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ABSTRACT

An emergency service system provides mobile units such as ambulances, police cars, fire engines ... etc. to respond to requests for service which can occur at any time and any place throughout a specified area such as a city or a metropolitan area. Emergency service systems perform a vital role in maintaining the safety and well-being of the public. Consequently, an efficient support system that aids management in deciding upon the most appropriate equipment allocation, personnel staffing, operating policies and procedures, short- and long-term planning is of critical importance.

This paper presents an empirical research study to design and implement a decision support system for the analysis and management of an emergency service system. It discusses the nature of the problem and the efforts made to render the system flexible for handling different types of emergency service systems. It then demonstrates the implementation of the system to the problem of allocating police patrol vehicles to non-homogenous precincts with different demand patterns.

§1. Introduction

An emergency service system provides mobile units such as ambulances, police cars, fire engines ... etc. to respond to requests for service which can occur at any time and any place throughout a specified area such as a city or a metropolitan area. Emergency service systems perform a vital role in maintaining the safety and well-being of the public. Typical examples of emergency service systems are ambulance stations, fire stations, police stations and patrol cars, bomb disposal units, certain tow trucks, and emergency repair trucks for gas, electric and water services (Chaiken and Larson, 1972; Savas, 1969). Consequently, an efficient support system that aids management in deciding upon the most appropriate equipment allocation, personnel staffing, operating policies and procedures, short- and long-term planning is of critical importance.

Optimizing emergency service systems has received considerable research interests in the past two decades. Two different approaches were used to address the problem. The first approach finds the optimal number and locations of the emergency service facility that will optimize some objective function subject to certain constraints. Different choices of the objective functions and constraints can result in drastically different emergency service siting models. For example, the earliest work under the title "location covering model" tried to find the least number and positions of ambulances such that all demands have at least one ambulance stationed to respond within a time or distance standard (Toregas et. al., 1971). Failure in the earlier work to consider the frequency of demand and the cost to cover distant demand areas led to the maximal covering location problem (Church and ReVelle, 1974; White and Case, 1974). Given a limited number of ambulances, the maximal covering location problem sought to find the locations of ambulances to maximize the number of people (or calls for service) covered by an ambulance within the time or distance standard. Numerous extensions of the maximal location covering problem have been proposed to solve more realistic and practical problems. For instance, backup coverage models were developed by Daskin and Stern (1981), Hogan and ReVelle (1986), Pirkul and Schilling (1988) and Batta and Mannur (1990) to account for the possible unavailability of the emergency service units. Queuing theory was also applied to address the issue of server availability, e.g., the work by Larson (1974, 1975), Halpern (1977), and Benvensite (1985), among others. Capacitated versions of maximal location covering problem are developed by Chung et. al. (1983), Current and Storbeck (1986), and Pirkul and Schilling (1991) to include capacity constraints on the emergency service facility's workload. ReVelle (1991) provides a review of emergency service siting models that are representatives of this approach.

The second approach assumes given locations of the emergency facilities and attempts to find the optimal allocation of personnel and vehicles which reduces the response time of the emergency service units to a preset level. Examples of this approach that seek to find the optimal number of emergency units (vehicles) include analytical models by Cobham (1954), Larson (1969) Stevenson (1971); and simulation models of an automated dispatch system for the San Jose Police Department by Adams and Bernard (1970), of fire department operations by Carter and Ignall (1970) and the New York emergency ambulance service by Savas (1969).

We choose to address the latter problem because majority of the emergency service systems are already located in certain sites and are difficult, if not impractical, to relocate. In some cases, emergency medical vehicle bases are "constrained to be fire stations where paramedics can rest and perform routine maintenance and resupply while not on call," see Goldberg, et. al. (1990). Moreover, the emergency services in metropolitan areas have branches or secondary sites for their units located at certain places so as to cover the whole city, e.g., fire stations, police precincts, hospitals, etc. This distribution of facilities within the total area partially, if not completely, addresses the first problem. Thus, the issue that actually faces the emergency service administrators is the management and allocation of resources to the existing facilities.

So far, the emergency service models of both approaches in the literature fail to consider the randomness of the operating environment. As explained in ReVelle (1991), "the environment of these models is not merely random, it is also dynamic, evolving through the day, week, and season. Demand may also exhibit a trend, and new demand areas may evolve over time. None of the probabilistic siting models have yet been extended to changing and evolving environments." By analyzing the real world environmental factors, one notes that:

1. The real world response time is dependent upon the stochastic occurrence of incidents that are spatially distributed according to some probability distributions. The travel time to and from the scene of the incident is, in turn, a function of the traffic congestion, the time of the day, the weather conditions, etc. In addition, not all the incidents are of equal significance (severity); different incidents require different numbers of emergency units which may require assigning priorities and possibly preemptions. None of the above mentioned analytical models capture all these aspects of the problem. Restricting assumptions such as no priorities, exponential service times (Stevenson, 1971), only one unit responds to each call (Cobham, 1954), etc. are usually necessary to make the analytical models tractable.

2. The real world systems operate in a complex environment that includes ill-defined objectives, implicit and explicit administrative, legal, and political constraints (Chaiken and Larson, 1972). A solution that is acceptable in one environment (city/region) may be infeasible or unacceptable in another environment. Many of the solution techniques mentioned above are designed for decisions that relate to a specific problem in a given environment. The model, the user interface, and the model solution process are coupled in a self-contained system. As a result, these models are inflexible and are difficult to adapt to different decision making styles or changes in their dynamic environment (Elam, Henderson and Miller, 1980).

The purpose of this paper is to present a generalized, robust, and flexible decision support system (DSS) for allocating resources of an emergency service system located in a given area. More specifically, the emergency service systems addressed in this paper possess the following characteristics:

1. Random incidents occur at random locations throughout the area which give rise to requests for services.
2. In response to each request, one or more emergency units are dispatched to the site of the incident.
3. The quality of service is a function of the response time defined as the elapsed time between the reception of the request for service and the beginning of the treatment. For example, returning a patient to the nearest hospital or arrival of a police car to the scene of the incident.

The methodology presented in this paper is quite general and can be applied to develop decision support systems for all types of emergency service systems. A police patrol car system is used to demonstrate the specifics of the development of such decision support system. The rest of the paper is structured as follows. Section 2 discusses the design objectives of the emergency service decision support system. Section 3 presents the results of system investigation and analysis. The model subsystem is described in Section 4. Section 5 discusses the system implementation.

§2 The Decision Support System Objectives

Since the system is intended for use by general users, it is designed to provide a variety of options that caters to a wide range of managerial styles (Huber, 1983). The emphasis of the DSS is friendliness and flexibility of operation rather than a system that replicates a single user decision-making process. Specifically, the objective of the DSS described in this paper is to provide the users with a means to:

1. Investigate and analyze the current dispatching system to identify areas with unacceptably long response times based upon existing or new criteria.
2. Test and evaluate the effects of proposed policy changes on response times to all or particular calls, units and personnel utilization rates, units availability, etc.
3. Conduct "what if" type queries to investigate the impact of changes on the priority assignments, the number of units assigned to different types of incidents, the number of resources assigned to shifts, preemption rule, or intersector dispatching.

§3 System Investigation and Analysis

To design a practical and meaningful system, a sample city with a population of approximately one million was chosen for modeling and data collection purposes. The system will be tested on the allocation of police patrol cars to the city's four contiguous and overlapping sectors (precincts). In this paper, the terms precinct and sector are used interchangeably. The reason for choosing the police patrol car system is that the delineation of the police precincts corresponds in many aspects to the delineation of fire stations, ambulance stations, hospitals, etc.

The population of each sector has a quasi-homogenous set of characteristics that are a function of (1) the income level, (2) proximity of the sector to business district(s) or shopping centers, (3) type of sector, e.g., residential, industrial, transient, and (4) ethnic origins of the residents.

The characteristics of a sector together with the time of the day, e.g., morning and evening or regular and peak hours affect the rate of occurrence of different types of incidents, and the travel time to and from the location of the incidents. An incident, in this context, is defined as a set of conditions that necessitate the dispatching of one or more emergency units, or in general, create a demand for one or more emergency units. Incidents vary in severity and thus claim different amounts of remedial/corrective action. Priorities are assigned to incidents based upon their degree of severity and the number of emergency units required where priority one represents the highest severity, e.g., a fire in a residential area, a bomb threat, a homicide, etc.

Process Description

The process description is based upon our observations and personal interviews with the manager, dispatchers, and police officers.

1. Calls arrive to a central switchboard and are routed to the appropriate precinct based upon the location of the incident.
2. The precinct's dispatcher assigns a priority for each call and schedules the necessary number of vehicles to it.
3. If all or some of the necessary patrol cars are available, they are dispatched instantaneously. Else, the call is queued according to its priority until all or some of the required vehicles are available.
4. As a preventive measure, some patrol cars are assigned routine patrols to act as deterrents to certain types of crimes (Chaiken & Larson, 1972). However, these cars are considered available to the dispatcher and can be assigned to any incident site if deemed necessary.
5. The average transit time from a precinct patrol car pool or from a car on patrol to the scene of the incident differs according to the time of the day and also between sectors. The difference is due to precinct congestion, traffic density, freeway availability, and road and weather conditions.
6. The time to process a call (the time between arrival at the scene of the incident and completion of necessary remedial/corrective activities) is a function of the priority of the call. The time to process calls of the same priority follow the same probability distributions for all precincts.
7. Once a call is processed, the patrol car(s) return to the precinct to file a report and deliver arrested persons, if any.
8. Calls that originate within a precinct are exclusively served by the precinct's patrol cars. A policy option to be investigated in this system is the impact on the average system response time if partol cars are allowed to be borrowed from neighboring precincts.

Data Collection and Analysis

Another advantage for choosing the police patrol car system is that most of the needed data is recorded and readily available for analysis. Data for twelve 24-hour days representing every day of the week over a six month period was used to identify the distributions for time between arrivals, service times for different types of incidents, and travel times in different sectors during different hours of the day under different weather conditions.

Direct observation was used to collect data about the time it takes the sector dispatcher to receive a call, assign a priority, and schedule the necessary vehicles. Interviews and direct questioning were used extensively during the initial system investigation and during the system validation phase.

The collected data was then arranged into several records/files, one for each event/activity, constituting the nucleus of the data subsystem. The files are formatted in a way so that they can readily interface with the available statistical analysis software packages and the model subsystem according to activity time and location. The process of establishing the data management component has now become much easier due to the availability of powerful microcomputers with their multitude of user friendly software such as data bases, SAS, MINITAB, etc. Tables 1 and 2 illustrate the values of system variables derived from the statistical analysis and testing of the compiled data.

§4 The Model Subsystem

The analysis of the emergency system in the previous section indicates that a real world system is characterized by a stochastic demand that usually follows more than one probability distribution based upon the time of the day, the characteristic of the region, and sometimes the season of the year. The number of emergency units necessary to service the demand is dependent upon the severity of the incident which is also a random variable described by some probability distribution. Each sector within the region has its own probability distribution for demand type which may vary with the time of the day and also the season. The travel time to and from the incident scene is also a random variable that follows a probability distribution that changes according to the time of the day, the weather, the season, etc.

Analytical techniques are not sufficient to provide a solution to such complex systems. In addition, administrators need an easy to comprehend and apply technique that can help them evaluate several options or policies. The technique most suitable for this type of application is simulation. General flow diagrams for an emergency service system without and with preemptions are illustrated in Figures 1 and 2, respectively.

Table 1
Probability of Demand and Number of Vehicles Currently Available

Travel Time within Sector (in minutes)	Probability of Demand for Service		Number of Vehicles Currently Available	
	Regular Hours	Peak Hours	Regular Hours	Peak Hours
Sector 1 Normal (4.3, 1.2)	0.33	0.37	9	10
Sector 2 Normal (3.0, 5.0)	0.37	0.34	14	16
Sector 3 Normal (2.0, 5.0)	0.14	0.17	6	7
Sector 4 Normal (3.2, 0.9)	0.16	0.12	4	5

Regular hours: from 4:00 a.m. to 8:00 p.m.
Peak hours: from 8:00 p.m to 4:00 a.m.
Incidents Interarrival Times:
Regular hours are exponential with mean 9.8 minutes,
Peak hours are normally distributed with (mean, standard deviation) = (7.8, 1.2) in minutes.

Table 2
Probability of Occurrence of Different Types of Demand/Sector

Sector No. / Processing Time in minutes	1		2		3		4		Probability that two vehicles are necessary
	R	P	R	P	R	P	R	P	
Priority 1 Triangular (80, 100, 130)	0.11	0.15	0.13	0.17	0.09	0.13	0.07	0.10	1.00
Priority 2 Uniform (46, 100)	0.26	0.33	0.27	0.35	0.15	0.18	0.11	0.11	0.75
Priority 3 Normal (61, 3.5)	0.45	0.39	0.42	0.33	0.44	0.36	0.44	0.40	0.36
Priority 4 Uniform (30, 57)	0.18	0.13	0.18	0.15	0.33	0.33	0.38	0.35	0.12

R: Regular hours
P: Peak hours

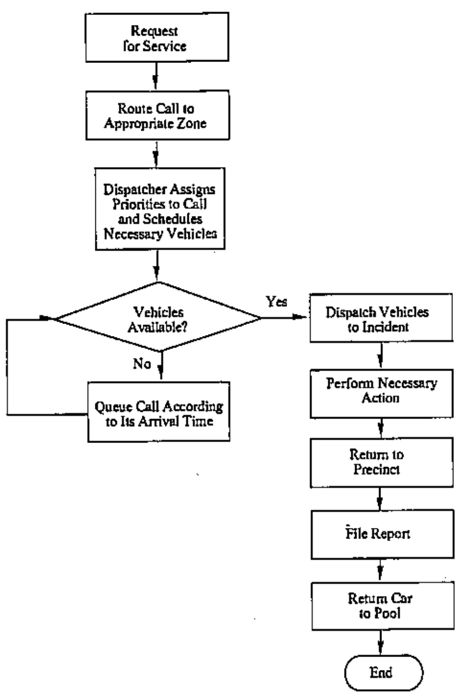

Figure 1: Flow Diagram of Vehicle Dispatching Without Preemption

Model Features

1. Some or all of the demand rates, service and travel times can be stochastic. Their probability distributions can take any shape and maybe defined in a closed form or as a table look-up.
2. The time spent routing a call from the central switchboard to the appropriate sector is negligible. However, if it is not, it can be easily added to the model.
3. All vehicles (equipments) including those on routine duty/patrol, are devoted exclusively to servicing calls.
4. Breakdowns in vehicles (equipments) can be repaired or replaced instantaneously.
5. The service time for a call includes the time necessary to file a report. Thus, there is no time lag between the return of a vehicle to the sector pool and its dispatch to another call.

The above features enhance the system's versatility so that it can handle all different types of emergency service systems in different environments. The model was then translated into a SLAM II network. The reasons for selecting the SLAM II simulation language over other procedural or general purpose languages are:

1. The SLAM II program is portable and runs on a wide variety o mainframes and microcomputers.
2. The ease of programming, production, and clarity of the statistical outputs and graphs.
3. The enhanced modeling and graphics capabilities that makes the system user friendly and easy to use by nonprogrammers.
4. The SLAM II program is being used in over 400 industrial, academic, and government installations.

§5 DSS IMPLEMENTATION

The decision support system can be implemented to investigate the following possible operating policy alternatives of a police patrol car system.

1. Each sector (precinct) serves only its own population and no preemption is allowed.

Table 3: Emergency Units Response Time and Utilization Statistics

Sector	Vehicle Allocation	Percent of Response Time Below: 6 minutes	15 minutes	25 minutes	40 minutes	Utilization Ratio
1	Priority 1	42.9	71.5	85.8	100.0	
	Priority 2	36.0	60.0	95.2	96.0	
	Priority 3	67.9	89.4	89.4	93.0	
	Priority 4	83.3	92.6	92.6	100.0	
	Overall	56.9	77.8	89.0	96.0	78.1%
2	Priority 1	100.0	–	–	–	
	Priority 2	85.7	95.3	100.0	–	
	Priority 3	84.6	88.4	88.4	96.2	
	Priority 4	92.9	92.9	92.9	100.0	
	Overall	88.6	92.9	94.3	98.6	59.5%
3	Priority 1	100.0	–	–	–	
	Priority 2	100.0	–	–	–	
	Priority 3	89.0	89.0	89.0	100	
	Priority 4	92.0	92.0	92.0	92.0	
	Overall	92.0	92.0	92.0	96.0	26.5%
4	Priority 1	100.0	–	–	–	
	Priority 2	100.0	–	–	–	
	Priority 3	100.0	–	–	–	
	Priority 4	100.0	–	–	–	
	Overall	100.0	–	–	–	34.5%

2. Each sector serves only its own population, however, a priority 1 call can preempt priority 4 incidents. If no priority 4 incidents are being served, then the priority 1 call will attempt to preempt a priority 3 incident. However, priority 1 calls can not preempt priority 2 incidents.

3. No preemption is allowed. However, a sector that receives a priority 1 or 2 call can request service from a neighboring sector if it has no units available and the neighboring sector has unassigned units.

At the present state, the system is operational only for the first scenario. The second policy is considered impractical and difficult to administer by the potential users of the DSS. Additional data collection and analysis for the third policy option are in progress. We expect the system to be fully operational within the next 6 to 8 weeks. Table 3 shows a sample output of the DSS for a patrol car system. The implementation of the DSS under scenario one provided some valuable insights. For example, Table 3 shows the existence of intersector work load imbalance. This leads to dissatisfaction among the personnel and the utilization factor in the fourth sector is relatively low indicating a possible underutilization.

§6 Conclusion

The purpose of this study is to design a flexible, adaptable, easy to implement, and most importantly, practical decision support system for emergency units allocation. Although emergency service systems have many characteristics in common, they do have their idiosyncrasies. To design a practical DSS that will be applicable to all the different emergency service systems, many stipulations/assumptions had to be made in the model. Care was taken so as not to render the model subsystem complicated for the administrators and users.

To test the practicality of the system, it was applied to the problem of police patrol vehicles allocation in a medium sized city. The results of the first trial was encouraging. The system proved to be a valuable managerial tool for understanding the dynamics of the problem and suggesting possible solutions. It also provided answers and reasons to problems that management was not aware of such as the real reasons behind personnel dissatisfaction.

It would be presumptuous to say that this DSS is perfect or even in its final shape. Decision support systems, in particular, are never in final shape. They need to change to accommodate the changes in their volatile environment such as the users, the problem, etc. (Sprague and Carlson, 1982). This is why care has been taken during the design phase to make sure that the system is flexible enough to accommodate additions or modifications with the least possible cost and without a major upheaval.

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