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A COMPUTER SIMULATION OF POLICE DISPATCHING AND PATROL FUNCTIONS

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INTRODUCTION

The first attempt to apply a computer simulation model of the police dispatch and patrol function to the full-scale operations of a police department is currently underway in Washington, D.C. The scope and far reaching potential of the effort is revealed when it is realized that currently in Washington, D.C., there are 138 Scout Car beats and during the course of a year some 3/4 million dispatchable calls for service must be handled.

In order to research this operational environment, a means of testing and evaluating proposed alternative policies and solutions is necessary to give us the ability to conduct controlled scientific experiments. The results of such experiments will enable us to determine which, if any, of the proposed alternative policies will improve the current operations in a measurable way. Within the law enforcement environment, the ability to try new dispatch and patrol concepts has largely been limited to the direct approach of "let's try it out." This limitation has greatly hampered what should be a vital area of law enforcement research.

Direct field experimentation on patrol and dispatch operations is in most cases an inadequate research tool. Our present ability to know which policies stand a reasonable chance of improving operations is extremely limited. Field experiments tend, therefore, to exact high costs in terms of money, morale, and public confidence. The means of conducting controlled tests simply does not exist within the day-to-day patrol activity. The combined effect of uncertainty (e.g., the amount and location of crime), the dynamic interactions between decisions and subsequent events, and the extremely complex interdependencies among the many variables rule out definitive cause and effect conclusions. It is difficult if not impossible to hold "all other things constant" while varying, for example, the amount of preventive patrol in a beat.

As a solution to this limitation, the Metropolitan Police Department, under a grant from the Law Enforcement Assistance Administration (LEAA), entered into a contract with MATHEMATICA, Inc. in order to develop a computer simulation model of the police dispatch and patrol function.

HISTORY

The President's Commission on Law Enforcement and Administration of Justice of 1967 provided great impetus to research in this area. The establishment of the Law Enforcement Assistance Administration in 1968 has led to a small but growing body of valuable work aimed at providing procedures with which police administrators can, in an experimental sense, try out new ideas before actual field testing. This work can be divided into two groups: analytical mathematical procedures and computerized simulation models.

The analytical procedures have been directed towards particular, reasonably well defined problems. For example, a number of strong contributions have been made in the area of allocation of resources. In particular, the work of Larson[3] and Heller[2] may be cited. Heller, working with the St. Louis Police Department, has developed a number of "ready to implement" methods for assigning patrolmen to tours of duty. Larson's paper expands a section of his Master's Thesis at M.I.T., investigating the hourly allocation of dispatchers, complaint clerks, and patrol personnel. Larson was a staff member of the President's Commission, and currently is Associate Professor at M.I.T. as well as an advisor to MATHEMATICA.

Despite the progress which these papers exemplify, investigation of the total police patrol and dispatch system is too intricate and too complex to be handled by available analytic methods. Computer simulation models have attempted to fill this critical void between the "cost" of field experimentation and the limits of analytic methods. It is only by means of such computerized approaches that we can grasp the myriad interlocking activities which encompass the police dispatch and patrol functions. Simulation, in general, is a method of experimenting with complex models, and has been used for years, in particular by physicists and engineers. What is new is the development during the last decade of a set of techniques that provide a means of analyzing very intricate models using digital computers. The goal of a computer simulation is to understand and predict the behavior of complex systems. To prepare a model, the situation is abstracted and put into a form compatible with computer usage. Next, the simulation model is tested to gain confidence that it is a valid representation of the real world problem. Finally, various factors representing proposed changes to the actual situation are tested to gain understanding of the system's behavior, and to discover means whereby the real world system may be improved.

The drawback to simulation models is that they must be handled with great care. The first reason lies in the nature of simulation results. Whenever the model contains stochastic (chance) events, the outputs of simulation runs should be viewed as estimates subject to statistical error. In simulation of police dispatch and patrol, the chance elements, such as the times and location of calls for service, tend to exert a dominant influence. Hence, conclusions comparing alternative procedures must be drawn in a manner that recognizes the statistical errors inherent in the model.

Secondly, good simulation models tend to be rather sensitive to input data. Thus, great care must be taken during the testing phase of model development to ensure that simulation data, as well as the model structure, is as accurate as possible. Finally, it is important to reiterate that computerized simulation models are tools for experimentation. They do not provide specific solutions; the models do, however, allow comparison of possible solutions.

Despite these technical problems, successful, though limited work in this area has been done. Several large manufacturers have achieved excellent results from simulations of their "repairman" dispatch function. A simulation of emergency ambulance service for the City of New York[6] has led to revisions in that city's dispersal of ambulances with very promising results. Within the law enforcement field, the work of Larson[4] and Adams[1] is of particular note. The latter model, although somewhat general, was directed towards the simulation of an aspect of a particular city's dispatch and patrol problems (San Jose, California). Larson's outstanding and pioneering work has been used to investigate a generalized nine unit patrol command with excellent results. Using this simulation model, he has experimented with numerous dispatch strategies, reassignment policies, preemption capabilities, and car location estimators. Comparison of numerous different modes of operation were carried out and are summarized in his recently published book *Urban Police Patrol Analysis*[5]. His results, though limited by the small command being simulated, are a strong testimony to the role and promise of computer simulation for law enforcement agencies. Larson's model is designed about a logical simulation structure and can be applied to any geographic situation. It is this key feature which led us to use this model as the framework for our project.

THE CURRENT PROJECT – AN OVERVIEW

Under a grant from LEAA, the Metropolitan Police Department of Washington, D.C., and MATHEMATICA, Inc., are developing a computer simulation model of police dispatch and patrol functions that will be sufficiently general so that it can be used by other police departments and law enforcement researchers. We feel our work is significant in that it represents the first attempt to model the full-scale dispatch and patrol operations of a police department.

In a general sense, the simulation model will be of value to police administrators in the following ways:

- It will facilitate detailed investigations of operations throughout the city or in a part of the city.
- It will provide a consistent framework for estimating the value of new technologies and new approaches to the patrol and dispatch functions.
- It will provide the probable results of policy changes before such changes are put into effect. Thus we will be able to select the most promising approaches without resorting to the trial and error methods now necessary for evaluating decisions.
- In addition, it will serve as a training tool to
  - increase awareness of the system interactions and consequences resulting from everyday policy decisions and,
  - to develop new dispatchers and to improve the operations of veteran dispatchers.
- Finally, it will suggest new criteria for monitoring and evaluating actual operating systems.

More specifically, we plan to use the simulation to test and evaluate concepts such as the following:

1. What changes will result from dispatching rules based on the priority assigned to a call for service? For example, rules which prohibit the dispatch of patrol cars to low priority incidents at times when the system has a high load level will be investigated. Another example might be to divide the patrol force into two groups, where one group deals exclusively with low priority calls on an appointment basis.
2. What will be the effects of modified or completely new patrol beat structures? In other words, can system performance be improved by adjusting beat boundaries, by eliminating beats altogether and assigning territorial responsibility to small groups of cars, by overlapping beats so that any given area continues to receive preventive patrol even when many patrol cars are servicing calls?
3. What will be the impact of adding or subtracting patrol units? Using more sophisticated performance measures (e.g., requiring

that a given percentage of the highest priority incidents receive a response within a set time limit, the number of units required to patrol an area may not equal the number as indicated by present allocation schemes. For example, we have found that cars in one police district make an average of 3.2 radio runs per tour of duty, while cars in another district average 4.6 runs. This difference may or may not be to the best interest of an equal workload. When the simulation is in use, we will be better able to evaluate workload and how it ties in with the overall service to be rendered the city.

4. Which analytic procedures for allocating manpower are in fact "best" for our city? Recent analytic studies have advanced a number of promising techniques that should allow improved tour scheduling and deployment of patrol manpower. The simulation model will permit us to evaluate these schemes for possible adoption.
5. What impact will new technologies have on the patrol function? We will investigate the effect which various car locator systems may have on police operations. Such investigations will answer questions regarding the locator resolution desired, the impact on dispatch decisions, and the improvements in total operational performance which may be expected.
6. Are there viable techniques for dynamically repositioning patrol units before and after servicing a call? At times, a rash of calls will draw patrol units to a small area, leaving large gaps in geographic coverage. In general, we wish to determine if it is feasible to reposition the remaining units so that future service is maintained at a desired level, given the present conditions.

In addition to these basic questions, we also hope to investigate saturation patrol, the interactions between radio-cars, scooters and foot patrol, the effect of computerizing some aspects of the dispatch function, and the application of random preventive patrol strategies.

SOME DETAILS OF THE SIMULATION MODEL

The following Figure 1 depicts the overall flow chart of the simulation process. Inputs and initial conditions are classified into three groups: Geography, Parameters and Policies. Using this data, beats, patrol assignments, the simulation clock, dispatch queues, etc., are structured during initialization. Calls for Service (CFS) are generated to follow historical or hypothetical patterns. On the basis of dispatch policies, units are assigned to the CFS or are placed in queue. If a unit is assigned, travel, service and report/arrest times are generated using the input parameters. Upon completion of service, a unit may be assigned to a CFS waiting in queue or it may resume preventive patrol, considering the latter as a default assignment.

During processing, operating statistics are gathered and, at the user's option, may be printed out. In addition, provision has been made to display a snapshot of the entire state of the system or to trace a number of units during the simulation. At the conclusion of the model run, summaries of the simulation performance are printed. In the following paragraphs we present a more detailed discussion of two interesting aspects of the model:

1) Geography

The geographic aspects of the simulation model consist of two sets of data: the physical aspect of the city and the structure of police districts and beats.

System Geography
Physical – city blocks Police – districts beats

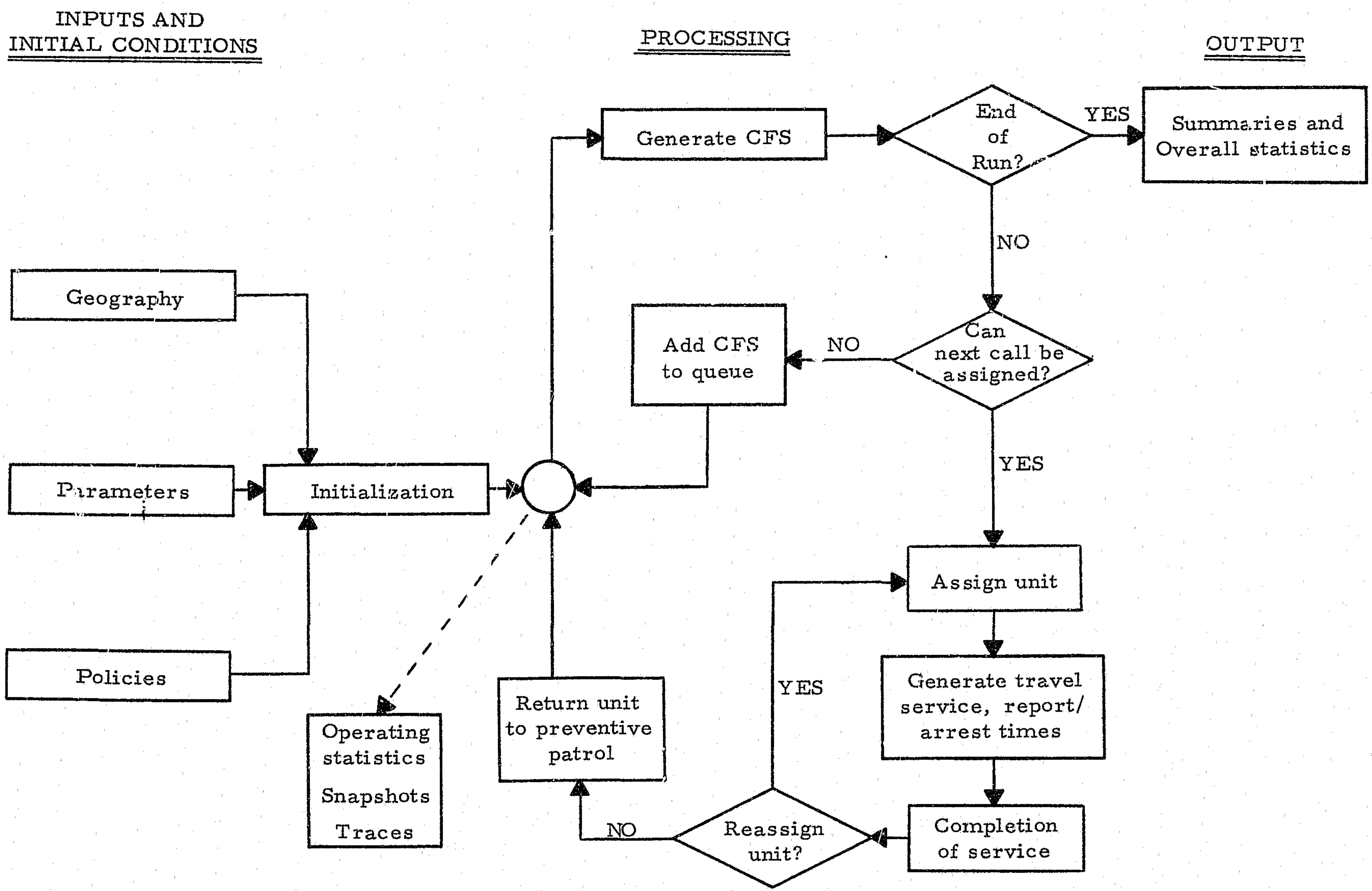
The city's geography is coded by individual city (surveyor) block. Each block has been given an x and y coordinate. These centroid coordinates were derived from census files (census tract and block) and converted to surveyor blocks using a translation tape which had previously been prepared by the District of Columbia government. Thus, the model views the city as a discrete collection of points, and all incidents which occur on a block are assumed to be located at the centroid. The maximum error using this method is a bit larger than 2 x half the length of a city block—a completely adequate level of resolution.*

The city blocks are grouped to form a set of beats. The grouping need not be static or exclusive. In other words, beats may be changed during the course of a simulation run to reflect a different structure for varying tours. In addition, non-exclusivity implies that beats may overlap. The beats in turn are grouped into districts and provisions will be made to allow the districts to be grouped into an additional administrative level.

2) Parameters

The input parameters can be divided into three groups: characteristics of the patrol units, the attributes of CFS, and the properties which delineate the police department's response.

*If such accurate geographical data had not been available, the view of Larson's models (the city as a continuous collection of reporting areas characterized by the coordinates of the vertices of these areas) would undoubtedly have proved adequate.



OVERALL FLOW CHART OF THE SIMULATION MODEL

Figure 1

System Parameters
Units – Number Types Responsibilities Calls – Times Locations Types Priorities Responses – Communication delay times Travel times Service times Arrest/Report times

For each simulation run, the number of patrol units must be specified. In addition, initialization requires entry of the type of unit and its responsibilities (e.g., its "home" beat(s) and district).

Reading "call" and "response" in a broad sense, Larson[5] traced a CFS in time as follows:

TIME	PROCESSES		EVENTS
↓		t_0	Incident Occurrence
	Time to Detection		
		t_1	Incident Detected
	Time to "Calling"		
		t_2	Police Called
	Telephone Queue Waiting Time		
		t_3	Call Received
	Communications Delay Time		
		t_4	Dispatcher Receives Call Information
	Dispatch Queue Waiting Time		
		t_5	Police Unit Dispatched
	Police Unit Travel Time		
		t_6	Police Unit Arrives at Location of Incident
	Incident Service Time		
		t_7	Police Unit Returns to Patrol Car
	Report and/or Arrest Time		
		t_8	Police Unit Back in Service

It should be noted that all events and processes may not be required for a given CFS (e.g., if a patrol unit initiates service of an incident, the time span $t_1 - t_6$ would be zero and the processes and events during this span would not occur).

As no reliable data is available, the time span $t_0 - t_3$ will not be simulated. This span represents the time which elapses while a citizen or automatic device detects the incident and attempts to dial the police and waits for the call to be answered. The simulation thus starts to model a CFS at time t_3, the arrival time of a call. It is this time that is generated by the (CFS) event generator. Before becoming dispatchable, the CFS is delayed for a time $t_3 - t_4$. This interval represents the time required for the telephone clerk to obtain CFS information, to record this information on a complaint form, and to transmit the form to the dispatcher. For a number of high priority complaint codes (e.g., officer in trouble) this time can be very short. Therefore, we had planned to model the communications delay time so that it is dependent on the seriousness priority attribute (see the next section) generated for the CFS at the time t_3 that the call arrives. Analysis of a large sample of delay times has demonstrated, however, that no statistical differences exist between these times for various priorities.

Other attributes of a CFS are also generated at time t_3. They include: location of the call, and whether or not the "call" represents a self-initiated action. The location is generated because the priority class of a CFS depends upon its location. The question of self-initiation must be settled at this time so that the simulation program can determine if the span $t_3 - t_6$ must be modeled. (This time delay in police response to the scene would not occur if the call were self-initiated.)

Once the CFS joins the set of dispatchable calls (time t_4), the simulation algorithm transfers programs control to the Dispatch Algorithm. This algorithm determines if a police unit can be assigned immediately. If the assignment can be made, the assigned unit is "transferred" to the location of the incident. After this, the appropriate statistical quantities are collected and filed. If no assignment can be made at time t_5 (i.e., immediately), the CFS is placed in a list representing a queue of its priority class. As units come back in service (when they complete service of another CFS), the queues are examined for calls to which the free unit can be reassigned. In this manner the dispatch queue waiting time is dynamically modeled, the time span $t_4 - t_5$ being dependent on the load level of the system.

Once a unit is dispatched, a travel time $t_5 - t_6$ is calculated. This time is a function of the location of the incident, the current position of the assigned unit, the priority class of the CFS, and the simulation time load level. The dependence of travel time on location of incident and unit is obvious. The further these are apart, the longer the unit must travel. The priority class of the incident determines the speed at which the unit travels (e.g., a higher speed will be recorded for "robbery in progress" than for "larceny report"). The simulation time load level represents the factor which models "other" conditions (e.g., rush hour traffic, 4:00 A.M., etc.). The time which elapses between t_2 and t_6 is termed police response time and is one of the important measures of police effectiveness. During uncongested periods, travel time tends to be the largest component of police response time. Travel time is, of course, highly dependent upon the dispatcher's choice in assigning a police unit. Thus the simulation will model this aspect in particular detail.

Incident service time ($t_6 - t_7$) represents the time which a police unit spends at the scene of the incident. For the present, it is assumed that during this time the unit cannot be preempted. The final time span ($t_7 - t_8$) models time required (if any) to file a report or to process an arrest. In the next section we will discuss the means whereby estimates of these parameters will be obtained.

DATA COLLECTION AND ANALYSIS

In this section we present a review of the data requirements of the simulation model as well as the sources and methods to be used to satisfy these requirements.

The data may be classified as follows:

- The patterns of calls-for-service (CFS),
- The structure of police patrol, and
- The police response parameters.

The remainder of this section will present an overview of data handling for the first two of the above classifications. The collection of data on the structure of police patrol has been straightforward.

A. The Pattern of CFS

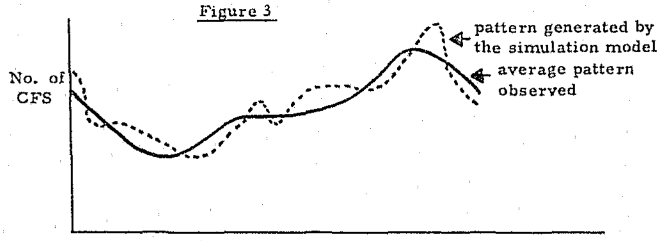
The major parameters of the pattern of CFS are:

(1) the time of arrival,
(2) the geographic location to which the police must respond,
(3) the seriousness of the CFS and hence, the type of response which the police must provide, and
(4) the originator of the CFS.

The number of CFS which arrive during a given hour of the day may be expected to vary due to numerous variables. Of these variables, the effect of some, such as the day of the week and the season of the year may be readily analyzed. The derivation of the CFS arrival pattern by the above temporal patterns has been completed. Using records of all radio runs representing the spring of 1972 data, the number of CFS by hour of day, for each day of the week, averaged over the season is shown in Figure 3 below.

We are thus able to determine the average number of CFS for, say, Mondays between 10:00 P.M. and 11:00 P.M. during the spring. There are numerous other factors which may influence the CFS arriving at the dispatch center during a given hour. The effect of these additional factors (for example, weather, public events, etc.) cannot be calculated within the scope of the present project. This does not mean, however, that these variables will be ignored. Instead of treating the effects of the weather, for example, as a deterministic factor, the simulation will use stochastic (random) arrivals of CFS, where the randomness is limited by the basic temporal pattern shown in the figure. The following Figure 3 serves to display this concept.

Figure 3

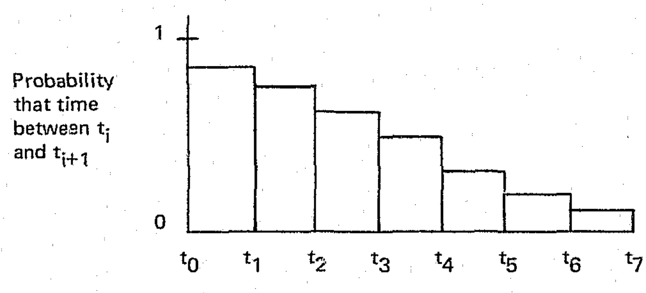


Thus the arrivals of CFS used by the simulation "varies about" the average pattern observed.

In generating the simulated CFS arrival times we make the following assumptions:

(1) CFS interarrival times are negative exponentially distributed, and
(2) CFS arrival times during a given day are properly simulated by randomizing about that day's average distribution.

By interarrival time we signify the time which elapses between successive arrivals of CFS. The assumption that these times are negative exponentially distributed means that we assume that the chance of a given time elapsing between successive CFS follows the pattern:



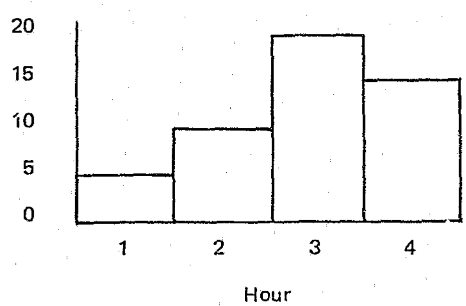
Thus the chance that interarrival times are relatively small is far greater than the chance that the times are large. The importance of assuming this distribution is that it allows us to infer that the total number of CFS arriving during a given day is Poisson distributed.

The second assumption implies that, once the total number of simulated CFS during a given day has been calculated, we may distribute these calls by employing a uniform random number generator. The numbers so generated can then be translated to vary about the average distribution determined by historical records. The discussion below will serve to further clarify the meaning of these concepts.

The first step is to determine the number NCALLS, of CFS which will arrive during the "day." By assumption 1 above, the number is Poisson distributed with a mean equal to the seasonal average for that day. Using a Poisson sampling subroutine such a number is generated.

Having determined the number of calls, NCALLS, which the model will simulate, the arrival times are generated. The method used is best explained by means of an illustrative example.

Suppose we have a 4 hour "day" and that on the average 5 CFS arrive during the first hour, 10 the second hour, 20 the third, and 15 the fourth. A plot of this distribution appears as:



The total number of calls arriving during this average day is 50. Since 5 out of 50 CFS arrive during the first hour, 10% (5/50) of the CFS arrive during hour 1. Similarly 20% (10/50) arrive during hour 2, 40% during hour 3, and 30% during hour 4. A number, x, between 0 and 1 is chosen at random. The chance that x is between 0.0 and 0.1 is by definition 10%. Thus we assign a CFS to arrive during the first hour if x lies between 0.0 and 0.1. In like manner, if the random number, x, is between 0.1 and 0.3 (a 20% chance), a call is assigned to hour 2. If x is between 0.3 and 0.7 (a 40% chance) a CFS is assigned to hour 3, and finally if 0.7 x 1.0, a call is assigned to hour 4. Thus by choosing NCALLS random numbers and allocating times of day based on these numbers and the historical pattern, the random arrival of CFS is simulated.

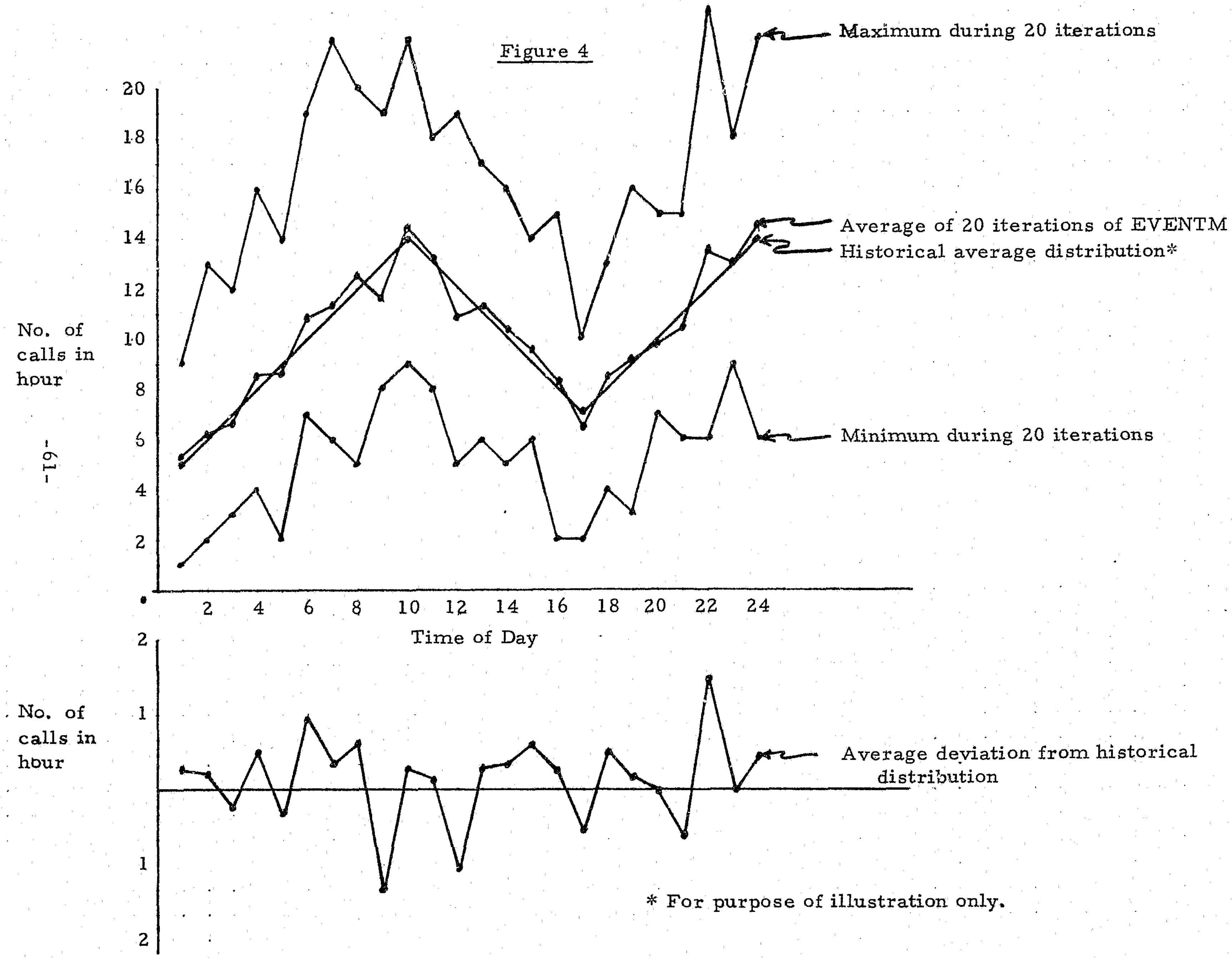
The following Figure 4 illustrates the output of testing the event generation subroutine. The test ran for 20 iterations to determine convergence to and variance about the historical pattern assumed.

The geographic location to which the police unit must respond will be aggregated by city (surveyor) block. All calls-for-service which require response to some part of a block will be assumed to be at the centroid of that block. The spatial distribution of CFS by block can be expected to vary considerably. For example, there is little chance that a CFS requires a police unit to respond to a large office building late at night; at that time however, responses to an entertainment area could be expected to be quite numerous. On the other hand, during morning hours when places of entertainment are closed, the response pattern would be reversed. Such shifts in the spatial distribution of police response will be modeled as follows: Ideally one would like to vary the simulated spatial distribution of CFS to capture each shift in the "real-world" distribution. Such a course is clearly impossible; the core storage requirements (or I/O demands) are outside the computer's capabilities. Thus a compromise must be made between the accuracy of simulation and the "cost" of running the simulation. The method selected to make the compromise is to stratify CFS arrivals into a limited number of "typical" groups, and to use one representative spatial distribution for each group.

The type of response which the police must provide to a CFS has as its main controlling variable the location (block) to which the response is to be made. In other words, response to a family argument is more likely in a residential area, while response to a robbery probably occurs more frequently in a commercial area. To simulate the type of response, data has been collected for each block to determine by groups of complaint codes the chance that a group occurs. As the response location depends on the simulation time load level (load level, for short), the response group also depends on the load level. These two load level dependent distributions were generated using as data all offense reports from June, 1971 to May, 1972.

As one of the major indicators of the quality of a patrol strategy is the response time to a CFS, it is important that self-initiated police actions (response time = 0) be incorporated into the simulation model. The chance that a given call is initiated by a patrolling unit depends heavily on

Figure 4



* For purpose of illustration only.

the load level of the police system as a whole. Thus, when most police units are busy servicing calls, there is little opportunity for preventive patrol. Hence, the chance of a unit spotting a police response situation before it is called into service by the dispatch center is slight. On the other hand, when the service load level is low, most cars will be on preventive patrol and are therefore more likely to initiate service before a CFS request is made through the dispatch center. Once again the load level serves as the mechanism whereby the pattern of self-initiated actions may be modeled. Using sample data, we are preparing a file which will contain the chance that a service action is self-initiated given the load level, the beat number, and the priority of the "call."

B. Response Parameters

As noted above, the major simulation input parameters of police response to a CFS are:

(1) Communications delay time,
(2) Patrol unit travel time,
(3) CFS service time,
(4) CFS report time, and
(5) CFS arrest time.

Since this data is not otherwise available, a number of field sampling studies were conducted. The most important of these was a field sample to determine with reasonable accuracy numbers (2) through (4) above. A select number of scout cars patroling a set of "typical" and representative beats has completed the following short form for CFS which they handled.

The completed forms, representing a sample of approximately 1200 CFS, are currently being coded for analysis. Some difficulty had been anticipated regarding the conduct of the field sample; expecting a police officer to fill in a form before he dashes from his car to answer an emergency call had appeared rather optimistic. However, it appears that a most satisfactory and reliable sample was obtained due to the Department assigning additional officers so that all sample cars were two-man units.

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METROPOLITAN POLICE DEPARTMENT
WASHINGTON, D. C.
DAILY ACTIVITY REPORT

Unit Car No._____ Shop No. _____ Tour of Duty_____

Day of Week ____ Date____ X Car Used ____ Shop No. _____

TIME OF CALL					
TIME ARRIVED					
NATURE OF RUN					
LOCATION OF CAR					
LOCATION OF CALL					
INITIAL ODOMETER READING					
TIME BACK IN CAR					
TIME BACK IN SERVICE					
LIGHTS AND/OR SIREN					
FINAL ODOMETER READING					
REPORT (YES/NO)					
ARRESTS (YES/NO)					

END