APPLICATION OF A SIMULATION MODEL TO TEST ALTERNATIVE RURAL EMERGENCY MEDICAL CARE TRANSPORTATION SYSTEMS

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The discrepancy of health care provided to rural and urban areas has centered on soaring costs, uneven quality, and limited availability. Due to economies of scale associated with the increasing sophistication, specialization, and cost of health services, people, money, research equipment, major medical centers, and ambulatory services are being concentrated in urban areas. However, it is just as important to the low population density rural areas to have an adequate level of medical care available to them. To improve the transportation facilities provided to rural areas, we developed a stochastic simulation model to test alternative systems for providing emergency medical care. These alternatives examined the impact of changing the number and location of ground ambulances within a rural area, introducing new technology (helicopters) to the medical care system, and utilizing the helicopter for supplemental functions to help off-set the costs of the system. For the Huntington, West Virginia, case study area, it was found that the addition of a helicopter to the emergency care system improved the performance characteristics of the system but increased system costs. Also, it was determined that fewer ground ambulances could provide at least the same level of service (with or without a helicopter) as that now being provided by an excessive number of ground ambulances. Relocating and reducing the number of ground ambulances within the study area resulted in a higher level of performance than simply reducing the number of ground ambulances while keeping vehicle base stations fixed. Finally, the individual vehicle utilization rates for both ground ambulance and helicopter were markedly improved when vehicles were relocated and when helicopters provided supplemental services other than purely emergency medical care to rural areas.

•IN RECENT YEARS much attention has been focused on the problem of improving the quality of ambulance care for the sudden illness or accident victim. With the number of highway fatalities exceeding 55,000 per year, questions are being raised on the quality and extent of the emergency medical system responsible for rushing life-saving aid to the highway accident victim. Although extensive programs have been developed to reduce the number and severity of highway accidents through education, enforcement, and engineering, it is estimated that the loss of life on the nation's highways, by present trends, could reach 100,000 deaths per year by 1980. Although the fatality rate has been reduced from 15+ per million vehicle-miles of travel during the 1920s and 1930s to approximately 5.3 per million vehicle-miles of travel in 1969, the absolute number of fatalities is still excessive and can be expected to increase as more vehicle-miles are driven (1).

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In addition to fatalities, more than 4.6 million persons were injured in more than 20 million motor vehicle accidents in 1969. The resulting economic loss attributed to automobile accidents has been estimated to be as high as $16.2 billion per year. Beyond the need to respond to highway accident victims, an improved emergency medical system can also service the victims of accidental injury and sudden illness (1).

MEDICAL CARE TRANSPORTATION SUBSYSTEM

It is clear that a comprehensive attack on the emergency medical problem requires a systems viewpoint that considers not only the hospital or emergency room but also the transportation component. Transportation initially reduces the time between recognition of a need for emergency care and initiation of definitive medical aid and secondly dispatches the individual to the most appropriate hospital for treatment.

A recent study completed by a medical-engineering group concluded: "Ambulance services throughout the United States are inadequately performing their dual function of administering emergency treatment at the scene of the motor vehicle crash and other emergencies and of transporting victims without aggravating their injuries" (2). Further, Gerald Looney, physician-in-chief of the Kennedy Memorial Hospital in Boston, stated (3): "Once the injured are inside the majority of hospitals in this country, medical and surgical treatment is competent and capable of steadily reducing the fatal or disabling effects of accidental injury—the difficulties arise before reaching the hospital!"

The special importance of having an adequate transportation system for providing emergency medical services in rural areas becomes evident when the characteristics of such areas are considered. Within these areas, large distances usually separate rural communities from neighboring centers, and rural roads are often in poor physical shape. If the rural area is further characterized by mountainous terrain, as is most of West Virginia, the transportation problem becomes even more acute. Besides consideration of the physical characteristics of the roads, the transportation system has to be viewed in total, including organization, hardware, communications, documentation, and spatial separation (4).

As shown in Figure 1, the difficulties of delivering emergency medical aid by ground vehicles in rural areas are extensive. For one, extensive time delays are encountered on primary and secondary road systems because the speed of emergency vehicles is restricted by roadway alignment, inclement weather, and traffic congestion. The low population density precludes sufficient demand to adequately finance an ambulance system with the latest vehicles, equipment, and communications and trained personnel. Also, there are critical shortages of treatment facilities and paramedical personnel of any kind. The emergency care system is all too frequently associated with fragmentation of noncoordinated elements (5).

These noncoordinated elements are not the only factors complicating the issue of providing adequate emergency medical transportation to rural areas. Recently, increased stress has been placed on funeral home and private ambulance purveyors, who represent the predominant means of delivering emergency medical care in rural areas, by legislation that has (a) increased labor cost, (b) increased bookkeeping cost while reducing cash flows due to collection delays, and (c) imposed minimum standards for ambulance equipment and ambulance attendant training (2).

Now that groups such as the Regional Medical Program and the Comprehensive Health Planning Organization are emerging to consider the emergency medical system on a regional perspective and with interest in using the helicopter to provide emergency medical services, it is necessary to develop systematic procedures for evaluating the cost and effectiveness of alternative delivery systems (6, 7, 8). One method of implementing such a concept is through the development of a Monte Carlo simulation model, which can simultaneously examine the factors that influence the emergency medical transportation system. The model could then be used to economically and efficiently evaluate, on a regional level, alternative proposals for improving the emergency medical care delivery system.

Figure 1. Transportation problems encountered in providing emergency medical care to rural areas.

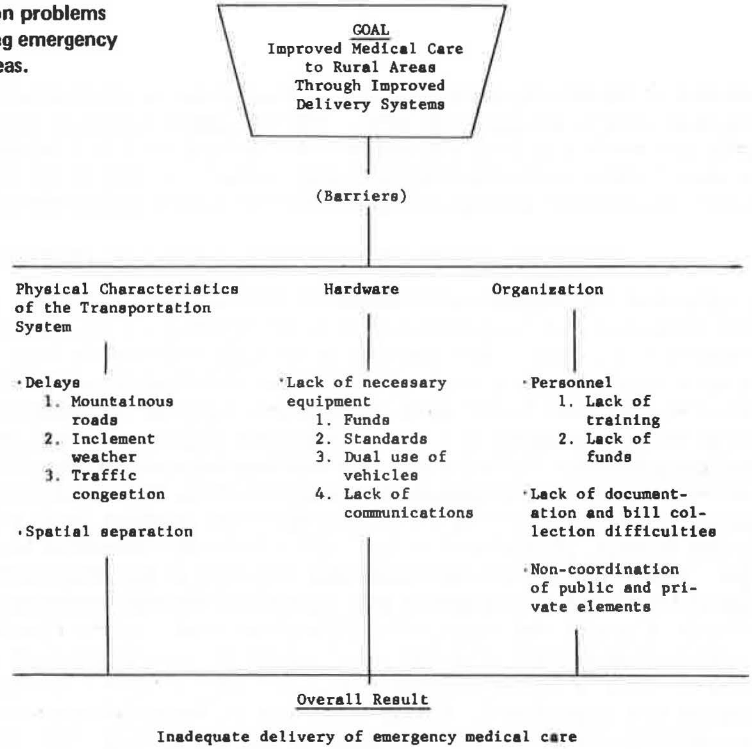
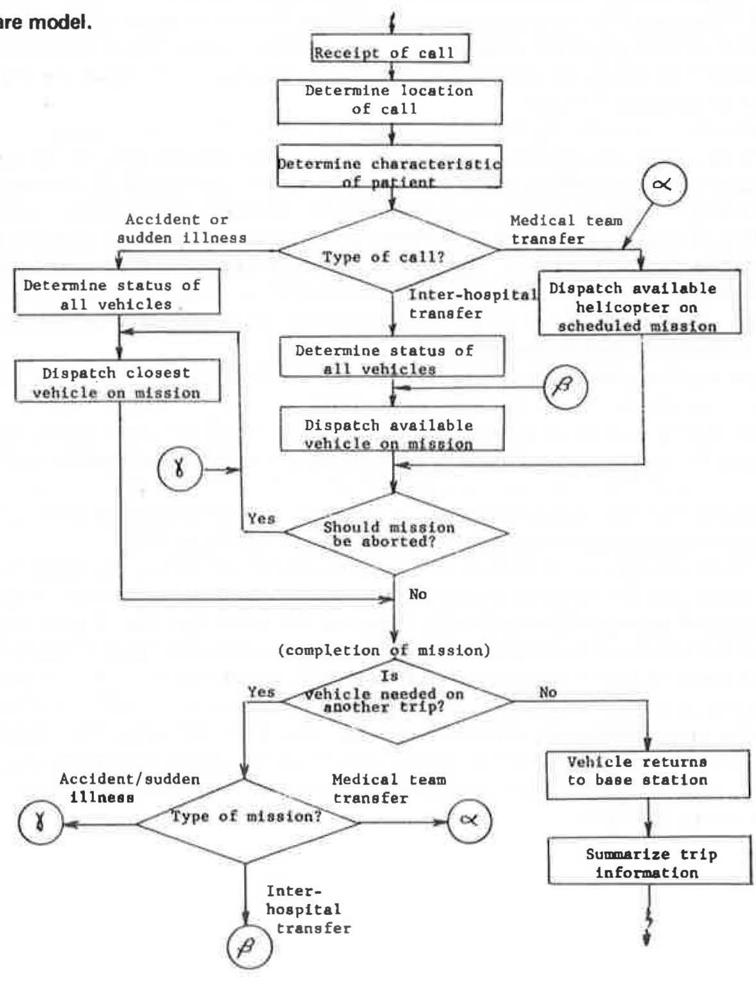


Figure 2. Emergency care model.



OBJECTIVE

The objective of this study was to develop and test a stochastic simulation model capable of examining alternative systems for providing emergency medical services to residents of rural areas. The model was designed to evaluate the use of a ground ambulance system to provide emergency services, specifically the effect of ambulance designs and operational procedures on response time, and the use of a helicopter system to provide these same emergency services. The simulation model could be used to aid a decision-maker in examining the effects of changes in the ground ambulance and helicopter systems, such as altering (a) operating hours, (b) location of the vehicle bases, (c) number and mix (air or ground) of vehicles located at each base, and (d) missions, such as transporting routine interhospital transfers or preventive care medical teams to rural clinic sites.

With these alternative delivery systems under study, it then became possible to determine the performance and cost differences between the alternatives. From this information, the effect of using helicopters as air ambulances and restructuring the ground ambulance system within rural areas could be evaluated. The ouput from the model included the following:

1. Response time for all helicopters and/or ground ambulances that respond to at least one call,
2. Helicopter and/or ground ambulance utilization rates,
3. Delays encountered on a mission per vehicle used,
4. Number of missions aborted or postponed, and
5. Overall travel time for all missions.

The model was tested for application to the Huntington, West Virginia, medical trade area. The inaccessibility of the Huntington metropolitan area, where the health facilities and personnel are located, to those in the remote rural areas surrounding it creates time and distance costs for persons seeking emergency medical assistance. In particular, the helicopter's maneuverability, speed, and flexibility appear attractive to link distant parts of the rural area with a greater spectrum of medical facilities. However, a key question became whether the helicopter could be justified over the existing or restructured ground ambulance system in terms of performance and cost.

SIMULATION MODEL—MACRO LOGIC

The logic used in the model to identify an accident or sudden illness call and dispatch the appropriate emergency vehicle to pick up the victim is shown in Figure 2. The logic starts at the point when a call is received by the system for an emergency vehicle. The next step is to determine the nature of the call. After it is decided that an emergency vehicle is needed, the specifics of the call are determined. This includes information necessary to pinpoint the location of the victim and the severity of the victim's condition. Once the location of the accident or sudden illness victim and the location of the ground ambulances and helicopter(s) are known, the model then assigns a vehicle that can arrive at the scene in the shortest period of time. If information on the nature of the incident is sufficiently detailed, the vehicle, air or ground, with the most appropriate medical equipment and personnel can be dispatched. Because the main concern is to get medical aid to the critically injured persons in the least response time, vehicles are aborted in their present mission when their future mission is deemed more critical.

After the vehicle is dispatched to pick up the accident or sudden illness victim, all times are updated within the model. It then is necessary to determine the time that another call is received on the system. These new and updated times, representing the times when calls are received for emergency vehicles, are then compared with the time at which one or more of the already dispatched vehicles completed a segment of its operation. Segments of the operation are defined as the vehicle arriving at the location of the accident or suddent illness scene, delivering the victim to the hospital, etc. With no other demands, the vehicle is routed to complete another segment of the operation. An example of this would be when the vehicle arrives at an accident scene and loads the patient; if no other priorities are established, the vehicle enters the "en route to hospital" operational segment. At this point the model determines the closest emergency room facility to the accident scene and routes the vehicle to it. Where information is available, the hospital designation can be determined as a function of spatial proximity and the unique capabilities of the hospital emergency room. Here patients are taken to the closest hospital able to treat their specific medical need.

Along with the logic necessary to dispatch vehicles to pick up and deliver accident or sudden illness victims to hospitals, the model performs the same functions for routine interhospital patient transfers and other supplemental uses, such as transferring medical teams to rural clinic sites. Only helicopters were dispatched on the supplemental mission of transferring medical teams to rural areas. These missions were dispatched on a preselected schedule, unless a higher priority emergency call was received.

STUDY REGION

The Huntington tri-state region was selected as a case study because it represents the diverse socioeconomic and topographic conditions encountered in Appalachia. The region's focal point is the Huntington-Ashland-Ironton metropolitan area, which had a total 1970 population of 253,742. Included in the study area are the industrial Big Sandy and Ohio River Valleys with linear urban development surrounded by rural nonfarm settlements. In total, the 1970 study area population contained 455,343 persons living in three states and 11 counties. The study area was defined as an approximation to the Huntington medical trade area with Cabell County at the core as identified by a recent hospital admission-patient flow survey (8).

In addition, the region had recognized difficulties with the delivery of emergency medical services, which is so often characteristic of mountainous rural areas. Funeral home operators were keenly interested in leaving the ambulance business because of existing and projected deficits. Of the 40 ambulance operators located in the study area, only one was publicly operated, one was a professional ambulance service, and the remaining 38 purveyors were operated in conjunction with funeral homes. Of the 52 designated ambulances and 62 backup hearses, only 17 vehicles were equipped with any form of radio communications, and personnel training in many cases was marginal.

To provide a data base for a model calibration, we made a survey of all hospital emergency room arrivals at nine of the 12 hospitals and 35 of the ambulance purveyors in the Huntington tri-state region for a representative 2-week period (November 9 to 22, 1970). The purpose of the survey was to identify regional utilization of hospital emergency rooms and to identify those individuals who were in need of rapid transportation to medical aid. Basically, the survey attempted to document regional emergency room flows on a macroscale.

A code system was devised to identify the general condition of each patient entering the emergency room and each patient being transported by a ground ambulance. In all cases the evaluations relied on personal observations and the experience of those individuals directly attending the patient. The emergency room study was cross-checked with the ambulance study, inasmuch as both were conducted simultaneously. Besides patient classification, the geographic location of the point where the patient was picked up was recorded as were all the event times for each transfer.

Over the 14-day period, 2,949 emergency room forms were completed and 95 patients were identified as in need of rapid transportation where time was highly critical. Out of the total number of 2,949 emergency room arrivals, only 404 patients were subsequently admitted to the hospital. Further, 84 percent of the total patient population arrived at the emergency room by private vehicles.

Information obtained from these sources yielded data used to obtain the distribution of time between calls for accident or sudden illness cases for the entire study area. Accidents and sudden illnesses represented calls for emergency care vehicles and were generated by the model through use of a coordinate system. It was assumed that sudden illness calls were a function of community population, whereas average daily traffic was assumed the critical factor in vehicle accidents. Thus, towns with larger populations and highways carrying greater numbers of vehicles would generate more frequent calls for emergency vehicles. Frequency distributions, based on 24-hour days, were obtained by plotting the emergency room arrival data from the 2-week period. From this information it was determined, by use of the Kolmogorov-Smirnov goodness of fit test, that the data representing times between arrivals at the emergency room were drawn from populations following exponential distributions.

In turn, verification checks were conducted to ensure that the model replicates the real world as observed during the 2-week test period.

ALTERNATIVE EMERGENCY CARE DELIVERY SYSTEMS

Nine alternatives were studied for improving the delivery of emergency medical services in the Huntington tri-state region. The output parameters obtained from simulating the operation of each alternative were then compared against each other and the existing case to determine whether significant differences were incurred by changing the "design" of the emergency medical care delivery system. The alternatives under analysis fell into the following three general classes of analysis:

1. Determining the effect of supplementing the existing ground ambulance system with helicopter capabilities while servicing the same level of demand as encountered during the 2-week data collection period,
2. Determining the effect of modifying the existing ground ambulance system by reducing the number of bases, relocating the bases to better coordinate demand, and then supplementing the ground service with helicopter capabilities, and
3. Determining the effect of modifying the ground ambulance system and supplementing it with helicopter capabilities while doubling the number of calls on the system.

Each class was represented by alternative "designs" reflecting some variation in terms of services provided, number of ground ambulances or helicopters deployed, and the like.

For the purpose of the Huntington example, a medium-sized, Fairchild Hiller 1100 helicopter was selected on the basis of a previous study (9) that determined its efficiency and suitability for emergency transfers in civilian use. This craft has also been deployed on demonstration emergency evacuation projects in Mississippi and Arizona (1, 7). The helicopter was assumed to be based at Huntington, which was the center of the roughly 60-mile-diameter study area.

The individual simulation runs given in Table 1 were designed to examine the existing medical care system and a series of proposed alterations to the existing system. Comparing the results from each simulation run then allows the analyst or user of the model to examine what effect, if any, the proposed alterations to the system have on measures of cost and effectiveness. It is then possible for an analyst to use the simulation model to test proposed changes rapidly and economically. Many other alternatives can be structured, but the ones presented represent one application in the form of an example.

The model was used first on a macrolevel to examine the effect of using different numbers and locations of ground ambulances and helicopters to provide medical care to rural areas. After the decision has been made that the emergency care system can be improved by reducing the number of ground ambulances, relocating ground ambulances, adding a helicopter to the medical care system, or any combination of these, then the model can again be used on a microlevel to pinpoint the best system design. The microanalysis would proceed with maximum local participation and should be part of a comprehensive planning methodology.

RESULTS FOR THE HUNTINGTON TRI-STATE STUDY REGION

Table 2 gives the system performance and total cost associated with each of the nine alternatives under analysis. In each case response time was taken as a representative measure of performance. Total system costs were viewed as the simulation analysis proceeded on a regional level. Consideration was not given to who incurred the cost and benefits. This approach is valid inasmuch as the emergency care delivery system in many areas of West Virginia is moving toward public responsibility. Alternative 1, the existing ground ambulance system with 114 primary and secondary ground vehicles,

Table 1. Description of alternatives.

Alternative	Title	Function: Emergency and Routine Transfer	Function: Medical Team Transfer	Transportation: Ground Ambulance	Transportation: Ground Ambulance Plus Helicopter	Demand[a]	Status of Ground Ambulance System
1	Base comparison	X		X(114)		Base level	Existing
2	Impact of supplementing ground ambulance with a helicopter	X		X(114)	X(1)	Base level	Existing
3	Impact of extending role of helicopter to include medical team transfers	X	X	X(114)	X(1)	Base level	Existing
4	Impact of modifying the ground ambulance system	X		X(19)		Base level	Relocate ground ambulances
5	Impact of modifying ground ambulance system and providing helicopter capabilities	X	X	X(45)	X(1)	Base level	Relocating ground ambulances via Missouri Guidelines[b]
6	Impact of further reducing the number of ground ambulances to increase utilization and providing helicopter capabilities	X	X	X(19)	X(1)	Base level	Improved utilization from alternative 5
7	Impact of doubling number of calls on modified ground ambulance system	X		X(45)		Number of calls doubled	Same as alternative 5
8	Impact of doubling number of calls on modified ground ambulance system	X	X	X(45)	X(1)	Number of calls doubled	Same as alternative 5
9	Impact of doubling number of calls on modified ground ambulance system with two helicopters provided	X	X	X(45)	X(2)	Number of calls doubled	Same as alternative 5 with two helicopters

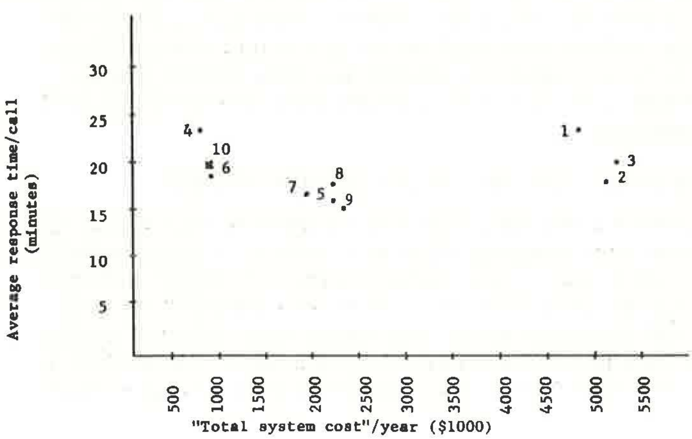
[a]Location of ground ambulances, operating hours, and time between calls are assumed to be identical to those encountered during survey conducted in November 1970.
[b]One ground ambulance provided for approximately every 20,000 individuals.

Table 2. Summary of results and costs for individual simulation runs.

System Alternative	Ground Ambulances: No. Available	Ground Ambulances: No. Used	Ground Ambulances: Utilization Rate (percent)	Helicopters: No. Available	Helicopters: No. Used	Helicopters: Utilization Rate (percent)	Average Response Time (min)	Standard Deviation	Emergency Transfers by Ground Ambulance (percent)	Total System Cost per Year[a] (dollars)
1	114	21	18.4	0	0		23.4	6.7	100	4,895,055
2	114	23	20.2	1	1	100	18.9	6.24	74	5,066,455
3	114	24	21.1	1	1	100	20.46	6.3	75	5,077,133
4	19	18	94.7	0	0		23.1	6.2	100	818,403
5	45	36	80.0	1	1	100	15.54	4.32	80	2,107,017
6	19	19	100	1	1	100	17.34	5.04	82	987,416
7	45	37	82.2	0	0		16.26	4.08	100	1,937,657
8	45	34	75.6	1	1	100	16.32	4.2	84	2,117,930
9	45	34	75.6	2	2	100	15.42	3.96	78	2,196,369

[a]Operating costs for ground ambulance = $0.60/hour; fixed cost per year for ground ambulance = $42,000. Operating costs for helicopter = $33/flight-hour; fixed cost per year for helicopter = $120,000.

Figure 3. Average response time and total system cost for each alternative.



costs approximately $4.8 million annually to operate (i.e., not considering potential revenues or shared costs with funeral home operations) and provides an average response time of 23.4 min. Supplementing this system with helicopter capabilities providing only emergency service (alternative 2) greatly expanded total system costs and cost per transfer but reduced response time to 18.9 min. Using the helicopter to perform supplemental services such as transferring medical teams to rural clinics on a scheduled basis increases helicopter flight time at a sacrifice in average response time (20.5 min) and increases total system cost by $181,000 (alternative 3). Although not included in this analysis, it was assumed that other agencies using the helicopter would share in the high initial cost of having a helicopter component available. Thus, helicopter cost would not be borne exclusively by the emergency care system. It then appears in response to the first analysis that a helicopter can reduce average response time but at a sizable increase in cost. Of particular interest were the consistently low utilization rate of the ground ambulance fleet (21 to 24 of the 114 available vehicles) and the potential cost savings associated with reducing the number of ground ambulances.

Alternative 4 represented a variation of the existing case with a reduction in the number (19 versus 114) and relocation of ground ambulances without the availability of a helicopter. For approximately the same response time as with 114 ground vehicles and no helicopter, the vehicle utilization rate was increased to 95 percent and total system cost was reduced by a factor of approximately six. Thus, it appeared that substantial economies could be initiated by simply reducing the number of and relocating ground ambulances on a regional level. Further, when the number of ground ambulances was reduced to 45 (alternative 5) and 19 (alternative 6) with the availability of a helicopter providing emergency and routine transfers along with medical team transfers, the average response times were reduced to 15.5 and 17.3 min respectively. This was accomplished at a reduction in total system cost of $2,789,038 annually for 45 ground vehicles and $3,908,639 annually for 19 ground vehicles. In response to the second analysis, relocation of ground ambulances on a regional level closer to the sources of demand made it possible to reduce both response time and total system costs. The reduction in response time was greater than that effected by simply introducing helicopter capabilities into an uncoordinated, unplanned ground ambulance system. In fact, it was possible to derive the same level of service, measured as response time, when just the number was reduced, the ground ambulances were relocated, and no helicopter capabilities were introduced. With the restructured ground system, it was less costly to introduce helicopter capabilities than to operate the existing system with no helicopter and 114 ground vehicles. Introduction of helicopter capabilities reduced the average response time by 5 to 7 min.

The third analysis tested the flexibility of the system to respond to increased demand. Alternative 5 was repeated with the number of calls on the system doubled and no helicopter capability (alternative 7), one helicopter provided (alternative 8), and, finally, two helicopters provided (alternative 9). With reference to Table 2 it can be noted that doubling the number of system calls increases total system costs slightly and also increases average response time by less than 1 min either with or without a helicopter. The introduction of two helicopters provided only a marginal reduction in average response time. This indicated that, even by doubling the number of calls, use of ground vehicles was not sufficient in the study region to suport two helicopters. Again, comparison with the existing case (alternative 1) indicated that even by doubling the calls on the system a 7-min reduction in average response time was achieved at less than half the cost with 45 ground vehicles.

With reference to the Huntington tri-state case study, Figure 3 shows the average response times and total system costs per year for each alternative. From this figure and the discussion presented previously, a decision-maker can initiate a detailed analysis at the macrolevel for determining the design of the emergency care system best able to service a rural area such as Huntington. In examining Figure 3, the decision-maker must realize that alternatives 7, 8, and 9 operate at a level of demand different from that currently experienced within the study area. Alternative 10 represents the relative system cost per year and average response time when a hypothetical system is formed by using 19 ground ambulances (as in alternative 4) along with several

National Guard helicopters. The helicopters would not be used full time as emergency care vehicles; rather, they would be used only on weekends. There is assumed to be no additional cost to the emergency care system for the helicopter component, inasmuch as they would be provided as a public service. The helicopter, which would be flown as part of the reserve training program, would be diverted to emergency care missions with no resulting charge for aircraft capital costs, aircraft maintenance costs, or personnel costs. This program is now being operated in a number of cities such as San Antonio, Seattle, and St. Louis as part of the Military Assistance to Safety and Traffic program undertaken in 1970 to explore the feasibility of utilizing military helicopters and service paramedical personnel to respond to civilian medical emergencies (10).

If all things are assumed to remain constant and response time is to be minimized, along with a specific restriction in cost, then alternative 7 would probably be recommended for further study. This alternative represents reduced costs over the existing systems with or without helicopter capabilities (alternatives 1 through 3). Even with fewer ground ambulances, it provided a level of service comparable to alternative 1 (response times of 23.4 min versus 23.1 min). In recommending this alternative for further study, the service level of the emergency medical care delivery system could be improved by utilizing National Guard helicopters on a part-time basis. Thus, the decision-maker has reduced the costs of the emergency medical care delivery system for a given level of service and has provided the flexibility of incorporating locally supported helicopters into the system at a later date if so desired. If sufficient funds were available for a high-quality emergency delivery system, then alternative 5 would be preferred because the level of service would be improved (response time reduced from 23.1 to 15.54 min over alternative 4). In either case, it appears that a ground ambulance system with 19 ground ambulances would be a good starting point to utilize the simulation model to initiate a microanalysis. With the introduction of a helicopter, average response time could be reduced with increased cost. However, this could be conducted on a stage basis with an introduction of National Guard reserve helicopters on weekends and perhaps eventual expansion to a full-time program. In either case, if a helicopter could not operate due to finances, maintenance needs, weather conditions, and the like, the system with 19 ground ambulances would provide the same level of service as the existing system is currently providing at substantially reduced costs.

In a microanalysis, the decision-maker would want to examine the influence of placement of vehicles at specific locations within a study area. At that point the decision-maker might supplement response time with other level-of-service measures, such as maximum response time, distribution of response times, distribution of distances the vehicles traveled from their base station to the accident or sudden illness patient, and distribution of distances the vehicles traveled from the accident or sudden illness site to the closest appropriate hospital. Using these parameters, the decision-maker would have to consider details such as institutional constraints, political ramifications, and cost constraints.

CONCLUSIONS

1. It is only practical to provide helicopter capabilities into the Huntington emergency medical care delivery system if the high costs associated with helicopters can be shared with other functions such as police surveillance, medical team transfers, and National Guard training. The helicopter utilization rate of 1.9 emergency calls per day was not sufficient to warrant full-time service because, with existing levels of calls, the region still has too many underutilized ground ambulances available for emergency care.

2. It is possible that, through planning of a regional ground ambulance system, inclusion of a helicopter would significantly reduce average response time at a cost substantially less than operating the present ground ambulance system. Even if the helicopter was removed temporarily, due to maintenance or weather, 19 ground ambulances could continue to provide emergency care without a significant decrease in average response time.

3. A sensitivity test indicated that doubling the number of calls on the Huntington emergency care system failed to fully utilize all of the available ground ambulances

with or without helicopter availability. A restructured ground ambulance system would have the ability to respond to future needs. Through use of a Monte Carlo simulation model the impact of altering the design of an emergency medical care delivery system can be assessed. The simulation model would be of value to a decision-maker concerned with improving the level of emergency care provided to accident and sudden illness victims in rural areas. The model permitted the testing of alternative system configurations more rapidly and more cheaply than was possible by influencing its real-world counterpart through demonstration projects.

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