VALIDATION OF A POLICE PATROL SIMULATION MODEL

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ABSTRACT

In 1973 The New York City-Rand Institute developed a simulation model of police patrol activities for the New York City Police Department. In order to demonstrate to the Department that the simulation was an accurate description of its field operations, and could be used for analyzing policy decisions, a validation experiment was conducted. Field observations were made to gather data on actual event sequences which were then compared with simulation event sequences. Details of the experiment and a discussion of the results are presented.

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I. INTRODUCTION

This paper describes the results of an empirical validation of the patrol car simulation model that was developed by The New York City-Rand Institute for the New York City Police Department (NYCPD). The simulation models the process of receipt of calls for police service, the assignment of these calls or "jobs" to patrol cars, the travel of the patrol cars to the scene, the servicing of the job by the car or cars for some time interval, and the release of the cars for reassignment to other jobs or to resume patrol. The activities of a single command region are modeled by imitating the space-time behavior of individual patrol cars on a grid map on which individual city blocks are represented. The simulation is driven by an input stream of jobs requiring police service. The deployment and assignment of patrol cars is modeled in imitation of the rules and practices of the New York City Police Department as derived from the stated operating policies of the Department and from our firsthand observation of operations in the field.

The primary purpose of the simulation is to enable the NYCPD to evaluate alternative patrol deployment policies without undertaking costly and potentially dangerous field experimentation. The model also serves as a research tool for analysts whose job it is to develop and evaluate policy options and to create and test simpler analytic models for use by the Department. A complete and detailed description of the model is given in [1].* Some description of its use in evaluating deployment changes and validating other models is given in [2].

Validation of a model such as this simulation presents a dilemma. Although it is the standard test of validity, we may not be strictly concerned with the question, "Does the model accurately depict reality?" Since the purpose of the model is to answer policy-related questions, we may want to pose the validation question as, "Does the model correctly identify the significant consequences of alternative policies at least accurately enough for us to distinguish them from each other?" That is, if one policy is actually better than another, will the simulation show it? In the context of policy analysis,

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*Figures in square brackets identify references located at the end of this paper.

the latter question, whether the model has policy validity, is more appropriate than the former question, whether the model has representational validity.

One disadvantage of a model that has been checked only for policy validity is that it might be policy dependent; that is, valid only for some types of policies. It would be useful for evaluating one class of policy choices but not another class. For instance, a model that is valid for determining outcomes when the number of patrol cars is varied may be useless for comparing alternative dispatching policies.

A strong argument for producing a representationally valid model is that such a model will also be policy valid. Accurate representation of fundamental events guarantees that the results of policy changes will also be accurately described.

In our validation effort, we were tempted to focus on a precise representation of fundamental events because we knew that if the model were valid in this respect it could be used with confidence for all policy evaluations. However, to require perfectly accurate event-by-event reproduction of the real world is to guarantee failure. In a sequential discrete-event simulation such as ours, it is quite possible that once a single event does not correspond exactly to reality, no subsequent event will. On the other hand, to test validity only in terms of overall long-term statistical performance on some set of measures leaves us in jeopardy of having the model valid for only the policies tested and for only the same set of measures. There is no perfect solution to this dilemma. We attempted to resolve it by testing the validity of the model with respect to a hierarchy of standards, starting with overall statistical measures of performance, then looking at more and more detailed measures, and finally examining the sequence of fundamental events.

In order to perform the validation, we first gathered detailed data on actual activities of patrol cars during two distinct tours of duty. This effort is described in Section III. The simulation model was then run using the observed job input stream. Some minor simulation modifications were made to yield a highly detailed simulation output record showing the results of each fundamental event. These changes are described briefly in Section IV. Comparisons were then made between actual event sequences and simulation event sequences. After comparisons using the data of the first field observation were made, two of the model parameters, travel speed and the number of cars sent to high-priority jobs, were changed so that the model would correspond more closely with the observed events of the first data set. The model was then run using the second set of data and the new parameter values. The correspondence was improved using these values. The results of these comparisons are given in Section V. Section VI contains a discussion of the conclusions of the validation experiment. On the basis of our results, we have concluded that the simulation model is a valid model for evaluating many types of alternative police deployment policies.

In the following section, we present a brief general description of those features of the simulation that are relevant to a discussion of the validation effort.

II. DESCRIPTION OF THE SIMULATION MODEL

The simulation model, which is written in SIMSCRIPT II.5, consists of a mathematical and logical representation in the computer of the process of receipt of calls for patrol service, dispatching of patrol units to service these calls, and servicing of the calls by patrol units. The key elements of the model are:

- *The geography of the region.* A region is represented by a set of points on a grid, each point representing the center of a city block. All incidents and patrol units are referenced to this grid.
- *The patrol resources.* Each patrol unit is represented as a discrete entity in the computer. The computer keeps track of the location, status, sector assignments, etc., of each unit at each instant of simulated time.
- *The operating rules in force.* These are the rules governing the dispatching of units, the priorities assigned to jobs, the sector boundaries, unit response velocities, and work times at jobs. These rules are used by the computer in assigning patrol units to jobs, determining travel times, and determining work times.

The simulation program itself coordinates the above elements so that the proper logical, spatial, and temporal relations are maintained through time. The program also keeps track of the desired performance measures, which are summarized and printed out after the simulation is concluded.

The performance characteristics produced by the simulation fall into the following three categories:

- *Response time measures.* The mean, variance, and distribution of response times (travel times) are gathered by job priority and by sector.
- *Queueing delays.* The mean, variance, and distribution of the dispatching queue sizes and waiting times are displayed by job priority.

- *Car activity.* The proportion of time each patrol unit spends working, on patrol, etc., as well as the mean, variance, and distribution of the number of precinct cars available to respond to calls are displayed.

These performance measures are only proxies for measures of patrol effectiveness; smaller response times and queueing delays, and higher patrol availabilities should yield better police service. But, since the nature of the relationships between these performance measures and crime suppression, arrests, and other primary goals of the patrol force are not known, we have not attempted to incorporate them in the simulation.

The input to the simulation model consists of a sequence of jobs, each of which requires one or more patrol cars. Associated with each job is its entry time, location, duration, and priority. The generation of job streams is not an integral part of the simulation; that is, the job stream is constructed before using the simulation. This is done for several reasons:

(1) The New York City Police Department currently maintains on computer tape historical records of all radio-dispatched jobs that are serviced by its patrol cars. This record can be used as input to the simulation. Instead of this input source, data from special studies and randomly generated job streams can be used.
(2) Computer time is conserved when rerunning the same stream of jobs under several different deployment options since the jobs do not have to be regenerated each time the simulation is run.
(3) Some statistical analyses can be done outside the simulation itself.

We now describe the heart of the simulation model, the dispatch rules and the car working time rules. Each possible job location in the simulation is assigned to a neighborhood. Associated with this neighborhood is an ordered nomination list of patrol cars called ADJACENT.CARS. The order indicates the preference for sending a particular car to a particular neighborhood. One or more of the first cars on the nomination list are called sector cars and, following these, are one or more cars called adjacent cars. The cars are assigned to jobs in different ways for different priority jobs (see the discussion of dispatch rules below).

The simulation keeps track of each car as its status changes over time. When a job enters the simulation, its priority, along with car availability, determines how many cars are assigned to the job. The amount of time a car (or cars) spends working on a job is determined by the duration of the job (an input variable associated with the job). One car, the primary car, always works for the entire job duration. In the case of jobs that are assigned two or more cars, the working times of the second, third, etc. cars are some fixed proportions of the entire job duration.

There are five different job priorities, Priority 1 being the highest. The rules for dispatch are the following.

Priority 1

Priority 1 jobs are the most serious incidents. They generally include robberies in progress, police officers in danger, etc. The simulation dispatches the first MAX.SENT of the available cars on ADJACENT.CARS to Priority 1 jobs. If fewer than MAX.SENT are available, all of the available cars are dispatched. Cars are available if they are on patrol or responding to lower-priority incidents. Starting from the top of ADJACENT.CARS, the cars are assigned as follows:

- *A primary car*--the job is assumed to start upon its arrival at the scene and it works for the entire duration.
- *A backup car*--works for a proportion P.DURATION(2) of the duration of the job, starting work upon the arrival of the primary car. In our simulations, P.DURATION(2) was set equal to .5.
- *Tertiary cars*--all other cars work for a proportion P.DURATION(3) of the duration of the job, starting work upon the arrival of the primary car. In our simulations, P.DURATION(3) was set equal to zero.

If no cars are available, it is assumed that the job is handled by units from another region. The fact that this occurs is recorded, and the job is not considered further by the simulation. Thus, the simulation never queues Priority 1 jobs. The preempting of cars to respond to Priority 1 jobs that are responding to lower-priority calls is the only preempting included in the simulation.

Priority 2

Priority 2 jobs are less serious than Priority 1 jobs. Either one or two patrol cars are assigned to these jobs as follows:

- If no cars are available in the region being simulated, the job is queued for the first available car. Jobs in the Priority 2 queue get assigned units on a first-in-first-out basis before jobs in other queues. A job that is queued gets assigned only one car. One car is sent unless a sector car is available to act as primary car and another sector car or one of the adjacent cars from the neighboring sectors is available. In this case, a primary and backup car are sent. The primary car works for the duration of the job and the backup car works for a proportion P.DURATION(2) of the duration. Work starts upon the arrival of the primary car.

Priority 3

Exactly one car is assigned to Priority 3 jobs. This car can be any available car in the region being simulated. The car dispatched is the first available car on the adjacent cars list associated with the neighborhood from which the call emanated. If no cars in the region are available, the job is queued for the first available car. Priority 3 jobs are dispatched only if the Priority 2 queue is empty.

Priority 4

This priority level covers "pickup" jobs--incidents spotted by patrolmen during the course of their preventive patrol activities. As is the case for Priority 3 jobs, exactly one car is assigned. However, the car assigned will always be a sector car whose area of responsibility includes the block where this incident occurs. Since the car was theoretically at the incident's location when it occurred, the car does not have to travel at all to reach the scene. To imitate this, the simulation instantaneously changes the car's location to the grid coordinates associated with the pickup job. If no sector car is available, the job is placed on the Priority 4 queue. Priority 4 jobs are assigned to--that is, picked up by--cars only when the Priority 2 and Priority 3 queues are empty.

Priority 5

Priority 5 jobs are similar to Priority 4 jobs, but no instantaneous travel is assumed. These jobs are assigned only to a sector car for the neighborhood associated with the job. This class is meant to imitate low-priority jobs that may be assigned to a patrol unit by a supervisor to take a report on a past burglary, etc. If no sector car is available, the job is placed on the Priority 5 queue. A Priority 5 job is assigned only when the Priority 2 and Priority 3 queues are empty and the Priority 4 queue does not contain a job waiting for the same sector car(s).

III. DATA-GATHERING EFFORT

The first step in the validation procedure was to obtain accurate information about actual events on a patrol car tour. We wanted a detailed record of every event that took place in each patrol car of one police precinct. We obtained permission from the New York City Police Department for an observer to ride in the rear seat of each patrol car in the 26 Precinct on the West Side of Manhattan. Each observer was equipped with a clipboard, a flashlight, and data collection forms on which were recorded all events for that car. The data collection form is shown in Appendix A and instructions for its use are given in Appendix B. The form allowed the observer to record chronologically the following events:

1. Start (or resume) patrol.
2. Accept a radio job.
3. Begin response.
4. Arrive at the scene of the job.
5. Accept a pickup job.
6. Accept a station-house job.
7. Inform the dispatcher of job disposition.
8. Begin out of service (e.g., a mealbreak, arrest processing, etc.).
9. End job or out of service.

In addition, a space was provided for observer comments on the types of jobs, the number and identity of other patrol cars responding to a job, etc. The above events are defined more precisely in the instructions in Appendix B.

Observations were made on three different occasions. The first was a two-hour practice run on February 19, 1974 to allow the observers to become familiar with the data form and the nature of the task. After this run, the data form was modified slightly, and on March 5, 1974, the entire 4 p.m. to midnight tour was observed in the 26 Precinct. Ten observers rode in the 10 cars fielded that evening--eight sector cars and two supervisory sergeants' cars. On July 14, 1974, a second 4 p.m. to midnight tour was observed. During each of the observation periods, the data-gathering effort was shared almost equally between personnel of The New York City-Rand Institute and the New York City Police Department.

These observations provided us with a detailed record of the activities of ten patrol cars over two different 8-hour tours of duty. The next step was to prepare the input data for the simulation model and make simulation runs for the two different tours using the observed stream of calls as input.

IV. DATA PREPARATION AND SPECIAL MODIFICATIONS

As described in Section II, the simulation model accepts a job stream with five priority classes. The basic source of the job stream in our case was a computer-based file that is maintained by the Police Department. The jobs contained in this file for the observation periods were supplemented by activities that we observed but which were not recorded by the central computer system. These activities and the methods by which they were handled are:

(1) Pickup jobs--jobs initiated by a patrol car that may or may not be reported to the central dispatch system. These jobs were inserted as Priority 4 jobs unless they were reported to central dispatch. In the latter case, the job record was taken from the computer record.

(2) Station-house jobs--jobs originally assigned by the precinct house rather than the central dispatcher. If these jobs were not reported to central dispatching, they were entered as Priority 5 jobs.

(3) Out-of-service jobs--there are times when a patrol car is not available to accept a radio job due to non-service-related activities, such as mechanical failure, getting gas, etc. If these times were not reported to and captured by the central computer system, they were entered as extra mealtimes for the cars involved.

The priority of all jobs was assigned according to rules the dispatchers are supposed to follow. In the discussion of results in Section V, we shall see that the dispatchers did not always follow these rules.

The standard simulation output provides summaries of the activity of each car including the number of jobs it handled by priority class and the fraction of time spent working and on patrol. Patrol time and working time is broken down into in-sector and out-of-sector components (a sector is a group of contiguous geographical locations that has one or more patrol cars assigned as primary cars for that area). However, normal simulation output does not show the specific identities of each job handled by each car nor does it provide a time record of each car's status during the model run. For the validation effort, we needed this information so we could compare it to the actual sequence of events. A special output report was created that listed the status of each car any time one (or more) of the cars underwent a change in status.

V. RESULTS OF THE VALIDATION

The 26 Precinct in Manhattan is divided into eight sectors. On both of the observed tours, the Precinct Commander assigned one patrol car to each sector and two supervisory cars to cover the entire Precinct, making a total of 10 cars in the field. The eight sectors and their sector cars are identified by the letters A, B, C, D, E, F, G, and H. Supervisory cars are identified as SGS and SGN. These supervisory cars are assigned to jobs only when all other cars are unavailable or when their presence is requested by a patrol car at the scene of a job.

On March 5, a Tuesday night, 32 radio-dispatched jobs were handled by the 26 Precinct on the 4 p.m. to midnight tour. On June 14, a Friday night, 39 radio-dispatched jobs were handled. These figures correspond well with the number of jobs expected to occur in this precinct on the 4 p.m. to midnight tour. Almost all of these jobs were Priority 3 jobs. There were only three Priority 1 jobs on each night, four Priority 2 jobs on March 5, and no Priority 2 jobs on June 14. For the validation runs, priorities were assigned by following the Police Department conventions for car assignment. However, the Department allows the individual dispatcher to use his judgment in changing job priorities from those recommended by the computer system. We shall see that this discretion produces some differences between actual dispatching delays and those generated by the simulation model.

The comparisons we made between the observed behavior of the system and its simulated behavior can be divided into five main categories:

(1) Overall car availability;
(2) Individual car activity characteristics;
(3) Job assignment characteristics;
(4) Job travel time characteristics;
(5) Queueing and dispatcher delays.

Overall Car Availability

One of the most important measures of the simulation's validity is the degree to which it traces the number of cars on patrol. This measure determines both the overall patrol effectiveness and the ability of the system to respond to calls for service. Figure 1 shows the time profile of the actual and simulated numbers of cars on patrol for the observed tour of March 5. The agreement is excellent, the only exceptions being the sudden reductions of short duration in the number of cars on patrol in the simulation when Priority 1 jobs are received. For this simulation run MAX.SENT, the maximum number of cars that could be assigned to a Priority 1 job, was set at 10. Thus, every available car was sent to a Priority 1 job. Looking at the number of cars actually assigned to the Priority 1 jobs on March 5, we saw that a more realistic value of MAX.SENT is three. This was incorporated in the simulation run of the second observed tour. The results are presented in Fig. 2, which shows better agreement between the simulation results and actual results than that of Fig. 1. It is recommended that for future use of the simulation MAX.SENT should be assigned a value of three.

The histograms of car availability are shown in Tables 1 and 2. These are taken from the graphs of Figs. 1 and 2 and show excellent agreement between the actual and simulated results.

Table 1

COMPARISON OF CAR AVAILABILITY
MARCH 5, 1974, 26 PRECINCT, 4x12 TOUR

No. of Cars on Patrol	Percent of Time Available	
	Actual	Simulated
0	0.0	1.4
1	0.0	.1
2	.8	2.1
3	10.8	11.7
4	22.1	14.4
5	22.1	23.2
6	15.4	12.0
7	7.5	18.9
8	14.6	14.0
9	6.7	2.3
10	0.0	0.0

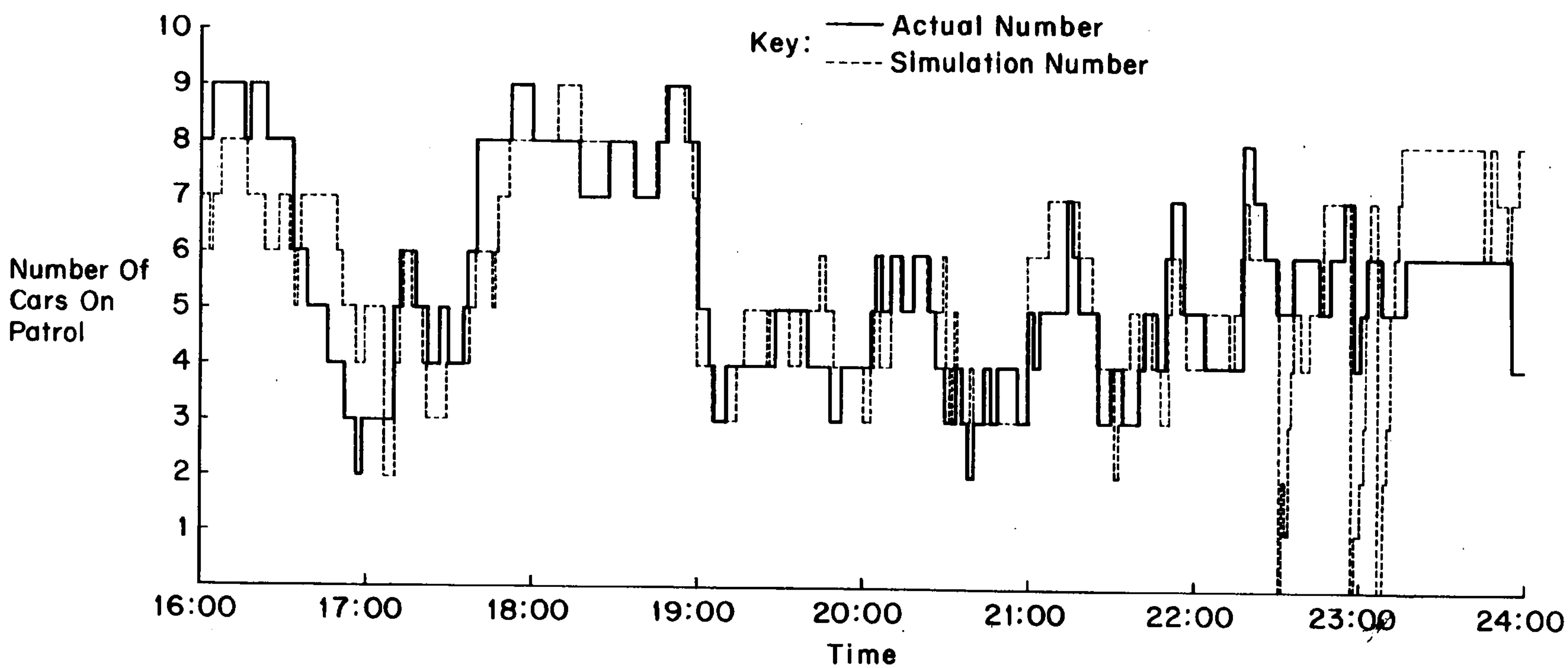

Figure 1: Car Availability, March 5, 1974, 26 Pct., 4 × 12 Tour, 10 Cars Fielded

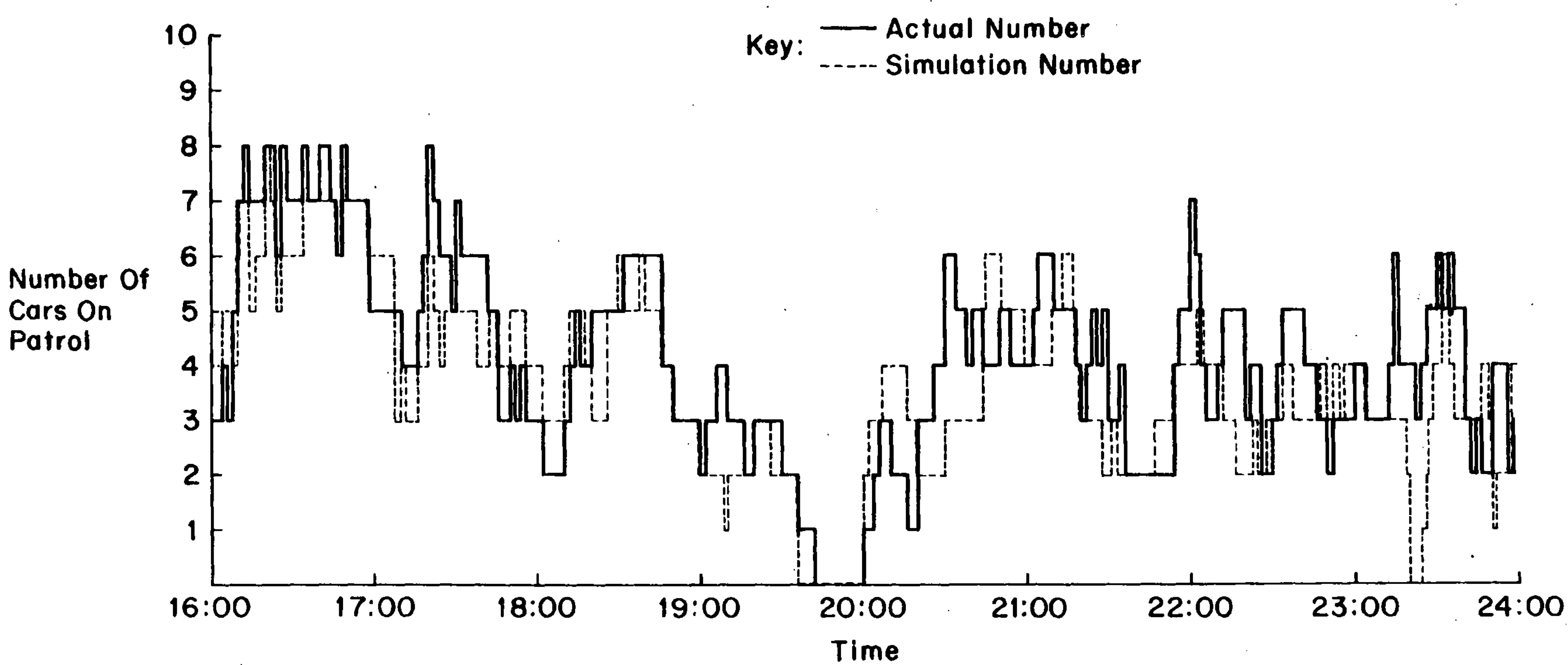

Figure 2: Car Availability, June 14, 1974, 26 Pct., 4 × 12 Tour, 10 Cars Fielded

Table 2

COMPARISON OF CAR AVAILABILITY
JUNE 14, 1974, 26 PRECINCT, 4x12 TOUR

No. of Cars on Patrol	Percent of Time Available	
	Actual	Simulated
0	3.7	5.8
1	2.9	1.0
2	12.5	16.0
3	21.2	28.0
4	18.7	20.4
5	19.1	12.9
6	10.8	10.2
7	7.0	5.1
8	3.7	.4
9	0.0	0.0
10	0.0	0.0

Individual Car Activity Characteristics

In this section, we examine how well the simulation corresponded to the actual patrol system with respect to the number of jobs handled by specific patrol cars and how each car split its time between working and responding, being on patrol, and being out-of-service. Tables 3 and 4 present this information for the two tours.

For the first tour, shown in Table 3, the total number of car-job assignments made by the simulation exceeds the total number of actual car-job assignments. This is because, for this run, MAX.SENT was set equal to 10 and the Priority 1 jobs were assigned to many more cars by the simulation than by the dispatcher. This is seen in Table 5, which presents the actual car assignments for each of the SPRINT jobs. There it is shown that the three Priority 1 jobs on March 5 were assigned a total of 23 cars by the simulation whereas in reality the dispatcher dispatched a total of only 8 cars to these three jobs.

For the second tour, the value of MAX.SENT was reduced to three and the number of simulation car-job assignments (Table 4) is less than the actual number. We expected the number of simulation car-job

Table 3

COMPARISON OF CAR ACTIVITY
MARCH 5, 1974, 26 PRECINCT, 4x12 TOUR, ALL JOBS

Sector Car Designation	Assigned No. of Jobs		% Time on Patrol		% Time Working and Responding		% Time Out of Service	
	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
A	6	5	28.5	50.0	25.2	10.1	46.3	40.0
B	6	9	54.9	44.0	20.4	31.6	24.8	24.4
C	8	10	67.5	51.0	17.9	35.3	14.6	13.8
D	5	6	54.6	54.9	16.3	18.0	29.1	27.1
E	6	4	20.2	27.1	50.8	46.9	19.0	25.8
F	7	9	44.4	45.5	28.8	27.7	26.9	26.9
G	7	8	51.0	57.1	24.2	18.2	24.8	24.8
H	4	5	50.6	73.2	20.4	4.8	29.0	22.1
SGS	6	3	63.3	82.2	20.0	1.2	16.6	16.7
SGN	0	4	84.6	82.0	0.0	2.6	15.4	15.4
All Cars	55	63	52.96	56.7	22.4	19.64	24.65	23.7

Table 4

COMPARISON OF CAR ACTIVITY
JUNE 14, 1974, 26 PRECINCT, 4x12 TOUR, ALL JOBS

Sector Car Designation	Assigned No. of Jobs		% Time on Patrol		% Time Working and Responding		% Time Out of Service	
	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
A	8	9	32.3	27.2	32.5	34.8	35.2	32.9
B	5	5	11.9	11.4	72.0	74.6	16.0	14.0
C	11	10	49.0	54.3	28.1	26.1	22.9	18.2
D	12	12	37.5	29.2	35.4	55.1	26.4	13.3
E	12	12	46.2	27.4	38.7	51.4	14.5	14.6
F	9	10	33.6	30.6	46.0	46.6	20.4	16.7
G	8	7	36.4	25.4	42.7	50.8	20.8	20.8
H	0	0	0.0	0.0	0.0	0.0	100.0	100.0
SGS	5	4	70.6	79.5	16.8	5.0	12.5	12.5
SGN	3	2	73.1	77.4	14.1	1.3	12.7	19.8
All Cars	73	69	39.06	36.31	32.63	34.62	28.14	26.2

Table 5

CAR ASSIGNMENTS, TRAVEL TIMES, AND DISPATCH DELAYS: ACTUAL VS. SIMULATION
MARCH 5, 1974, 26 PRECINCT, 4x12 TOUR, RADIO-DISPATCHED JOBS ONLY

Job No.	Priority of Job	Sector of Job	Actual Car(s) Assigned	Simulation Car(s) Assigned	Actual Travel Time (min.)	Simulated Travel Time (min.)	Actual Dispatch Delay (min.)	Simulated Dispatch Delay (min.)
4886	3	F	F	F	3	2	3	0
5082	3	G	F,SGN	F	4	1	4	0
5253	3	C	H	C	8	0	4	0
5405	3	E	G	D	6	1	12	0
5498	3	D	B	B	2	2	1	0
5767	3	A	C	D	3	3	7	0
6367	3	G	G	G	2	0	1	0
6390	3	A	A	A	2	1	6	0
6478	3	G	F	F	18	1	9	0
6696	3	F	E	H	4	3	9	0
6808	3	D	C	C	3	1	3	0
6947	3	B	B	B	1	1	7	0
7107	3	B	B	B	0	0	1	0
7168	3	B	H	B	N.A.[a]	1	5	0
7173	3	F	E	G	3	1	1	0
7210	3	D	B	B	1	2	2	0
7294	3	C	E	E	5	2	11	0
7609	3	G	G	G	1	1	3	0
7673	2	C	C,A	C,D	1	1	1	0
7748	3	G	G	G	3	1	0	0
7812	3	B	A	D	4	3	4	0
7877	3	G	G	G	0	0	0	0
8002	2	F	F,C	F	2	2	1	0
8061	3	E	F	F	2	2	1	0
8141	1	C	G,SGS	D,B,A,G,H SGN,SGS	2	1	1	0
8176	2	D	D	A	2	1	1	0
8246	3	E	F	F	2	2	0	0
8417	1	A	A,C,H,SGS	A,B,C,F,G,H SGN,SGS	2	0	0	0
8502	3	B	D	SGN	0	4	0	2
8506	1	F	F	F,G,H,D,C SGN,SGS	1	0	1	0
8804	2	F	B,G	F,H	0	1	10	0
8856	3	H	C	B	2	1	2	0
			March 5 Average:		2.780	1.312	3.471	0.062
	Combined Average: March 5 and June 14:				2.897	1.366	5.973	.197

[a]N.A. = Not Available.

assignments to decrease, but it was somewhat surprising that it fell below the number of such actual assignments. The reason is that, on the night of June 14, the dispatcher actually assigned more than one car to five Priority 3 jobs, which nominally call for only one car to be assigned by the simulation. This is seen in Table 6 in the column "Actual Cars Assigned."

One of the simulation output reports divides each patrol car's activity into three components: (1) the percent of time the car spent on patrol, (2) the percent responding and working, and (3) the percent out of service. Each of the tours we observed was eight hours long, so these percentages can be easily converted into hours.

Looking at the percentages given in Tables 3 and 4, we see that the differences between actual and simulated results are generally quite small. The largest differences are for the supervisory cars SGS and SGN in the percent time working and responding. This is because the simulation does not assign these cars to a job unless no other cars are available. However, in actuality, these cars are requested by regular patrol cars at the scene of a job when certain procedural or administrative decisions are required and the patrolmen want to consult a sergeant. Therefore, the simulation tends to understate the amount of work done by supervisory cars.

The percentages averaged over all cars show very good correspondence between the simulation and the actual situation. It is more important for these percentages to agree than for the individual car percentages. When considering each car's breakdown, it is important to realize that only about 30 radio-dispatched jobs were handled by the 10 cars on each tour. The assignment or nonassignment of one job of long duration to a specific car can have a significant effect on its percentage breakdown. This will not be a problem when many more jobs are simulated. Typically, 50-90 tours are simulated in one simulation run rather than the single tours we used for this validation. Of course, we would have liked to have accumulated more data, but gathering the data for a single tour requires 10 man days of effort.

Table 6

CAR ASSIGNMENTS, TRAVEL TIMES, AND DISPATCH DELAYS: ACTUAL VS. SIMULATION
JUNE 14, 1974, 26 PRECINCT, 4x12 TOUR, RADIO-DISPATCHED JOBS ONLY

Job No.	Priority of Job	Sector of Job	Actual Car(s) Assigned	Simulation Car(s) Assigned	Actual Travel Time (min.)	Simulated Travel Time (min.)	Actual Dispatch Delay (min.)	Simulated Dispatch Delay (min.)
5614	3	F	F	G	4	2	30	0
5623	3	C	C	C	4	1	30	0
5690	3	F	F	F	3	5	25	0
6051	1	B	B	B,C,D	2	1	1	0
6086	3	E	E	G	1	3	3	0
6208	3	G	D,G	E	3	3	2	0
6257	3	E	D,F	D	5	1	6	0
6358	3	A	A	A	1	0	4	0
6760	3	E	C	F	2	5	0	0
6951	3	G	F	F	2	2	4	0
7051	3	A	C	E	5	7	1	0
7398	3	F	G	E	2	3	29	0
7514	1	H	C,SGS	C,SGS	6	3	1	0
7520	3	F	C	SGS	1	4	8	12
7729	3	B	A	SGS	4	6	14	0
7917	3	D	D	D	2	1	1	0
7949	3	F	G	F	0	3	19	0
8060	3	E	E	G	2	6	7	0
8270	3	B	A	A	1	4	2	0
8443	3	A	E	E	10	8	2	0
8542	3	B	C	A	2	3	1	0
8555	3	E	F	F	1	4	1	0
8570	3	F	F	D	0	4	11	0
8782	3	E	E,D	F	3	1	1	0
9115	3	A	E,A	A	4	2	1	0
9268	3	F	G	F	2	3	7	0
9324	3	G	C	G	4	1	3	0
9593	3	A	A	A	3	1	4	0
9809	3	F	G,E	F	1	1	7	0
9864	3	D	D	D	2	1	5	0
10084	3	E	C	A	4	6	8	0
10100	3	A	A	SGS	4	2	2	0
10107	3	F	E	SGN	9	3	22	0
10312	3	G	G	G	0	1	6	0
10318	3	E	E,C	F	4	3	2	0
10328	3	A	A	A	?	2	2	0
10442	3	B	(a)	C	(a)	2	36	0
10452	3	C	(a)	F	(a)	3	14	2
10461	1	F	E,G,A	G,A,SGN	5	1	1	0
			June 14	Average:	3.000	2.921	8.282	.369

(a) Job assigned in next tour after midnight.

Job Assignment Characteristics

In this case, we are interested in obtaining answers to: (1) Are the same number of cars assigned to a particular job, and (2) are they the same cars? Tables 5 and 6 show the actual car assignments and simulation car assignments for the two tours. Only jobs taken from the Police Department's computer file are represented here. Other jobs were automatically assigned correctly by using the Priorities 4 and 5 and out-of-service input records as described in Section IV.

Differences in the number of cars sent to a job are due to dispatcher decisions that are not in accordance with the Priority 1, 2, and 3 conventions discussed in Section II. He may assign one car to a job that is nominally a Priority 1 job and he may assign more than one car to a job that is nominally a Priority 3 job. For instance, job number 8506 was assigned one car by the dispatcher even though it is a Priority 1 job (see Table 5). In the first simulation run, the value of MAX.SENT, the parameter in the simulation that determines the maximum number of cars to try to assign to a Priority 1 job, was set equal to 10. Thus, in that simulation run, all available cars are dispatched to a Priority 1 job. Of course, not all of them remain for the entire duration of the incident. The primary car works for the entire job duration, the secondary car works for one half of the job duration, and all other cars are released immediately after their arrival. So, for example, job 8506 has seven cars assigned in the simulation. They all travel to the scene, but only the first two arriving cars work. The others are immediately released and start to return to their sector. The effect of this policy on the simulation results can be seen in Fig. 1, which was discussed above. The number of cars available dips to zero for a brief time after receipt of a Priority 1 job, but quickly returns to the correct level. It is seen in Table 5 that 3 would have been a better value for MAX.SENT than 10. This value was used in the June 14 simulation run. The results of the June 14 run, presented in Table 6 and Fig. 2, show that by using MAX.SENT=3 we obtain a better correspondence between the number of cars sent to Priority 1 jobs in the simulation and in actuality.

In Table 6, jobs 8782 and 9115 are assigned two cars by the dispatcher, but only one by the simulation. These jobs are both radio code 10-10 (investigate prowler, suspicious person, etc.) and, in the dispatcher's view, deserved to have two cars assigned. However, jobs 6760 and 6951 were also 10-10 calls and were assigned only one car. It is impossible to model perfectly such a flexible and judgmental dispatch policy. The results will be useful only if, as we have observed, such departures from normal procedure are not made too frequently, or are not of great consequence when they do occur.

Looking at the 71 jobs in Tables 5 and 6, we see that 60 of these jobs were assigned the same number of cars in the simulation as were assigned by the dispatcher. Seven jobs were assigned more cars by the dispatcher than by the simulation and four jobs (all Priority 1 jobs) were assigned fewer cars by the dispatcher than by the simulation. Over both tours, there were only seven more car assignments to radio-dispatched jobs in the simulation than in actuality.

Turning now to the identification of the sector cars assigned to jobs, the police dispatcher has, for each sector of job occurrence, an ordered list of three cars that he consults for making car assignments. If all three of these cars are unavailable, he uses his knowledge of the precinct geography and car availability to select cars. In the simulation, each job location has a nomination list that contains all 10 cars fielded.

There are two reasons why car assignments made by the dispatcher and the simulation may differ. First, the car to be selected according to the simulation nomination list may not be selected by the dispatcher on the basis of his own judgment. Second, the dispatcher and the simulation may wish to select the same car but the car availability may differ at that time, e.g., the car is available in the simulation but not in actuality.

Looking at Tables 5 and 6, and considering only those jobs that were assigned the same number of cars, we see that of 60 such radio-dispatched (car) assignments, 23 of them were identical matches and 37 of them were not. This lack of agreement causes problems with respect to the representational validity of the simulation, but will affect the policy validity only if the workload balance of the cars differs considerably as a result. In the section on car activity characteristics, we saw that the workload discrepancies are small.

Job Travel Time Characteristics

The simulation model has a response speed parameter for each priority class. In the first simulation run for March 5, this speed was set equal to 20 miles per hour for each priority class. Table 5 shows that the average travel time of the simulation, 1.312 minutes, is considerably less than the observed average travel time of 2.780 minutes. Travel time is defined as the interval between the time a car receives an assignment and the time it arrives on the scene.

After seeing this result, it was decided that for the second simulation run, the speed parameter for all but the Priority 1 jobs would be reduced to 10 miles per hour. Table 6 shows that this gives much better agreement of actual and simulated travel times. It has been recommended that for future simulation of New York City patrol operations the speed for Priority 1 jobs be set at 20 miles per hour and the speed for all other jobs be set at 10 miles per hour.

Queueing and Dispatcher Delays

Because of the small numbers of jobs received during our observations in the 26 Precinct in relation to the number of cars fielded, it can be predicted on the basis of elementary queueing models that there should have been no appreciable delays in job assignment due to the unavailability of patrol cars. Consistent with this expectation, we found that only two radio-dispatched jobs were delayed in the simulation runs.

However, Tables 5 and 6 show that there were actual dispatching delays for almost all jobs. The figures for actual observations in Tables 5 and 6 were obtained from the Police Department's computer logs and are rounded to the closest minute so a figure of zero actually means a delay between zero and one-half minute. In the simulation, dispatch assignments are made instantaneously if at least one car is available, so a zero in those columns actually means a zero delay.

In the police dispatching system, assignment delays can arise in two ways: (1) if all patrol cars are busy, and (2) if the dispatcher is busy with other work, even though at least one car is available. To assign a car to a job, the dispatcher must contact the car by radio, give the patrolmen the job information, and then enter this assignment on his computer terminal. All of these tasks take time. So, even if there are cars available, a job might not be assigned immediately due to the assignment of higher-priority or earlier-arriving jobs. However, these two possibilities do not appear to account for the magnitude of the actual dispatch delays shown in Tables 5 and 6. The average actual delay is 3.471 minutes for the March 5 tour, 8.282 minutes for the June 14 tour, and 5.973 minutes for both tours combined. Figs. 1 and 2 show that all the patrol cars were, in fact, simultaneously busy for only 20 minutes on June 14, and not at all on March 5. Thus, on March 5, it would have been theoretically possible to assign all jobs immediately. Despite this fact, eight of the 32 jobs on March 5 experienced delays of more than 5 minutes. These substantial delays suggest that one or more of the following may be occurring:

(1) The dispatcher's workload is too heavy. He has the responsibility for dispatching the cars in three precincts (we are only looking at one of them) and the situation may be such that his total radio and terminal time requirements are enough to create substantial dispatching delays.

(2) The dispatcher is judgmentally creating a new type of job priority, namely jobs that can be held for dispatch until a specific car becomes available. These jobs may be continually kept at the bottom of the dispatcher's assignment list (which is in his head) for all Priority 2 and 3 jobs. A dispatcher does not follow a strict first-in-first-out rule for dispatching. He uses his judgment so that calls that sound most urgent (even within the same priority class) are assigned first.

(3) The dispatcher may not be pushing himself to keep up with calls. Perhaps his training could be improved and his performance monitored more closely.

It is not suggested here that any one of the above is necessarily true. It has been recommended that the New York City Police Department undertake a careful study of its dispatch operation to try to determine exactly how calls are dispatched, the causes of any delays in dispatch that occur when cars are available, and whether any changes in dispatching procedures would be desirable.

The relationship between response time (dispatch delay plus travel time) and police effectiveness is not known but there is reason to believe that shorter total response times make for better police effectiveness. Looking at the average response time over the two actual tours we observed gives:

Actual average response time = Average dispatch delay + Average travel time

= 5.973* + 2.897 = 8.870 (minutes).

It is clear that dispatch delay contributes more than two thirds of the average response time. Thus, any percentage reduction in dispatch delay would be more than twice as beneficial in reducing response time as the same percentage reduction in travel time.

The fact that the simulated response times include almost no dispatcher delays is not significant in our opinion. Their absence creates a slight time shift in the car availability pattern; cars start working on jobs at later times in actuality than in the simulation, but they also end later in actuality than in the simulation. The car workload balance, car assignments, and car availability are not likely to be affected in any significant manner. Of course, the actual pattern of dispatch delays could be built into the simulation by constructing an internal dispatch delay subroutine but the changes that would result do not seem to merit the effort involved. Moreover, such a modeling effort could be undertaken only after completing a study of dispatching delays as discussed above.

*This average is over all jobs. The average dispatch delay for the six Priority 1 jobs is substantially less.

VI. CONCLUSIONS OF THE VALIDATION EXPERIMENT

The results of the validation experiment showed the following:

- There was a need to recalibrate two parameters of the model, the response velocity of cars and the number of cars sent to Priority 1 jobs. Recalibration of both parameters using data from the first night's observations resulted in excellent correspondence with the results of the second night's observations.
- The simulation of activities occurring after the assignment of patrol cars to jobs is accurately represented. Overall workload measures by car and by sector are accurate, the distribution and time sequence of car availability is accurate, and even the number and identity of cars assigned to individual jobs is quite precise.
- The modeling of dispatching delays is currently unsatisfactory. The model's assumption that the dispatcher himself is not a bottleneck is wrong and needs to be corrected.

Our general conclusion is that the simulation model is a good representation of the actual patrol system--given the above proviso about dispatching delays. We believe that it can be used with confidence to examine policy questions related to: the effect of changes in sector boundaries, the effect of varying the number of patrol cars on duty, the effect of alternate car assignment rules, and the effect of car locator systems.

Appendix A

DATA COLLECTION FORM FOR PATROL CAR OBSERVERS

OBSERVER: ____________________________ Page ___ of ___

Date___Precinct___Car___Tour(Ck) 8x4__, 4x12__, 12x18__, Other(Specify)____________

Type of Patrol(Ck one) RMP__, Supervisory__, Anti-Crime__, NPT__,Other(Specify)______

Time	Start or Resume Patrol	Accept Radio Job	Begin Response	Arrive at Scene	Accept Pickup Job	Accept Station-House Job	Inform Dispatcher of Disposition	Begin Out of Service	Begin In Service (Stationary)	Comments, explanations, location of incident

Appendix B

INSTRUCTIONS FOR USE OF THE DATA COLLECTION FORM

This is a guideline for use of the data collection form. General definitions of the tasks are given. In the light of your experience last Tuesday, bring up any questions you have before we go out on March 5.

Our primary goal is to get an accurate record of the times during the tour that each car is unavailable to accept a radio job. The three categories of this other than any radio calls are:

1. Accept Pickup Job.
2. Accept Station-House Job.
3. Begin Out-of-Service.

We would like an accurate record of which cars respond to each job so please note in the comments column the sector letters of any other cars at a job.

- The leftmost column, labeled time, will be used to record the time at which tasks or events begin.
- The remaining columns will be checked to indicate that a certain task or event has started. The completion of one task will be indicated by the commencement of another task. One exception to this is the task labeled Inform Dispatcher of Disposition, which is intended to be a snapshot record of when the cars report themselves available or unavailable.
- Definitions of the tasks are:
  - (a) *Start or Resume Patrol:* When the car becomes available for accepting calls. Following a job, the car does not resume patrol until the dispatcher has been informed.
  - (b) *Accept Radio Job:* Self explanatory.
  - (c) *Begin Response:* Usually at same time as accepting radio job.
  - (d) *Arrive at Scene:* Self explanatory.
  - (e) *Accept Pickup Job:* Starting a job which is not received by radio, i.e., a job instituted by the patrolmen. A note should be made in the comments column if the job is called into SPRINT. If a parking ticket is being given but both patrolmen are in the

car listening to the radio, they are still on patrol and the pickup job column should not be checked. Check it only when the pickup job makes the car unavailable for other calls.

(f) *Accept Station-House Job:* Starting a job assigned by the precinct house which is not a SPRINT-recorded job and when the car is unavailable to accept a radio job.

(g) *Inform Dispatcher of Disposition:* To be checked when the patrol car informs the dispatcher of its activity, primarily if they are finishing a job or starting an out-of-service time. This event will usually take place at the same time some other task starts, such as resuming patrol.

(h) *Begin Out of Service:* Starting an activity which makes the car unavailable for responding to radio calls. Activities such as meals, being called to the station house, mechanical trouble, etc. This should be checked only when the car would not be given or would not accept a radio job.

(i) *Begin In Service (Stationary):* Starting a task such as report writing, after informing dispatcher that the car is available, while the car remains stationary. This is being kept distinct from patrol to get an idea of how much time is spent in what could be termed "Stationary Available" activity. This would include such things as one patrolman leaving the car while the other remains in the car listening for calls. It would be possible to eliminate this category and simply say that the car is on patrol whenever it is available for response regardless of its movement.

(j) *Comments, Explanations, Location of Incident:* This space can be used for job description, location or type of out-of-service time. Please note the sector number of any other cars that respond to a particular job.

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