Measuring the Response Patterns of New York City Police Patrol Cars

Richard C. Larson
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PREFACE

This Report summarizes the results of a two-week data gathering experiment performed in 1969 for the New York City Police Department. The experiment focused on the delay between receipt of a call from the public at police headquarters and the arrival of a patrol car at the scene of the incident. Such delays can be attributed to the activities associated with processing of calls, the unavailability of patrol cars which may have responded to earlier incidents, and the time required for cars to travel to their destinations. Also of interest were the percentage of time spent by the police officers on various activities and the extent to which cars are dispatched to points outside their own patrol sectors.

During the period of time since this experiment was undertaken, the Police Department has made substantial changes in its procedures related to dispatching patrol cars. The most important change has been the installation of a computer-assisted dispatch system, called SPRINT, which has eliminated the preparation of hand-written incident cards and their transmittal to dispatchers via conveyor belts. The system automatically displays for the dispatcher a list of available patrol cars whose sectors are close to that of the reported incident. Administrative guidelines for dispatchers have also been modified, and the number of patrol cars on duty now varies substantially from morning to evening in precincts which utilize a fourth platoon.

The results described here are nonetheless of interest because many police departments operate according to procedures like those used previously in New York, but comparably detailed data may not have been collected elsewhere. In addition, the information provided in this Report can be
used as a benchmark to determine the extent to which changed dispatched procedures have in fact brought about desired improvements in patrol car response times and selection of the best car to dispatch.
SUMMARY

In 1969 a two-week data-collection effort was conducted with the cooperation of the New York City Police Department. The objective of the experiment was to determine empirically the operating characteristics of the radio-dispatched patrol force and related personnel in the Communications Division, including the percentage of time spent on various activities, the response time to calls for service, the spatial distribution of the force, the dispatching algorithm, and similar issues. The experiment was planned to provide parameter values for existing mathematical models of patrol and dispatch activity, to help check the validity of these models, to provide information which would help us to construct more realistic models, and to give rise to recommendations that would improve operations.

The following is a representative list of results of the experiment, obtained from analysis of 54 precinct-tours:

- The average time between receipt of a call by telephone operators at 911 and dispatch of a patrol unit to the call ranged from 2.4 minutes to over 15 minutes, where the average is taken over a tour. The median value was 5.8 minutes. The larger delays occurred when the dispatcher was forced to enter some of the arriving incident reports in queue. A queue is formed when the patrol force is "saturated," meaning that there are no available patrol units sufficiently close to the reported incident; the queue is depleted as patrol units report completion of...
service on previous dispatch assignments. The delays in queue are particularly large during "workload peaks" which occur during a tour. Since the time of the study, revised operating rules have been implemented (Appendix B) which should reduce these delays, at least for high-priority calls.

- Average time for the dispatched patrol unit to travel to the scene of the reported incident ranged from 3.6 minutes to 9.8 minutes, with a median value of 6.2 minutes. The larger travel times are usually associated with precincts which have relatively large sectors and/or which have relatively large workloads.

- Average travel distance ranged from 0.78 miles to 2.91 miles, with a median value of 1.62 miles. The larger distances were usually associated with precincts in which the "density" of available cars (i.e., average number of available cars per square mile) was relatively low.

- The average time required to service a call at the scene ranged from 16.6 minutes to 49.3 minutes, with a median value of 27.5 minutes. Fully 68 percent of the precinct-tours exhibited average on-the-scene service times differing from the median value by no more than five minutes. Adding approximately six minutes for mean travel time, the average total service time for an incident can be approximated to be 33 or 34 minutes. This value may be modified somewhat when the mixture of incident types is considered for each precinct.

- The average number of radio runs per car (during a tour in one precinct) varied widely from 0.14 to 6.45, with a median value of 2.2.
In addition, five precinct-tours were analyzed in greater detail, yielding the following findings:

- There were several dispatches of distant patrol units at times when other closer patrol units indicated on their data forms that they were "available for dispatch."

- A total of 65 cars were fielded to provide patrol coverage for 91 sectors. Fully 36 percent of the non-sergeant cars were assigned to two sectors, 3 percent were assigned to three sectors. About 8 percent of the sectors were not assigned to any patrol car.

- About 10 percent of the radio runs were of sufficiently high priority to require siren and/or lights.

- Fully 51 percent of all dispatch assignments were inter-sector (rather than intra-sector) assignments. This extent of inter-sector dispatching is predicted fairly accurately by a model developed in Appendix A.

- Twenty-three percent of all dispatches found the assigned car initially outside its own patrol sector(s).

- In examining 24-hour activity profiles, it is not unusual to find reported time spent on fuel and auto repairs by all the cars in one precinct to equal (approximately) the useful time spent by one patrol car during one tour.
ACKNOWLEDGMENTS

We gratefully acknowledge the support of the U.S. Department of Housing and Urban Development, and of the New York City Police Department during the period when data were collected.

Many individuals at the New York City-Rand Institute contributed to the data-gathering and analysis efforts reported in this paper. In particular, Dan Brown wrote the computer programs that analyzed the raw data and suggested several useful ways of displaying results. Barbara Schwartzfarb provided excellent research assistance throughout the data analysis effort. Jan Chaiken, Keith Stevenson, and Sorrel Wildhorn provided many useful suggestions.

We are particularly grateful to the many officers in the New York City Police Department who cooperated in the design, execution, and interpretation of this data-gathering experiment. These included Captain Howard E. Anderson, Inspector Anthony Bouza, Commanding Officer, Planning Division, Deputy Inspector Harry Burns, Captain William Devine, Deputy Inspector John T. O'Brien, now Public Safety Director, New Brunswick, New Jersey, Captain Donald Rowan, former Chief of Patrol Harry Taylor, Inspector Steven Walsh, and the patrolmen and officers of Divisions 8 and 16.
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I. DESCRIPTION OF THE EXPERIMENT

In 1969 a data-collection effort called the "RMP Experiment"* was conducted during the two-week period from February 17 to March 3 in Divisions 8 and 16 in New York City. The objective of the experiment was to determine empirically the operating characteristics of the radio-dispatched patrol force and related personnel in the Communications Bureau, ** including the percentage of time spent on various activities, the response time to calls for service, the spatial distribution of the force, the dispatching algorithm, and similar issues. The experiment was planned to provide parameter values for existing mathematical models of patrol and dispatch activity, to help check the validity of these models, to provide information which would help us to construct more realistic models, and to give rise to recommendations that would improve operations.

In this section we outline the operation of the Communications Bureau and the radio-dispatched patrol force, and we describe the types of data collected. The descriptions refer to a time prior to the installation of the SPRINT computerized dispatch system.

TRACING A CALL FOR SERVICE

Much of the collected data concerned the police response to calls from the public requesting police service. Typically, a citizen attempts to contact the New York Police Department (NYPD) via the emergency telephone

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*In the New York City Police Department, "RMP" refers to Radio Motorized Patrol. An "RMP Unit" is a two-man patrol car that responds to calls for service and performs preventive patrol.

**Now called Communications Division.
number 911, resulting in a sequence of activities represented schematically in Figure 1. Tracing a typical call, we denote by $t_1$ the time at which the number 911 is successfully dialed. At time $t_2$, the call is answered by a police "turret operator" (emergency telephone operator), the delay $t_2 - t_1$ representing telephone queue waiting time. (During this time the caller hears a ringing phone.) The turret operator then gathers information about the call (e.g., type of incident, number of persons involved, address of incident) and decides whether further police service is required. If not, the caller is provided any relevant information and is informed that additional police service is not required. If the call does require the dispatch of an RMP car, the relevant information is recorded on an "incident slip." In either situation, the time the call is terminated is denoted by $t_3$, the interval $t_3 - t_2$ representing the telephone conversation time.

Assuming that further police service is required, the incident slip is completed and forwarded to the dispatcher at time $t_4$, the duration $t_4 - t_2$ representing total turret operator "service time" for the call. Sometime between answering the call and forwarding the incident slip to the dispatcher, the turret operator records on the incident slip the present time, $T_1$, as observed from a wall clock. This recorded time, called "arrival time" on the incident slip, is truncated to the nearest minute and tends to fall close to the termination time of turret operator service on a call.

The incident slip, now transported via conveyor belt, arrives at the dispatcher's position at a time called $t_5$. The dispatcher attempts to assign, or dispatch, an RMP car to the scene of the reported incident. The

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*The times indicated by lower-case letters are theoretically observable, but not all of them were recorded during this experiment.*
FIG. 1: POLICE EMERGENCY RESPONSE SYSTEM: TIMED SEQUENCE OF ACTIVITIES

- $T_1$: "Arrival Time" (Recorded During this Interval)
- $T_2$: Recorded Dispatch Time
- $T_3$: Recorded Arrival Time at Scene of Incident
- $T_4$: Recorded Time Car Completes Service

1. Citizen Dials 911
2. Call Answered by Turret Operator
3. Call Completed
4. Incident Slip Forwarded to Dispatcher
5. Incident Slip Arrives at Dispatcher
6. RMP Car Dispatched
7. RMP Car Arrives at Scene of Incident
8. RMP Car Notifies Dispatcher that Service on Radio Run is Completed

$t_1 - t_2$: telephone queue waiting time
$t_3 - t_4$: telephone conversation time
$t_4 - t_5$: total telephone service time
$t_5 - t_6$: total internal processing time
$t_6 - t_7$: total police response time
$t_7 - t_8$: total RMP car service time
time of dispatch, \( t_6 \), represents the instant at which a designated RMP car confirms, or accepts, assignment to a call. The recorded dispatch time, \( T_2 \), is obtained from a time-stamp clock (truncated to the nearest minute) situated near the dispatcher. The time difference \( t_6 - t_5 \) typically assumes values from 1 minute to 60 minutes or more. The larger magnitudes are caused by patrol force "saturation" in the field, which occurs when there are no available cars sufficiently close to the scene of the reported incident. In such a situation the dispatcher will hold the incident ticket (perhaps in a queue of other unserviced tickets) and assign cars to calls from the queue as the cars become available.

Although the procedure for depleting the queue is quite flexible, allowing the dispatcher maximum discretion, the very great majority of dispatch assignments are to patrol units assigned to the precinct of the reported call. That is, there is very little inter-precinct dispatch, regardless of queue length. Even if cars are available for dispatch to a call, moderate values of \( t_6 - t_5 \), say 5 to 10 minutes, can be incurred by "dispatcher saturation." This occurs when a number of incident slips arrive in a flurry, faster than the dispatcher can physically process them. Thus, the recorded time difference \( T_2 - T_1 \) is an aggregate measure of internal processing time and queueing delay at the dispatcher's position. Clearly, it represents an under-estimate of the time from attempted police contact \( (t_1) \) until dispatch of an RMP car \( (t_6) \).

The service completion time, \( t_8 \), is the time the officer in the RMP car notifies the dispatcher that the unit has completed service on its previous

---

*Supervisors kindly agreed to check the synchronization of the time-stamp clocks and the turret operator clocks several times daily during the experiment, since the time-stamp clocks tended to wander.*
assignment ("radio run") and is again ready for dispatch. The recorded completion time, $T_4$, is time-stamped on the incident slip by the dispatcher shortly after he receives the RMP completion message. The quantity $t_8 - t_6$ is the "total RMP car service time" for the incident, comprising travel time to reach the scene and service time at the scene. A typical value for $t_8 - t_6$ is 35 minutes.

The above description of call processing accurately describes the handling of the great majority of calls received from the public during February and March, 1969. There are, of course, special situations involving preemption of certain activities or assignment of large numbers of patrol units to unusual and urgent situations, but these are not included as a subject of this study.

The recorded times ($T_1$, $T_2$, $T_4$) on the incident slips provided one source of data for the RMP Experiment. Although problems of time truncation, clock inaccuracy, and human error limit the extent of conclusions that can be drawn from these data, the recorded times do represent the best knowledge we have about the system and provide useful indicators of the actual processing times incurred while responding to and servicing a call. In addition to the recorded times, a brief word description of each incident and a "radio run number" were obtained from each incident slip. The word description indicated the type of situation being responded to and suggested the urgency of the call. The radio run number was a special number assigned during the course of this experiment only, so that we could coordinate the incident-slip data with other data recorded in the RMP car.
THE EX1 FORM

A special EX1 form was designed to be filled out by the non-driving or "passenger" officer in each RMP car (Figure 2).* For each dispatch assignment (or radio run), the following information was entered on the form:

- Time at dispatch [col. (b)]
- Radio run number [col. (c)]
- Initial odometer reading to nearest tenth of a mile [col. (d)]
- Nearest intersection at point of dispatch [col. (e)]
- Whether the siren and/or red lights were used [col. (g)]
- Time of arrival at the scene [col. (h)]
- Time returned to the car [col. (i)]
- Final odometer reading [col. (j)]
- Nearest intersection at scene of incident [col. (k)]
- Time that Communications Bureau (CB) was notified of service completion [col. (l)]

The passenger officer can record the first five entries while traveling to the scene, thereby not increasing the time required to arrive. The time of arrival at the scene is recorded just before the officers leave the car, and its recording does not increase response time measurably. All other information regarding the scene of the incident and service completion can be recorded after the officers return to their car. Recording this information did not entail more than a minute of the officers' time in the cases observed.

---

*This particular arrangement of the form was arrived at only after several trial and error 8-hour tours spent by Institute personnel in the rear seat of RMP cars in Precincts 103 and 111 (Queens). Useful suggestions for designing the forms were offered by Jan Chaiken, Joel Edelman, Ike Hunt, Dan Brown, and Sorrel Wildhorn.
FIG. 2: EXI FORM

<table>
<thead>
<tr>
<th>Date</th>
<th>Car Number</th>
<th>Odometer</th>
<th>Time (military)</th>
<th>(to nearest 10th mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tour</td>
<td>Sector(s) Assigned</td>
<td>Sgt. Car? Yes</td>
<td>No</td>
<td>Start of tour</td>
</tr>
<tr>
<td>Precinct</td>
<td>Officer's Surname</td>
<td></td>
<td></td>
<td>End of tour</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>(a) Type of Act.</th>
<th>(b) Time at start of activity</th>
<th>(c) Radio run Number</th>
<th>(d) Initial Odometer Reading</th>
<th>(e) Nearest Intersection at point of dispatch</th>
<th>(f) Dispatcher notified?</th>
<th>(g) Siren and/or red lights</th>
<th>(h) Time of arrival at scene</th>
<th>(i) Time returned to car</th>
<th>(j) Final odometer reading</th>
<th>(k) Nearest intersection at scene of incident</th>
<th>(l) Time CB notified</th>
</tr>
</thead>
</table>
Note that time of dispatch is recorded in two places for each radio run -- on the incident ticket from the CB time-stamp clock and on the EX1 form from the officer's wrist watch. This double recording serves to calibrate the officer's time against the "standard" CB time. The recorded arrival time at the scene, \( T_3 \), is set equal to the EX1 entry [col. (h)], plus any calibration term necessary to synchronize the dispatcher's and officer's clocks. The time difference \( T_3 - T_2 \) is the recorded travel time, which, due to time truncations, may deviate from actual travel time by as much as one minute.

We have now summarized the information recorded for each radio run. In addition, we collected information concerning all other patrol activities which would make a patrol car unavailable to respond to a dispatch. The activities were broken down into eight categories as follows:

1. Radio run
2. Meal
3. Station house
4. Auto repairs
5. Fuel
6. Traffic
7. Patrol-initiated action
8. Other

Precise definitions of these activities are given in Table 1. A replica of the instructions for completing the EX1 forms is given in Figure 3.

*These definitions were circulated to the RMP officers.
### TABLE 1

#### DEFINITIONS OF ACTIVITIES

<table>
<thead>
<tr>
<th>Code Number</th>
<th>Activity</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radio Run</td>
<td>Any called-for service for which the RMP is notified and requested to go to the scene by CB dispatcher. Each dispatcher will have an associated radio run number for identification purposes.</td>
</tr>
<tr>
<td>2</td>
<td>Meal</td>
<td>Any break from preventive patrol due to a meal. (With a two-man car, if each officer takes his meal separately and the car remains patrolling, this should <strong>not</strong> be considered to be a meal break.)</td>
</tr>
<tr>
<td>3</td>
<td>Station House</td>
<td>Any time spent in the precinct station house (except that associated with a radio run or meal).</td>
</tr>
<tr>
<td>4</td>
<td>Auto Repairs</td>
<td>Any time spent in an auto maintenance shop (i.e., time taken away from preventive patrol) due to repairs on the patrol car.</td>
</tr>
<tr>
<td>5</td>
<td>Fuel</td>
<td>Time spent on a fuel stop.</td>
</tr>
<tr>
<td>6</td>
<td>Traffic</td>
<td>Any time spent directing or assisting traffic (other than that associated with a radio run).</td>
</tr>
<tr>
<td>7</td>
<td>Patrol-Initiated Action</td>
<td>Time spent by one or both officers out of the car on questioning of persons, door and window checks, automobile checks, etc. -- all of which was initiated by the RMP officers, not CB.</td>
</tr>
<tr>
<td>8</td>
<td>Other</td>
<td>Include in this category all other activities which are not included in activities 1-7 and which remove the RMP from the air (i.e., make the unit unavailable for dispatch duty). An example would be a signal 10-13, &quot;Assist Patrolman.&quot;</td>
</tr>
</tbody>
</table>
FIG. 3: INSTRUCTIONS FOR THE EX1 FORMS

The EX1 form is to be filled out by the RMP officers. Two forms are issued to each unit assigned to a tour. An entry is made on the form for each activity which causes the unit to perform tasks other than preventive patrol.

INSTRUCTIONS FOR COMPLETION OF FORM EX1

1. Two EX1 forms are to be issued at roll call to each RMP assigned that tour. (The second form will be used only if all the space on the first is filled in.)

2. Upon receiving the form, one of the officers assigned to the RMP car should complete the appropriate entries at the top of one of the forms. These entries are as follows: date, tour number, officer's surname, precinct number, car number, sector(s) assigned, time at start of tour, odometer (mileage) reading at start of tour. If use of the second form becomes necessary, only the date, tour number, and car number need be filled in on the second form.

3. During the tour, for each of the defined activities an entry should be made on the form. For a radio run, this entry includes all of the following information:

   (a) Type of activity (by code number 1 through 8)

   (b) Time at start of activity (military time to nearest minute from officer's wristwatch)

   (c) Radio run number (assigned by dispatcher)

   (d) Initial odometer reading (reading of odometer to nearest tenth mile at instant of dispatch)

   (e) Nearest intersection at point of dispatch (e.g., 42nd Street, Broadway)

   (f) Dispatcher notified? (Check "✓" if yes)

   (g) Siren and/or red lights used? (Check if yes)

   (h) Time of arrival at scene

   (i) Time returned to car

   (j) Final odometer reading

   (k) Nearest intersection at scene of reported incident

   (l) Time Communications Bureau (CB) notified that car back in service.
FIG. 3 (Continued)

For activities which are not radio runs, items c, d, e, g, h, j, and k can be left blank.

For activities for which the dispatcher is NOT notified, item (l) can be left blank.

There should be ample space on two forms for an entry to be made for each activity during an 8-hour tour.

4. At the completion of the tour, the officer should enter the final time and odometer reading.

5. Possible Complications:

(a) Whenever some of the information is either unknown or inadvertently not recorded at the appropriate time, leave the corresponding item BLANK. For instance, if the closest street intersection at the time of dispatch is not known, leave item (e) blank. Or, if the time of arrival cannot be recorded, leave item (h) blank.

(b) Occasionally a radio run may be interrupted by another activity (e.g., an injured person) and another unit may or may not be assigned to the original incident. In such cases, notify the dispatcher that the radio run is being interrupted and write in item (l) the time of interruption and the letters "INTRPT." Leave blank any items not already filled in and treat the activity causing the interrupt as a new activity (with associated activity code, time at start of activity, etc.). If the unit is reassigned to the original radio run after completion of the interrupt activity, the reassignment is to be treated as a new regular radio run.

(c) If the radio run involves travelling to the precinct station after servicing the call at the scene of the incident, record in item (i) (time returned to car) the first time returned to the car to go to the precinct station. Item (l) would then contain the time CB was notified that the car is back in service following the necessary time spent at the precinct station.
TIME AND PLACE OF EXPERIMENT

The experiment was run in Division 16 (Queens) from 4:00 p.m., Monday, February 17, 1969, to 4:00 p.m., Monday, March 3, 1969. In addition, it was run in Division 8 (Bronx) for the 24-hour period starting at 4:00 p.m., Monday, February 17, 1969. (The experiment had been scheduled one week earlier, but a 15-inch snowfall postponed the starting time.)

Division 16 (Figure 4) comprises five precincts (103, 105, 107, 109, 111) in the eastern part of Queens. During the winter of 1969, Division 16 had 91 RMP units assigned (11.46 percent of the total force) and experienced 8.53 percent of the city-wide radio run workload. Within the Division, the RMP allocation and radio run workload were apportioned as follows (Winter 1969):*

<table>
<thead>
<tr>
<th>Precinct</th>
<th>No. of RMPs Assigned</th>
<th>Radio Runs</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>103</td>
<td>22</td>
<td>12,770</td>
<td>27.5</td>
</tr>
<tr>
<td>105</td>
<td>20</td>
<td>10,680</td>
<td>23.0</td>
</tr>
<tr>
<td>107</td>
<td>18</td>
<td>8,700</td>
<td>18.7</td>
</tr>
<tr>
<td>109</td>
<td>16</td>
<td>7,620</td>
<td>16.4</td>
</tr>
<tr>
<td>111</td>
<td>15</td>
<td>6,630</td>
<td>14.4</td>
</tr>
</tbody>
</table>

The precincts are further described by the following data:

*Throughout the city, only five precincts experienced a radio run workload greater than that of Precinct 103. About one-half of the precincts experienced a workload less than that of Precinct 111.
FIG. 4: THE LOCATIONS OF DIVISIONS 8 AND 16 AND THEIR RESPECTIVE PRECINCTS

Map shows New York City Police Department Patrol Divisions
<table>
<thead>
<tr>
<th>Precinct</th>
<th>Area (sq. mi.)</th>
<th>Street-Mileage</th>
<th>Estimated Population</th>
<th>Total Felonies per 100,000 (1967)</th>
<th>Business Establishments and Licensed Premises</th>
</tr>
</thead>
<tbody>
<tr>
<td>103</td>
<td>14.20</td>
<td>230</td>
<td>126,000</td>
<td>7,016</td>
<td>55,623</td>
</tr>
<tr>
<td>105</td>
<td>14.04</td>
<td>195</td>
<td>207,000</td>
<td>2,578</td>
<td>35,832</td>
</tr>
<tr>
<td>107</td>
<td>10.20</td>
<td>150</td>
<td>165,000</td>
<td>2,526</td>
<td>25,602</td>
</tr>
<tr>
<td>109</td>
<td>9.65</td>
<td>200</td>
<td>147,000</td>
<td>2,158</td>
<td>26,132</td>
</tr>
<tr>
<td>111</td>
<td>11.35</td>
<td>162</td>
<td>142,000</td>
<td>1,823</td>
<td>19,805</td>
</tr>
</tbody>
</table>

Precinct 111, as one extreme, comprises the highly residential area of Little Neck, Queens. Precinct 103, to the south and west of 111, includes most of Jamaica, Queens, an older community with a moderate number of stores and licensed premises.

Similar data for Precincts 41, 43, and 45 (Division 8) are given in Table 2.
### TABLE 2

SUMMARY DATA FOR PRECINCTS 41, 43, AND 45

<table>
<thead>
<tr>
<th>Precinct</th>
<th>No. of RPMs Assigned</th>
<th>Radio Runs (Winter 1969)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>17</td>
<td>14,620</td>
<td>53.5</td>
</tr>
<tr>
<td>43</td>
<td>15</td>
<td>9,780</td>
<td>35.8</td>
</tr>
<tr>
<td>45</td>
<td>9</td>
<td>2,910</td>
<td>10.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Precinct</th>
<th>Area (sq. mi.)</th>
<th>Street-Mileage</th>
<th>Estimated Population</th>
<th>Total Felonies per 100,000 (1967)</th>
<th>Business Establishments and Licensed Premises</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>2.50</td>
<td>60</td>
<td>161,000</td>
<td>6,428</td>
<td>5,201</td>
</tr>
<tr>
<td>43</td>
<td>6.52</td>
<td>135</td>
<td>198,000</td>
<td>2,070</td>
<td>3,328</td>
</tr>
<tr>
<td>45</td>
<td>7.77</td>
<td>117</td>
<td>67,000</td>
<td>1,471</td>
<td>1,398</td>
</tr>
</tbody>
</table>
II. EXAMINING ONE TOUR OF DUTY IN ONE PRECINCT

In this section we examine patrol operations in one precinct during one eight-hour tour of duty. By focusing on individual patrol cars and radio runs, we can develop typical scenarios that classify the various sequences of activities in which a patrol unit may engage. These examples also illustrate the intricacies of operation which are important in understanding and interpreting the statistical data.

CAR ASSIGNMENTS

For Precinct 103 the 4:00 p.m. roll call on Friday, February 28, 1969, resulted in 12 RMPs being manned. A thirteenth RMP was fielded at 7:00 p.m. There were 22 RMP sectors in the precinct. In order to cover the precinct, some cars were assigned to patrol two or three sectors:

<table>
<thead>
<tr>
<th>Car No.</th>
<th>Sector Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>G,H</td>
</tr>
<tr>
<td>5</td>
<td>I,J</td>
</tr>
<tr>
<td>6</td>
<td>K,Y,T</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>P</td>
</tr>
<tr>
<td>9</td>
<td>Q</td>
</tr>
<tr>
<td>10</td>
<td>R</td>
</tr>
<tr>
<td>11</td>
<td>U</td>
</tr>
<tr>
<td>12</td>
<td>V</td>
</tr>
<tr>
<td>13</td>
<td>W,X</td>
</tr>
</tbody>
</table>

No car was assigned to patrol Sectors D, E, F, and M. The sector assignments are illustrated in Figure 5.
FIG. 5: SECTOR ASSIGNMENTS FOR THE TOUR

Map shows Precinct 103 in southeastern Queens. Letters are the names of the patrol sectors.
DETAILED ACTIVITIES

The first radio run to be given in the new tour was a request for an ambulance, which arrived in CB at 3:58, two minutes before the start of the tour. The incident was at 169 Street and 111 Avenue, in Sector K. The K-Y-T Sectors’ car was dispatched at 4:01 directly from the station house (168 Street and 91 Avenue). The car arrived on the scene three minutes after dispatch, traveling slightly more than one mile. The car remained on the scene until 4:40, at which time it notified the dispatcher that it was again ready for dispatch. By termination of the eight-hour tour (midnight), the K-Y-T car had responded to 11 radio runs, three of which were of sufficiently high priority to require use of siren and/or lights during response. Even though the car had responsibility for three normal sectors, five of the 11 dispatches were in sectors other than K, Y or T. A summary of response paths for the car is depicted in Figure 6. Three calls arrived from K, Y, or T when the K-Y-T car was unavailable; these were handled by other units. The eight hours were apportioned among the various activities as follows: radio runs, 3.3 hours; meal, 1.0 hour; station house, 10 minutes; preventive patrol, 3.54 hours.

Returning to the beginning of the tour, an abandoned auto was re-
ported to CB at 4:05 from an address in Sector M (without car coverage). Sector R car was dispatched directly from the precinct house as soon as it was reported available. The car arrived at the scene 10 minutes after dispatch, traveling just over 1.5 miles. The car spent 10 minutes at the scene. The next recorded activity for the R car was a one-hour meal break which started at 7:30, although during the interval from servicing the first call until 7:30 there occurred five calls for which it appeared that car R was a preferable choice over the car actually chosen. Through the entire tour, the R car handled a total of six radio runs, five of which were not in Sector R.
FIG. 6: THE RADIO RUNS OF THE PATROL CAR ASSIGNED TO THE THREE SECTORS, K, Y, AND T

Initial Position of Patrol Car

Position of Incident

Map shows Precinct 103.
At 4:05 the officers in Sector N car noticed that auto repairs were required. The car went off the air until 7:00 p.m., at which time the officers changed vehicles. Apparently, the officers took their meal break during this 2-hour, 55-minute period for auto repairs. Between 7:00 p.m. and the end of the tour, the N car responded to four radio runs, two of which were outside of Sector N.

Although this tour would not be an unusually heavy one in terms of call-for-service workload, several calls required the dispatch of distant cars, even when there apparently were nearby available cars. For instance, a call was reported from Sector M (unmanned) at 6:46 (Figure 7). The G-H car would probably have been the closest car, but it did not start the tour until 7:00 p.m. The K-Y-T car would have been the next logical choice, but for some reason, which is not apparent from the data, it was not dispatched to the scene. Moments later (6:55) the K-Y-T car went off the air at the station house. The next closest choice would have been the N car, but it was still out of service due to auto repairs. The I-J car was busy in Sector F (unmanned), servicing an ambulance case. The R car was apparently available, but was not assigned. The car that was assigned was the Sector A car, which travelled three miles to reach the scene, requiring 12 minutes travel time. Inexplicably, at the moment of dispatch, the A car was outside its own sector (it was in Sector B), thereby increasing the time required to get to the scene. Service time at the scene was 24 minutes. Thus, travel time consumed one-third of the total service time for this incident.

The G and H sectors, which were unmanned until 7:00 p.m., generated significant workload throughout the tour. In fact, all three radio runs handled
FIG. 7: CALL FROM SECTOR M RESULTING IN DISPATCH OF A DISTANT UNIT

Map shows Precinct 103 at 6:46 p.m., Friday, February 28, 1969.
by C car before 7:00 p.m. were in Sectors G and H. The G-H car, once it was fielded at 7:00 p.m., managed to respond to six radio runs during its abbreviated four hours of service (the period from 9:00 to 10:00 p.m. was spent on meal break). Two of these occurred "back-to-back." After completing a suspicious auto call at 118 Avenue and Lakeview at 10:35, the car was immediately reassigned to a felony call three miles distant in Sector N. (The N car was busy on an ambulance call in the northern part of its sector.)

Such back-to-back dispatches can reduce response delays dramatically in some cases, especially if the unit reports availability directly from the scene of the previous incident. For instance, an ambulance call had caused the Sector C car to travel about two miles to the northern edge of Sector H. The car reported completion of service at the scene at 5:08 p.m., and was en route back to Sector C. But at 5:04, a "dispute" call had been reported from a point (in Sector H) just one block south of C car's position, and at that time no nearby car was available to dispatch to the scene. The dispatcher immediately dispatched the C car (at 5:10), resulting in a very short travel distance to get to the scene. The car completed service on this call at 5:50 and then returned to Sector C.

Occasionally a car will "volunteer" to service a call when it believes it is considerably closer to the scene than the car selected by the dispatcher. This apparently occurred at 5:05 p.m. on an abandoned auto call in Sector A which was serviced by B car. Although A car was available, B car (inexplicably) was in Sector A, only about four blocks from the scene.

The Q car had a peculiar tour, responding to four calls for service, all outside Sector Q! Ironically, the two calls for service generated within
Sector Q each encountered the Q car unavailable, once on a previous call for service and once due to activities listed as "other."

**SUMMARY OF PATROL CAR ACTIVITIES**

At this point, it is useful to summarize the sequence of activities in which a patrol car may engage. At roll call the car will be assigned to patrol a specified sector or combination of sectors. From the moment of entry into the car, the officers are eligible for dispatch to incidents anywhere in the precinct; and it is not unusual for the first dispatch to occur while the car is still at the station house. Any needs for fuel and/or auto repairs are likely to be taken care of near the beginning of the tour. At the moment of requested dispatch, the car chosen by the dispatcher is usually within its own sector(s), but it may be in another sector. Hearing the dispatch request, another available car which is closer to the incident may volunteer for the call. The car finally selected will travel to the incident, which may be outside the car's own patrol sector(s). After servicing the call at the scene, the car may be required to return to the station house. After completion of all service on the call, the car notifies the dispatcher that it is again available for dispatch. At this time the dispatcher may immediately reassign the unit to a nearby unserviced call. Otherwise, the car returns to its sector and resumes patrol.

Meal breaks of one hour duration are usually scheduled during the third to sixth hour of the tour. Patrol-initiated action and other activities that remove the unit from dispatch-available status can occur any time during the tour. It is unusual to find a car accepting radio runs within 15 minutes of its designated meal break or within 15 minutes of tour completion.
SUMMARY OF TOUR

Summarizing the activity of Precinct 103 during Tour 3 (February 28),
a total of 74 radio runs were serviced, nine of which (12.2 percent) were high
priority. Workloads varied markedly throughout the tour, with the K-Y-T car
responding to 11 calls, while A car responded to only three calls.

Of the total of 101 RMP hours in the field during the tour, 28.52 were
spent servicing radio runs; 11 hours were consumed for meals; * 3.09 for
auto repairs; 2.08 at the station house; 4.18 on patrol-initiated action;
and 52.13 on preventive patrol. If the patrolling speed was 10 mph, this
was enough patrol time to allow each point in the precinct to be passed at
least two times during the tour (on the average).

While responding to calls for service, the effective speed was typi-
cally between 10 and 20 mph. The travel distance averaged 1.31 miles for
all calls and 0.95 miles for priority calls. The average travel time was
4.7 minutes, and the average service time at the scene was 22.8 minutes.
The average CB processing delay was 4.4 minutes. (T₂ - T₁ on Figure 1.)

More dispatches required the dispatched unit to travel outside its
own sector than inside. About 55 percent of all dispatches were inter-sector
rather than intra-sector dispatches. About 21 percent of all dispatches found the
dispatched unit initially outside its own patrol sector; less than half of
these were accounted for by previous out-of-sector assignments or station
house assignments. The average travel time for inter-sector dispatches was
approximately 40 percent greater than that for intra-sector dispatches; the
average travel distance was about 53 percent greater, suggesting that ef-
factive travel speeds increase with travel distance.

*The meal breaks were distributed between 6:00 p.m. and 10:00 p.m.
Of all the inter-sector dispatches, 50 percent were clearly optimal decisions, given the dispatcher's knowledge about the patrol force. Another 22 percent were dispatches for which the sector car was available, but where the dispatched car may have volunteered for the call, thinking that it was closer than the sector car. The remaining 28 percent were clearly non-optimal (given available information), either because the sector car was available and, if within its own sector, could not have been further from the scene than the one dispatched, or because even though the sector car was busy, the car dispatched was not the closest car reported available.
III. DIVISION-WIDE TOTALS

A total of 65 cars, including six sergeants' cars, were fielded on Tour 3, February 28 in Division 16. (The total number of sectors is 91.) To provide patrol coverage of 91 sectors, 36 percent of the non-sergeant cars were assigned to two sectors, three percent were assigned to three sectors. The sergeants' cars patrolled "zones" within the precinct, a zone comprising about 30 to 50 percent of the sectors of the precinct. About eight percent of the sectors were not assigned to any patrol car.

A division-wide total of 271 radio runs were answered, 26 (9.6 percent) of which were high priority. Averaged for each precinct, the number of radio runs per car varied from 5.7 (Precinct 103) to 2.9 (Precinct 107). The percentage of time spent on radio runs ranged from 12 (Precinct 107) to nearly 30 (Precincts 103, 105, 111). The percentage of time spent on meals, station house calls, auto repairs and fuel stops ranged from 13 (Precinct 105) to 18 (Precinct 109). The percentage of time spent on preventive patrol varied from 41 (Precinct 105) to 64 (Precinct 111).

The average CB processing time was lowest for Precinct 111 (3.7 minutes) and highest for Precinct 105 (6.8 minutes). Average travel times varied from 3.9 minutes (Precinct 107) to 6.7 minutes (Precinct 111), and average travel distances varied from 1.31 miles (Precinct 103) to 2.34 miles (Precinct 111).

Fully 51 percent of all dispatch assignments were inter-sector assignments (i.e., they assigned the car to an incident outside its primary patrol area). And 23 percent of all dispatches found the car assigned initially outside its own patrol sector(s).
IV. A MODEL FOR INTER-SECTOR DISPATCHING

The percentage of inter-sector dispatches is an important measure of the extent to which a patrol car loses "identity" with its designated sector(s). This sector identity, which patrol administrators often use as a strong argument in favor of assigning individual officers to the service area, is derived from patrolling and from citizen contacts made while responding to calls for service. It is supposed to cause the officer to feel personally responsible for public order in the sector. However, we have seen empirically that a patrol car is quite frequently dispatched to incidents in sectors other than its designated sector, a phenomenon known in police circles as "flying."

Given non-overlapping sectors, one can show by a simple probabilistic argument that the fraction of dispatches which cause units to travel outside their own sector(s) is usually equal to or greater than the average fraction of time that units are unavailable for dispatch. We checked this predicted amount of inter-sector dispatching for Division 16, Tour 3, Friday, February 28, 1969. The results are as follows:

*The average is weighted. See Appendix A for details of this argument.
<table>
<thead>
<tr>
<th>Precinct</th>
<th>Percentage Of Time Unavailable</th>
<th>Percentage Of Dispatches Which Are Inter-Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>103</td>
<td>48</td>
<td>55</td>
</tr>
<tr>
<td>105</td>
<td>59</td>
<td>57</td>
</tr>
<tr>
<td>107</td>
<td>38</td>
<td>48</td>
</tr>
<tr>
<td>109</td>
<td>38</td>
<td>37</td>
</tr>
<tr>
<td>111</td>
<td>36</td>
<td>48</td>
</tr>
</tbody>
</table>

The extent of inter-sector dispatching is never significantly less than the percentage of time unavailable, and it may be significantly more. As the argument in Appendix A illustrates, one would expect a greater amount of inter-sector dispatching if rates of demands for service varied markedly over the tour, and if certain sectors are not assigned any patrol coverage.
V. 24-HOUR ACTIVITY PROFILES

The RMP forms provided the information necessary to determine the amount of time consumed by various activities. Figure 8 depicts the 24-hour profile for Precinct 103 for Friday, February 28. The figure indicates how nearly all radio run activity is concentrated in Tours 2 and 3. In addition, it shows how meal breaks are distributed during the third to sixth hour of each tour. Although time spent on auto repairs and fuel stops appears insignificant, these activities were reported to consume 5.2 hours over the 24-hour period, which is approximately 75 percent of the useful time spent by one patrol car during one tour.
FIG. 8: 24-HOUR ACTIVITY PROFILE, PRECINCT 103, FEBRUARY 28, 1969

Hours of patrol time

0 2 4 6 8 10 12 14 16 18 20 22 24

Radio run  Meal  Repair or fuel  Traffic, PIA*  or other

Preventive Patrol

Radio Runs

*Patrol-initiated activity.
The 24-hour profile for Precinct 105 during the same day is depicted in Figure 9. Note how increased radio run activity decreases preventive patrol levels (probably at the time when it is needed most).

In this precinct, 8.85 hours were spent on auto repairs and fuel stops during the 24-hour period; this is more than 125 percent of the useful time spent by one car during one tour.
FIG. 9: 24-HOUR ACTIVITY PROFILE, PRECINCT 105, FEBRUARY 28, 1969

*Patrol-initiated activity.*
Precincts are this busy not only on Fridays and Saturdays. Figure 10 depicts the 24-hour profile for Precinct 105 for Tuesday, February 18, 1969. Note how meal breaks are taken during the hours of maximum public demand for police service (6:00 - 10:00 p.m. in Figure 10); in fact, near saturation occurs from 7:00 to 8:00 p.m. During this 24-hour period, 8.64 hours were consumed by fuel and auto repair activities. This is again about 125 percent of the useful time spent by one car during one tour.
FIG. 10: 24-HOUR ACTIVITY PROFILE, PRECINCT 105, FEBRUARY 18, 1969

*Patrol-initiated activity.
VI. SUMMARY STATISTICS

In this section we report some of the summary statistics which describe operation during the two-week period in Divisions 8 and 16. In Figures 11-15 we have displayed distributions of the following statistics:

Figure 11: Average recorded communications room time, $T_2 - T_1$
Figure 12: Average recorded travel time, $T_3 - T_2$
Figure 13: Average recorded travel distance
Figure 14: Average recorded service time at the scene of the incident, $T_4 - T_3$
Figure 15: Average number of radio runs per car.

Each value of a statistic is determined for one precinct during one tour. A total of 54 different "precinct-tours" during the two-week period were analyzed to arrive at 54 values of each statistic. The cumulative distributions of these values are shown in the figures. To illustrate the use of the figures, we read from Figure 11 that 50 percent of the precinct-tours had an average recorded communications room time ($T_2 - T_1$) less than about 5.8 minutes; 25 percent had values greater than about 9.8 minutes.

COMMUNICATIONS ROOM TIME

Average communications room time ranges from 2.4 minutes to over 15 minutes, with a median of 5.8 minutes.* The smaller values are

*As noted in Section I, these recorded communications times are obtained by subtracting the time of receipt of the call, as manually recorded by a turret operator, from the time of dispatch, as recorded by the dispatcher using a time-stamp clock. Although the synchronization of these clocks was checked several times daily by supervisors,
FIG.11: CUMULATIVE DISTRIBUTION OF AVERAGE RECORDED COMMUNICATIONS ROOM TIME, $T_2 - T_1$
(AVERAGED BY TOUR AND BY PRECINCT)

$\% \left( \frac{T_2 - T_1}{T_1} \right) \leq x$

The length of each solid bar is proportional to the percentage of time cars are unavailable during the tour.

The graph is derived from 54 precinct-tours (recorded during Feb. 1969)

$\overline{T_2 - T_1} = \text{average time between completion of turret operator processing and dispatch of a patrol car (averaged over one tour and one precinct)}$
attributable to the time necessary to record information, to transport it to a dispatcher, and to dispatch an available patrol unit. The larger values are due to patrol force saturation, which occurs when the dispatcher can find no available patrol units sufficiently close to the reported incident.

For each precinct-tour, we also computed the total fraction of time that cars reported activities which made them unavailable for dispatch. These fractions, which ranged from 12 to 62 percent of time unavailable, are indicated for each precinct-tour by the length of the corresponding heavy line shown in Figure 11. The hypothesis was that the larger communications room delays occur when patrol units are relatively busy. Although the 54 precinct-tours lumped together precincts of differing sizes and tours of different manning levels, one can see that the hypothesis tends to be valid. The 13 precinct-tours which had the smallest average communications room delays averaged 31.7 percent patrol unavailability. The 13 precinct-tours which experienced the largest communications room delays averaged 46.2 percent patrol unavailability. Yet, this relatively small range of percent of time unavailable does not explain the large variation in delays. The large delays seem to occur because of peaks of demand within an 8-hour tour. If it is found that the times of these peaks are fairly predictable, a rescheduling of patrol manpower would greatly reduce response delays.

---

there still is the possibility that the two timing mechanisms occasionally lost synchronization. Thus, due to possible clock inaccuracies, these figures of communications room delay should be treated as illustrative of the magnitude of delays that were incurred. The fact that the times were truncated to the nearest minute should not bias the statistical averages in any way (see Appendix A).
TRAVEL TIME

Average travel time ranges from 3.6 minutes to 9.8 minutes (Figure 12). The median value is 6.2 minutes. The variation in mean times is due to several factors, including patrol unavailability, size and shape of sectors, and traffic conditions. For instance, the 13 precinct-tours having the lowest mean travel time were characterized by a 13.5 percent patrol unavailability. The 13 having the highest mean travel time experienced 49.8 percent unavailability. When patrol units are unavailable a considerable fraction of the time, dispatches require units to travel greater distances, into sectors other than their assigned sector(s). Average travel times were also increased by the fact that a considerable fraction of radio runs found the dispatched patrol unit outside is assigned sector(s).

TRAVEL DISTANCE

Average travel distance ranges from 0.78 miles to 2.91 miles, with a median of 1.62 miles. As one would expect, the value of average travel distance depends strongly on patrol car "density," as measured in cars per square mile. Its value is also dependent on the unavailability of the patrol force, the greater unavailabilities causing larger mean travel distances. One can combine these concepts by defining the "available patrol car density" to be the average number of available cars per square mile (during a precinct-tour). For instance, the 13 precinct-tours with the lowest average travel distance (combined average = 1.12 mi.) averaged 1.16 available cars per square mile. The 13 with the
FIG. 12: CUMULATIVE DISTRIBUTION OF AVERAGE RECORDED TRAVEL TIME, $T_3 - T_2$
(AVERAGED BY TOUR AND BY PRECINCT)

The Graph Is Derived From
54 Precinct - Tours (Recorded
During Feb., 1969)

$T_3 - T_2$ - Average Time Required
For Dispatched Patrol
Unit to Travel to Scene
of Incident

% Average Travel
Time Less Than
or Equal to $x$

$x$, Minutes
FIG. 13: CUMULATIVE DISTRIBUTION OF AVERAGE RECORDED TRAVEL DISTANCE
(AVERAGED BY TOUR AND BY PRECINCT)

The Graph is Derived From
54 Precinct-Tours (Recorded
During Feb., 1969)

\[ \bar{D} = \text{Average Travel Distance}
\text{ (From Moment of Dispatch Until Arrival At the Scene)} \]
highest average travel distance (combined average = 2.29 mi.) averaged only 0.614 available cars per square mile.

The largest mean travel distance occurred in Precinct III (area = 11.35 mi²) during Tour 2 on February 28 with eight patrol units assigned. These units were unavailable for dispatch 60 percent of the time. Thus, the average number of available cars per square mile was $8 \cdot (0.40)/11.35 \approx 0.282$. The smallest mean travel distance occurred in Precinct 41 (area = 2.5 mi²) during Tour 3 on February 17 with 13 patrol units assigned. These units were unavailable for dispatch 54 percent of the time. Thus, the available patrol car density was 2.39 (available cars/mi²).

The ratio of the respective mean travel distances is $0.78/2.91 \approx 0.268$, which is not incompatible with the notion that mean travel distance grows as the square root of the inverse of the available patrol car density.* The ratio is 0.344 in this case.

**SERVICE TIME**

Average service time at the scene of the incident ranges from 16.56 minutes to 49.26 minutes, with a median value of about 27.5 minutes. A remarkable property of the service time distribution is that about 68 percent of the observed values differ from the median value by no more than five minutes. Thus, for patrol

FIG. 14: CUMULATIVE DISTRIBUTION OF AVERAGE RECORDED SERVICE TIME AT THE SCENE OF THE INCIDENT, $T_4 - T_3$
(AVERAGED BY TOUR AND BY PRECINCT)

$\% \frac{T_4 - T_3}{T_3}$ less than or equal to $\chi$

The Graph is Derived From 54 Precinct-Tours (Recorded During Feb., 1969)

$T_4 - T_3$ = Average Time Required For Patrol Unit to Service a Call at the Scene (Averaged Over One Tour And One Precinct)

$\chi$, Minutes
allocation purposes, it appears reasonable to set the average service
time at the scene equal to 27.5 minutes. Adding approximately six minutes
for mean travel time, the average total service time for an incident is
about 33 or 34 minutes.

**NUMBER OF RADIO RUNS PER CAR**

Figure 15 indicates the wide variability of workloads over precinct-
tours, ranging from 0.14 radio run per car to 6.45 radio runs per car.
The median value is 2.2 radio runs per car.

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*A breakdown of calls by type would indicate that mean service time
depends on type of incident. It would be preferable to include this
dependence in any patrol allocation procedure. See, for example,
N. Heller, "1967 Service Time Histograms for Police Patrol Activities
in St. Louis" (available from the St. Louis Police Department); or
Operations Research Center Technical Report No. 26, Cambridge,
Massachusetts, 1967.*
FIG. 15: CUMULATIVE DISTRIBUTION OF AVERAGE NUMBER OF RADIO RUNS PER CAR
(AVERAGED BY TOUR AND BY PRECINCT)

% $\overline{RR/C}$ less than or equal to $x$

The graph is derived from 54 precinct-tours (recorded during Feb. 1969)

$\overline{RR/C} =$ average number of radio runs per car during one tour on one precinct
VII. TEST OF THE RIGHT-ANGLE DISTANCE METRIC

In models of patrol response, it is necessary to make some assumptions about the response path which is selected by the responding vehicle. The maps of Precinct 103 shown in Figures 5 and 7 illustrate typical street topography. Although the street grid appears to be quite irregular, one finds by tracing possible response paths that typically there exists no path connecting two points directly "as the crow flies," but usually a shortest path can be found by following the patrol unit's initial street until reaching an appropriate cross street, then making a right-angle turn and following down that street until reaching the point of the incident (or a point very near the incident). In other words, most minimum distance response paths (at least to sufficiently nearby incidents) consume a travel distance equal to the sum of the two sides of a right triangle, rather than the hypotenuse of the triangle, where the sides are defined parallel to street directions. This is the reason for calling such responses "right-angle" responses. Complications such as barriers, one-way streets* and expressways cause this model to be an oversimplified one, but one would expect it to be better than an "as the crow flies" model.

Since in the RMP Experiment the responding unit recorded its initial and final positions (to the nearest intersections) and odometer readings (either to the nearest mile or nearest tenth of a mile), it is possible to

*See R. Larson, Response of Emergency Units: The Effects of Barriers, Discrete Streets, and One-Way Streets, R-675-HUD, New York City-Rand Institute, April 1971, for a discussion of some effects of these complications.
get some idea of the validity of the right-angle distance hypothesis. One test is just to examine possible response paths, given initial and final positions, and to compare the associated travel distances with both the predicted right-angle distance and the recorded travel distance from the odometer. This was done for over 50 responses, with rather mixed results. For some responses the right-angle distance and the recorded distance were in agreement to within one or two-tenths of a mile. But in several cases, the two distances were far apart. For instance, there was one incident for which the car recorded its initial position two blocks south of the incident's position (on the same two-way thoroughfare), but the recorded travel distance exceeded two miles. Some of the problems were caused by the approximations inherent in recording positions to nearest intersections and distances to nearest tenths of miles (or miles). Yet these did not explain inordinately long response journeys in about 18 percent of the responses.

Another, more detailed, test was tried, with all responses recording distances to tenths of a mile in Division 16, Tour 3, February 28. (There were 60 such responses.) The test involved the ratio of the recorded distance to the Euclidean or "as the crow flies" distance. If the right-angle hypothesis is valid and if all distances are known exactly, the cumulative distribution of this ratio should resemble the graph drawn in Figure 16. The actual (empirical) distribution is shown in Figure 17.

As can be seen readily, the empirical distribution does not resemble the theoretical distribution. First, about 13 percent of the samples have values less than one (an impossibility if recorded locations and mileages contained no errors). Most of these, however, were associated with short journeys in
FIG. 16: CUMULATIVE DISTRIBUTION FUNCTION OF THE RATIO OF THE RIGHT-ANGLE AND EUCLIDEAN TRAVEL DISTANCES

$$F_R(\alpha)$$

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.0 1.1 1.2 1.3 1.4 1.5 $\alpha$
FIG. 17: EMPIRICAL DISTRIBUTION OF THE RATIO OF THE RECORDED AND THE EUCLIDEAN TRAVEL DISTANCES

Samples from 60 radio runs, February 28, 1969, Tour 3, Division 16

Fraction of samples having ratio less than or equal to $x$

1.0  0.5  0.0

6 samples greater than 3.5

Empirical Mean

Theoretical Mean

Empirical Median

Theoretical Median
which the tenth-of-a-mile truncations and intersection approximations could explain the unusually low values of the ratio. More disturbing is the fact that over 50 percent assume values greater than \( \sqrt{2} \approx 1.414 \), which is the theoretical maximum, given the assumptions of the model. Upon examining these cases more closely, however, one finds that a significant fraction could also be explained by errors due to mileage truncations and intersection approximations. For instance, the 10 responses having the largest values of the ratio (recorded distance to Euclidean distance) averaged a Euclidean distance of only 0.5 mi. (compared to 0.94 mi. for the remainder of the sample). For such relatively short journeys, mileage truncations, intersection approximations and complications, such as barriers and one-way streets, could account for the unexpectedly high values of the ratio. In addition, any error in reporting initial position of the patrol unit, such as recording an intersection passed during response as the initial position, could cause unusually high values of the ratio. Comparing aggregate features of the distributions, the theoretical median value of the ratio is 1.306, whereas the empirical median is about 1.60; the theoretical mean is 1.27, but the empirical mean is 1.89.
Appendix A

MATHEMATICAL RESULTS

This Appendix develops some mathematical results which are useful in studying certain aspects of the RMP Experiment. The topics considered include interrelationships between travel times, distances, and speeds; a test of the right-angle distance metric; some effects of data truncation; and the extent of inter-sector dispatching. A summary of results is found in Section 5 at the end of the Appendix.
1. TRAVEL TIMES, DISTANCES, AND SPEEDS

The recording of odometer readings and arrival times in the RMP Experiment made possible an analysis of the travel times, the distances traversed while traveling, and the "effective speed" maintained while traveling. If the patrol unit travels $d$ miles in $t$ minutes, the effective speed is simply $d/t$. This effective speed "averages out" all speed fluctuations due to traffic lights, traffic congestion, etc., and can be interpreted to be that speed which, if constantly maintained over the path of the response journey, would result in the same travel time as that recorded by the RMP officers.

Define the random variables

\[ D = \text{distance traveled during a response}, \]
\[ S = \text{effective travel speed during response}, \]
\[ T = \text{travel time}. \]

These are related by the equation

\[ T = D/S, \]

which means that for a particular response with numerical outcomes $D = d$, $S = s$, and $T = t$,

\[ t = d/s. \]

The average, or expected, travel time is

\[ E[T] = E[D/S]. \]

Since we are dealing with ratios of random variables, care must be taken not to estimate the mean of one as the ratio of the means of the other two (i.e., $E[T] \neq E[D]/E[S]$). As an example, if $D$ and $S^{-1}$ are uncorrelated,* then

\[ * \text{In practice we do not expect } D \text{ and } S^{-1} \text{ to be uncorrelated, but this example illustrates the type of biases one may encounter.} \]
E[T] = E[D]E[S^{-1}].

It is a convexity property of mathematical expectations* that for any non-negative random variable S,

E[S^{-1}] > (E[S])^{-1}.

Thus, if D and S^{-1} are uncorrelated,

E[T] = E[D]E[S^{-1}] \geq E[D]/E[S].

Hence, using (E[D]/E[S]) to estimate E[T] in such a case results in an optimistically low estimate of average travel time.** For instance, if S is a second-order Erlang random variable with mean 20 mph, then

E[D]/E[S] = E[D]/20,

whereas, the true expected travel time is a factor of two greater,

E[D]E[S^{-1}] = E[D]/10.

To further illustrate this idea, assume that two responses give the following numerical outcomes:***

\begin{align*}
    d_1 &= 1 \text{ mile} \\
    t_1 &= 1 \text{ minute} \\
    d_2 &= 1 \text{ mile} \\
    t_2 &= 2 \text{ minutes}
\end{align*}

Clearly,

\begin{align*}
    s_1 &= 1 \text{ mile/minute} \\
    s_2 &= 0.5 \text{ mile/minute}.
\end{align*}

Now, let \( \bar{X} \) denote the statistical average of the variable X, averaged over the two outcomes. Clearly,

\begin{align*}
    \bar{D} &= 1 \text{ mile} \\
    \bar{T} &= 1.5 \text{ minute}
\end{align*}


** Similarly, using (E[D]/E[T]) to estimate E[S] results in a low estimate of mean travel speed.

*** The subscript i denotes the i^{th} response.
\[ \bar{S} = 0.75 \text{ mile/minute} \]
\[ \bar{S}^{-1} = 1.5 \text{ minutes/mile}, \]

and
\[ \bar{T} = 1.5 = \bar{D} \bar{S}^{-1} > \bar{D}/\bar{S} = 1.333 \text{ minutes}. \]

2. TEST OF THE RIGHT-ANGLE DISTANCE METRIC

In this section we derive a test for the "reasonableness" of the right-angle distance metric. If the positions of the response unit and the incident are \((x_1, y_1)\) and \((x_2, y_2)\), respectively, and if the coordinate axes are defined parallel to directions of travel, then the right-angle distance metric requires that the travel distance be

\[ d = |x_1 - x_2| + |y_1 - y_2|. \]

In an experiment such as the RMP Experiment for which we have the initial and final response coordinates, there is no guarantee that travel directions will remain parallel to any prespecified set of coordinate axes. In fact, since street directions change from one area to another, the right-angle travel distance could assume any value between

\[ \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2} \quad \text{and} \quad \sqrt{2} \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2}. \]

One way to test the reasonableness of the right-angle distance metric would be to measure the Euclidean travel distance for each response, to compute the ratio of the recorded travel distance to the measured Euclidean distance, and to plot the empirically found cumulative distribution of this ratio. This is particularly convenient since the theoretical distribution of this ratio, given the validity of the right-angle metric and given an isotropy assumption, does not depend on the origin and rotation of the particular coordinate system used.

*Approximated to the nearest intersection.
Consider two points \((x_1, y_1)\) and \((x_2, y_2)\) defined relative to any fixed coordinate system. Let \(\Psi(0 \leq \Psi \leq \pi/2)\) be the angle at which the directions of travel are rotated with respect to the straight line connecting the two points. Given \(\Psi\), the right-angle travel distance between \((x_1, y_1)\) and \((x_2, y_2)\) is
\[
[\cos \Psi + \sin \Psi \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2}]
\]
(See Figure 18.) Thus, given \(\Psi\), the ratio of the right-angle and the Euclidean distances is
\[
(R | \Psi) = \cos \Psi + \sin \Psi = \sqrt{2} \cos(\Psi - \pi/4).
\]
The cumulative distribution function of \(R\) is
\[
F_R(\nu) = P[R \leq \nu] = P[\sqrt{2} \cos(\Psi - \pi/4) \leq \nu].
\]
(2.1)

Now, if we make the isotropy assumption that \(\Psi\) is uniformly distributed over the interval \([0, \pi/2]\),
\[
F_R(\nu) = 2 \int_{\cos^{-1}(\nu/\sqrt{2})}^{\pi/2} \frac{2}{\pi} \, d\nu
\]
or
\[
F_R(\nu) = 1 - \frac{4}{\pi} \cos^{-1}(\nu/\sqrt{2}), \quad 1 \leq \nu \leq \sqrt{2}.
\]
(2.2)
This function is plotted as Figure 16 on page 47. The probability density function is
\[
f_R(\nu) = \frac{d}{d\nu} F_R(\nu) = \frac{4}{\pi} \frac{1}{\sqrt{2 - \nu^2}}, \quad 1 \leq \nu \leq \sqrt{2}.
\]
(2.3)
The median is \(\sqrt{2} \cos(\pi/8) \approx 1.306\). The mean and variance are
\[
E[R] = \frac{4}{\pi} \approx 1.27 \quad \text{(2.4)}
\]
\[
\sigma_R^2 = 1 + \frac{2}{\pi} - \frac{16}{\pi^2} \approx 0.121. \quad \text{(2.5)}
\]
FIG. 18: RELATIONSHIP BETWEEN RIGHT-ANGLE AND EUCLIDEAN TRAVEL DISTANCES, GIVEN A ROTATED STREET GRID

\[ \Psi = \text{Angle of rotation of street grid, relative to the straight line connecting } (x_1, y_1) \text{ and } (x_2, y_2). \]

\[ (R1\Psi) = \text{Conditional ratio of right angle and Euclidean travel distances, given } \Psi \]

\[ = \cos \Psi + \sin \Psi \]
Thus, on the average, the response unit travels about 1.27 times the Euclidean distance (given the model assumptions). A reasonable test of the right-angle distance metric would be to compare empirical distribution of ratios of recorded travel distances and Euclidean distances to \( F_R(\cdot) \) and to compare the empirically found average \( R \) to 1.27.

3. SOME EFFECTS OF DATA TRUNCATION

Many of the data entries in the RMP Experiment were truncated,* either to the nearest minute or to the nearest mile or tenth of a mile. In this section we discuss some of the quantitative effects of such truncations.

3.1 Travel Distances

Assume that recorded travel distances are quantized by the odometer, where the unit of quantization is one mile.** Then for a journey of length \( D \), the recorded travel distance equals the sum of \( D \) and the accumulated odometer mileage at the moment of dispatch since the last odometer change, the sum truncated to the largest integer in the sum. This recorded travel distance can either underestimate or overestimate the actual travel distance by as much as one mile.

Let

\[
\begin{align*}
D & = \text{actual travel distance}, \\
\theta & = \text{a random variable distributed over the interval [0,1]}. 
\end{align*}
\]

---

* As the discussion will show, these truncations are not simple "roundings" of a number to an integer, but involve an additive "phase angle" before rounding.

** With a simple redefinition of a unit of distance, this discussion is applicable to other levels of quantization (e.g., tenth-of-a-mile quantizations).
If \( \theta \) represents the accumulated odometer mileage at the moment of
dispatch since the last odometer change, then the recorded mileage for the
journey, \( K \), can be written

\[
K = \lfloor D + \theta \rfloor, \quad (3.1)
\]

where

\[
\lfloor x \rfloor = \text{greatest integer less than or equal to } x.
\]

It is convenient to think of \( \theta \) as a random "phase angle." The sets
of \((D, \theta)\) pairs that give rise to different values of \( K \) are shown in
Figure 19.

From physical considerations, the following assumptions seem
reasonable:

1. The random variables \( D \) and \( \theta \) are independent;
2. \( \theta \) is uniformly distributed over the interval \([0,1]\).

Given these assumptions, if the cumulative probability distribution of
\( D \) is known, say \( F_D(\cdot) \), then the probability distribution for \( K \) is
readily computed:

\[
P[K = k] = \int_0^1 d\theta [F_D(k+1 - \theta) - F_D(k - \theta)], \quad k = 0, 1, 2, \ldots \quad (3.2)
\]

Regardless of the functional form of \( F_D(\cdot) \), one can show that

\[
E[K] = E[D] \quad (3.3)
\]

\[
E[K^n] \geq E[D^n] \quad n = 2, 3, \ldots \quad (3.4)
\]

Thus, (1) \( K \) is an unbiased estimator of \( D \); (2) the variance of \( K \)
\((E[K^2] - E^2[K])\) is greater than or equal to the variance of \( D \). To obtain
(3.3) and (3.4), let \( f_D(\cdot) \) denote the probability density function of \( D \) and write

\[
E[D^n] = \sum_{k=0}^\infty \int_0^1 (k+\mu)^n f_D(k+\mu) \, d\mu, \quad n = 1, 2, \ldots \quad (3.5)
\]
FIG. 19: SETS OF (D, θ) PAIRS THAT GENERATE DIFFERENT VALUES OF K

D = Travel distance
θ = Random phase angle
K = [D + θ]
Similarly,

\[ E[K^n] = \sum_{k=0}^{\infty} \int_{0}^{1} E[D + \theta]^n | D = k + \mu] f_D(k + \mu) d\mu, \quad n = 1, 2, \ldots \tag{3.6} \]

But, if \( D = k + \mu, \)

\[ [D + \theta]^n = \begin{cases} 
  k^n \text{ with probability } 1-\mu, \\
  (k+1)^n \text{ with probability } \mu.
\end{cases} \]

Thus,

\[ E[(D + \theta)^n | D = k + \mu] = k^n(1-\mu) + (k+1)^n\mu. \tag{3.7} \]

For \( n = 1, \) we see that the integrands of (3.5) and (3.6) are identical and thus (3.3) is shown to be true. For \( n = 2, 3, \ldots, \) it is clear that (3.4) will hold if

\[ (k+\mu)^n \leq k^n(1-\mu) + (k+1)^n\mu, \quad k = 0, 1, 2, \ldots \quad 0 \leq \mu \leq 1 \tag{3.8} \]

But (3.8) is easily shown to be true by expanding both sides and comparing term-by-term.*

In the context of a data gathering experiment (e.g., the RMP Experiment), several observations about (3.3) and (3.4) are relevant. First, for the statistical average of the recorded mileages to be an unbiased estimator of the "true" average travel distance, it is necessary that "zero-mileage" journeys be recorded and used in the statistical tabulation. Second, since the results do not depend on the level of quantization, it is appropriate to estimate \( E[D] \) by averaging together responses quantized to the nearest mile as well as those quantized to the nearest tenth of a mile. Third, since in all likelihood the variance of any estimator using \( K \) will be greater than the variance of the corresponding esti-

*The inequality (3.8) is strict everywhere except at the end-points, \( \mu = 0 \) and \( \mu = 1. \) Thus, (3.4) is a strict inequality as long as \( D \) has some non-zero probability of assuming a non-integer value (a reasonable assumption in practical situations).
mator using $D$, sample sizes will have to be larger, in general, than they
would have to be if one had direct samples from $F_D(\cdot)$.

3.2 Recorded Times

Truncations similar to those of the previous sections occur when
durations of activities are computed. Assume an activity commences at
time $t_1$ and terminates at time $t_2$. The exact duration of the activity
is $t_2 - t_1$.

Now assume that the times are recorded by some mechanism that re-
cords time $t$ as $[t + \alpha]$, for some fixed $\alpha$. For instance, a time-stamp
clock may be set to record a time "m minutes, s seconds," as "m
minutes" (i.e., $\alpha = 0$). For a person who rounds to the nearest minute,
$\alpha = 0.5$. As long as $\alpha$ is fixed, its exact value is not important.*
Using this mechanism, the recorded duration of the activity is
$[t_2 + \alpha] - [t_1 + \alpha]$.

The discussion of the previous section now applies directly once
we identify the correspondence:**

\[ D: t_2 - t_1 \equiv T \]
\[ \theta: t_1 + \alpha - [t_1 + \alpha] \equiv \phi \]
\[ K: [t_2 + \alpha] - [t_1 + \alpha] \equiv J. \]

*In fact, the value of $\alpha$ may be unknown.

**The analogue of Eq. (3.1) is

\[ J = [T + \phi]. \]

It is obtained by writing

\[ J = [t_2 + \alpha] - [t_1 + \alpha] = [t_2 + \alpha - ([t_1 + \alpha])] \]
\[ = [t_2 + \phi - t_1 - \alpha] = [t_2 - t_1 + \phi] = [T + \phi]. \]
3.3 Computed Speeds

For a journey of length $D$ and duration $T$, the effective response speed is $S \equiv D/T$. The average effective speed is $E[S] = E[D/T]$.

In practice, the computed travel speed, $S_c$, is obtained by taking the ratio of two truncated variables, i.e.,

$$S_c \equiv \frac{K}{J},$$

where $K = \text{truncated travel distance (as in Sec. 3.1)}$ and $J = \text{truncated travel time (as in Sec. 3.2)}$.

We wish to show that

$$E[S_c] \geq E[S];$$

that is, $S_c$ is a biased estimator of $S$, the bias tending to overestimate actual effective travel speeds. To obtain this result it is convenient to write

$$E[S] = \sum_{k=0}^{\infty} \sum_{j=0}^{\infty} \int_0^1 \int_0^1 Q_1(k,j,\mu,\nu) f_{D,T}(k+\mu, j+\nu) \, d\mu d\nu,$$  \hspace{1cm} (3.10)

where

$$f_{D,T}(\cdot, \cdot) = \text{joint probability density function of } D \text{ and } T,$$

$$Q_1(k,j,\mu,\nu) = (k+\mu)/(j+\nu).$$

Now the expected truncated travel speed can be written

$$E[S_c] = \sum_{k=0}^{\infty} \sum_{j=0}^{\infty} \int_0^1 \int_0^1 E[S_c(\theta,\phi)|D = k+\mu, T = j+\nu] f_{D,T}(k+\mu, j+\nu) \, d\mu d\nu,$$  \hspace{1cm} (3.11)

where

$$E[S_c(\theta,\phi)|D = k+\mu, T = j+\nu] = \text{conditional expected truncated travel speed, given } D = k+\mu \text{ and } T = j+\nu, \text{ the expectation taken with respect to the phase angles } \theta \text{ and } \phi.$$
From physical considerations, it is reasonable to assume that $\theta$ and $\phi$ are (1) each uniformly distributed over $[0,1]$ and (2) statistically independent of $D$ and $T$ and of each other. Given these assumptions, we can write

$$E[S_C(\theta, \phi) | D = k+\mu, T = j+\nu] = \int_0^1 \int_0^1 \frac{(k+\mu+\theta)}{(j+\nu+\phi)} \, d\theta d\phi$$

$$= \left[ k(1-\mu) + (k+1)\mu \right] \left( \frac{1}{j} (1-\nu) + \frac{1}{j+1} \nu \right)$$

$$= Q_2(k,j,\mu,\nu). \quad (3.12)$$

Comparing (3.12) and (3.11) with (3.10), it is clear that (3.5) will be true if

$$Q_2(k,j,\mu,\nu) \geq Q_1(k,j,\mu,\nu) \quad \text{for } k=0,1,\ldots$$

$$j=0,1,\ldots$$

$$0 \leq \mu \leq 1$$

$$0 \leq \nu \leq 1 \quad (3.13)$$

But (3.13) is readily verified by direct computation, and thus (3.6) must be true.

Without further assumptions, it is not possible to obtain an upper bound for $E[S_C]$. In fact, if $J$ has a non-zero probability of assuming the value zero, $E[S_C] = +\infty$.

A similar argument to that above shows that

$$E[S_C^{-1}] \geq E[S^{-1}] \quad (3.14)$$

Thus, in estimating typical values of travel speeds and inverse travel speeds, statistics such as medians should be more helpful than means.

*For the case $j = 0$, we set $(1/j) = +\infty$. 
4. THE EXTENT OF INTERSECTOR DISPATCHING

In this section we give a formula that predicts the fraction of dispatch assignments which are intersector assignments (i.e., assignments requiring the patrol unit to travel to an incident outside its ordinarily assigned sector).

For a given command (e.g., "precinct") with I patrol units assigned, let

\[ \lambda_i(t) = \text{average rate (calls/hour) at which calls for service are generated in a Poisson manner from sector } i \text{ at time } t, \]
\[ i = 1, 2, \ldots, I, 0 \leq t \leq T; \]
\[ \rho_i^*(t) = \text{probability that patrol unit } i \text{ is unavailable for dispatch at time } t, \ i = 1, 2, \ldots, I, 0 \leq t \leq T; \]
\[ \lambda = \frac{1}{T} \int_0^T \sum_{i=1}^I \lambda_i(t) \ dt; \]
\[ \mu^{-1} = \text{average time required for a patrol unit to service a call}; \]
\[ \frac{\lambda}{I\mu} = \text{call-for-service utilization factor for the command.} \]

Given a call that arrives from sector \( i \), we assume the dispatching algorithm is as follows:

1. Dispatch car \( i \), if available.
2. Otherwise, dispatch some car \( j \), \( j \neq i \), where the particular choice depends on the state of the system.

This last assumption implies that the probability that all units are simultaneously busy is negligibly small; in other words, with probability one there is at least one unit available to dispatch to any reported call.

Given the above assumptions, it is easy to see that the probability that a random dispatch which occurs in \([0,T]\) will be an intersector dispatch is

\[ f = \frac{1}{T} \int_0^T \sum_{i=1}^I \rho_i^*(t) \frac{\lambda_i(t)}{\lambda} \ dt \quad (4.1) \]

*In general, a unit may be "unavailable" because of a prior dispatch assignment, a meal break or any number of other activities.*
By the weak law of large numbers, we would expect the actual fraction of dispatches which are intersector dispatches to come quite close to \( f \) (in a distributional sense), as the number of dispatches in the sample becomes large.

\[
\text{If } \lambda_i(t) = \lambda_i, \quad \rho_i^*(t) = \rho_i^*, \quad (4.1) \text{ reduces to } \\
\quad f = \sum_{i=1}^{I} \rho_i^* \frac{\lambda_i}{\lambda}.
\]

(4.2)

There are two interesting special cases of (4.2):

1. If each unit is unavailable an equal fraction of time, i.e., if

\[
\rho_i^* = \rho,
\]

then

\[
f = \rho \sum_{i=1}^{I} \frac{\lambda_i}{\lambda} = \rho.
\]

That is, regardless of the average rate of calls from sector \( i \), \( \lambda_i \), if each unit is unavailable an equal fraction of time \( \rho \), then the fraction of dispatches which are intersector dispatches equals \( \rho \). Furthermore, if units can only be unavailable for call answering duties,

\[
f = \rho = \frac{\lambda}{I \mu}.
\]

2. If each sector has an equal share of the call volume, i.e.,

\[
\lambda_i = \lambda/I
\]

then

\[
f = \frac{1}{I} \sum_{i=1}^{I} \rho_i^* = \text{average fraction of time units are unavailable.}
\]

That is, regardless of the actual fraction of time \( \rho_i^* \) that unit \( i \) is unavailable, if the call rates \( \lambda_i \) from each sector are equal, then the fraction of dispatches which are intersector dispatches equals the command-wide average fraction.
of time units are unavailable. Furthermore, if units can only be unavailable for call answering duties, then

\[ f = \frac{1}{I} \sum_{i=1}^{I} \frac{\lambda_i^*}{\mu_i} = \frac{\lambda}{\lambda \mu}, \]

where \( \lambda_i^* \) = average rate at which unit \( i \) is dispatched to calls.

Referring again to equation (4.1), if the system is time-varying (i.e., if \( \lambda_i(t) \neq \lambda_i \), \( \rho_i^*(t) \neq \rho_i \)), then, in general, \( f \) could be greater or less than that which would be achieved by a non-time-varying system with

\[ \lambda_i = \frac{1}{T} \int_0^T \lambda_i(t) \, dt \]
\[ \rho_i^* = \frac{1}{T} \int_0^T \rho_i^*(t) \, dt. \]

At one extreme, if meal breaks of unit \( i \) were scheduled to coincide with periods of zero demand from sector \( i \), then during such intervals we would have

\[ \lambda_i(t) = 0 \]
\[ \rho_i^*(t) = 1 \]
\[ \lambda_i(t) \rho_i^*(t) = 0. \]

When averaged with other periods for which \( \lambda_i(t) \neq 0, \rho_i^*(t) \neq 0 \), it is possible that

\[ \lambda_i \rho_i^* > \int_0^T \lambda_i(t) \rho_i^*(t) \, dt. \]

On the other hand, for many operating systems, it is not unreasonable to assume that

\[ \rho_i^*(t) \geq \rho_i^* \]
when \( \lambda_i(t) \geq \lambda_i \)

and that

\[ \rho_i^*(t) \leq \rho_i^* \]
when \( \lambda_i(t) \leq \lambda_i \).

Heuristically, these assumptions imply that when the call volume from sector \( i \) is greater (or less) than average, then the probability that unit \( i \) will be busy is greater (or less) than average.
If these assumptions are valid, then one can show that the extent of intersector dispatching is at least as great as that which would be obtained if the system were non-time-varying, i.e.,

\[ f \geq \frac{\sum_{i=1}^{I} \rho_i^{*} \frac{\lambda_i}{\lambda}}{I} \cdot \tag{4.3} \]

To obtain (4.3), let

\[ \rho_i^{*}(t) = \rho_i^{*} + \rho_i^{\Delta}(t), \]

\[ \lambda_i(t) = \lambda_i + \lambda_i^{\Delta}(t). \]

From (4.1), we have

\[ f = \frac{1}{\lambda T} \sum_{i=1}^{I} \int_{0}^{T} \left( \rho_i^{*} \lambda_i + \rho_i^{*} \lambda_i^{\Delta}(t) + \lambda_i \rho_i^{\Delta}(t) + \rho_i^{\Delta}(t) \lambda_i^{\Delta}(t) \right) \, dt. \]

Since the second and third terms in the integrand integrate to zero,

\[ f = \sum_{i=1}^{I} \rho_i^{*} \frac{\lambda_i}{\lambda} + \frac{1}{\lambda T} \sum_{i=1}^{I} \int_{0}^{T} \rho_i^{\Delta}(t) \lambda_i^{\Delta}(t) \, dt. \]

Now, since

\[ \text{sgn}\left\{ \rho_i^{\Delta}(t) \right\} = \text{sgn}\left\{ \lambda_i^{\Delta}(t) \right\}, \]

we have

\[ \int_{0}^{T} \rho_i^{\Delta}(t) \lambda_i^{\Delta}(t) \, dt \geq 0, \]

and thus, (4.3) must be true.
5. SUMMARY OF APPENDIX A

We have discussed various topics relating to the interpretation and analysis of the RMP Experiment.

Section 1 defined "effective response speed" and identified an inequality (1.1) which, if not recognized, could result in an underestimate of mean travel times.

Section 2 derived some results to test the reasonableness of the right-angle distance metric. The ratio \( R \) was defined to be that factor, which when multiplied by the Euclidean distance between two points, gives the right angle travel distance between two points. The value of \( R \) depends on the angle at which the mutually perpendicular directions of travel are rotated with respect to a straight line connecting the two points. Given an isotropy assumption, the exact distribution of \( R \) was obtained (2.3). The expected value of \( R \) is about 1.27, which means that on the average the response unit travels about 1.27 times the Euclidean distance.

Section 3 considered various effects of data truncation. Section 3.1 modeled the recorded (quantized) travel distance as the sum of the actual travel distance and the accumulated odometer mileage since the last odometer change, the sum rounded to the largest integer in the sum. Given some physically reasonable assumptions, we showed that the truncated travel distance is an unbiased estimator of the true travel distance (3.3). Section 3.2 demonstrated that the same model applies to time truncation. Section 3.3 showed that effective travel speeds computed by dividing the truncated travel distance by the truncated travel time are biased estimators of effective travel speed, the bias tending to overestimate actual effective travel speeds (3.6). A similar statement (3.11) applies to effective inverse travel speeds computed in this manner.

Section 4 developed a model predicting the fraction of dispatch assignments which are intersector assignments. The resulting formula (4.1) has two interesting special cases. If the system is time invariant and operating in the steady state, then (1) if each unit
is unavailable an equal fraction of time \( \rho \), then, regardless of demand distribution, the fraction of dispatches which are intersector dispatches is \( \rho \); (2) if each sector has an equal share of the call volume, then, regardless of the distribution of actual workload, the fraction of dispatches which are intersector dispatches equals the command-wide average fraction of time units are unavailable. If the system is time varying, then, given one additional assumption, the extent of intersector dispatches is at least as great as that which would be obtained if the system were non-time-varying.
Appendix B

REVISED OPERATING PROCEDURES

On the following pages we reproduce a Communications Division Memo which revised dispatching procedures as of April 1, 1969. The new procedures were designed to reduce delays in dispatching RMP units to important calls.
TEXT OF COMMUNICATIONS DIVISION MEMO #8

Revised April 1, 1969

SUBJECT: TIME DELAYS IN DISPATCHING RMP

In order to reduce instances of delay between the receipt of calls over 911 and the time of dispatch of RMP Units, the following procedures will be followed.

1. Promptly upon completion of the necessary entries on Radio Dispatch slips, the ACD operator receiving the call will route the dispatch slip via conveyor belt to the radio dispatcher. Care will be exercised to insure that the proper conveyor belt is utilized.

2. Radio dispatchers at the time of receiving dispatch slips, check the slip to ascertain if any unusual delay has occurred between the time the call was received on 911 and the time it arrived at the dispatcher's position. It shall be incumbent upon the radio dispatcher to bring to the attention of the supervisor any such delay noted.

3. When an unusual delay is called to the attention of the supervisor, he will immediately investigate and ascertain the reason for the delay and take appropriate action.

4. The captions "RMP OUT" and "RMP BACK" will only be time stamped when a unit accepts an assignment or when a unit completes an assignment, respectively. When an assignment is complete, the dispatcher will also enter the disposition code and his operator's number in the appropriate captioned space before filing the radio slip.

5. Radio dispatchers will attempt to dispatch each message received as soon as possible. All attempts to dispatch will be recorded on the face of the dispatch card. If after calling the sector concerned, the adjoining sector, the patrol supervisor (Lt., Sgt.), no car replies, ask for any available unit. If the assignment is still not accepted, mark the rear of the card "NCA" (No Car Available), add the operator's number and time stamp. Each such successive failure to dispatch will be recorded in the same manner.

6. All radio dispatchers will be conversant with Communications Section Memo #21cs, relating to Radio Backlogs.

Captain Howard E. Anderson
Commanding Officer
Communications Section
TEXT OF COMMUNICATIONS DIVISION MEMO #21

Revised April 3, 1969

SUBJECT: RADIO BACKLOG PROCEDURES

1. PURPOSE:

(a) It is the intent of this memo to:

Insure that all radio runs are promptly dispatched and,

(b) In instances where the volume of work begins to exceed the Radio Motor Patrol Units available (Impending backlog situation), adequate records are maintained and proper notifications are made.

2. EVALUATION BY RADIO SUPERVISOR:

(a) When a radio dispatcher is unable to dispatch an RMP Unit within 10 minutes of receipt of said slip he shall forthwith notify a supervisor via the Supervisors Call Light or by dialing the Desk Officer on Ext. 7334. However, if the dispatcher at any time feels that the existing situation indicates that a radio backlog is imminent, he should not wait 10 full minutes before calling a supervisor.

(b) The supervisor notified shall respond immediately to the radio room concerned and determine whether this is an isolated instance or if this is a condition likely to continue or worsen. If it is an isolated instance the supervisor will cause the job to be dispatched as soon as possible.

3. PREVENTION:

If the situation is not isolated in nature and it is apparent that it might worsen, then the following preventive measures will be initiated by the supervisor concerned:

(a) The Platoon Commander will be notified forthwith.

(b) The dispatchers shall be instructed to use all available radio cars including the sergeant or lieutenant on patrol, Safety Emergency Units, (including Motorcycle Units), Tactical Patrol Force and Boro Task Force Units when working, and Walkie-Talkie Units, in assigning radio runs.

(c) Assign an additional Patrolman to the radio room concerned to establish a priority to the incoming jobs. All but the most important jobs will be given back to the precinct for assignment to available Foot Patrolmen. The Desk Officer will be advised that no RMP's are available to handle these jobs.
(d) If there are no Footmen available in the precinct or precincts concerned, notifications will be made to the Desk Officers to ascertain if the Radio Car availability listed is correct and to alert the Supervisor on Patrol to the existing condition.

(e) In either case listed in paragraph 3c or 3d the name of the person ntf'd. shall be listed on the rear of the radio slip with the operator's # of the one making the notification and then time stamped.

(f) If a group of less serious runs (nuisance, noise, etc. - not to include reports of crimes) still remains and they cannot be given over the air to a unit, or to a Pct. for a Foot Patrolman, they will be time stamped "NCA" - No Car Available, and only with the approval of the Supervisor, filed.

4. BACKLOG IN EFFECT:

If all the prescribed preventive measures fail to prevent an actual backlog and runs are being held in excess of 20 minutes without indications that the situation will improve, then a backlog will be declared and the following steps will be initiated:

(a) A second experienced patrolman will be assigned to the Division suffering the backlog if in the opinion of the Platoon Commander this would assist in alleviating the condition. (This is in addition to the man described in paragraph 1c.) This man will assist the dispatchers in assigning precincts and sectors to units and generally work to reduce the waiting periods.

(b) A CRD 7 will be prepared and time stamped listing the precincts within the Division for which jobs are being held and the approximate number of those jobs. The length of the backlog must also be noted. This information will be brought to the immediate attention of the Platoon Commander who will direct notifications to be made to the Operations Section, Patrol Boro Command, Division and Patrol precincts concerned. The reason for the backlog also be given with these notifications.

(c) The radio room will immediately be notified of any additional units assigned by Boro or Operations to assist those commands in need. Unit designations, complement, and radio frequency will be included in this notification.

(d) The Platoon Commander will cause immediate chronological entries to be made in the Radio Backlog Index completing all captions, with special attention given to reasons for the backlog and action taken by the Communications Section to remedy same, and the names of those notified.

(e) Blotter entries will not be made unless extenuating or highly unusual factors are involved in the Backlog, i.e., Work Stoppage, Civil Disorder, etc.
5. GENERAL:

(a) The Platoon Commander will give special attention to any backlog situation and will, where possible, assign a supervisor to remain in the radio room concerned until such time as the backlog is diminished.

(b) Each attempt to dispatch a unit will be noted on the face of the dispatch slip. If no cars answer then the rear of the card will be marked "NCA" (No Car Available) and time stamped, including the operator's #. Each future attempt will also be time stamped and noted. The supervisor will sign the rear of those cards when possible. As already mentioned, in paragraph 3f of this memo no unassigned job will be filed unless signed and approved by a supervisor.

(c) If dispatchers feel that there are available units not responding to calls they will notify their supervisor who will confer with the patrol supervisors concerned.

(d) When the backlog is corrected immediate notifications will be made to the Patrol Boro Office and the Operations Section by the Platoon Commanders, and the Radio Backlog Index will be noted accordingly.

6. DURATION AND EFFECT OF MEMO:

(a) This procedure shall be effective immediately and shall remain in effect until revised, amended or expanded.

(b) C.S. Memo #3, 1968 dated June 3, 1968 is still in effect and should be studied by all personnel of this Command.

(c) C.S. Memo #8, c.s. dated January 20, 1969 has also been revised effective this date and should be familiar to all personnel of this Command.

(d) The following Communications Section Memo's s. 1968 are replaced by this Memo and are no longer in effect:

C.S. Memo 49, 49-1, 49-2, 49-2a, 49-3 and 78.

Howard E. Anderson
Captain
Commanding Officer
Communications Section