A SIMULATION MODEL OF POLICE PATROL OPERATIONS: EXECUTIVE SUMMARY

PREPARED FOR THE DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

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PREFACE

This report describes in nontechnical terms the nature and uses of a computer simulation model of police patrol car operations. The report was written to help police department administrators and other local government officials understand how the simulation model can be applied to studies of police department procedures and policies.

The simulation was originally written under a contract with the New York City Police Department. Preparation of this report and generalization of the simulation program were funded under contract H-2164 with the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development. Among the objectives of this HUD contract are the development, field testing, and documentation of methods for improving the deployment of municipal emergency services.

For more detailed information about the model, readers should consult the user's manual for The New York City-Rand Institute Police Patrol Simulation Model:

> R-1625/2-HUD/NYC, *A Simulation Model of Police Patrol Operations: Program Description*, Peter Kolesar and Warren E. Walker, 1975.

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

SUMMARY

This report presents a nontechnical overview of a simulation model of police patrol operations. It has been designed to help local government officials and police deparment administrators understand what the simulation is, when it should be used, how it works, what information it provides as output, and what data and computer resources are needed to use it. Since the simulation is large, complicated, and relatively expensive to implement and operate, a description is given of the circumstances in which simpler models might be used instead.

The simulation program tracks each of a large number of calls for service from their receipt in the dispatching office, through their dispatch, the arrival of cars at the scene, completion of work, and the cars' return to patrol activity. Its primary use is in the analysis of proposed patrol car deployment policies, such as new dispatching procedures or changes in the number of patrol cars assigned to a region. Results are reported in terms of dispatching delays, response times, and the activities of the patrol cars.

ACKNOWLEDGMENTS

The simulation model described in this report was developed under funding from the New York City Police Department and includes features suggested by members of the Department as well as staff members of The New York City-Rand Institute.

We are particularly indebted to Captain Daniel Cawley of the New York City Police Department, who checked the reasonableness of many of the assumptions that we built into the model. Jack Hagouel and Harry Elam modified the original simulation program. Thomas Crabill helped us ascertain the validity of the program for the New York City environment. We are also grateful to Grace Carter, Jan Chaiken, and Edward Ignall who wrote an Executive Summary of the Fire Operations Simulation, which we used as a basis for this report.

CONTENTS

I. INTRODUCTION

The Police Patrol Simulation Model is a computer program that imitates step-by-step the activities of police patrol cars in the field. It was designed principally to evaluate deployment policies for police patrol cars (response areas, dispatching rules, patrol plans, the usefulness of car locators, etc.).

The computer program tracks each of a large number of imaginary or actual incidents through a series of events. The events include receipt of the call itself, the dispatch of one or more patrol cars, their arrival at the scene, work at the incident, completion of the job, and return of the cars to patrol and availability for another dispatch. The simulation acts much like an "all-knowing" dispatcher who can keep in mind at all times the location and status of all the patrol cars and incidents, but who does not pay attention to police tactics or activites at the scene. The simulation imitates the patrol operations in a region of a city having one or more patrol cars on duty. In New York City it has usually been used to imitate operations within a police precinct in which between 5 and 15 patrol cars are placed on duty.

To use the Police Patrol Simulation, the program must first be adjusted to imitate the current operations of the department being studied. The imaginary or historical incidents chosen to be typical of those actually faced by the department are then run through the program. The program is then changed to imitate some proposed new deployment policy, and the same incidents are run through again. The printout from each run tells what the performance measures, such as response times, workload, dispatching delays, and patrol availability, would be in each case. Then the department's administrator can compare the results of the two runs and see whether one policy is clearly better than another or if he wants to try something else. If the input data for the simulation have been carefully prepared to represent the region accurately, the administrator can have high confidence that the policy that looks better in the simulation will actually be better in the real world.

The simulation model described in this report was programmed, tested, and refined during 1972 and 1973 by The New York City-Rand Institute with the help of personnel from the New York City Police Department. Since then it has been applied to the analysis of police deployment policies in New York [1],* and in 1975 it was modified slightly and used by a team of planners in the Seattle Police Department.

The computer program that constitutes the Police Patrol Simulation Model, and its documentation, are now available to any police department for the cost of duplication on request to The Rand Corporation. It is supplied with test data (used to check the correct operation of the program) and a complete guide for programmers. This material is contained in Peter Kolesar and Warren E. Walker, *A Simulation Model of Police Patrol Operations: Program Description*, The New York City-Rand Institute, R-1625/2-HUD/NYC, January 1975.

This executive summary is a companion to the program description and tells when the simulation might be needed, how it works, what it can be used for, and the amount of effort and expertise required to use it.

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

II. WHEN TO USE THE SIMULATION MODEL

The New York City Police Department has found the Police Patrol Simulation Model to be a valuable tool, but there are several factors to be carefully weighed before a police department attempts to use it. The model is a complicated computer program that can best be used by programmers or analysts who understand computer simulation techniques. It also requires a moderately large computer to run it and a substantial amount of data as input.* For many applications the computer program can be used "as is" in the version documented in [4]. In these cases, only the input data may need to be changed. For other applications, such as testing a new dispatching policy, the program itself may have to be modified to correspond more closely to the system being simulated. This can be done by a programmer who understands the special language used.

The Police Patrol Simulation Model should not be used for certain purposes. It should not, for example, be used to get rough estimates of the current performance of a patrol force. Nor should it be employed to explore preliminary ideas about changes in the number of patrol cars assigned, dispatch policy, or designs of response districts or patrol areas. Other less precise but easier to use models, which will be described later, are available. Moreover, the simulation does not directly suggest any changes as being desirable; it simply predicts what would happen if a proposed change were implemented. Thus its main use is for careful evaluation of a proposed deployment policy that has already been analyzed in some detail.

What is meant by a "deployment policy"? It is the set of departmental rules, procedures, and decisions related to the following:

- The number of patrol cars on duty at various times of day and in various seasons.
- The sector assignments (beats) of the patrol cars.
- The number of patrol cars that respond to various kinds of calls for police service.
- The manner in which calls are queued and particular units are dispatched to each call depending on the priority and location of the incident.
- The circumstances under which patrol cars are relocated to cover another car's sector.
- How the command is divided into sectors.

If a police department administrator is considering a change in any of these characteristics, he is implicitly or explicitly thinking of a new deployment policy, and the Police Patrol Simulation Model may be the appropriate tool to help him evaluate it.

Where do the proposed deployment policies come from? Frequently, experienced police department managers have several ideas for improving the deployment of their department's patrol cars, but they lack hard evidence to justify the changes. Sometimes a change in deployment is desired as a consequence of changing crime

* Details on these points are given in Section V.

patterns, and sometimes it is forced upon a department by budgetary restrictions or other factors.

Whether or not ideas for new deployment policies have already been generated by the department, it is best before using the simulation to try simpler computer programs first if they are suitable. For example, such programs have been developed for analysis of policies involving a change in the number of patrol cars or their sector assignments. These are substantially easier and cheaper to operate than the Police Patrol Simulation Model, and they require much less data. Moreover, they can ordinarily be operated by the city's data services unit without the assistance of outside experts.

One such computer program is the Patrol Car Allocation Model developed by The New York City-Rand Institute [2]. It estimates the consequences of changes in the number of patrol cars assigned to the precincts in a city. It is most useful for determining how many patrol cars should be on duty in various parts of a city at different times of day. The Patrol Car Allocation Model can ordinarily be operated after only a few days of data collection and it takes into account in an approximate fashion many of the key elements of patrol operations, including the unavailability of patrol units and dispatching delays. But it gives only a general picture of changes that may result. A more detailed picture can then be obtained, if necessary, by running the simulation.

Another simple model, which can be used to estimate the effects of changes in the design of response districts or patrol areas, is the Hypercube Queueing Model [3]. The user specifies the number of patrol units, the patrol areas for each one, the preventive patrol strategy, and the dispatching strategy, and then the Hypercube Queueing Model calculates a set of descriptive measures of the patrol system's performance. This model is less expensive to operate than the simulation model, requires somewhat less data, needs fewer statistical skills for interpretation of output, and requires only such programming capabilities as would ordinarily be available at a city's data processing unit. However, it does not provide the detailed results available from the simulation, and it embodies several assumptions about patrol car behavior that make it less realistic than the simulation.

Why may the Police Patrol Simulation Model be needed after these simpler models have been used? In some cases, all proposed changes in deployment policy may be completely analyzed using simple models, and the simulation will not be needed. But in other cases, the greater capabilities and better accuracy of the simulation model will be important. For example:

- Some models report the effect of policies only in terms of average response time and average workload in an entire region. The simulation provides more information, including how often long response times will occur, the workload of individual patrol cars, and the amount of preventive patrol in each sector.
- Some kinds of proposed deployment changes cannot be analyzed at all with simple models. One may be interested in policies that are more complex than those for which analytic solutions are available. Or one may be interested in the interaction of several policy variables that can be separately analyzed, but whose joint effects are difficult to predict.
- Some simple models of necessity make assumptions about such things as work times, travel times, and the number of cars assigned to calls that do

not hold in actual operations. For example, both the Patrol Car Allocation Model and the Hypercube Queueing Model assume that one patrol car handles each call. The simulation model, which does not make these assumptions, provides a way of checking the reliability of the estimates provided by the simpler model. By making selective tests with the simulation model it may be possible to gain confidence in the usefulness of a simpler model for answering certain types of questions.

Even if the special capabilities of the simulation model are not essential, the simulation may still be useful. For example, it has sometimes been found that using the simulation model provides confidence and assurance among decisionmakers that a proposed new policy will actually work as predicted.

Which police departments should consider using the police patrol simulation model? The simulation can be used to model a region having only one car or a region with many. (We have simulated regions with 20 cars, and the model can handle even larger numbers.) However, small departments might find that the considerable effort needed to collect data and set up the model for their own use would not be justified by the probable benefits. In larger departments, if the only changes under consideration are related to the number of patrol units to place on duty or the units' patrol areas, the required analysis can also ordinarily be carried out without the simulation model. If a department wants to study possible changes related to the number of cars initially dispatched to calls or other aspects of dispatching or patrol strategies not assumed by the simpler models, then the police simulation is the most desirable tool to use. It is readily available and, with enough effort, can be adjusted to represent any department's operations very accurately. It can also be used to test the department's performance in detail for a specific historical stream of calls for service.

III. HOW THE SIMULATION WORKS

The Police Patrol Simulation Model is a representation, inside a computer, of a police department's patrol cars, the calls for service to which they respond, and the geography of the region from which the calls emanate and in which the cars patrol. Key happenings in the system are represented by "events." These include: the reporting of a call for police service, the dispatch of patrol cars, the arrival of a patrol car at the scene of the incident, and many others. The computer keeps track of the time at which events would happen in the real patrol system by means of a simulation clock. After each event the computer checks to see when the next event would occur in the real world and updates the clock to this time before processing the new event. In this way, time is compressed so that activities that take several days in the real world can be simulated in a few seconds on the computer. The simulation model is not a "real time" program; that is, it is not tied to actual field operations. When it is running on the computer, whatever may be happening in the police department at that exact moment has no relationship to the operation of the simulation program.

In the simulation, patrol cars, supervisors' cars, patrol areas, city blocks, and calls for service are each described by a set of attributes. For example, an attribute of a city block is its location, which is specified by a pair of coordinates on a map of the city. Many of the attributes are specified as input to a particular simulation run, and these may be changed from run to run to enable several policies to be compared. Thus, one could run the simulation once with all the patrol areas in the region specified to be as they are currently assigned; then, by changing the blocks that constitute each car's patrol area and the dispatcher's nomination lists, one could simulate a possible new patrol configuration. Then the output of the two simulation runs could be compared.

In a computer simulation, decisions made in the real world are translated into mathematical and logical relationships for representation inside the computer. For example, when a dispatcher receives a call notifying him of an accident, he first determines its location. (In the simulation, location is an attribute of the call.) Then, under one possible dispatching procedure, he determines the patrol area from which the call originates and finds the nomination list for that area. The nomination list displays patrol cars in order of their probable distance from the call. He checks to see if the first car on the list is available; if it is, he sends it and is finished. If it is busy (perhaps handling a previous call), he checks to see if the second closest car is available, and so on. If no car in the region is available, the call is placed on a queue and waits until there is a car available to be dispatched. This dispatching procedure, and others, are incorporated in the simulation. If the procedures used by the department are not already included in the simulation, some additional programming will be necessary.

Despite the great accuracy of the simulation, some decision processes are not imitated exactly by the computer. Instead, approximations are made to simplify calculations or data collection. For example, when a car is assigned to a call, the driver must choose the route he will travel to the scene of the incident. In the simulation, however, we do not represent all the streets of the city inside the computer and find the path that the driver would choose. Instead, we use a simple mathematical formula (easily derived from timed patrol car runs) to calculate the expected travel time of the vehicle to the incident. The calculation requires only the coordinates of the car and the coordinates of its destination. The simulation allows the speed of the patrol car and the predominant street directions to be chosen to represent the particular part of the city being simulated. We use this approximation because it is much faster to process by the computer, and it requires the user to gather less data than would be needed to represent the street network of a city accurately. The approximation does not provide accurate travel times for individual trips. It does, however, provide response time estimates that are usually accurate enough to be used to compare policies. If additional accuracy is desired, the user can substitute his own formula for calculating response times.

The Police Patrol Simulation Model was designed to include most aspects of patrol car operations that are necessary to evaluate alternative deployment policies. Accordingly, the model includes a geographic representation of the part of the city being simulated, travel times, location of potential incidents, and the patrol assignments of the cars. The simulation can also represent the discovery of incidents while on patrol ("pick-up jobs"). In addition, it can imitate how patrol cars take meal breaks and how they go out of service for other reasons.

One of the key elements of the simulation model is the description of the incidents to which the patrol cars respond. This description is, in general, a historical sequence of calls. For each call, the description includes:

- Geographical location;
- Type of incident (e.g., crime in progress, auto accident, family dispute, false alarm, etc.) specified by a priority code;
- Duration of the incident, that is, the length of time the principal patrol car at the incident will work handling the call.

Instead of call histories, the user can input a series of calls generated according to some statistical model of the environment. This is usually more difficult to do.

The events in the simulation model are best described by tracing what happens to a particular incident. First, the call is received by the dispatcher, at which time the "job-entry event" occurs. The program uses the dispatching policy to decide which patrol cars to send to the call based on the call's priority and the current status of all of the patrol cars. In the appropriate dispatching routine the arrival at the scene is scheduled for each of the patrol cars selected to respond. For each of these cars, the time of the "arrival event" is computed by determining travel times on the basis of the distance to be traveled.

When the principal patrol car arrives at the scene, "completion events" are scheduled for all cars already there. After a car completes work at the scene, it is either dispatched to a call that has been waiting in queue for an available car, or it is placed on preventive patrol. If it has been servicing a call outside its patrol area and is being placed on patrol, it proceeds back to its patrol area, causing a "patrol area arrival event" upon arrival. Meals and other occurrences that take a car out of service are treated in much the same way as jobs.

It is worth noting that the simulation model does not take into account all aspects of police department operations. For example, no description of a policeman's tactics at the scene is included. Consequently, the simulation cannot be

used to examine the effect on arrests of different numbers of patrol cars fielded, different patrol car manning, or different procedures for preventive patrol (e.g., directed patrol). Also, as presently implemented, the simulation does not allow for the possibility that an emergency situation may worsen or change if response is delayed or inappropriate. A high level of analytical skill and concrete knowledge of the effects of response time on arrests, escalation, etc., would be required to adapt the simulation model for studies of issues such as these.

IV. WHAT INFORMATION IS IN THE SIMULATION OUTPUT

The performance characteristics produced as output by the simulation fall into three categories: (1) response times; (2) queueing delays; and (3) patrol car activity and availability. These performance characteristics are only proxies for measures of patrol effectiveness associated with the goals of a police department (such as crime suppression and arrests). Smaller response times, smaller queueing delays, and higher patrol availabilities, should produce better police service. But not enough is yet known of the relationships among these measures and the primary goals of the patrol force to model them with a reasonable degree of accuracy.

Response time is the elapsed time between the moment a patrol car is dispatched and its arrival at the scene. It is unlikely that one deployment policy will result in response times that are superior to those under another policy for each and every incident. Consequently, the simulation provides statistics describing the response time to groups of incidents. One group consists of all the calls received from a particular response area; another group contains all the calls in a particular priority class. For each group of incidents the simulation provides the average response time and a frequency distribution of response times by type of incident. The frequency distributions can be used to see how often very long response times occur using a particular policy.

The queueing statistics indicate how many calls had to wait for a patrol car to become available before being dispatched and how long the delays were. This information is particularly useful in determining the number of patrol cars to have on duty and in evaluating alternative dispatching policies.

The simulation output also contains information on the activities of each simulated patrol car, showing how it spent its time during the course of the simulation. For each car, the following information is produced: the number of jobs to which it responded within (and outside) its patrol area; the time spent on preventive patrol in its patrol area; the time spent working at incidents; and the time spent out of service. These numbers can be used to determine whether or not a particular deployment policy results in enough preventive patrol in each sector or if it places an undue strain on a particular patrol unit. The simulation also prints a report showing the percentage of time that any given number of cars were on preventive patrol in the simulated region.

The information provided in the simulation model output is both very large and highly detailed. Police department administrators would ordinarily have no occasion to look at all of it. Instead, members of the project team with appropriate statistical skills would identify important results in the output and prepare suitable summarized tables or graphs. Typically, the results from several different runs of the simulation program would be summarized in a single display, so that the administrator could see directly the relative effects of different policies.

The simulation output may show that one policy will improve response times in one area while degrading them in another area. Another policy may reduce the queueing delays for high priority calls. Ultimately, only the administrators who

understand the entire operational and political environment of the department can decide which of the policies already studied appears best, all things considered, or whether still more policies should be analyzed.

V. WHAT DATA AND RESOURCES ARE NEEDED

The Police Patrol Simulation Model requires a symbolic description of the particular region and particular police department being simulated. In order to build this model, much data must be gathered and analyzed. The most important categories of data are as follows: locations at which calls for service can occur and their coordinates on a grid; for each call, its location, priority, and the service time required; the response area for each patrol car; and the travel speeds of police units.

In some cities, the model can incorporate data already collected for other management purposes. For example, if response times are routinely collected, or if geographically coded service-call data are already entered on incident reporting forms, then the effort required to produce the description of the city for the simulation will be much less than it would be without such data.

The simulation also requires a specification of the rules to be used to decide which patrol units to dispatch to calls for service. In some cases these rules will require that sections of the simulation be reprogrammed to reflect specific policies unique to the city.

Using the simulation requires data processing skills to install the model on a computer, statistical expertise for analysis of the output data, and programming skills to make the necessary changes in the simulation. Most police departments do not possess staffs with these skills and will require the assistance of trained personnel from outside the department. In New York, personnel from The New York City-Rand Institute aided the Police Department in using the simulation. However, a team of civilian analysts in the Seattle Police Department were able to implement the model with little outside assistance.

The simulation requires at least a moderately large computer system. (The minimum core storage requirements are 164K bytes for compilation and 142K bytes to run the program. To run the program, the system should also have an auxiliary storage device, such as a tape or disk drive.) The simulation requires a SIMSCRIPT II.5 compiler, a software package that is commonly available at university and commercial computation centers, but is unlikely to have been acquired by a city's data processing unit. If the compiler is not furnished by Consolidated Analysis Centers, Inc., then additional programming changes may be required.

On an IBM Model 360/85, approximately 190 calls for service can be processed in one second of computer time. Using the computing facilities of a commercial service bureau, the typical computer charge for a run simulating about 1,700 calls is approximately $13.00. However, the cost of a typical simulation run may vary greatly from installation to installation. In addition, one should note that the major portion of the cost of using the simulation is likely to be in the preparation of the input data, rather than in computer charges.

A police department considering use of the simulation should plan on allowing at least three months between receiving the program and final analysis of policies. About one-half man-year of effort by analysts and department staff personnel together is required to prepare and use the model properly.

The interested reader wishing to use the simulation may obtain all necessary materials as indicated in the Introduction. A complete description of the program

is given in [4]. The authors of this Report or one of the persons listed in the Appendix may be able to answer questions by telephone or letter, but neither The New York City-Rand Institute nor The Rand Corporation provides full consultation or user services in connection with the products of its research.

REFERENCES

1. Peter Kolesar, *A Simulation Analysis of the Effects of a Car Locator System for New York City Patrol Cars*, The New York City-Rand Institute, to appear.
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3. Jan M. Chaiken, *Hypercube Queuing Model: Executive Summary*, The New York City-Rand Institute, R-1688/1-HUD, 1975.
4. Peter Kolesar and Warren E. Walker, *A Simulation Model of Police Patrol Operations: Program Description*, The New York City-Rand Institute, R-1625/2-HUD/NYC, 1975.

NOTE: See Appendix for addresses.

Appendix

ADDRESSES FOR FURTHER INFORMATION

1. For documentation of the Police Patrol Simulation Model, copies of the program on card or tape, or answers to questions about the program:

   Jan Chaiken
   The Rand Corporation
   1700 Main Street
   Santa Monica, California 90406
   (213) 393-0411

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

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3. Research sponsor:

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END