ON-LINE SIMULATION OF URBAN POLICE PATROL AND DISPATCHING

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Abstract

This paper describes a computer simulation of police patrol forces that has been implemented for resource planning in several police departments. The work is based on the simulation methodology described in Urban Police Patrol Analysis (M.I.T. Press, 1972). Accompanying the presentation will be an on-line computer demonstration of the model using a data base supplied by the Boston Police Department. The developed system is general and can be adapted to suit the needs of any police department in evaluating policies in the following areas:

- o the allocation of preventive patrol effort and the effect of changes in patrol resources and manpower scheduling on the allocations.
- o the design of standard or overlapping sectors.
- o the costs and benefits of an automatic car locator system.
- o response patterns for specialized units (e.g., police ambulances).

I. Introduction

Until very recently police departments did not have access to quantitative decision-aiding tools that have gained wide acceptance in industrial and military settings over the past two decades. Prior to the work of the President's Commission on Law Enforcement and Administration of Justice[1], the urgent need for these tools was not widely known. The Commission's recommendations and the 1968 Omnibus Crime Control and Safe

Street Act[2] provided the impetus for research and development to assist police administrators in addressing a wide range of important policy questions:

- o Is a ten percent increase in manpower justified?
- o What are the tradeoffs between the activities of responding to calls and performing preventive patrol?
- o How is an automatic car locator system to be evaluated?
- o What would be the effects of shifting to one-man cars in parts of the city?
- o Should the tour structure be changed?
- o Should dispatching procedures become more formalized?
- o How should sectors be designed?
- o If ambulance runs were made the responsibility of police, how would overall performance be altered?

That these questions were not receiving systematic attention is evidenced by the fact that far less than one percent of the budgets of police departments had been devoted to research or development and that usually 90 percent or more of the costs of a police department were consumed directly by salaries and fringe benefits.

One response to these needs is the recent development and implementations of a general purpose simulation model of police dispatch and patrol operations. This model is constructed to allow its users to replicate to a very great extent the actual dispatch and patrol operations of most urban police departments, thereby providing a tool to assist in answering the types of questions listed above. Police administrators should find simulation models valuable for the following purposes:

1. They facilitate detailed investigations of operations throughout the city (or part of the city);
2. They provide a consistent framework for estimating the value of new technologies;
3. They serve as training tools to increase awareness of the system interactions and consequences resulting from every day policy decisions;
4. They suggest new criteria for monitoring and evaluating actual operating systems.

A recent article by Colton[3] reporting survey results from approximately 500 police departments revealed that police themselves view the use of computers for resource allocation as the single most important application of computers in the coming years. Simulation models and other analytical tools should play an important role in this work.

This paper will outline the structure of the model developed by the author, its use in an on-line interactive mode, and its current implementation status in several large U.S. cities. Accompanying the oral presentation of the paper will be a demonstration of the model, using data derived from the implementation at the Boston Police Department (Boston, Massachusetts).

II. Overall Model Structure

The simulation works in the following way: Incidents are generated throughout the city, distributed randomly in time and space according to observed statistical patterns. Each incident has an associated priority number, the lower numbers designating the most important incidents. For instance, a "priority 1" incident would be "officer-in-trouble," "felony-in-progress," or "seriously injured person;" a "priority 4" incident could be "open fire hydrant," "lock-out," or "parking violation." As each incident becomes known, an attempt is made to assign (dispatch) a patrol unit to the scene of the incident. In attempting this assignment, the computer is programmed to duplicate as closely as possible the decision-making logic of an actual police dispatcher. In certain cases this assignment cannot be performed because the congestion level of the force is too high; then, the incident report (which might in actuality be a complaint ticket) joins a queue of waiting reports. The queue is depleted as patrol units become available.

The model is designed to study two general classes of administrative policies:

1. The patrol deployment strategy
2. The dispatch and reassignment policy.

The patrol deployment strategy determines the total number of patrol units, whether units are assigned to non-overlapping sectors, which sectors constitute a geographical command, and which areas are more heavily patrolled than others. The dispatch and reassignment policy specifies the set of decision rules the dispatcher follows when attempting to assign a patrol unit to a reported incident. Included in the dispatch policy are the priority structure, rules about cross-precinct dispatching, the queue discipline, and so forth.

There are several important measures of operational effectiveness that the model tabulates. These include statistics on dispatcher queue length, patrol travel times, amount of preventive patrol, workloads of individual patrol units, the amount of intersector dispatches, and so on.

The simulation program is organized to reflect the spatial relationships inherent in patrol operations, as well as the sequential time nature of events which is common to all simulations. First the spatial or geographical structure is discussed, then the time sequence of events.

II. 1. Geographical Structure

The city, or arbitrary shape, is partitioned into a set of "geographical atoms." Each atom is a polygon of arbitrary shape and size. The atoms are sufficiently small so that any probability density functions over the atom (depicting, for instance, the positions of reported incidents) can be considered uniform over the atom. This does not restrict accuracy of results, because the atoms can be arbitrarily small.

A patrol unit's sector is a collection of atoms. The atoms in the collection need not be contiguous (spatially) or consecutive (in the numerical ordering of atoms.) In general, each atom may belong to any number of (overlapping) patrol sectors.

A patrol command (for instance, "precinct," "district," or "division") is also a collection of atoms. Each sector must be fully contained within a command.

The technique that is essential if one is to structure the geographical data in this way is the point-polygon method. This method provides a computer algorithm for answering the following question: "Given a point (x,y) and a polygon specified by its I clockwise ordered vertices $(x_I, y_I), (x_2, y_2), \ldots, (x_I, y_I)$, is the point (x,y) contained within the polygon?" The basic idea of the method, which is fully discussed by S. Nordbeck[4], is to extend a ray in any direction from the point in question; if the ray intersects the sides of the polygon an odd (even) number of times, the point is (is not) within the polygon. The method is completely general and does not require any special properties (for example, convexity) of the polygon. It is particularly well suited for machine implementation, since the tests for intersection are quickly performed on a computer.

In the simulation model the point-polygon method provides a convenient way to generate samples (x,y) uniformly distributed over a geographical atom. The atom, which is a polygon of arbitrary shape, is enclosed in the smallest rectangle fully containing it. Then, using two random numbers, a candidate point that has a uniform distribution over the rectangle is obtained. If this point is also within the polygon, it is accepted as the sample value; otherwise it is rejected and new points generated until one is accepted. The probability that any candidate point will be accepted is equal to the ratio of the area of the polygon (A_p) to the area of the rectangle (A_R). The number of candidate points that have to be generated until one is accepted is a geometrically distributed random variable with mean A_R/A_p. For reasonably compact polygons, this number, reflecting sampling efficiency, is usually less than 2 (and often quite close to 1).

II. 2. Time Sequence of Events

The simulation is an event-paced model. That is, once a certain set of operations associated with one event is completed, the program determines the next event that occurs and updates a simulation clock by adding to the present time the time until the next event. The program then proceeds with the set of operations associated with that event. Once the clock reaches some maximum time (T_{max}), the simulation is terminated and summary statistics are tabulated and printed out. One completed run of the simulation entails inputting data, initialization of simulation status variables, executing the program for an equivalent time T_{max}, and printing the summary statistics.

We do not have space here to provide details of the various dispatching algorithms or patrol deployment policies, but we provide a brief discussion of the important parameters at each point in the simulation.

The main type of event that occurs is a reported incident or a "call for police service." The times of occurrence of calls are generated as in a Poisson process with rate parameter LAMBDA (=average number of calls per hour). The greater the value of LAMBDA, the more likely it is that the system will incur congestion (saturation) of resources. The location of the call is determined from historical patterns which indicate the fraction of calls that originate from each atom; given the atom of the call, its spatial location within the atom is assumed to be uniformly distributed. The priority of the call is determined from historical data which may vary by atom.

Once the position and priority of the incident are known, the program executes a DISPATCH algorithm that attempts to assign a patrol unit to the incident. This algorithm is governed by the dispatch policy specified by the user. One component of the dispatch policy specifies the geographical area from which a unit may be dispatched:

Option 1: Only assign a unit whose patrol sector includes the geographical atom containing the incident (a sector policy)

Option 2: Only assign a unit whose precinct or district designation is the same as that of the incident (a precinct or district policy)

Option 3: Only assign a unit whose division* designation is the same as that of the incident (a division policy)

The particular option on a given run is usually specified at the start of the run, although the user may choose to use the interactive feature to alter the dispatch policy during the course of a run.

Given that a patrol unit is within the correct geographical area for a particular incident, the algorithm then determines whether the unit is considered "eligible for dispatch" to this incident. This determination focuses on estimated travel time to the incident, the priority of the incident, and the current activity of the patrol unit. In general, the user may specify a dispatch policy that allows very important incidents to preempt (interrupt) patrol units servicing incidents of lesser importance. In addition, the "importance" of preventive patrol may vary with each unit, thereby giving the user the capability of assuring at least some minimal level of continuous preventive patrol.

If no unit is found eligible for dispatch, the reported incident is inserted at the end of a queue of other unserviced incidents. There may be separate queues for each command and each priority level.

*A division contains several precincts or districts.

If at least one unit satisfies the eligibility conditions, one is selected for dispatch according to a prespecified criterion such as minimal expected travel time. The assigned unit's priority status and position are changed accordingly.

A second major type of event occurs when a patrol unit completes servicing an incident. A REASSIGNMENT algorithm is then executed that either (1) reassigns the returning unit to an unserviced incident or (2) returns the unit to preventive patrol. The eligibility conditions regarding priorities, travel distances, and geographical areas, which are necessary to specify a dispatch policy, are also an integral part of the reassignment policy. In addition, it is necessary to specify how one unserviced incident is given preference over another. This part of the reassignment policy, called the reassignment preference policy, parallels the queue discipline in ordinary queuing systems.

II. 3. Location Estimation

If not all available position information is used or if the unit is performing preventive patrol, the method of estimation of patrol unit position must be specified. Three options are available, one which simulates the information provided by an automatic car locater system, and two which simulate estimation guessing procedures that are commonly found today in most police operations.

II. 4. Simulation Variables

The simulation program can tabulate statistics on any algebraically defined variable. The variables that have been most often recorded in our studies are:

1. Total time required to service an incident, that is travel time plus time at the scene.
2. Workload of each patrol unit (measured in total job assignments and in time spent on jobs).
3. Fraction of services preempted.
4. Amount of preventive patrol.
5. Travel time of a unit to reach the scene of the incident.
6. Dispatcher queue length.
7. Dispatcher queue wait.
8. The number of intersector dispatches.
9. The fraction of dispatch and/or reassignment decisions for which the car position was estimated, rather than known exactly.
10. The fraction of dispatch decisions which were nonoptimal, in the sense that there was at least one available unit closer to the scene of the incident.
11. The extra distance traveled as the result of a nonoptimal dispatch assignment.

As will be discussed below, each variable may be tabulated at any one of several levels of aggregation.

III. On-Line Interactive Capabilities

During the past two years a great deal of effort by J. Williamson, R. Couper, and

C. Vogel* has been devoted to implementing an easy-to-use on-line Input/Output package with the simulation. This effort has resulted in a program that is readily usable by someone without detailed knowledge of computer operation, the simulation logic, or statistics.

The core of the I/O package is a sequential tree structure that presents to the user the options that are available to him. If the user expresses interest in a particular option, details of use are printed out, the level of which is determined by the responses of the user. Default options are standard, so that if the user does not know what to do at a particular point, a simple carriage return yields additional helpful information. A sample "I/O session" is depicted in Figure 1.

Once the initial I/O session is completed, the user has specified the following: the particular geographical data base he wishes to employ (these data are usually stored on disk), the dispatch procedures, the method of car location estimation, the length of the run, and whether he desires to trace the simulation (and possibly interact with it) while in progress.

Following completion of the simulation, a "LEVEL 1" output is printed. A sample is shown in Figure 2. This contains a small number of highly aggregated statistics describing the run: average travel time, average total response time (including queuing delay), average workloads, etc. The LEVEL 1 output contains no statistical jargon (for instance, "variance" or "sample size") and no program variables. It is self-contained and self-explanatory. We have found LEVEL 1 to be quite useful for introducing police planners and administrators to the capabilities of the simulation and for quickly eliminating runs with obviously poor performance characteristics.

At this point the user may request LEVEL 2 output. A sample is shown in Figure 3. As can be seen, this level is less aggregated and provides average values of many variables by priority level. We expect that a sizable number of users will find the information presented in LEVEL 2 adequate for certain high-level planning and decision-making problems (e.g., determining overall manning levels).

If the user desires even more detail, he now requests portions of a LEVEL 3 output. A sample is shown in Figure 4. As one can see, this level presents many detailed statistics and can be of great assistance in very fine-grain planning problems, for instance, sector design. We expect that very experienced users will usually demand LEVEL 3 output before making decisions affecting actual operating procedures in the field or at the dispatcher's position.

Regarding the other on-line capabilities, we have found that the TRACE option (which prints out the details of each call, assignment, and reassignment in real-time) assists new users in learning of the operation of the model and in

*All of Urban Sciences, Inc. of Wellesley, Massachusetts.

developing a good intuition for system operation. We also have in mind the use of the TRACE option for training dispatchers in new dispatching procedures. In this mode of operation, the computer would request the user to make the dispatch or reassignment decision at the appropriate times (and the standard DISPATCH and REASSIGNMENT algorithms would be by-passed). Once the "dispatch-user" settles on a particular strategy that he wishes to test in detail, he can stop the TRACE, input the control parameters describing his strategy, and run the model for a sufficiently long time to obtain reliable statistics.

IV. Implementations

IV. 1. Boston, Massachusetts

To date, the model has been implemented in detail for the city of Boston[5] and used in a preliminary way in a number of other cities. The Boston implementation requires call-for-service data for each of over 800 "reporting areas" (geographical atoms) and for each of four priority levels. Boston is partitioned into 12 districts (patrol commands), with a total of approximately 90 radio-dispatchable patrol units in the field at any one time. The model has already been used to analyze the effects of various automatic car locator systems for the city. It is currently being used to perform sector redesigns and to determine the effects of adding additional "district-wide" cars to certain districts during heavy workload hours. Deputy Superintendent John Bonner hopes to educate field commanders in its use so that many decisions that are made at the district level could be made with the assistance of the simulation model.

IV. 2. Washington, D.C.

A somewhat different off-line version of the model is being created and implemented for the Washington, D.C. Metropolitan Police Department, under the technical guidance of Mathematica, Inc. and with the support of the Law Enforcement Assistance Administration. Here the city's geographical structure is modeled as a set of discrete points, rather than polygons, each point corresponding to one city (surveyor) block. For Washington, D.C. this represents approximately 6,000 points, or sufficiently fine-grain detail to make the model useful for sector redesigns for the 138 Scout cars distributed throughout the city. The selection of a point geography was based on detailed block-level statistics that are available for Washington, D.C. and on the fact that an off-line model need not produce rapid turn around times (in the same sense as an on-line real-time model). This effort started in January of 1972 and is reported in periodical publications of Mathematica, Inc. and the Washington, D. C. Metropolitan Police Department.

IV. 3. New York City

In August 1972 the New York City Police Department contracted with the New York City Rand Institute to adapt the on-line simulation and related allocation tools* to the special requirements of New York City and to implement these tools for analysis of the entire patrol force (distributed throughout 75 precincts in over 700 regular radio-dispatchable patrol cars, plus special-assignment cars and radio-dispatchable foot patrolmen). The Department hopes eventually to provide each precinct commander with a readily understandable set of on-line decision tools, with easy terminal access from each of the 75 precinct station houses. Thus, as in Boston, it is hoped that these tools will be used for short-term decentralized decision-making, as well as for longer-term, centralized resource allocation and planning and research. As of this writing this work is still in the planning stages, but its progress will be documented in reports from the New York City Rand Institute.

IV. 4. National Research Council of Canada

During the past year or so T. Arnold and F. R. Lipsett of the Radio and Electrical Engineering Division of the National Research Council of Canada have reprogrammed the version of the model detailed in Ref. [7], in order to adapt the programs to their computing system. Their work is currently in progress, aimed at determining the potential usefulness of simulations to small police forces. Recently they have started simulating a co-operating police force near Ottawa which operates with 5 sectors and 5 patrol cars. They anticipate preliminary documentation of this work by January 1973.

*See, for instance, the resource allocation algorithm described in Chapter 5 of Ref. [8].

IV. 5. Demonstrations in Other U.S. Cities

The New York City Rand Institute, as part of a contract with the U.S. Department of Housing and Urban Development, is demonstrating the use of the on-line simulation model in a number of cities. This is done by identifying cities with expressed interest in quantitative tools to assist planners and decision makers, selecting a subset of these cities, and traveling to the cities with a portable computer terminal which can be connected to the central computer in either Waltham, Massachusetts or San Francisco, California via a simple telephone call into a nation-wide WATS* line network. The long range goal in this work is to assess the usefulness of the model in cities with diverse characteristics, to introduce system planners and decision-makers to the notion of using a simulation model, and to arrive at recommendations for improvement of the model. This work is still in progress and is reported in periodical technical reports published by the New York City Rand Institute.

*Wide Area Telecommunications Service.

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ENTER DISTRICTS TO BE SIMULATED (OR ENTER "ALL")
15
ENTER DISTRICTS YOU WISH TO MODIFY
NONE
DO YOU WANT TO CHANGE ANY VARIABLES?
YES
          SIMULATION VARIABLES AND THEIR VALUES
     1.  LENGTH OF SIMULATION RUN = 2.00 HOURS
     2.  NUMBER OF CALLS PER HOUR =
         DISTR.  1   2   3   4   5   6   7   11   13   14   15
         NO.         8  17   8  12   5   6   4   10    5    5    3
     3.  VEHICLE SELECTION METHOD = STRICT CENTER OF MASS
     4.  SERVICE TIME AT SCENE AND VEHICLE RESPONSE SPEED
         PRIORITY                1   2   3   4
         SERV. TIME (IN MIN.) 33  33  33  33
         RESP. SPEED (IN MPH) 15  12  12  10
     5.  TYPE OF SIMULATION OUTPUT = CITY
     6.  MORE DETAILED INFORMATION
ENTER NUMBER(S) OF THOSE TO BE CHANGED

1,3,5
     1.  ENTER THE LENGTH OF THE SIMULATION IN HOURS =
20.
     3.  THERE ARE 3 VEHICLE SELECTION PROCEDURES, THEY ARE =
     1.  MODIFIED CENTER OF MASS
     2.  STRICT CENTER OF MASS
     3.  THE RESOLUTION OF A VEHICLE LOCATION SYSTEM
     PLEASE ENTER THE NUMBER OF YOUR CHOICE =

2
     5.  DO YOU WANT CITY-WIDE OR DISTRICT SIMULATION OUTPUT?
DISTRICT
```

FIGURE 1

SAMPLE I/O SESSION WITH

POLICE DISPATCH AND PATROL SIMULATION

11 A

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

FIGURE 2

SAMPLE LEVEL 1 OUTPUT OF
POLICE DISPATCH AND PATROL SIMULATION

11 B

DO YOU WANT TO SEE LEVEL 2 STATISTICS?
YES
STATISTICAL SUMMARIES - DISTRICT NO. 15

AN AVERAGE OF 34.21% OF THE 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 BELOW THIS FIGURE:

UNIT NO.	UNIT TYPE	%
1	SECTOR CAR	79.14

AVERAGE TIMES FOR EACH TYPE OF CALL WERE AS FOLLOWS (STATED IN MIN.)

PRIORITY	DISPATCH DELAY	TRAV. 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
ALL CALLS	3.62	3.19	6.81

THE AVERAGE TRAVEL TIME WAS 3.19 MINUTES WITH REGULAR SPREAD
10.53% OF THE CALLS INCURRED A QUEUING DELAY DUE TO CAR UNAVAILABILITY
0.32= AVER. EXTRA MILES TRAV. DUE TO DISPATCHING OTHER THEN CLOSEST CAR

THE AVERAGE TOTAL JOB TIME (TRAV. 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 0.00
3 0.00
4 0.00

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

FIGURE 3

SAMPLE LEVEL 2 OUTPUT OF
POLICE DISPATCH AND PATROL SIMULATION
11 C

DO YOU WANT TO SEE LEVEL 3 STATISTICS?
YES

DISTRICT SUMMARY

	PARAMETER	OVERALL AVERAGE	STANDARD DEVIATION	MAXIMUM VALUE
1.	WORKLOAD (%)	34.2	28.6	79.1
2.	reSPONSE TIME (MINUTES)	6.8	10.9	39.8
3.	TRAVEL TIME (MINUTES)	3.2	2.0	10.5
4.	EXTRA DISTANCE (MILES)	0.3	0.4	1.2
5.	TOTAL JOB TIME (MINUTES)	34.6	49.2	227.3

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%)

FOR WHICH PARAMETER DO YOU WANT A FURTHER BREAKDOWN?

	------WORKLOAD BY PRIORITY------				
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%

DO YOU WANT MORE DETAIL FOR ANY OTHER PARAMETERS?
YES
FOR WHICH PARAMETER DO YOU WANT FURTHER BREAKDOWN?
7
BY PRIORITY?
NO
FOR WHICH UNITS?
ALL

CALLS ASSIGNED TO UNIT ON PREVENTIVE PATROL

PATROL UNIT	NO. CALLS	PER CENT
1	6	100.0%
2	6	85.7%
3	5	83.3%
4	0	0.0%

FIGURE 4

SAMPLE LEVEL 3 OUTPUT OF
POLICE DISPATCH AND PATROL SIMULATION

12 A

Acknowledgments

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Other technical details of the model are found in Reference 8.

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