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Application of Fire Protection Models in Urban Planning

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APPLICATIONS OF FIRE PROTECTION MODELS
IN URBAN PLANNING

BY

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B.S., Florida Institute of Technology, 1971

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
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INTRODUCTION

This research report was orginally intended to present the results of investigation into:

- aspects of fire protection with respect to urban planning existing in Orange County, Florida;

- some of the models and techniques which could be used in planning and implementing fire protection services;

- evaluating the various models against the needs of Orange County, Florida, and recommending the model(s) which

  best serve these needs.

Due to the author's inability to obtain such information, and his relocation from Orlando, Orange County, Florida, to Herndon, Fairfax County, Virginia, emphasis was shifted to Fairfax County, Va.

The research effort consisted of:

- interviewing and consulting urban planning and fire department officials;

- consulting individuals in various organizations such as National Fire Prevention and Control Administration, National Science Foundation, University of Maryland, and Northern Virginia Community College;

- consulting literature wherever available;

- writing this research report.

URBAN PLANNING

Basic Elements

Population

Analysis and projection of population are at the base of almost all major planning decisions. As measures of the size and density of the various groups within the urban or regional population, they determine the level of demand for future facilities. The substantial importance of population projections to all aspects of planning programs justifies the use of adequate time and resources to produce results that are reliable, flexible enough to reflect local change, and sufficiently detailed.

The entry of new institutions into the area, the opening of land for residential development through the extension of utilities or transportation systems, and annexations which change the desirability of localities because of changes in taxes and services, zoning, etc., are all potential forces for a change in the growth and distribution of area population.

Economic Studies

A study of the urban economy has been the underlying purpose of improving the understanding of the economy and how it works. Economic studies have two purposes from a technical point of view. The first principal purpose is to provide materials about the local economy that will assist the community in arriving at a series of goals and objec-

tives. The second purpose is to provide quantitative estimates on future employment and population. A refined and effective application of the results of economic studies and planning combines qualitative measurements with quantitative estimates. Additional purposes of economic studies pertain to economic development and social welfare. The development of ad hoc community groups has made the economic aspects of planning not only visible but also challenging.

One of the key concerns in economic studies is the effect on the community in the case of destruction of property due to fire or vandalism. Adequate safeguards need to be installed to keep the impact of destruction due to fire at a minimum. Unforeseeable changes in the economic base of an area will change population settlement greatly. Extreme instances of such changes, such as the location of Cape Kennedy in Brevard County, Florida, and Walt Disney World, Martin Marietta, and Sea World in Orange County, Florida, totally obviate previous population predictions. From various economic indications such as occupation, income and education levels, urban economic planning and social welfare planning share a close relationship.

Specifically, economic planning is aimed at many of the key problems associated with what is generally implied by social welfare. These key problems include employment opportunity and regularity, income levels and distribution, taxation policies, and housing finance and subsidy systems. The purpose of urban economic studies can be summarized as being expressed as a series of questions:

- Why does the community exist?
- What are the principal causes of economic change?

- What are the most important forms of imbalance in the community economy, and how can they be remedied?

- How can the economic problem remedies be expressed as community development objectives?

- How do the facts of community economic structure, problems, remedies, and development objectives relate to one another?

Land Use Studies

Growth at present and in the future is one of the primary concerns of communities throughout the nation. The form of growth can be noted in many areas - population, residences, institutions of learning at all levels, employment opportunities, etc. - and all require the one common key element - land. Problems related to growth such as water and air usage, transportation, power source requirements, educational facilities and revenue determination are some of the more prevalent arising from rapid urban growth. The optimal planning and programming use of land, air, water and human resources are becoming a vital instrument for guiding urban growth. While the growing population accounts for a major portion of the expected doubling in urban land use, the tendency of increased use per unit contributes to the urban land explosion. Analytical studies indicate that within the larger cities of the nation, net land use densities are declining for population and manufacturing employment, while commercial employment densities appear to be holding constant. Planning for land usage relies heavily on reliable population forecasts, sound economic projections and thorough understanding of the various interrelationships

of types of urban land use. Some of the factors which provide infor-
mation on the use of urban land are:

- graphic features
- land-survey
- hydrological and flood potential
- structural and environmental
- cost-revenue and land value
- public attitudes and preferences

To assist in the assessment of urban land use, a variety of maps
are used, such as engineering survey; topographic showing contour
lines, drainage courses and other natural features; tax maps indi-
cating property lines; and miscellaneous references such as insurance
and highway maps.

Land use patterns vary from one community to another, and there-
fore a classification system corresponding to the types of land use
currently existing and emerging should be adopted. There is no pre-
scribed system suitable for all communities, even for those of similar
population, land area size, or stage of development. However, there
are some broad categories of land usage that generally prevail in
classification systems (see Table 1). While most classification
systems have a category for undeveloped land and water areas, there
generally is no provision for determining the suitability of vacant
land for major types of urban use.

Transportation Studies

Transportation planning (see Figure 1) is the service concerned
with the design of systems, which will hopefully maximize accessability

TABLE 1

ILLUSTRATIVE URBAN LAND USE CATEGORIES

1. Residential

    Low density
    Medium density
    High density

2. Business and Industry

    Local
    Central
    Regional

3. Transportation

    Land
    Air
    Water

4. Education

    Elementary
    Intermediate
    High Schools
    Colleges and Universities

5. Medical Facilities

6. Vacant
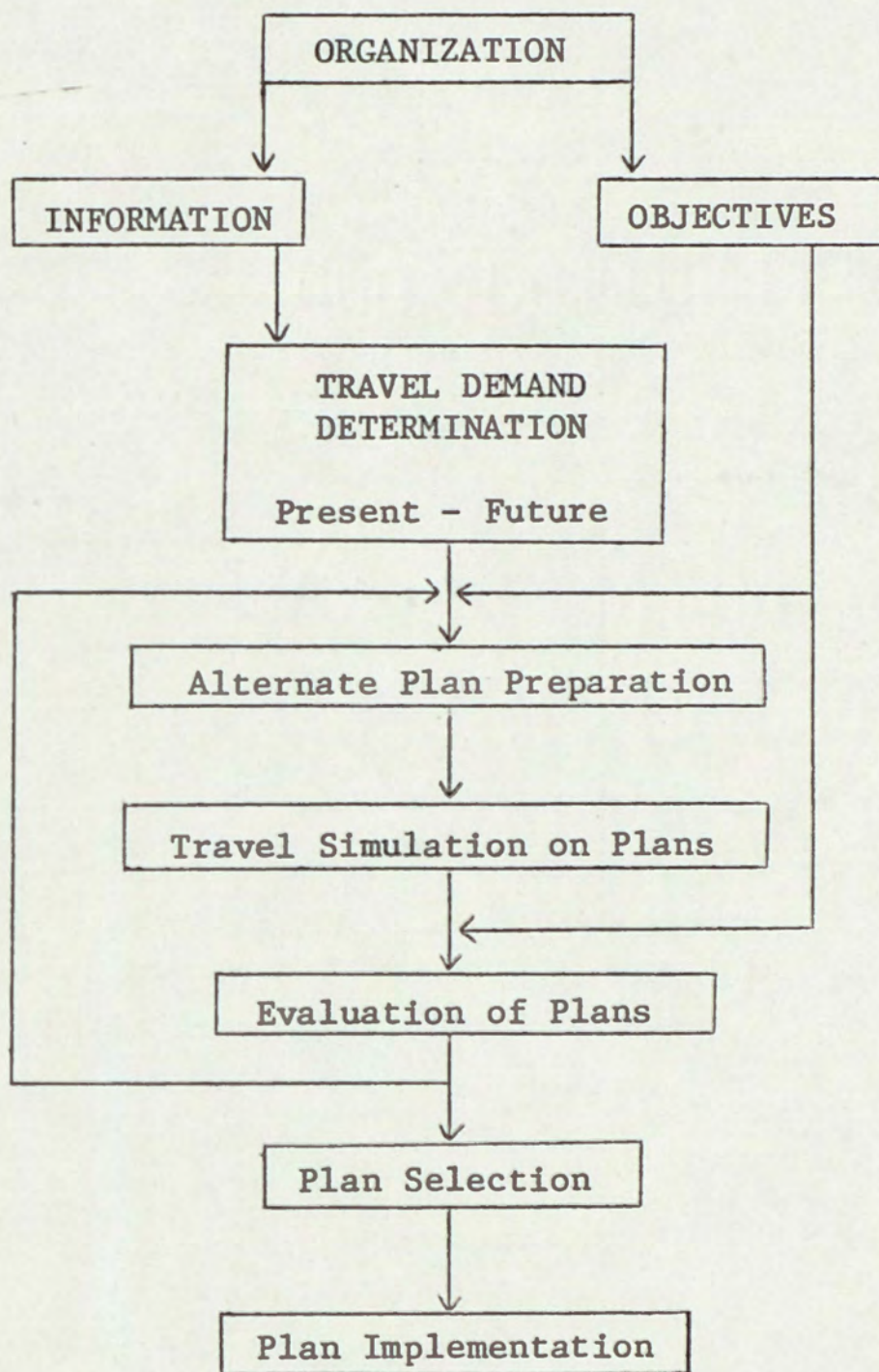
Fig. 1. Transportation planning process

for movement between areas with consideration of safety, comfort and cost. Also included are all modes of transportation which are economically feasible to an area and all types of improvements, such as:

- traffic engineering
- signal systems
- traffic channelization at intersections
- road signs and off-street parking facilities
- reconstruction of existing facilities

The automobile has greatly influenced the development pattern of cities and urban areas today. Increasing automobile ownership and individual mobility has brought vast areas around existing metropolitan areas into urban use. The rate of technological progress is accelerating at a fantastic rate, and transportation plans must take into consideration those activities continually generating traffic.

Understanding the nature and characteristics of travel in the various areas is very desirable as a basis for the design of transportation systems. The design must take into consideration not only the characteristics and functions of the future system, but also the properties on which it will pass. Most of the current knowledge about means of travel has been gathered from "origin-destination" surveys, of which key elements considered are:

- mode of travel
- purpose of trip
- desired routes
- frequency of usage

All are dependent upon one another. The purpose of a trip affects or determines the mode of travel chosen, the frequency, length and desired routes.

Many procedures are used in planning transportation systems; one of the more widely used is the reduction of total transporation costs within a rigid set of land development constraints. This procedure is an excellent indicator of decreases in congestion, since reducing congestion is one of the ways of reducing costs. Knowledge of the specific transportation traits of an urban area, or at least of desired traits of the future community, is necessary before attempting to plan a transportation system. The basic data required are the present transportation system characteristics (performance, travel pattern, land use pattern, and urban economy).

Water Studies

Water systems designed for use in today's environment must have multiple uses: domestic consumption and fire prevention. Domestic consumption can be subdivided into a number of categories, a few of which are cooking and drinking, washing, waste usage, and irrigation of crops. The rate of consumption can be divided into three basic categories:

- average daily
- maximum daily
- peak periods daily

The primary sources of water are rivers, lakes, springs and sub-surface supplies. Although the oceans and seas contain vast amounts

of water, they are unfit for domestic consumption due to their chemical composition. Geographical and geological conditions will dictate both the availability and also the supply of water. The U. S. Geological Survey and state water departments frequently are a source of valuable data on sources and amounts of water in the U. S. In rural and some suburban areas, individual wells provide water for residences; however, the increased population densities are rendering supplies inadequate or unsafe for use. Throughout the U. S. as a whole, water tables are falling dangerously low because of the large amounts of land being converted into parking lots and buildings.

The demand for water is related directly to population and is generally expressed in gallons per capita per day (GPCD). Consumption varies from the small, predominantly residential, areas with a consumption of no more than 40 GPCD, to the large metropolitan areas with extensive industry which consume 250-300 GPCD. Averages for most medium-sized communities is about 150 GPCD. Industrial uses impose the major demand on water usage and must be studied very closely in urban planning. Storage and distribution systems are also important factors to be considered.

Generally, water should be free from bacteriological or other contamination, clear, colorless, odorless, pleasant to the taste and containing a minimal amount of soluble minerals. The nature of the treatment will vary depending upon the source and the quality. Nearly all public water supplies are protected against contamination from bacteria by chlorination or other processes.

In order for water to be used, it must be collected and distribu-

ted. There are three types of collection and distribution systems:

- gravity

- distributing reservoir

- direct pressure

A problem which deserves a considerable amount of attention is the collection of liquid and solid waste for subsequent treatment or disposal. This problem is generally categorized into two areas: sanitary sewers and storm sewers. Sanitary sewers collect sewage from the plumbing systems of buildings and carry it to a treatment plant. Storm sewers collect and carry rain or surface water to some natural water body in such a way as to prevent flooding. Sewage problems vary with the size of a city but increase in complexity much faster. The problem is further complicated by the discharged waste from industries into municipal or urban systems. Perhaps one of the most difficult decisions is whether to combine or separate sanitary and storm sewer systems.

One of the important uses of water is for the extinguishing of fire. When planning an urban community, care must be exercised so that in residential or industrial areas, outlets which provide water are situated in such a manner that all structures can be reached. This necessitates cooperation between urban planners and fire prevention and control representatives; for without each other, they are useless and non-productive.

Fire Protection

Traditionally, the mission and purpose of fire protection safeguards are to prevent fires from occurring. In addition, the scope

of fire protection includes responding to those that do occur and extinguishing them in a timely manner with minimum impact on people and materials (buildings, equipment, etc.). Fire departments have been organized primarily to serve in times of crisis. Since fire is inherently a physical and chemical phenomenon, there is a substantial technological orientation from prevention to extinguishment. Fire service functions include inspection or advice on building plans; commercial, public and residential buildings; research into the kinds and types of equipment used in combatting fires; recommendations to the urban development planning board regarding the transportation system; public education programs; and actual fire extinguishing.

Fire departments are essentially line-operating agencies (see Figure 2), and as a result of the bureaucracy, are often poorly equipped in outlook, skills, equipment, and organization to undertake significant change, let alone the job they exist to perform. Conditions both organizationally and politically are such that the rewards for success are too small and the price of failure disproportionately high. Little support for or by fire departments is received from industry, educational institutions, or government. Instead, information and new ideas come predominantly from a few dedicated special interest groups and professional associations. These groups infortunately are supported by limited financial resources and research. It is for mainly these reasons, and in spite of new techniques and types of equipment, that basic fire department practices appear to have changed little over the past century. As with all urban protective services, the demand for service has grown much more rapidly than resources. The rate for

CHIEF

Public Relations
—
Captain

Fire Investigation
—
Captain

Executive Officer
—
Assistant Chief

Finance
—
Captain

Research
—
Captain

Personnel
—
Captain

Assistant Executive Officer
—
Assistant Chief

Training
—
Assistant Chief

Divisional Staff Officers
Assistant Chief for each Div.

Fire Prevention Bureau
—
Assistant Chief

Communications
—
Battalion Chief

Water Bureau
Hydrants/Emergency Water
—
Battalion Chief

Service Bureau
—
Battalion Chief

Division Commanders
—
Assistant Chiefs

District Commanders
—
Battalion Chiefs
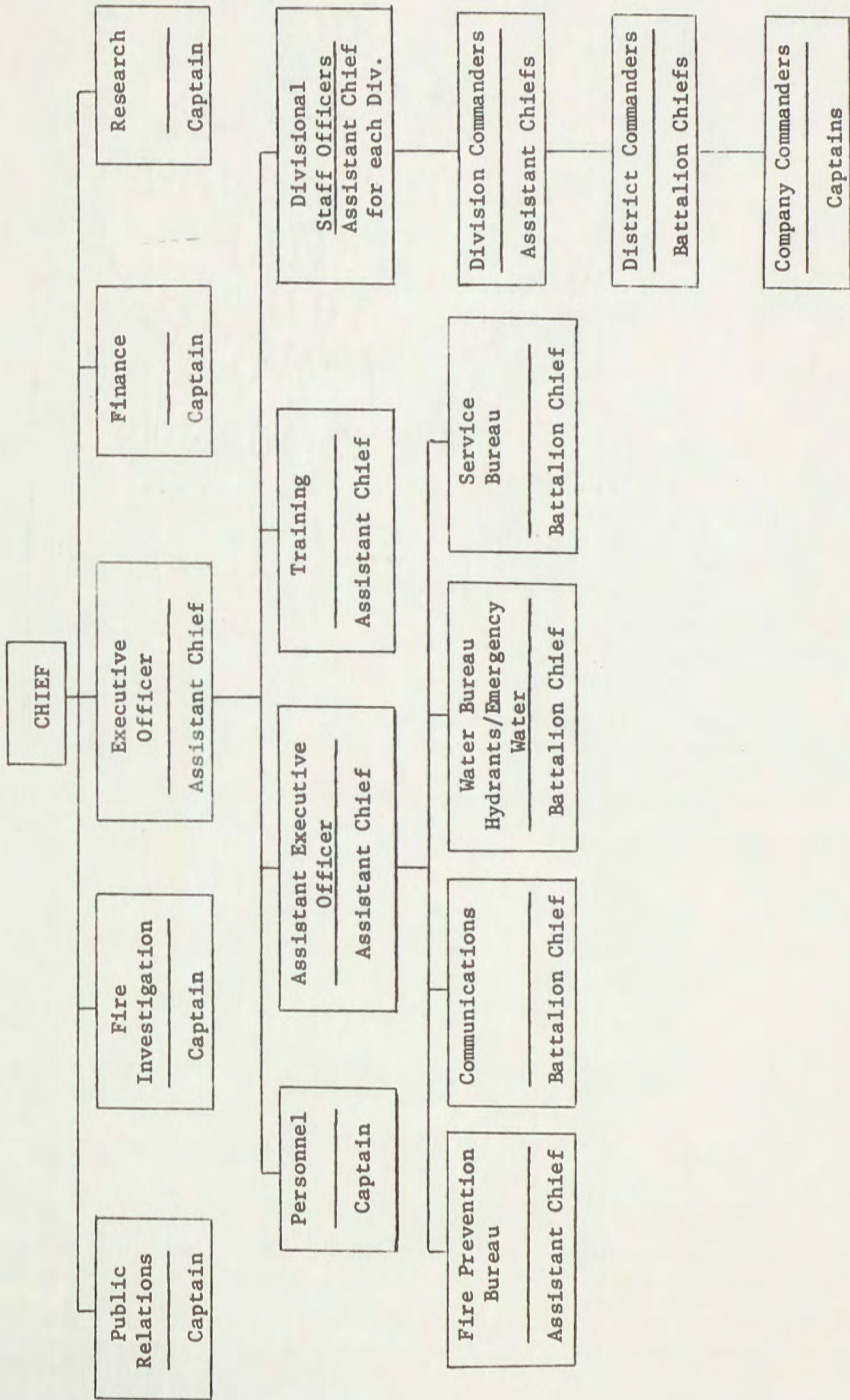
Company Commanders
—
Captains

13

Figure 2. Illustration of relationship between platoon forces and headquarters staff.

every type of incident has been increasing exponentially. Curiously, false alarms, fires in vacant or abandoned buildings, rubbish fires, non-fire emergencies, and deliberate fires now outnumber the accidental fires that used to be the fire department's main concern.

Four areas in which research has made gains are:

● Communications

● Deployment

● New technology

● Management information and control systems

The communications effort has emphasized the dispatching centers which form the link between alarms from the public and the department's response. The two aspects of dispatching are receiving, interpreting and identifying alarms; and allocating and dispatching free fire-fighting units of the right composition to respond adequately. The deployment effort emphasizes the allocation of fire-fighting units, while technological advances in fire detection systems and fire extinguishing have been considerable.

Fire departments exist to provide a multitude of services and must coordinate their activities with numerous public and private sectors in the community in order to accomplish their objectives. A considerable number of these agencies in return provide services of both emergency and support to the fire departments in their areas. Listed below is a broad grouping of some of the kinds of agencies which are involved in some phase of fire service support.

● Law enforcement

● Utilities and public works

- Pollution control
- Medical services
- Transportation services
- Educational services
- Insurance services

Fire services across the nation are linked by a sense of tradition and brotherhood, perhaps more than any other municipal service. The keystones of this common link are heroism, dedication, reliability and self-sacrifice. Public adulation and even sympathy for fire-fighting units has waned, costs are rising sharply, and demand for service is increasing at a fantastic rate. The crumbling of tradition forms the basis for several of the fire services' more serious problems. Fire-fighting units are becoming more disturbed because their traditions and the values they represent appear to be disintegrating. Changing public attitudes, deteriorating relations with minority communities, and a trend towards more bureaucracy have taken the luster out of the job and changed the fire fighter's image. In the large metropolitan areas where unions are on the increase, militancy has accelerated, which in turn has led to growing demands on wages and working conditions and a willingness to strike. This crisis has drastically affected fire service management. All too often, destruction by fire has been, and is, the means of venting feelings of anger and frustration. These feelings have often been turned onto the fire-fighting units' attempting to do their jobs. Recruiting of highly qualified men has become more difficult, and labor and community relations have become increasingly important. Public resistance and

opposition to increased budgets and taxes has stiffened. Management

itself has become more difficult and complex now that tradition no

longer suffices to motivate and guide the manpower on which fire

services depend.

INVESTIGATED AREAS

Orange County, Florida

Orange County, Florida, is a large, rapidly developing county comprising some 400 square miles situated in central Florida. The county can be said to be comprised of basically two types of communities: the older, more established, such as Winter Park, Holden Heights, Pinecastle, Conway, Taft, and Killarney; and the newer, more recently established communities, such as Pine Hills, Union Park, Goldenrod and Lockhart. Fourteen Fire Control Districts (see Table 2) currently form the organizational arrangement through which fire protection is provided in the majority of the county's unincorporated areas. Collectively, these districts operate 20 fire stations. Nineteen additional fire stations are located within municipalities, with two being volunteer service areas. Each district is independent operationally but has mutual aid arrangements with some of the others. District operations financing is accomplished through special ad valorum assessments which vary from one district to the next. The assessments cannot exceed three mils and are set by the Board of County Commissioners, which exercises no operational or policy control over the various districts. Actual control over the various fire districts is accomplished by 70 elected fire commissioners.

Many of the developed areas of Orange County are not provided with central (large sources serving multiple uses) water systems. Other areas do not have adequate central water systems to produce flows

TABLE 2

ORANGE COUNTY FIRE CONTROL DISTRICTS

1. Apopka

2. Conway

3. Disney

4. Goldenrod-Dommerich

5. Holden Heights

6. Lake Barton

7. Lake Sue

8. Municipal

9. Orlo Vista

10. Pinecastle

11. Pine Hills

12. Taft

13. Union Park

14. Zellwood

sufficient to support fire fighting operations. Dispatching is accom-
plished separately by each fire department. Each fire control district
currently uses 2-channel mobile communications equipment; channel A for
interstation and committed units contact, and channel B for interagency
use. There is no central communications center for keeping track of
units. Each station functions as a self-sustaining, autonomous entity,
and there is no time shift operation of the personnel within the
various stations. The current existing county emergency medical system
consists of one ambulance service and one hospital, with assistance from
one fire department (Apopka). The present fourteen fire districts and
four municipal fire departments supplement basic coverage. Seven of
the fire control districts are licensed and authorized to treat at the
scene of a crisis, and also to transport in case of life-and-death
situations. Equipment maintenance and procurement are on a district-
by-district basis with four districts having full-time mechanics and
repair facilities. Allocation and distribution of stations are compli-
cated by the presence of internal boundaries. Large employment elements
have caused residential and commercial expansion throughout the county
with emphasis in the central northern, southern and western areas.
Data was not available on the aspect of urban planning.

Fairfax County, Virginia

Fairfax County, Virginia, is a large, rapidly developing county
comprised of 400 square miles, situated in the northeastern section of
the state. It is also basically comprised of two types of communities:
the older, more established such as McLean, Vienna, Annandale and

Fairfax; and the newer, more recently settled such as West Springfield and Reston in Upper Potomac (see Figure 5). Prior to 1971 the county was comprised of twenty-one autonomous fire stations with limits defined by the primary area in which they intended to serve. The Division of Fire and Rescue Services was created in 1970 by the County Executive (an appointed official). This organization was charged with developing and maintaining a centralized county fire service. Under the guidance of the Planned Land Use System (PLUS), the county was grouped into four major areas as listed in Table 3.

Each major area in conjunction with the Fire and Rescue Services Division was tasked with developing a master plan. The four area master plans were approved over a period of time (Area 1-January 1973, Area 2-September 1973, Area 3-October 1974, Area 4-June 1973), and the overall County Master Plan was adopted in 1975. At the present time there are 28 fire stations in Fairfax County with 12 owned outright by the County; 7 have been turned over to the county for ownership, operation and maintenance; 5 have been built by the county; 3 are in the beginning stages of construction; and additional stations are being planned.

There are 31 watersheds in the county, of which 3 are major, the primary being the Occoquan Reservoir Basin. Water supply is rapidly becoming a major problem due to pollution from residential and commercial areas which are being established in the county at a rapid rate. Dispatching is accomplished via a centralized communications system which is situated in Fairfax City and operates in conjunction with the Fairfax County Police communications system. The county has been grid
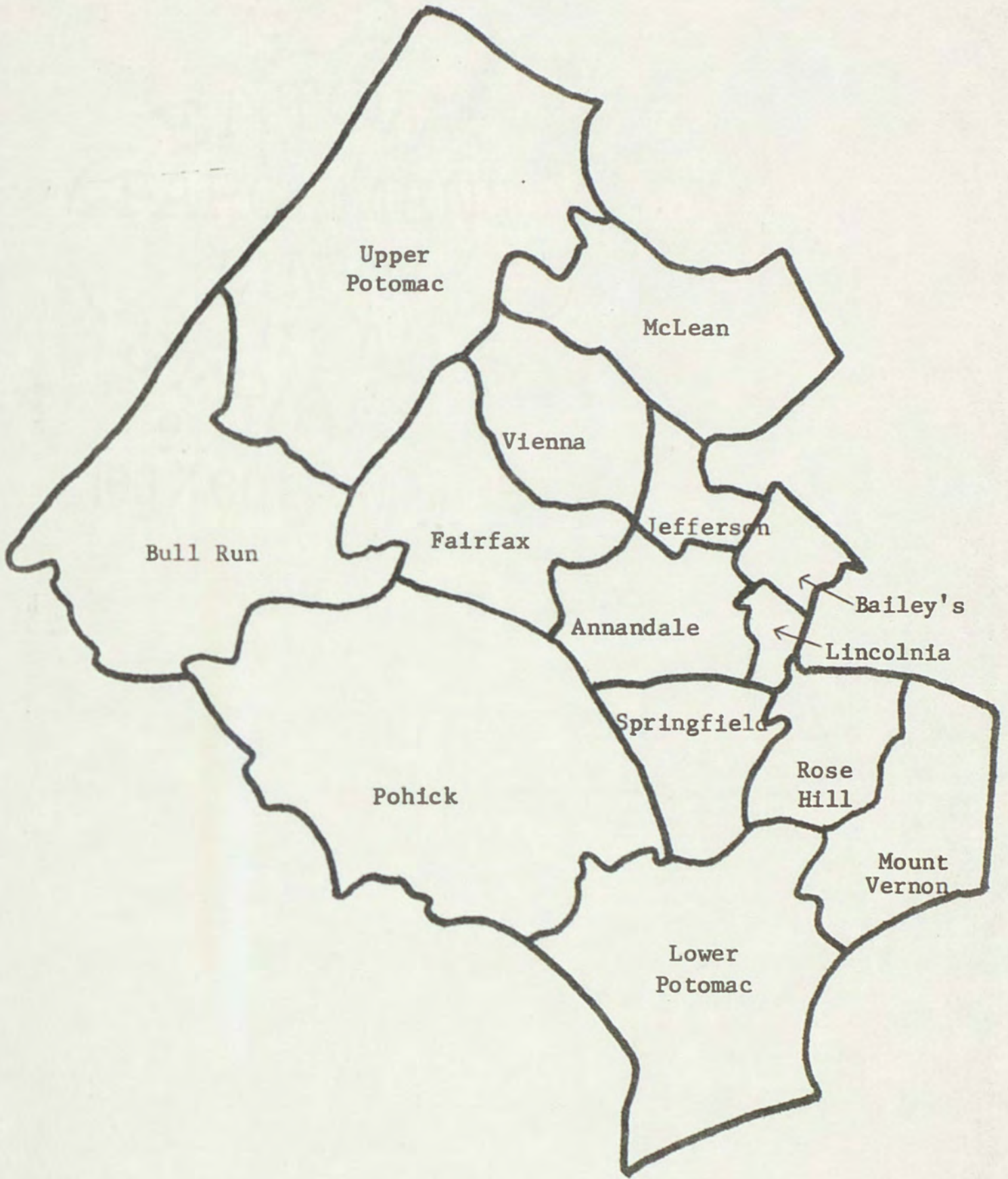
Figure 3.   Fairfax County planning areas and districts.

TABLE 3

FAIRFAX COUNTY PLANNING AREAS

Area 1

Annandale

Bailey's

Jefferson

Lincolnia

Area 2

McLean

Vienna

Fairfax

Area 3

Pohick

Bull Run

Upper Potomac

Area 4

Lower Potomac

Mount Vernon

Rose Hill

Springfield

simultaneously into Patrol Areas, Map Grids and Box Numbers. The map

designations are used by both the Police and the Fire and Rescue

Service Division. Each box area identified on the map is comprised of

a number of streets, and with the assistance of a computerized dis-

patching system, specific units can be called into service (see

Figures 4 and 5). Mutual aid agreements effective in October 1975

exist with Fairfax County, Arlington County, and the City of Alexandria,

and through mutual consent each has separate fire unit identification

numbering schemes as follows:

- Fairfax County - Identification Numbers 1 through 28

- Arlington County - Identification Numbers 60 through 69

- City of Alexandria - Identification Numbers 70 through 79

The mutual aid agreement which covers the deployment of the first

six engine companies is of noticeable benefit in areas where Fairfax

County borders Arlington and/or Alexandria. The mobile medical inten-

sive care units had not been incorporated into the system at the time

the data listed in Figures 4 and 5 were obtained. It is understood

that at the current time these units are in the initial stages of imple-

mentation. The basic units dispatched are three engine companies and

two truck companies in the event of a commercial alarm, and two engine

companies and one truck company in the event of a residential alarm.

Additional support from other engine and truck companies or other units

(tankers, ambulances, air rescue units) are provided on an as-required

basis. Additional communication capabilities are provided by three-

channel mobile units, thus permitting all three districts (Fairfax,

Arlington and Alexandria) to communicate with each other and with

Fairfax County Fire and Rescue Service

Box 4218

1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
ENG	ENG	ENG	ENG	ENG	ENG	ENG	ENG	ENG	ENG	ENG	ENG
02	13	03	01	25	23	21	18	08	04	12	15

1st	2nd	3rd	4th	5th	6th	7th	8th
TRK	TRK	TRK	TRK	TRK	TRK	TRK	TRK
02	13	03	01	25	18	08	10

1st	2nd	3rd	4th		1st	2nd	3rd	4th
SQD	SQD	SQD	SQD		AIR	AIR	AIR	AIR
01	26	09	19		01	18	26	09

1st	2nd	3rd	4th		1st	2nd	3rd	4th
LGT	LGT	LGT	LGT		TNK	TNK	TNK	TNK
01	02	18	26		12	17	DL	19

1st	2nd	3rd	4th		1st	2nd	3rd	4th
FU	FU	FU	FU		4W	4W	4W	4W
03	49	DL	WN		02	13	03	01

1st	2nd	3rd	4th
MIC	MIC	MIC	MIC

1st	2nd	3rd	4th	5th	6th	7th	8th
AMB	AMB	AMB	AMB	AMB	AMB	AMB	AMB
02	02	13	13	03	03	01	01

ENG = Engine   TRK = Truck   SQD = Squad Unit

AIR = Air Rescue Unit   LGT = Light Truck   TNK = Tanker

FU = Mobile Phone Unit   MIC = Mobile Intensive Care

4W = Four Wheel Drive Unit   AMB = Ambulance

Figure 4.   Example of Fire Box File.

Fairfax County Fire and Rescue Service

Street	Block Odd	Evn	Patrol Area	Map Grid	Engines 1	2	3	4	Trucks 1	2	3	Box Nbr
Arlington Boulevard	8300	8900	21	049-3	18	23	13	02	18	13	02	1827
Arlington Boulevard	9000	9300	21	048-4	03	18	23	02	03	18	02	0312
Arlington Boulevard	9400	9500	91	048-4	03	23	02	18	03	02	18	4303
Arlington Blvd. & Rte. 495	7800	8000	21	049-2	18	13	08	23	18	13	08	1850
Arlington Blvd. - Melpar	7700		23	049-4	18	08	13	02	18	08	13	1830
Arlington Drive	2600	3000	02	093-3	09	11	24	05	11	24	22	0942
Arlington Terrace	2000	2200	01	083-1	11	09	05	24	11	24	22	1101
Armada Street	2600		31	025-0	21	04	25	15	25	03	02	2104
Armfield Street	3700		31	034-4	15	21	17	04	03	25	02	1529
Armory Court	3200		91	047-4	03	23	02	18	03	02	18	4309
Armstrong Street	10400		91	057-4	03	23	14	02	03	02	08	4300
Arnheim Street	3900		20	060-3	08	18	10	23	08	18	10	0812
Arnold Lane	3300	3330	19	060-1	18	08	23	10	18	08	10	1800

Figure 5. Example of Street Locator File.

headquarters. The tax budget of approximately $13 million covers the operation and maintenance, personnel and equipment for all 28 fire stations, but does not cover new construction. The financing is provided by bonds which the county determines on a five-year basis.

Additional features of the Fairfax County Fire and Rescue Services Division are the centralized purchase agreements, centralized training agreements (within the county only), and computerized transportation modeling system. The purchase agreements are basically provisions whereby if any district (Fairfax, Arlington or Alexandria) purchases equipment or supplies, and one or both of the other districts wish to make purchases also, then the prices offered to the initial buyer are also applicable to the additional buyers. The training agreement is basically the consent of the four major areas of the county to send all fire station personnel to a centralized institution (George Mason University) for training. Plans are currently in progress to change the current training agreement in order to include Arlington County and the City of Alexandria, and to select an institution located regionally central to all. Transportation planning is accomplished via the use of a computerized fortran programming model called the Transportation Integrated Modeling System (TRIMS). This model, developed by an industrial firm, is available to local jurisdictions to assist them in planning the road network of their community based on several factors. The criteria used by the Fairfax County Fire and Rescue Services Division in the operation of their fire departments is a five-minute response time (including time for dispatch) for a given unit to respond to an alarm. Implicit in this standard is consideration

of the existing and proposed road network in relation to fire station
locations.

FIRE PROTECTION MODELS

Overview

One of the fundamental problems facing fire departments today is situating fire station houses in a given area in order to provide the maximum quantity and quality of fire protection service. A second fundamental problem is how many stations need to be placed in a given area. The results of change in an area, and in the fire department, frequently pose a problem and challenge to the planning group. The steadily increasing operating costs and public outcry for better service demand that fire-fighting resources be utilized most effectively and efficiently.

Obtaining the answers to these two questions is only the beginning of solving fire protection problems and generally involves subjective judgments and trade-offs on critical competing objectives. A few of these objectives are:

- maximize resource allocation (men, equipment)
- maximize traffic throughput in the transportation network configuration
- minimize delays
- minimize response time
- minimize travel distance

It is basically the particular allocation policy which determines the following properties of a system: [1]

- total number of units of each type on duty

- manpower allocation per unit

- responsibility area of each station house

- priority attached to different types of calls

- factors influencing the queuing manner

- number of units of each type dispatched

- particular units dispatched

- circumstances under which assigned locations of units are changed

- upon requirement of relocation, the number of units and the fire stations to which they will relocate

- fire stations from which they are being relocated

In recent years, the tools of system analysis and optimization techniques have been increasingly applied to determining the level of performance of fire protection and prevention. A few of these tools are:

- mathematics and statistical analysis

- simulation

- modeling

- performance testing and evaluation

- reliability/maintainability

Another problem which deserves considerable attention is deployment. In general, deployment problems can be subdivided into two broad categories: strategic and tactical.[2] Strategic deployment can involve issues on resource planning and allocation, and long range planning issues such as definition of areas of responsibility for units, and factors influencing the number of location changes. Tactical

deployment usually involves situations at the scene of an alarm and daily operational procedures such as:

- number of units to be dispatched

- class of fire most likely to be reported (see Appendix A)

- when and how many available units to be relocated to improve overall protection

- which vacant station houses should be filled

Fire station house allocation can be approached using a number of different criteria as the basis for the allocation. A few of these criteria are:

- minimize response time

- minimize response area

- minimize travel time

- equalize protection to all areas

- reduce the hazardous workload in some areas

- minimize the time alarms must wait in a queue before being serviced

- minimize the number and frequency of relocations

In the following sections is a presentation of some of the models which are used in working the fire station location/allocation problem.

Square-Root Laws Model

Of the many factors important to the performance of emergency service vehicles, response time (time that elapses between call for service and arrival of the responding unit) is certainly one of the most critical. Of the key components of response time, generally the only one affected by a change in deployment procedures is travel

time (time from start of travel to arrival at alarm), and it is directly related to distance.

The Square-Root Law has been found to give accurate estimates of the average travel distances for emergency service vehicles. The basis for this is that under some restrictions, it can be proven mathematically that the average travel time of the closest available unit of a given type to the scene of an alarm in a given region is proportional to the square root of the region's area, and inversely proportional to the square root of the number of units of that type available in the region at the moment of dispatch.[3] Specifically, if A is the area of the region in square miles and N is the number of units available, then the expected travel distance (in miles) of the closest unit in a region to the scene of an alarm is given by:

$$E(D) = C(A/N)^{\frac{1}{2}} \qquad \text{(SRL. 1)}$$

where C is a constant which depends on the street configuration, distribution procedure of the units throughout the region, and whether or not the units operate from fixed locations. The same relationship exists for the distance to the second, third, etc., closest units.

Since the number of available emergency vehicles varies with time, equation SRL. 1 cannot be used directly in estimating the average travel distance to call for service over the course of an hour. If the average number of available units in a region is not too small, an estimate of the average response distance to the closest available unit in a region is given by:

$$E(D) = K(A/(M-B))^{\frac{1}{2}} \tag{SRL. 2}$$

where M is the number of units assigned to the region, B is the average number of units busy, and K is the constant of proportionality (slightly different from C). Equation SRL. 2 is called the Square Root Model and is used primarily as a component of other models. It can be used easily by itself to:

- describe current average response distance of emergency vehicles or to compare response distances in different regions

- determine effect on response distance of adding additional units or removing units

- determine effect of projected rates of calls for service on response distances

- determine number of units required to achieve desired average response distances

The input data required is as follows:

- area A of the region in square miles

- number M of units of the given type in the region

- estimates of the hourly incident rate - X

- expected total work time - S - in hours for all units of a given type

- proportionality constant of the region - K or C

The model is a useful and versatile tool in deployment analysis, because it can be used both to describe a given allocation policy, and also to prescribe a new one. For a given incident rate and allocation

of units in a region, the expected distance to the closest available unit is obtained from SRL. 2. The average number of busy units is obtained by X - S, the average number of units available is M - B, and the average number of units busy per square mile is given by B/A. In deployment planning one might want to assign units to areas to achieve a desired level of average response distance or time. The equation is:

$$M = B + A \cdot (K/D)^{\frac{1}{2}} \qquad \text{(SRL. 3.)}$$

Travel Time Analysis Model

Travel time is also an important measure of the effectiveness of the response of an emergency vehicle to an alarm. Analysis of data of over 2,000 responses made by fire companies to actual alarms in New York City revealed two different functional forms for relating travel distances to expected travel time. For short response where units do not attain cruising speeds, travel times increase with the square root of the distance traveled:

$$T = C(D)^{\frac{1}{2}} \qquad \text{(TTA. 1.)}$$

where:

T = the expected travel time in minutes

D = the travel distance in miles

C = proportionate constant

For long responses where units reach cruising speeds, the travel time increases linearly with the travel distance:

$$T = a + bD \qquad \text{(TTA. 2.)}$$

where a and b are constants. Combining the two equations, a piecewise square-root/linear travel time function is obtained that can be applied to any travel distance:

$$
T = \begin{cases} C(D)^{\frac{1}{2}}, & D \leq d \\\\ a + bD, & D \geq d \end{cases}
$$

(TTA. 3.)

where d is a cutoff distance where the two curves join.[4] The travel time is widely used as a measure of effectiveness in how an emergency service agency serves a region and is related to travel distance.

The determination of the best relationship between travel distance and travel time for a particular region requires certain items of data which are not usually collected. These are:

- travel distance
- travel time
- incident location
- time of day and season
- weather conditions at the time

The computer program used for this model uses statistical curve-fitting (regression) methods to determine appropriate values of the parameters a, b and c in equation TTA. 3. Analysis of data from cities other than New York showed consistency in the values of the parameters a, b and c in equation TTA. 3. Figure 6 depicts equation TTA. 3 with the average values of a = 0.65, b = 1.70, c = 2.10, and d = 0.38.[5] It should be noted that Fairfax County, Virginia, uses travel time as one of the main factors in determining where to situate fire station houses.
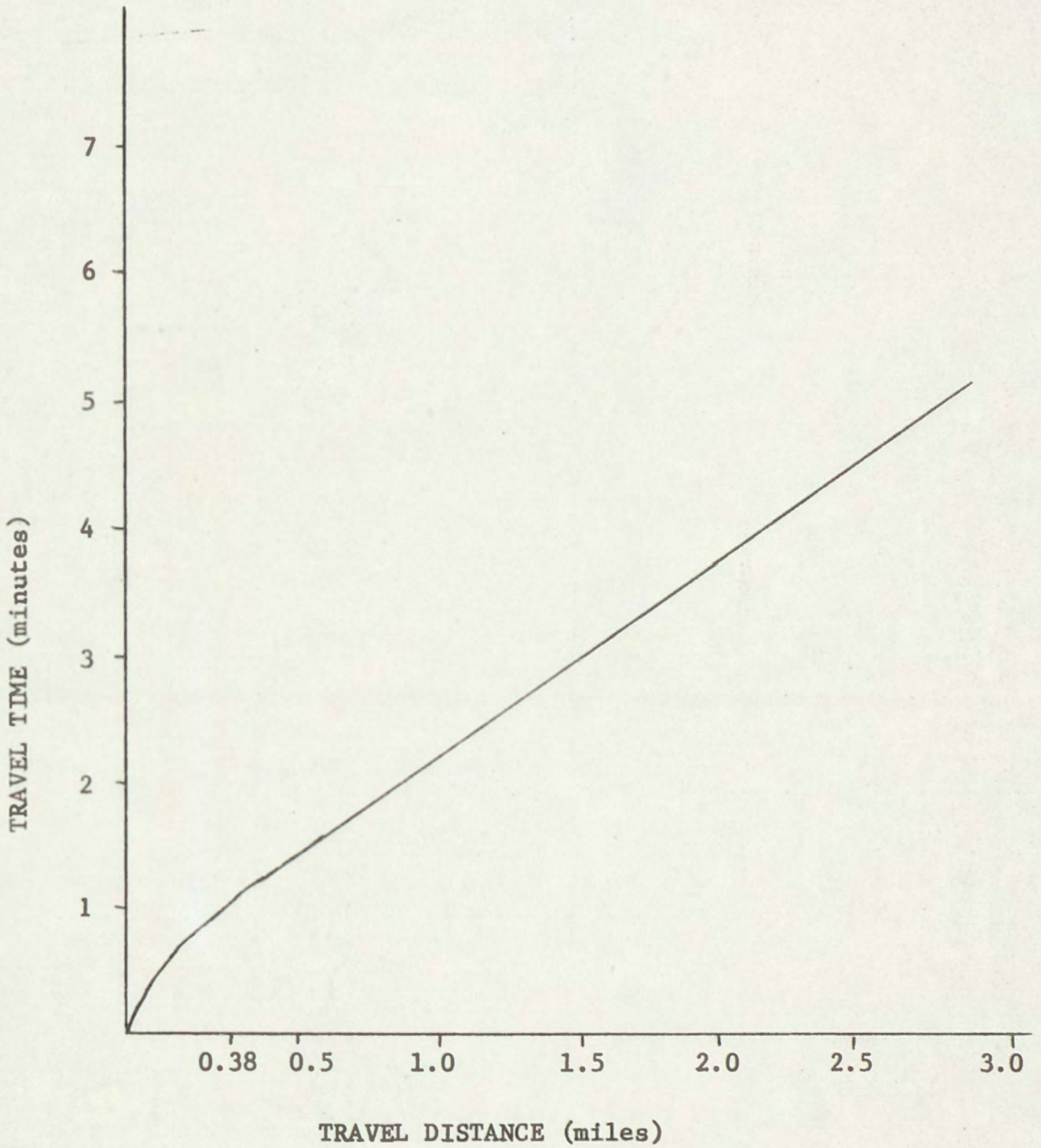
Figure 6. Relationship between travel time and travel distance.

("average" parameters)

There is a minimum limit to travel time, and is usually the time required for the responding fire company to get out of the firestation house and underway. This time can be affected by the following:

- experience level of the firefighters
- whether the fire department is comprised of strictly salaried, volunteer, or combination of both types of firefighters
- location of the equipment used to combat the fire frequency of alarms in a given area
- size of the area to be protected in square miles
- particular route the responding fire company takes
- obstacles which may be in the route.

In addition there is also a maximum travel time for units responding to an alarm. This time limit is affected by nearly all of the factors which affect minimum travel time plus the factor of what level of fire protection service is desired by the community. This time limit is also determined by officials within the community, and is usually the time after which additional firefighting units are dispatched if previously dispatched units have not arrived at the scene of the alarm.

Parametric Allocation Model

The Parametric Allocation Model is capable of generating fire company allocations based on a wide range of objectives.[6] This is accomplished by assigning different values to an input parameter called tradeoff. The interactive computer program which implements the model,first reads a previously created file containing data on the various types of fire alarms in each region. The user then inputs the

total number of companies to be allocated and the value of the tradeoff parameter. The program assigns the minimum number of companies required to respond to work at the average number of incidents that occur in each region. It then allocates the remaining companies according to the specified value of the tradeoff parameter which indicates the balance among the performance objectives desired by the user. Once the allocation is determined, the program calculates and prints out values of various performance measures it predicts will result if the allocations are made. The model can also be used to predict the value of performance measures that would result from implementation of any specific allocation supported by the user.

The Parametric Allocation Model also provides users with a general picture of the number of fire companies to be assigned to different regions. It can be used also to compare average travel times and workloads, and depicts whether or not current distribution of fire companies is satisfactory. If sizable imbalances are found, the model can also be used to determine how to reallocate the existing units among the various regions to provide a more balanced fire protection level. If proposals for fewer or additional fire companies are being considered, the model can also be used to determine the regions that should gain or lose. The best documented and most widely used version of this model is written in the programming language called BASIC. A batch version has been written in PL/1 programming language.

The basic philosphy behind the Parametric Allocation Model is that any preference for one allocation over another is a managerial decision based on the analysis of all the objectives and consequences.

The model produces the best allocation possible based on the objectives and constraints which were input. It does not address the determination of the proper level of fire department resources. Management determines an equitable balance of resources based on the output produced by the model. Equipment(engines, and ladders) are treated separately,and the model assumes that fire companies are given reasonable locations throughout the various regions of the area being considered.

To use the model, an area must be divided into demand regions, with each region containing at least two fire companies of the same type. Each region should have a reasonably compact shape and be relatively homogenous with respect to fire hazards to life and property, other potential fire fighting problems, and alarm rates. For each region, the user must supply the following:

- area in square miles
- alarm rates for different types of alarms
- number of engines and ladders currently in the region
- estimate of the relationship between travel time and travel distance
- specification of the dispatch policy being used (send 1 or send 2 if available)
- manner in which deployment objectives are to be weighted (specified in terms of the value of the tradeoff parameter P)

    P = 0 equalize average travel times in all regions

    P = 1 minimize average travel time to all incidents

$0 \leq P \leq 1$ produces some compromise between equal and minimum average travel time

$P > 1$ equalize the workload among all units.

The model can be used in either the descriptive mode or the prescriptive mode. In the prescriptive mode the results yielded are:

- number of vehicles to be assigned to each region to produce the desired deployment objective

- for each region(s) combined, the resulting average travel times for first and second due units, average travel distance for first due unit, average number of units busy, and average number of units busy per sq mile.

In the descriptive mode, the number of units is input for each region, and the program calculates the same performance measures listed above. The mathematical formulation of the model starts with the Square-Root equation as a basis:[7]

$$E(D) = c(A/n-b)^{\frac{1}{2}} \tag{PA.1}$$

where   A = area of the region in sq. miles

n = number of fire companies allocated to the region

b = average number of companies busy

c = constant which depends on street configuration and company placement.

The relation between response distance and travel time is dependent on the effective velocity of a motorized vehicle, but in general, is not linear and can be approximated by:

$$ETT = A_1 * E(D)^{A_2} \tag{PA.2}$$

where

ETT = expected travel time

A_1 and A_2 = coefficients determined by the travel characteristic

of fire companies and street configurations in the region.

For $A_2 = 1$, the average travel velocity is constant. If A_2 is less

than 1, longer runs are made at a faster velocity than shorter runs.

The relation of expected travel to the number of companies in a region

is given by;

$$RL = c(A/n-b)^{\frac{1}{2}} \tag{PA.3}$$

where A,b,c,n are as described for equation PA.1.

The general form of the allocation model is:

$$\text{Min} \sum_i W_i \left[RL_i(N_i) \right]^P$$
$$\text{subject to } \sum_i N_i = M$$

where

W_i = weight for region i

$RL_i(N_i)$ = expected travel time in region i if N_i companies are

assigned to it

N_i = number of companies assigned to region i

M = total number of companies to be allocated

P = tradeoff parameter

Firehouse Site Evaluation Model (FSEM)

The FSEM (sitting model) was developed by Rand Institute to help planners evaluate alternative arrangements of fire companies. It is a descriptive model which estimates a large number of performance measures for a given proposed arrangement of fire companies. Using grid locations assigned by the user to alarm boxes and firehouses, the model estimates the distances traveled by companies to each alarm box. The distances are used to divide the city into response areas. After calculating the response distances, the program estimates travel times by using mathematical formulae to relate fire vehicle travel time and distance. It then aggregates travel time by region and response area, and prints summary statistics on travel times and estimated workloads for each group of bases.

The data required for the sitting model for fire companies includes:

- location of each fire house given by its coordinates (x, y) on a grid map of the area;

- ordered list of the closest fire companies to each alarm box. If the latter is not easily available, the program can generate it using the grid locations of fire companies and alarm boxes. The data for each alarm box includes:

- location given by coordinates (x, y) on the same grid used for identifying firehouses;

- number of alarms that occurred at each box in the past year (or that are projected to occur);

- number of structural alarms that occurred at that box;

- indication of whether a given box is considered a target hazard (more important than others for achieving rapid response);

- demand region to which a given alarm box belongs (same as demand region in Parametric Allocation model);

- determination of the relationship between travel distance and time as in Travel Time Analysis Program.

Since one arrangement of firehouses will rarely result in travel times superior to those of another arrangement for every alarm box, the information provided is on travel times to groups of alarm boxes which are grouped in several ways:

- area-wide (aggregate results printed for the area as a whole);

- demand region (results printed separately for each of the previously defined demand regions constituting the region);

- company response area (boxes responded to by each company are aggregated and summary results printed);

- affected region (the set of boxes for which travel times in the current configuration are different from those in the proposed configuration - results are presented for two configurations, a previously defined configuration called current and a new one called proposed);

For each of the above groups of alarm boxes, except company response area, the sitting model provides values of the following performance measures for both current and proposed configurations:

- average travel time to an alarm box

- average travel distance to an alarm box
- average travel time to a serious fire (taking into account some alarm boxes have more serious fires than others)
- average travel distance to serious fires
- maximum travel time to any box in the group

All of the above statistics are calculated separately for engine companies and ladder companies, and can be obtained for first due, second due, third due, and further responses, up to the response level requested by the user. The output for each demand region and whole area as well includes a report that shows the number of alarm boxes where travel time under the proposed configuration falls into each of a number of half-minute intervals. For each company response area (current and proposed), the program prints the number of boxes in the area, average and maximum travel times, and alarm rates in the area. The alarm rates provide an estimate of the workload of the fire companies and can be used to determine whether a proposed configuration will result in an undue strain on a particular fire-fighting unit or large workload imbalance among all units.

The model assumes that units are always available in their fire houses to respond to an incoming alarm and that the closest units are always dispatched. Travel distance estimates are obtained by using grid coordinates to calculate either right-angle distances between two points or the Euclidean distance which is then multiplied by a factor of 1.15, unless the user supplies a different factor. Travel times are estimated from the travel distances by using one of the formulae described in Travel Time Analysis with parameters supplied

by the user.

The model is written in Fortran and can be run as a batch program or in an interactive mode. On a PDP-10 computer, the model requires 27K words of core storage for an area with 750 alarm boxes and 30 fire companies. Cost of a run using time-sharing services with the above elements is approximately $5.00.

Fire Station Location Model

The Fire Station Location (FSL) package was developed, tested, and documented by Public Technology, Inc., in three cities: Wichita, Kansas, Newark, New Jersey, and Dallas, Texas. The model is structured around a computer program which focuses on response time and is comprised of three routines, each with a different function. The required data for the model is extensive, and a given area must be analyzed to determine existing and potential fire hazards. The elements of a community which are required to run the model are as follows:

- identification of all properties by geographic location, human occupancy level, type, and associated fire hazard level;

- detailed layout of the area's street network configuration in terms of nodes (street intersections) and links (sections of street between intersections);

- aggregation of similar properties;

- identification of environmental barriers (rivers, rifts, dense woodland, open fields, and other geographic features);

- identification of human barriers (freeways, railroad tracks, limited access roads and unusual structural features);

- identification of special fire hazard districts (downtown business area, industrial complexes, large university campus, railroad yards or airports);

- fire station locations, existing and potential.

The strategic importance of the above factors requires considerable attention because of its impact on response time requirements. The three computer programs which comprise the Fire Station Location Model are named PATH, CONFORM, and LOCATION.

The routine PATH which is written in Fortran calculates the shortest travel time paths between station sites and focal points (a point within an area identified as a fire demand zone, FDZ, which represents all of the properties and human occupancies in the zone). The second routine, CONFORM, which is written in PL/1, converts the results from the routine PATH into a travel time matrix acceptable by the third routine. The third routine, LOCATION, also written in PL/1, assesses the capability of station sites identified to respond to focal points within specified time constraints.

PATH will produce matrices of the shortest travel times between each origin node and all destination nodes; and in addition, upon request, the actual travel paths through the network which produce these shortest travel times. Several basic assumptions are:

- there shall be a transportation network defined;

- the network shall consist of nodes uniquely identifying street

intersections of the network and of links which will be uniquely defined by pairs of nodes;

- each link, in addition to its defining pair of nodes, shall also have associated with it a speed, distance and direction (one or two ways);

- a finite subset of nodes shall be defined as origin nodes, and a second finite subset shall be defined as destination nodes;

- a link node in a one-way link cannot be an origin;

- a source node in a one-way link cannot be a destination;

- speeds on a two-way link may differ according to the direction of travel.

The routine LOCATION computes the minimum number of station sites needed to meet all time average requirements, and it reports on the location of a set of stations which actually provides that coverage. Several basic assumptions are:

- there shall be a finite set $I = (1, 2, 3, \ldots i, \ldots m)$ of demand points (focal points) which will be identified by ascending sequence numbers $1, 2, 3 \ldots m$;

- there shall be a finite set $J = (1, 2, 3 \ldots j, \ldots n)$ of supply points (station sites) which will be identified by ascending sequence numbers $1, 2, 3 \ldots n$;

- there shall be a travel time matrix T which will give the travel times, t_{ij} which can be achieved between each station site j and all focal points i;

- there shall be a standard maximum response time, s, which

will identify the desired level of service to each focal
point;

- there shall be a response time deviation file D = (d_1, d_2, d_3
  . . . d_n), which will identify the deviation from s of the
  response time requirement for each focal point;

- some station sites will be considered fixed J_{fx} (appear
  in the final solution with no respect to minimization
  constraints);

- some station sites will be considered deleted, J_d ;

- some station sites will be considered free J_{fr} (available
  for inclusion into a final solution if appropriate).

Figure 7 depicts an overview of the Fire Station Location Model.
Following is a generalized framework for using the FSL model:

- identify the demand for fire protection

- identify sources of fire station supply

- prepare a street transportation network

The above three major categories can be further subdivided into the
following:

A. Identify demand for fire protection

- identify and respond to constraints influencing fire
  station location

- establish practical boundaries on data collection

- clearly define the extent of the study area

- address location issues with neighboring jurisdictions

- review internal relations

- apply guidelines which can ensure consistent boundaries

Fig. 7. Overview of Fire Station Location System.


```
┌──────────┐        ┌──────────┐        ┌──────────────┐
│Parameter │        │ Network  │        │Station Site  │
│ Records  │        │   Link   │        │and Focal Point│
│  File    │        │   File   │        │ Node Numbers │
└──────────┘        └──────────┘        └──────────────┘
        │                │                  │
        └──────┐      ┌──┘            ┌──────┘
               ▼      ▼               ▼
            ┌──────────┐
            │   PATH   │
            │ Program  │─────────┐
            └──────────┘         │
                 │               │
                 ▼               ▼
            ┌──────────┐    ┌──────────┐
            │   PATH   │    │ Table of │
            │  Output  │    │  Travel  │
            │ Displays │    │  Times   │
            └──────────┘    └──────────┘
                                │
        ┌──────────┐            │
        │  Format  │            ▼
        │Instructions│──►  ┌──────────┐
        └──────────┘       │ CONFORM  │
            ┌──────────┐   │ Program  │
            │  Travel  │◄──└──────────┘
            │   Time   │
            │  Matrix  │
            └──────────┘
  ┌──────────┐    │
  │  Policy  │    │
  │Instructions│──┘
  └──────────┘ ▼
        ┌──────────┐
        │ LOCATION │
        │ Program  │
        └──────────┘
             │
             ▼
        ┌──────────┐
        │ LOCATION │
        │  Output  │
        │ Displays │
        └──────────┘
```
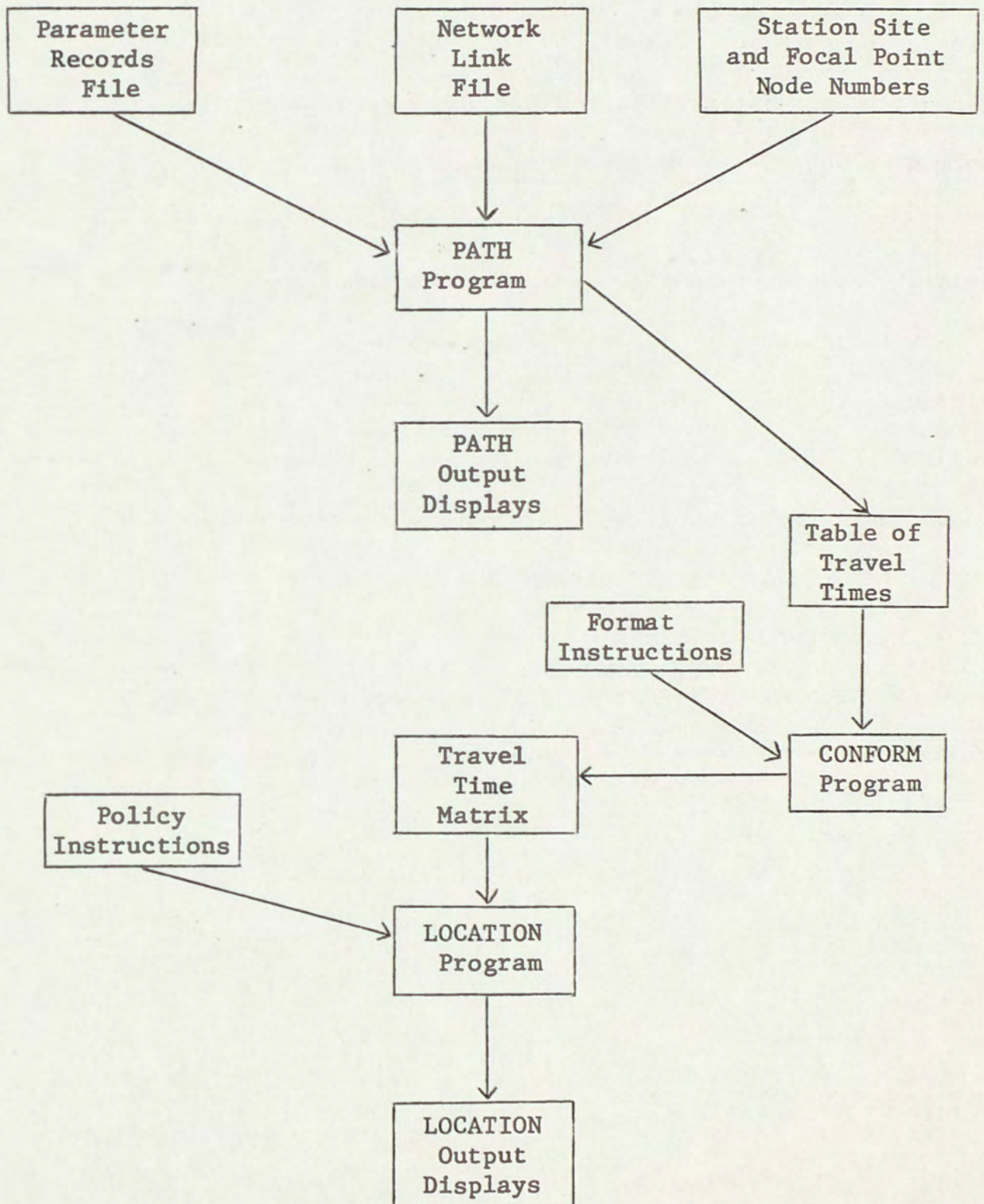
- locate key properties and determine concentrations of people

- determine and categorize property types

- aggregate similar properties

- assess strategic importance

- determine response time requirements

- determine and select focal points and fire demand zones

- determine acceptable safety margins

- assign boundaries to fire demand zones

- develop travel paths across zones

B. Identify sources of fire station supply

- identify potential fire station sites

- determine fire protection demand

- limit the number of sites

C. Prepare street transportation network

- identify and select streets and other arterials

- determine nodes and links

- determine speeds for each node and link

The mathematical model which is basically comprised in the initial part of the routine LOCATION uses a set-covering formulation of the location model:

$$\text{Min} \sum_{j=1}^{N} X_j \qquad \text{(FSL. 1.)}$$

subject to:

- $\sum_{j=1}^{N} X_j \leq 1$ for $j \in N$ \qquad (FSL. 2.)

- $X_j = 1$ for $j \in J_{fr}$ (FSL. 3.)

- $X_j = 0$ for $j \in J_d$ (FSL. 4.)

- $N_i = (j \mid T_{ji} \leq s_i)$ for all i   (FSL. 5.)

In using the FSL model, the programs must be compiled and executed with test data, and then installed into a specific computer configuration. The decision on how to execute is impacted by the following:

- all three programs are relatively inexpensive to compile and link;

- programs PATH and LOCATION are executed many times but require the most space in a load module library.

As a general guide during the course of a project, PATH is executed between five and fifteen times; CONFORM is executed between three and five times; and LOCATION is executed between fifteen and thirty times. The decision of what medium to use for each file is straight forward. Input files to PATH and LOCATION change constantly, and tape or disc is advisable. The output files can be handled by either straight printing or to an intermediary device for batch printing.

ANALYSIS AND RECOMMENDATIONS

Technical Analysis

In the planning of a community, fire prevention should and must receive consideration equal to or perhaps greater than other factors being considered. Fire department officials must be included in every aspect of community planning, for their capability to provide service is dependent upon the structure and composition of the community. The major elements of consideration in community development planning are:

- population
- land usage
- water
- transportation
- community services
- economic base

These are so dependent upon one another that they cannot effectively be separated and dealt with individually. Two examples of this interdependence are listed:

1. The size, composition and distribution of a community's population will affect:

   - the nature of the usage of the land;
   - the economic base from which the community can operate;
   - the usage and distribution of required water;
   - the types and quantity of services needed;

- the transportation services required, most prominent
  being the types, quantity, quality and location of roads.

2. The existence or nonexistence of a convenient water supply
   will affect:

   - the size and distribution of the population;

   - the nature of the land use.

From the best available information, the National Fire Preven-
tion and Control Administration, there is evidence that the early
detection of fires, coupled with the automatic transmission of detailed
information pertaining to the fire, can significantly reduce the number
of fires and produce basic changes in the nature of demand for service.
Such changes in the demand for service would allow the fire depart-
ment to modify its response patterns and operational and tactical
procedures. Over a period of time, these modifications would increase
the effectiveness of the fire department, which in turn could lead to
a reduction in the demand for service and a strain of department capa-
bilities in the affected areas. Viewed in cost versus benefit terms,
the economic feasability of an Early Warning Detection System (EWDS)
depends to a considerable extent upon the magnitude and distribution
of past, present and projected losses resulting from fire. Determi-
nation of direct losses from fire is fairly straightforward, while
determination of indirect fire-caused losses is rather difficult.

All of the following elements associated with fire prevention
are related to and dependent upon the community in which they are to
be used:

- water

- communication

- transportation routes

- equipment

- personnel

- fighting techniques

- public education

It appears that the single most critical concern in the allocation of fire station houses is the response time of units throughout the area. Although having adequate resources (men and equipment) provided is important, if in the time it takes to reach the site of an alarm the fire has all but destroyed that which was burning, then all the manpower and sophisticated equipment are useless. Ideally, fire departments would like to minimize their average travel time to fires throughout the entire area while providing equal coverage to all areas at all times. Four factors which appear to have the most direct influence on obtaining minimum response times are:

- the level of fire protection desired;

- finances in the budget allocated for fire services;

- number of fire companies;

- strategic location of fire companies within a region.

A response time of almost zero could be obtained by allocating minimum response areas. Fire companies would then have a minimum distance to travel in their respective response area. This concept is immediately eliminated because operating expenses in terms of (equipment, manpower, facilities) and maintenance cost, greatly out-

weigh the benefits of fire protection service provided to the community. The basis for obtaining minimum travel times is a combination of the above factors. The key factor of the above mentioned, is level of fire protection desired. Fire department officials and other key officials in a community arrive at a satisfactory level of fire protection by adjusting the other three. Figure 8 illustrates the problem when two regions of an area have widely differing rates of fire incidence. If fire station houses are allocated to minimize average travel time, then many more companies will be assigned to the high-incidence region than to the low-incidence region, thus resulting in travel times within the two regions not being equal. Using this allocation method, residents of the low-incidence region may be concerned about possibly receiving inferior protection.

If the average travel time were made equal in both regions, the travel time in the high-incidence region will be increased in order to reduce those in the low-incidence region, and average travel time throughout the entire area will be longer than its feasible minimum. The problem becomes even more complicated as the number of regions in an area increases.

In addition to locating fire station houses, other methods (response time minimization, response distance minimization, manpower/hazardous workload allocation, etc.) have been used to determine how best to provide fire protection service to a community. When a large fire or several medium fires occur, generally a number of fire fighting units respond. This results in the fire houses from which they come being empty; thus, the areas which they primarily serve are with-

High Demand   Low Demand
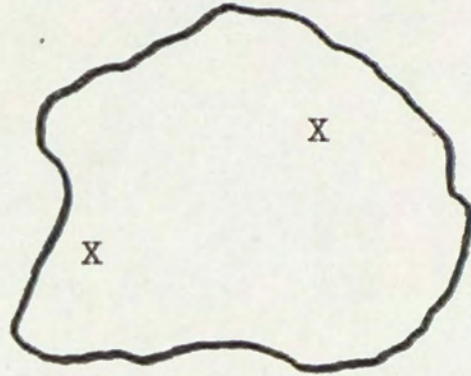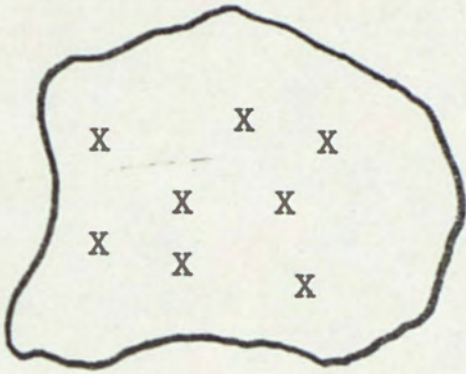
MINIMUM TOTAL RESPONSE TIME TO ALL FIRES
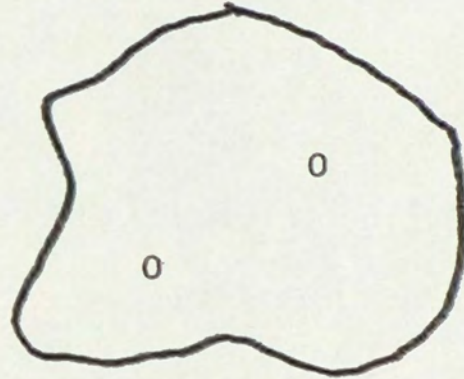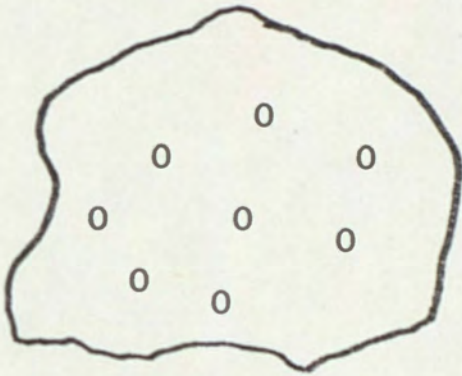
EQUALIZED COVERAGE TO BOTH REGIONS
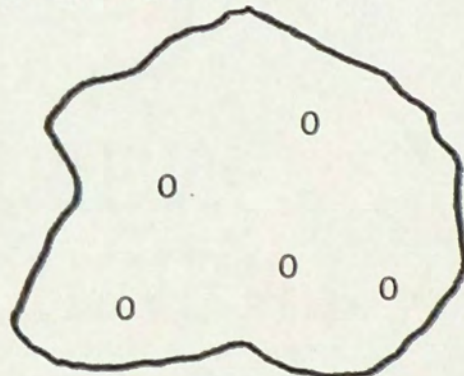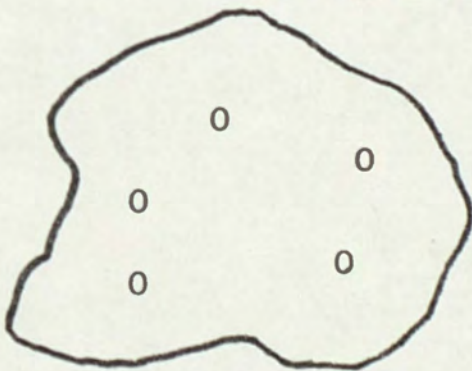(total response time higher)

Fig. 8.   Two allocation policies for fire companies.

out adequate protection in the event of a fire elsewhere. It is a standard practice in many urban fire departments to provide protection to these areas by temporarily relocating other fire companies into some of the vacant houses. Situations requiring such relocations surface on the average of ten times daily in New York City.

In traditional deployment procedures for an alarm at a given location, an assignment sheet is consulted to dispatch units. The units are generally ordered by proximity. In some areas, a predetermined relocation order to cover the area around the site is also listed in the event a large fire should require many units. These assignment sheets unfortunately implicitly assume that only one incident is active in an area at a given time. In active periods, areas with high alarm densities can quickly deplete coverage and cause deployment problems which have to be settled by improvisation. Common deployment issues are:

- obstacles and obstructions in travel routes

- coverage and dispensing of workloads

- response of adequate units

- nuisance alarms

- relocation of available units

- adjustment to shifting alarm patterns.

The many models developed to date all have merit, and in general address the following issues:

- how many units of each kind should exist, and where they should be located depending on area and alarm rate

- how many, and which units should initially be dispatched to

an incoming alarm taking into account probable severity of the
incident, number of available units, and likely future demands

- how, when, and the number of units to relocate

- how to vary all of the above with time, and changes in
  circumstances.

Specific models and methods developed to date are:

- geography and land use model

- hazard and workload model

- queuing model

- response-time model

- response area model

- response distance model

In the geography and land use model, firestation houses and
police stations are determined as the community grows. When geo-
graphical growth stopped, any further construction would be primarily
for the replacement of deteriorating structures. Therefore any
allocation policy would be determined by the existing facility
locations. Problems are peculiar to a community, therefore allocation
policies relying exclusively on geographical standards are inadequate.
The main deficiency of these standards is that they are meant to be
substitutes for standards involving time between receipt of a call for
service and the arrival of units. However this time depends on
factors such as:

- delays incurred in dispatching units

- travel speeds of the various units

- availability of specific units.

Generally, it is not possible by inspecting a community map which illustrates the home location of units to determine whether an adequate number of units are located in each geographical area.

Workload and hazard formulas attempt to combine virtually all factors which might be relevant for allocating personnel. Basically, these formulas result from combining indicators of activity with other factors to arrive at a hazard scale for an area. The hazard formula excludes the description of highly nonlinear and complex interactions among system components often observed in practice. Considerable difficulty arises in trying to determine how to improve the selection of subjective weightings, given information regarding the system's performance.

Queuing models are applications of operations research concerning systems service performance where customers (alarms or calls requiring the dispatch of vehicles) wait in a queue (line or service bay) before being serviced. The nature of the arrival times and service times of calls is such that it can never be guaranteed that every call will be able to obtain the immediate dispatch of a unit if one is required. The objective of queuing models in the analysis of emergency service units must be to assure that the probability of important calls encountering a queue is below some specified threshold. The difficulity of the analysis depends upon how many different types of calls for service are received and the circumstances under which it may be placed in a queue. It is difficult to measure quantitatively the dependence of service times on the number of busy units which is characteristic of most urban

emergency systems. Average travel time is increased when distant units must be dispatched, and an incident may escalate when units do not arrive quickly enough. Fire departments frequently dispatch several units to an alarm,with each unit having distinct duties, and each unit does not necessarily complete service simultaneously.

In response-time models,the feature of interest is the average response time to all important incidents by different units. As a result, formulae are required which relate measures of response time to the number of units on duty,nature of the geographical region to be served, arrival rates of alarms, and length of service time at incidents. Several models have shown that average travel time is inversely proportional to the square root of the number of available units, with the proportionality constant depending upon the travel speeds, and location of the units.

In response-area models, analysis has shown that not sending the closest available units to selected locations can serve both to balance workload among units situated in an area, and also to reduce average response time. The exact units to respond to alarms are prescribed if average response time is to be minimized.

The Parametric Allocation model provides the user with a general picture of the number of fire companies needed in different parts of an area, and the fire protection levels that can be obtained with different numbers of companies. It is quick and inexpensive, requires little data to be collected, but cannot be used to evaluate specific locations of fire stations.

The Firehouse Site Evaluation model (sitting model) developed by the Rand Corporation, Santa Monica, California, does not by itself generate alternate firehouse configurations. Instead it helps fire department and urban planning officials evaluate the various alternate configurations created by their planning personnel. It must be emphasized that this model is purely descriptive. It does not recommend specific configurations, but only estimates what would happen if a specific one existed.

The Fire Station Location model developed by Public Technology Inc, Washington D.C. ,is similar to the Firehouse Site Evaluation model in that it does not generate specific station allocations. Based on data comprising the community, and the factor relating response time, the model produces data summaries which are used to measure consequences of alternate proposals.

Recommendations

It is the recommendation of the author based on the research conducted, and the material presented in this report, that the model which would be of the most benefit to a community such as Orange County, Florida, is the Fire Station Location model. The reasons this particular model was selected are as follows:

- the model includes the basic features of two other models, Square-Root Laws Model(minimize response distance), and the Travel Time Analysis Model(minimize travel time)

- the inclusion of the factors listed below more accurately describe a community than any other method investigated;

- street network configuration identification
- travel paths determination
- human concentration identification and categorization
- property type specification and categorization
- hazardous area identification
- alarm type and rate identification
- resource identification (facilities,manpower, equipment)

Use of the FSL model will require Orange County to incorporate a number of changes in their fire department and community structure (if not already in existence) as listed below:

- division of the county into a number of fire districts
- delegation to a single organization the responsibility for the operation of county wide fire protection services
- allocating common equipment in all station houses in the county.

A number of additional recommendations in the opinion of the author,also based on his research effort,would aid in improving the level of fire protection provided in Orange County, Florida. These are as follows:

- cross-training of all fire service personnel in the use of special equipment, and various firefighting methods
- establishing a training facility located within the county
- train all fire service personnel to the first level of medical care
- establish a facility for the purpose of rendering

repair and maintenance on fire service equipment in the
county

- initiate and adopt a purchasing agreement with
neighboring jurisdictions for the purpose of minimizing
new equipment purchasing costs   .

- identify special hazard areas and situate needed special
equipment in the station houses of first due companies.

APPENDIX A

Classes of Fires

Class A Fires: Fires involving ordinary combustible materials (wood, cloth, paper, rubber, many plastics) which require the heat-absorbing effects of water, water solutions, or the coating effects of certain dry chemicals.

Class B Fires: Fires involving flammable or combustible liquids, flammable gases, greases, and other materials where extinguishment is most readily secured by excluding air, thus inhibiting the continuation of combustion or combustible vapors.

Class C Fires: Fires involving live electrical equipment where safety to the operator requires the use of electrically nonconductive extinguishing agents. (Note: When electrical equipment is de-energized, the use of Class A or Class B extinguishers may be indicated.)

Class D Fires: Fires involving certain combustible metals (magnesium, titanium, zirconium, sodium, potassium, etc.) requiring a heat-absorbing extinguishing medium not reactive with the burning metals.

FOOTNOTES

[1]Jan M. Chaiken and Richard C. Larson, Methods for Allocating Urban Emergency Units, R-680-HUD/NSF (New York: Rand Institute, September 1975), p. 5.

[2]Warren E. Walker, The Deployment of Emergency Services: A Guide to Selected Methods and Models, R-1867-HUD (New York: Rand Institute, May 1971), p. 2.

[3]Peter Kolesar and Edward H. Blum, Square-Root Laws for Fire Company Travel Distances, R-895-NYC (New York: Rand Institute, June 1975), pp. 1-2.

[4]Walker, Deployment of Emergency Services, p. 8.

[5]Ibid., p. 9.

[6]Kenneth L. Rider, A Parametric Model for the Allocation of Fire Companies, R-1615-NYC/HUD (New York: Rand Institute, April 1975), p. 4.

[7]Ibid., pp. 4-6.

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