an emergency medical system. The model simulates medical treatment and evacuation of casualties within a military combat zone. In addition, the simulation of a variety of logistical, medical, and administrative problems can predict requirements for the necessary resources to best manage the emergency situation.[1]

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 Fig. 1. Casualty receiving facilities may be added or removed at any level. 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.

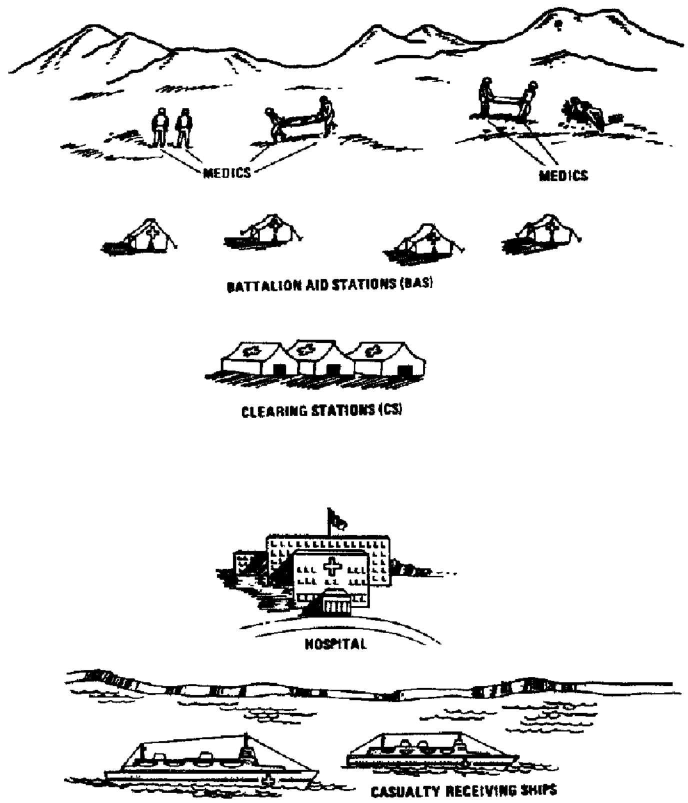

Fig. 1. Basic chain of medical evacuation.

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 wait for treatment until there are no other patients at a higher priority requiring commitment of medical resources. Each patient's class also indicates whether he occupies a litter or ambulatory status, and assigns to the patient an ordered sequence of medical treatments, called work units, that are determined by the type and severity of the injury. 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

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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.

At the medic level, all patients undergo triage and receive first aid on a first-in, first-out basis. Patients who survive this initial treatment are then evacuated to the rear for further treatment; outpatients are returned to duty. At all other facilities, patients are treated on a priority basis After undergoing triage, each patient receives his sequence of work units, provided appropriate medical personnel are assigned. The NAMES II Model allows flexibility in designating medical specialists by identifying preferred and alternate medical personnel for each work unit. An expected treatment time is associated with the performance of each particular work unit.

If an appropriate medical specialist 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 with the evacuation policy at his particular facility; i.e., the period of time which a patient is allowed, by military considerations, 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 (called the first-aid 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 provided convalescent bed capacity is sufficient. Otherwise, he will be stabilized and evacuated further to the rear.

When a patient is evacuated from any facility, his destination is designated by the user. 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 there until he dies, returns to duty, or until one of the three conditions is met to force his stabilization and evacuation.

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. These output data provide the model user with a quantitative method of observing 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 include 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 medical personnel are not assigned, because the patient's convalescent time exceeds the facility evacuation policy, or because of the shortage of convalescent beds, and the convalescent time associated with patients. The output also includes measures of resource requirements, including medical staff, convalescent beds, and evacuation vehicles; and measures of resouce utilization.

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 US Marine Corps combat division, and used the same number of battle casualties that were recorded during the Chosin Reservoir Campaign in Korea in 1950. Approximately 3,600 inpatients were admitted to the system during the 15-day simulated combat period, and an additional 150 outpatients were treated each day. Each patient was assigned to one of 75 classes, which were defined by the US Army Academy of Health Sciences,[2] and correspond to diagnostic codes defined in the US Department of Defense Disease and Injury Codes. These patient classes encompass those wounded in action (WIAs) as well as diseased and non-battle injury (DNBI) patients, and also include outpatients as well as inpatients. The patient "mix" and the associated work units were such that about nine per cent of all patients required immediate emergency first aid in order to survive; 63 per cent of all patients would die if they did not receive specified critical mortality work units in time but, in all these cases, it was possible to save the patients if

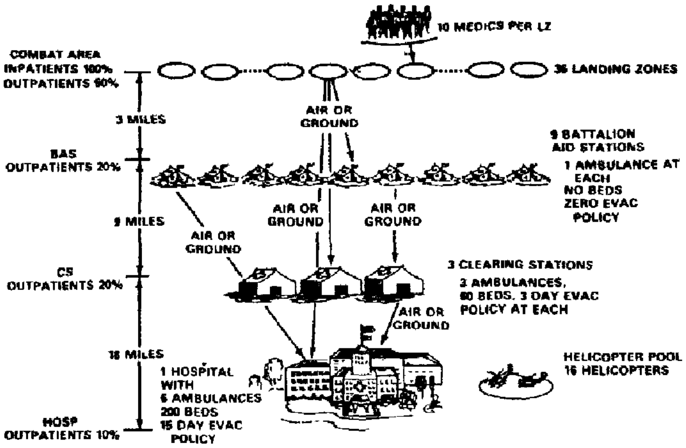

Fig. 2. NAMES II. Baseline simulation operational area showing possible evacuation routes.

evacuation procedures and resources were adequate. Thus, the mortality rate was very sensitive to changes in medical personnel assignments, evacuation vehicle availability, and medical regulating procedures. The patients who had critical mortality work units also had first-aid work units to assure that they would not be evacuated before it was medically safe, provided necessary treaters were assigned to their facility. The 37 per cent of all patients who had no critical mortality work units also had no first-aid work units, since they all had lesser injuries or illnesses. However, 96 per cent of all patients had critical convalescent work units, which meant that their convalescent times would be doubled due to complications if designated work units were not administered in time. This made the number of patients who returned to duty more sensitive to factors which affected the speed of their medical care, such as remaining time in queues, vehicle speeds, and physician availability, as well as to the evacuation policies employed at the various facilities.

The configuration of the baseline system is illustrated in Fig. 2. There are 360 medics supporting the forces in the combat area; 10 medics are assigned to each of 36 evacuation terminals or landing zones (LZ). All of the inpatients and 50 per cent 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 combat area return to duty after receiving first aid; none of them die.

Three miles behind the combat area 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.

Nine miles further to the rear are three 60-bed clearing stations (CS), each with a three-day evacuation policy. Twenty per cent 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 staff.

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

Within the evacuation chain of the baseline simulation, ambulances (capacity: eight spaces; speed: 25 mph) are requested from the closest support facility that has any available, including the requesting facility itself. Helicopters are provided only by a central pool, adjacent to the hospital, which contains 16 helicopters (capacity: 24 spaces; speed· 100 mph). The NAMES II Model logic requires that a helicopter be requested when a single urgent patient enters a facility's evacuation queue, unless a helicopter is already enroute to the facility in response to an earlier request for a helicopter. If a helicopter is not available to respond to such a request, a ground vehicle (ambulance) is immediately requested, unless an ambulance is enroute to the facility in response to an earlier request for an ambulance. For nonurgent patients, the number of patient spaces (one required for an ambulatory patient, two required for a litter patient) in an evacuation queue that are necessary to trigger a request for a helicopter is six, and for an ambulance it is two. Helicopters are always dispatched at any time day and night, to pick up Priority 1 (urgent) patients in the NAMES II Model. For all other patients, helicopters respond only in daylight, which was prescribed, in the baseline simulation, to be the period from 6 AM to 6 PM.

Helicopters are always 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 combat area, battalion aid stations, and clearing stations by whichever kind of vehicle arrives first, by priority, and it then proceeds to the closest facility to which any patient on board is designated to go. 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 combat area. Each vehicle returns home when it unloads its last patient and there are no further patients waiting to be evacuated.

Results

Using the baseline simulation configuration, resources and procedures as a standard for comparison, numerous other simulated evacuation systems have been examined. All the systems discussed here retain the patient loads, work units, and other medical technology inputs used in the baseline simulation.

The three principal measures of patient dispositions—the number returned to duty (RTD), the number evacuated from the combat zone (EVAC), and the number who died—are shown in Table I for the baseline simulation and six other simulations in which the number of surgeons, the number of helicopters, the number of casualty receiving facilities, and the evacuation vehicle employment rules were varied. These changes had their greatest impact on the mortality rate.

COMPARISON SIMULATIONS	RETURNED TO DUTY	EVACUATED	DIED
BASELINE	57.5%	38.5%	4.0%
BASELINE WITH 12 SURGEONS AT HOSPITAL, INSTEAD OF 8	57.7%	40.0%	2.3%
BASELINE WITH NO HELICOPTERS	55.4%	30.8%	13.8%
BASELINE WITH NO BATTALION AID STATIONS OR CLEARING STATIONS	48.4%	42.8%	8.8%
BASELINE EXCEPT THAT HELICOPTER DESTINATION IS THE SUPPORT FACILITY REQUIRED BY PATIENT WITH HIGHEST PRIORITY, INSTEAD OF CLOSEST FACILITY TO WHICH ANY PATIENT IS DESIGNATED TO GO	57.0%	37.1%	5.9%
BASELINE EXCEPT ALL EVACUEES FROM COMBAT AREA GO BY AMBULANCE TO BATTALION AID STATION LEVEL. ONLY THOSE DESIGNATED FOR THAT LEVEL ARE UNLOADED THERE	55.6%	31.2%	13.2%
BASELINE EXCEPT ALL EVACUEES FROM COMBAT AREA GO BY AMBULANCE TO BATTALION AID STATION LEVEL. THEY ARE ALL UNLOADED THERE AND REMAIN UNTIL THEY NEED A TREATER WHO IS NOT ASSIGNED OR UNTIL THEY RECEIVE THEIR FIRST AID WORK UNIT	57.1%	36.5%	6.4%

Table I. NAMES II. Patient dispositions expressed as percentages of total number of casualties entering system during combat period.

Increasing the number of surgeons from eight to 12 at the hospital cut the mortality rate almost in half (from 4.0 per cent to 2.3 per cent), despite the fact that these physicians performed other functions in addition to surgery, notably triage. If there were no helicopters for medical evacuation, the mortalities rose sharply (to 13.8 per cent). Additional simulations have demonstrated that the capacity of evacuation vehicles is relatively unimportant in the combat zone; what is vital to saving lives is the number of high speed vehicles. The need for high speed, presently attainable only with helicopters, is obvious with a patient population containing a large number who will die if they don't receive timely medical attention. The reason why it is important to have many helicopters, but not necessarily large ones, is apparently because the casualties are spread out at any one time over the many landing zones and other facilities, and the availability of helicopters to respond to a medical evacuation request is therefore more important than the load each helicopter can carry.

The seriousness of large delays in transporting seriously wounded patients to treatment centers is further illustrated in Fig. 3, where the percentage of mortalities among surgical patients at the combat zone hospital is plotted as a function of the ratio of surgeons to surgical patients at the hospital. While more research is needed in this area to determine the effect of other parameters that influence mortalities, the two curves shown in Fig. 3, obtained from two simulations which differed only in that one baseline had 16 helicopters and the other had none, illustrate two very significant points. First, provided the delay time in transporting surgical patients to the hospital is not so great that the patients are practically dead on arrival, the mortality rate of surgical patients rises very sharply when the ratio of surgeons to surgical patients drops below some numerical value, which is strongly affected by the delay time in reaching the hospital. Second, even with a favorable surgeon-to-patient ratio, a delay of approximately one hour in transporting surgical patients to the hospital may multiply the mortality rate by a factor between five and 10. For example, most surgical patients in the simulations under discussion are transported directly from the combat area to the hospital, a distance of 30 miles. In the baseline simulation, most of these patients go by helicopter, which makes the trip in 18 minutes. If there are no helicopters, this trip takes 72 minutes by ambulance, or 54 minutes longer. From Fig. 3 it can be seen that, for a surgeon-to-patient ratio of .20 (one surgeon for every five patients), the mortality rate of surgical patients rises from two per cent to 10 per cent when there are no helicopters. Even with a surgeon-to-patient ratio of .30 (one surgeon for approximately three patients) the mortality rate increases from about one per cent to over six per cent when there are no helicopters. At surgeon-to-patient ratios below .20, the mortality rate among surgical patients becomes completely intolerable when there are no helicopters. These results indicate that there is clearly a need for finding feasible alternatives to helicopter medical evacuation.

Looking again at Table I, it is seen that the resources provided by the battalion aid stations (BAS) and clearing stations (CS) have considerable impact on the overall mortality rate and on the number of patients returned to duty. When these facilities were removed, the existing hospital resources—medical staff, ambulances, and beds—and the helicopter pool were not sufficient to cope with the increased load placed on them. As a result, more patients died at the combat area while awaiting evacuation, and more patients died at the hospital, either in treatment or while waiting for treatment. The overall mortality rate in the combat zone rose from 4.0 per cent (baseline) to 8.8 per cent. Correspondingly, more patients had to be evacuated from the hospital, and hence from the combat zone, because of the increased demand placed on the hospital's 200 convalescent beds, which were overtaxed even in the baseline simulation.

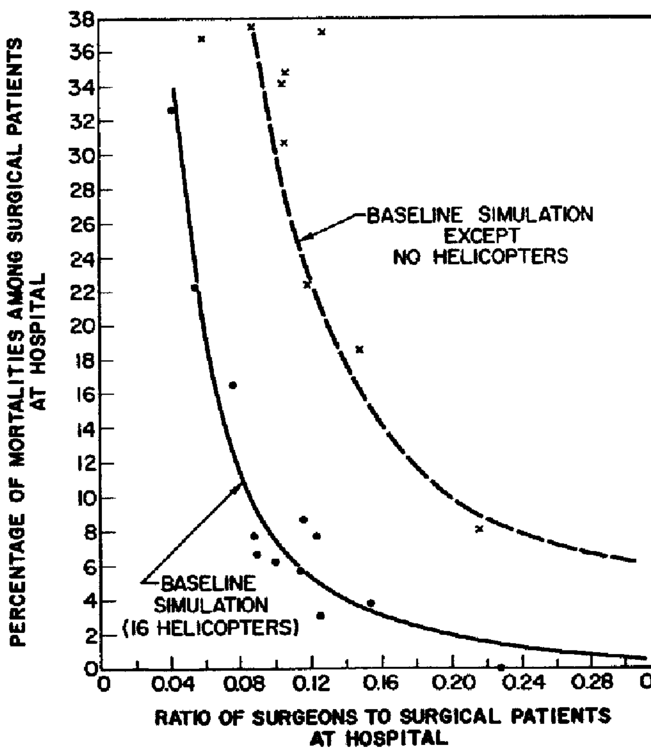

Fig. 3. Variation of surgical patient mortalities at hospital with the number of assigned surgeons.

With the removal of the battalion aid stations and clearing stations, the percentage of casualties evacuated from the combat zone rose from 38.5 per cent (baseline) to 42.8 per cent; the percentage of casualties returned to duty dropped from 57.5 per cent (baseline) to 48.4 per cent.

The significance of changes in medical regulating procedures, or procedures which govern the flow of patients through the evacuation system, is also shown in Table I. The overall mortality rate rose from 4.0 per cent to 5.9 per cent simply by changing the rule governing the destination of helicopters such that, when evacuating patients from a facility, each helicopter went directly to the medical support facility required by the patient with highest priority, instead of going, as in the baseline simulation, to the closest facility to which any patient on board the helicopter was designated to go. This simple change in the employment of helicopters delayed the evacuation process and made the helicopters less available to respond to evacuation requests. Consequently, mortalities rose not only at the battalion aid stations and clearing stations, but primarily in the combat area, where considerably more patients died while awaiting evacuation.

The mortality rate rose to 13.2 per cent when the baseline simulation was modified to exclude helicopters from landing in the combat area, while at the same time retaining all other baseline rules for the employment of evacuation vehicles. This meant that all evacuees from the combat area went by ambulance to the battalion aid station level, but only those designated for that level were unloaded and treated there. The rest remained in the ambulances until they reached their designated facility. As a result, ambulances were overtaxed, helicopters were under-utilized, and the mortalities rose sharply, especially at the hospital because of the long trip time from the combat area, and also in the combat area because of the long waiting time in the evacuation queues. This situation was improved considerably (mortality rate 6.4 per cent) when all patients were unloaded from the ambulances at the BAS level and remained there for treatment until they needed a medical specialist who was not assigned, or until they had received their first-aid work unit, which meant they could be moved safely. In this case, the heaviest mortalities occurred at the battalion aid stations, where not enough medical personnel were assigned, and also in the combat area due to the shortage of ambulances. Physicians at the hospital were apparently idle a good deal of the time, compared with those at the battalion aid stations. Not one patient requiring major surgery died at the hospital throughout the combat period, while 178 such patients died at the battalion aid stations.

Summary

This study reports the design and development of a computer model that can be utilized to evaluate the requirements for any emergency medical system. The concepts employed represent the logical relationships that exist in the care of the most serious trauma patient. For any given military or civilian emergency, this model encompasses the individual parts required to make the EMS work. The only assumptions are that the problem exists and treatment is required.

Patients are categorized according to anatomical location and severity of injury. The user of the model can decide the patient mix, the modes of transportation, the number of facilities, and the number of medical personnel, as well as other variables. It is clear from the results that this model can be a valuable tool in determining the resource requirements for optimal function of any emergency medical system.

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