J. King Saud Univ. Vol. 2, Architecture *and Planning,* pp. 23-41, Riyadh (1410/1990)

The Spatial Distribution and Resource Allocation of Fire Safety Service Systems

Ibrahim Sanli and **Faisal** Al-Tamimi
College of Architechue and Planning, King Saud University, Riyadh, Saudi Arobia

Abstract. An urban setting is by nature a system of spatial relationships and socio economic interactions. Protection and safety is a service subsystem in this setting. This kind of subsystem is influenced by the needs, spatial distribution, type, and location of activities of the population as well as by communication and transportation networks. The character and structure of such a subsystem also depends on its organization and the management of services allocation, location, and delivery. In this paper, we review principles affecting the performance of these service systems with regard to spatial relationships and communication patterns within cities. We thereafter discuss principles related to the location and allocation of fire services. Finally, we evaluate two widely used computer based models integrating several of the analytical principles toward satisfaction of the desired objectives for the location and delivery of fire services.

Introduction

Emergency services include police patrol, ambulances, fire protection, towing, and emergency repair for gas, electricity and water. Fire Service has conceived of as an organized public service having the primary objective of preventing fires from occurring and reducing the loss of life and property due to fires. Fire protection services and fire service related activities are conducted in relation to both the characteristics of the spatial environment as well as to the socio economic and demographic characteristics of the population. Individually or in combination, spatial, social, and economic factors, contribute to the incidence of fire and to the response capability of a fire protection service. These factors, to a large extent, determine the nature of fire hazards and influence the location of fire stations and the effective delivery of services.

Spatial considerations are primary to planning fire services, in order to determine the distribution of fire stations and their specific locations given social and economic needs and the existing communication and transportation networks. Non-spatial aspects, ranging from the nature of the fire to that of the fire service itself, its resource inputs, organizational set-up, and resource allocations and deployment policies for fire service delivery, are also involved. While most features of the spatial environment, are relatively static, e.g. the urban layout, non-spatial aspects are continuously changing. Furthermore, the spatial and non-spatial environment constantly interact. But it is particularly the spatial environment which presents significant constraints on, and potential solutions for, effective and efficient urban fire protection.

The main objective of a fire service is to minimize the loss of life and property caused by fire. This objective is to be realized vis-a-vis a set of performance measures which depend on the content of the local service provided. Six frequently used performance considerations [1-5] are:

- Adequate level of fire protection
- Acceptable fire risk
- costs
- Availability of fire companies
- Fire company work load
- Response time

Neither the adequacy of fire protection nor the level of acceptable risk are specific quantifiable performance measures against which alternative fire protection policies and station locations can be evaluated. Cost of service can be considered a performance measure if it allows for evaluation of the effect of alternative policies given equal resources, i.e., equal costs. The fourth performance measure, availability of fire companies in the event of fire, is based on the assumption that a fire company is available and that travel time to the site of fire is minimized. Fire company work load refers to the average number of times per day that a fire company responds to alarms, or the average period of time it spends at the scene of a fire. Finally, the central theme of any deployment poeicy response time is defined as the period of time from the moment the fire department is notified until a fire company is ready to operate at the scene of an incident. Minimization of response time would be expected to reduce life and property losses. As indicated in Fig. 1, response time consists of four

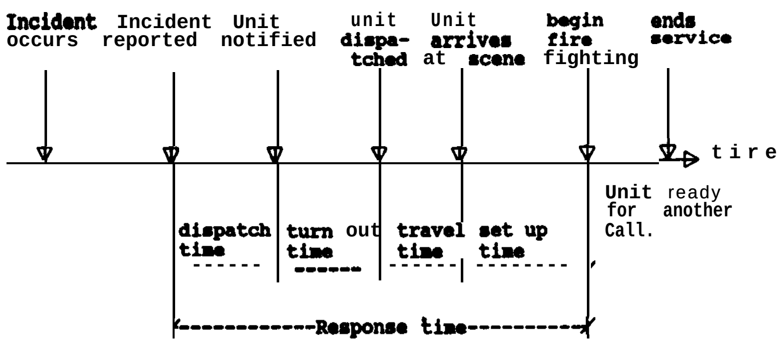

Fig. 1. Time-dependent fire service activities

time components: dispatching time, turn out time, travel time and, set up time. In most instances, the only component of response time that is affected by changes in the deployment of fire companies is travel time where travel time depend on the number and location of fire companies.

Because different types of units (for example, engines and ladders) perform different functions at a fire, it is important to determine the travel time for each type of equipment. And, because two units of the same type working together may be able to take an action that neither could handle alone, the travel time of each arriving piece of equipment is important. It is generally agreed that the first five minutes of any fire is the determining factor as to whether that fire will remain a small fire or become a large fire [6,7]. In addition to average travel time, obtained by measuring travel times between fire stations and actual incidents, travel times between fire stations and potential fire hazard areas (such as hospitals, schools, chemical plants, nursing homes, and high rise buildings), are important as measures of fire department performance and in deployment analysis.

Obviously, more performance criteria are involved implicitly, if not explicitly, in evaluating the performance of a fire protection service and the alternative possibilities for fire station location [8,9]. The fulfillment of all of these performance measures requires attention to both allocation and location of services. Careful distribution of services accompanied by proper operational strategies improve performance by ensuring availability of equipment and coverage of designated primary service zones within the city, reducing travel time, and contributing to efficient assignment and operation of resources (equipment and manpower).

Methods and Approaches for the Allocation and Location of Fire Services

Geography and land use guidelines

A commonly used method of locating fire service facilities is based on geography and land use. In its simplest from, this method relates the location of facilities to a predetermined structural unit of the city such as an urban sector or a district of a given population size. A service area’s population ranges anywhere from 10,000 to 80,000. For example, an urban district having a population of 1535,000 is commonly suggested to be an appropriate unit for the location of a fire station. In larger cities, the recommended population size of a sector or a district to be served by a fire station increases to 3550,000. The geography based location criteria is regarded as no more than a broad, rule of thumb standard, attempting to ensure the minimum requirement. The Riyadh Master Plan study [9] suggests, for example a minimum service radius of 1000m in high hazard areas and 400 m in other areas with variations based on fire hazard rates in the city as well as accessibility and water pressure. The recommended standards for the location of fire stations are as follows:

-Population size : 50,000 – 80,000
-Size of station : 2-6 Engines
-Floor area : **1500 – 5000 M^2**
-Land area : 1000 – 4000 M^2 (with/quarters)
-Service radius : 1000-4000
-Location : Direct access to main arterial radius.
-Special requirement : minimum 20 m frontage.

In the new town of Jubail a theoretical structure of the city, shown in Fig . 2, was used for planning the fire service facilities; i.e., a fire station was recommended for each of the eight district centers to serve an area of some 50,000 people or 4 km x 4 km square.

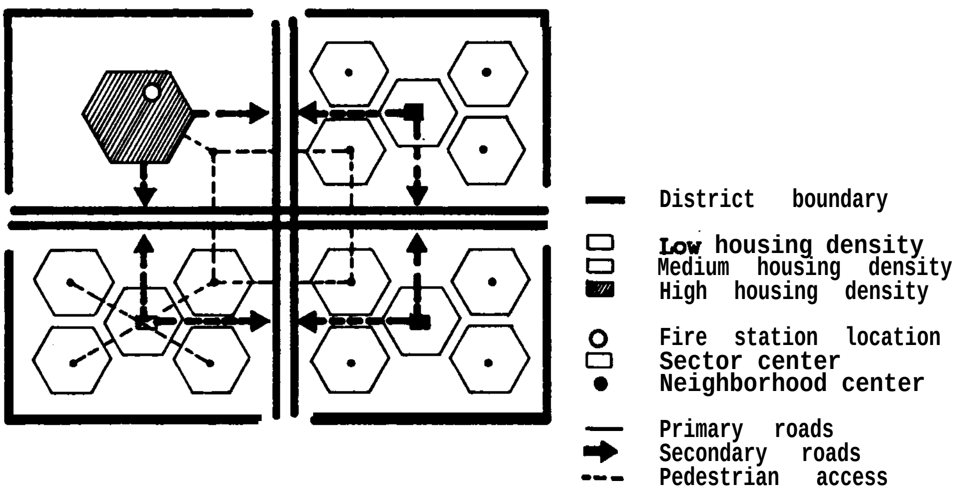

Fig. 2. **A theoretical city structure.**

Insurance services office (ISO) guidelines

The IS0 guidelines provide an improvement on the geography based methods of allocating and locating fire stations. They take physical distances into consideration along with a rating of fire fighting ability according to type of land use and facilities as well as the availability of suppression capabilities including water. This approach involves grading municipalities on the level of fire services they provide for the purpose of establishing a basis for subsequent fire insurance rates for individual properties in the municipality. The grading procedure is based on the number of deficiency points that each municipality has. Fire service elements and the maximum deficiency assigned for each element is shown in Table 1 [10].

Table 1. Relative values and maximum deficiency points

Feature	Percent	Points
Water supply	39 - 40	2950
Fire department	39-50	1950
Fire service communication	9 – 10	450
Fire safety control	13	650
	100	5000

Note: Water supply is measured by the flow, gallons of water per minute, required for different buildings, or different zones of development in the city[lO]. "Fire department" includes items such as training, equipment, and manpower. Fire safety control includes building conditions, fire prevention programs, building codes, and enforcement, Bare[11].

The implications of the ISO guidelines [12], are that in a hypothetical high fire hazard area, optimum location of fire companies would be uniformally distributed on a hexagonal grid as shown in Fig. 3. The IS0 requirements for maximum travel distances would call for spacing engine companies 1.3 miles (2.08 km) apart and ladder companies, 1.73 miles (2.77 km) apart. Thus, first alarm requirements for three engines and two ladders would be 0.41 miles (0.66 km) for engines and for ladders, 0.61 miles (0.98 km). The density of companies per square mile would be 0.68 (1.74 sq. km) for, engines and 0.38 (0.38 sq. km) for ladders [8,13]. These maximum distances and recommended densities were suggested as guidelines subject to modification to suit local conditions in the zone of protection, for example, traffic routing and congestion, topographical features, man-made barriers such as railroads and highway structures, etc. [8,13]. The IS0 guidelines, in addition, attempt to establish a hypothetical allotment of fire stations based on the maximum distance requirements as reflected in city size. See Table 2 below.

Table 2. Allocation of engine and ladder companies by size of city

Population	Pumper Co's	Ladder Co's
1000	1	1
10000	1	1
25000	4 2	2 1
50000	7	3
100000	10	4
150000	14	6

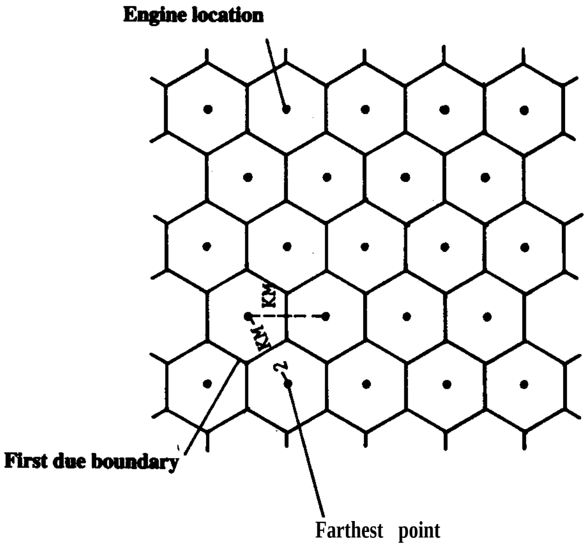

Fig. 3. Fire station location & distribution [3].

The problem of fire station location within the above discussed framework involves the allocation of manpower and of the different types of fire company resources to a city or to subzones of a city. A good rule of thumb is to provide one pumper company (plus supporting units) for each 500 gpm that may be needed, plus personnel for rescue and other operations which need to be performed simultaneously with the advancing of hose. The following levels of response have been recommended, relating crew size and type to the type and severity of fire [1,6]:

High Hazard Occupancies: (Schools, hospitals, nursing homes, explosive plants, refineries, high rise buildings, and other high life hazard or large fire potential occupancies). At least 4 pumpers, 2 ladder trucks, 2 chief officers, and other specialized apparatus as may be needed to cope with the combustibles involved: not less than 24 fire fighters and 2 chief officers.

Medium Hazard Occupancies: (Apartments, offices, mercantile and industrial occupancies not normally requiring extensive rescue or fire fighting forces). At least 3 pumpers, 1 ladder truck, 1 chief officer, and other specialized apparatus as may be needed or available: not less than 16 fire fighters and 1 chief officer.

Low Hazard occupancies: (One, two or three family dwellings and scattered small businesses and industrial companies). 'At least 2 pumpers, 1 ladder truck, 1 chief officer, and other specialized apparatus as may be needed or available; not less than 12 fire fighters and 1 chief officer.

Rural Operations: **(Scattered dwellings,** small business and farm buildings). At least 1 pumper with a large water tank (500 or more gal.) on mobile water supply apparatus (1,000 gal. or larger) and such other specialized apparatus as may be **necessary** to perform effective initial fire fighting operation; at least 6 fire fighters and 1 chief officer.

Additional Alarms: At least the equivalent of that required for Dual Operations for second alarms; equipment as may be needed according to the type of emergency and capabilities of the fire department. This may involve the immediate use of mutual aid companies until local forces can be supplemented with additional off-duty personnel.

It should be emphasized, however, that the IS0 guidelines are not designed specifically to determine the number and location of fire stations; and that in specifying many of the apparent relationships (e.g., the recommended maximum allowable distances for first arrival, first alarm, and maximum multiple alarm fires), the guidelines appear to be based on subjective judgments rather than on scientific or empirical foundations. The standards seem to aim at a rather general distribution with a wide safety margin built into the calculations. These rule of thumb standards for distances and different hazard levels fail to take into account or deal with some important concerns of fire services, such as delays incurred in dispatching the appropriate unit from the station, the availability of units, and the travelling speed of the units on the streets.

Drawbacks of the above two methods along with developments in fire system analysis have produced a search for new' approaches to allocating and locating fire services. New methods address the issue of reducing the distance between a fire and the responding units, and that of the contribution of management in deployment and resource allocation decisions. Locating the fire service stations in a city is not an end in itself, but an important part of the total effort to implement the objectives of fire department (e.g., to reduce the actual and potential loss of life and property due to fires). This approach involves deployment analysis, which relates the location of fire facilities to optimal allocation of fire service resources in order to meet service **demands.**

Allocation and location of fire companies

Once the number of fire companies is determined the issue becomes one of ensuring the best distribution of these companies throughout the protection area. The distribution is arranged in a manner that helps satisfy the selected performance *measures,* e.g., availability of units, minimization of total travel time, equalization of protective coverage, work load, etc. In an emergency response system in which calls are received by a central dispatcher, who screens and processes the calls, the dispatcher assigns one of the units to the scene of an incident. If all units are busy, calls must be held until a unit becomes available, causing congestion of service. A fundamental issue here is the average waiting time before service is rendered. Unacceptable waiting time raises many questions about deployment operations and the time consumed by service units at every stage of the process.

Two basic assumptions are usually made here: that an urban emergency system travels short distances and that alarm rates are high. These assumptions vary from one area to another. High service area can, therefore, be identified to enable potential utilization of available units from other areas. Where there is a high demand for service queuing of service units and efficient dispatching is of great importance [14-17]. New methods of queuing analysis include both the number of vehicles and the overall deployment policy. By dividing a city into a number of well defined disjoint sectors to be serviced by a certain number of vehicles. This approach attempts to reduce the total response time and at the same time distribute the work load equally among all fire units. Larson [18,19] developed the hypercube model for response sectors and optimum dispatch policies. In this model the probabilistic nature of demand for service is considered along with the potential assistance from other sectors. The model is based on ability to distinguish the call rates for each sector and the availability of units in adjacent sectors. The probability that one or more free unit can be rep resented by a hybercube indicating all possible probability states of vehicle availability. Fig. 4 shows an example for 3 units.

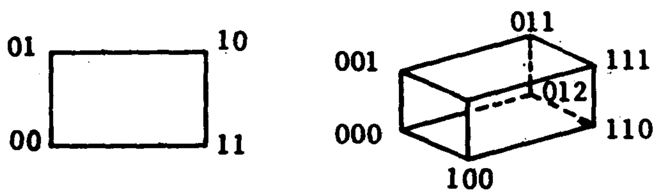

Fig. 4. Hybercube model

When a city is divided into sectors, the probability that a call originating in one sector can be answered by a unit in another sector can be determined. The total response time is determined by:

$$T = 1/\lambda \sum_i \sum_j \lambda_j P_{ij} d_{ij}$$

Where λ is the total calls, λ_j is the calls in sector j, P_{ij} is the probability that a call in sector j will be answered by a unit in sector i, and d_{ij} is the distance (travel time) between sector j and a unit in sector i. Both j and d_{ij} depend on the partitioning of the sectors and the objective to find that division of responsibility that will equitably distribute the work load in P_{ij}.. As we might expect, an increase in number and type of service units, nature of calls and sectors, expands the computational time for such problems. However, computer programs such as those descriped in Larson [20] can handle large problems thus turning the hypercube methodology into a flexible planning tool.

The above approach is based mainly on waiting time and availability of response units. It can reach maximum utilization if the dispatcher is able to distinguish urgent calls and allow each a priority dependent on the type of service allowing service time to vary with the availability of response units [16,21,22]. One important advantage of using a queuing principle is better utilization of resources because the number of response units needed increases nonlinearly and not in direct proportion to call rates.

It is possible that travel time may be the largest component of total response time in an emergency. Hence it is necessary to consider the geographical characteristics affecting travel time along with the spatial distribution pattern of response units. This relationship can be determined geometrically using empirical data for travel time and travel distance, to provide an estimate of the time for a given spatial distribution of units [21,23,24]. Where units are randomly located, the relation is generally found to follow the square root inverse laws such that travel time is defined as: α/r^{β} where a and β are empirically observed data for each region or sector with an average of r units. The sector units, however, may not be randomly positioned. One can further assess the geographical boundaries by setting limits on allowable travel time and thus, maintain the desired level of availability of response units in the overall system.

In addition to availability of units, which involves queuing and travel time, the analysis can be expanded to consider the work load on alternative response units [25,26]. With this expansion, marginal improvements are realized in response time and in equity of work load distribution among units due to increased availability of units. The division of areas into zones according to administrative responsibility adds another spatial dimension to the overall planning for the delivery of fire emergency services. The delineation of sectors, or primary response areas, is done with multiple objectives in mind, including the minimization of response time, equalization of work load, demographic homogeneity, land use and hazard potential, and administrative convenience. Street patterns and other urban physical characteristics play an important role in the definition of sector boundaries. The main principle here is proximity in time to a potential fire hazard. Carter, Chaiken and Ignall [27] have shown that using equal travel time division between districts does not lead to minimization of total average travel time. They also show that work load imbalance will be reduced with the minimization of travel time. The basic principle here is to minimize the total travel time for each response areas and in the mean time assign a unit in one district to incidents in other districts.

Closely related problem to the design of response areas is the location and relocation of fire service units, i.e., the selection of a site for initial or additional facilities and the changing of sites in order to accommodate changes in deployment. Scott [13] has proposed a dynamic location – allocation process. The primary assumptions of this process are that (a) the demand points are fixed, (b) the facilities are introduced one by one, and (c) once located, a facility remains in its location. Fig. 5 shows the process of districting an area into five sectors to minimize overall travel time to the located stations. As shown one central location is chosen first, then the remaining ones are added in progression to minimize overall distance cost.

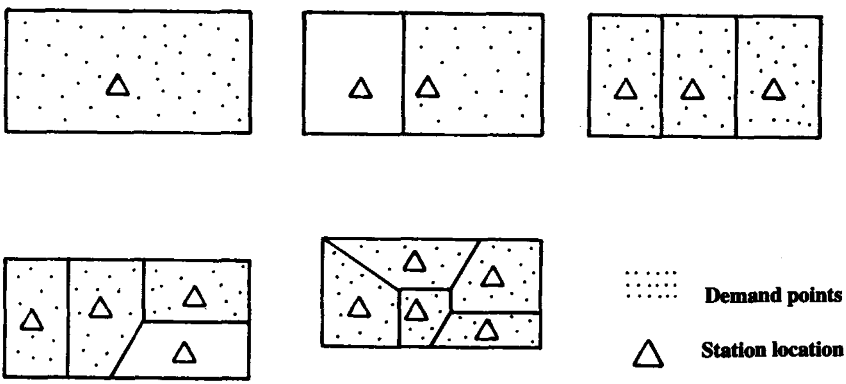

Fig. 5. **Dynamic allocation-location** of central **facilities** [13].

Computer-Based Models

As the above demonstrates, fire service allocation and location is a multidimensional problem. All the dimensions are interdependent, and also dependent of the involvement of decision makers. The above-mentioned techniques need to be linked to form a comprehensive approach to the problem because different techniques and models address different policy issues and there is no one technique or model that, by itself, is sufficient to deal with the multitude of deployment issues. Determining the most effective allocation and location of fire stations in a city, particularly a large city, is indeed an appropriate subject for computer-based models.

The two most commonly used computer-based models have been developed in the united states, one by the Rand Institute of New York City, and the other by Pub lic Technology Incorporated. The models vary in their approaches, assumptions, and other operational procedures, but both are used to determine fire station sites in cities.

1. The NYC-and allocation and location models

The fire station allocation and location model developed by the New York - Rand Institute in the early 1970's consists of a two-stage model with two additional submodels. The first stage, called the Parametric Allocation Model, allocates a given number of fire stations to a selected number of fire stations to a selected number of relatively uniform fire incidence hazard zones of a city and predicts the values, for a number of selected performance measures that result from various arrangements of those stations. Once an acceptable arrangement is found, the second stage, called Site Evaluation Model is used to locate specific sites in each zone; i.e., to evaluate the consequences of locating a fire station on a specific site within a zone.

The parametric allocation model

The parametric allocation model allocates a given total number of fire companies to the designated fire protection zones of a given city and also evaluates whether or not the current allocation of fire companies to the protection zones is satisfactory [28]. The model operates on the basis of "trade-off parameter" (hence the name parametric allocation model) which describes how much emphasis should be given to selected performance objectives. The two general performance objectives commonly associated with the operation of the model are the following:

1. Equalizing the average travel times to fire incidents in each protection zone of the city;

2. Minimizing the average travel time to all fires throughout the city;

The model is based on an objective function which contains average zonal travel times raised to a power and weighted by factors reflecting the relative incidence-hazard rates within the zone. The general mathematical form of the model is as follows [2]:

$$\text{Minimize } \sum_i w_i \, (T_i \; n_i)^{1/p}$$

$$\text{Subject to } \sum_i n_i = m$$

where:

m	= total number of companies to be allocated
n_i	= number of companies to be assigned to zone i
$t_i(n_i)$	= expected travel time in zone i if (n_i)
w_i	= weight for zone i
P	= trade-off parameter $(P \geq 0)$

The model allows the decision-maker to examine allocation implications with different weights assigned to objectives; i.e., different values for the trade-off parameter. The values of the parameter (p) range from zero to very large numbers. But there are certain values which clearly represent a certain level of emphasis on specific performance measures. For example:

$p = 0$ will equalize average travel times in all protection zones;
$p = 1$ will minimize average travel time to all fires in the city;
$p > 1$ (significantly greater) will tend to equalize the work load of all units;
$0 < p < 1$ will produce some compromise between equal average travel times in each zone and minimum average travel times at city scale. In fact a value of $p = 0.25$ has been found to produce approximations close to the actual fire company allocations in several U.S. cities.

The program assigns the minimum number of companies required to respond to and work at the average number of incidents that occur in each zone, Subsequently, the remaining fire companies are allocated to the zones in accordance with the given value of the trade-off parameter. The chart in Fig. 6 shows the steps of the operation of the Parametric allocation model. The PAM, as shown, allows the planners and the decision makers to compare average travel times and work loads. If sizable imbalances are found, the model can also be used to determine how to reallocate the existing units amongst the regions in order to provide more balanced fire protection. If proposals for additional fire companies or for fewer fire companies are being considered the model can be used to determine the regions where additional or fewer companies will be needed.

Firehouse site evaluation model

Once the number of companies and their allocation to the fire protection zones of a city is determined through use of the PAM, the deployment problem becomes one of locating the several fire companies in each zone of protection. Obviously several alternative locations might be worth testing with respect to one or several performance criteria. When the city and the number of fire companies to be located in each protection zone are small, the possible alternatives are reduced in number and complexity.

The site evaluation model, developed by the Rand Corporation, is a useful tool for evaluating the consequences of several complex alternative siting possibilities in a given city [2,3]. It is essentially a descriptive model, designed primarily to assist in evaluating the adequacy of existing fire company locations within each fire protection zone on one hand, and examining the corisequences of possible alternative arrangements of companies on the other. In doing so, this model, like the PAM, uses travel times and company work loads as performance measures.

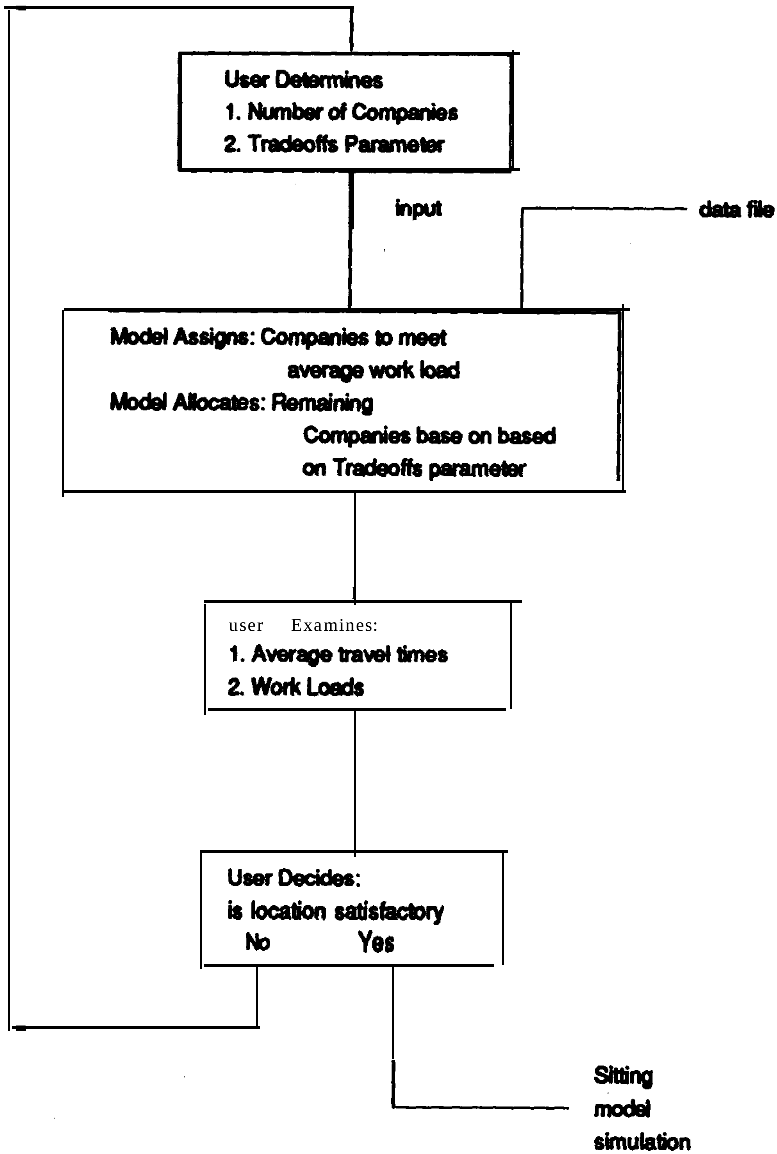

Fig. 6. Flow diagram of model's activities

The primary input to the model is a given distribution of fire stations. The model then estimates the values, of a selected set of performance measures that would result from the implementation of that distribution. An acceptable or the “best” distribution of the fire stations can be selected from amongst the test of similar distributions. Operation of the model requires designation by the user as input, through a grid coordinate system, of both the alarm boxes (discrete incident location of fire alarm boxes) and locations of existing or proposed fire companies.

The model then estimates the distance travelled by companies to each alarm box (or alarm point). Using these distances, the protection zones are divided into response areas so that a fire company’s first-arriving response area would be the zone of the city to which it is closer than any other company. Similarly, its second-arriving response area would be the zone to which it is second closest.

The model operates on the basis of the assumption that weighted Euclidean straight lines or straight-angle distances provide simple and valid approximations to the distances travelled by fire companies, and that those distances can be translated into travel times, e.g., by using the Square Root Law. The site location model further assumes that fire companies are available (at approximately a 90% level), to respond to fires, and that the closest units respond to a given fire alarm, Walker [2,3].

Once the travel distances are calculated, they are converted into travel times using the mathematical formula below, the Square Root Law:

$$T = c\sqrt{D} \qquad D < d$$

$$T = a + b\,D \qquad D < d$$

Where: T = travel time in minutes

D = travel distance

a,b,c,d = empirically determined constants.

Subsequently, the program aggregates travel times by response area and by fire protection zone and computes the work loads of each company.

The model can provide the user with values for selected parameters including average travel time and distance to any alarm box or to a serious fire (so designated by the user), minimum travel time to any box in the group of boxes considered, and city-wide and individual area travel time statistics. This information can be provided for existing and proposed sitings of stations at city-wide, protection zone-wide, and alarm box-wide levels of aggregation. Furthermore the information can be provided separately for ladder and engine companies up to the response level required by the user. The model also allows the planner to use the information to determine whether a proposed configuration of fire houses will result in an excessive work load for a particular fire comapny or excessive imbalances among companies.

2. Public Technology Inc. – fire station location package

The fire station location package (FSLP) developed by public technology incorporated (PTI) serves the same function of allocating and locating firehouses as the N.Y.C.-Rand models described above. Therefore, the following brief discussion of the FSLP model will focus on its basic difference [29].

The major difference in this model is its use of operational data for estimating travel times. The FSLP uses the street map of a city, converted into a computer-readd&network description in which street intersections are represented as nodes, and streets as the connecting arcs between those nodes. An estimate of the average speed of a fire company on the network is made (based primarily on professional experience, experimental trips, or other specific traffic surveys). The travel time from any fire station to any protection would be estimated by finding the shortest time path connecting the two nodes.

Since travel time is the most important element of fire station location, it is informative to compare the FSLP model and the N.Y.C. – Rand (Siting Model) in this respect.

Both the RAND and PTI models have been used extensively in the U.S. with results that appear to be comparable. But certain operational considerations along with the particular characteristics of community may lead to the choice of one model over the other. For example:

Tests of the two models in the U.S. showed that the travel time estimates were extremely close to each other, and the Siting Model's estimates of the travel times have been validated against actual travel times in several U.S. cities.

Construction of the computer-readable street network on which the FSLP is based is a time-consuming and expensive task; the Siting Model requires a more simple data base. And if such a computer-readable street network of a city is not available, the Siting Model is simpler, faster, and less costly to use.

The FSLP approach is preferable if a city's geographic configuration is peculiar (e.g., a peninsula, etc.) or if it has extensive barriers to vehicular movement (e.g., hills, railroad tracks, rivers, airports, major parks, one-way street systems, tightly knit urban fabric, etc.).

It should also be noted that once a computer-readable network is produced, it can be used for the location of other urban services (e.g., the ambulance system, etc.).

Also, many fire department officials feel more comfortable with the FSLP travel-time estimates as these estimates are based on the simulation of routes actually followed by fire companies.

Synopsis

It should be noted from the above discussion, that there are tools and approaches that help planners use "rule of thumb" standards to help allocate and locate fire services. These fall short, however, in providing the necessary flexibility for dynamic and efficient allocation, location, and management of these services. Some of the methods of fire station location are more relevant than others under certain specific circumstances. Compared with the geography, land use, and fire hazard score based models, the mathematical, computer-based models offer better opportunities for improving decisions regarding fire protection service operations in general, and fire station location in particular, especially so in large cities where fire service and station location are complex matters.

Indeed, the use of computer-based models increases opportunities for considering and evaluating the effects of significant changes in the allocation of fire service resources, in deployment strategies, and in the distribution of fire stations in a city. By increasing the capacity of the planning and decision making bodies to evaluate several possible alternatives within a short period of time, the use of these models allows planners and managers to spare more time to consider other important matters directly and indirectly related to the location of fire stations, e.g., continuous evaluation and adjustments of the system.

But it should be born in mind that extensive use of computer-based models may lead to concentration on a technical angle and disregard for many other issues (e.g., the local decision-making context, and other social and cultural variables), as has been expressed, ". . . policy analysis and planning officers must address operational questions in a context of both explicit and implicit administrative, legal, and political constraints. They cannot expect mathematical methods and models.. to tell them the 'best' solution to whatever problem their department faces, and they must be prepared to use all such methods with caution, imagination and common sense." [3] There is a need to expand upon these models to incorporate interactive decision making inputs and responses. And their outcome should be evaluated within a general master plan and with particular attention to the relevance for other planning issues and in the local context.

As spatially-based systems, fire protection services and the location of fire stations can be organized using generally applicable planning principles and standards as well as other modern tools of analysis and decision-making. It should be emphasized, however, that variations in both the spatial and non-spatial context of a fire, (reflected in variations in urban patterns, institutions, service levels and utilization of human and material resources), make it difficult to attempt to prescribe universally applicable outcomes for the organization of these services. It should also be emphasized that any fire station locating technique should be applied with respect to local context. The methods discussed above are only tools in the hands of the capable planners and managers.

References

[1] **Schaenman,** P. and Swartz, J. "Measuring Fire Protection Productivity in Local Government." *National* Fire *Protection* Association, Boston, (1974).

[2] **Walker,** W., "The Deployment of Emergency Services: A guide to Selected Methods and Models." New York City-Rand *Institute Report* **R-1867/HUD,** New York, (1975a).

[3] *Walker, W.,* "Firehouse Site Evaluation Model: An Executive Summary." *Rand Institute Report* **R-**1618/l-HUD, New York, **(1975b).**

[4] *Walker, W.,* Chaiken, J. and Ignall, E. *Fire Department Deployment Analysis: A Public Policy* Analysis Case Study. New York; Elsevier-North Holland Publications, 1979.

[5] **Colner,** D. and **Gilsinn,** D. **"Fire** Service Location Allocation Models." *Report 10833, National* Bureau of *Standards,* Washington D.C. (1972).

[6] *National* Fire Protection Agency, NFPA, *Fire Protection Handbook.* Boston; National Fire Protection Agency, 1980.

[7] Santone, L. and Berlin, G. "Location of Fiie Stations." In: *Systems Analysis for Social Problem,* Washington Operation Research Council, National Bureau of Standards and the International City Management Association, Washington D.C., 1970.

[8] **Scet** International, "Riyadh Master Plans." *Technical Report,* 1, No. 9 (1398 H), pp. 47-48.

[9] **Huggot,** M., **"The** Siting of Fire Stations.:' *Operation Research Quarterly, 19* **(1968),** pp. **275-287.**

[10] **Insurance Service** *Office,* **ISO;** *Grading Schedule for Municipal Fire Protection. New* York: **Insurance 'Service** office, 1974.

[11] **Bare,** *W.K., Introduction to Fire Service and Fire Protection.* New York: John Wiley and Sons, **1978.**

[12] Swersy, A.J. et al, "Fire Protection and **Local** Government: An Evaluation of Policy-*Related* Research." *NYC-Rand Inst. Report, (1975).*

[13] **Scott,** A.J. *Combinatorial Programming, Spatial Analysis and Planning;* London: Methuen Pub**lishers,** 1971.

[14] **Beltrami,** E.J., *Mod& for Public Systems Analysis. New* York: Academic Press, 1977.

[15] Chaikea, J. **Ignall,** E.J. and Walter W.E. "Deployment Methodology for Fire Departments." New *York City-Rand Inst. Report R-1853-HUD, New* York, (1975).

[16] **Chaiken,** J., **"Number** of Emergency Units Busy at Alarms which Require Multiple Services." New *York City-Rand Institute, R-531-NYC/HUD,* (1971).

[17] **Larson,** R., "Methods of Allocating Urban Emergency Units: A Survey." *New York-Rand Inst., Report,* **(1971),** p. 47.

[18] **Larson,** R., "A Hypercube Queuing Model of Facility Location and Redistricting in Urban **Emergency** *Services." Computers and Operation Research,* **(1974),** pp. 67-95.

[19] Larson, **R.j, "Hypercube** Queuing Model: a) user manual, Rep **R-1688/2-HUD;** b) Program **Description: R-1688/3-HUD."** *NYC-Rand Inst., N.Y, (1975).*

[20] **Cobham,** A., "Priority Assignment in Waiting Line Problems." *Operations Research, 2* (1954) p. 70.

[21] **Larson,** R.. "Models for the Allocation of Urban Police Patrol Forces." *MIT Operations Research Technical Report No. 44* **(1969).**

[22] **Chaiken,** J., "Estimating Numbers of Fire Engines Needed in New York City Fire Divisions.'* *New York City-Rand Institute, R-508-NYC,* (1971).

[23] **Kolesar,** P. and **Blum,** E. "Square Root Laws for Fire Company Travel Distances. " *Rand Report R-895-NYC,* (1975).

[24] **Hogg,** J., "Planning for Fire Stations in Glasgow in 1980. " *Scientific Advisors Branch of Home Office Report 1/68;* Glasgow Fire Master and Scottish Home and Health Department (1968).

[25] Carter, G. and Ignall, E. "A Simulation Model of Fire Department Operations: Design and Preliminary Results." *IEEE Transactions on Systems Science and Cybernetics, SSC -6* (1970) pp. 282-293.

[26] Fisher, I, and Midler, J. "Analyzing Municipal Fiie Protection: A Theoretical Framework." New *York City-Rand Inst., R-594-NYC,* (1970).

[27] Carter, G., Chaiken, J. and Ignall, E. "Response Areas for two Emergency Units." New *York* ***City-Rand*** *Inst.,* ***R-532-NYC/HUD,*** (1970).

[28] Rider, K.L., "A Parametric Model for the Allocation of Fire Companies." The *NYC-Rand Report* ***R-1615-NYC-HUD,*** *New* York (1975).

[29] Public Technology Inc., PTI, Fire ***Station*** Location *Package.* Washington D.C.: Public Technology Inc., 1980.

التوزيع الفراغي وتحديد مواقع أنظمة السلامة من الحريق

إبراهيم سانلي وفيصل التميمي

كلية العمارة والتخطيط، جامعة الملك سعود، الرياض، المملكة العربية السعودية

ملخص البحث. يعتبر الإطار العمراني بمثابة نظام يحدد ارتباطات المساحات العمرانية وعلاقاتها ببعضها بما فيها المواقع المخصصة لتقديم الخدمات، أما نظام الحماية والسلامة من الحريق فهو نظام متفرع عن هذا النظام ويخضع لتأثيرات عائدة إلى مدى احتياجات المجتمع من توزيع للمساحات وطبيعة المواقع التي يمارسون منها نشاطاتهم وشبكات الطرق التي لها تأثير على اتصالاتهم، كما يتأثر هذا النظام الفرعي أيضا بنوع التنظيم والإشراف على توزيع الخدمات والمواقع التي توفر من خلالها تلك الخدمات.

وسنقوم في هذا البحث باستعراض تلك المباديء التي تؤثر على إنجاز نظام خدمات الحماية من الحريق من حيث مدى علاقة توزيع المساحات ونظم الاتصالات في المدن، وسيجري فيما بعد الرجوع إلى أساليب التحليل ذات الصلة بتحديد المواقع وكيفية توزيع خدمات مكافحة الحريق، وختامًا سنقوم بتقويم نظامين للحاسب الآلي مستخدمين على نطاق واسع بالرجوع إلى المباديء المستخدمة في التحليل وذلك لنفي بالغايات المرجوة من توفير الخدمات وتحديد أماكن تواجدها.