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SIMULATION MODELING FOR EMERGENCY MEDICAL SERVICE SYSTEMS

Wafik H. Iskander
Department of Industrial Engineering
West Virginia University
Morgantown, WV 26506-6101, U.S.A.

ABSTRACT

A simulation model was developed with the purpose of providing EMS planners and managers with a tool to help them in the planning of their operations and in their decision making role in general.

The model was successfully tested on one of the seven EMS regions in the state of West Virginia. Policy changes were tested by running the model under different conditions, and measuring their impact on the performance of the EMS system. Policies investigated include the elimination and addition of squads, reallocation of vehicles, and changing the level of personnel training and preparedness.

1. INTRODUCTION

In the last three decades, incidents warranting emergency treatments have occupied the top charts of most health statistics as the leading causes of injuries and deaths. Planners and management personnel involved with Emergency Medical Services (EMS) are often confronted with difficult decisions and situations which require the use of scientific analysis and the knowledge of advanced decision-making tools. These situations stem from the need to allocate huge resources, in terms of personnel, equipment, and funds to individual squads in the EMS system, and the need to identify the number, make-up, and location of these squads. The decisions made are usually reflected on the quality and effectiveness of the EMS system, which are measured in terms of life savings and health maintenance as well as dollar savings.

A simulation model was developed to provide EMS personnel with help in planning their operations and in making decisions. Several simulation models were developed earlier in the area of Emergency Medical Services. Savas (1968) used a simulation modeling approach to analyze proposed changes in the number and locations of ambulances in the city of New York. Seiler (1971), and Baker (1978) concentrated their effort on the location of EMS squads in urban and rural areas, respectively, in order to minimize the ambulance response time. Gochenour (1972), Okeugo (1981), and Currie, et al. (1984) developed simulation models that are more general in nature. Unlike many of the previous EMS simulation models that have been limited in their application to a very narrow spectrum, or are too specialized to be easily applied in a general basis, the model developed can be easily used in the planning of day to day as well as long term operations of EMS systems. It considers the planning and management of EMS equipment, personnel, and processes. It helps in making decisions that range from large capital expenditures such as the purchase of ambulance vehicles or the decision on number and location of squads, to lesser cost decisions as in the hiring and training of personnel. Special emphasis was placed on the needs of the user and also on the flexibility of the model so that it can be applied to a wide range of situations.

2. EMS SETTING

An EMS setting consists of the population of emergency events created by the daily activities of people. These events are responded to by squads, made up of equipment and personnel trained for this purpose. In general calls come into the system through a central dispatcher who then routes the calls to the appropriate squads. The squads then dispatch vehicles to conduct the emergency care, transport patients to hospitals, and either return back to their bases or respond to other calls.

The EMS operation can hence be considered as having the following five components:

1. Receipt of an emergency call.
2. Dispatch of an ambulance and crew to the scene of the incidence.
3. Treatment of patient at the scene.
4. Transport patient to the hospital.
5. Return of the ambulance to its base, or dispatch to the scene of another call.

3. MODEL INPUT

The simulation model takes advantage of a large data base that consists of several years of detailed information on all emergency calls made in the state of West Virginia. Input to the model includes the following:

1. Squad information. This information

includes the squad code, name, zip code, location (X and Y coordinates), number of vehicles, and number and level of training of personnel.

2. Emergency calls information. Information on frequency and location of the calls are vital to the model. Statistical distributions for time between calls and location of calls (Zip code and X & Y coordinates) need to be fed to the model. Additional information required by the model include the nature of call, case severity, patient status at scene, incident cause, patient suspected problems, and time spent at the scene.

3. Hospital information. The basic information required for every hospital includes the hospital name, location (zip code and X & Y coordinates), and the hospital classification (primary care, secondary or tertiary).

4. Geophysical information. This includes population densities and travel times between squads and centers of all zip code areas assigned to the squad, as well as travel times between hospitals and centers of the different zip code areas.

4. MODEL OUTPUT

The output produced by the model reflects the operating characteristics and measures of effectiveness which are prominent in the decision maker's interest. These include the following:

1. Response time to calls, and travel times and distances for the different segments of the EMS runs.

2. Waiting time (if any) for an ambulance to be available.

3. Number of calls received and handled by each squad.

4. Number of persons taken to each hospital.

5. Utilization of vehicles in each squad.

Policy changes in the EMS system can be easily tested by changing the values of the model input parameters and measuring their impact on the system through the evaluation of the performance indicators obtained in the output. This enables the decision maker to compare the difference between various alternatives. Then with intuition and experience, better decisions can be made.

5. MODEL DEVELOPMENT

The area to be considered in the simulation model needs to be divided into a fairly large number of smaller zones. The exact size and number of zones are determined at the model implementation and depend mainly on the degree of accuracy required and on the availability of data. In the data preparation phase, and prior to model implementation, the following tasks should be performed:

1. Determine the X and Y coordinates of the center of each zone.

2. Determine the standard travel times between each squad and the centers of all zones that can be served by the squad. The model modifies these times stochastically to account for the scatter of emergency calls over the area covered by the zone and for the different traffic conditions. Travel times for urgent calls are assumed to be only a fraction of the modified standard times. If travel times are not available the model uses the X and Y coordinates to calculate the linear distance between the two points, divide it by the average speed, and multiply the time obtained by a factor to make up for the non linearity of the traveled distance.

3. Find the distribution of time between arrivals of emergency calls for the entire area under consideration.

4. Determine the relative frequency of the emergency calls generated from the individual zones.

5. Determine all other statistical distributions and frequencies that are used in the model. (e.g. time spent at scene, nature of call, case severity, etc.)

6. Prepare all other squad, hospital, and geophysical information.

The model was developed using FORTRAN and SLAMII (Pritsker, 1986). The following three events were identified for the model:

1. Arrival of a call.

2. End of service at the hospital (or at the scene if there is no transport to a hospital.)

3. Arrival at base.

The model has five main modules, one for initialization, one for output production at the end of the simulation, and the remaining three correspond to the above three events. Following is a brief description of each of these modules.

1. Initialization. In this module all input data are fed to the model, initial conditions are set, and initial events (including arrival of first call) are scheduled.

2. Arrival of a call. As soon as a call is received the next call is scheduled. The location of the incoming call is defined using the predetermined distributions, and the call is assigned to the nearest squad. If an ambulance is available or if one is on its way back to the base,

this ambulance is directed to the scene of the incident. Otherwise, the dispatcher tries the next nearest squad. If no ambulance is available in all the neighboring squads, the call waits in the queue of the nearest squad. If the call is answered without waiting, the dispatch time, travel time to scene, time spent at scene, and travel time to hospital (only if patient is transported to hospital) are determined. The emergency calls information and distributions are used to generate all specifics of the call under consideration and all the above times. The dispatch time, time to scene, time at scene, and time to hospital (if any) are then added to the current time and an "end of service" event is scheduled.

3. End of service. If a call is waiting, the ambulance will be routed directly from the hospital or from the scene of the incident to the scene of the new incident. Travel time between scenes of the two incidents are estimated using the X and Y coordinates of the two locations, average speed of the ambulance, and a correction factor. The waiting time of the incoming call is calculated and considered as the "dispatch time", and the travel time to the scene, time spent at the scene, and travel time to the hospital are determined as in the event of "arrival of a call" and added to the current time to schedule an "end of service" event. If no call is waiting, the travel time to the squad base is calculated and used to schedule an "arrival at base" event.

4. Arrival at base. The ambulance is set idle at the base where it waits for the next call. Note that both this event and the end of service event should have a higher priority over the event of "arrival of a call".

5. End of Simulation. This module uses all the statistics accumulated in the above modules to generate the final statistics and outputs described earlier.

6. APPLICATION OF THE MODEL

The simulation model was applied to one of the seven EMS regions in the state of West Virginia.

The state of West Virginia is characterized as a rural state, primarily because of its geographical location and its mountainous terrain. It covers an area of 24,071 square miles and has a population of slightly less than 2 million. The state is divided into seven EMS regions. As an administration unit, each region serves as the center for coordinating the activities of the squads within its boundaries. Region 3, the largest in the state in both size and population was selected for the application of the above model. It covers an area of 5,924 square miles and has a population of about 450,000 persons. It comprises sparsely populated areas such as Pocahontas (pop. 10,000), as well as densely populated areas such as Charleston (pop. 224,000), the capital of the state. The region has 47 active squads with 128 vehicles, and 1,476 service personnel. During the year of 1985-86 the squads of this region responded to 56,409 calls. Of these calls, about 85% were directed to 18 hospitals within the region, and 15% to 58 hospitals outside the region.

The area covered by the region, and some of the surrounding areas that may get covered by its squads were divided into 342 zones, each identified by its unique zip code. Using a system developed by Borbash (1976), X and Y coordinates were assigned to the zip code of each of the zones, squads, and hospitals. These coordinates were measured in miles from the center of the region. With the help of the STAM zone model developed by the State Department of Transportation, travel times were estimated between each of the squads and hospitals, and all the zones used in the application.

Using the data available from EMS prehospital care records, frequencies and distributions were compiled and statistically tested for the emergency calls information.

After performing the necessary testing and validation, the simulation model was applied and statistics were collected for one year of operation. Samples of the results produced are given in Tables 1 through 5. Table 1 shows that with the existing 47 squads, and the current rate of arrival of calls, the average response time is 15.9 minutes. This response time can be divided into 4.5 minutes to dispatch an ambulance, and 11.4 minutes to travel to the scene of the incident. The ambulance dispatch time includes both time to get the crew and the vehicle ready, and waiting time when ambulances are not available. The average waiting time is 1.4 minutes, and the average total trip time is 72.5 minutes.

Table 1: Summary of Average Times obtained Under Current Conditions

Time Category	Average (Minutes)
Dispatch Time	4.5
Time to Scene	11.4
Time at Scene	12.6
Time to Hosp.	18.9
Time to Return	25.1
Total Trip Time	72.5
Number of Calls Generated 57716	

Table 2 shows a sample of the frequency of calls generated from the different zones of the region.

Table 3 shows a sample of the frequency and percentage of calls received , and calls responded to, by each squad. When a call cannot be answered by the nearest squad, it may get directed to the next nearest squad. In this case the call is considered to be received by the first squad only, and responded to by the second squad only. This explains why some squads have responded to more than, or less than, the number of calls received.

Table 2: Frequency and Location of Calls

Fayette County				
Zone	X-Cord	Y-Cord	Freq	Pcnt
Alloy	-22.78	4.36	68	0.12
Bepd.Frk	-20.26	9.07	211	0.37
Bcomer	-23.59	3.33	125	0.22
Canneltn	-24.04	.46	52	0.09
Chrltn H	-20.44	5.17	125	0.22
Deep Wtr	-22.06	5.17	378	0.65
Gauley	-18.64	2.53	54	0.09
Glen Frs	-19.63	3.33	11	0.02
Kanawha	-19.09	3.90	97	0.17
Kimberly	-24.40	4.48	45	0.08

Table 3: Frequency of Calls Handled by Squads

County	---Squad--- Name	No	-Calls-Rec Freq	Pcnt	Calls-Resp Freq	Pcnt
Pocahnt	Bartow	31	139	0.24	162	0.28
	Lttl.Lvl	32	276	0.48	232	0.40
	Marlnton	33	108	0.19	134	0.23
	Natl.Rad	34	172	0.30	165	0.29
	Total		695	1.20	693	1.20
Putnam	Putnam	35	2632	4.56	2630	4.56
	Total		2632	4.56	2630	4.56

A sample of the percentage utilization of the vehicles of each squad is given in Table 4. This is the percent of time each of the vehicles in the squad was out of its base responding to a call. It was assumed that the first vehicle would respond always, if possible, to the incoming call, otherwise the second vehicle would, than the third, and so forth. This assumption was made in order to find out the number of vehicles needed by each squad.

Table 4: Percent Utilization of Vehicles

County	----Squad---- Name	No	Vehicle Number	Percent Util.
Fayette	Danese	5	1	31.12
			2	15.26
	Gen.Amb	6	1	9.98
			2	4.43
			3	1.18
			4	0.12
	Jan-Care	7	1	8.92
			2	4.51
			3	1.28
			4	0.42
			5	0.09

Table 5 shows a sample of the frequency of patients transported by the squads of the region to each of the hospitals.

Table 5: Number of Patients Transported to Hospitals

Hosp.Name	Code	Frequency	Percentage
Montgmry	306	7441	12.89
Oak Hill	307	5628	9.75
Pick Mem	308	584	1.01
Poca Mem	309	612	1.06
Scrd.Hrt	310	1286	2.23
St.Fran.	311	7165	12.41
Staats	312	9052	15.68
Smrville	313	4117	7.13
Thomas M	314	2488	4.31
Wbster M	315	418	0.72
Highland	318	2178	3.91

Many of the results generated by the model were compared with the actual data, and no significant difference was found.

7. EVALUATION OF ALTERNATIVES

The simulation model was used to investigate the system performance under six different scenarios and modes of operation. A summary of the important results obtained under the alternatives investigated is given in Table 6. Under the first alternative, a squad that has two vehicles was eliminated from the system. In the second and third alternatives the rates of emergency calls were increased by 25% and 100% respectively. Since 6 vehicles were not used under the current conditions, the fourth scenario investigated the elimination of 5 vehicles, and reassignment of the remaining vehicle, together with 3 other vehicles that are seldom used, to other squads. Even though substantial savings can be realized with the reduction in the number of vehicles, the results obtained show either a slight improvement or no significant difference in the system performance measures . The new distribution of vehicles was used in both alternatives 5 and 6. In the fifth alternative, it was assumed that with the help of safety regulations and awareness programs, the rate of emergency calls would

Table 6: Comparison of Important Measures of Performance Between the Current Mode of operation and the Different Alternatives

Perform. Measure	Crrnt Mode	Alt1	Alt2	Alt3	Alt4	Alt5	ALT6
Wait Time	1.4	1.5	1.8	2.5	1.3	0.5	0.4
Resp Time	15.9	16.6	16.5	16.9	16.1	15.1	12.8
Trip Time	72.5	73.4	72.9	73.8	72.4	72.2	67.6
Veh.%Util	6.2	6.4	7.7	12.5	6.5	3.1	6.0
# Unusd V	6	6	4	0	0	11	11

be reduced by 25%. In the sixth and last alternative it was assumed that, with proper personnel training and use of more professionals rather than volunteers, the level of personnel preparedness and efficiency would improve and lead to a 50% reduction in the dispatch time and 25% reduction in the time spent at the scene. The alternatives stated above are just a few examples of how the model can be used. Additional alternatives can be developed to investigate the impact of relocating squads, adding new squads to the system, relocating hospitals, etc.

8. CONCLUSION

A simulation model was developed to help EMS planners and managers in planning their operations and in making decisions. The model developed is versatile and easy to use. It is flexible enough to be easily expanded or contracted to include different number of squads, to cover areas of various sizes and to examine different alternatives. It can be applied to either urban or rural areas or both.

The model was successfully tested on one of the seven EMS regions in the state of West Virginia. Outputs were produced under the normal rate of calls as well as increased and reduced rates. The outputs produced helped answer questions on the elimination and addition of squads, reallocation of vehicles, and appropriate level of personnel training.

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AUTHOR BIOGRAPHY

WAFIK H. ISKANDER is a professor of Industrial Engineering at West Virginia University. Before joining WVU, he was a consultant and a branch manager with CBM, Inc. He received a B.S. in Mechanical Engineering from Cairo University in 1968, a M.S. in Industrial Engineering from West Virginia University in 1971, and a Ph.D. degree from Texas Tech University in 1975. He has been involved in various simulation studies. His current research interests include simulation analysis, and other aspects of operations research and production planning and control. He is a member of IIE, ORSA, and TIMS.

Wafik H. Iskander
Department of Industrial Engineering
West Virginia University
Morgantown, WV 26506-6101, U.S.A.
(304) 293-4607