A PARAMETRIC MODEL FOR THE ALLOCATION OF FIRE COMPANIES: EXECUTIVE SUMMARY

PREPARED FOR THE OFFICE OF POLICY DEVLOPMENT AND RESEARCH, DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

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R-1646/1-HUD
AUGUST 1975

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PREFACE

This report describes in nontechnical terms a computer program called the Parametric Allocation Model. The report was written to help fire department administrators and other local government officials understand how the model can be used to allocate fire-fighting resources to various regions of a city.

Preparation of this report was funded under contract H-2164 with the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development. Among the objectives of this HUD contract are the development, field testing, and documentation of methods for improving the deployment of municipal emergency services.

For more detailed information about the model, readers should consult the companion volumes to this report:

R-1646/2-HUD, *A Parametric Model for the Allocation of Fire Companies: User's Manual*, by Kenneth Lloyd Rider

R-1615-NYC/HUD, *A Parametric Model for the Allocation of Fire Companies*, by Kenneth Lloyd Rider.

Documentation of the Parametric Allocation Model constitutes part of a series of HUD-funded reports describing several different deployment models for police, fire, and ambulance services and applications of the models in several cities. Further information about the models and their applications can be obtained from The Rand Corporation.

The HUD contract with The New York City-Rand Institute is one of the efforts supported under HUD's Community Development and Management Research Program. The Program is designed to develop, field test, and provide to state and local officials new approaches and methods for responsive community management. The Program intends to provide these officials with new methods of identifying alternative policies and actions. It is also intended to provide new methods of assessing the feasibility, cost, and consequences of these alternatives. The methods are tested in representative communities under actual operating conditions, and the results are made available to users in other communities.

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I. INTRODUCTION

The appropriate distribution of fire companies relative to need is a fundamental concern of municipal fire department management. The Parametric Allocation Model (also simply called the "allocation model") is a computer program that uses both fire-incidence data and managerial judgment to help determine the allocation of fire companies to various regions of a city. It has been used in the analysis of fire company deployment in New York City, Yonkers, New York [1],* Jersey City, New Jersey [2], and Wilmington, Delaware [3]. Most of these cities are in the process of making substantial changes in the number and arrangement of their fire-fighting resources based on the results of the analyses.

Even if a city's firehouse locations once made sense, they should be reevaluated periodically. As a city changes over the years, its fire experience also changes. Formerly well-maintained neighborhoods may become run-down and suffer increasing fire hazards, or vacant land may be built-up and create a need for fire protection where none existed before. On the other hand, urban renewal may turn a problem area into one of low risk.

A decision must also be made about where to locate a new firehouse whenever an outmoded firehouse is scheduled to be closed. Should the new house be at the same location as the old one? Should it be put into an area of increasing fire risk? Or should it be put into a low-density area that currently has a low level of fire protection? Similar questions arise if a company is to be eliminated or if a company is to be added to the department.

A fire department delivers two principal types of fire suppression service: (1) actual fire-fighting is performed when demanded, and (2) fire companies are kept available for potential need. While most of a city's fire-fighting resources may be idle at any one time in the sense of "not busy fighting fires," when they are needed they are needed quickly. The idle companies provide insurance against major catastrophe and loss of life. In general, companies are readily available to fight fires. In most cities, the average number of companies physically required to fight

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*Numbers in brackets identify references listed at the end of this report.

fires at any one time is substantially smaller than the number of companies being maintained.

Deciding how to provide coverage for potential need is more difficult. While it may be assumed that under the constraint of a fixed budget a fire department will try to balance the availability of its service throughout its city in an equitable manner, this concept is difficult to translate into an operational policy. The *Standard Grading Schedule*, published by the Insurance Services Office, provides some guidelines for fire company placement. But once the standards are met, the *Schedule* offers no advice on where to put additional companies. And the standards do not explicitly consider the city's alarm rate.

A major concern in the allocation of companies should be the variation in alarm rate between the low-incidence and high-incidence areas of a city. Ideally, a fire department would like to be able to concentrate its companies in the areas of greatest alarm activity. However, the department must also provide a reasonable level of service to the lower alarm rate areas. Figure 1 illustrates the problem. Suppose that two regions in a city have widely different rates of fire incidence. Imagine that travel time (the time it takes a company to travel to a fire after leaving its house) is used to measure the quality of fire protection being provided. Imagine also that companies are allocated to minimize the average travel time to all fires in the city. Then many more companies will be assigned to the high-incidence region, and the fires in this region will get faster response than those in the low-incidence region. If this allocation is used, residents of the low-incidence region may claim they are getting substandard protection and are being penalized for having few fires.

Suppose, on the other hand, that average travel times are made equal in both regions. In that case, the travel time to the many fires in the high-incidence region will be increased in order to reduce those to the few fires of the low-incidence region. Moreover, the average travel time throughout the city will be larger than the minimum possible. Under this policy, therefore, total fire losses in the city would be greater than under the minimum travel time policy because many fires would be getting slower responses. In addition, the companies in the high-incidence region would have a higher workload than the companies in the low-incidence region. This is a serious consideration in some cities.

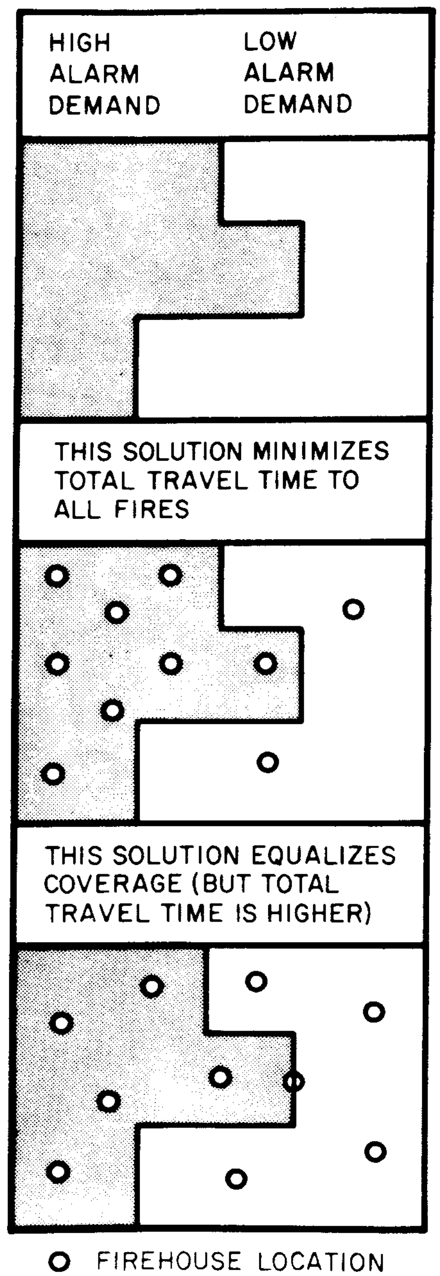

Figure 1. Two allocation strategies for fire companies.

How *should* a given number of fire companies be allocated to different areas of a city? The two conflicting objectives--minimizing average travel time to alarms and equalizing travel times--must somehow be balanced, but in a way that is not easy to specify in advance. So we identify a "parameter" (hence the name *Parametric* Allocation Model) that indicates the relative weight to be placed on satisfying each objective. The Parametric Allocation Model allows a range of values to be tried for the weight, or tradeoff parameter, and finds an appropriate allocation of companies for each weight. For each allocation the average travel time and company workload in each region of the city are displayed, along with the citywide average travel time. Fire department personnel can then compare these workloads and travel times. Based on the results, the department can decide which allocation of fire companies to regions of the city would be most desirable.

The Parametric Allocation Model is therefore designed to allow the decisionmaker to examine the consequences of allocations that result from various weightings of the two conflicting objectives. The manager's judgment can then be added to the model's output in making allocation decisions.

A typical application of the allocation model might involve running the computer program several times. First, the model is used to calculate the travel-time and workload characteristics of the existing allocation. This might show that the travel times in one region are unacceptably high compared to the travel times in other regions. The model can then be used to generate allocations for several values of the tradeoff parameter. If the user of the program feels that the level of fire-fighting resources in the city is too low or too high (or wants to see the effect of adding or eliminating companies), the model can be used to evaluate the travel-time and workload characteristics of allocations with various total numbers of fire companies.

This approach is different from one requiring prior specification of performance levels to be achieved in each region. Such an approach would determine the total number of companies required to achieve the given performance levels. The allocation model, on the other hand, tells the user what performance levels can be achieved with any given amount of resources. This is often a more useful approach because the number of fire companies that a city can maintain is usually predetermined by budgetary and other considerations.

The Parametric Allocation Model cannot be used to determine specific firehouse sites. The exact locations of fire companies, given that they are assigned to a region of the city, can be determined with the assistance of other deployment models (see Section II).

The computer program that constitutes the Parametric Allocation Model is now available to any fire department, for the cost of duplication, by request to the address listed in the Appendix. It is supplied with a complete user's manual: Kenneth Rider, *A Parametric Model for the Allocation of Fire Companies: User's Manual*, R-1646/2-HUD.

This executive summary is a companion to the user's manual and tells when the Parametric Allocation Model might be needed, how it works, how it can be used, and the amount of effort and expertise required to use it.

II. WHEN TO USE THE PARAMETRIC ALLOCATION MODEL

Determining a configuration of fire companies for any city (or other local jurisdiction) involves two questions:

(1) How many fire companies does the city need to provide a certain level of fire protection?

(2) Where should the fire companies be located?

Answering these questions involves subjective judgments and tradeoffs among competing objectives. The Parametric Allocation Model is one of several complementary models that can be used to help make the decisions. Sometimes several models are used in a deployment study; sometimes only one.

The Parametric Allocation Model provides a general picture of the number of fire companies to be assigned to different regions of the city. It is simple, inexpensive to use, and requires very little data. But it cannot be used to evaluate specific locations for the companies in detail. Its primary purpose is to assist in the initial steps of a fire station location study.

The allocation model can be used to compare average travel times and workloads among regions of the city. This will help determine whether or not the current distribution of fire companies is satisfactory. If sizable imbalances are found, the model can be used to determine how to reallocate the existing units among the regions so that the balance of fire protection is improved. If changes in the number of fire companies to maintain are being considered, the model can also be used to determine the regions that should gain or lose them.

Once a fire department has chosen the number of companies to be assigned to each region of the city, alternative configurations of station sites within each region can be evaluated in detail using the Firehouse Site Evaluation Model [4] or the Fire Operations Simulation Model [5]. Both require substantially more data than the Parametric Allocation Model.

The Firehouse Site Evaluation Model (also called the "siting model") is a computer program that estimates the travel times to specific locations that would result from implementation of a given arrangement of firehouses. By comparing travel times resulting from one arrangement to those resulting from others, a fire department can make rational decisions about the specific location of its fire companies.

If it is uncommon for companies to spend more than 10 percent of the day at alarms, the siting model is the one to use. When company unavailability is high, then the Fire Operations Simulation Model estimates travel times more accurately. The simulation model is a complex computer program that can only be used by persons who understand the special programming language in which it is written; it requires a moderately large computer, it is expensive to operate, and it requires a great amount of data as input. In comparison, the siting model can be used by persons who know nothing about programming; it is easier and less expensive to operate, and requires a smaller computer and much less data than the simulation. Therefore, the simulation should be used in preference to the siting model only if its greater capabilities and better accuracy are required for the analysis of the deployment policies being considered (see [5]).

III. THE PARAMETRIC ALLOCATION MODEL'S OUTPUT

It is not yet possible to quantify the effect of a rearrangement of fire companies on loss of life and property (the primary measures of the effectiveness of a fire department). Therefore, the allocation model uses travel time (the elapsed time between the dispatch of a fire company and its arrival at the fire) as its primary output measure. The assumption is that shorter travel times will lead to fewer lost lives and less property damage.

Different types of units perform different functions at a fire, depending mostly on the equipment they carry. For example, at a particular fire a ladder company may be able to rescue a person who could not be saved by an engine company. So, in the allocation model, travel times are calculated separately for each type of unit. In addition, two units of the same type working together may be able to take some action that neither could perform alone. Therefore, the time of arrival of each piece of equipment is of importance. The primary measures of effectiveness calculated by the model are the average travel times for the first- and second-arriving engines and ladders in every region of the city. The program also prints out for every region the average first-due response distance, the average number of companies busy, and the average number of companies busy per square mile. Citywide averages of these measures are also printed out.

To make most effective use of the program's output, the department's planners would identify and summarize the output from several runs so that the relative rankings of the various allocations (resulting from different values of the tradeoff parameter) could be assessed. In some cases, an allocation may prove to be obviously unacceptable. For example, a low-density region might be found to have an average travel time that is disproportionately long. A new value of the parameter would then be chosen and a new allocation produced. The new output from the model would be examined to determine whether an adequate improvement had been made.

It is unlikely that the allocation model results for several values of the parameter will produce a particular allocation that is obviously the best. For example, one allocation might improve travel times in the busiest regions while degrading them in outlying areas. Another may even out first-due travel times throughout the city while making the workload in the busiest regions too high. Ultimately, an administrator who understands the entire operational and political context of the department must decide which of the allocations studied appears best, all things considered, or whether still more allocations should be analyzed.

IV. HOW THE PARAMETRIC ALLOCATION MODEL WORKS

The Parametric Allocation Model is designed to take both fire-fighting and protective coverage into account when it produces allocations. The general procedure for using the model is shown in Figure 2. The computer program that implements the model first reads a previously created file containing data on various types of fire alarms in each region of the city. The user then provides two input quantities: the total number of companies to be allocated and the value of the tradeoff parameter. The program begins its calculations by assigning the minimum number of companies required to respond to and work at the average number of incidents that occur in each region. Generally, this average number is based on experience during the busiest time of the day (e.g., 4 p.m. to midnight). If a city had only this number of companies assigned, there would be no companies available to respond to a greater than average number of incidents, the workload of the assigned companies would be unreasonably large, and travel times to fires would be too long. Therefore, additional companies are needed in each region to provide coverage by being available to respond quickly to alarms and to share the burden of fighting fires.

Coverage is provided in the next step of the allocation procedure. Because the number of companies maintained by a city is usually much greater than the average number of companies needed to fight fires, a large number of companies will remain to be assigned in this step. These companies are allocated according to the specified value of the tradeoff parameter that balances two types of demand for fire protection.

One type of demand is related to the hazards and fire-fighting difficulties in an area. For example, one part of a city may have gas storage tanks or high-rise buildings, which could create serious problems in case of fire. Another region might have narrow streets and heavy traffic that could hinder the access of fire equipment to a fire. This type of demand is related to fire-fighting needs in case a fire occurs and might be referred to as *potential demand.*

Another type of demand is related to the alarms actually experienced in the city. *Realized demand* is reflected by the actual incidence of fires in a region. Even if the potential hazards in a region are small, if that region has many fires and calls heavily upon fire department resources, its realized demand is large.

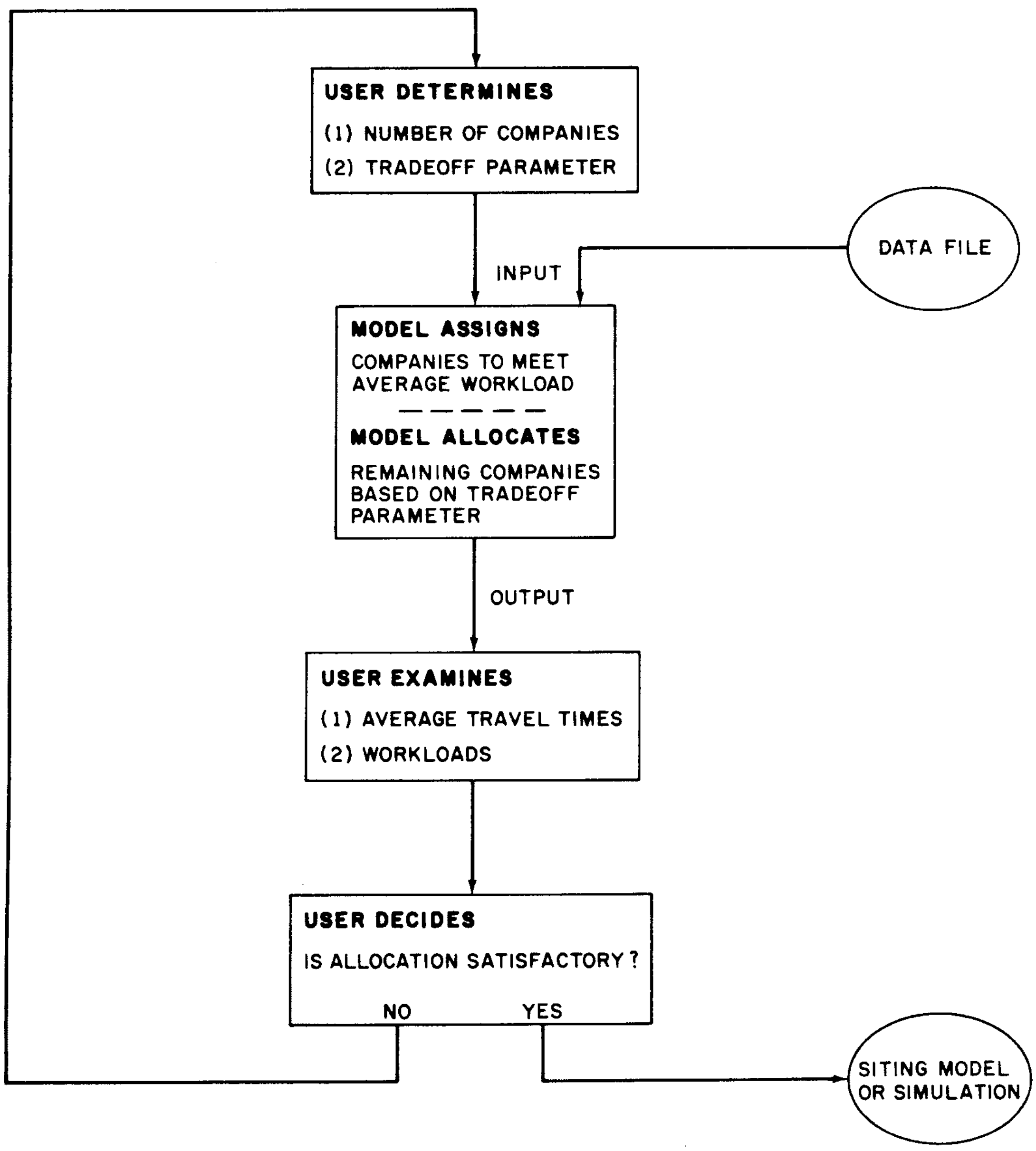

Figure 2. Steps in the use of the Parametric Allocation Model.

The user of the allocation model chooses the relative amount of weight to be placed on each type of demand by specifying an input parameter to the computer program. If this parameter is set equal to 1, most weight is placed on realized demand and the busier regions of the city will be allocated a larger proportion of the remaining fire companies than the less busy regions. On the other hand, if the parameter is set equal to 0, the remaining companies are allocated in proportion to the potential demand of each region. Parameter values between 0 and 1 can be used to produce allocations that weight or trade off realized and potential demands in various proportions. In addition, if a large value of the parameter (say 50) is used, all the weight is placed on realized demand and the allocation of the remaining companies is in proportion to the workload of each region.

Figure 3 shows how the number of fire engines allocated to two regions of similar size, but with different types of demands, will change as the parameter is varied. These allocations resulted when engines were assigned to all of New York City. "Downtown" is densely packed with high-rise buildings, and it has few fires. Therefore, its potential demand is large and its realized demand is relatively low. The "Lower East Side," on the other hand, has a lower potential demand because it is a residential region, but its realized demand is large because it is an area that experiences many fires. As the tradeoff parameter is varied from 0 to 1, more weight is placed on realized demand and less on potential demand. Therefore, the number of engines allocated to the Lower East Side increases while the allocation to Downtown decreases.

Figure 4 shows how average travel times for the first arriving engine in four regions change with the tradeoff parameter for a given total number of engine companies to be allocated. The "equal coverage" allocation (parameter 0) yields a lower travel time for Downtown than for the Lower East Side because Downtown's potential demand is higher. The average travel times for the Lower East Side and Staten Island, a residential region that has a low realized demand, are the same because their potential demands are the same. As the tradeoff parameter is increased to 1, the travel time for Staten Island increases while that for the Lower East Side decreases. This happens because the realized demand of Staten Island is low compared to the Lower East Side. At the same time the average citywide

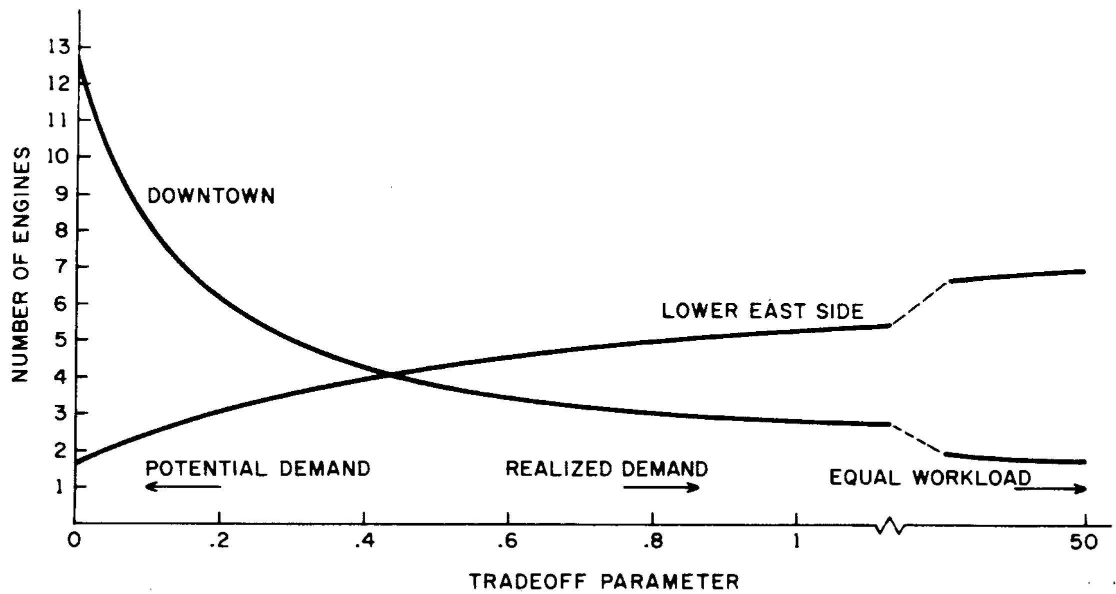

Figure 3. The effect of the tradeoff parameter on the allocation of companies.

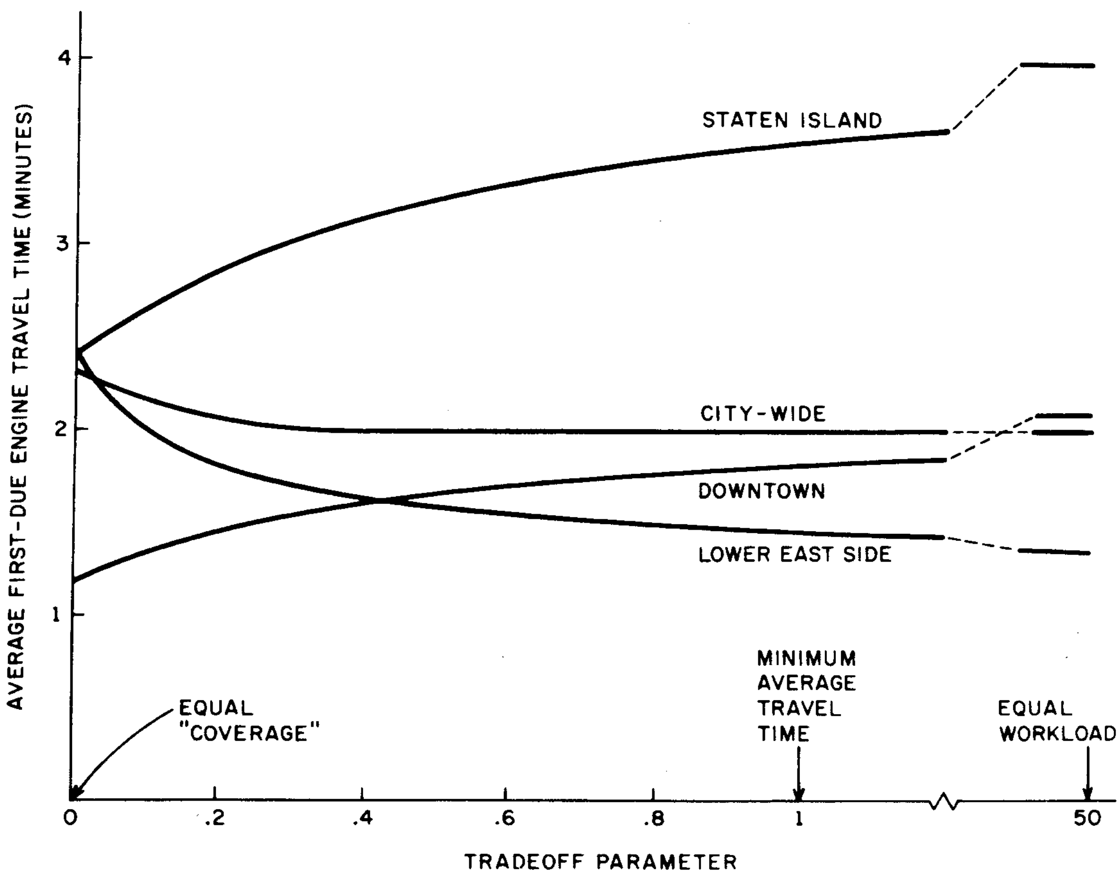

Figure 4. The effect of the tradeoff parameter on travel times.

travel time reaches a minimum when the parameter equals 1, but shows very little change past a parameter value of .25.

Figures 3 and 4 demonstrate that no single allocation gives the best values for all travel times. Therefore, the manager is faced with the responsibility of choosing the allocation that provides the best compromise for the city.

V. WHAT DATA AND RESOURCES ARE NEEDED

To use the Parametric Allocation Model, the city to be studied must be divided into "demand" regions. Each demand region should contain at least two fire companies of the same type. It should have a reasonably compact shape and should be relatively homogeneous with respect to both potential and realized demand (as defined in Section IV). With demand regions defined in this way, it is possible to compare fire protection in regions of the city that have similar demand characteristics to see if imbalances exist. Also, through the process of describing the characteristics of each region, areas can be identified that, by virtue of their greater fire hazards, require higher levels of fire protection.

The area of each demand region must be measured and the alarm rate in each region must be estimated by the user (in most instances from past data) for different types of alarms (structural fires, false alarms, etc.). Data on the existing number of fire engines and ladders in each region must also be supplied to the program. In addition, estimates of potential demand (called "hazard factors") must be supplied.

The computer program for the allocation model is written in an interactive language called BASIC. An agency wishing to use the program must have access to a computer on which this language is available.*

On a PDP-10 computer, the allocation model requires 4K words of core (approximately equivalent to 16K bytes of storage on an IBM 360/370). A single run using the model costs approximately 20 cents, although the cost of a run will vary from installation to installation depending upon the price structure.

The time and effort required to create the input data file needed by the allocation model for use in a particular city will depend on: (a) whether or not computerized files of incident reports have been maintained, and (b) whether or not the city has already been divided into regions of similar fire-fighting demands. If these conditions are met, then in less than a week a management analyst can prepare the data file. A

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*The program is available for use through a national computer time-sharing service. An agency wishing to use the model in this way need only have access to a computer terminal that can be coupled to the computer via telephone. Information on using the program in this manner is available from the Rand Corporation, as indicated in the Appendix.

few days of assistance from data processing personnel may be required. Otherwise, an additional two man-months will probably be required to collect and process the data. Persons with the skills to prepare the data, run the model, and analyze its output are likely to be found in most municipal governments. Little or no outside technical assistance should be required.

Fire departments wishing to use the Parametric Allocation Model may obtain all necessary materials as indicated in the Appendix. Questions can be addressed by phone or letter to one of the persons listed in the Appendix, but the Rand Corporation does not provide full consultation or user services in connection with the products of its research.

Appendix

ADDRESSES FOR FURTHER INFORMATION

1. For documentation of the Parametric Allocation Model, copies of the program on cards or tape, or answers to questions about the program:

Jan Chaiken
The Rand Corporation
1700 Main Street
Santa Monica, California 90406

(213) 393-0411

2. For copies of the reports listed in the references:

Publications Department
The Rand Corporation
1700 Main Street
Santa Monica, California 90406

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3. Research Sponsor:

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REFERENCES

1. Jack Hausner, Arthur Swersey and Warren Walker, *An Analysis of The Deployment of Fire-Fighting Resources in Yonkers, New York,* The New York City-Rand Institute, R-1566/2-HUD/CY, October 1974.

2. Kenneth Rider and Jack Hausner, *An Analysis of The Deployment of Fire-Fighting Resources in Jersey City, New Jersey,* The New York City-Rand Institute, R-1566/4-HUD, August 1975.

3. Warren Walker, David Singleton and Bruce Smith, *An Analysis of The Deployment of Fire-Fighting Resources in Wilmington, Delaware,* The New York City-Rand Institute, R-1566/5-HUD, July 1975.

4. Warren E. Walker, *Firehouse Site Evaluation Model: Executive Summary,* The New York City-Rand Institute, R-1618/1-HUD, June 1975.

5. Grace Carter, Jan Chaiken and Edward Ignall, *Simulation Model of Fire Department Operations: Executive Summary,* The New York City-Rand Institute, R-1188/1-HUD, December 1974.

Related Reports

Kenneth Rider, *A Parametric Model for the Allocation of Fire Companies: User's Manual,* The New York City-Rand Institute, R-1646/2-HUD, August 1975.

Kenneth Rider, *A Parametric Model for the Allocation of Fire Companies,* The New York City-Rand Institute, R-1615-NYC/HUD, April 1975.