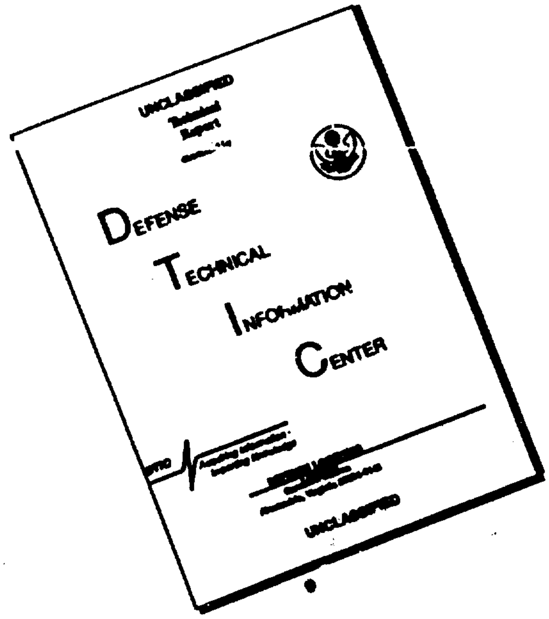
APPLICATIONS OF SYSTEMS ANALYSIS TO URBAN FIRE PROTECTION

Arthur J. Swersey

November 1971

P-4741

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

APPLICATIONS OF SYSTEMS ANALYSIS TO URBAN FIRE PROTECTION

Arthur Swersey*

The New York City Rand Institute
545 Madison Avenue
New York, New York

RESEARCH OVERVIEW

Since the spring of 1968, the staff at The New York City-Rand Institute have been conducting fire protection research in association with the Fire Department of the City of New York.

To begin, let us look at the sequence of events that take place after a fire occurs. After some time, the fire is detected and an alarm is turned in to the borough Fire Department Communications Office. The alarm is processed and units are directed to respond to the alarm; some time later these units arrive; and finally, the fire is extinguished and the units return to service.

The primary objective of the Department is to minimize loss of life and property. In order to do so, an attempt is made to first prevent fires, and then given the occurrence of a fire, to reduce the time between occurrence and extinguishment. The latter may be accomplished in several ways, each alternative an attempt to decrease one of the intervals in the process described above.

Our research falls into several areas. The first two are concerned with the demand for fire protection. One of these, Incidence Analysis, uses historical data to develop statistical forecasting models, which are needed as input to our deployment models and are useful for long-range planning. The other. Origins of Fire Demand, builds on the Incidence work in an attempt to determine the causes of the tremendous

---

*Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of The New York City-Rand Institute or the official opinion or policy of the City of New York. Papers are reproduced by The Rand Corporation as a courtesy to members of its staff.

This paper was presented at the Third Annual Meeting of the American Institute for Decision Sciences, October 27-29, 1971.

increase in demand and to develop programs for the reduction of fire incidence.

A third area of research has been New Technology. One example of staff work in that area concerns the interval between fire occurrence and detection. An analysis has been performed of the engineering and economic feasibility of the widespread use in residences of automatic devices which react to heat or smoke and signal an alarm. Although the total cost of such a system would be high, the potential benefits of the system are great.

Once an alarm is received by the appropriate borough Communications office, some time may elapse (especially during busy periods) before units are directed to respond. Thus, a more efficient operation of these centers can contribute to lowering the time it takes for units to arrive at the scene of a fire. Considerable research effort has gone into this area of Communications, and our results are described in a later section.

Decisions which affect the time between when units are dispatched and when they arrive are part of the Deployment problem. In the past, the response times of units to fires was mainly a function of the spatial distribution of fire houses. However, recently, with the increase in demand, the problem has become a complicated one of decision-making under uncertainty. Our major research effort has been in Deployment and some examples of the work are given later.

Improved technology is a means of extinguishing fires more rapidly. The benefits derived are twofold: a reduction in the losses due to fires, and a faster return of units into service. An example of our work in this area within the general research category of New Technology is the development of rapid water [1]. Rapid water results from a chemical called polyox being injected into the hose stream in minute quantities. The polyox reduces the turbulence of the flow and thereby results in a 70 percent increase in the flow and a doubling of the reach of the stream at the same pumping pressure. The value of rapid water derives from the use of smaller and lighter hoses for fire-fighting which, with polyox, can deliver as much water as heavier, less mobile hoses.

Several elements of our research have served as input to our system definition of a computer-based Management Information and Control System. Building on the work in Incidence Analysis, Communications, and Deployment, the computerized system will serve as a vehicle for our research results.

THE NEED FOR RESEARCH

The need for urban fire research, particularly in New York City, is accelerated by both the tremendous increase in demand for service, and a concomitant increase in cost. The number of incidents has risen exponentially--increasing from 66,000 in 1956 to over 260,000 in 1970. As a result, there has been an increase in the workload of fire companies. For example, one fire company in the Bronx responded approximately 9,000 times in 1969, an average of about 1 response per hour. Since demand varies by both time of day and time of year, the figure is considerably higher during summer evenings. In addition, demand varies geographically--increasing fire incidence (along with other indicators) reflecting the decay of a neighborhood. Thus, in New York City at least, the picture of the fireman sitting around playing checkers is no longer a very accurate one.

Department operating expenses have increased from $99 million in fiscal year 1957-58 to $311 million in fiscal year 1970-71 with manpower costs accounting for over 90 percent of the total expenses.

THE DEPLOYMENT PROBLEM

Definition

The deployment problem is one of allocation of resources to meet demand for service. These resources consist of approximately 375 fire-fighting units--the basic types being engine companies and ladder companies.

There are two types of tactical deployment decisions: dispatch decisions and relocation decisions. The former decision is how many and which units to dispatch to a particular incident. If the incident is a new one, we call the decision the initial dispatch decision. Any decision which moves a unit from one fire house to another (to provide better coverage) is called a relocation decision.

Fire Department Solutions

The basic dispatch and relocation decision structure is contained in the alarm assignment card. For each of the approximately 14,000 alarm boxes in the city there is one alarm assignment card. The first line on the card lists the closest three engines and two ladders to that alarm box. The dispatch policy depends to some extent on whether the alarm is received directly from the street box or by telephone. If the alarm is received by street box the Fire Department policy is in general to dispatch as many of the closest three engines and two ladders as are available. If at least one engine and one ladder on the first line are not available, the closest available engine and ladder are dispatched. Thus street box alarms receive at least one engine and one ladder and at most three engines and two ladders. For telephone alarms, the Fire Department dispatcher attempts to dispatch what is required.

If all of the units on the first line of the alarm assignment card are working at the incident and more units are needed, the Chief in charge will ask that a second alarm be transmitted. The alarm assignment card specifies the additional units to respond as well as the relocations to be made to replace some of the units dispatched to the fire. As the fire escalates, additional "higher alarms" may be transmitted and additional relocations specified. The assumptions underlying the relocations specified is that only one major incident is taking place at the same time.

When the alarm assignment card was devised and up until the recent past, the dispatch and relocation rules used were adequate. When the alarm activity is low, sending the closest units and sending three engines and two ladders makes sense, as there is little reason to look at the effect on the future of the unavailability of these units. However, as the alarm rate increases, there is more need to do so, and doing so may result in alternative and improved rules. Alarm assignment relocations were also valid in the past. Then, the assumption that only one major fire is taking place at any time was a good one, and because of the relatively low alarm activity, there was no need for relocations other than in response to higher alarms.

Finding Better Policies

The heart of the Institute work in deployment is a simulation model [3], which represents fire operations in one borough, the Bronx. Incidents requiring different numbers of units are generated according to a Poisson process while units are placed at their actual locations. If fewer units than are required are dispatched to an incident, the additional units needed are dispatched when the first arriving unit reaches the scene. The simulation allows us to test alternative deployment strategies by measuring the response time of each piece of equipment dispatched to an incident.

An example of the applicability of the simulation model is given by its usefulness in recent Fire Department labor negotiations. In response to the increase in company workload, the unions were asking for the addition of new companies, while Department management offered as a solution a reduced response policy to street box alarms (e.g., dispatching exactly two engines and one ladder to each alarm). The unions objected, claiming such a policy would result in a degradation of response time.

We tested each option with the following results: Adding companies resulted in a much lower improvement in workload than was expected. This was due to the fact that the additional units served to "fill out" responses, that is, on the average more units responded to each incident than previously. Reducing response (sending two engines and one ladder) resulted in improvements in time to first and second engine and time to first ladder but degraded somewhat the time to third engine and second ladder.

We then tested a third option (which subsequently was adopted), namely, reducing response, and adding a few additional units but only during the nighttime or high-demand period. The result was a substantial reduction in the number of responses per unit (workload). In addition, response time was improved for each arriving piece of equipment, including time to third engine and second ladder. In other words, during busy periods and after adding a few units, we found the somewhat surprising result that it is better to send the second ladder and third engine after the first unit has arrived, if they are needed, rather than attempting to dispatch three engines and two ladders to all alarms. In effect, by sending less we get more, a result explained by the increased availability of units under such a policy. Thus, the new policy resulted in a reduction of workload and better service.

Traditionally, the Fire Department always dispatches the closest units to each alarm. The result of an analytical model developed by Carter, Chaiken, and Ignall [2] shows that such a policy does not always minimize response time.

Consider any area served by two companies, A and B. Draw a line connecting the two companies and then draw the perpendicular bisector of that line. Any alarm occurring to the left of the line is closer to one company, A, while all other alarms are closer to B. Assume that the set of points closer to A is a high alarm rate area while the set closer to B is a low alarm rate area. Assume that an alarm is received at some point X within A's area but close to the dividing line. According to the closest unit policy, A would respond to the alarm at X. Now, assume that while A is busy another alarm occurs--and since the alarm rate is higher in A's area it is more likely to occur in this area--at some point Y to the left of X. Since A is unavailable, B responds to the alarm at Y. Clearly, if we had sent B to the first alarm near the boundary and saved A for the second alarm, a reduction in total response time would have been achieved. Thus, shifting the boundary line to the left results in an improvement in response time. In addition, since A is in a high demand area, it also results in a balancing of the workload between the two companies. These results are formally developed in the Carter, Chaiken, and Ignall paper [2].

COMMUNICATIONS

The Deployment problem and the alarm processing problem in the Communications Office are closely related. It should be clear that any time saved between when a unit is dispatched and when it arrives on the scene may be offset by delays between the receipt of the alarm and the dispatch of units. And, as with deployment, an alarm processing system designed fifty years ago is no longer adequate to handle the increase in alarm activity.

The alarm processing procedure consists basically of alarm receiving and dispatch decision-making, and we represent this system by means of a multi-stage queueing model. After extensive data collection and curve fitting for each operation in the procedure, a computer simulation was run to determine the dispatching time for varying alarm rates, that is, the time from alarm receipt until its transmission to Fire Department units. The results showed that the expected dispatching time increases slowly until about twenty-five alarms per hour. At that point the curve becomes more steep, increasing to over three minutes at thirty alarms per hour and rising to approximately eleven minutes at thirty-five alarms per hour. This result was particularly significant since at the time of the analysis in the borough of Brooklyn the alarm rate during busy periods was approaching the steep part of the curve.

From the analysis, it was clear that the difficulty was at the second stage of the process, the decision-making point. This was due to the existence of a single channel at the point--decisions being made essentially one at a time by a single decision maker. In addition, the expected decision time increases as a function of the number of active incidents in the field. The primary reason for this is that the dispatch decision becomes more difficult as the number of units unavailable increases.

Given this bottleneck, improvements may be made by reducing the decision-making time (for example, by providing better unit status information by means of digital status reporting from the field) or by adding a second-stage channel. The latter may be accomplished by dividing the borough into two parts, with a separate decision-maker responsible for units and alarms in each half. This notion was tried and proved to be successful. In fact, during a particular test 27 alarms were dispatched in 30 minutes and 43 alarms in one hour, more than had ever been accomplished before. A difficult period of implementation began (perhaps the subject for another paper) resulting in the installation of the new procedure in the Brooklyn office.

REFERENCES

1. Blum, E. H., Urban Fire Protection: Studies of the Operations of the New York City Fire Department, The New York City-Rand Institute, R-681, 1971.

2. Carter, G. M., J. M. Chaiken, and E. Ignall, Response Areas For Two Emergency Units, The New York City-Rand Institute, R-532, 1971.

3. Carter, G. M., and E. Ignall, A Simulation Model of Fire Department Operations, IEEE System Science and Cybernetics, 6, 282 (1970).

4. Swersey, A., An Analysis of the Dispatching Problem in the FDNY Communications Offices, Unpublished Mimeograph.