A Geographic Information System Simulation Model of EMS: Reducing Ambulance Response Time

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Response time is a very important factor in determining the quality of prehospital EMS. Our objective was to model the response by Israeli ambulances and to offer model-derived strategies for improved deployment of ambulances to reduce response time. Using a geographic information system (GIS), a retrospective review of computerized ambulance call and dispatch logs was performed in two different regional districts, one large and urban and the other rural. All calls that were pinpointed geographically by the GIS were included, and their data were stratified by weekday and by daily shifts. Geographic areas (polygons) of, at most, 8 minutes response time were simulated for each of these subgroups to maximize the timely response of calls. Before using the GIS model, mean response times in the Carmel and Lachish districts were 12.3 and 9.2 minutes, respectively, with 34% and 62% of calls responded within 8 minutes. When ambulances were positioned within the modeled polygons, more than 94% of calls met the 8-minute criterion. The GIS simulation model presented in this study suggests that EMS could be more effective if a dynamic load-responsive ambulance deployment is adopted, potentially resulting in increased survival and cost-effectiveness. (Am J Emerg Med 2004;22:164-170. © 2004 Elsevier Inc. All rights reserved.)

EMS focus on cardiac, vascular, respiratory, trauma, and other emergencies. Many factors determine the quality of EMS, and response time is an important EMS industry benchmark.[1-4] This is also reflected in the term "The Golden Hour" that was derived from the observation that survival of patients who receive in-hospital definitive treatment within 1 hour of injury was much higher than of those who received it later.[5,6] This benchmark is driven by cardiac arrest survival and the likelihood of successful defibrillation of fatal cardiac arrhythmia.[7] Other factors such as proficiency of the EMS personnel, the quality of equipment and ambulances, and the suitability of organization, communications, and control are also important for patients who require EMS.

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Consequently, various national strategies have been developed for increasing the quality of EMS, especially the administration of life-saving procedures at the earliest time. Although citizens trying to give first aid can deliver such procedures sooner than the EMS,[8] the organization of the EMS for timely and proper response remains the responsibility of local governments. Indeed, many models of organization of integrated EMS for delivery of trauma care exist worldwide.[8-11]

In Israel, civilian ground prehospital EMS are the mandate of Magen David Adom (MDA, Red Star of David).[12] It is a publicly funded nonprofit organization, the structure and modus operandi of which reflect its history, and is based on salaried and volunteer staff. It is organized in 12 regional districts, each having a single control center directing the launch of ambulances and personnel from any of several stations. MDA responds to approximately 300,000 calls per year with basic life support (BLS) ambulances that have basic equipment and are operated by medics and with advanced life support (ALS) ambulances outfitted with advanced resuscitation equipment and a team of a physician and a paramedic or a paramedic and an EMT. Each district had two ALS ambulances that operated during all shifts 24 hours a day for 365 days per year. The distribution of BLS ambulances varied by shift and day according to need. In 1997, in the Lachish district, ALS ambulances treated 5,020 cases, whereas the BLS ambulances treated 15,565. In the Carmel district, ALS treated 7,184 cases and BLS treated 29,245. Deep historical and political roots are the foundation of the present structure and mode of operation of MDA.

The main objective of the present study was to study and apply the use of geographic modeling systems to deploy ambulances to fulfill demand and quality and performance requirements, and to offer model-derived strategies for improving the response time through modified deployment of MDA ambulances potentially increasing the efficiency of MDA services.

MATERIALS AND METHODS

A retrospective review of local ambulance calls recorded for a 12-month period during the years 1996 through 1997 was performed on computer-logged data from two of the 12 MDA regional districts. These two regions were selected to represent the full range of needs for EMS and the whole gamut of extrinsic factors affecting ambulance response time, namely distances, traffic conditions, and population load, and to enable testing a model of optimal ambulance deployment.

One district was Carmel, in the major metropolitan district of Haifa, Israel's largest port and a heavy industry center. It includes urban residential neighborhoods and industrial zones of diverse characteristics, from heavy and petrochemical industries to high-tech parks, and is afflicted with typically heavy, yet variable, traffic loads. It is served by three major hospitals: one level I and two level II trauma centers. The second MDA district chosen is Lachish, a southern rural district with three small and one medium urban center interspersed with numerous agricultural communities. It contains one level II trauma center and a second one is located in the adjacent district, and reaching a level I center takes ambulances 30 to 60 minutes.

Records were taken from each region's computerized logbook, in which data are entered by the dispatcher in real-time. In the Lachish district, it was available for an entire year, and in the Carmel district for a period of 9 months. The entering calls and subsequent communications are also available on tape and could be verified against the logbook. This verification was done only for the questionable data.

The Carmel district had 33,163 logs, but approximately 2,600 were administrative rides (eg, refueling, service), and several more belonged to neighboring districts and were therefore ignored. Excluded were also calls whose exact address could not be pinpointed (first by software and then manually) and address-matched by a geographic positioning software (Geocode, ArcView 3.1, ESRI, Redlands, CA). Only 73% of the net logged calls were therefore included, resulting in 21,643 records. A similar yield was obtained for the 27,085 logs of the Lachish district (after subtracting approximately 1,700 administrative rides), resulting in a database of 17,230 records (68%). The characteristics of calls that were removed from analysis were not different from those used, especially with regard to response times.

From each included log, data were extracted on the type of ambulance and times of call, driver notification, take off, arrival on scene, departure from scene, arrival at the hospital, departure from the hospital, and return to base or to the next mission.

All data were categorized, by district, and into five daily shifts representative of the degree of traffic load: 07:00-09:00 (rush hour), 09:00-16:00 (business), 16:00-19:00 (rush hour), 19:00-02:00 (going out), and 02:00-07:00 (off-hours). Further stratification was by the days of the week, resulting in a total of 70 data subgroups. In Israel, Saturday is the day of rest, and business activity on Fridays is limited.

The number of ambulances needed for each shift in each day was calculated from the turnaround time (from the initial call until return to base) of calls in each subgroup. The turnaround time consists of the response time to the call, travel time to the point of call, treatment time at point of call, travel time to the hospital, time spent in the hospital, and travel time back to the dispatch point. Based on these times for the various shifts, we could calculate the average number of calls that an ambulance can respond to during each shift. Then we calculated the probability of another call in a given area when the ambulance was making a "round." We wanted to assure a situation in which this probability will not exceed 5%. In the Lachish district, this was calculated separately for each of the towns. From the mean turnaround time, the number of ambulances needed per shift on any given weekday was determined after accounting for the 73% inclusion of the logged calls and an extrapolation to the full call volume.

The Geocode software was fed the exact address of every call by shift and by day. Then, the density of calls was calculated by using the Spatial Analyst extension of the Geocode software, and density maps were generated per district, per day, and per shift. A map showing various shades for differing densities was generated. In the most dense call areas, we initially positioned dispatch points for ambulances so that travel to any point within the time line (polygon) will not exceed 8 minutes, taking into account road signs, one-way streets, and so on.

Ambulance speeds were calculated from randomly chosen logs (at least 12 per subgroup), considering the distances using only routes permitted by traffic regulations. Travel speeds were calculated using the actual travel times as taken from the logbook and the distance as calculated by the GIS (which is very precise and takes into account one-way streets, and so on). When significant speed differences were observed in specific subregions, they were applied in the analysis.

A response time (from receipt of call until arrival at the scene) of 8 minutes or less was set as the working criterion, based on MDA's own recommendations from 1994 and on those of the Pre-Hospital Trauma Life Support (PHTLS).[5] Polygons in which this response time was maximally achieved were simulated for each of the subgroups calculated with the Network Analyst extension of the Geocode package. We wanted to assure that the derived polygons achieve the desired response time for at least 95% of calls. Initial polygons had one ambulance per polygon, and then an interactive polygon determination was performed to maximize the number of calls with a response time of 8 minutes or less, accounting for the number of ambulances required for the call load. In a shift with a higher probability than 5% for an additional call, we added a backup ambulance using for it a polygon of 15 minutes response time. The likelihood of ambulance unavailability was calculated using the Poisson distribution for probable calls. Figure 1 presents a flowchart of the analysis applied on the data for the determination of polygons.

RESULTS

The response times (from receipt of call to arrival on scene) by MDA teams in the Carmel and Lachish districts are tabulated in Table 1. The mean response times in these districts were 12.3 and 9.2 minutes, respectively. The 95th percentiles of response in these districts were in excess of 26 and 23 minutes, respectively. Indeed, with 8 minutes set as the standard, only 34% of the calls were responded to in the Carmel district, implying that 66% of them were late (Fig 2A). In Lachish, 62% of calls were answered within 8 minutes (Fig 2B).

When mobile ALS ambulances, which respond only to EM calls (as opposed to nonemergencies handled by MDA such as transporting nonendangered pregnant women or minor trauma) were analyzed separately, only a slight improvement in the 8 minutes response fraction was found. Approximately 40% of these calls in the Carmel district were answered within the standard amount of time.

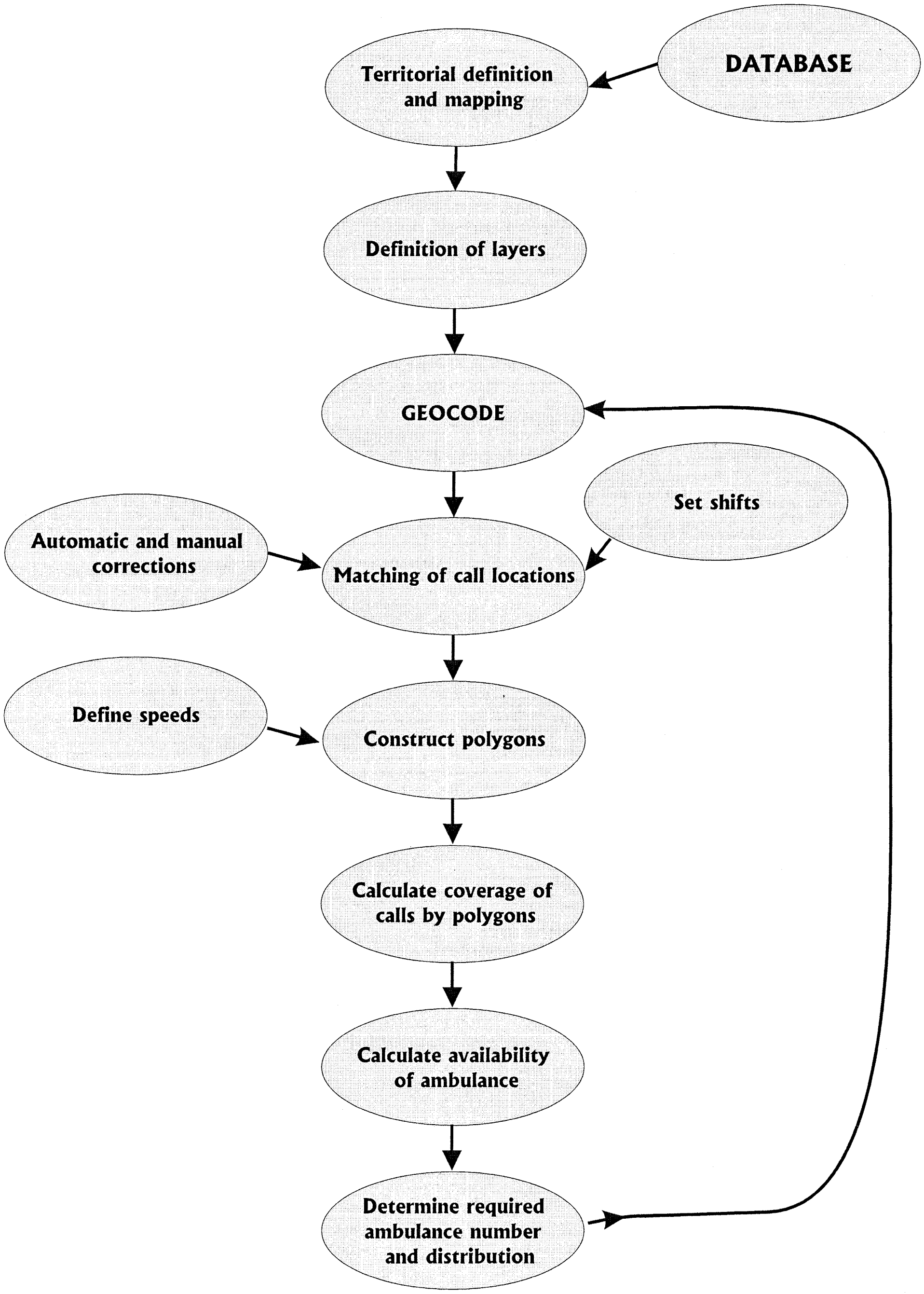

FIGURE 1. Flowchart of analysis.

In both districts, a substantial component of the response time was the activation time, the time from receipt of a call to departure. In the Carmel district, it was 2.5 ± 6.2 minutes and in the Lachish district 2.4 ± 4.7 minutes, accounting for approximately 20% of the actual and more than 30% of the desired response time. The time of travel to the scene, which is the second major part of the response time, was also spread out, and only 25% and 34% of MDA ambulances traveled in less than 8 minutes to the scene in the Carmel and Lachish districts, respectively. This was reflected in the mean ambulance traveling speed that was calculated for each shift in each district to allow the subsequent derivation of response polygons. In the metropolitan Carmel district, the mean driving speed during the first shift (7 AM–9 AM) on working days (Sunday–Thursday) was 25 km/hr (15.6 mph), whereas in the equivalent shift on Saturday morning,

TABLE 1. Response Time of Magen David Adom Teams (minutes)

District	Mean ± Standard Deviation	Median	5th Percentile	95th Percentile
Carmel	12.3 ± 9.5	10.1	3.9	26.5
Lachish	9.2 ± 8.2	6.8	3.0	23.0

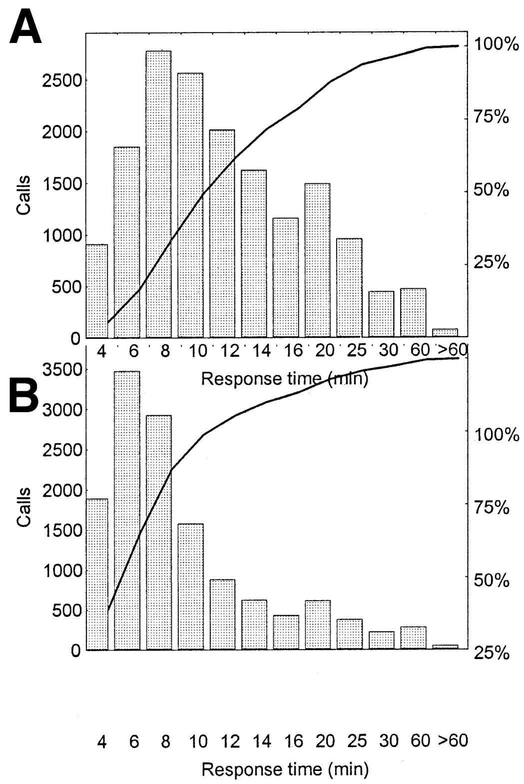

FIGURE 2. Distribution of response times in Carmel (A) and Lachish (B).

it was 40.7 km/hr (25.4 mph); in Lachish, the corresponding speeds were 26.3 km/hr (16.4 mph) and 23.9 km/hr (14.9 mph). Subregional variations of driving speeds were noted in each district. For instance, in the northern suburbs of Haifa, long stretches of highway resulted in traveling speeds of 34.2 km/hr (21.4 mph) and 57.1 km/hr (35.7 mph) in these shifts, and these local speeds were applied when appropriate. There were big differences in travel speeds among shifts but the standard deviations within shifts were small.

Figure 3A depicts the frequency of calls throughout the day and Figure 3B during the week. These distributions were statistically similar in both districts and display a typical daily pattern of activity and traffic.

During shifts when more than 5% of calls were not answered within 8 minutes, two backup ambulances were added. These ambulances had a response time not exceeding 15 minutes, and they covered an area of more than one polygon. Figure 4A depicts the layout of the 8-and 15-minute response time polygons for the first rush hour shift and Figure 4B the 8-minute polygon for the fifth, off hours (2 AM–7 AM) shift in the Carmel district. Figures 5A and 5B depict the polygons for the Lachish district in the first and fifth shifts. Similar polygon maps were constructed for each shift on every weekday using the density of calls and the average driving speeds.

With the polygons so positioned, it was possible to calculate what percentage of calls received in a particular daily shift could be responded by arrival on the scene within 8 minutes, as illustrated by the data of the Sundays and Saturdays in Table 2 (data of other weekdays are not shown). For example, of the 341 calls received on the first shift of Sunday, 98.5% were within the 8-minute polygons (Table 2). If ambulances were positioned within the polygons every shift of the entire week, more than 94% of incoming calls would have been responded to within 8 minutes in the Carmel district, and similar data were obtained for the Lachish district (not shown).

However, when only a single ambulance is placed within each polygon, sometimes it might not be possible to respond promptly to all the calls. The maximal number of potential responses per shift and the probability that demand will exceed this maximum is illustrated for shifts on Sundays and Saturdays in the Carmel district in Table 3. For example, a mean of 8.9 ± 4.36 calls were received during the first shift of all Sundays examined, with a minimum of two and a maximum of 23 calls. If seven ambulances were on duty during this shift, as suggested from the polygon model, approximately nine calls could be answered in this shift, calculated from the turnaround time. However, a likelihood of 40% existed that more calls might be received. Of the 35 weekly shifts, 19 had a potential inability to answer all potential calls with a probability exceeding 0.05. To rectify this, additional polygons, each with an additional ambulance of 15 minutes response time, were constructed in all the shifts with

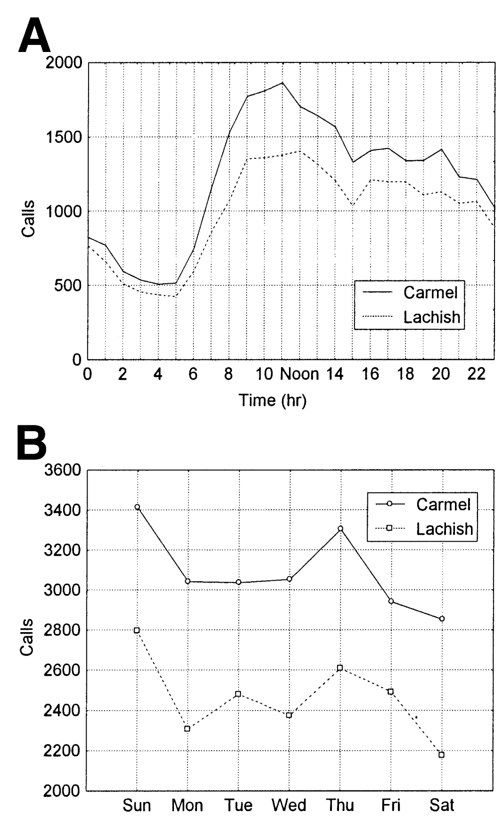

FIGURE 3. Distribution of calls by hour (A) and by day (B).

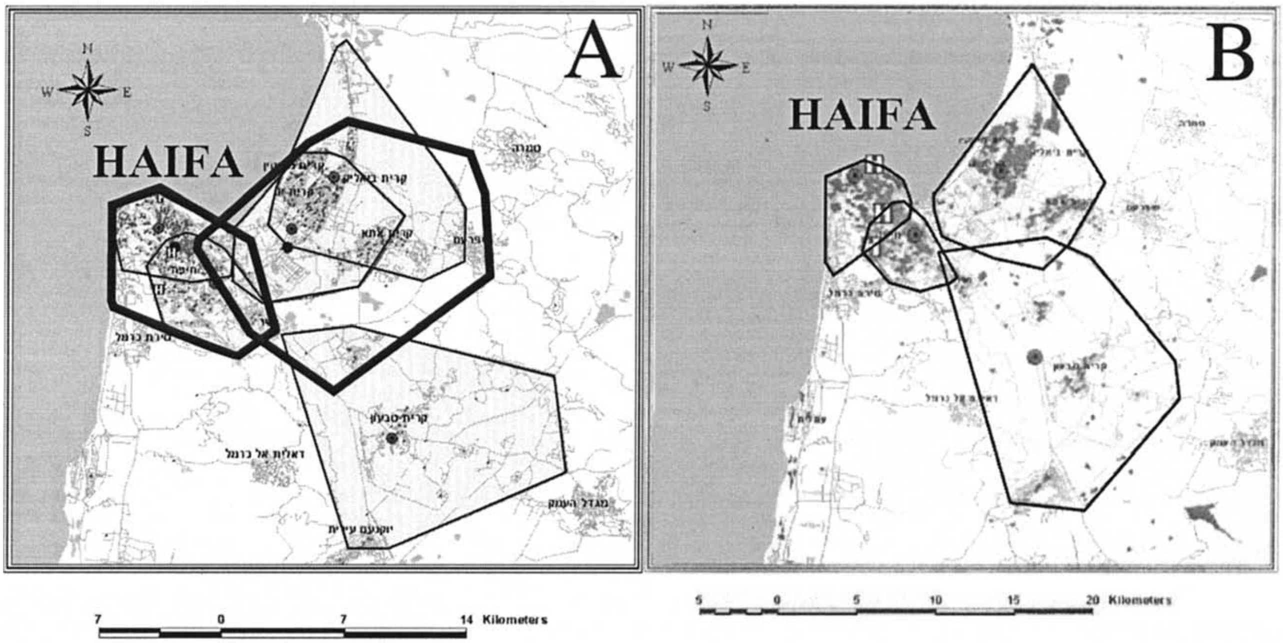

FIGURE 4. Polygon overlay of maps for the Sunday's first (A) and last (B) shifts for the Carmel district (thin lines—8 minutes polygons; heavy lines—15 minutes polygons).

insufficient potential response capacity (Fig4A). As illustrated in Table 3, this scheme enabled response to 13 calls in the previously mentioned example and lowered the likelihood of potential excessive calls to 0.07 (this is, however, a short 2-hour shift). In all other 18 weekly shifts that were previously potentially shorthanded, the addition of 15 minutes polygons remedied the potential ambulance deficit. In the Lachish district, there was ample capacity to respond just with the 8-minute polygons.

DISCUSSION

The simulation model that was constructed and presented in this study suggests that EMS could become more effective if a dynamic, load-responsive ambulance deployment model is adopted. This model can be tailored for any district and EMS system in which call data are available for retrospective analysis.

The response time is critical for the patient's survival and reduction of disability, and many have shown a direct rela-

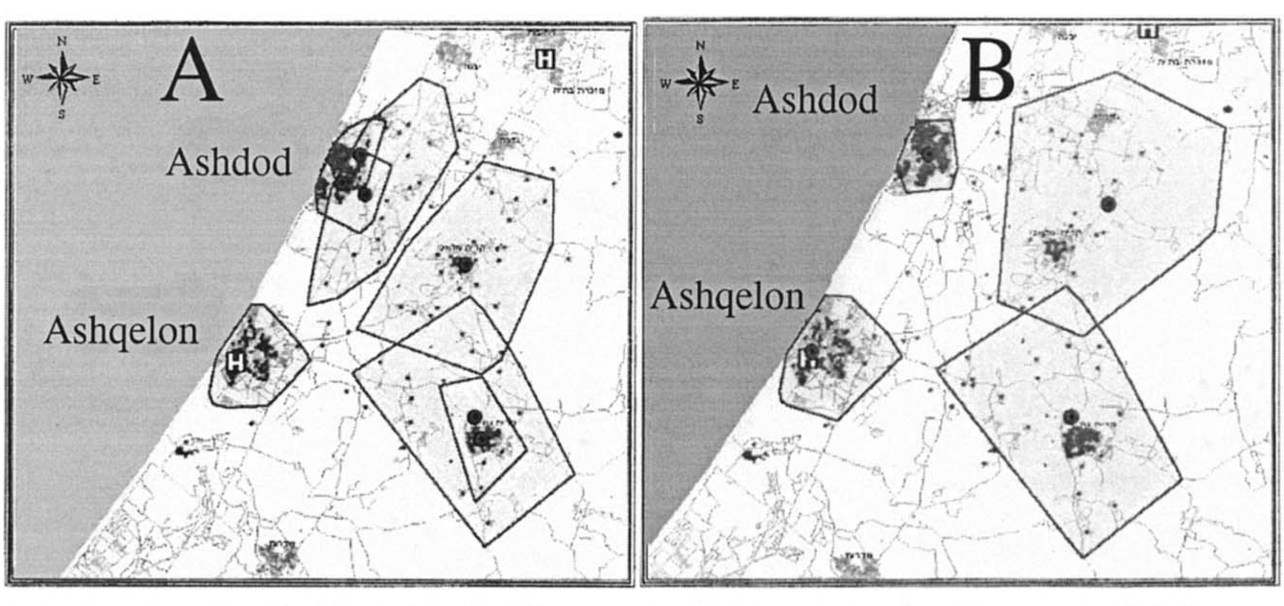

FIGURE 5. Polygon overlay of maps for Sunday's first (A) and last (B) shifts for the Lachish district.

TABLE 2. Carmel District Polygon Analysis for Sundays and Saturdays, Stratified by Shift*

Day	Shift	Calls	Responses Within the Polygons (%)	Mean Number of Calls Responded
Sunday	1	341	98.5	8.9
Sunday	2	1,402	97.2	37.0
Sunday	3	489	95.7	12.8
Sunday	4	823	94.9	21.5
Sunday	5	358	95.5	9.2
Saturday	1	171	97.1	4.5
Saturday	2	914	95.8	23.8
Saturday	3	422	94.8	10.8
Saturday	4	978	95.5	25.0
Saturday	5	368	96.5	9.4

*Actual calls over the study period and the extent of their coverage by the 8 minutes polygons.

tionship between prehospital medical treatment or resuscitation[1-6] and survival.[8,13] A rapid response time is also reflected in an overall shorter turnaround time for ambulances, thus increasing their availability for additional calls.

The simulation model also resulted in a significant (alas, only theoretical) savings of resources in personnel hours, ambulances, and equipment in each of the districts, permitting more cost-effective organization of the EMS services. This is reflected in the reduced number of ambulances and personnel assigned to different shifts and the improved organization of working shifts (manuscript in preparation). System savings from the implementation of a geographic positioning system (GPS) have been demonstrated elsewhere.[14] However, this does not necessarily carry over to the present analysis, which relates to planning of services, whereas GPS relates to operational, dynamic aspects of providing service.

Presently, ambulances are dispatched from a few fixed stations, but the simulation model suggests that additional EMS posts should be established within the territory contained in the polygons. This arrangement could perhaps also reduce the activation time spent between transmission of the call to the EMS team and their actual departure. The preferred alternative would be for the EMS crew to stay in the ambulance during the entire shift, except for patient care.

We must remember that the data reflect the situation in 1996 through 1997. Today, ambulances are equipped with location technology. However, to be effectively used, location and allocation have to be carefully planned.

In our analysis, travel from one district to another is not relevant because the two districts are geographically remote from one another. Ambulances can, however, travel outside their designated polygon. One must remember that polygon construction was based on existing call patterns. If an ambulance travels beyond the limits of its polygon, there is a probability of momentary shortage of ambulances to respond to calls and ambulances from adjacent polygons might have to respond.

Although this model has dealt only with surface EMS services, the incorporation of airborne EMS teams for areas not covered by the polygons should be considered, especially in distant regions where the "Golden Hour" cannot be attained.

There are many other factors that contribute to the quality of EMS that might be added to any comprehensive model for the refinement of policies on EMS. They could include analysis of the training levels required of ambulance teams, the ratio of ALS units to regular BLS ambulances, the equipment carried by either, the organization of the EMS under national or regional hierarchy,[15] the public nature of these services, and more.

We must be aware of some of the limitations of our study. The conclusions are based on the results of the model, but its functionality has not been demonstrated. Implementation could encounter political and operational problems that cannot be dealt with in a formal model. Sensitivity analyses were not performed on all parameters (eg, travel speeds); the extrapolation to the full call volume might not be appropriate. The model must be updated at regular intervals to account for changes in travel times and speeds as a result of changing urban and rural environments, changes in road directions, expansion of lanes in roads, and so on. Operational issues relating to frequent repositioning of ambulances and varying the on-duty personnel were not addressed in this study. In conclusion, a suitable model based

TABLE 3. Carmel District Polygon Analysis for Sundays and Saturdays, Stratified by Shift*

		Only 8 Minutes Polygons		Polygons of 15 Minutes Added	
Day	Shift	Maximum Possible Responses	Probability of Demand Above Maximum	Maximum Possible Responses	Probability of Demand Above Maximum
Sunday	1	9	0.4	13	0.07
Sunday	2	35	0.35	50	0.02
Sunday	3	16	0.15	22	<0.01
Sunday	4	30	0.032	45	<0.01
Sunday	5	22	<0.01	34	<0.01
Saturday	1	7	0.1	12	<0.01
Saturday	2	38	<0.01	53	<0.01
Saturday	3	16	0.05	23	<0.01
Saturday	4	32	0.07	48	<0.01
Saturday	5	24	<0.01	36	<0.01

*Calculated maximum potential responses per shift and the probability that demand will exceed it, under two scenarios: with only 8 minutes polygons and with 15 minutes polygons added.

on retrospective EMS data can help to potentially improve these essential services and result in higher survival rates and reduced disability of their clients.

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