Patrol Force Allocation For Law Enforcement

—An Introductory Planning Guide

National Criminal Justice Information and Statistics Service
Law Enforcement Assistance Administration
United States Department of Justice

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 027-000-00748-1

☆ U.S. GOVERNMENT PRINTING OFFICE : 1978 O—281-380 (4544)

Patrol Force Allocation For Law Enforcement

—An Introductory Planning Guide

R.L. Sohn
R.D. Kennedy

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

September 1978

National Criminal Justice Information and Statistics Service
Law Enforcement Assistance Administration
United States Department of Justice

ACKNOWLEDGEMENTS

The authors hereby acknowledge the many contributions to the field of patrol force allocation made by Professor Richard C. Larson of the Massachusetts Institute of Technology and Dr. Jan Chaiken of the Rand Corporation. The material presented in Chapters 4, 5, and 6 is based in large part on publications by these two researchers, and it is with their kind permission that it is included in the present document.

Robert L. Sohn

Robert D. Kennedy

U.S. DEPARTMENT OF JUSTICE
Law Enforcement Assistance Administration

James M. H. Gregg, Acting Administrator

Harry Bratt, Assistant Administrator
National Criminal Justice Information
and Statistics Service

Wayne P. Holtzman, Director
Systems Development Division

This document presents results of work supported by the Law Enforcement Assistance Administration, U.S. Department of Justice, under the Omnibus Crime Control and Safe Streets Act of 1968, as amended. It was sponsored under an inter-agency agreement with the National Aeronautics and Space Administration through Contract NAS 7-100. Points of view or opinions stated in this document are those of the authors and do not necessarily represent the official position of the U.S. Department of Justice.

FOREWORD

This volume has been prepared and distributed to provide public safety planning personnel with a compact source of information on one aspect of police command and control, namely patrol force allocation. Methods are presented for analyzing and optimizing the allocation of available forces to best match the demand in the form of calls for service, which vary considerably in place and in time.

This volume is one of a series prepared under the sponsorship of the Law Enforcement Assistance Administration (LEAA) to provide planning guidelines on the various aspects of police command and control automation. The complete series consists of the following documents:

Title	Document No.
Application of Mobile Digital Communications in Law Enforcement	JPL SP43-6 Rev. 1
Application of Computer-Aided Dispatch in Law Enforcement	JPL 5040-16
Application of Automatic Vehicle Location in Law Enforcement	JPL 5040-17
Patrol Force Allocation in Law Enforcement	JPL 5040-18
Multi-Community Command and Control Systems in Law Enforcement	JPL 5040-19

The series was prepared by the Jet Propulsion Laboratory of the California Institute of Technology, using the results of studies sponsored by LEAA at JPL as well as at other institutions. The documents are being distributed as part of LEAA's mission of giving technical assistance to state and local law enforcement agencies. They are addressed to the local law enforcement planner who must face practical working problems in deciding what degree and kind of automation best suits his department. Our intention has been to give him the basic understanding he needs to make such a decision, and procedures for making the associated analyses or having them made. The manuals are developed within the framework of the overall command and control system so that potential benefits of individual innovations can be evaluated in terms of improved system performance.

The technologies that are available to law enforcement agencies today have the promise of making their operations more efficient as well as more effective. Our hope is that this series of documents will provide a clear and concise picture of what that promise is and what is involved in making it a reality.

S.S. Ashton, Jr.
Systems Development Division
National Criminal Justice
Information and Statistics Service
Law Enforcement Assistance Administration
United States Department of Justice

CONTENTS

CONTENTS (Continued)

FIGURES

ABSTRACT

Previous and current methods for analyzing police patrol forces are reviewed and discussed. The steps in developing an allocation analysis procedure are defined, including the prediction of the rate of calls for service, determination of the number of patrol units needed, designing sectors, and analyzing dispatch strategies. Existing computer programs used for this purpose are briefly described, and some results of their application are given.

This document is one of a series of five guideline manuals on mobile digital communications, computer-aided dispatch, automatic vehicle location, patrol force allocation, and multicommunity command and control systems for law enforcement applications.

1. INTRODUCTION

In recent years a number of advances have been made in police command and control operations through the application of computers. These advances include computer-aided dispatching, mobile digital communications and message switching, and automatic vehicle location systems. These innovations have made possible the reporting and analysis of crime patterns on a near-real-time basis, better anticipation of incidents, and reduced response time to calls for service. Computer techniques can also help agencies to improve the allocation of their forces by analyzing the effects of different allocation strategies.

This volume is addressed to police planners and administrators who are responsible for the day-by-day assignment of field forces, for periodic review of field force performance, and for any necessary reallocation of those forces. It describes analysis and planning tools that are available to support these activities and decisions. Most of the methods described are based on the use of computers, but (unlike the other computer-based techniques described in this series) they do not require full-time access to a computer. The computer serves to analyze how well patrol forces are being distributed to meet varying work loads in different places and at different times. It also permits the evaluation of different allocation strategies with respect to certain measurable factors such as work load and response time. Where it is not feasible for an agency to acquire and operate these computer-based analysis tools, a knowledge of the available techniques and programs will be useful as a basis for soliciting assistance and interfacing with consultants and organizations specializing in field operations analysis.

The discussion of allocation techniques in later chapters makes a clear distinction between early methods based on hazard or work load formulas and recently-developed methods. The earlier methods do not provide any reliable indication of the effects of using different allocation schemes and cannot be used to develop an allocation scheme that will meet some specified criterion of performance. With modern performance-oriented techniques it is possible for the planner to specify some level of performance (such as minimum delay in responding to calls for service, a given patrol frequency, or a maximum permissible imbalance among work loads of different units or precincts) and have the computer program calculate the patrol force allocation that best satisfies the performance requirement. Another drawback of the older methods is that they often lead to results that are the opposite of those intended. For example, placing more emphasis on serious crime by giving it a higher weight in a hazard formula may in fact reduce the forces allocated to a precinct with a higher number of serious crimes. This is discussed in detail in Chapter 3. The planner needs to be aware of recent developments so that he can apply them to his department if the need is indicated.

When does the police planner need to establish or reexamine his force allocations? Probably the most useful indication is an evident imbalance in the work loads of different units, beats, tours, or precincts. Excessive response times to calls for service, delays in answering calls, inadequate preventive patrol hours, major changes in patrol beat boundaries, rapid growth of crime rates in certain areas, all indicate the need for changes in force allocations. The factors affecting patrol performance are numerous and have complex interactions that can vary under different circumstances; such situations are difficult to handle by simple formulas, but are easily analyzed by computer-based patrol force allocation techniques. These can optimize force allocations to improve key performance factors and can resolve work load imbalances as well.

Efficiency of patrol force allocation is of interest because it has the potential of alleviating the cost pressures felt by police departments everywhere. Typically, 80 to 90 percent of a police department's budget is taken up by salaries and payroll-related expenses such as fringe benefits. Therefore even a small percentage increase in the efficiency of personnel utilization can yield a large dollar saving, or can at least minimize the cost of attaining a given level at service.

Dollar savings are not the only reason for considering patrol force allocation analysis. Some other effects of improving allocations are not measurable in dollar terms, but are still important. Among these are shortened response times, better equalization of work loads, and improved officer morale.

Chapter 2 describes the steps in patrol force allocation. Chapter 3 presents a comparison of patrol force allocation methods, from the early hazard and work load formulas to the modern computer-based techniques. The latter are clearly superior in achieving allocations that meet specified performance standards of work load balance, patrol frequency, and minimal delays in responding to calls for service. Chapter 5 indicates the data necessary to use the various analysis programs, and methods for predicting the need for services. The subsequent chapters illustrate techniques for determining the total number of units necessary to provide a specified level of service, and for designing beat boundaries to balance the work loads within a precinct or division. Chapter 8 discusses the relative merits of various dispatch strategies, using computer simulation techniques; these latter techniques are useful in broadening patrol force allocation studies into overall command and control system analysis including complaint board, dispatch, and communication system operations. The Reference list provides a comprehensive review of the methodologies presented in this volume.

2. STEPS IN PATROL FORCE ALLOCATION

The discussion of patrol force allocation studies in this volume will be organized around the four sequential steps in such a study:

(1) Predicting rates of calls for service.

(2) Determining how many patrol units are needed.

(3) Designing patrol sectors or beats.

(4) Analyzing different dispatching strategies.

A comparison of early hazard or work load formulas with the recently developed allocation-by-performance techniques is given in Chapter 3 to better acquaint the planner with the historical developments in allocating techniques, and to point out the fundamental advantages offered by the newer methods described in this volume.

2.1 Predicting Rates of Calls for Service

Predictions of rates of calls for service are necessarily based on the department's previous experience with calls, and it is essential to have a good base of statistics indicating the pattern of calls for given hours of the day, days of the week, and seasons of the year. These statistics should also show a breakdown of calls by type, since each type tends to have its own pattern. The data should include the length of time required to service calls. For a department with a computer-aided dispatch system, the required statistics are readily generated from the computerized logs of incidents.

A feature of calls for service that must be taken into account in a patrol force allocation study is the random nature of such calls. This feature makes it impractical to predict rates simply in terms of average rates; allowance must be made for the considerable fluctuations about the average, by hour of the day, day of the week, and seasons of the year.

Chapter 5 discusses the prediction of rates of calls for service, indicating what statistics are needed and how they are used in predictions.

2.2 Determining How Many Patrol Units Are Needed

Once the work load in terms of calls for service has been established, it is possible to estimate how many patrol units will be required to meet that work load. Two techniques that were developed some decades ago, and that are essentially equivalent, are "hazard" formulas and work load formulas. These are reasonably straightforward, although the calculations can become tedious without a computer, and are widely used today. Their main drawbacks are that they can easily lead to strategies having the opposite of the desired effect, and cannot tell the planner in advance what impact the reallocations will have on patrol force performance measures such as work load balance, patrol frequency, and delays in responses to calls for service.

In a hazard or work load formula, the department defines as many factors as it thinks are influential in establishing the total work load, and gives each factor an arbitrary weight. Factors are typically different types of incidents or crimes. The projected number of each factor in each precinct is then multiplied by its weight. The two formulas then assign patrol units to precincts based on the "weighted" proportion of the total work load in each precinct. A fixed total force can be allocated among the precincts in these proportions, or if there is a known factor of how many patrol units are needed per work load unit, the numbers needed in each precinct are calculated and added to derive a required total force.

The difficulty with the hazard formula is that the weights assigned to different factors (which are necessarily arbitrary) can bring about a situation in which assigning more weight to a given factor can result in assigning fewer units to a precinct with more of that factor. The work load formula has the drawback that it can at best equalize the work load of different precincts, without regard to any of the other measures such as response time, queuing delays, travel times, or others. It can also have the perverse effect of indicating a need for more units in an area that already has a disproportionately large share (if an area has more units, it is likely to have more arrests and more reports of crimes, which would lead to assigning still more units at the expense of other areas where crimes may be going unreported and arrests are few because there are too few patrol units).

There are better methods, based on computer simulations, that can be used to determine how many patrol units are needed to meet specified performance standards or how a fixed number should be allocated to different areas on the basis of best overall performance. The recently developed allocation-by-performance methods are significantly better than the early hazard formulas because they give the planner a much better indication of changes in performance that he can expect as a result of reallocations. These will be discussed in detail in Chapter 6.

2.3 Designing Patrol Sectors or Beats

There is nearly always an existing set of geographical areas called sectors or beats, with one or more patrol units assigned to each. Usually these have been determined more or less subjectively on the basis of area and population density, history of calls for service, type of neighborhood, and natural dividing lines such as rivers, main arteries or freeways, parks, hills, etc. Nevertheless, many sector boundaries can easily be moved if there is reason to think that such changes would improve one or more factors such as:

- Work load balance among patrol units.
- Response time average for the precinct or for a given sector.
- Fewer dispatches of patrol units outside their beats.
- Improved administration through consolidation (or splitting) of beats or precincts.

Evaluating the potential effects of changing sector boundaries is nearly impossible without making use of a computer. Considerable work has been done on developing computer models to support such analyses, and these are discussed in detail in Chapter 7.

2.4 Analyzing Different Dispatching Strategies

When the rates of calls for service have been predicted, the number of patrol units per precinct determined, and the boundaries of individual beats defined, it is then possible to put all these results together into a computer simulation of the complete precinct patrol force. For maximum usefulness, such a simulation should include the command and control center operations such as receipt of calls by complaint board operators, messages between dispatchers and patrol units, and the dispatching operation itself. In this way it is possible to evaluate not only the effects of different dispatching strategies, but the loading on the radio channels and the queuing delays at all points in the system from complaint board operators to dispatcher and patrol unit (which may experience a delay in gaining access to the radio channel).

The performance measurement that is affected by all the links in the command and control chain is response time, as measured from the receipt of a call at the complaint board to the arrival of a unit at the scene of the incident. Figure 1 shows graphically all the elements that enter into police response time; these can be affected by call rate, number of

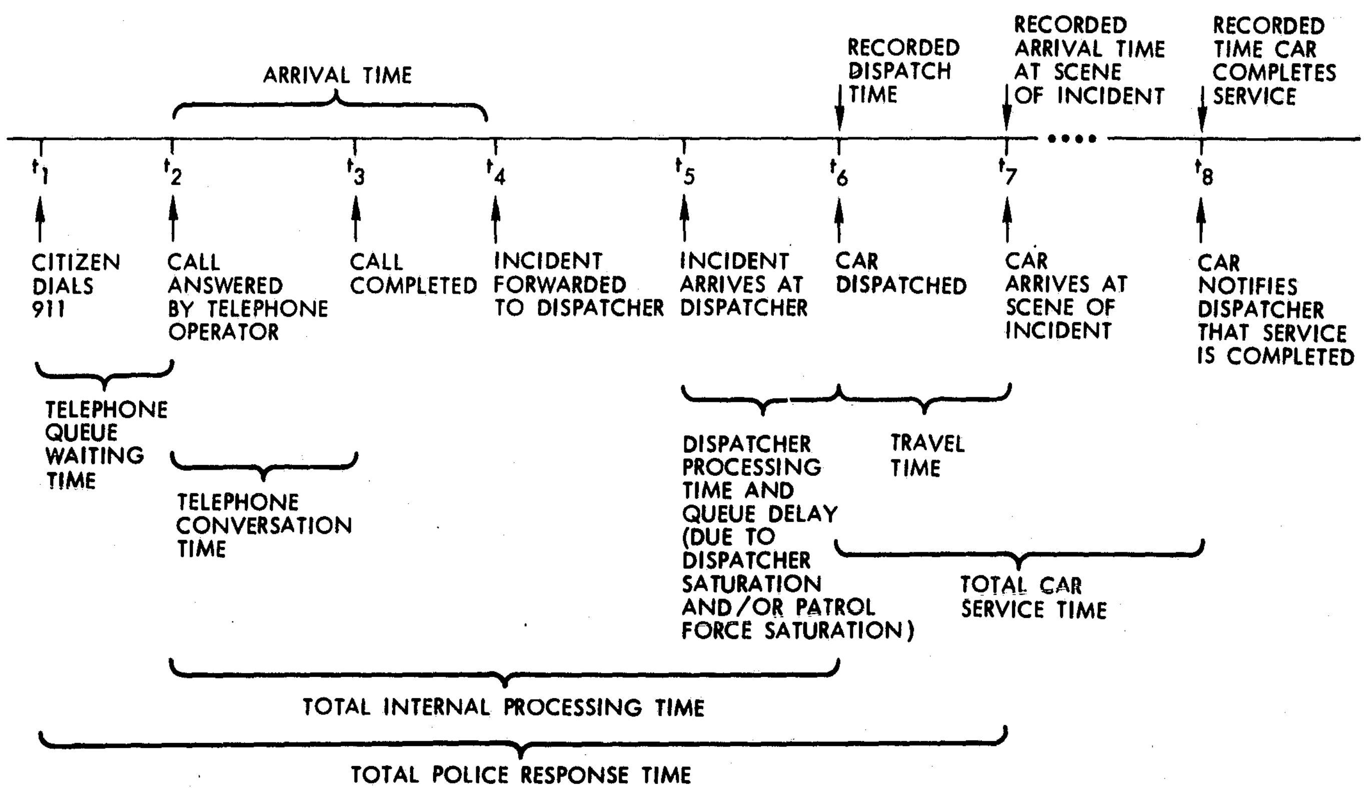


Fig. 1. Police emergency response system: Timed sequence of activities

complaint board operators, number of dispatchers, dispatching procedures (which are usually accelerated by computer-aided dispatch), communication channel availability, patrol unit availability, and travel time.

Construction of a simulation, whether of the complete command and control system or only of the portions necessary for patrol force allocation studies, is not difficult with the special simulation languages (such as GPSS) that are widely available. Some models that have been developed, and some typical results, are presented in Chapter 8.

Some elements of dispatching strategy that can be evaluated with such a simulation as to their effects on specific quantitative performance measures are:

- Number of patrol units dispatched to various types of incidents.
- Selection of a patrol unit for dispatch, primarily on the basis of geographical considerations.
- Priority structure – how many levels of priority are required, the rules for dispatching calls of different priority, and the response times to be expected for each priority level during busy periods.
- Queuing policy, determining when a given call will be placed in a queue (when the individual dispatcher's units are all busy, when all units are busy, when all but some specified number of reserve units are busy, when the call is of a lower priority, etc.).
- Dynamic changes in the call-for-service rates.
- Communications channel limitations.

All in all, simulation techniques offer much greater insight into the physical operation of patrol fleets, and are easier for the planner to understand and work with than the more complex analytical methods.

3. COMPARISON OF PATROL FORCE ALLOCATION METHODS

This manual deals with a sequence of steps in the allocation of patrol forces, including data collection, estimating the number of patrol units required, designing of patrol beats and analyzing dispatch strategies. Before describing these procedures in detail, it will be helpful to the planner to review the historical development of patrol force allocation methods. These include the original "hazard" formulas introduced in the 1930s by O.W. Wilson (Refs. 2-4) and the closely-related work load formulas, and the more modern computer-based patrol car allocation models. The hazard and work load formulas were developed in an attempt to allocate patrol units so as to balance the work loads between precincts or districts, modified to account for unusually high rates of serious crimes in one precinct or another, higher-than-average street miles to patrol, and other factors that tend to influence manpower requirements. Eventually, some agencies used as many as 15 factors in the work load formulas to better respond to community needs. However, performance measures such as response time, patrol frequency, and time spent on preventive patrol could not be specified ahead of time in such a way that the planner would be assured that these measures would be met.

The more modern computer-based patrol car allocation methods, on the other hand, are given a set of performance standards to meet, such as response time, patrol frequency and so forth, and then compute the number of patrol cars that must be deployed in order to meet the performance standards. Hence, these computer-based methods give the planner much better insight into the performance results he can expect from a given deployment allocation. With these techniques it is also much easier to achieve a balanced allocation of patrol forces to cover the wide variations in calls for service throughout the day, week, and season. The following discussion will emphasize these differences in allocation methods as well as give the planner a better understanding of the basic problems and solutions.

3.1 Hazard or Workload Formulas

Hazard or work load* formulas are widely used for allocating patrol units (or manpower) by time and geography. This method takes into account several factors thought relevant in determining the needs for patrol services: it "weights" each factor by its importance, and sums all the weighted values to arrive at a single work load number. Patrol cars or manpower are then distributed in proportion to the relative work load scores.

A typical work load formula is given by Wilson as:

Work load index = 4 • number of Part I crimes
+ 3 • number of Part II crimes
+ 1 • number of other calls for service

The resulting work load score applies to a given district or precinct. The scores for all districts are added together, and patrol units are then assigned to precincts on the basis of their percentage work load score; for example, if a precinct score is 30 percent of the total, it is allocated 30 percent of the total number of patrol units. The assignment formula is easily derived.

W_p = Work load score for precinct p

= w_1 • number of Part I crimes in precinct p

+ w_2 • number of Part II crimes in precinct p

+ w_3 • number of other calls for service in precinct p

where the w's are the relative "weights" assigned to each type of activity. The number of patrol units assigned to precinct p is then

$$N_p = \frac{W_p}{W_1 + W_2 + \cdots W_n} \cdot N$$

where N is the total number of patrol units available to the department.

Over the years, departments have introduced more factors into the formula, and different weights for the several factors. For example, the Los Angeles Police Department recently used the following set of factors:

Factor	Weight
1. Selected crimes and attempts	5/19
2. Radio calls handled by radio cars	4/19
3. Felony arrests	3/19
4. Misdemeanor arrests	1/19
5. Property loss	1/19
6. Injury traffic accidents	1/19

*The terms hazard and work load are used interchangeably in the literature but the two formulas in fact have slight differences in calculation procedures.

7. Vehicles recovered 1/19
8. Population 1/19
9. Street miles 1/19
10. Population density 1/19

The work load or hazard formula methods are unsatisfactory for several reasons. The additive weighted combination of the many factors does not reflect the complex interactions among them, and it is difficult to manipulate the relative weights of the factors to cause a desired change in emphasis from one factor to another, as we will show. More importantly, the formulas do not tell the planner how well a particular allocation will perform in terms of response time, patrol frequency, etc., as noted before. Also the formulas do not indicate how many patrol units are required to give a desired overall level of performance. This is because the changes in performance values do *not* change in proportion to the number of units, or to other factors such as calls for service, etc. Hence, the planner cannot predict how the reallocated patrol force will perform. The computer-based allocation methods have been successful in overcoming this problem.

We mentioned that the work load formulas do not always reallocate a patrol force in the way the planner's intuition might suggest. For example, suppose the planner is concerned with two precincts, and uses a relatively simple formula of two factors, Part I crimes, and all other calls for service, which are distributed between the precincts as follows:

Factor	Precinct A	Precinct B	Total
Part I crimes	600	800	1,400
Other calls for service	5,000	11,000	16,000

If the work load formula gives equal weights to both factors, the work load scores for the precincts are:

$$W_A = 1 \cdot 600 + 1 \cdot 5{,}000$$
$$= 5{,}600$$

$$W_B = 1 \cdot 800 + 1 \cdot 11{,}000$$
$$= 11{,}800$$

If N patrol units are available for assignment, the units assigned to precincts A and B are, respectively:

$$N_A = \frac{5{,}600}{5{,}600 + 11{,}800} \cdot N$$
$$= 0.322N$$

$$N_B = \frac{11{,}800}{5{,}600 + 11{,}800} \cdot N$$
$$= 0.678N$$

Precinct A receives 32.2 percent of the available patrol units, and Precinct B receives 67.8 percent.

Now, if the planner wishes to emphasize the control of Part I crimes, he would assign a greater weight to this factor, and would expect Precinct B, which has more of this type of crime, to receive additional patrol units. If he assigned weights of 5 and 1 to Part I crimes and all other calls for service, respectively, the work load scores would change to:

$$W_A = 5 \cdot 600 + 1 \cdot 5{,}000$$
$$= 8{,}000$$

$$W_B = 5 \cdot 800 + 1 \cdot 11{,}000$$
$$= 15{,}000$$

and the patrol units would be assigned as follows:

$$N_A = \frac{8{,}000}{8{,}000 + 15{,}000} \cdot N$$
$$= 0.348N$$

$$N_B = \frac{15{,}000}{8{,}000 + 15{,}000} \cdot N$$
$$= 0.652N$$

Precinct B now receives 65.2 percent of available patrol units, versus the 67.2 percent originally allocated, even though it has more Part I crimes than Precinct A. Hence, the planner's original intent to shift more resources to the precinct with more Part I crimes by according more weight to this factor in fact *reduced* its allocation. This occurs, of course, because the work load formula allows for the relatively heavy load imposed by other calls for service within Precinct B, which has only 57.1 percent of the Part I crimes, and would receive only this percentage of available patrol units if the allocation were made strictly on the basis of this one factor. In any case, the planner can only guess as to the effects of the reallocation on patrol force performance.

3.2 LEMRAS (Law Enforcement Manpower Resource Allocation System)

A computerized version of the work load formula was developed by IBM in the late 1960s (Ref. 5). It has since been withdrawn from the market, but several agencies adopted

LEMRAS programs for their use. The basic features offered by LEMRAS include:

- Prediction of the calls for service, travel time, and call service time, by hour, day, and week based on historical data.
- Allocation of patrol units between precincts to equalize the time spent on dispatches.
- Allocation of sufficient numbers of patrol units to respond to 85 percent of calls within a specified time (usually 3 minutes for high priority calls).
- Work load-type formulas to "weight" factors such as crime rate.

The significant new approach taken by LEMRAS was the allocation of patrol forces to meet a specified performance standard, namely, response time. Hence, if the call for service rates could be predicted with reasonable accuracies, the allocated patrol force could respond with the desired promptness.

Unfortunately, LEMRAS did not always prove satisfactory in actual operation (Ref. 6). It was the experience of the Los Angeles Police Department that calls for service could not be predicted with the desired accuracy on a day-by-day basis. Error rates of up to 50 to 75 percent were experienced in some instances, which proved both frustrating and burdensome to operations personnel who were responsible for making patrol team assignments. Also, the LEMRAS formulas frequently called for more units than were available for assignment.

This experience points up the difficulties of predicting work load requirements for a specific tour or day of the week. Generally, predictions of total calls for service for an extended period of time, over a period of one month, for example, will be reasonably accurate, usually within 10 percent. But call rates for a specified tour some time in the future cannot be predicted with similar accuracy, and the erratic behavior of the predictions quickly leads to frustrations on the part of operations personnel. The Los Angeles Police Department has since reverted to the use of historical averages for patrol force allocation. The current method, called ADAM*, allocates patrol units on the basis of four factors:

- Calls for service.
- Officer-initiated activity.
- Reported time unavailable for administrative reasons.
- Selected crimes and attempts.

The first three factors are expressed in hours consumed and the fourth in numbers of occurrences. Percentages by precinct (or area) are developed for total hours of work and for total occurrences. These two percentages are then averaged to give the final proportionate allocation for each precinct.

The Department intends to combine the ADAM data gathering system with a computer-based patrol car allocation method in the near future. This method is described briefly in the following section, and in detail in Chapter 5.

3.3 Computer-Based Patrol Unit Allocation Methods

The LEMRAS technique of allocating patrol units to meet a specified service level by responding to most (85 percent) calls within a given time limit, was extended by Larson to include other performance standards, such as work load, travel time, and patrol frequency. More recently researchers at the New York City-Rand Institute developed improved versions of this performance-oriented program that can be accessed by the planner in an interactive mode. The user must provide basic input data such as call rates, service times, travel speeds, precinct area and street miles, crime rates, and time spent on non-call-for-service activities. The computer program then responds with estimates of:

- Average number of units available.
- Patrol frequency.
- Travel time to incidents and total response time.
- Fraction of calls delayed and the amount of the delay.

In addition the user can specify some of the listed parameters and the computer will estimate the minimum number of patrol units necessary to meet the desired performance value. The example presented in Chapter 6 demonstrates these features.

To illustrate the important advances made by the performance-oriented allocation methods over the old work load formulas, Ferreira (Ref. 8) recently developed detailed comparisons of the following techniques as applied to New York City (Ferreira refers to performance-oriented allocation methods as Allocation By Objective, ABO):

*Automatic Disposition of Available Manpower (Ref. 7).

(1) ABO_S – allocation to meet performance standards listed below.

(2) ABO_U – allocation to minimize the average dispatch delay.

(3) HF_W – "work load balance" formula

$$H_i = 10 \cdot \text{\% of calls for service in district i}$$

(4) HF_C – "crime-oriented" hazard formula

$$H_i = 8 \cdot (\text{\% of outside crimes in district i}) + 2 \cdot \left(\text{\% of other calls for service in district i}\right)$$

(5) HF_G – "geographic - demographic" oriented hazard formula

$$H_i = 3.0 \cdot \left(\text{\% of population residing in district i}\right) + 1.3 \cdot \left(\text{\% of city area contained in district i}\right) + 2.0 \cdot \left(\text{\% of city street miles in district i}\right) + 3.7 \cdot \left(\text{\% of total outside crimes in district i}\right)$$

The ABO_S type of allocation method is represented by the PCAM (Patrol Car Allocation Model) described in Chapter 6. The ABO_U type is represented by the LEMRAS program described above. The important difference is that the ABO_S methods allow the user to specify a performance standard and the program determines the allocation that best meets that standard. The ABO_U method is somewhat similar, but allocates on the basis of one performance measure only, namely, minimal queue delays. The performance measures for which comparisons were drawn include:

- Workload – percent utilization.
- Dispatch delay – fraction of calls delayed.
- Travel time.
- Patrol hours per outside crime.
- Patrol frequency – passes per tour.
- Manning level – number of patrol units.

Several simplifying assumptions were made in computing the allocations for the formulas given above:

- The average time required to service calls was assumed to be 40 minutes in all precincts.
- Patrol speed and response speeds were assumed to be 6.5 and 10 mph, respectively.
- Administrative time was not subtracted from assigned patrol unit time.

The results of the analysis are shown in the following table. A total of 600 patrol units were available in each case.

Performance Level	Number of Districts With Poor Performance*				
	ABO_S	ABO_U	HF_W	HF_C	HF_G
1. Work load over 60%	0	0	0	11	16
2. Probability of dispatch delay over 25%	0	0	1	7	10
3. Travel time over 6 minutes	0	9	9	13	1
4. Patrol hours per outside crime less than 4 hours	0	1	3	3	17
5. Patrol passes per tour less than 2	0	14	16	20	2
6. Patrol units less than 4	0	0	3	3	1

*Out of a total of 69 districts.

The ABO_S method is clearly the best of the allocation techniques considered; the method does what it is designed to do – insure a specified level of performance in all districts with a minimum of dispatch delays. The ABO_U method avoids high work loads and dispatch delays, but does not always meet travel time and patrol frequency standards. Both ABO methods perform much better than the hazard or work load formulas.

The HF_C and HF_G methods meet neither the performance nor the work load and delay standards. For both methods nearly 30 percent of the districts fail to meet performance standards, including districts that could not be identified in advance as likely to be troublesome.

The HF_W method is the best of the hazard formulas, but is inferior to both ABO techniques. The HF_C method has fewer districts with poorer performance in only one instance.

Ferreira concludes by observing that it is much easier to avoid having districts with extreme (i.e., poor) performance measures when some type of ABO method is used rather than a hazard formula. Moreover, the deficiencies in performance with the hazard formulas cannot be easily remedied by reshuffling blocks of patrol units to the poor-performing districts; many additional units are required to make up the deficiencies. The average differences in the number of units assigned to the districts varied by 10 to 40 percent among the five methods.

The planner is referred to Ferreira for a detailed discussion of the comparison of allocation methods, but the above summary clearly emphasizes the significant advantages of the modern computer-based allocation techniques.

4. SOME DEFINITIONS

Before we proceed with detailed discussions of the four steps in patrol force allocation studies, we will provide the reader with some background information that is helpful for the interpretation of these discussions. This information is primarily in the form of definitions of the terms that will be used.

One term that will not be used is "best" (or "better" or "optimized"). The reason is that there is no acceptable definition of what constitutes the "best" police command and control system, or even the "best" allocation of patrol forces. Analysts who concern themselves with patrol allocation are in the position of not being able to base their studies on any of the usual objectives of police patrol (crime deterrence, arrests, recovery of stolen property, public attitudes toward police) because the effect of patrol force allocation on these factors is vague, and not subject to precise quantification. For example, if the number of patrol units is doubled, or halved, no one can state with any certainty what will happen to crime rates or to the fraction of incidents that result in a patrol arrest.* It may be possible to determine that patrols arrive faster at the scene of an incident, but exactly how small changes in response time deter crime is not known. In any case, high priority incidents such as crimes in progress are usually responded to very rapidly, whereas low priority calls are often delayed until units are cleared from other calls; response time is very much priority-dependent and should be treated in that context.

A system as complex as an urban police department is subject to so many social, legal, and political factors in addition to those that govern its internal operations that it would be meaningless to define any particular system configuration or set of policies as "best". A police planner with an intimate knowledge of his own city can be an excellent judge of what qualitative factors are relevant and how best to take them into account. A computer simulation can help him determine the effects on certain quantitative performance measures of making specified changes in patrol force allocation. By trying a number of different allocations he can establish a basis for defining an allocation policy that makes use of these results in combination with his knowledge of all the other factors in the situation.

Although it is not practical to define some given patrol force allocation policy as "best," or even "better" in an overall sense, there are certain performance parameters that can be measured and, it is generally agreed, must be considered in formulating allocation policy. These are the measures of performance that will be used in the following technical discussions. They are listed in Table 1.

Terms used in police command and control operations are naturally specialized, and often differ from one jurisdiction to another. As a reference for the precise meanings of the terms as used in this document, Table 2 is included. It is a glossary of terms used, with alternatives where applicable.

---

*There is some current disagreement as to the effectiveness of preventive patrol activity. Most departments operate on the assumption that crime is deterred by the frequent, observed presence of patrol units; this is called preventive patrol. The disagreement arises primarily over interpretation of the results of a recent experiment carried out in Kansas City. The complete results are contained in a 960-page technical report, supplemented by a 50-page summary report, and only a very brief account can be given here.

Fifteen of the beats in Kansas City were used in the experiment. These were randomly divided into three groups. In one group, routine preventive patrol was eliminated and officers were instructed to respond only to calls for service. In the second group, routine preventive patrol was maintained as before. In the third group of beats, preventive patrol was intensified to a level two or three times the normal. The objective was to determine what effects could be observed as a result of the elimination or intensification of routine preventive patrol activity.

A number of special measures were taken to assure the objectivity of the experiment, but critics of the results have stated that the experiment was not sufficiently rigorous. In summary, the experimenters found that in all three groups the following factors were essentially the same:

- Numbers of burglaries, auto thefts, larcenies involving auto accessories, robberies, and vandalism.
- Rates of crimes reported to the police.
- Departmental reported crime.
- Citizen fear of crime, attitude toward police services, satisfaction with encounters with police officers, or satisfaction with response time.
- Actual response time.

All of the above factors are frequently thought to be affected by the amount of preventive patrol, but the experiment appears to show that they are not. A summary of the experiment, a critique of the summary report, and several comments on the issues involved are collected in the June 1975 issue of *The Police Chief*. Interested officials are referred to this source for a full discussion of the pros and cons. The question is included here because it may be an important element in analyses of patrol force allocation. If preventive patrol is useful, it should be given some weight in such analyses; if it has no effect, it should not be included as a factor in allocation decisions.

Table 1. Measures of Performance

Measure	Definition
Response time	See Fig. 1. In the context of patrol force allocation, response time is taken as $t_7 - t_5$, since this is the interval that can be affected by patrol force allocation decisions and queue delays.
Travel time	Time interval between the time the patrol unit receives the dispatch and the time it arrives at the scene ($t_7 - t_6$ in Fig. 1).
Travel distance	The distance in miles from the point where the patrol unit receives the dispatch and the location of the incident. Although there may be factors affecting speed differently in different cases, travel time can be estimated quite accurately from travel distance by assuming an average speed. Typical average speeds are quite low (10 to 20 mph).
Out-of-beat dispatches	When the patrol unit assigned to a beat or sector is busy and a new incident occurs in that beat, a unit from another beat must be dispatched. It is desirable to allocate forces (especially beat design) in such a way as to minimize the fraction of dispatches that take a patrol unit out of its home beat, or keep it out if it is already out of its home beat.
Queue delay	This can be expressed in terms of what fraction of calls for service have to be placed in queue because no patrol unit is available, or in terms of average delay time for calls placed in queue, or average delay time for all calls, including those placed in queue. This factor is referred to as queuing effect, delay in queue, or simply delay time.
Work load balance	It is desirable that individual patrol units, and patrol forces in different precincts, be busy equal fractions of the time as nearly as possible. Small differences are inevitable, but significant differences that continue over long periods of time are wasteful of resources and can give rise to morale problems. This measure is usually expressed as the difference between the percent-of-time-busy of the busiest patrol unit and the percent-of-time-busy of the least busy unit. Thus a 9 percent work load imbalance means that the busiest patrol unit or precinct is busy 9 percent more of the time than the least busy one (say 47 and 38 percent, respectively, for example).
Preventive patrol	While patrol units are not answering calls for service or engaged in other, nonpatrol activities they are presumed to be patrolling their beats. This activity is called preventive patrol on the assumption that the frequent presence of police vehicles has a deterrent effect on crime or reassures the public. Thus it is considered desirable to increase the amount of preventive patrol* provided by a given number of patrol units. Note that the assumption of the effectiveness of preventive patrol has been questioned recently.
Patrol frequency	This is expressed as the number of times per hour a police car passes a given point, and is used as another measure of the extent of preventive patrol.
Probability of dispatch error	This is expressed in terms of the probability that a dispatch will be assigned to a unit that is not the closest available unit to the incident. In most systems the dispatcher does not know the location of available units exactly and must choose the one he thinks is closest on the basis of his most recent information.
Cost	Cost is a measure for any system. In the case of patrol allocation, it is expressed in terms of a lower cost to maintain the same level of service (as defined by some or all of the above measures), or an improvement in one or more of these measures without an increase in cost.

*Percent of total patrol unit hours devoted to preventive patrol.

Table 2. Glossary of Police Command and Control Terms (Ref. 9)

Beat identity	A term applied to an officer's personal commitment to maintain public order and provide effective police service within his *home beat.**
Call for service	A communication to the police originating from a citizen, an alarm system, a police officer, or other detector, reporting an incident that requires on-scene police assistance.
Command (or district)	An area or region comprising several *beats* that is administratively distinct, usually having a station house used as a base of operations. Often called precincts or (as in Boston) districts. A patrol officer is usually assigned to one command for a period of time. *Dispatch assignments* are nearly always intracommand assignments.
Dispatch assignment	A directive by the *dispatcher* to a *patrol unit* assigning the unit to respond to the scene of a reported incident or *call for service.*
Dispatcher	An individual who has responsibility for assigning available radio-dispatchable *patrol units* to reported incidents.
Effective travel speed	That speed which, if constantly maintained over the path of a response journey, would result in the same *travel time* as that actually experienced by the responding *patrol unit.*
Flying	A term applied to a *patrol unit* responding frequently to calls outside its *home beat.*
Hazard formula	A summation of crime statistics, geographical statistics, and other factors thought to be important in determining the need for *patrol units* in a region, each factor multiplied by a weighting indicating its subjective importance.
Home beat	The *beat* in which a *patrol unit* is assigned to perform *preventive patrol.*
Interbeat (or cross-beat) assignment	A *dispatch assignment* to a *beat* other than the unit's *home beat.*
Overlapping beats	*Beats* that at least partially share common regions.
Overlapping tours	A patrol *tour* that is initiated prior to termination of the preceding tour. This technique is used to better match the number of field units with calls for service during busy periods. A split tour is used for the same purpose.
Patrol status	The condition of a *patrol unit,* particularly pertaining to dispatch availability. In some police departments the dispatch status of a *patrol unit* is restricted to one of two possibilities: available or unavailable; in others, finer distinctions are made, including such possibilities as meal break, automobile maintenance, patrol-initiated action, station house, or type of incident currently being serviced.
Patrol unit	A patrol car, scooter, or wagon and its assigned police officer(s); or a radio-dispatchable footpatrolman.
Preventive patrol	An activity undertaken by a *patrol unit,* in which the unit tours an area, with the officer(s) checking for crime hazards (for example, open doors and windows) and attempting to intercept any crimes while in progress.
Reporting area	A subarea within a *command,* typically no more than a few city blocks in size, that is used as the smallest geographical unit for aggregating statistics on the spatial distributions of *calls for service* and *preventive patrol* coverage.
Sector (or beat)	An area in which one *patrol unit* has (usually exclusive) *preventive patrol* responsibility.
Service time	The total "off the air" time per *call for service* for a *patrol unit;* includes *travel time,* on-scene time, and possibly related off-scene time.
Tour	Shift, such as midday, PM, or AM.
Travel time	The time required for the dispatched *patrol unit* to travel to the scene of the reported incident.
Utilization factor	The fraction of time a *patrol unit* is unavailable to respond to dispatch requests. It is assumed that a unit can only be unavailable because of call-servicing duties. Sometimes called utilization rate.
Work load	Same as *utilization factor.*

*Words in italics are defined elsewhere in the glossary.

5. PREDICTING RATES OF CALLS FOR SERVICE

5.1 Characteristics of Calls for Service Rates

Most police departments have adequate records of calls for service over an extended period, with breakdowns by type of incident, location, and time and date. These are readily averaged, and it would seem to be a simple matter to extrapolate any trends (growing population, changing neighborhood, changing crime patterns) to derive estimates for future work loads on patrol units. These estimates must necessarily be expressed in terms of averages, however. If they are to be used as a basis for determining the numbers of patrol units needed and how best to allocate them in space and time, however, averages alone are somewhat misleading because of peak loads caused by the random rate of calls for service. Patrol strengths must be set to handle these peak rates.

Calls for service are random in nature. A month or a week, or even a day, may be average but any particular 10-minute period is very unlikely to be average. If calls average 10 per hour over the course of one day they will average one every 6 minutes, but any police department knows that during the busy hours there will probably be two to five times as many calls; and that during a busy hour, some 10-minute periods will have twice the average number of calls.

Ideally, a police department would like to have a patrol unit available to handle every call for service with no waiting, even during peak load periods. Practically, this would mean having too many units most of the time because short-term peak loads are brief and come at unpredictable intervals. What is done in most cases is to try to have enough units to handle all but the highest peaks -- those that occur only a small fraction of the time. Stated the other way, the department can define a level of service in terms of having calls answered without delay 85 percent of the time, or some other percentage that appears practical. Another standard can be to define a desired maximum delay time for calls that have to be placed in queue. This too has to be stated in terms of percent, however, for example, "85 percent of delayed calls shall remain in queue no longer than 3 minutes".

Given the complete statistics of calls for service in the past, a computer program incorporating the standard equations for statistical probability can determine the probabilities of given peak loads. These are given in terms of means and deviations, or confidence limits. Confidence limits are expressed in such terms as: "The pattern of calls for service in the past indicates that if I provide 20 patrol units during the second tour, 90 percent of all calls will be assigned to patrol units without delay and 98 percent will be dispatched with a delay of no more than 10 minutes." If the command and control system makes use of a (formal or informal) priority structure, the computer can readily incorporate this into its calculations and indicate the probability of no delay or of a specified delay for dispatches in each priority category.

The calculations of probabilities and confidence limits are complex and tedious to do by hand, but are carried out quickly by computers. The necessary computational routines are standard modules available to any computer user and do not have to be programmed by each new user.

5.2 Statistics Needed to Derive Predictions of Calls for Service

To provide a basis for projecting rates of calls for service and for the subsequent steps in the patrol force allocation study, a department needs to collect certain data as inputs to the computer programs or models. The data listed in Table 3 are usually sufficient, although some studies may require additional types of data if special analyses are to be made. Note that many of the statistical values such as street miles, travel times, etc., need be determined only once; incident data must be collected and processed on a continuous basis, although sampling techniques can greatly reduce the processing requirements once the basic averages and hourly/weekly/seasonal patterns become known.

As noted earlier, a department having a computer-aided dispatch system can have the system provide the listed data at little or no cost, provided the right information is input to the computer and the computer is programmed to do the necessary sorting and combining. For example, a computer can be programmed to search its street index and automatically determine the reporting area of each incident. In computer-aided dispatch systems, times are automatically recorded by the computer for each successive event in a dispatch.

Note that statistical programs used to calculate probabilities require data on individual incidents, and not averages. Acceptable inputs would be in the form of numbers of incidents in a fairly fine-grained breakdown: so many each reporting area of each type, so many with travel times between 1 and 2 minutes, 3 and 4 minutes, etc. On the other hand, the statistical program can be designed to read the complete activity log and pick off the data it needs to make such compilations. It can then sort the data by reporting area, beat, precinct, time, type of incident, or any other breakdown.

5.3 Prediction Methods

As noted in Table 3, the patrol force allocation analysis programs described in the following chapters require a limited amount of geographical data, the numbers and types of patrol units by beat and tour, and statistics on calls for service. The first category of information is obtained only once and involves a relatively modest amount of effort. The number and type of patrol units by beat and tour is also easily obtained from department records. Statistics for calls for service are a different matter, and may require considerable ongoing effort to collect and process in form suitable for patrol force allocation studies. The planner's department may already have an adequate data gathering and processing procedure in operation but, for those wishing to modify their present system, the following comments are offered. The planner will find a detailed description of the method in Ref. 5.

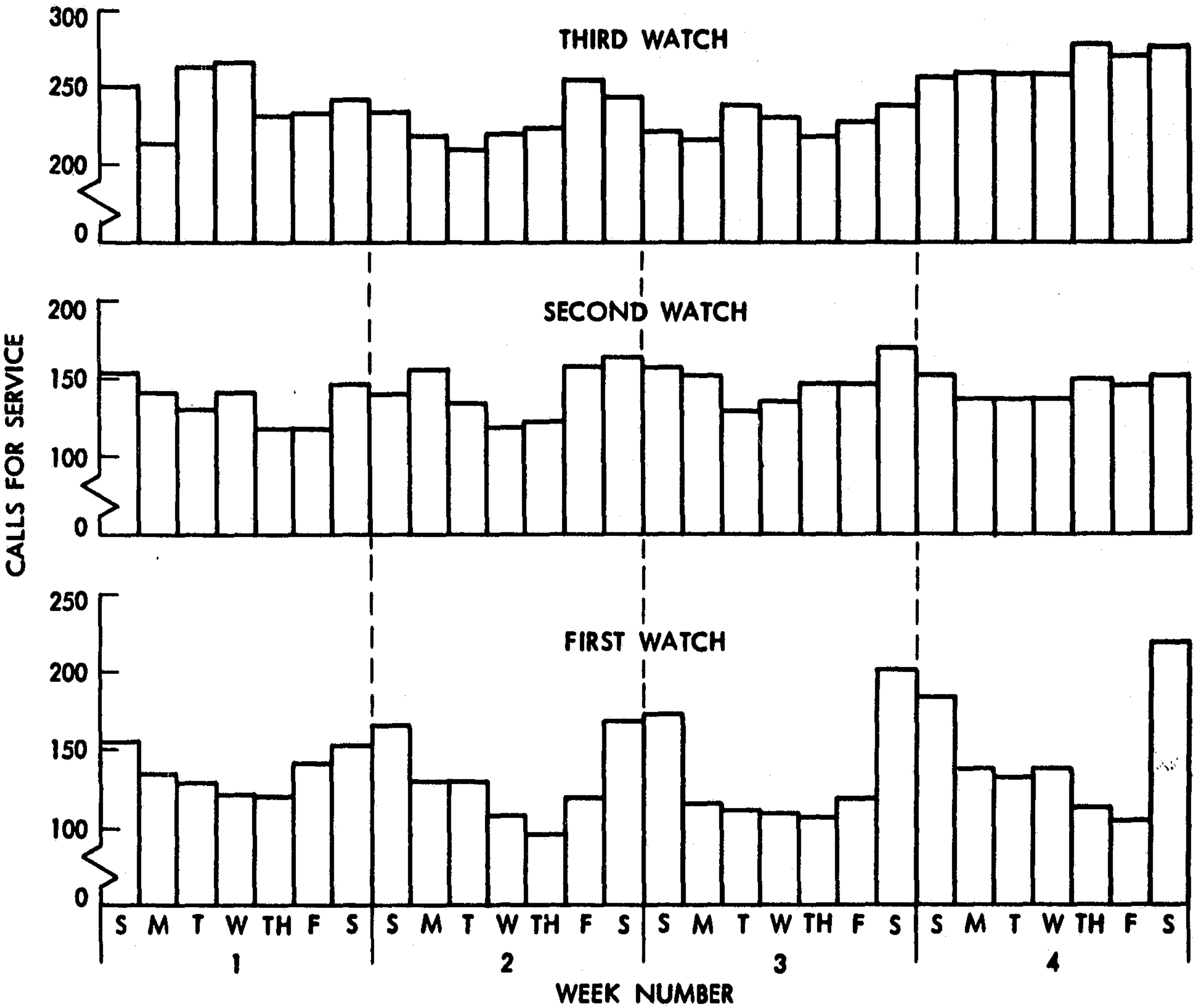
Before proceeding, we should point out that two sets of statistics are of interest to the department: one that deals with those calls for service or events that result in the dispatch of patrol units, and a second that deals with all incidents reported to the agency. While we are primarily concerned with the number of dispatches made in response to calls, a knowledge of crime patterns gained from the second set of data is valuable in predicting trends and basic changes in the rate of calls for service.

A method for predicting the number of dispatches is needed because of the variability in the rate of calls for service and dispatches with time of day, day of the week, and season of the year. Rates within any given hour also show considerable variation, but since service times typically extend to 30 minutes or longer, data accumulated by the hour usually is adequate. Typical hourly and seasonal variations in calls for service are shown in Fig. 2. Basic changes or trends in dispatch rates can occur as well, and the prediction procedure should reflect these; for this purpose we need a procedure that follows significant trends, but does not overreact to short term fluctuations.

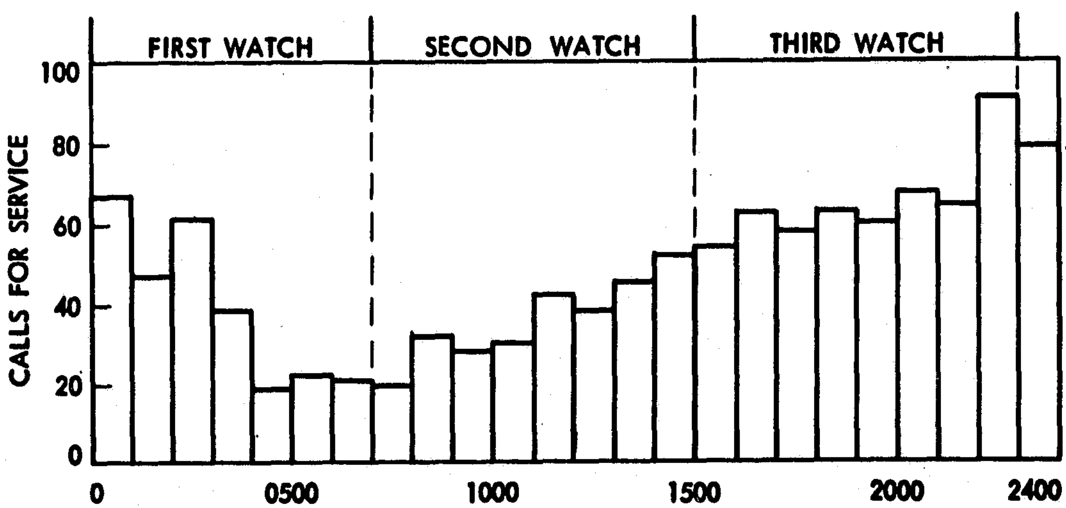
Many departments already have manual or computerized record-keeping systems from which calls for service can be predicted. Processing can be accomplished by establishing two data files, one for recording calls for service by hour of the day and day of the week, and a second file to accumulate statistics by week of the year. The first file contains 168 records, one for each hour of the week – for example, hour number 56 is 0700-0800 hours on Tuesday; the hourly and daily variations over the day and week are given by this file. Similarly, the weekly totals are recorded for week numbers 0 through 52. This procedure assumes that if we can predict the total number of calls for a given week (from the weekly files), we can dis-

Table 3. Data Required for Patrol Force Allocation Studies

Data Type	Notes
Geographical data:	
Area – total – of each beat	
Street mileage – by precinct – by beat	
Impediments to travel	Freeways, rivers, parks, campuses, other features that prevent a patrol unit from taking the most direct route from one point to another.
Population density – by beat	
Land use patterns	Commercial, residential, multiple-dwelling, single dwelling, public buildings, etc.
Reporting areas – coordinates of each reporting area	These are the smallest units of area used in analyses; a reporting area is usually only a few city blocks or equivalent. Statistics are collected by reporting area.
Patrol units:	
Number of each type on duty each tour	"Type" referes to one-man or two-man, supervisory, traffic, reserve, type of vehicle (wagon, scooter, car, etc.).
Beat assignments	Both numbers and type of units by beat.
Calls for service:	
Locations	Reporting area of each call for service.
Types	Category of each call, in accordance with whatever categories are used by the department.
Times	Time of each call, in particular time received by dispatcher, time assigned to a patrol unit, time patrol unit arrived on scene, and time unit cleared.
Travel distances	If the location of the patrol unit at the time it receives the dispatch is provided (by street intersection, for example), the computer can calculate travel distance to the address of the incident by formulas that give good accuracy as compared to the actual distance. Thus travel distances need not be determined in advance and input to the computer.



(a) Weekly variations in calls for service



(b) Hourly variations in calls for service

Fig. 2. Typical variations in rates of calls for service

tribute the calls over each hour of the week using the distribution pattern obtained from the hourly records. Further, yearly totals can be adjusted or "seasonalized" to give the longer term seasonal distributions.

Separate records are maintained for each reporting area, which usually consists of a number of blocks within a beat (census tracts are frequently used for this purpose). Finally, records are maintained by type of incident since different types of incidents have different hourly and seasonal variations. Departments generally have a standard list of incident types; a typical set is given in Table 4.

Processing consists basically of computing arithmetic averages for rates of calls for service for the entire week or entire year, plus factors to adjust the averages for hourly variations within the week, and weekly variations within the year. Separate averages and adjustment factors are maintained for each reporting area and for each type of incident.

Since the numbers of calls for service for a given reporting area, type of incident, or time period are likely to vary considerably about the average, we require a method for smoothing the data such that trends and long-term changes in the averages are properly accounted for, but occasional short term fluctuations are damped out. A technique used for this purpose is known as exponential smoothing. This procedure is described in Ref. 5, and in many standard texts on statistics; the reader should consult these for details.

The analyst should prepare graphs of the actual data from time to time to determine if new patterns of incidents are developing; if so, adjustments should be made in the data base to assure closer agreement with current values.

The patrol car allocation programs described in the following chapters also require estimates of response and service times, since the number of patrol units to be allocated depends on the total number of patrol hours spent answering calls plus the non-call-for-service activities, including preventive patrol. Travel and service times are usually available from the time stamps on the dispatch tickets and can be summarized by beat and type of incident, or lumped into one overall average value. (Computer-aided dispatch systems time-tag all dispatches automatically, which simplifies the processing task.) Whether or not a lumped average service time is used rather than averages for individual beats is a matter of department policy. This point is discussed further in the next chapter, but the decision to use the more detailed records by individual beat depends on personnel reaction to the process of allocating patrol units partially on the basis of service time. The issue is often raised that any improvement in service time in a beat will only result in fewer units being assigned to that beat.

Table 4. Event Classifications (Ref. 5)

Assignment Code	Nature of Assignment
CRIMES AGAINST PERSONS	
1	Homicide
2	Sex offense
3	Robbery
4	Assault
CRIMES AGAINST PROPERTY	
5	Burglary
6	Larceny
7	Automobile theft
8	Theft from automobile
INTOXICATED PERSON, DISTURBANCE, FAMILY	
9	Intoxicated person
10	Disturbance
11	Family argument
TRAFFIC	
12	Traffic accidents
13	Hit and run
ALARMS	
14	Assist an officer
15	Traffic control
16	Fire alarm
17	Burglar alarm
18	Ambulance
19	Fire or disaster
20	Prowler, other suspicious circumstance
21	Juvenile activity not otherwise covered
MISCELLANEOUS	
22	Miscellaneous incidents
PATROL	
23	Self-initiated patrol duties
ADMINISTRATIVE	
24	Administrative details

One department's experience with service time data indicated that many inaccuracies find their way into the system unless considerable care is taken in recording the basic data.

For example, follow-up times to hospitals, and times for booking a suspect were not allowed for in the initial data acquisition procedures; measurements during a subsequent test period showed an increase in average service time from 39 to 42 minutes. Stacked calls, although not a common practice in all departments, were all time-stamped simultaneously rather than as each call was activated; thus the time for the second call included the service time of the first call, etc. Not only was service time increased erroneously, but dispatch waiting time was artificially reduced.

Wide variations are often noted in service times for low priority calls that are simply delayed during busy periods until patrol units can clear higher priority calls. The analyst must use considerable care in applying such data in allocation programs.

6. DETERMINING HOW MANY PATROL UNITS ARE NEEDED*

We have already seen that the number of patrol units on duty cannot be derived by simply multiplying the average number of calls per hour times the average service time per call to find the total number of patrol-unit hours to be provided per hour. This would be satisfactory if calls for service could be scheduled, but in fact they arrive at random intervals, and the laws of statistics tell us that a certain percent of the time the rate will be half again as high as the average, another (smaller) percent of the time double the average, and so on. All random events such as the roll of dice, the drawing of cards, accidents, and calls for service follow the same laws of probability.

The number of patrol units needed, therefore, has to be stated in terms of probabilities: there should be enough units in a given geographical area so that calls for service can be assigned to an available patrol unit without delay a certain percent of the time, or with not more than a specified delay a certain percent of the time.

The use of hazard and work load formulas was briefly discussed in Chapters 2 and 3. These are principally methods of allocating a given number of units to different geographical areas and, as noted, have serious drawbacks. These drawbacks result from the fact that patrol units are assigned on the basis of existing work load, sometimes weighted by the seriousness of the incident, and service time per call. If more units are added to a beat or precinct, or if the units clear calls more quickly, fewer units will be assigned in the next allocation. Hence, there is less incentive to improve the productivity of the patrol force.

Since all of the steps in patrol force allocation described here are based on the use of a computer, we will describe computer-based techniques for determining numbers of units. These techniques are equally applicable to allocating a fixed number of units to different geographical areas (or time periods).

There are existing computer models that can be used to determine required numbers of units in accordance with specified performance measures such as those listed in the second paragraph above or others listed in Table 1. The most recent of these is PCAM (Patrol Car Allocation Model), developed by New York City - The Rand Institute. It incorporates most of the features of previous programs, but does not estimate call rates and service times itself. This must be done first, as described in Chapter 5.

PCAM calculates performance measures according to the principles of statistical probability. For each geographical area, the user provides the following input information:

- Call rates and service times by hour of the day and day of the week and by up to three priority levels.
- Area to be served, in square miles.
- Street miles in the area.
- Response speed and patrol speed of patrol units.
- Crime rates.
- Data indicating what fraction of a patrol unit's time is spent, on the average, on activities other than patrol or responding to calls for service.

From this data, PCAM will estimate all of the following performance measures if the total number of units on duty is known:

- Average number of units available (i.e., the number not responding to calls for service or not available because of other activities).
- Frequency of preventive patrol.
- Average travel time to incidents.
- **• Probability that a call will be delayed in queue.
- **• Average waiting time in queue for calls of each priority level.
- **• Average total response time.

PCAM can be used in either a batch mode (the program, with its input data, is run through the computer, which prints out the results) or in an interactive mode (the user sits at a console with a display screen, calls up the program, and enters the input data in response to requests for it displayed on the screen; the output parameters are then displayed on the screen). It operates by having the user specify some allocation of units to geographical areas and telling him the effect this allocation will have on the performance measures listed in the output. It can also determine the minimum number of units needed to meet any standard of performance specified in terms of these measures.

*This section is based on material presented in Ref. 10.

**Parameters that can be selected by the analyst.

Another mode of operation allows the user to *choose* any of the performance measures marked with an asterisk in the above list, and PCAM will allocate a specified total number of unit-hours so as to minimize this measure. The allocation may be by time period or geographical area or both. In other words, the user can specify the total number of units on duty in the city at a particular time of day and the program will allocate them among geographical areas. Or he can specify the total number of unit-hours than can be fielded in a week (in one area, several areas, or all areas together) and the program will allocate patrol units to tours so as to add up to the total number of unit-hours specified. This feature is an important one because – as planners well know – budget and manpower constraints are very stringent in most agencies.

An example of a typical PCAM run is shown as Table 5. Note that this program concerns the allocation of multiple patrol units to large areas such as precincts; it does not treat individual sectors for single patrol units. This is the subject of beat design, covered in the next chapter.

The assumptions made for this run of the model are as follows:

- The city has five precincts.
- Available records indicate the call rates by precinct for each of the three tours (midday, PM, AM) for each day of the week. The day chosen for the sample run is Sunday.
- Calls are assigned to one of three priorities in accordance with historical percentages of call priorities.
- The number of cars assigned to each tour of a precinct can be varied to measure the effect on performance.

For each precinct, the table shows the values of all output parameters with an initial allocation of cars to tours and with a second allocation made to improve the performance in terms of delay and response time. The car allocations are listed in the first column of the lower set of numbers under the heading "ACT. CARS". Call rates and service times are input parameters and do not change. Columns 5-8 show the values of the performance parameters of interest:

- The probability that a call will experience a delay in having a car dispatched because all cars are busy (PROB CALL DELAYED).
- The average delay in dispatching a car to a Priority 2 call (AVG P2 DELAY).
- The average delay in dispatching a car to a Priority 3 call (AVG P3 DELAY).
- The average response time (delay plus travel time) for all calls (AVG TOT DELAY).

Comparing the entries in these four columns for the "before" and "after" cases (initial allocation and final allocation), it can be seen that fairly large reductions can be made by changing the allocations of cars to tours. In Precinct 1, for example, two cars are taken off the AM shift and assigned to the midday shift, with the result that the probability of a delayed call is nearly cut in half, the average delay for Priority 2 and 3 calls is cut to about a third and a fifth, respectively, and the average total response time is reduced by about a third. Note in particular that the average delay for a Priority 3 call on the AM tour is reduced from a very undesirable 13.48 minutes to less than a minute, at the small expense of increasing the delay on the midday tour to slightly over a minute.

The results for all five precincts are summarized in Table 6.

It is of interest to note that the reassignment of two cars from Precinct 5 to Precinct 3 causes, for Precinct 5, only a slight increase in the probability of a delayed call and in the average Priority 2 delay, and the other two performance measures are slightly improved. Reference to Table 5 shows that in Precinct 5 the average Priority 3 delay on the AM tour has been sharply reduced, from 7.44 minutes to 1.87 minutes, which accounts for the overall reduction in average time delay even though the number of cars has been reduced.

For the entire city (all five precincts combined), the reallocation based on use of the PCAM model shows a significant improvement in performance:

	Before	After
Probability of delayed call	0.108	0.076
Average Priority 2 delay, minutes	0.85	0.50
Average Priority 3 delay, minutes	3.45	1.11
Average total delay (response time), minutes	6.11	4.10

Table 5. Sample PCAM Run

(a) Precinct 1

INITIAL ALLOCATION

PRECINCT: ONE; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP. CR PER HR	AVG CARS AVAIL.
MIDDAY	.269	3.1	9.09	.44	.245	5.11
PM	.429	3.5	3.36	.34	.418	3.99
AM	.468	5.2	7.60	.23	.071	2.66
AVERAGE	.381	3.9	5.60	.33	.245	3.92

PRECINCT: ONE; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	7.0	56.0	3.1	36.6	.008	.05	.07	3.19
PM	7.0	56.0	5.5	32.6	.056	.31	.61	4.07
AM	5.0	40.0	3.9	36.2	.310	2.88	13.48	16.13
AVERAGE	6.3	50.7	4.2	34.7	.123	1.04	4.47	7.60
TOTAL	19.0	152.0						

FINAL ALLOCATION

PRECINCT: ONE; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.377	4.1	5.54	.27	.149	3.11
PM	.429	3.5	3.36	.34	.419	3.99
AM	.334	3.5	13.31	.40	.127	4.66
AVERAGE	.381	3.7	5.60	.33	.213	3.92

PRECINCT: ONE; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	5.0	40.0	3.1	36.6	.080	.68	1.25	5.19
PM	7.0	56.0	5.5	32.6	.056	.31	.61	4.07
AM	7.0	56.0	3.9	34.2	.070	.44	.98	4.38
AVERAGE	6.3	50.7	4.8	34.7	.067	.44	.88	4.44
TOTAL	19.0	152.0						

Table 5 (contd)

(b) Precinct 2

INITIAL ALLOCATION

PRECINCT: TWO; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.228	2.9	8.16	.49	.325	5.40
PM	.421	3.3	5.79	.37	.233	4.05
AM	.335	4.4	7.42	.36	.154	3.99
AVERAGE	.328	3.5	7.08	.41	.258	4.48

PRECINCT: TWO; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	7.0	56.0	2.8	34.1	.006	.03	.04	2.98
PM	7.0	56.0	5.2	34.1	.040	.22	.40	3.69
AM	6.0	48.0	2.9	41.7	.241	2.17	13.04	14.88
AVERAGE	6.7	53.3	3.6	36.1	.085	.69	3.66	6.48
TOTAL	20.0	160.0						

FINAL ALLOCATION

PRECINCT: TWO; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.319	3.8	5.14	.31	.205	3.40
PM	.421	3.3	5.79	.37	.233	4.05
AM	.287	3.6	9.28	.45	.197	4.99
AVERAGE	.345	3.5	6.55	.38	.210	4.15

PRECINCT: TWO; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	5.0	40.0	2.8	34.1	.059	.46	.81	4.50
PM	7.0	56.0	5.2	34.1	.040	.22	.40	3.69
AM	7.0	56.0	2.9	41.7	.129	.96	3.29	6.37
AVERAGE	6.3	50.7	3.6	36.1	.069	.48	1.27	4.61
TOTAL	19.0	152.0						

Table 5 (contd)

(c) Precinct 3

INITIAL ALLOCATION

PRECINCT: THREE; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.456	2.7	10.87	.57	.199	3.81
PM	.493	2.8	13.52	.53	.123	3.55
AM	.356	3.3	60.07	.67	.047	4.51
AVERAGE	.435	2.9	17.25	.59	.140	3.95

PRECINCT: THREE; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	7.0	56.0	5.4	35.6	.073	.44	.92	3.54
PM	7.0	56.0	7.7	26.8	.085	.38	.80	3.50
AM	7.0	56.0	4.2	35.6	.222	1.47	9.30	10.74
AVERAGE	7.0	56.0	5.8	31.7	.115	.66	2.90	5.27
TOTAL	21.0	168.0						

FINAL ALLOCATION

PRECINCT: THREE; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.456	2.7	10.87	.57	.199	3.81
PM	.493	2.8	13.52	.53	.123	3.55
AM	.277	2.4	86.74	.97	.068	6.51
AVERAGE	.397	2.7	20.16	.69	.146	4.62

PRECINCT: THREE; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	7.0	56.0	5.4	35.6	.073	.44	.92	3.54
PM	7.0	56.0	7.7	26.8	.085	.38	.80	3.50
AM	9.0	72.0	4.2	35.6	.066	.32	.92	3.14
AVERAGE	7.7	61.3	5.8	31.7	.077	.39	.86	3.43
TOTAL	23.0	184.0						

Table 5 (contd)

(d) Precinct 4

INITIAL ALLOCATION

PRECINCT: FOUR; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.408	3.0	11.05	.50	.186	4.14
PM	.429	2.9	4.21	.48	.471	4.00
AM	.528	4.4	4.97	.28	.088	2.36
AVERAGE	.447	3.4	5.83	.42	.234	3.50

PRECINCT: FOUR; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	7.0	56.0	5.0	34.2	.073	.43	.90	3.82
PM	7.0	56.0	4.7	38.0	.038	.23	.40	3.28
AM	5.0	40.0	3.5	45.6	.307	3.55	12.85	15.00
AVERAGE	6.3	50.7	4.4	38.6	.122	1.18	3.86	6.56
TOTAL	19.0	152.0						

FINAL ALLOCATION

PRECINCT: FOUR; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.408	3.0	11.05	.50	.186	4.14
PM	.500	3.4	3.16	.36	.353	3.00
AM	.377	3.0	9.18	.52	.180	4.36
AVERAGE	.425	3.1	6.39	.46	.227	3.83

PRECINCT: FOUR; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	7.0	56.0	5.0	34.2	.073	.43	.90	3.82
PM	6.0	48.0	4.7	38.0	.099	.74	1.43	4.63
AM	7.0	56.0	3.5	45.6	.065	.50	1.01	3.88
AVERAGE	6.7	53.3	4.4	38.6	.080	.56	1.12	4.13
TOTAL	20.0	160.0						

Table 5 (contd)

(e) Precinct 5

INITIAL ALLOCATION

PRECINCT: FIVE; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.215	2.2	87.96	.87	.055	5.50
PM	.418	2.6	7.24	.65	.333	4.07
AM	.318	3.3	24.80	.54	.056	3.41
AVERAGE	.317	2.7	17.02	.69	.126	4.33

PRECINCT: FIVE; DAY: SUN-MON

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	7.0	56.0	2.4	37.3	.004	.02	.04	2.25
PM	7.0	56.0	4.7	37.3	.060	.37	.75	3.25
AM	5.0	40.0	2.6	37.3	.191	1.82	7.44	9.43
AVERAGE	6.3	50.7	3.2	37.3	.080	.67	2.34	4.63
TOTAL	19.0	152.0						

FINAL ALLOCATION

PRECINCT: FIVE; DAY: SUN

TOUR	AVG UTIL. (EFF)	AVG TRAV. TIME	PATROL HRS PER SUPP CR	AVG PATROL FREQ.	AV PTL FREQ TIMES SUPP CR PER HR	AVG CARS AVAIL.
MIDDAY	.376	3.4	39.96	.40	.025	2.50
PM	.418	2.6	7.84	.65	.333	4.07
AM	.265	2.7	32.07	.70	.074	4.41
AVERAGE	.354	2.8	14.40	.58	.117	3.66

PRECINCT: FIVE; DAY: SUN

TOUR	ACT. CARS	CAR HRS	CALL RATE	SERV TIME	PROB CALL DELAYED	AVG P2 DELAY	AVG P3 DELAY	AVG TOT DELAY
MIDDAY	4.0	32.0	2.4	37.3	.137	1.51	3.08	6.10
PM	7.0	56.0	4.7	37.3	.060	.37	.75	3.25
AM	6.0	48.0	2.6	37.3	.092	.70	1.87	4.34
AVERAGE	5.7	45.3	3.2	37.3	.088	.74	1.63	4.25
TOTAL	17.0	136.0						

Table 6. Summary of Reallocation Results

Precinct	No. of Cars Reassigned	Prob. Call Delayed		Avg. P2 Delay		Avg. P3 Delay		Avg. Tot. Delay	
		Before	After	Before	After	Before	After	Before	After
1	2	0.123	0.067	1.04	0.44	4.47	0.88	7.60	4.44
2	1	0.085	0.069	0.69	0.48	3.66	1.27	6.48	4.61
3	2*	0.115	0.077	0.66	0.39	2.90	0.86	5.27	3.43
4	2*	0.122	0.080	1.18	0.56	3.86	1.12	5.56	4.13
5	3**	0.080	0.088	0.67	0.84	2.34	1.63	4.63	4.25

*Total number of cars increased.
**Total number of cars reduced by 2.

These differences are striking enough to be perceived by the public. They illustrate clearly one of the benefits of having an allocation model available to a police department. As noted previously, such a computer simulation can easily carry out all the complex probability calculations that are required to make realistic estimates of how changes in patrol force allocation will affect the performance of a department, whatever measures are chosen for performance.

In addition to PCAM and the work load and hazard formula methods mentioned in this chapter, a number of agencies use the LEMRAS program described in Chapter 3. One agency's experience with LEMRAS indicated that supervision and field personnel tended to react adversely to its recommendations because of the same shortcomings exhibited by work load formulas, namely, that an increase in productivity by the patrol forces in terms of increased arrests, reduced crime rates, or reduced response times will only lead to fewer patrol units being assigned to the high performance beats. This is in fact a valid observation by operations personnel even though assurances are made that LEMRAS is only an "advisory" procedure.

It must be noted that, to some extent, PCAM suffers the same shortcoming because field forces are allocated on the basis of the number of anticipated incidents; the fewer incidents the fewer assigned units. A significant difference in PCAM is the fact that the program does not distinguish between service times by individual beats, but uses precinct - (or city -) wide values. Hence, patrol forces are not removed from a beat if the patrol teams succeed in reducing service times. Thus a major objection to its use is removed.

7. DESIGNING PATROL SECTORS OR BEATS*

Extensive work has been done on the development of computer models that can be used to analyze different beat or sector designs to determine how these different designs would affect certain selected performance measures. The performance measures most likely to be affected by redesign of patrol unit beats are:

- Work load balance among patrol units.
- Response time.
- Fraction of dispatches that take a patrol unit out of its home beat.
- Average travel time for all the beats in a precinct taken together.

Another factor that can be influenced by beat design, but which is not usually taken as a measure of performance, is reasonably equal access to police service in the different parts of a precinct. Response times to some areas should not consistently be significantly longer or shorter than the average for the precinct as a whole.

Design of beats is, as noted in Chapter 2, not entirely arbitrary; there are usually natural boundaries that determine at least some beat boundaries and geometry. Even so, in most cases, there still remains considerable flexibility for the adjustment of boundaries.

The work that has been done on patrol beat design has brought out some general relationships that appear to be consistent and that are useful starting points for any exercise in beat design. These can be stated as useful rules of thumb, and are summarized in the following paragraphs.

Beat Area and In-Beat Travel Time. In general, it has been shown that the travel time average within any area, including a beat, is proportional to the square root of the area; thus a sector twice as big as another will have travel times only 1.4 times as great. What this means in practical terms is that travel times are unlikely to vary appreciably among beats as long as they are roughly similar in area. It also means that there is a built-in conflict between work load balance and travel times in cases where some sectors have a high population density and others have a low population density. If beats are designed so as to equalize work loads, those in low-population-density areas will be much larger and have longer travel times. If they are designed to have roughly equal areas in order to make travel times equal, the high-population-density beats will have a much higher work load than the low-density beats.

Beat Shape. Within the constraints of existing barriers, the beat designer will want to provide good police accessibility to every point in the beat for the assigned patrol unit and, to the extent possible, for units from other beats. This usually dictates a fairly "compact" shape, in which the long dimension is not more than twice the wide dimension. Other considerations, such as one-way streets or major arteries, may lead to exceptions to this rule of thumb. If a planner is concerned with the worst possible situation, he will want to determine the longest possible travel time within the beat and use that as an element in his beat design.

Travel Speeds. Travel speeds may differ in different directions; a clear case is that of Manhattan in New York, where travel in the north-south direction is much faster than in the east-west (crosstown) direction. In such cases the beats may be designed longer in the faster direction of travel in order to equalize travel times in the various directions within the beat.

Fraction of Out-of-Beat Dispatches. Both experience and computer models indicate that dispatches in which the patrol unit assigned is not the one in whose beat the incident is located become an increasing fraction as the work load of the precinct increases. A rule of thumb is that the fraction of out-of-beat dispatches is very nearly the same as the "busy time" fraction of the patrol units. That is, under light load conditions the patrol units may be busy answering calls for service only 15 percent of the time, and about 15 percent of the dispatches will require a unit to leave its beat because the "normal" patrol unit is already busy on a call for service. When the load increases to 50 percent busy time, 50 percent of the dispatches will take a unit out of its beat. When the system is saturated to the point where significant numbers of calls are held in queue, the fraction of out-of-beat dispatches drops to slightly less than the work load or busy time fraction.

Patrol Unit Work Load vs. Beat Work Load. Since patrol units spend a considerable amount of their time answering calls outside of their beats, the work load of a patrol unit is not necessarily the same as the work load of its beat. The actual relationships are quite complicated, and can best be handled in a computer model, but in the design of patrol beats it should not be assumed that, for example, "If beat A generates twice the work load of beat B, then patrol unit A works

*This section is based on material presented in Refs. 11 and 12.

twice as hard as patrol unit B". And a design that equalizes beat work loads will not necessarily equalize patrol unit work loads.

The Burden of Central Location. A patrol unit in a beat that is centrally located in its precinct will be a frequent candidate for out-of-beat dispatches because it will be the nearest unit in more than half of the dispatches to the ring of beats surrounding it (if the assigned unit is not available). On the other hand, a patrol unit in a beat on the outer perimeter of the precinct will seldom be a good choice for out-of-beat dispatches. This is called the "burden of central location". About all the beat designer can do is to design his centrally-located beats with a less-than-average call for service volume and his outlying beats with higher-than-average call for service volume. This, however, will create another problem: the higher the work load of outlying beats, the longer the average travel times for patrol units dispatched to those beats from others.

The operation of a beat design analysis using a computer model can best be illustrated by an example. Richard C. Larson of the Massachusetts Institute of Technology has been developing computer models to analyze police command and control systems for several years, and in 1972 used his most recent model in a beat redesign experiment for a selected district (precinct) in Boston. The experiment assumes that calls for service arrive at the average rates experienced in the past, but with a typical distribution for random events, in which the exact time of arrival is not predictable. The same distribution is used for service times at the scene (the time to service a call excluding dispatching and travel time). The average service time determined from prior data was 38 minutes, but the service times of individual calls varied in accordance with a random distribution.

For the purpose of designing or redesigning beats, the entire area of the precinct is divided into 70 reporting areas. These are small areas of a few blocks; calls are located in reporting areas (not at exact addresses). Since the reporting areas are small, the following procedures can be used:

- All beats can be designed to consist of some number of complete reporting areas (no reporting areas are split in any configuration of beats).
- The locations of the reporting areas can be designated by a set of coordinates centered on a major intersection in the precinct. Thus a reporting area location can be specified as $x = 0.15$, $y = -0.05$, meaning that the center of the reporting area is 0.15 miles east of the major intersection and 0.05 miles south of it. With these coordinates, the computer can readily compute the distance from one to another.
- Travel distances within a reporting area are so small (in this case less than a tenth of a mile) that they can be neglected in computing travel distances from one reporting area to another (although the computer has a table of average travel distances within each area and can add these to the travel distance if desired).

In computing travel distances, the model uses a scheme called the "metropolitan" distance metric. This procedure assumes that a unit responding to a call will proceed along the street grid, going as far north or south as necessary and then going east or west as far as necessary to reach the scene. Options are provided for cases where this assumption is not realistic, however, The user can input any exception, or he can calculate in advance the average travel times between all possible pairs of reporting areas (4900 in this case) and input these as a table to which the model will refer in each case.

Travel times are estimated directly from travel distances by assuming an average travel speed for all cases. The speed used in the experiment was 10 mph, based on a 1966 sample taken in Boston that showed an average of 9 mph. The user can input any travel speed he chooses as typical of his system. Or, as noted in the preceding paragraph, he can calculate all the individual travel times between reporting areas, taking into account any variations in travel speed that will make the estimates more realistic in individual cases.

The basic input to the model is the number of calls for service in each reporting area. These were collected for the previous year; they ranged from 451 for the least busy reporting area to 2703 for the busiest. These were then assumed to be evenly distributed throughout the year. In reality, the rates of calls for service in a given reporting area show trends by time of day, day of week, and season. Since times of day were not included in the data collected, this factor could not be included; the Boston police department plans to include this data in the future. Weekly and seasonal variations were also not reflected in the model, but they could be added easily.

The other major input to the model is the dispatcher assignment procedure, also called the dispatching policy or strategy. This is a set of rules the computer uses to select from available units, and is as close to the actual dispatching policy as possible. Dispatchers frequently apply selection factors that are not included in a set of rules; nevertheless, the model can make selections based on a set of dispatching rules that will resemble actual dispatching policy well enough to show the effects of changing beat boundaries.

The model assumes that the dispatcher has a rank ordering of preferred patrol units to dispatch to each reporting area.

For the precinct analyzed there were six patrol units, and any given reporting area would be in the beat of one of these units. One dispatching strategy is always to dispatch the unit in whose beat the reporting area of the incident is located. Next in order would come those units whose beats border the beat where the incident is located, and then those whose beats are further away. The computer can refer to a table listing the preferred rank order of units to be assigned to each of the 70 reporting areas, and for each dispatch consult the table listing the order for the reporting area of the incident. It then assigns the highest unit on that list that is available at the time.

The above procedure requires the computer to store 70 rank-ordered lists of the six patrol units, making a table with 420 entries. To simplify the procedure, the Larson model has eight "canned" strategies from which the user can pick the one he wants to exercise. These differ primarily in how much knowledge the dispatcher is assumed to have about the locations of incidents and of his patrol units. In one set of strategies he is assumed to know nothing about the location of a patrol unit that is available, and his estimate of travel time is based on assuming that the unit is in the exact statistical center of its beat (in terms of the distribution of service calls among the reporting areas in the beat). The location of the incident is also assumed to be in the statistical center of the unit's beat. There are four strategies, reflecting the dispatcher's use of the information available to him on the locations of patrol units and incidents. The two sets of four strategies differ only in whether or not they always give preference to the patrol unit in whose beat the incident is located.

The user of the model can input his own strategies, or can modify any of the "canned" strategies by adding special cases. For example, if he prefers to assign a unit with a Spanish-speaking officer to incidents in beats with predominantly Spanish-speaking populations, he can cause the model to select such a unit.

The experiment consisted of running the model four times, once for each of four alternative beat designs. The assumptions and input data are listed in Table 7.

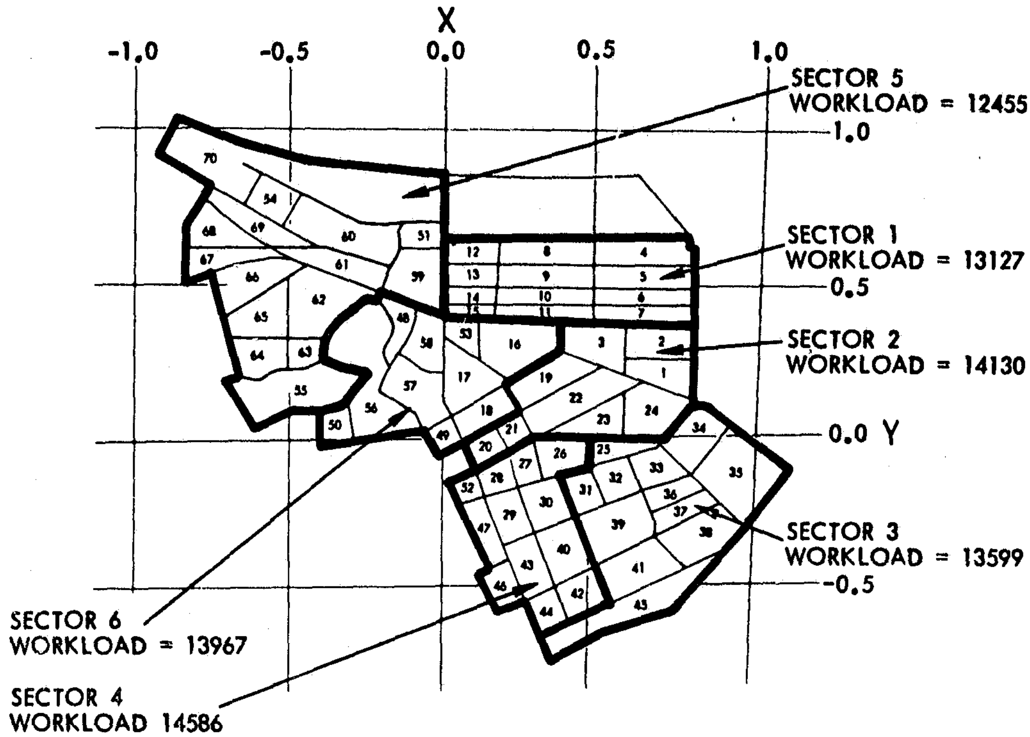
Table 7. Assumptions and Inputs for Boston Beat Design Experiment

Area analyzed	Boston District (Precinct) 4
Number of reporting areas	70
Number of beats	6
Number of patrol units on duty	6
Distribution and average rates of calls for service	Taken from 1971 statistics for each reporting area
Travel times	Estimated from travel distances determined by "metropolitan" distance metric.
Average travel speed	10 mph
Average service time	38 minutes per call for service (includes travel time and time to close incident)
Rate of calls for service for entire precinct	4.737 per hour average

The designer began with a preliminary estimate of good beat geometry, based on trying to have equal internally-generated work loads, to maintain neighborhood integrity, and to follow natural boundaries. After examining the results of this first iteration, he adjusted certain beat boundaries to try to reduce the work load imbalance among beats. Figure 3 and Table 8 summarize the results of all four iterations, and indicate that he was successful in reducing the imbalance, particularly the heavy work load of Beat 2. This remains the busiest beat, however, and travel times increased in Beats 5 and 6.

Deciding that the work load imbalance should be further reduced, the designer readjusted boundaries and produced the results shown for Iteration 3. Despite the fairly significant changes in beat boundaries, the results show little or no change in the performance measures. Beat boundaries were shifted more drastically for Iteration 4, and this time the work load imbalance was reduced appreciably (note that the difference between the maximum and minimum percents is 5 for Iteration 4, while it was 10 for Iteration 3 and 9 for Iteration 2). The fraction of out-of-beat dispatches changed very slightly. Although average travel times for individual patrol units and beats changed from one iteration to another, the total average travel time for the precinct remained the same for all iterations.

The above example is given as an illustration of how a beat design program was used on a specific police precinct to attempt to find a beat design that would optimize certain specific performance measures. This same model can be used to analyze more complex situations, including those with overlapping beats. On the other hand, it does not allow for different priorities among calls for service; this would probably give unrealistic results in an analysis of response times, and of overall command and control system performance. Also, as noted previously the input data in this case did not reflect time variations in rates of calls for service from different reporting areas or beats. Including these variations might suggest beat designs that improve performance during peak periods at the



Maximum work load imbalance = 26%
Region-wide average travel time = 3.402 minutes
Average travel time for queued calls = 5.178 minutes
Fraction of dispatches that are cross-sector = 0.485

Profile of Patrol Unit Operations

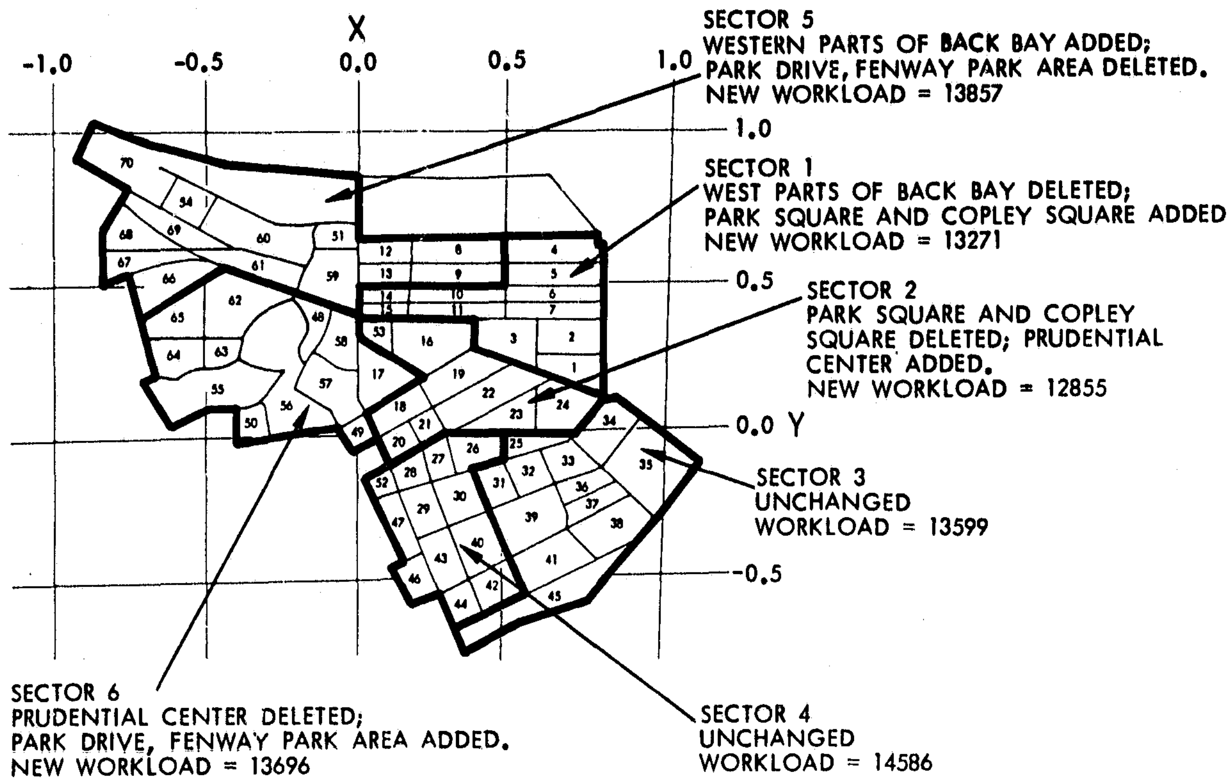
Patrol Unit No.	Work Load	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.519	103.8	0.539	111.3	3.432
2	0.559	111.7	0.576	118.7	3.378
3	0.496	99.2	0.477	98.5	3.090
4	0.490	98.0	0.426	87.9	3.180
5	0.428	85.7	0.373	77.0	3.978
6	0.507	101.5	0.487	100.4	3.414

Profile of Sector Operations

Sector No.	Fraction of District's Total Work Load	% of Mean	Fraction of Dispatches That Are Cross-Sector	Average Travel Time
1	0.160	96.2	0.503	3.312
2	0.172	103.6	0.542	3.120
3	0.166	99.7	0.480	3.324
4	0.178	106.9	0.474	3.258
5	0.152	91.3	0.412	4.218
6	0.170	102.4	0.491	3.258

a. Sector configuration for Iteration 1

Fig. 3. Sector configurations (Ref. 13)



Maximum work load imbalance = 9.98%
Region-wide average travel time = 3.456 minutes
Average travel time for queued calls = 5.178 minutes
Fraction of dispatches that are cross-sector = 0.483

Profile of Patrol Unit Operations

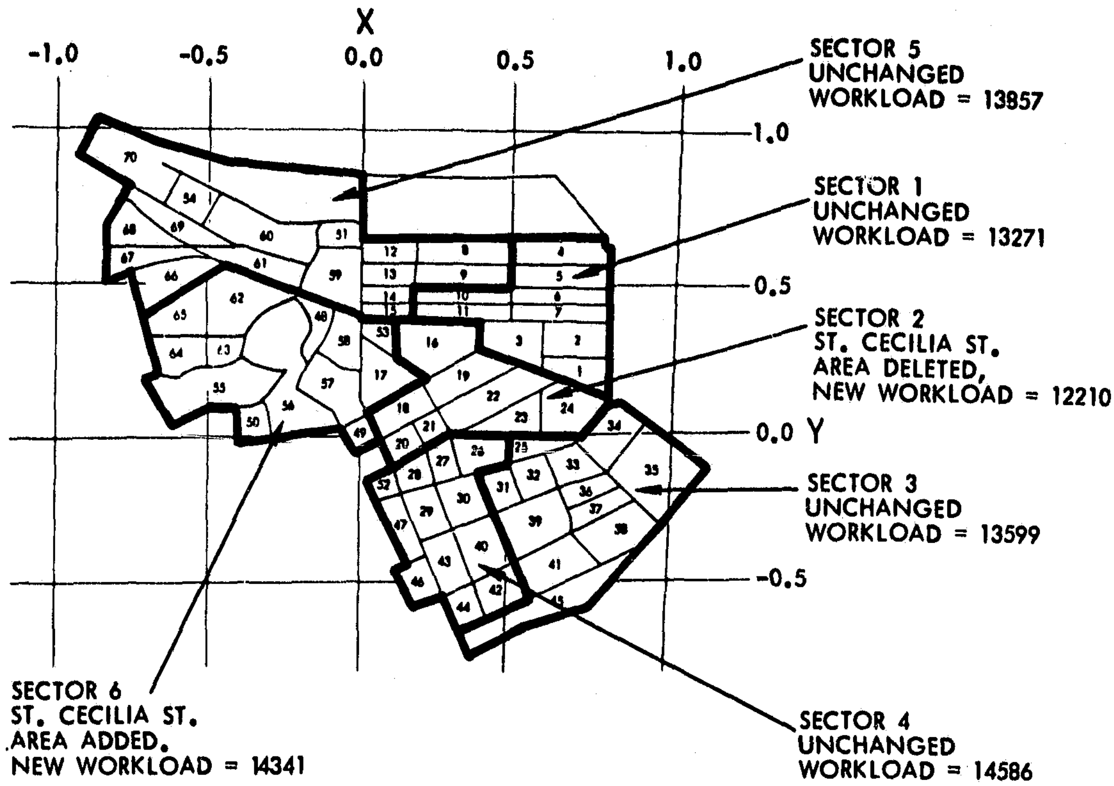
Patrol Unit No.	Work Load	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.509	101.9	0.516	106.8	3.246
2	0.527	105.5	0.563	116.5	3.360
3	0.501	100.1	0.486	100.7	3.210
4	0.504	100.8	0.457	94.5	3.168
5	0.477	95.5	0.426	88.3	4.164
6	0.481	96.2	0.441	91.3	3.636

Profile of Sector Operations

Sector No.	Fraction of District's Total Work Load	% of Mean	Fraction of Dispatches That Are Cross-Sector	Average Travel Time
1	0.162	97.3	0.493	3.018
2	0.157	94.2	0.511	3.066
3	0.166	99.7	0.484	3.318
4	0.178	106.9	0.488	3.258
5	0.169	101.6	0.461	4.422
6	0.167	100.4	0.465	3.612

b. Sector configuration for Iteration 2

Fig. 3 (Contd)



Maximum work load imbalance = 9.88%
Region-wide average travel time = 3.444 minutes
Average travel time for queued calls = 5.178 minutes
Fraction of dispatches that are cross-sector = 0.483

Profile of Patrol Unit Operations

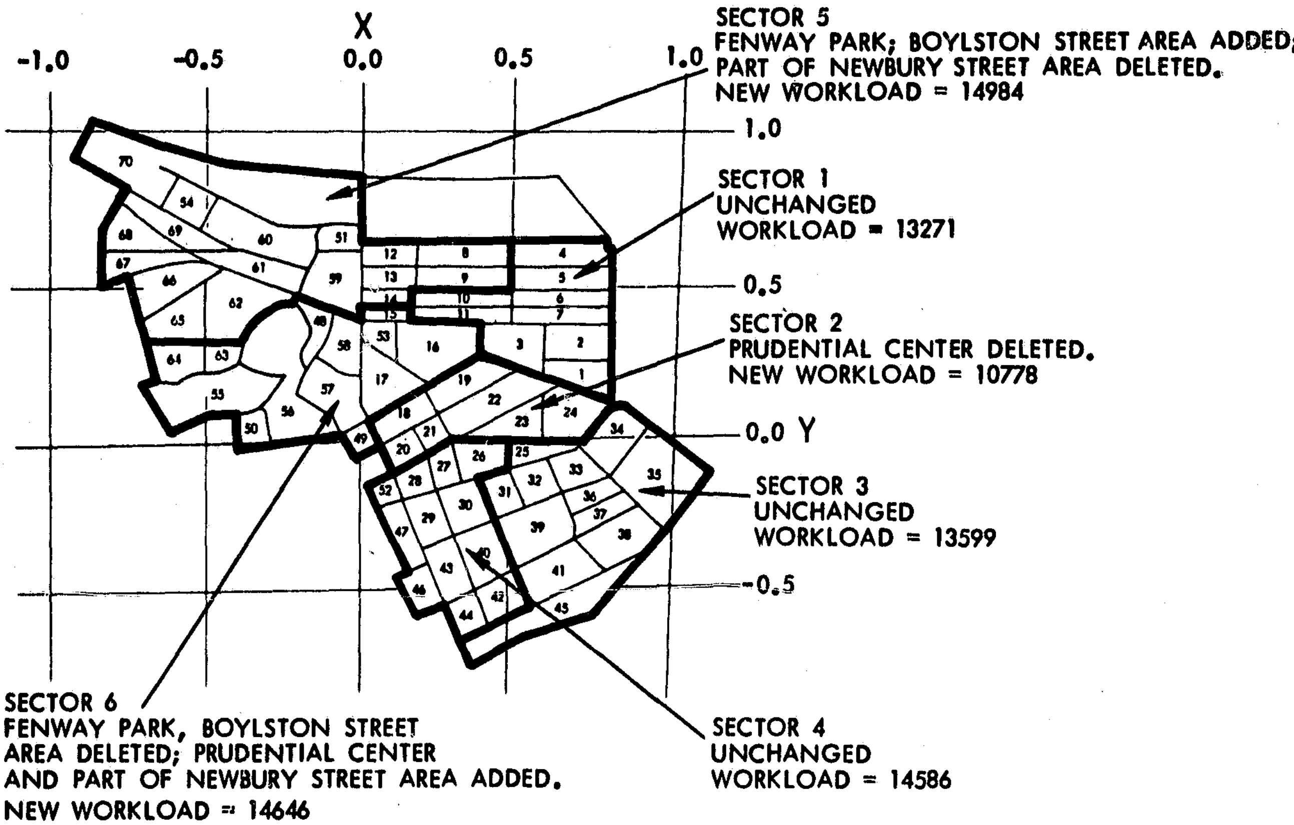
Patrol Unit No.	Work Load	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.507	101.5	0.512	106.0	3.246
2	0.523	104.6	0.578	119.6	3.324
3	0.500	99.9	0.484	100.3	3.204
4	0.503	100.6	0.454	94.1	3.162
5	0.474	94.7	0.418	86.5	4.116
6	0.493	98.7	0.443	91.7	3.672

Profile of Sector Operations

Sector No.	Fraction of District's Total Work Load	% of Mean	Fraction of Dispatches That Are Cross-Sector	Average Travel Time
1	0.162	97.3	0.491	3.006
2	0.149	89.5	0.506	2.988
3	0.166	99.7	0.483	3.294
4	0.178	106.9	0.486	3.246
5	0.169	101.6	0.457	4.428
6	0.175	105.1	0.477	3.642

c. Sector configuration for Iteration 3

Fig. 3 (contd)



Maximum work load imbalance = 5.48%
Region-wide average travel time = 3.426 minutes
Average travel time for queued calls = 5.178 minutes
Fraction of dispatches that are cross-sector = 0.483

Profile of Patrol Unit Operations

Patrol Unit No.	Work Load	% of Mean	Fraction of Dispatches Out of Sector	% of Mean	Average Travel Time
1	0.499	99.7	0.495	102.5	3.222
2	0.512	102.4	0.611	126.6	3.318
3	0.497	99.4	0.479	99.3	3.192
4	0.502	100.4	0.453	93.7	3.174
5	0.485	97.0	0.398	82.3	4.074
6	0.505	100.1	0.456	94.5	3.612

Profile of Sector Operations

Sector No.	Fraction of District's Total Work Load	% of Mean	Fraction of Dispatches That Are Cross-Sector	Average Travel Time
1	0.162	97.3	0.482	2.958
2	0.132	79.0	0.496	2.886
3	0.166	99.7	0.481	3.234
4	0.178	106.9	0.486	3.204
5	0.183	109.8	0.468	4.524
6	0.179	107.3	0.488	3.534

d. Sector configuration for Iteration 4

Fig. 3 (contd)

Table 8. Summary Results of Beat Design Study

Patrol Unit	Fraction of Time Busy				Percent of Mean				Fraction of Dispatches Out of Beat				Average Travel Time, min.			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	0.52	0.51	0.51	0.50	104	102	101	100	0.54	0.52	0.51	0.50	3.4	3.2	3.2	3.2
2	0.56	0.53	0.52	0.51	112	105	105	102	0.58	0.56	0.58	0.61	3.4	3.4	3.3	3.4
3	0.50	0.50	0.50	0.50	99	100	100	99	0.48	0.49	0.48	0.48	3.1	3.2	3.2	3.2
4	0.49	0.50	0.50	0.50	98	101	101	100	0.43	0.46	0.45	0.45	3.2	3.2	3.2	3.2
5	0.43	0.48	0.47	0.48	86	96	95	97	0.37	0.43	0.42	0.40	4.0	4.2	4.1	4.1
6	0.51	0.49	0.49	0.51	102	96	99	100	0.49	0.44	0.44	0.46	3.4	3.6	3.7	3.6

expense of somewhat nonoptimum performance during slack periods. Beat design must remain constant at least over the period of a tour of duty, and for a given tour should be the same day after day so as to allow patrol officers to become familiar with their beats. However, overlay beats (overlapping tours) and overlapping beats, in which some patrol units are assigned to more than one beat, are techniques that can be used to meet busy-hour demands.

There are other models that can be used for beat design exercises, and an overall simulation of a command and control system can include the necessary capabilities. Although the example given above does not show dramatic results from adjusting beat boundaries, it is possible to make significant differences by applying certain beat design strategies. The most common one is the use of overlapping beats. These may be in the form of areas that are included in two or more beats, or of a separate beat overlaid on the regular, nonoverlapping beat structure. Both of these techniques can cut down on the fraction of out-of-beat dispatches, and may help reduce response times if carefully designed. A computer model is indispensable for trying out such designs to see their effects on the performance measures of concern.

Another existing model for beat design is that designed by Deepak Bammi (Ref. 14). It differs from the Larson model described above in that:

- It calculates travel times from travel distances and speeds between adjacent reporting areas as input by the user. In this way it is possible to allow for varying travel speeds in different locations.
- It allows for two levels of priority in calls for service.
- It will calculate a beat design that minimizes average response time in the whole precinct, rather than only analyzing designs proposed by the user.

The field of model development for police command and control is developing rapidly, and a planner wishing to make use of such a model should consult the references to find out the current state of development. Certain of these programs are available from the developers, and if the planner has access to a computer he can exercise such a model either separately or as part of an overall simulation of the police command and control system.

8. ANALYZING DIFFERENT DISPATCH STRATEGIES

Only when the three preceding steps have been carried out and their results are in hand is it possible to proceed with a complete simulation of patrol force allocation. Up to this point we have determined, by separate analyses:

(1) What rates of calls for service we need to be able to handle.

(2) How many patrol units it will take to handle them, and in a multiprecinct city how they should be allocated to precincts.

(3) What arrangement of beats and beat boundaries will be most likely to optimize the performance measures we are interested in (work load balance, response time, out-of-beat dispatches, or other).

A different approach to allocating patrol units and designing beat boundaries is described here, namely, simulation techniques, which are widely available and relatively easy to develop for a given agency in a short period of time. These simulations can be written in higher order languages such as GPSS and SIMSCRIPT. The principal advantage of simulation techniques is that a more realistic model of actual patrol operations can be developed, and a wider range of patrol strategies explored without extensive program modifications. Simulations can analyze the hourly variations in the number of calls for service and illustrate the effects on dispatch backlog and waiting time.

A possibly more important advantage lies in the ability to handle calls by priority, which the analytical techniques of Chapters 6 and 7 are unable to do. As dispatchers well know, peak demands for service are almost always accommodated by assigning priorities to calls, and responding to the more urgent calls as rapidly as possible. Lower priority calls are left unassigned until units become available and are not needed for new high priority dispatches. This procedure gives the patrol force a great deal of flexibility in providing needed service during busy hours without seriously compromising essential services. Being able to accommodate priority dispatching is an important aspect of analysis methodology.

It is also highly desirable to be able to include in the analysis procedures command and control center operations such as incoming calls, dispatching operations, and the communications links between the center and the patrol units. Such a complete simulation can then be used not only to analyze different dispatch strategies, but any other aspects of the system. Specifically, it can serve the following purposes:

- Detailed investigations of operations throughout the city or in parts of the city.
- Evaluations of new technologies being considered for adoption.
- Training to increase awareness of system interactions and the consequences of everyday police decisions.
- Developing new criteria for monitoring and evaluating existing systems.
- Assessing the contributions of reduced time for command and control operations on overall response time, which is as important as reduced travel time (see Fig. 1).

Several models have been developed to simulate a complete police command and control system. These can be used directly or adapted to the requirements of a particular police department, or a model can be developed specifically for a given department either by outside consultants or by the department's or city's own programming personnel.

The simulation technique used in the following example is limited to patrol activities and does not include the complete command and control function; however, it is consistent with our discussion of patrol force allocation as distinct from overall command and control operations.

8.1 Patrol Force Simulation

The type of simulation required for evaluation of dispatching strategies (or for the other purposes mentioned above) is one that is quite similar to the model described in the preceding chapter for beat design. It must contain a description of the geographical area to be served, in a form that can be interpreted by the computer. A set of small cells can be used, as in the previously described model, or the computer can work with a master street index that includes the coordinates of all intersections in some common system of coordinates. If cells are used, they must be small enough that all their characteristics can be assumed to exist at the center of the cell (in other words, that they can be considered as points in the determination of travel distances and as the source of calls for service).

Once the geographical area is defined in computer-readable form, the boundaries of beats (and precincts, if city-wide analyses are to be made) are defined in the same form. This would already have been done if a beat design study had been made.

Since the calls for service were projected in the first step of our procedure, this information should already be available. It will include the data on calls for service listed in Table 9 (a more detailed list than that given in Table 3). It assumes that the simulation will be used to generate output data for each hour of simulated operations.

The computer simulation operates by going through the same operations as a real police system handling the same load of calls for service, in the sense that it allows for each operation a length of time that is realistic for that operation (a fixed length for predictable times such as travel over a known distance, a variable time for random times such as intervals between calls or service times). Since the computer is not actually performing the operations, however, it does not take an hour of computer time to simulate an hour of actual operations. Even including the calculations required to generate the random times and to compute travel distances from point locations, the computer requires only a few seconds to simulate an hour of patrol unit operations.

The simulation program accepts a stream of calls for service that are distributed in time, in location, in priority level, and in length of time on scene in the same way as actual calls for service over the time period that is being simulated. This input data results from Step 1 of our procedure, as mentioned above.* The computer also maintains a table indicating the status of all the patrol units, so that like a dispatcher it will know what units are available at any given moment. Nonpatrol activities are not simulated except in the form of a fraction of total patrol unit time during which the unit is neither answering a call for service nor available on patrol. The status table is updated by the computer each time a unit is assigned to an incident and at the end of the service time assumed for the incident (consisting of the travel time plus the randomly selected service time at the scene). The table thus indicates either "available" or "not available" for each unit, with an indication of the reason for the nonavailability such as meals or "other" non-call-for-service activities.

Table 9. Calls for Service Data Used for Simulation Input

Item	Minimum Data	Desirable Data
Rate (mean and deviation)*	Annual totals of incidents by reporting area used in simulation.	Number of calls for each hour of a 24-hour day for each day of the week (also for reporting areas used in simulation). These rates can be modified by seasonal trends if such trends have been observed.
Location	If data is available only by beat, an average rate for each reporting area used in the simulation can be computed. If exact addresses are known, the rates can be defined as above.	Exact addresses are converted to numbers of incidents in each reporting area used in the simulation.
Priority	No priority data used.	Priority categories by percent in each reporting area, each beat, or each precinct.

*This is the same as "average and spread". Deviation or spread is a measure of how widely the events vary from the mean. That is, if the mean arrival rate of calls for service is 6 per hour, will a range of 2 to 10 calls per hour include 90 percent of all hours observed, or 95 percent, or 99 percent?

For each incident in the stream of calls for service, the computer attempts to assign a patrol unit, using whatever dispatching strategy the analyst has selected. The computer must make some assumption about the location of the units, in order to determine which unit is nearest, and compute travel times. The rules for making these assumptions are part of the initial input to the program. At certain times the location of a patrol unit can be assumed to be known: at the beginning of a tour, before it has been dispatched to any incident, it can be assumed to be in its beat (although the location within the beat is not known and is usually assumed to be the geographical or statistical center).** When a patrol unit has been dispatched to the scene of an incident, it can be assumed to be at that location until the end of the service time assigned to that incident

*Departments having a computer-aided dispatch system will have a magnetic tape log of actual incidents and can use this as input rather than an artificially-generated randomized stream of calls.

**If an automatic vehicle location (AVL) system is employed, the location of the unit will be known within the accuracy of the system. The simulation program can be made to assume a random location within the circle of uncertainty, or assume exact knowledge of the unit's location if a highly accurate AVL system is used.

(even though there are exceptions such as arrests and bookings). And if a patrol unit has been in available status for a certain length of time, it can be assumed to be back in its beat. Similar assumptions are made by actual dispatchers in guessing the locations of units in order to select the nearest one for assignment to an incident; these can easily be programmed into the logic of the computer simulation.

Some different dispatching strategies that might be analyzed with such a simulation for their effect on various performance measurements are listed in Table 10.

Since the computer is keeping track of the status of all patrol units at all times, it will not assign a call for service to a patrol unit if all units are busy at the time the call arrives. In this case it will place the call in a queue until a unit becomes available, unless the dispatching strategy calls for preempting units that are answering low priority calls to dispatch them to high priority calls if no other units are available. Additional calls arriving while all units are busy will also be placed in the queue and dispatched in turn as units become available (again unless the priority rules call for dispatching higher priority calls first even though they are lower in the queue).

The length of time to be simulated by the computer run is specified by the user at the start, and when this time has elapsed the computer stops the simulation and prints out or displays the results. These results are also specified in advance, and can be in a number of different forms. If the analyst is interested only in the effect of changing the input variables, or any one of them, on a given performance measure he can request the display or printout of only that data. He can go to any desired addtional level of detail and request output in several different forms if they are of interest. Typical outputs are shown in Table 11. When the simulation is being operated in an interactive mode, the analyst can ask for display of any or all of the parameters of interest, even to the lowest level of detail. Larson reports that the output variables he has most often been interested in are the following:

- Total time required to service an incident (travel time plus time at the scene).
- Work load of each patrol unit, measured in number of assignments as well as time spent on assignment.
- Fraction of assignments preempted.
- Amount of preventive patrol.
- Travel time to the scene of an incident (by patrol unit, beat, or average for the precinct).
- Length of queue at dispatcher station.
- Average and maximum time spent in dispatcher queue.
- Number and proportion of out-of-beat dispatches.
- Number and proportion of dispatch and/or reassignment decisions for which patrol unit position was estimated rather than known.

Table 10. Possible Dispatching Strategies

Patrol unit location at time of dispatch	1. Unit is always assumed to be at the geographical or statistical center of its beat. 2. Unit is always assumed to be at the center of its beat unless it has just completed a previous call. 3. Unit is assumed to be at the location of its last incident until some specified interval (say 10 minutes) after the time the last incident is assumed to have been completed, after which it is assumed to be at the center of its beat. 4. For systems having an automated vehicle location system, unit is assumed to be at the last location indicated by that system.
Selection of patrol unit for dispatch	1. Unit selected is always the unit in whose beat incident is located. 2. Unit selected is always the nearest available unit (according to location strategy being used). 3. Unit selected for Priority 1 (or 2) calls is always nearest unit, with lower priority calls being placed in queue if necessary until "home beat" unit becomes available. 4. Nearest unit is selected for Priority 1 calls, regardless of whether it is busy or not on previous incident (preemption policy).
Number of patrol units dispatched	1. One unit always dispatched. 2. Backup units dispatched to Priority 1 calls or other incidents for which backup is provided by department operational procedures.

Table 11. Patrol Force and Dispatching Simulation (from Ref. 15)

SAMPLE LEVEL 1 OUTPUT

Statistical summaries – District No. 15
The average patrol unit spent 34.21% of its time servicing calls.
Average response time to high priority calls was 6.40 minutes.
Average response time to low priority calls was 7.27 minutes.
Average travel time was 3.19 minutes.
Average total job time was 34.59 minutes.

SAMPLE LEVEL 2 OUTPUT

Statistical summaries – District No. 15
An average of 34.21% of time of all units was spent serving calls.
The following units were substantially below this figure:

Unit No.	Unit Type	%
4	Wagon	0.00

The following units were substantially above this figure:

Unit No.	Unit Type	%
1	Sector Car	79.14

Average times for each type of call were as follows (stated in minutes):

Priority	Dispatch Delay	Travel Time	Response Time
1	0.00	1.60	1.60
2	5.06	3.40	8.46
3	0.00	0.00	0.00
4	3.72	3.55	7.27
	3.62	3.19	6.81

The average travel time was 3.19 minutes, 10.53% of calls incurred a queuing delay due to car unavailability.
0.32 = Average extra miles traveled due to not dispatching closest car.
Average total job time (travel time + time at scene) by priority was:

1. 77.54 minutes
2. 37.45 minutes
3. 0.00 minutes
4. 18.05 minutes

The average queue length for each type of call was:

1. 0.00
2. 0.51
3. 0.00
4. 0.43

The maximum delay in queue for each type of call was:

1. 0.00 minutes
2. 35.39 minutes
3. 0.00 minutes
4. 33.46 minutes

Table 11 (contd)

SAMPLE LEVEL 3 OUTPUT

District Summary

	Parameter	Overall Average
1.	Work load (%)	34.2
2.	Response time (minutes)	6.8
3.	Travel time (minutes)	3.2
4.	Extra distance (miles)	0.3
5.	Total job time (minutes)	34.6
6.	Number of calls preempted for higher priority	= 0 (0%)
7.	Number of calls assigned to unit on preventive patrol	= 17 (89%)
8.	Number of calls assigned to unit assigned to sector	= 17 (89%)
9.	Number of calls assigned to cars other than closest	= 7 (37%)

Workload by Priority (percent)

Patrol Unit	1	2	3	4	Total
1	47.4	17.6	0.0	14.2	79.1
2	0.4	17.3	0.0	7.1	24.8
3	0.7	19.7	0.0	12.5	32.9
4	0.0	0.0	0.0	0.0	0.0

Calls Assigned to Unit on Preventive Patrol

Patrol Unit	No. Calls	Percent
1	6	100.0
2	6	85.7
3	5	83.3
4	0	0.0

- Fraction of dispatch decisions in which the patrol unit dispatch was not the nearest available one to the incident, and the extra travel distance and time resulting from these nonoptional dispatches.

8.2 Command and Control System Simulation

We have already mentioned the usefulness of a simulation program for the overall command and control system, which can determine loading and waiting times for complaint board stations, dispatch stations, and communications channels as well as utilization of patrol units. Purely mathematical techniques have not been developed for this purpose because of the extreme complexity of so doing.

Although not illustrated here, a general simulation of this type was developed for the mobile digital communications manual (JPL SP 43-6 Rev. 1), and is described briefly to acquaint the planner with this useful program. A flow diagram of the program is shown in Fig. 4. It consists basically of two separate elements, representing the base station and the patrol units, respectively. Beginning with the base station sequence (on the left), calls for service are generated and placed in a queue for the attention of the complaint board operator (CBO). Some calls are not passed to the dispatcher but referred to other elements of the agency, such as the detective bureau, for action. Those calls that are referred to the dispatcher form a queue to wait for the attention of the available dispatcher. One or more dispatchers can be assumed, and the program continuously monitors each dispatcher's activity so that it can determine when he will have completed his previous task. This status-monitoring function also measures dispatcher loading (percentage of the total time he is handling calls, assigning units, acknowledging messages, etc.).

Once the call reaches the dispatcher, a specified time is allowed for the dispatcher to examine the information, determine what action is required, and select a patrol unit on the basis of patrol unit location and availability.

Each call is assigned a priority, and the number of backup units, if appropriate. The program automatically clears high priority calls before assigning other dispatches.

The next block represents the operation of contacting the selected patrol unit and giving it the assignment. A certain amount of time is allowed for monitoring and supporting the patrol unit after the dispatch has been made. This voice channel traffic load is based on taped observations of dispatch operations, and consumes a substantial fraction of the dispatcher's time, as well as air time on the RF link.

Upon completion of the service call, a block of time is allocated for the preparation of the dispatcher's report on each call. The program accumulates these blocks to provide the total time the dispatcher spends on a call, including subsequent conversations with the patrol unit working the call.

The patrol unit model begins with a set of patrols, the number specified as an input to the program. At the beginning of the run, each patrol unit is assigned a status (normally "available"). The program monitors channel usage by all patrol units and thus "knows" when the channel is clear. When the channel is clear, the patrol unit sends a status message.

The "dispatch call?" decision block is the link between the base station and the patrol unit with respect to the handling of service calls. At this point, the patrol unit sequence checks the corresponding block of the base station sequence to determine whether or not a dispatch call for that unit exists. If there is none, the model then determines whether or not a patrol-initiated event is to be assumed at this time.

If no patrol-initiated event is scheduled, the model next checks to determine whether the given patrol is scheduled for a break. If it is, the communications block is again used, except that the status reported is "on break" and the program changes the status of this patrol unit accordingly.

Returning to the "dispatch call" decision block, if a dispatch call for this unit has been issued by the base station sequence, the program again uses the communications block to report a change in status (the program changes the status of this unit accordingly).

The time allowed by the program for completion of the service call by the patrol unit is randomly selected from an exponential distribution, with a preset average.

There is some probability that a given service call will involve a data base query. If no query is involved, the program allows a second block of time for preparation of a report and returns to the beginning for a new status assignment for the given patrol unit. If there is a data base query, the communication block is simulated, with the addition of a time increment for transmission of the query and receipt of the response.

The general utility of this simulation program is readily apparent, and should be considered by the planner for his particular needs. A subroutine to randomize the location of the incident and location of nearby units is not in the program as shown in Fig. 4, but can easily be added to give a more precise determination of travel time.

8.3 Summary and Conclusions

The description of simulation methods and results in this chapter should give the planner a good idea of how such a simulation works and the kind of results that can be obtained from it. One of the major advantages of a simulation is that it can easily be modified and refined to represent operations more accurately or to provide new kinds of analysis and outputs. A relatively simple simulation can gradually evolve

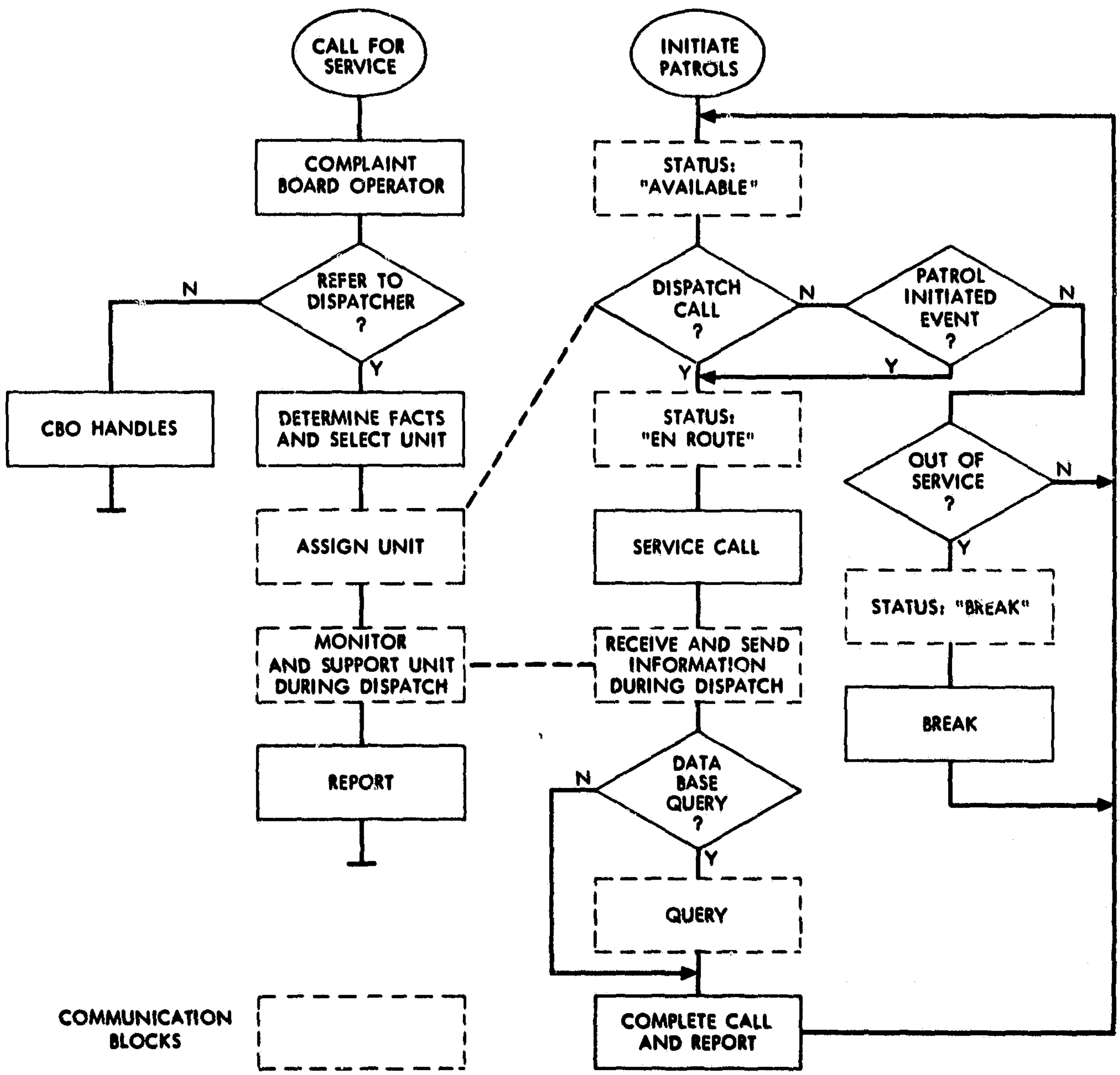


Fig. 4. Command and control system simulation

into a sophisticated model that takes into account a large number of variables. Even the most sophisticated command and control simulation, however, is a relatively simple task for the current generation of computers. Most of the expense is associated with running the program.

If the dispatch center is included in the simulation, as in the program just described, other types of analyses of interest to the planner can be carried out. Radio channel occupancy can be simulated to identify the times and the causes of channel overcrowding. The dispatcher station can be simulated to define the circumstances under which the dispatcher queue becomes too long and causes delays in overall response time. The same analysis can be made of the CBO station, and the combined effects of CBO delay, dispatcher delay, and radio channel delay can be evaluated.

The description of the complete command and control simulation indicates that such a complete, end-to-end simulation would be a very useful tool for a public safety planner for a variety of analyses in addition to those directly related to patrol force allocation. A department considering the acquisition of a computer program (or the development of a program by a consulting firm) for patrol force allocation should have as an ultimate goal the availability of a complete command and control simulation.

9. WHERE TO FIND ADDITIONAL INFORMATION

The planner interested in learning more in general about patrol force allocation studies can select from the list of references items that appear to be on the special topics of interest to him. Those that are not available in the open literature can usually be obtained from the author or the issuing agency.

For the planner who is seriously interested in setting up a patrol force allocation model in his department, it would be advisable to contact a department that has implemented and used such a model. This list changes rapidly as more departments undertake this kind of analysis, but those known to have conducted patrol force allocation studies include:

- Boston Police Department
- New York City Police Department
- Washington Metropolitan Police Department
- San Diego Police Department
- Dallas Police Department
- National Research Council of Canada

REFERENCES

1. Larson, Richard C., *Measuring the Response Patterns of New York City Police Patrol Cars,* The Rand Corporation, R-673-NYC/HUD, 1971.

2. Wilson, O. W., *Distribution of the Police Patrol Force*, Publication 74, Public Administration Service, Chicago, Ill., 1941.

3. Wilson, O. W., *Police Planning*, 2nd ed., Charles C. Thomas, Springfield, Ill., 1958.

4. Wilson, O. W., *Police Administration*, 2nd ed., McGraw-Hill, New York, 1963.

5. IBM Corporation, *LEMRAS Application Description Manual*, Document H20-0629; *Law Enforcement Manpower Resource Allocation System (LEMRAS) Program Description Manual*, Program 5736-G21, Document SH20-0695-0.

6. Chamberlain, R. G., *Law Enforcement Manpower Resource Allocation System (LEMRAS) Evaluation,* JPL Report 650-150. Jet Propulsion Laboratory, Pasadena, Calif. Feb. 28, 1972.

7. *Automated Deployment of Available Manpower (ADAM) Users Manual.* Los Angeles Police Department. July 1, 1975.

8. Ferreira, J., *Comparing Methods of Allocating Patrol Units*, Massachusetts Institute of Technology, Cambridge, Mass. 1975.

9. Larson, Richard C., *Urban Police Patrol Analysis*, MIT Press, Cambridge, Mass., 1972.

10. Chaiken, Jan M., and Peter Dormont, *Patrol Car Allocation Model,* R-1786/1 (*Executive Summary*), R-1786/2 (*User's Manual*), R-1786/3 (*Program Description*), The Rand Corporation, 1975.

11. Larson, Richard C., *Hypercube Queuing Model: User's Manual*, The Rand Corporation, R-1688/2-HUD, 1975.

12. Chaiken, Jan M., *Hypercube Queuing Model: Executive Summary,* The Rand Corporation, R-1688/1-HUD, 1975.

13. Larson, R. C., *Urban Service Systems Course Notes*, Massachusetts Institute of Technology, Cambridge, Mass., 1975.

14. Bammi, Deepak, "Allocation of Police Beats to Patrol Units to Minimize Response Time to Calls for Service," *International Journal of Computers and Operations Research*, Vol. 2, pp. 1-12, 1975.

15. Larson, R. C., "Decision-Aiding Tools in Urban Public Safety Systems", *Sloan Management Systems*, Winter 1972-73.

Additional relevant literature (not cited in text):

16. Bammi, Deepak, *Design of Police Patrol Beats to Minimize Response Time to Calls for Service*, Ph.D. Thesis, Illinois Institute of Technology, Chicago, Ill., 1972.

17. Chelst, Kenneth, *An Interactive Approach to Police Sector Design*, Massachusetts Institute of Technology, Cambridge, Mass., WP-03-74, 1974.

18. Crowther, Robert F., *The Use of a Computer System for Police Manpower Allocation in St. Louis, Missouri,* Department of Police Administration, Indiana University, Bloomington, Indiana, 1964.

19. Heller, Nelson, J.,Thomas McEwen, and William Stenzel, *Computerized Scheduling of Police Manpower, Volume 1: Methods and Conclusions*, PB-232-071; *Volume 2: Evaluations and Program User's Manual*, PB-232-072, National Technical Information Service, U. S. Department of Commerce, Washington, D. C., 1973.

20. Ignall, Edward J., Peter Kolesar, and Warren E. Walker, *Using Simulation to Develop and Validate Analytical Emergency Service Deployment Models*, New York City-The Rand Institute, P-5463, 1975.

21. Jarvis, James P., *Optimal Dispatch Policies for Urban Service Systems*, Massachusetts Institute of Technology, Cambridge, Mass., TR-02-73, 1973.

22. Kolesar, Peter, and Warren Walker, *A Simulation Model of Police Patrol Operations*, The Rand Corporation, R-1625/1-HUD (*Executive Summary*), R-1625/2-HUD/NYC (*Program Description*), 1975.

23. Kolesar, Peter, Kenneth Rider, Thomas Crabill, and Warren Walker, *A Queuing-Linear Programming Approach to Scheduling Police Patrol Cars*, The Rand Corporation, P-5260-1, 1974 (to appear, *Operations Research*).

24. McEwen, Thomas, Project Director, *Allocation of Patrol Manpower Resources in the Saint Louis Police Department*, Vols. I and II, Report of the St. Louis Police Department, 1968.

25. Smith, Spencer B., et al., *Superbeat: A System for the Effective Distribution of Police Patrol Units and Superbeat Program Manual*, Illinois Institute of Technology, Chicago, Ill., 1971.

26. Urban Sciences, Inc., "Computer Simulation of the Boston Police Department," 177 Worcester Street, Wellesley, Mass., 1971.

27. Urban Sciences, Incorporated, "Police Resource Allocation Program (RAP)," 177 Worcester Street, Wellesley, Mass., 1972.

END