Patrol Car Allocation Model

User's Manual

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Rand

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PREFACE

This report describes a computer program designed to assist police departments in determining the number of patrol cars to have on duty in each geographical command at different times of the day and week. The program (PCAM85) is a modernized version of the Patrol Car Allocation Model (PCAM) developed in 1975. Section I of the report is written for police department administrators and planning officials who wish to understand how the patrol car allocation model can be used in policy analysis. Sections II and III provide all the information needed to use the program once it has been installed on a computer system. The summary of this report is separately published as

- R-3087/1-NIJ, *Patrol Car Allocation Model: Executive Summary*.

A third report provides detailed information for installing the program, preparing databases, and modifying the program (if desired):

- R-3087/3-NIJ, *Patrol Car Allocation Model: Program Description*.

If the program is operated on a mainframe computer, only the installation's data processing personnel will need a copy of the Program Description. These reports supersede reports of identical titles numbered R-1786/1, R-1786/2, and R-1786/3.

Development of the original version of PCAM was funded by the Office of Policy Development and Research of the United States Department of Housing and Urban Development (HUD) and by the National Institute of Law Enforcement and Criminal Justice. The modernization was funded by the National Institute of Justice under grant 81-IJ-CX-0088.

ACKNOWLEDGMENTS

This work was funded by the National Institute of Justice. Because the program documented here was based on concepts embodied in previous patrol car allocation programs, we wish to express our indebtedness to the designers of those programs, especially Richard Larson, Richard Mudge, the IBM Corporation, and the Public Systems Analysis class at the University of California, Los Angeles. A component of PCAM75 was contributed by Peter Kolesar, and David Jacquette wrote a subsidiary program described in the *Program Description* (R-3087/3). Peter Dormont programmed PCAM75, which is incorporated largely unchanged in the modernized version. Fred Finnegan did most of the programming that was required to change PCAM75 into PCAM85. We thank him for his untiring efforts, many of which were beyond the call of duty.

The model in PCAM85 that estimates queuing delays when multiple patrol cars are dispatched to calls for service was developed by Linda Green. She and Peter Kolesar programmed the model for inclusion in PCAM85, compared its estimates with those produced by PCAM75, and validated its estimates by comparing them with empirical data supplied by the New York City Police Department.

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FIGURES

GLOSSARY

ALGORITHM
A procedure for performing a calculation.

ALLOCATE
1. Assign a certain number of cars to each shift.

2. Divide a fixed total number of car-hours among shifts.

AMPERSAND (&)
At the end of a line of PCAM instructions, signifies that the command continues on the following line.

ASTERISK (*)
1. At the start of a line of output from the DISP command, indicates that the tour is overlaid by another tour.

2. In input commands, represents the current number of car-hours allocated.

AVAILABLE
1. Ready to be dispatched to a call for service.

2. Not engaged in cfs work or non-cfs work. Not busy.

3. Same as UNCOMMITTED.

BATCH
A mode of operating a computer program in which all instructions are prepared on cards or other input device prior to program execution, and output is received later, usually from a high-speed printer. Contrasted with INTERACTIVE.

BLOCK, TIME
A period of time (whole number of hours) over which the number of patrol cars on duty does not change. One or two time blocks constitute a tour.

BUSY
Unable to be dispatched to a call for service. Busy on cfs or non-cfs work.

CALL RATE
Average number of calls for service received per hour.

CALL RATE PARAMETER
A parameter for each day in each precinct. When multiplied by the hourly call-rate factor, gives the expected number of calls for service in the hour.

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CAR (see PATROL CAR)

CAR-HOUR
One patrol car on duty for one hour.

CFS
Call(s) for service.

CFS WORK
1. All activities of a patrol car from the time it is dispatched to a call for service until the time it is available again for dispatch.

2. Number of car-hours spent on such activities.

CFS WORKLOAD
1. Loosely speaking, the extent to which cfs work is a burden on a patrol car.

2. Technically, the number of car-hours of cfs work in a given period of time.

COMMAND
1. An instruction to the PCAM program.

2. An administrative unit in a police department that is supervised by a superior officer. (Used in the expression *geographical command*.)

CONSTRAINT
A number specified as the largest or smallest value permitted for a performance measure.

CURRENT-DATA
Some or all of the data in DATABASE, which have been read into the computer memory by a READ command and are used and/or modified by PCAM commands.

DATABASE
The data prepared by the user for input into PCAM.

DAY
A 24-hour period used for organizing PCAM data. Not necessarily a calendar day; in fact, a DAY should usually be started at a time when there are few calls for service, for example, 0400, 0500, 0600, 0700, or 0800.

DELAY, TOTAL
Sum of queuing delay and travel time. (Same as TOTAL RESPONSE TIME.) Shown in headings as "QUEUE +TRVL".

DELIMITER
Any character other than a letter, digit, parenthesis, asterisk, hyphen, period, or ampersand. Examples of delimiters are blanks, commas, colons, and equal signs.

DESCRIPTIVE MODE
Capability of the PCAM program to calculate and display performance measures by time of day and geographical command when the numbers of patrol cars on duty in each shift have been specified.

DIVISION
A combination of precincts. Some police departments use the word "division" for a precinct. This is permitted in PCAM by changing the keyword PRECINCT.

EFFECTIVE CAR
The equivalent of a patrol car that does not engage in any non-cfs work.

EXPONENTIALLY DISTRIBUTED
A random variable T is exponentially distributed if there is a parameter μ such that

$$\text{Prob}(T > t) = e^{-\mu t}.$$

The mean of T is $1/\mu$. The assumption that service times for calls to the police are exponentially distributed is not verified by data, but the assumption is technically necessary in PCAM. (This is a source of PCAM's simplicity.)

FIELDED
In the field. A patrol car is fielded if it is on duty.

FILLER WORD
One of the following words, which may be entered in a PCAM command if desired, but will be ignored by the program: FOR, CAR, HOUR, HOURS, TO, ON, BY, DATA.

HOURLY CALL RATE FACTOR
A parameter for a single hour in a single precinct. When multiplied by the call rate parameter for the day, gives the expected number of calls in the hour.

HOURLY SERVICE TIME FACTOR
A parameter for a single hour in a single precinct. When multiplied by the service time parameter for the day, gives the expected service time (in minutes) for calls received during the hour.

INTERACTIVE
A mode of operating a computer program whereby the user enters instructions at a terminal and receives output immediately at the same terminal. Contrasted with BATCH.

KEYWORD
A character string that has a special meaning to the PCAM program. These are either filler words or one of the following: DAY, P, C, T, F, ADD, ALOC, DISP, END, HEADR, LIST, MEET, READ, SET, WRITE, TOUR (or a substitute provided by the user), DIVISION (or a substitute), PRECINCT (or a substitute).

LIMITING CONSTRAINTS
When meeting constraints, the performance measures whose constrained values lead to a need for the largest number of patrol cars. (If these constraints were eliminated, a smaller number of patrol cars would meet all the constraints.)

LIST
Command that causes PCAM to print out the values of the data items associated with all precincts, days, and tours within its scope.

MINIMUM ALLOCATION
The smallest whole number of actual patrol cars that can be assigned to a shift to handle the call-for-service workload.

NEW-DATA
A permanent file created by the WRITE command from all or part of CURRENT-DATA.

NON-CFS WORK
1. Any activity of a patrol car that makes the car unavailable for dispatch but was not generated by a previous dispatch to a call for service.

2. Number of car-hours spent on such activities.

OBJECTIVE FUNCTION
The performance measure to be minimized by an allocation.

OFFICER HOUR
One police officer on duty for one hour.

OPTIMAL
Yielding the smallest possible value of the objective function.

OUTPUT ORDER
A choice of displaying output tables either by tour within day within precinct, or by precinct within tour within day.

OVERLAY TOUR
A tour that begins during one tour and ends during the following tour.

PARAMETER
A number that characterizes a particular hour, block, shift, day, or precinct. See also SERVICE TIME PARAMETER and CALL RATE PARAMETER.

PATROL CAR
A mobile vehicle that can respond to calls for service from the public. Includes vehicles other than automobiles that serve the same function, e.g. scooters.

PATROL INTERVAL
The interval (hours:minutes) between successive times that a random point will be passed by a car, if all uncommitted time is devoted to random preventive patrol.

PCAM
Patrol Car Allocation Model.

PLUS (+)
1. At the start of a line of output from the DISP command, indicates that the tour is an overlay.

2. In the heading +TRVL, means that travel time is added to queuing delay.

POISSON PROCESS
In the PCAM context, the occurrence of calls for service in a given precinct during a given hour constitutes a Poisson process if there is a parameter λ such that the time between calls has the distribution

$$\text{Prob(time between calls} > t) = e^{-\lambda t}.$$

This assumption is well verified by data.

PRECINCT
A geographical area that is treated as independent from other areas by the patrol car dispatcher. Each patrol car is assigned to an entire tour in one precinct, although it may work in only part of the precinct.

PRESCRIPTIVE MODE
Capability to suggest the number of patrol cars that should be on duty during each shift, so as to meet standards of performance specified by the user.

PREVENTIVE PATROL
The practice of driving a patrol car through an area, with no particular destination in mind, looking for criminal incidents or opportunities, suspicious occurrences, etc.

PRIORITY
Importance of a call for service. PCAM permits three priority levels. Priority 1 calls are so important that the dispatcher will violate ordinary dispatching practices to get a patrol car to respond immediately. The PCAM program ignores these special efforts of dispatchers and may, as a result, indicate delays that are somewhat higher than actual for priority calls. Priority 2 calls are important enough that a rapid response is preferred over a slow response. Priority 3 calls can wait in queue without deleterious effect.

QUALIFIER
Phrase(s) associated with a computer command, defining the scope of the command. May be any subset of these phrases, separated by delimiters: 'TOUR=<NAMELIST>', 'DAY=<NAMELIST>', 'DIVISION=<NAMELIST>', 'PRECINCT=<NAMELIST>'.

QUEUE
In the PCAM context, a collection of calls for service that are waiting to be assigned to a patrol car because no patrol car is available at the moment.

QUEUING DELAY
The length of time a call for service waits in queue.

REGRESSION ANALYSIS
A procedure for fitting a straight line to data so as to minimize the sum of the squares of the deviations of the data from the straight-line estimate.

RESPONSE TIME, TOTAL
Sum of queuing delay and travel time. (Same as TOTAL DELAY.)

SCOPE
The collection of precincts, tours, and days to which the action of a PCAM command applies.

SERVICE TIME
Number of minutes a patrol car will be unavailable from the time it is dispatched to a call until it is available to respond to another call.

SERVICE TIME PARAMETER
A parameter for each day in each precinct. When multiplied by the hourly service time factors, gives the expected service time in each hour.

SHIFT
A particular tour in a particular precinct on a particular day.

SMOOTHING
A method of calculating delays, available in PCAM by user option. Queuing behavior is smoothed over time by averaging queuing delays and queuing probabilities in two successive hours of a day. If smoothing is not chosen, the PCAM program calculates delays as if each hour was in steady state.

SQUARE-ROOT LAW
An equation for the average travel distance D in a region of area A when N patrol units are available:

$$D = (\text{constant}) \times \sqrt{\frac{A}{N}} \; .$$

STEADY STATE
In the PCAM context, a situation where the probability of finding n cars available does not change over time.

TIME BLOCK
See BLOCK, TIME

TOTAL DELAY
Same as RESPONSE TIME, TOTAL; the sum of queuing delay plus travel time.

TOUR
A period of time (whole number of hours) beginning when a patrol officer starts work for the day and ending when the officer finishes work. In PCAM, tours are assumed to start at the same time in every precinct on every day (but overlay tours need not be present on every day in every precinct).

TRAVEL TIME
The length of time from the moment a patrol car is dispatched to an incident until the moment it arrives at the scene.

UNAVAILABILITY PARAMETERS
A pair of constants B1 and B2 for each precinct that give the best regression fit to the linear equation

$$\begin{pmatrix}\text{fraction of time} \\ \text{on non-cfs work}\end{pmatrix} = \text{B1} \times \begin{pmatrix}\text{fraction of time} \\ \text{on cfs work}\end{pmatrix} + \text{B2}$$

UNCOMMITTED TIME
The minutes or hours during a tour when a patrol car is not engaged in either cfs work or non-cfs work. This time can be used for directed patrol, preventive patrol, or any activity that does not make the car unavailable for dispatch.

UTILIZATION
The fraction of time a patrol car is busy on cfs work.

I. CAPABILITIES AND USES OF THE MODEL

INTRODUCTION

The Patrol Car Allocation Model (PCAM85) is a computer program designed to help police departments determine the number of patrol cars[1] to have on duty in each of their geographical commands. Typically, the number of patrol cars needed will vary according to the season of the year, day of the week, and hour of the day. The PCAM program tells a department how to match its actual allocations to these needs, consistent with the overall manpower resources of the department, the levels of performance it desires for patrol cars in responding to calls for service, the hours of the day at which its patrol officers start work, and its dispatching policies.

Although patrol car operations are only part of police work, in most police departments the patrol function consumes over half of the annual budget. Therefore, careful attention to the allocation of patrol resources should be the concern of all police administrators. PCAM provides a tool by which an administrator can establish objectives for the performance of the patrol force and identify those allocation policies that come closest to meeting these objectives. It is intended to substitute for the use of "hazard" or "workload" formulas, which are still widely popular although their failings have been pointed out repeatedly.[5,9,13,20,31][2]

The original version of this computer program (here called PCAM75) was written at The New York City-Rand Institute in 1975 after a careful review of various patrol car allocation programs that were previously used by police departments.[3] Of these, the best known ones are the Law

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[1]By "patrol car" we mean a mobile vehicle that can respond to calls for service from the public. Typical names for a patrol car include "squad car," "radio car," "RMP unit," "black-and-white," and "cruiser." Other vehicles, such as scooters, can be counted as patrol cars in PCAM if they serve the same function.

[2]Numbers in square brackets identify citations in the Bibliography at the end of this report.

[3]This review covered all patrol car allocation programs that we were able to locate. A history of the development of such programs is

Enforcement Manpower Resource Allocation System (LEMRAS), [18] a product of the IBM Corporation, and the Resource Allocation Program described in Richard Larson's book, *Urban Police Patrol Analysis*.[31] PCAM incorporated many of the features of both of these programs, together with several improvements. In addition, PCAM was made available to any police department as a FORTRAN program that could be used "as is" or modified to meet any special requirements of the department, whereas the other programs are not generally available.

Between 1975 and 1978, over 40 police departments used PCAM, [3] and it was incorporated in the National Institute of Justice program called Managing Patrol Operations.[2] The model proved to be useful in handling the types of allocation questions for which it was designed. However, with the passage of time, certain improvements to the PCAM computer program and its documentation were needed to make the system more useful to police departments (e.g., the ability to produce accurate estimates of the performance of the patrol system under very high workloads). The National Institute of Justice provided funds to The Rand Corporation to modernize the program and improve its documentation. The major differences between PCAM75 and PCAM85 are summarized at the end of this section.

The PCAM program is designed to run in either batch mode (where the user's input is on cards or a suitable substitute) or in interactive mode (where the user types commands at a terminal and receives output at the same terminal). As the program is distributed, it requires 240K bytes of storage when compiled on an IBM 3032. Users in departments having more than eight geographical commands will want to modify the program and increase the memory requirements slightly.

A copy of the program may be obtained by writing to one of the addresses shown in App. C. The program is available on cards at a cost of $35, on magnetic tape at a cost of $25, plus $15 if we supply the tape, or on diskettes formatted for IBM DOS 2.0 at a cost of $40.[4] There is an added charge of $50 for all copies mailed outside the United States.

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given in [7]. A description of the capabilities of each program as compared with PCAM is given in Appendix A of [6].

[4]A postage charge is added on to all orders.

CAPABILITIES OF PCAM

The Patrol Car Allocation Model has both *descriptive* and *prescriptive* capabilities. The *descriptive* capabilities permit displaying quantitative information about any allocation of patrol cars by time of day and geographical command. This information may refer to the current allocation, any proposed allocation created by the user, or the particular allocations that are suggested by PCAM when operated in prescriptive mode. This information permits the user to compare allocations and determine which one he thinks is best. The *prescriptive* capabilities of PCAM specify particular allocations that best meet the standards of performance established by the user.

The information provided to the user when PCAM is operated in descriptive mode includes the following:[5]

- The number of patrol cars assigned to each geographical command at each time of day.
- Information about the workloads of the patrol cars.
- Information about the amount of uncommitted time of the patrol cars (time that can be used for directed or preventive patrol).
- Average length of time from the dispatch of a patrol car until its arrival at the scene of an incident (*travel time*).
- The percentage of calls that will have to wait in queue until a patrol car is available to dispatch to the incident.
- The average length of time (in minutes) that calls of various levels of importance (or *priority*) will have to wait in queue.
- The average *total response time* (time in queue plus travel time) for calls of various priorities.

In prescriptive mode, PCAM has several capabilities. One of them will tell the user the *minimum number* of patrol cars that must be on duty in each geographical command at all hours of the day to meet standards of performance related to the information listed above. Examples: What is the smallest number of patrol cars needed to assure

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[5]Details are given in Sec. II.

that no more than 20 percent of calls must be placed in queue? What is the smallest number of patrol cars needed to assure that the average total response time is less than 10 minutes? What is the smallest number needed so that both of these conditions are met?

The second prescriptive capability will tell the user the *"best" allocation of existing resources* among geographical commands and/or among different times of the day or week. PCAM permits the department to choose among several definitions of "best":

- the average percentage of calls that must be placed in queue is as small as possible, given existing resources,
- The average length of time calls of a given priority must wait in queue is as small as possible, or
- The average total response time is as small as possible.

The third prescriptive capability is a combination of the two already described. It permits the user to obtain an allocation that meets specified performance standards and is the "best" allocation that can be achieved while meeting those standards.

Although these capabilities are quite comprehensive, PCAM cannot tell police administrators everything they would like to know before making allocation decisions. For example, the reasons an administrator would be interested in reducing response times are to increase the number of on-scene apprehensions of criminals (thereby hoping to decrease crime rates) and to improve public satisfaction with the service provided by the department. But PCAM cannot calculate the number of criminal apprehensions that will result from a particular allocation policy because the information available from past research [10,18,20,35,36,38] is not adequate to make precise calculations. Generally the relationships between response times and crime rates or public satisfaction are quite complex and depend on many police operating policies not incorporated in the PCAM model.

Similarly, PCAM can tell the administrator what will happen to the amount of uncommitted patrol time from adopting a particular allocation, but it cannot tell how this will make service better or worse. Studies [14,21] have cast doubt on whether routine preventive patrol has any

effect on crime rates, but some departments may want to maintain a certain level of preventive patrol because it serves a traffic control function, permits searching for stolen automobiles, gives police officers an opportunity to provide needed services to the public, or otherwise enhances the police role.

Users of PCAM will also rapidly come to realize that the program cannot relieve them of the responsibility of making difficult decisions about their allocation policy. It is impossible for one allocation to be better in all parts of the city and at all times of day than another allocation that uses the same manpower resources, so the administrator will have to choose among conflicting alternatives. For example, a change in allocation policy may yield a lower *average* response time than current practices, but then some locations or times of day will have higher response times than they did in the past. Or one allocation might yield better average response time than another, but it has worse imbalances in workload for the patrol officers. These problems of conflicting objectives are not *caused* by PCAM, but the computer program highlights the fact that they exist. Ordinarily they are resolved by carefully reviewing the performance measures for several different allocations in light of the allocation problem being addressed. We illustrate this process by giving some examples in the next section.

We wish to point out that PCAM has certain limitations that should be understood by any department considering using this program. First, it is not entirely self-contained, because the user must prepare a database for PCAM. Most departments find it necessary to write subsidiary computer programs to calculate the required input data from computer-aided dispatch files, dispatchers' logs, or similar sources of basic information about the operations of patrol cars.

Second, PCAM is not a complete package for analysis of all questions a department might have about the operations of its patrol cars. For example, PCAM cannot be used to design patrol beats for patrol cars, nor can it analyze the potential advantages of a car locator system or the institution of new policies for selecting which patrol car to dispatch to each incident. For these purposes, other, more complex, models are required. The Rand Corporation can provide police departments with programs and user's manuals for two such models, the Patrol Car Simulation Model [28] and an early version of the Hypercube Queuing Model, [4,19] as well as this manual for PCAM. Interested readers should consult the documentation of those programs for further information.

If the calculations and analyses that a department wishes to perform match PCAM's capabilities, then PCAM has several advantages in comparison with a simulation model. First, no special programming skills are required to use PCAM. In fact, after it has been installed on the department's computer, PCAM can be operated by individuals who have no programming experience whatsoever. Second, considerably fewer data must be assembled for PCAM than for a simulation model. Finally, PCAM is inexpensive to operate and requires a fairly small amount of computer storage.

The primary disadvantage of PCAM in comparison with a simulation model is that PCAM's calculations are based on simplifying assumptions that may not represent a department's patrol car operations exactly. However, our experience suggests that having better estimates of performance measures as calculated by a simulation model would typically lead to exactly the same allocations as one derives using PCAM, or at most a difference of one patrol car at certain times or places. Indeed, errors that arise in collecting data often lead to greater inaccuracies than the approximations incorporated in the PCAM program.

TYPICAL APPLICATIONS

To illustrate the capabilities of the Patrol Car Allocation Model, we shall present a few hypothetical examples, explaining how the program would be used in each case. The reader should consult the Glossary for any unfamiliar terms in the examples.

Justification of a Budget Request

In past years, Department A was almost always able to find a patrol car available to dispatch immediately to a call from the public. However, during the last year or two, a rapid increase in the number of calls for service has led to a situation where approximately 15 percent of all calls must wait in queue before a car is available for dispatch. The department's chief considers this a marginally acceptable level of

performance but is concerned that the expected increase in calls for service next year will create even worse delays. For justification of a request to the City Council for an increase in the authorized strength of his department, the chief would like to know (1) what percentage of calls will have to be placed in queue next year if there is no increase in the size of the force and current trends in call rates continue, and (2) how many new patrol officers he would have to hire to assure that fewer than 15 percent of calls are queued next year.

Let us suppose that City A is divided into five patrol districts, each of which has somewhere between two and six patrol cars on duty, depending on the time of day and day of the week. Patrol officers in City A work one of three "watches," midnight to 8 a.m., 8 a.m. to 4 p.m., or 4 p.m. to midnight.

To apply PCAM to answer the chief's questions, it will be necessary for the Planning Unit of Department A to determine the average number of calls received in each of the districts during each watch of each day of the week. (Additional input data are needed for PCAM, and these will be described in Sec. II of this report, but the number of cars on duty and the call rates are the key items for this application.) After the database has been assembled, it would be prudent to have PCAM estimate the percentage of calls delayed and check that this figure agrees with the observed amount (15 percent). If so, the data have been prepared properly.

Next, the Planning Unit will have to estimate what the call rates will be next year. Although PCAM cannot help in making these estimates, a suitable approach would be simply to multiply current call rates by a number that incorporates the current annual rate of increase. (For example, if call rates are increasing by 17 percent per year in District 1, the current call rates in District 1 would be multiplied by the number 1.17.)

The Planning Unit now has a choice of preparing a new database that has the changed call rates in it, or simply entering a command to PCAM that increases the call rates. PCAM will then describe the queuing delays that will occur if the current allocations of patrol cars remain unchanged. Let us suppose the answer is that, on the average, 28 percent of calls will be queued, which is well past the standard set by the chief.

However, this does not quite answer the chief's first question, because it is possible that by changing the number of cars assigned to certain districts or watches next year, the delays would be reduced. By entering another command to PCAM, it is possible to determine how the *existing* total number of man-hours devoted to patrol should be reallocated among districts and watches so as to have the *lowest possible percentage of calls delayed* next year. Let us suppose the result is that, on the average, 23 percent of calls will be delayed if the cars are reallocated. This answers the chief's question regarding what will happen if he gets no budget increase.

To answer the chief's question about hiring, there are two ways to proceed. One is to note that each new officer hired can increase the number of car-hours provided in a week by about 32. (This reflects Department A's experience that about one day per week is not spent on patrol duty because of training, court time, vacation, etc., and the fact that each patrol car in City A is manned by a single officer.) Therefore, a series of commands can be entered into PCAM to increase the number of car-hours by various multiples of 32, each time reallocating to achieve the smallest possible average percentage of calls delayed. The smallest multiple of 32 that results in an average of under 15 percent of calls delayed represents the number of officers that would have to be added.

The second way to proceed is to enter a single command into PCAM that asks what is the smallest total number of car-hours needed to assure that under 15 percent of calls are delayed in *every* watch in *every* district. Subtracting the number of car-hours currently fielded from the answer given by PCAM and then dividing by 32 gives the number of new officers needed. This answer will, in all likelihood, be *different* from the answer given by the first procedure, because the first method tells how many officers are needed to keep the *average* number of calls queued under 15 percent. In this case, some watches in some districts will have more than 15 percent of calls queued; others will have fewer than 15 percent queued. But the second procedure will assure that in every watch in every district the average number of calls placed in queue will be under 15 percent of the total.

To resolve the difference, the chief will be shown both sets of results. He will decide which figures he would like to present to the City Council, because this is really a matter for his judgment and cannot be left to a computer program.

Managing Demand

Department B is in a worse, but perhaps more typical, situation than Department A. At the present time, over 40 percent of all calls in City B must be placed in queue, and even "emergency" calls experience an average delay of 9 minutes before a patrol car can be dispatched. (In Department B an "emergency" call is one that the department would like to respond to rapidly, but it is not as urgent as a "top priority" call, such as "officer needs assistance.") Moreover, the budget allocated to Department B for next year is the same as for this year. In light of recently negotiated salary increases, this means that Department B will have to reduce the number of car-hours devoted to patrol. Department B has already been using PCAM, so the chief is fairly certain that delays cannot be reduced substantially by reallocation, and therefore he wants to know what types of calls from the public will have to be excluded from receiving a response by a patrol car next year. They will be handled by another means, such as taking crime reports over the telephone.

For this application, the Planning Division in Department B already has the information it needs to prepare a PCAM database describing the current situation. But to answer the chief's question, it will be necessary to find out how many calls there are of each type that might be excluded from response. This will have to be done for each of Department B's 11 patrol precincts for each eight-hour tour during the week.[6] In addition, the Planning Division will have to estimate, from next year's budget, how many car-hours of patrol can be provided. Let

[6] Department B uses the name "precinct" to refer to the same kind of geographical command that Department A calls a "district," and Department B uses the word "tour" instead of "watch." Since one of PCAM's desirable features is that the user specifies the names that are applicable in his department, we use various names in these hypothetical examples without intending to imply any difference in meaning.

us suppose the answer is that Department B will be able to field 10,000 car-hours of patrol per week next year.

Now, PCAM's database does not include a count of the number of calls in each precinct and tour according to the type of the call. Instead, calls are aggregated into three priority levels in PCAM's database: priority 1 ("top priority"), priority 2 ("emergency"), and priority 3 ("all other calls"). If some types of calls were to be eliminated, this would change the total call rate and the fraction of calls that fall into each priority level. The planning staff will have to calculate what these changes would be.

Then a sequence of commands would be entered into PCAM to change the data in a way that imitates the elimination of each type of candidate call in turn. After each elimination of a type of call, a PCAM command would be entered to allocate 10,000 car-hours among all the precincts and tours so as to minimize some measure of delay, such as the average delay for priority 2 calls. When the resulting delay, as estimated by PCAM, is considered to be acceptable, then the exclusion process can stop.

At the end of this analysis, the planning staff would know (1) which types of calls will have to be excluded from dispatch, (2) how many officers should be assigned to each precinct next year for patrol car duty, and (3) how many patrol cars should be on duty during each tour in each precinct next year.

Reallocation Among Tours

Let us suppose that the chief of Department B approves the plan developed in the example described above. However, six months later, the plan is found to have been unrealistic in two aspects. First, although the public has accepted the fact that patrol cars will not respond to certain types of incidents during the daytime, at night they insist that the police respond, and dispatchers have been assigning patrol cars to the supposedly "excluded" incidents at night. Second, precinct commanders did not reduce the number of patrol cars in the field when their manpower was reduced, but instead they removed officers from other types of assignments.

So, rather than having 10,000 car-hours of patrol work per week, the department actually has 11,000 car-hours. Moreover, delays in dispatching are rare during the day but frequent at night. What is needed is a reallocation of manpower among the tours. The chief does not want to change the number of patrol officers assigned to each precinct until the next budget cycle, so the total number of car-hours in each precinct must remain the same.

To perform the required analysis, Department B's Planning Division must update the PCAM database to reflect what has actually happened to call rates in the three priority levels and also determine the number of car-hours currently fielded in each precinct. Then, for each precinct, the planning officers (or the precinct commander) would enter a small number of commands into PCAM that result in allocating the existing number of car-hours among the tours of the week. This would produce the desired new allocation.

Possibility of an Overlay Tour

The officers in Department C work tours that begin at midnight, 0800, and 1600. However, most of the call-for-service workload occurs during the hours 1800-0200. The department would like to analyze the possibility of reducing the number of patrol officers on the three existing tours and establishing an overlay tour that works from 1800 to 0200.

Department C already uses PCAM for patrol car allocation, so it takes only a minute or two to change the database to permit an overlay tour. There is no need to collect any additional data. In its previous use of the model, Department C decided that suitable allocations were obtained by minimizing the average response time after meeting two constraints:

- Not more than 20 percent of calls are queued.
- A random point is passed by a car on preventive patrol at least once every four hours.

To allocate the existing patrol resources among four tours instead of three, the department will use the same criteria. This can be done in such a way that the number of patrol officers assigned to each of Department C's five patrol divisions remains unchanged, or the officers can be reallocated among divisions as well as tours.

In the latter case, only three commands need to be entered into the PCAM program. One assures that the constraints are met, and the second allocates the remaining patrol resources so as to minimize average response time. The third command causes PCAM to display the estimated performance measures for the allocation with four tours. By comparison with current performance measures (previously calculated using PCAM) the department can determine the extent to which response time and queuing delays will be reduced and workloads will be balanced if it adds an overlay tour. The same display tables show the number of patrol cars that should be assigned to each tour, so the department will know how many patrol officers would have to be reassigned from each existing tour to the new overlay tour.

Adding Resources

Department C is about to graduate a class of 75 new recruits and wants to assign them to patrol car duty. A single command to PCAM will determine how many of them should be assigned to each patrol division so as to minimize average response time. (The constraints are already met.) One more command will display the results.

Seasonal Variations

City D has a large recreation area that is busy in the summer and closed in the winter. For this reason, Department D experiences fairly large fluctuations from month to month in the number of calls for service received from different parts of the city. The department adjusts to these variations by having a group of patrol officers (the Mobile Patrol Team) who are not assigned to any of the city's seven patrol districts but instead move from district to district every month.

Department D uses PCAM to determine how many of the Mobile Patrol Team officers should be assigned to each district each month. Part of the department's PCAM database describes the current allocation of those officers who are assigned to patrol districts. Another part of the

database is updated every month to describe the cfs workload expected in each hour of the week in every district during the upcoming month. These workloads are predicted by a computer program that was developed by the department and is based on a statistical technique known as "exponential smoothing." (The same method was used in LEMRAS.)

By entering a single command to PCAM, the total car-hours that can be provided by the Mobile Patrol Team are allocated among districts and watches, *as an addition* to the car-hours already provided by the district officers. By displaying PCAM's allocations after the addition and comparing them with the (fixed) allocation of district officers, the results tell not only the number of Mobile Patrol Team officers who should be assigned to each precinct but also which watches they should work.

THE ROLE OF JUDGMENT IN USING PCAM

As is illustrated by the above examples, PCAM is not a single-purpose automatic method for allocating patrol resources. Rather, it is a flexible tool that can adapt to a wide range of user requirements. Only the users can specify what type of allocation question PCAM is to answer, and only they can establish the standards of performance that PCAM will use in prescribing allocations.

The first few times that a department uses PCAM, it will be natural to try several different standards of performance to see what happens. But it will soon become apparent what standards lead to allocations that are both feasible and acceptable to the department. Thereafter, the department would ordinarily want to use the same standards in every run of the PCAM program.

For example, a department might *wish* it could allocate patrol cars in such a way that less than 5 percent of calls encounter a queue at all times of day in every precinct. But if the current situation is that about 15 percent of calls are queued in nearly every precinct, there will be no way that the desired objective can be achieved with existing resources. If users ask PCAM to tell them how many car-hours are needed to assure that under 5 percent of calls are delayed in every tour in every precinct, they will rapidly discover that the answer far exceeds the number of car-hours the department can field. This, then, is an *infeasible* standard, and the department will have to be satisfied with a less demanding standard.

Similarly, you might *think* you want an allocation that minimizes the citywide total of calls that will be queued. But after asking PCAM to allocate patrol cars according to this objective, you might find that although the resulting allocation brings the number of calls queued to under 7 percent of the total, it produces enormous delays in two precincts that have a low rate of calls for service. Such an allocation is *unacceptable*, and you will have to establish a new standard, perhaps including the condition that no precinct will be permitted to have more than 25 percent of its calls delayed.

In short, the choice of standards and objectives is a matter of judgment that can best be decided in each department by inspecting the allocations that PCAM produces using several different standards.

Another area for exercise of judgment is the preparation of a database. Although PCAM requires certain information to be in the database, the user may tailor the accuracy of the data to the particular application he has in mind. As an example, if PCAM is to be used for long-term planning related to total size of the force, then rough estimates of next year's call rates will be suitable input data. These need not be broken down carefully by hour; instead, as an approximation, the estimated average hourly call rate in a tour can be entered into the database for every hour in the tour. However, if the department is considering changing the hours at which tours begin, then it is important to estimate accurate call rates for each hour.

Similarly, if the department is not interested in distinguishing performance measures according to the priority level of the calls, it is free to count all calls as if they had the same priority. This eliminates the necessity for deciding which types of calls belong to priorities 1, 2, and 3 and collecting separate statistics for each level.

Other shortcuts in preparation of the data are possible if the department is not concerned with the accuracy of certain performance measures, and these will be indicated where appropriate in Sec. II.

MAJOR DIFFERENCES BETWEEN PCAM75 AND PCAM85

PCAM85 incorporates three major types of changes: (1) explicit modeling of multiple-car dispatches, (2) smoother performance measures over time, and (3) improved output reports. Each type of change is briefly described below.

Multiple-Car Dispatches

In many cities a substantial fraction of calls for police service require more than one patrol car. PCAM75 assumed that a single patrol car is dispatched to each call for service. Some adjustment in the input data (e.g., increase in average call rate or average service time) was needed in order for the PCAM results to give a good approximation of the performance of the actual system. Green [15] developed a multiple-server priority queuing model in which the number of cars (servers) assigned to each call depends on the call's priority. Green and Kolesar [16] showed that none of the ways of adjusting the input data for PCAM75 was very satisfactory and that the multiple-server model produced very good estimates of the performance of the New York City Police Department's patrol system.

PCAM85 uses their multiple-server queuing model. In addition to allowing for up to three priority classes (as in PCAM75) it allows for job types within each priority. For each job type, the user can specify the number of cars to be dispatched. A mathematical description of the model is given by Green.[15]

Smoothed Performance Measures

The level of demand for police service usually varies considerably through the day. Although PCAM75 permitted call rates and service times to change every hour, its performance measures were calculated by assuming that each hour's call rate and service time would persist for a long period of time (that the system would reach "steady state"), and that what happened in one hour did not affect what happened in the next hour. Thus, if the call rate were high in one hour and low in the next, PCAM would predict long delays in the first hour and short delays in the next. In actuality, the delays in the second hour might be as long as those in the first, because a large number of calls would be left in queue at the beginning of the second hour.

PCAM85 includes (as a user option) routines that smooth the performance measures over the day. With smoothing, queues appear to build and dissipate more slowly than if smoothing is not chosen. The smoothed results are more representative of actual performance. In addition, smoothing permits the average call rate to exceed the average service rate for short periods of time without causing the computer program to reject the input data as "impossible." As a result, PCAM85 is able to model extremely heavy workload situations, such as those many police departments have been experiencing in recent years. However, the smoothing option slows down the computer program and doubles the cost of making a PCAM run, so it should be used only when needed.

Improved Output Reports

Since PCAM75 first became available, the environment in which police departments have to operate has changed considerably. The era of expanding levels of service came to an end, and departments are now faced with increasing demands and smaller budgets. Police administrators are looking for ways to minimize the effect of cutbacks. PCAM's output reports have been extensively revised to provide them with more help in evaluating their alternatives.

Patrol performance measures that were considered interesting in 1975 (e.g., patrol hours per suppressible crime) have been replaced by measures police patrol analysts told us would be more useful (e.g., percent of time cars are busy on non-cfs work). PCAM75 provided only two types of output reports; PCAM85 provides five types of reports.

Error Checking

The computer program will check the database and give messages reporting any errors or unusual data found. This capability is intended to prevent the user from running the program with erroneous data that will produce mysterious FORTRAN interrupts or create infinite run-time loops. The user can override the error check routines once the database

is known to be satisfactory, after which the program will run more rapidly. (See R-3087/3-NIJ, Program Description, Sec. II, "Control Record.")

II. HOW THE MODEL WORKS

In this section we discuss the database required for PCAM, tell how the program calculates the performance characteristics it displays, and describe the procedures it uses to prescribe allocations. The discussion is nontechnical, with details relegated to a companion volume, the Glossary, appendixes, and references. We begin with some general terminology and principles that will be referred to throughout.

GENERAL PRINCIPLES

To simplify the discussion, we use the term "precinct" to refer to an independent geographical command that is variously called a precinct, division, district, area, beat, or sector. A "precinct" is not the area covered by a single patrol car, but rather is a larger area, ordinarily containing a station house to which the patrol officers report before and after their tours of duty. The important characteristics defining a precinct are that (1) its commander has the capability or authority to decide how many patrol cars will be fielded at various times, and (2) the dispatchers of patrol cars treat the precinct as an independent command by sending only its cars to incidents in the precinct, except in unusual circumstances.

Some police departments are small enough that they do not have separate geographical commands. For them, PCAM can be used to determine how the total number of patrol cars they field should vary by time of day. Such departments should think of themselves as a single "precinct" for purposes of the discussion that follows.

The Patrol Car Allocation Model operates on the principle that a call for service to the police requires the dispatch of a certain number of patrol cars (1, 2, or 3), which depends on the type of call. All cars are to be assigned from the precinct of occurrence. If a call requiring two cars arrives when fewer than two cars in the precinct are available, PCAM assumes that the call will be placed in queue. If more than two cars are available when the call arrives, then two cars will be dispatched. If several calls are already in queue when another call

arrives, PCAM assumes that the order in which the waiting calls will be assigned to cars depends on their priority or importance. PCAM allows three priority levels. All priority 1 calls in queue will be dispatched before any call of priority 2, and all priority 2 calls will be dispatched before priority 3. Some or all calls within each priority level can be assigned one, two, or three cars to be dispatched.

Ordinarily, none of the above assumptions is precisely correct in practice. For example, if an extremely urgent call arrives when all the precinct cars are busy, it will not actually be placed in queue. Instead, an additional car will be fielded specifically to answer the call, a sergeant's car will be dispatched, a patrol car from a neighboring precinct will be dispatched, a special-purpose unit such as traffic car or plainclothes unit will be sent to the scene, or some other way will be found to respond to the call.

If variations from the assumptions in the program occur infrequently, then they may be ignored for all practical purposes. However, if the variations are extreme, then either the input to the program must be adjusted to account for departmental practices or the output must be interpreted differently. For example, if a department would *usually* dispatch a car from a neighboring precinct rather than place a call in queue, then the term "precinct" has not been defined properly for that department, and larger areas should be considered precincts.

PCAM assumes that patrol cars can be busy on two types of activities. One, called *cfs work*, results when a patrol car is dispatched to a call for service. All other activities that prevent a patrol car from being dispatched to a call constitute *non-cfs work*. These activities include meals, auto repairs, on-view incidents requiring police action, special assignments by commanding officers, and the like. To compare the amount of preventive patrol among tours or precincts, the program assumes that all time not spent on cfs work or non-cfs work is spent on preventive patrol. This assumption is ordinarily not correct but is nonetheless useful for making comparisons.

Data collected in several cities show that non-cfs work consumes at least 20 percent of patrol car's time and sometimes as much as 60 percent, so its effect on unavailabilities of patrol cars is as great as, or even greater than, that of cfs work. Therefore, if an attempt is made to use PCAM without determining the amount of non-cfs work, the output from the program will bear little relationship to reality and will therefore be useless as a planning aid. In the absence of any information about the amount of non-cfs work, it is better to make an educated guess than to ignore the problem.

One method for taking non-cfs work into account is to consider every incident that causes a patrol car to be unavailable as if it were a call for service. If the department's estimates of non-cfs work are accurate, this method will result in a good match between PCAM's calculations of performance measures and the actual situation in the field. However, *the method is not recommended*, because it is extremely difficult to estimate what will happen to non-cfs work if the allocation of patrol cars is changed. Particularly in departments where patrol cars are unavailable for dispatch during meal times, it is apparent that increasing the number of cars on duty will increase the amount of non-cfs work, quite independently of how much non-cfs work there was in the past.

The recommended method for taking non-cfs work into account in PCAM is to assume that each patrol car will spend a certain fraction of its time on non-cfs work. For example, suppose the fraction is 1/3 in one precinct. Then if six patrol cars are on duty in the precinct, there will be two car-hours of non-cfs work per hour, but if nine cars are on duty, there will be three car-hours of non-cfs work per hour. A study conducted in cooperation with the Los Angeles Police Department [1] showed that the fraction of time spent on non-cfs work actually varied with the amount of cfs work per car, so PCAM permits the user to include two *unavailability parameters* in the database; these tell PCAM how the fraction of time spent on non-cfs work is related to cfs work. Below we describe how the department can determine its unavailability parameters.

PCAM uses the unavailability parameters to convert the *actual* number of cars fielded into *effective* cars. An effective car is the equivalent of a patrol car that spends all its time on cfs work and preventive patrol; it does not perform any non-cfs work. In the example of the precinct where cars spend 1/3 of their time on non-cfs work, when nine actual cars are fielded, there are six effective cars. (The number

of effective cars does not have to be an integer. Thus, if eight actual cars are fielded, there will be 5-1/3 effective cars, rounded in the output to 5.3.)

PREPARATION OF A DATABASE FOR PCAM

The database for PCAM must be prepared according to a format that is detailed in Sec. II of the companion *Program Description* (R-3087/3). An example of such a database is shown in App. A, "Demonstration Database," of the same volume. This section describes the information that must be collected to prepare a database. The user may prepare different databases for different purposes. These can be assigned names that will appear in the output from PCAM (e.g., "1990 Budget Proposal").

Geographical Information

As mentioned previously, PCAM imagines the city to be divided geographically into precincts. (However, a city having only one precinct is permitted.) Optionally, the precincts can be considered as belonging to larger geographical commands that we shall call "divisions." If the user wishes to allocate patrol cars within each division, one at a time, or to display summary statistics for each division, this can be a useful feature. Otherwise, the name of the division to which a precinct belongs serves no other function in PCAM; all data must be prepared separately for each precinct, whether or not the user aggregates precincts into divisions.

PCAM permits the user to substitute any words he wants for "precinct" and "division." The words he chooses will appear in the headings for all tables and will substitute for the words PRECINCT and DIVISION in all the commands to PCAM that are described in Sec. III. For example, if the department chooses the words DISTRICT and BUREAU, then the information printed out by PCAM for each district will appear under the heading "DISTRICT." These words are the first data items provided in the database.

Each precinct and division must have a *name*, such as MIDTOWN, NORTH, or FIFTH. PCAM permits names to be up to 8 characters long, of which the first must be a letter. The other 7 characters may be letters, numbers, periods, or hyphens, but no embedded blanks are permitted. If a department's precincts and divisions are numbered, it may choose names such as ONE, TWO, THREE, ..., or FIRST, SECOND, THIRD, ..., or P1, P2, P3, ..., or P-1, P-2, P-3, ..., or PCT.1, PCT.2, PCT.3, ... The names selected by the user are entered into the PCAM database.

Additional characteristics of precincts that must be entered into the database are their area (square miles) and number of miles of streets to be patrolled. If the department does not know the number of street miles in its precincts, a reasonable approximation is (street miles) = 35 × (square miles). The factor 35 may be different in some cities, depending on how close together the streets are.[1] The number of street miles is used primarily to calculate preventive patrol and does not have to be exactly correct if the user is not interested in preventive patrol.

PCAM will not allocate fewer than two patrol cars to any tour in any precinct. Therefore, it cannot be used for allocation to small geographical areas where occasionally only one car is needed (for example, team policing areas). So precincts should be selected to be large areas that usually need five or more cars.

Time of Day Information

For purposes of entering data into PCAM, time is divided into 24-hour periods called *days*. However, PCAM's days are not necessarily the same as calendar days. A PCAM day cannot begin in the middle of a tour, so a day must begin at the beginning of some tour.[2] A *tour* is defined to be a period of time during which a patrol car may be on duty. If a department has no tour that begins at midnight, a *day* cannot begin at midnight. If there is an overlay tour from 7 p.m. to 3 a.m. and some patrol cars are on duty from midnight to 8 a.m., then a *day* cannot begin at 3 a.m. either, but might start at 8 a.m. (See Fig. 1.)

[1] In case some locations are patrolled more heavily than others, the user will want to enter the "effective" number of street miles. See Sec. 4 of Ref. 31.

[2] Some users of PCAM75 asked whether the program could be modified to allow tour arrangements that do not line up with 24-hour days. For example, some departments have three 10-hour tours. Unfortunately, the structure of the PCAM program did not permit such a modification.

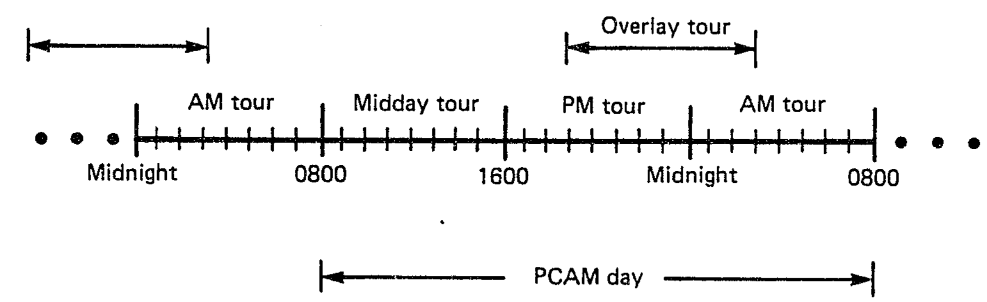

Fig. 1 — Example of overlay tour

The simplest situation is if the department's cars begin work at midnight, 0800, and 1600. Then, every day can begin at midnight, and there are three tours in each day. Any other arrangement of three 8-hour tours is nearly as easy to handle. The starting time of one of the tours is selected as the beginning of the day, and all the others will fall within the day. For example, if tours begin at 0715, 1515, and 2315, the department could choose to have PCAM's day begin with the hour from 0715 to 0815 or the hour from 2315 to 0015. In any event, *the first hour in PCAM's database is the first hour of PCAM's day*, which may or may not be the hour beginning at midnight. For the smoothing algorithm to produce good estimates of performance, you should begin PCAM's day when the call rate is fairly low, for example at 0400, 0500, 0600, 0700, or 0800, if a tour begins at one of these hours.

The PCAM database may contain any number of days. Common applications would involve a single day (a "typical" or "average" day) or seven days. However, if desired, all the days in a month can be included in the database.

PCAM allows tours to be any number of whole hours in length, although most applications will involve eight-hour tours. In addition, PCAM will permit one tour in each day to be an *overlay* tour, meaning that it begins during one tour and ends during the following tour. For example, if the department's tours begin at midnight, 0800, 1600, and 1900, then the tour from 1900 to 0300 is an overlay tour. (See Fig. 1.) This department can begin its PCAM *day* at 0800 or 1600, but not at any other time. (In the figure, it is assumed to begin at 0800.) If there is an overlay tour, PCAM does not require that it be present on every day of the week nor in every precinct. For example, it is possible to have an overlay tour only on Fridays and Saturdays in Precinct 4.

Some departments have multiple overlay tours; for example, eight-hour tours might start at 0300, 0800, 1100, 1600, 1900, and midnight. The PCAM program will not handle this arrangement exactly, but a reasonable approximation can be obtained by preparing a PCAM database having six imaginary tours, the first starting at 0300 and lasting five hours, the second at 0800 and lasting three hours, the third at 1100 and lasting five hours, etc. The allocation of patrol cars during, for example, the second imaginary tour is then found by simply adding together the number of cars starting on duty at 0300 and the number starting on duty at 0800.[3]

If, for some reason, the department does not wish to use PCAM for allocation of patrol cars over entire days, it may enter nonsense data, for example all zeros, for the hours of the day that are not of interest, so long as no attempt is made to have PCAM read the data for those hours.

[3]This suggestion yields only an approximate description of the department's operations. In prescriptive mode PCAM's suggested number of cars on duty during each imaginary tour might not actually be achievable by assigning cars to eight-hour tours. During the process of designing PCAM85, we developed a test version of PCAM that handled multiple overlay tours exactly. However, the test program was cumbersome, slow, and expensive; moreover, the output from the program was very difficult to understand. For these reasons, the multiple-overlay capability is not included in PCAM85.

PCAM requires that all tours begin at the same hour of the day in every precinct on every day. If this is not the case, the department may choose to make a reasonable approximation (for example, if some precincts begin tours at 0745 and others at 0815, it will do no harm to approximate all of these as 0800), or it may choose to prepare separate databases for each group of precincts having the same arrangement of tours, but then allocations can be made only among precincts in the same database.

Just as with divisions and precincts, PCAM permits you to choose your own word to substitute for "tour." For example, the words WATCH, SHIFT, or PLATOON can be selected. If this is done, the selected word will appear in all table headings and will be used in commands to PCAM.. However, for the remainder of this report we shall continue to use the word *tour* to refer to a period of time that is the same on every day in every precinct, and we reserve the word *shift* to mean a specific tour on a specific day in a specific precinct.

An important concept in PCAM is a *time block* (or *block* for short). This is a period of time during which the number of patrol cars on duty does not change. If the department has three 8-hour tours each day, then a time block is the same as a tour. However, in the example of the department with 8-hour tours beginning at midnight, 0800, 1600, and 1900, there are five time blocks: 0000-0300, 0300-0800, 0800-1600, 1600-1900, and 1900-2400. (See Fig. 2.)

Supposing that this department begins its PCAM *day* at 0800, then the time blocks are described to PCAM as follows:

Block 1	Hours 1-8
Block 2	Hours 9-11
Block 3	Hours 12-16
Block 4	Hours 17-19
Block 5	Hours 20-24

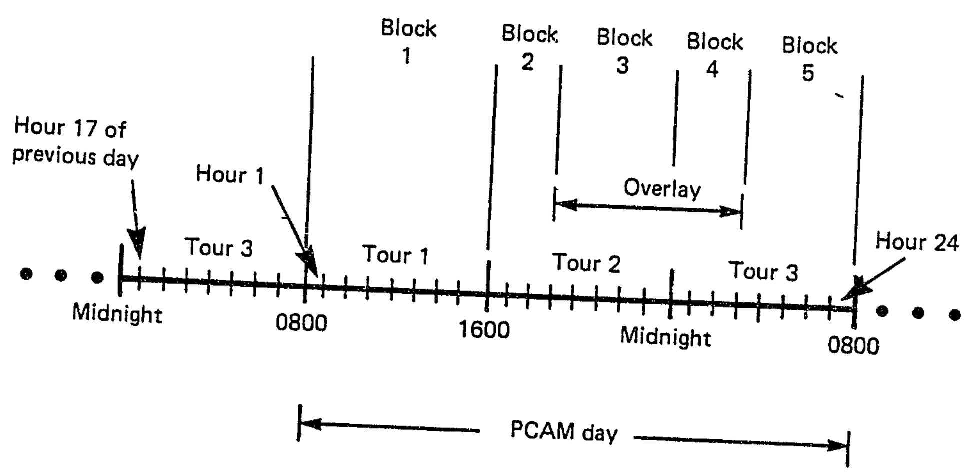

Fig. 2 — Time blocks with an overlay tour

Tours are described in terms of the blocks they include. Continuing the example, the tours in this department are:

Tour 1	Block 1
Tour 2	Blocks 2 and 3
Tour 3	Blocks 4 and 5
Overlay tour	Blocks 3 and 4

To describe temporal characteristics in the PCAM database, you enter the number of time blocks in each day (up to 24), the number of tours in each day, the *ending* hours of each block (8, 11, 16, 19, and 24 in the example), and the blocks that constitute each tour.

In addition, every tour and day is given a *name*. As with precincts and divisions, these are limited to eight characters, of which the first must be a letter. Examples of permitted tour names are FIRST, SECOND, THIRD, FOURTH, AM, PM, MIDDAY, NIGHT, GRAVEYARD, AFTRNOON, MDN-8, T9-16, T16-24, and W.8X16. You are not permitted to call a tour DAY unless you are willing to take special precautions when operating the program (see Sec. III). Examples of suitable day names are MONDAY, MON-TUE, and MARCH27.

DATA FOR EACH HOUR

For every hour of every day in every precinct, PCAM needs to know the average number of calls for service that are expected to occur (*call rate*) and the average *service time* (number of minutes a patrol car will be unavailable from the time it is dispatched to a call until the time it is available to respond to another call.)

PCAM provides that the call rate is entered into the database by specifying two numbers: a *call rate parameter* for the day and precinct and an *hourly call rate factor*. The product of these two is the call rate in the hour. This arrangement permits flexibility in organizing the data. Examples of how this feature might be used are as follows:

1. The call rate parameter could be the *total* number of calls in the day, and the hourly call rate factor could be the *fraction* of all calls occurring in that hour.
2. The call rate parameter could be the *average* number of calls in an hour of the day, and the hourly call rate factor could be a number near 1.0 that indicates how the number of calls in the hour differs from average.
3. The call rate parameter could be the *maximum* number of calls in an hour, and the hourly call rate factor could be a number less than or equal to 1.0 indicating how the hour differs from maximum.
4. The call rate parameter can be 1, and the hourly call rate factor equal to the expected number of calls in the hour. (This method facilitates considering what would happen if call rates change by a certain percentage.)

When running the PCAM program, you work with a copy of the database that is stored in the computer's memory and is called CURRENT-DATA (see Sec. III). You can modify the call rate parameter in CURRENT-DATA, but not the hourly call rate factors. This allows you to imitate what would happen if there is a general increase or decrease in the number of calls being received, leaving the proportion in each hour unaffected.

Service times are handled in the same way, with a *service time parameter* for the day and precinct, and an *hourly service time factor* for each hour; the product of these two is the average service time for calls that arrive during that hour. For example, the service time parameter could be 1.0 and the hourly service time factor 37 (minutes). Although service times will usually be found to vary from precinct to precinct, a reasonable assumption is that each *type* of call requires the same service time in each precinct, but the *mix* of calls varies among precincts. (For example, some precincts just happen to get more calls requiring over an hour of service time.) Thus, it is sensible to divide calls into 20 or so types, calculate the average service time for each type from *citywide* data, and estimate service times in each precinct according to the fraction of calls of each type.

Depending on the kinds of data available to the department, you are free to assume that call rates do not vary over a tour, that service times are the same in all precincts in all tours, etc. However, assuming that call rates do not vary from tour to tour will ordinarily be a very poor approximation.

Data for Each Shift

We define a *shift* to be a particular tour in a particular precinct. The data required by PCAM for each shift are as follows:

1. The average number of patrol cars that start work at the beginning of the shift.
2. The average speed (miles per hour) that cars travel when responding to calls for service. Although police officers often estimate rapid speeds of response, data in several cities show that this speed averages around 15 mph and is rarely over 25 mph. Some departments may have conducted experiments in which the travel time and travel distance of responding patrol cars were recorded. If so, they can determine the average travel speed from this information. Otherwise, because the travel speeds are used to estimate average travel times for precincts, it is best to collect some data showing travel times

under the current allocation and then simply adjust the input value of travel speed until PCAM's estimates of travel times agree with the actual data.
3. The average speed (miles per hour) that cars travel when on preventive patrol. This is ordinarily in the range of 7-15 mph.
4. The fraction of calls that are priority 1 and fraction of calls that are priority 2. (Recall that three priority levels are permitted by PCAM. Therefore, the sum of these two fractions must be 1.0 or less. PCAM will calculate the fraction that remains for priority 3 calls.) If the department does not wish to separate calls into priority levels, we recommend setting the fraction of calls that are priority 2 equal to 1.0, in which case the fraction of priority 1 calls must be entered as 0.0.
5. The percentage of patrol cars with two officers. (The remaining cars are assumed to have one officer; if all cars have one officer, you do not have to provide data for this item.)
6. The fraction of calls of each priority that receive a dispatch of two cars, and the fraction that receive three cars. (From these data PCAM will calculate, for each priority, the remaining fraction of calls that receive one car. If all calls receive a dispatch of a single car, you do not have to specify the number of cars dispatched.)[4]

Unavailability Parameters

PCAM assumes that each patrol car will be busy on non-cfs work a certain fraction of the time it is on duty. This fraction may vary from shift to shift, but PCAM does not accept data on the unavailability fraction in each shift. This is because data showing non-cfs unavailabilities in the past may be a poor guide to what will happen in the future if allocations change. Instead, PCAM assumes that the

[4]This is PCAM's simplified way of representing important aspects of dispatching policies that are, in most police departments, much more complex. In designing PCAM, we found that more precise ways of representing dispatch policies in the computer program were difficult to describe with input data, and the resulting output reports were difficult to understand.

fraction of time that a patrol car will spend unavailable on non-cfs work is given by the following equation:

$$\begin{pmatrix}\text{fraction of time}\\ \text{on non-cfs work}\end{pmatrix} = \text{B1} \times \begin{pmatrix}\text{fraction of time}\\ \text{on cfs work}\end{pmatrix} + \text{B2}.$$

The *unavailability parameters* B1 and B2 are constants that are entered separately for each precinct. They may not vary from day to day or tour to tour, unless separate databases are constructed for each day or tour.

The equation shown above was found to be valid in a study of data from the Valley Bureau of the Los Angeles Police Department.[1] To calculate B1 and B2 for each precinct, the user must collect data showing the fraction of time spent on non-cfs work and the fraction of time spent on cfs work for a number of tours in the precinct, and then draw a straight line through a graph showing (fraction of time on non-cfs work) versus (fraction of time on cfs work). The parameter B2 is then the intercept of this line, and B1 is its slope (positive for upward slope, negative for downward). See Fig. 3. Each point shown on this graph represents data from one tour on one day. For example, in the AM tour on July 27, patrol cars in this example spent 58 percent of their time on non-cfs work and 24 percent on cfs work. The remaining 18 percent was spent on patrol.

In the Los Angeles Police Department, the available data on non-cfs work were found to be unreliable, and therefore the amount of non-cfs work was estimated from data showing the actual fraction of calls that were delayed in each tour in each precinct. A computer program that calculates these estimates and then calculates B1 and B2 for each precinct (by a method called *regression analysis*) is shown in Appendix B of the companion *Program Description* (R-3087/3). *This is not a part of the PCAM program*, because many departments will collect data in a different form from that collected in Los Angeles. However, if a department is able to use this program to calculate the unavailability parameters B1 and B2, it will obtain a very good match between PCAM's estimates of calls delayed (see next section) and the actual experience of the department in regard to the fraction of calls delayed.

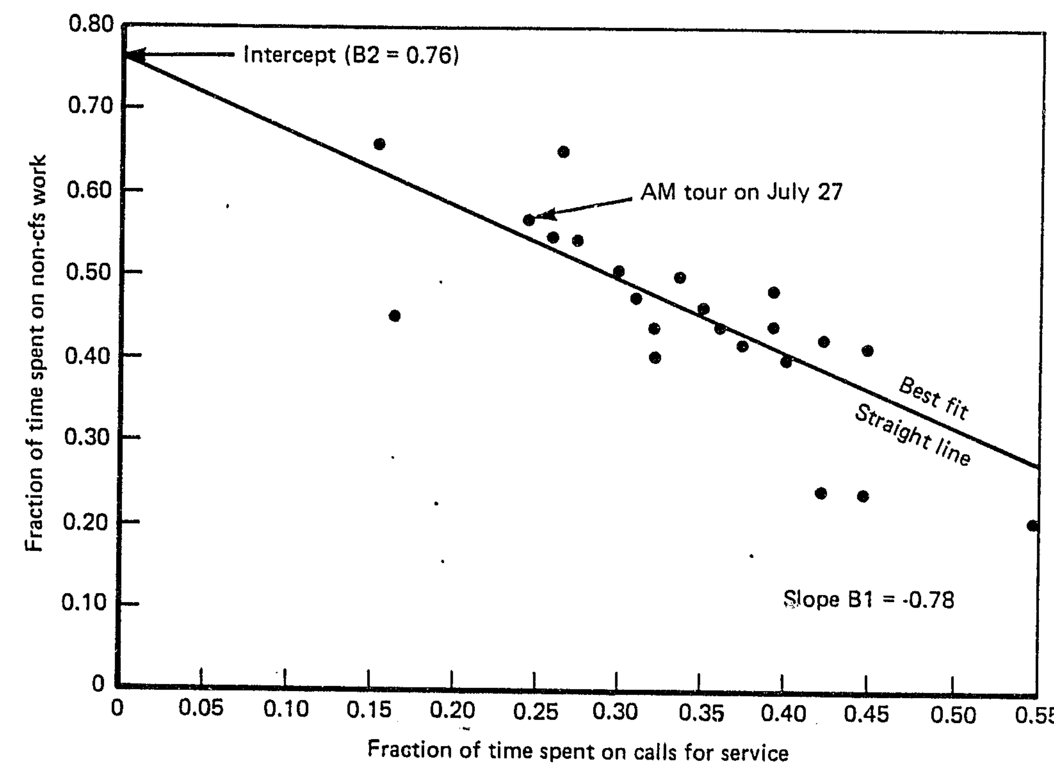

Fig. 3 — Example showing calculation of unavailability parameters

Calculating B1 and B2 may be the most difficult and controversial part of data preparation for PCAM. However, various shortcuts may be taken. First, as mentioned above, you may set B1 and B2 to zero and count non-cfs work in the call rate parameter and hourly call rate factors. This is not recommended but is preferable to ignoring non-cfs work entirely.

Second, you can set B1 to zero, and enter for B2 the average fraction of time spent on non-cfs work (averaged over all tours in the precinct). This will cause PCAM to assume that the same fraction of a patrol car's time (namely, B2) is spent on non-cfs work in every tour. If the department has no data from which to estimate B2, we recommend trying several values of B2 in the range from 0.3 to 0.6 and having PCAM estimate queuing delays for the current allocation of patrol cars.[5] Whatever value of B2 results in a match between PCAM's estimates and the actual experience of the department will be a "good guess" for B2.

If some precincts have especially high non-cfs unavailabilities, PCAM's prescriptive calculations will suggest allocating a large number of patrol cars to those precincts. Commanders from other precincts may then complain that the precincts in question are being "rewarded" for wasting much of the time of their patrol cars. For this reason, when operating PCAM in prescriptive mode, the department may prefer to enter values of B1 and B2 that reflect departmental standards for the maximum amount of non-cfs work permitted, rather than the values of B1 and B2 that fit the data for the precincts with large amounts of non-cfs work.

CALCULATION OF PERFORMANCE MEASURES

Queuing Delays

By making certain technical assumptions[6] it is possible to estimate the *percentage of calls* that will have to be placed in queue to await available patrol cars (PERCENT CALLS DELAYED)[7] and the *average length of time* (in minutes) that calls in each priority level will have to wait in queue (QUEUE DELAY). The queuing model that PCAM uses to make these calculations is explained in detail in Ref. 15.[8]

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[5]The SET command, described in Sec. III, will permit you to try several values of B2.

[6]These are: (a) incidents occur according to a Poisson process, (b) all patrol cars dispatched to an incident have the same exponential distribution of service time, and (c) the system is in steady state in each hour (unless the smoothing option is chosen). See Glossary for definitions.

[7]In this section, output measures appear in the text or on the left side of equations in the exact form in which they appear in the PCAM output, to facilitate recognition.

[8]Technically oriented readers can find details of these and other PCAM calculations in Ref. 15, Appendix B of Ref. 6, or Appendix A of this report.

According to the queuing model used in PCAM, calls of different priorities have the same probability of being placed in queue. However, high-priority calls wait in queue a shorter time than low-priority calls. PCAM calculates the average length of time spent in queue by all calls, *including* calls that do not wait at all. For example, if 70 percent of priority 2 calls are dispatched without delay, and the other 30 percent wait in queue for an average of 10 minutes, PCAM shows an average delay of three minutes for priority 2 calls.

PCAM calculates queuing statistics for each hour and then averages the hourly figures for each shift, weighting by the number of calls for service in each hour. This method has been found to be more accurate than calculations based on first averaging the call rates over a shift and then calculating queuing statistics.

Standard queuing models assume that the number of patrol cars is an integer, but, as we have seen, the effective number of cars may not be an integer but a fraction. PCAM handles this situation by calculating delays for the integers below and above the effective number of cars, and then interpolating between the two figures. This method is only an approximation, but it yields accurate estimates of queuing.

Workloads

Patrol cars handle two different kinds of work: cfs and non-cfs. The cfs workload is defined to be the percentage of time a patrol car is busy on cfs work. As an example, if one patrol car is busy on cfs work 20 percent of the time, it will spend 1.6 hours on cfs work in an eight-hour tour. Another patrol car that is busy on cfs work 40 percent of the time has twice as much cfs workload as the first car.

PCAM displays three different workload statistics: the cfs workload, the non-cfs workload, and the total workload. The cfs workload is defined by the equation:

$$\text{PERCENT TIME BUSY CFS} = \frac{\text{expected number of car-hours of cfs work}}{\text{total number of car-hours fielded}} \times 100.$$

For example, consider an 8-hour shift in which 5 cars are fielded and 12 calls for service are expected. The total number of car-hours fielded is $5 \times 8 = 40$. If the average service time for a call for service is 45 minutes (= 3/4 hour), then there will be $12 \times 3/4 = 9$ car-hours of cfs work during the shift. The cfs workload is then $9/40 \times 100 = 0.225 \times 100 = 22.5$ percent.

The workload is averaged over all 5 cars. Some cars will spend more than 22.5 percent of their time on cfs work, others less; but the average is 22.5 percent. By comparing the averages for different tours in one precinct, it is possible to see what times of day have the most workload per car, and by comparing the averages for different precincts during a single tour, the imbalance in workload among different geographical areas can be determined. PCAM also displays averages over all the tours in a day for each precinct, or over all the precincts in the city for a single tour, depending on the commands entered by the user. The definition given above applies to all these averages.

The second workload figure displayed by PCAM is the non-cfs workload. This is defined by

$$\begin{array}{l}\text{PERCENT TIME} \\ \text{BUSY NONCFS}\end{array} = \frac{\text{expected number of car-hours of non-cfs work}}{\text{total number of car-hours fielded}} \times 100.$$

Continuing the 5-car example from above, suppose that the relationship between the amount of cfs and non-cfs work is that shown in Fig. 3. Then, the non-cfs workload would be calculated as $76(0.78 \times 22.5) = 58.45$ percent.

The third workload figure displayed by PCAM is the total of the first two:

$$\begin{array}{c}\text{PERCENT TIME} \\ \text{BUSY TOTAL}\end{array} = \text{cfs workload} + \text{non-cfs workload.}$$

Continuing the 5-car example, an average car during this shift would be spending $22.5 + 58.45 = 80.95$ percent of its time on cfs and non-cfs work. This would leave about 20 percent of its time for directed or random patrol.

Average Number of Cars Available

Sometimes during a tour the dispatcher may find that no cars are available for dispatch in the precinct when a call for service arrives; then the call must be placed in queue. At other times, there may be one car available, or two cars available, and so forth. If the dispatcher wrote down the number of cars available for dispatch each time a call arrived and averaged these numbers at the end of the shift, he would have the *average number of cars available*.[9]

By definition, a car is *available* if it is not doing cfs work or non-cfs work, so in any shift we have

$$\begin{array}{c}\text{number of} \\ \text{car-hours} \\ \text{available}\end{array} = \begin{array}{c}\text{number of} \\ \text{car-hours} \\ \text{fielded}\end{array} - \begin{array}{c}\text{number of} \\ \text{car-hours} \\ \text{of cfs work}\end{array} - \begin{array}{c}\text{number of} \\ \text{car-hours of} \\ \text{non-cfs work}\end{array} .$$

The average number of cars available can then be simply calculated as

$$\begin{array}{c}\text{AVG. CARS} \\ \text{AVAIL}\end{array} = \frac{\text{number of car-hours available}}{\text{number of hours in the shift}} .$$

This figure is of interest because it is equal to the *average number of car-hours of preventive and directed patrol per hour* and can be used to compare the amount of patrol at different times of the day or week in a single precinct.

[9] Alternatively, he could write down the number of cars available every minute, and average these at the end of the shift.

Average Travel Time

A very simple relationship, called the *square-root law*, can be used to estimate how far, on the average, a patrol car will travel from its location at the moment of dispatch to the scene of the incident. If there are N patrol cars available, and the precinct has area A (in square miles), then the square-root law states that the average travel distance (in miles) is give by the equation

$$\text{average travel distance} = (\text{constant}) \times \sqrt{\frac{A}{N}}\,.$$

The constant is approximately equal to 2/3. This relationship was derived by mathematical modeling and has been validated using real and simulated data.

If the patrol cars respond at an average speed s (in miles per hour), then the average travel time (in hours) is

$$\text{average travel time} = \frac{\text{average travel distance}}{s}$$

The average travel time in minutes is then simply 60 times this figure.

Because the number of cars available (namely, the number N that appears in the equation) changes from time to time during a shift, the square-root law has to be modified slightly to take this into account. It has been found that a very good approximation is

$$\text{TRVL} = 60 \times \frac{(\text{constant})}{(\text{response speed})} \times \sqrt{\frac{\text{area}}{\text{AVG. CARS AVAIL}}}$$

if the average number of cars available is not too small. PCAM uses this relationship when the average number of cars available is at least

2.0, and makes an adjustment for smaller numbers of cars. Details are given in App. A.

Total Delay

The *total delay* or *response time* is simply the sum of the queuing delay and the travel time (QUEUE + TRVL). It tells how long a caller will wait, on the average, from the time he contacts the police department until a patrol car arrives at the scene.[10] PCAM calculates the total delay for each priority class and the average over all calls.

Average Patrol Interval

If patrol cars travel at speed s (miles per hour) while on preventive patrol, then in one hour the number of miles patrolled will equal s × (AVG. CARS AVAIL.). If this just happened to equal the number of street-miles in the precinct, then every point in the precinct could be passed by a patrol car once per hour. If the number of miles patrolled was half the number of street-miles in the precinct, a randomly selected point in the precinct would be passed once every two hours. In general, the average patrol interval is

$$\text{PATROL INTERVAL} = \frac{\text{number of street miles}}{s \times (\text{AVG. CARS AVAIL})}$$

where s is the patrol speed. The average patrol interval tells how many hours will elapse between successive times when a random point will be passed by a car on preventive patrol.[11] It is inversely proportional to the probability that a crime will be intercepted by patrol officers and is useful for comparing the amount of preventive patrol among precincts having different sizes.

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[10] The length of time the caller waits before reaching the police, the length of the telephone call, and processing delays in the dispatch center are not included in the total delay.

[11] If the user enters "effective" street-miles into the database instead of street-miles, the patrol interval describes how many hours will elapse between successive passes of locations with the heaviest patrol coverage. See Chapter 4 of Ref. 31.

PRESCRIPTIVE CALCULATIONS

Meeting Constraints

For most of the performance measures described in the preceding section, PCAM will permit you to specify a *constraint value*--i.e., to state that the department does not want the performance measure to be *higher* or *lower than* the specified value. A complete list of the measures subject to constraint appears in Sec. III in the description of the MEET command. In addition to specifying constraints on performance measures, the department can administratively decide that the number of cars on duty shall not be lower than a specified value.

All of the performance measures displayed by PCAM have the property that an increase in the number of cars on duty will lead to an improvement. (The improvement may be an increase or a decrease in the value of the measures; for example, availability increases and travel time decreases when more cars are added.) So PCAM simply checks whether the constraints are met for all the measures and, if not, increases the number of cars assigned by 1 and checks again. The process stops when all constraints are met.

You may specify that a constraint is to be met in all precincts during all tours of every day (i.e., in every shift), or just in certain precincts, or during certain tours, or in certain shifts. Whatever shifts are selected, PCAM assures that enough cars are on duty so that the average values of performance measures over each *time block* within the selected shifts meet the desired constraints. This is done because a time block is a period of time over which the number of patrol cars on duty does not change. Once PCAM has determined the number of patrol cars needed in each time block, it converts the results to shift allocations, using a calculation described in Sec. III of the companion *Program Description* (R-3087/3).

It may happen that a constraint is exceeded during particular hours, but PCAM will accept the allocation because the average over a time block is within constraints. It may also happen (in the case of shifts containing two time blocks) that PCAM will allocate more cars than are necessary to keep the average over the shift within the specified constraints. For example, suppose a shift is divided into two

four-hour blocks and you specify that the average number of cars available must be at least equal to 2. If one block currently has an average of 1.9 cars available and the other has 2.3, you will see that the average for the whole shift is 2.1. Nonetheless, PCAM will add a car to this shift in order to meet the constraint. You should not be surprised when this happens if you keep in mind that PCAM is meeting constraints in every block.

If meeting constraints is the first prescriptive calculation you request, PCAM begins by ignoring the data indicating how many cars are currently assigned and tentatively assigning to each specified time block the smallest whole number of patrol cars needed to handle the call-for-service workload. It then checks to see whether this allocation is adequate to meet all the constraints you entered. (It may happen that some constraints are met, but not all.) If one or more constraints are not met, it tentatively increases the number of patrol cars by 1 and checks again. This process continues until an allocation is achieved that meets all the constraints.

If some prescriptive calculation has been performed before you ask PCAM to meet constraints, PCAM does not reinitialize the allocation to the minimum number of cars needed to handle the cfs workload. Instead, it checks to see whether the current allocation meets constraints and, if not, adds cars to only those shifts that need more. See Fig. 4.

Allocating a Specified Number of Car-Hours

The algorithm used by PCAM to allocate a specified number of car-hours over selected shifts is somewhat complicated in the case of overlay tours and is described in Appendix B of Ref. 6. The algorithm is known to be optimal when there are no overlays and when there is an overlay tour having the same length as the two tours overlaid.[12] Here we shall only describe the situation where there are no overlays.

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[12] "Optimal" means that the allocation found by PCAM has the smallest possible value of the performance measures that the user chooses to minimize. Although we do not know of any departments with overlay tours that are shorter or longer than the overlaid tours, PCAM permits such an arrangement. However, the algorithm for allocating car-hours has not been proved optimal in this case. Consult Appendix B of Ref. 6 for details.

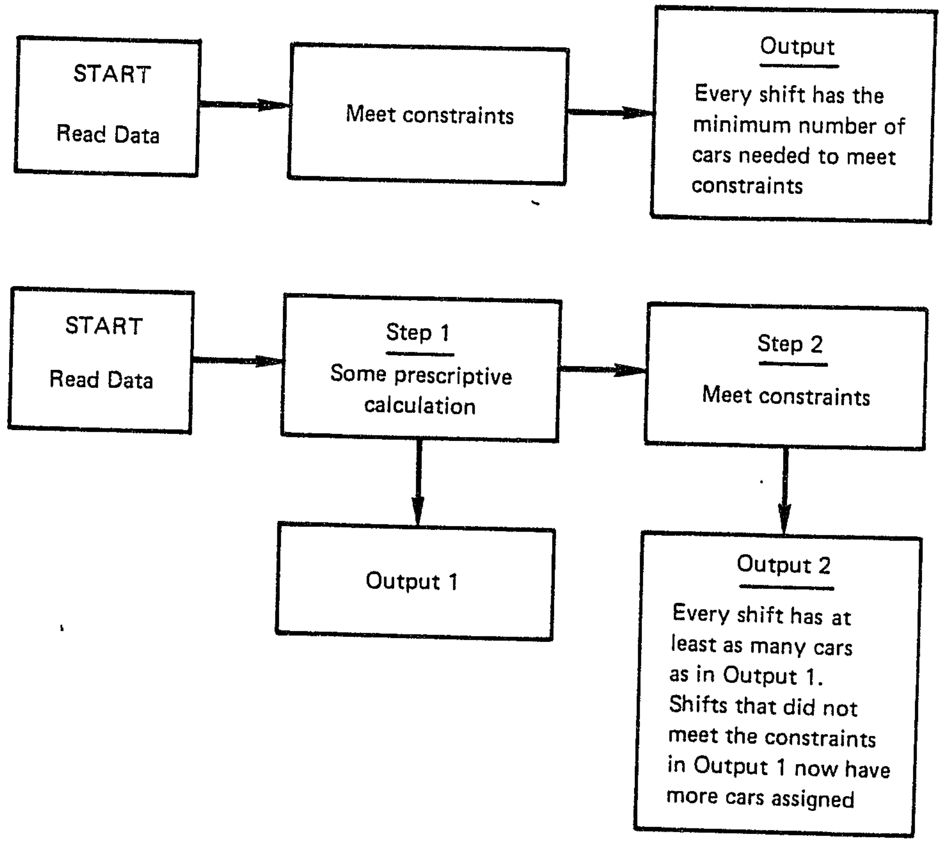

Fig. 4 — Two sequences for meeting constraints

PCAM begins with either the current allocation or the minimal allocation needed to handle the call-for-service workload in every block, depending on instructions from the user. It then calculates the value of the objective function[13] for the chosen allocation.

Next, PCAM imagines that a single car is added to the first selected shift and remembers what the value of the objective function *would be* if this car were added. Then it imagines that a single car is added to the second selected shift, and so on for all the selected shifts.

[13]This is the performance measure that the user selects to minimize to get the "best" allocation.

Now PCAM compares the potential improvement in the objective function *per car-hour added*[14] among all the selected shifts and adds one car to the shift that is best in this regard. This changed allocation then becomes the new "current" allocation, and PCAM starts at the beginning to imagine one car being added to each selected shift. This process continues until all the car-hours specified by the user have been assigned to some shift. (A small number of car-hours may remain unassigned if they are not enough to equal one car working for one shift.)

This simple iterative procedure guarantees the resulting allocation has the smallest value of the objective function possible with the specified number of car-hours.

Because we have adopted a special meaning for the word *shift*, this discussion may have obscured the fact that PCAM can allocate car-hours across precincts. Therefore, we specifically point out that the selected shifts could refer to a single tour in several precincts, in which case car-hours are allocated among the precincts for that tour. Or, you could select *all* shifts, in which case the allocation is performed across tours and precincts simultaneously.

Allocating with Constraints

To allocate a specified number of car-hours so as to minimize an objective function *subject to* constraints on other performance measures, you must enter two commands to PCAM. One of these meets constraints and the other allocates whatever car-hours are left after the constraints are met. (See Fig. 5.) The calculations performed by PCAM in this two-step procedure have already been described above.

[14]Some shifts may be longer than others.

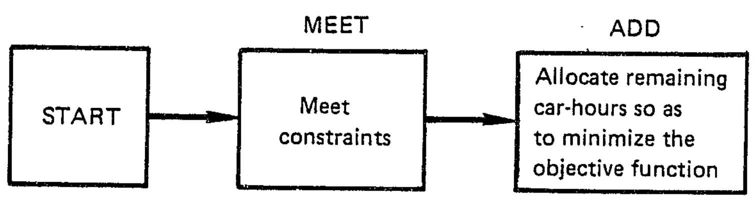

Fig. 5 — Two-step procedure for minimizing an objective function subject to constraints

III. USER'S GUIDE TO PCAM

This section provides instructions for entering PCAM commands and gives detailed descriptions of the format for each command and the actions taken by the program in response to each command. Appendix B summarizes command formats and lists valid specifications for objective functions, data items, and constraints. It provides, in a few pages, all the information you need to operate the program, once you are familiar with the contents of this section. If desired, you can begin to operate the program after reading App. B, and then consult this section as questions arise.

OVERVIEW OF PROGRAM OPERATION

The Patrol Car Allocation Model (PCAM85) is designed to run in either batch mode (where user input is prespecified on cards, tape, or disk and program output is on a line printer) or interactive mode (where the device for both user input and program output is a terminal). In either mode, you control the operation of the program with a sequence of commands, each of which instructs the program to perform a particular operation on the data.

When PCAM encounters a user command, it interprets the command and immediately carries out its implied action (we shall refer to this process as "command execution"). When PCAM completes the action for a command, it accepts the next command presented to it. This process continues until the program encounters a special command (END), telling it that you are finished with the program.

The kinds of actions that PCAM can perform fall into three general categories: data selection and modification, descriptive mode, and prescriptive mode. Once an initial selection of data is made, you are free to enter commands in any order. You may have the data printed out if desired, possibly change some of the data, then list the data again or not. You can ask PCAM to prescribe an allocation, and then display the resulting allocation or not. If you do not like the allocation, you can start all over. Thus in a typical session with PCAM, you will proceed back and forth through the different categories of commands.

Data Selection and Modification

For the purposes of this discussion, we will use the name DATABASE to refer to the input file that you must prepare as described in Sec. II. When operating the PCAM program, some or all of the data in DATABASE are read into the computer's memory, where they are available for the calculations that are performed by PCAM. This function is performed by the READ command. The version of the database that resides in the computer's memory will be called CURRENT-DATA. (See Fig. 6.)

Many of the commands that you enter into PCAM result in modifying CURRENT-DATA. For example, you might add cars to certain shifts, or you might change the unavailability parameters to see what happens to performance measures. PCAM "remembers" all these modifications. If, at any time, you are dissatisfied with what you have done, or if you are finished with the calculation, you can start again by reading part or all of DATABASE into CURRENT-DATA. This causes PCAM to "forget" whatever was in CURRENT-DATA before and to begin with a fresh copy of CURRENT-DATA.

There are several reasons why you might want to read only part of DATABASE into CURRENT-DATA. First, you may plan to do several different calculations, all of which refer to a single precinct, or all of which refer to the same tour. If you read the entire DATABASE into CURRENT-DATA, then each time you type a command into PCAM you will have to specify the particular precinct or tour that interests you. If you read only the relevant part of DATABASE, however, then your typing is simplified because you do not have to make the same specifications in later commands.

Second, the cost of operating PCAM may increase on some computer systems according to the amount of computer memory requested when executing the program. If none of the users will want to use the entire database at one time (for example, the users might be precinct commanders) the data processing personnel can install the program in such a way that the amount of memory requested is just enough for each user's needs. This will minimize computer costs while permitting each user to read the part of the database required.

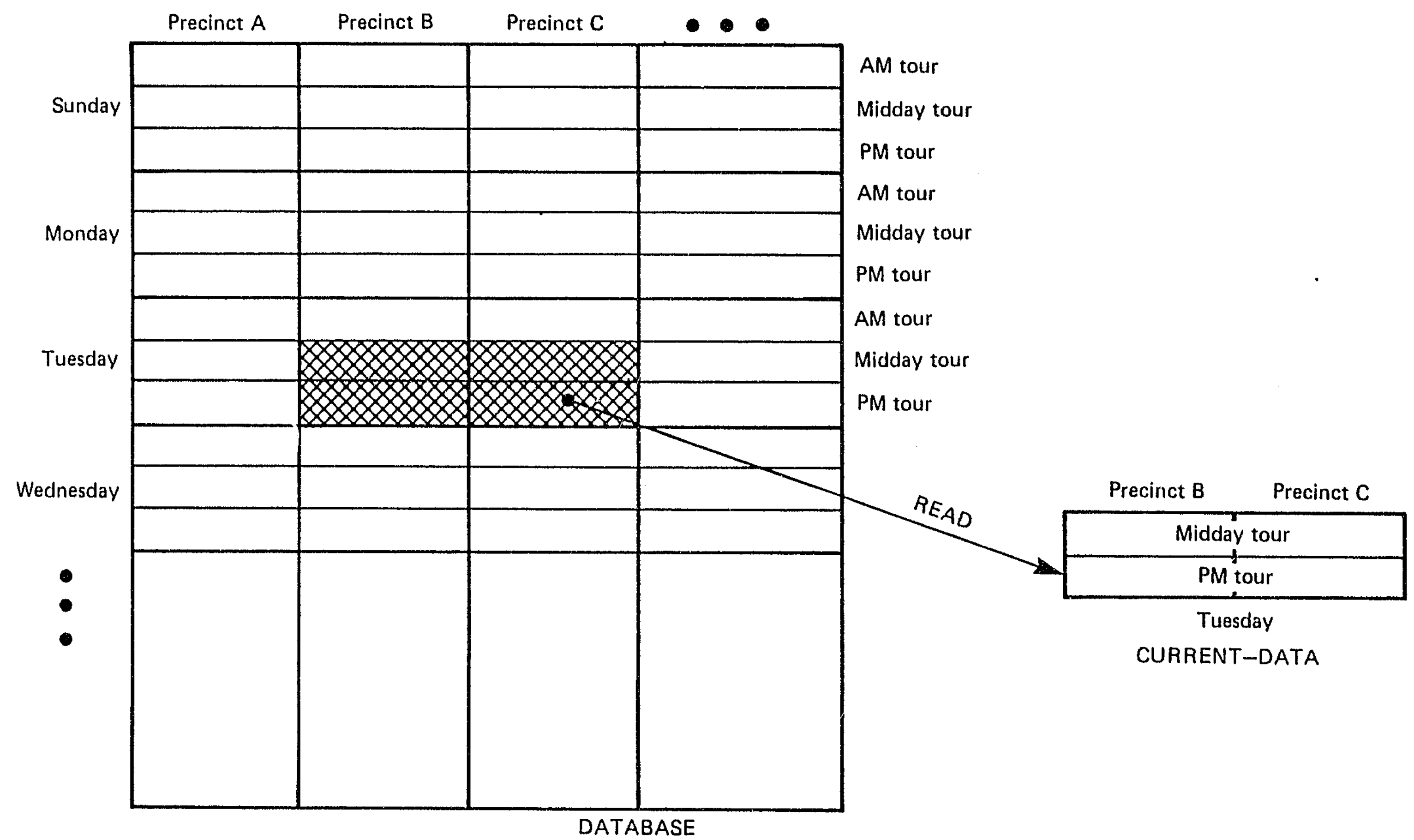

Fig. 6 – Conceptual example of a READ command
READ DATA FOR PRECINCT = (B,C), DAY = TUESDAY, TOUR = (MIDDAY, PM)

An important concept in PCAM is the *scope* of the command, which is the collection of precincts, days, and tours to which the action of the command applies. The scope of the READ command specifies what part of DATABASE is to be read into CURRENT-DATA. For example, the READ command shown in Fig. 6 would be entered into PCAM as follows:

READ DATA FOR PRECINCT=(B,C),DAY=TUESDAY,TOUR=(MIDDAY,PM)

The part of the command that specifies its scope is called the *qualifier*. In the above example the qualifier is PRECINCT=(B,C),DAY=TUESDAY,TOUR=(MIDDAY,PM).[1] If PRECINCT or DAY or TOUR is not included in the qualifier of a READ command, then the missing categories are assumed to be unlimited. For example, the command

READ DATA FOR PRECINCT=B

will read the data related to Precinct B for all tours of all days included in DATABASE. The unqualified command "READ" will read all of DATABASE into CURRENT-DATA.

After a READ command has been issued, all the commands that follow until the next READ or END command can refer only to the data in CURRENT-DATA. Thus, any command that follows the command READ DATA FOR PRECINCT=B can refer only to Precinct B, and therefore it is unnecessary to mention Precinct B in its qualifier. Such a command could, however, have a qualifier referring to DAY and/or TOUR.

Once PCAM has completed execution of a READ command, you may wish to modify the values of some of the data items in CURRENT-DATA. This is done by using the SET command. With a SET command it is possible, for instance, to change the average response speed in a precinct for one tour of a day. If the SET command has no qualifier, it will change the

[1]The words that may appear on the left side of an equal sign in a qualifier are DIVISION (or a substitute provided by the user), PRECINCT (or a substitute), TOUR (or a substitute), and DAY. For example, if a department calls its precincts AREAs, then AREA=(EAST,NORTH) would be a valid qualifier, but PRECINCT=(EAST,NORTH) would not be permitted.

values of data items of a particular type for all precincts, days, and tours included in CURRENT-DATA. Alternatively, by using qualifiers, a SET command causes a change in the values of data items for all tours of all days for a particular precinct or for all tours of a particular day for all precincts, etc.

If a SET command "overqualifies" the data elements for a data item, extraneous qualifications are ignored. For example, if a SET command indicates that the value of the call rate parameter for a particular precinct, day, and tour is to be changed, the tour specification is ignored, because call rate parameters apply only to days. This feature facilitates using one SET command to change several data item values that require different levels of qualification.

After you have completed all your data modifications and prescriptive calculations (to be described below), you may wish to save a new database that reflects all the changes that have been made. This is accomplished by means of the WRITE command, which copies all or part of CURRENT-DATA into permanent storage in a file called NEW-DATA. (See Fig. 7.) Whereas the information in CURRENT-DATA is lost whenever a READ or END command is issued, NEW-DATA is available for use as input in later runs of the PCAM program. However, the WRITE command has no

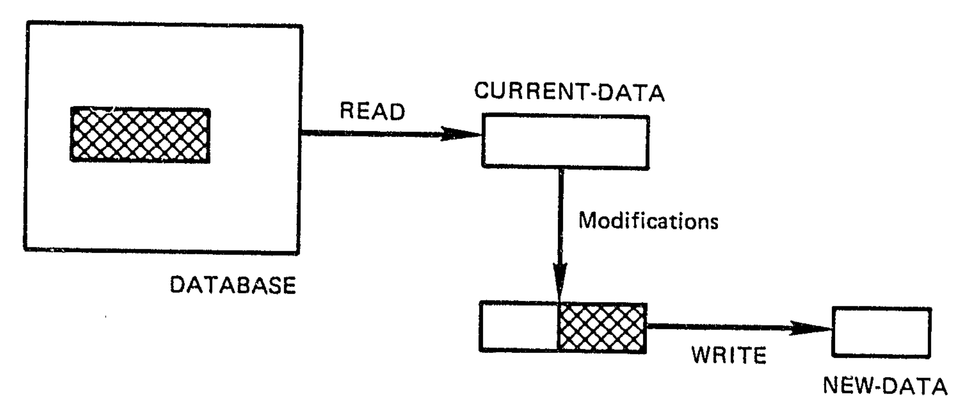

Fig. 7 — Data selection capabilities of PCAM

effect on DATABASE, and all subsequent READ commands will refer to DATABASE until the session is terminated and data processing personnel change the file specifications for the PCAM program.

Descriptive Mode

The PCAM program provides facilities for displaying data items and various performance measures derived from data items. The execution of a LIST command causes printing of the values of the data items associated with all precincts, days, and tours within its scope. As with all other commands except READ, the scope of a LIST command can extend only to data included in CURRENT-DATA. The LIST command prints the data items for each tour, within each day, within each precinct in its scope. Some of the values shown for tours are derived by averaging values that can vary within a tour.

The execution of a DISP (display) command causes printing of various performance measures that PCAM calculates from the data provided for the precincts, days, and tours within its scope. These measures include cfs workload, average patrol interval, average number of cars available, percent of calls delayed, and average delay for calls of different priorities.

At the user's option, DISP command output can be produced in order of tour within day within precinct or in order of precinct within tour within day. The difference between these two modes of output is explained in the detailed description of the DISP command, below. Except for summary statistics, both modes produce exactly the same information; the only difference is in the appearance of the output. Once you have seen illustrations of both modes of output, you will not have any difficulty in deciding which you prefer for a particular application.

Prescriptive Mode

PCAM's capabilities to allocate car-hours among tours and precincts are carried out by three commands: MEET, ALOC, and ADD. The MEET command causes PCAM to calculate the minimum number of car-hours needed in every shift within its scope to meet constraints established by the

user. The ALOC command allocates a specified total number of car-hours among the shifts within its scope so as to minimize a measure of performance selected by the user. The ADD command permits the user to allocate car-hours in addition to those already assigned in CURRENT-DATA.

The MEET command operates in either of two modes, depending upon the commands that have preceded it. If a MEET command is the first prescriptive command after a READ command, command execution begins by assigning exactly enough cars to handle the call-for-service workload in each precinct for each block of each tour of each day within the scope of the command. Then additional cars are assigned, as necessary, to meet constraints. In other words, a MEET command that follows a READ command ignores all information contained in CURRENT-DATA about the number of cars assigned to shifts. However, if some other prescriptive command (ALOC, ADD, or MEET) has been executed between the last READ command and the current MEET command, then command execution consists only of adding cars to shifts within the command scope where the number already assigned in CURRENT-DATA are not adequate to meet the constraints. This was shown in Fig. 4.

Execution of the ALOC command always begins by assigning just enough cars to all shifts within the command scope to handle the call-for-service workload. Any remaining car-hours are then allocated among shifts in such a way as to minimize the selected objective function. Execution of an ALOC command causes PCAM to ignore the assignments included in CURRENT-DATA, and all the assignments for shifts in the scope of the ALOC command are replaced by new values in CURRENT-DATA.

The ADD command will allocate a specified number of car-hours to the shifts within its scope over and above the number already assigned in CURRENT-DATA. Cars are allocated to shifts so that the average value of a selected objective function is minimized. Any constraints that have been set previously will still be met after execution of an ADD command. Thus, ADD differs from ALOC in that the allocation begins with the number of cars assigned to each shift in CURRENT-DATA just prior to execution of the ADD command.

If you wish to allocate a certain total number of car-hours so that your selected objective function is minimized, *subject to certain constraints*, you must execute two commands (as shown in Fig. 5). First, a MEET command is entered, and PCAM indicates the total number of car-hours needed to meet the constraints. Next, an ADD command is entered to allocate the remaining car-hours. You can subtract the number already allocated from your desired total and enter the difference in the ADD command, or you can have PCAM perform the subtraction.

ENTERING COMMANDS

When PCAM is run in the interactive mode, commands can be entered only in response to the message "COMMAND?" typed by the program. In batch mode, PCAM reads records containing commands, one command at a time. In either mode, the action specified by a command is carried out as soon as the text of the command has been read and interpreted.

All commands consist of an *identifier* (three, four, or five letters) followed, in most cases, by required or optional additional information, called *parameters*. When entering commands, the identifier must be entered first, and at least one space must be entered between the identifier and any parameters. The allowed identifiers (together with their meanings) are as follows:

HEADR	(read run identifier)
READ	(read data)
LIST	(list input data)
DISP	(display performance measures)
ALOC	(allocate a specified number of car-hours)
ADD	(add a specified number of car-hours)
MEET	(meet constraints)
SET	(set data values to new values)
WRITE	(write a new data file)
END	(terminate operation of program)

Commands can consist of as many lines of input as are required to specify them completely. Each line of a command, except the last, must end with an ampersand ("&"), which indicates that the command is continued on the following line. Ampersands cannot appear within numbers or words (see below).

Except for letters, digits, parentheses, asterisks, hyphens, periods, and ampersands, all characters and blanks are treated as *delimiters*. At least one delimiter must be entered whenever blanks appear in the command formats below. This means that blanks, commas, colons, semicolons, equal signs, etc. can be used freely to improve readability when entering commands.

COMMAND FORMAT CONVENTIONS

In describing the format of a PCAM command, we will use the following conventions:

- Any text in uppercase letters that is not contained in square brackets must be entered exactly as shown. For example, one must enter LIST to tell PCAM to list data item values.
- Any text in uppercase letters set off by square brackets ([]) is optional. That is, it may be entered as shown *without the brackets* or may be completely omitted. For example, [BY] means that one may enter the characters BY if one wishes, but they can also be omitted.
- Text in angle brackets (<>) indicates that one must replace the angle brackets and the text with a valid member of the class of items indicated by the text. For example, wherever <NUMBER> appears in a command format description, you must substitute a number, such as 1.3. The members of the specified classes make up the PCAM program vocabulary and are completely defined below.
- A *character string* is defined to be a sequence of characters made up of any combination of letters, numbers, hyphens, or periods with no imbedded blanks. Of course, certain character strings have specific meanings to the PCAM program, and these are explained below.

Filler Words

To improve the readability of commands, especially for those who are not familiar with the details of using the program, PCAM allows certain character strings, called *filler words*, to be interspersed among command parameters. These words are completely ignored by PCAM and may be used in any combination desired. Suggested uses of these words are indicated by their appearance in square brackets in the command definitions below. For example, the definition of the PCAM command that causes the program to list the user's input data is: LIST [DATA] [FOR] <QUALIFIER>. When the LIST command is entered, the filler words DATA and FOR may be included or not, as you wish. A complete list of filler words is provided in the next section.

PROGRAM VOCABULARY

The PCAM program vocabulary consists of all of the character strings that can be used to enter PCAM commands. These character strings fall into various classes, which are identified by angle brackets in the definitions that follow:

1. <FILLER> is any one of the following character strings: BY, CAR, CARS, DATA, FOR, HOUR, HOURS, ON, TO. A <FILLER> can appear in any position in any command and is always ignored.
2. <KEYWORD> is any one of the following character strings:
   a. DAY, P, C, T, and F. DAY is used to refer to days of the week, P is a label for data elements that can be changed by the user, C is a label for constraints, T is a label for tables to be displayed, and F is a label for objective functions.
   b. The command identifiers listed above: ADD, ALOC, DISP, END, HEADR, LIST, MEET, READ, SET, WRITE.
   c. All <FILLER>s.
   d. Three names that are provided by the user and will be referred to in this report as TOUR, DIVISION, and PRECINCT. PRECINCT refers to the smallest geographical region to which allocations may be made. A DIVISION is an aggregation of precincts, and may be defined to suit the needs of the user. (If the department has no geographical commands that encompass several precincts, then it can define all precincts to belong to a single division.) TOUR refers to a span of hours that is the same for every day of the week. For example, the PM tour could be the hours from 1200 to 2000 every day of the week.

   Except for the <FILLER>s, all <KEYWORD>s have specific meanings in the PCAM command language and may not be used as <NAME>s (see below) except when they appear in a <NAMELIST> enclosed in parentheses. For example, the user cannot have a "day" tour unless the tour name DAY always appears in parentheses as in TOUR=(DAY). The construction TOUR=DAY is invalid.
3. <NUMBER> is any decimal number, positive or negative, with or without a decimal point; e.g., 23 or -5.21.
4. <NUMBERLIST> is a <NUMBER> enclosed in parentheses or preceded by a delimiter, or a list of <NUMBER>s enclosed in parentheses and separated by commas, e.g. (1121) or (.023,1.1,50).
5. <NAME> is a string of one to eight characters that is not a <KEYWORD>. The first character of a <NAME> must be a letter. The remaining characters can be letters, numbers, hyphens, or periods with no imbedded blanks. <NAME>s are used to identify days, tours, precincts, and divisions.
6. <NAMELIST> is a <NAME>, or a list of <NAME>s enclosed in parentheses and separated by commas; e.g., PCT1 or (MORNING, AFTRNOON, NIGHT, OVERLAY). It is possible for a <NAMELIST> to consist of only left and right parentheses. This construction can be useful in a DISP command <QUALIFIER> (see below).
7. <QUALIFIER> consists of any subset of the following phrase types, separated by delimiters: TOUR=<NAMELIST>, DAY=<NAMELIST>, DIVISION=<NAMELIST>, PRECINCT=<NAMELIST>. A <QUALIFIER> defines the scope of the command with which it is associated (see "Overview of Program Operation," above). Examples of valid <QUALIFIER>s are TOUR=FIRST and PRECINCT=(P1,P2),DAY=SUNDAY. The uses of qualifiers are explained in the command definitions that follow.

COMMAND DEFINITIONS

HEADR Command

HEADR [Run name]

Action: The HEADR command causes PCAM to read and store an optional label that will appear at the top of all subsequent tables produced by PCAM. The run name may be any combination of up to 60 characters. It will be inserted after the words RUN NAME on the first line of output from a LIST command and preceding all tables produced by a DISP command. If no HEADR command is used, the RUN NAME line is omitted from all tables. A new HEADR command replaces the old run name. The new run name is printed on all subsequent tables.

Example: A HEADR command appears as the first line of Fig. 8 below. An example of the output it produces is shown at the top of Fig. 9 (and can also be found in Figs. 10-17). Figure 18 illustrates a change in run name.

READ Command

READ [DATA] [FOR] <QUALIFIER>

Action: The READ command causes PCAM to read all or part of the information contained in DATABASE, making this information available for use in CURRENT-DATA. The <QUALIFIER> specifies the precincts, days, and tours for which data are to be read. Any previously read data are replaced.

Effect of using qualifiers: The PRECINCT=<NAMELIST> phrase of the <QUALIFIER> provides a list of precincts for which data will be read. Each element of <NAMELIST> must be the name of some precinct that the user has entered into the database. The DIVSION=<NAMELIST> phrase tells PCAM to read data for all precincts of each division named in <NAMELIST>. If both the PRECINCT and DIVISION phrases are included in the <QUALIFIER>, then data will be read for all precincts in all specified divisions and for all other explicitly requested precincts.

As an example, consider two divisions named D1 and D2. D1 consists of precincts P1 and P2, and D2 consists of precincts P3 and P4. The qualifier DIVISION=(D1,D2) refers to precincts P1, P2, P3, and P4; the

qualifier DIVISION=D2 refers only to precincts P3 and P4; the qualifier PRECINCT=(P1,P3) refers to precincts P1 and P3; and the qualifier DIVISION=D1,PRECINCT=P4 refers to precincts P1, P2, and P4. If both the PRECINCT and DIVISION phrases are omitted from the qualifier, then data are read for all precincts in DATABASE.

The DAY=<NAMELIST> phrase of the qualifier provides PCAM with a list of days for which it will read data. Each element of the <NAMELIST> must be the name of a day entered into the database by the user. Data are read for the same days for all precincts specified by the PRECINCT and DIVISION phrases. If the DAY phrase is omitted from the qualifier, PCAM will read data for all days in the database for the specified precincts.

Continuing the above example with four precincts and two divisions, assume that the database contains data for days named MONDAY, TUESDAY, WEDNSDAY,[2] THURSDAY, FRIDAY, SATURDAY, and SUNDAY. Then the qualifier PRECINCT=P1,DAY=SUNDAY refers to the data for SUNDAY in precinct P1; the qualifier PRECINCT=P2 refers to the data for all days of the week in precinct P2; the qualifier DAY=THURSDAY refers to the data for THURSDAY for precincts P1, P2, P3, and P4; and the qualifier DIVISION=D2,DAY=(TUESDAY,WEDNSDAY) refers to the data for TUESDAY and WEDNSDAY for precincts P3 and P4.

The TOUR=<NAMELIST> phrase of the qualifier specifies the tours for which PCAM will read data. Data are read for the same tours for all days specified in the DAY phrase. If the TOUR phrase is omitted from the qualifier, then data are read for all tours in the database for the days and precincts specified in the qualifier.

Continuing with the same example, assume each day is divided into three tours, named FIRST, SECOND, and THIRD. Then the qualifier TOUR=SECOND,DAY=FRIDAY refers to the SECOND tour of FRIDAY for precincts P1, P2, P3, and P4; the qualifier PRECINCT=P3,DAY=TUESDAY refers to the FIRST, SECOND, and THIRD tours of TUESDAY for precinct P3; and the qualifier TOUR=(FIRST,THIRD), DIVISION=D2,DAY=(SATURDAY,SUNDAY) refers to FIRST and THIRD tours of SATURDAY and SUNDAY for precincts P3 and P4.

---

[2]Recall that the names of days are limited to eight characters.

READ command qualifiers also affect the order in which output measures are printed by the DISP command. See the section below on the DISP command.

Data Checking: When the READ command is entered, PCAM does more than simply read the data from the input file, it also checks to make sure that the data are all right. One check that it makes automatically is to determine whether enough cars have been assigned to each tour. If the user has not chosen to smooth queuing behavior over time, this check makes sure that the number of cars on duty is enough to handle the call-for-service workload in every hour. If smoothing is being used, the check makes sure that the number of cars on duty in a block is enough to handle the average workload in the block. If these conditions are not met, PCAM will not be able to perform its calculations correctly, so the READ command increases the number of cars assigned. When PCAM increases the number of cars assigned to a shift, it prints a message giving the precinct, day, and tour that specify the shift, and it indicates the number of cars it has assigned. When you receive such a message, it is a warning for you to check the accuracy of the data.

You have the option of asking the READ subroutine to make more extensive checks of the input data. If this option is chosen,[3] PCAM will print a message and terminate the program if any of the following conditions are found. (These are not necessarily errors but warnings for the user to check the accuracy of the data.)

Unavailability parameter B1	(B1 not between -1 and 1)
Unavailability parameter B2	(B2 not between 0 and 1)
Call rate	(not a positive number)
Service time	(increases or decreases by more than a factor 3 over the day)
Specification of priority classes	(different priority classes exist on different tours)
Street density	(less than 3 street miles per square mile in some precinct)

Normally this option should be used the first few times a new database is being tried. Once the errors and inconsistencies in the data have

[3]By entering a zero in column 49 of the first input record of the DATABASE.

been eliminated, the option can be turned off,[4] thus speeding up the program.

Reading overlay tours: If the database contains data for overlay tours, you have the option of reading the overlay tour data or not. If you choose not to read such data, then all tours that are read are treated as though no overlay tour existed. However, if you select the overlay tour in a READ command, then you must also select any tours that are overlaid.

Example: We now give an example showing the use of the READ command. Both the user's input and the program's output are reproduced from actual program runs. The demonstration data used in the examples are realistic, representing a section of a large city. However, some numerical values and all names of precincts and divisions have been changed. A listing of this database is given in App. A of the companion *Program Description* (R-3087/3).

Our sample city, which will be used to illustrate all of the commands, has two divisions: HIGHLAND and LOWLAND. HIGHLAND is made up of two precincts: NORTH and EAST. Lowland has three precincts: SOUTH, WEST, and CENTRAL. There are data for seven days for each precinct. The day names are: SUN-MON, MON-TUE, TUE-WED, WED-THU, THU-FRI, FRI-SAT, and SAT-SUN. The data for the first day begins with the hour 0800-0900 on Sunday and ends with the hour 0700-0800 on Monday. The other days are defined similarly. The selection of days that do not begin at midnight was done because no tour begins at midnight (see Sec. II). Each day has four tours: MIDDAY, PM, AM, and FOURTH. Each tour is eight hours in length, and the FOURTH is an overlay tour, beginning with the fourth hour of the PM tour and ending with the third hour of the AM tour.

Between 10 and 50 percent of cars fielded have two officers, depending on the particular shift; the rest have one officer. All priority 1 calls receive a dispatch of two cars; priority 2 and 3 calls receive one car.

A sample READ command and response are shown in Fig. 8; these are preceded by a HEADR command that specifies the RUN NAME.

[4]By entering a 1 in column 49 of the first input record of the DATABASE.

This command caused PCAM to read data from all tours of TUE-WED and SAT-SUN in precincts WEST and CENTRAL. The messages preceded by three asterisks indicate a possible error or problem with the input data: The number of cars listed in DATABASE for eight of the shifts was not sufficient to handle the call-for-service workload in every block. The program computed the minimum number of cars needed for each shift and assigned that number to the shift. The modified car assignments (which are rounded before being displayed) are entered into CURRENT-DATA and will be reflected in subsequent calculations and output.

For reference, the output also shows the number of cars that were input from the DATABASE before the increase. After reading all the data for a DAY in a PRECINCT, the program shows the total number of cars that it added to the input from the DATABASE. Those figures can be used to adjust the number of car-hours in subsequent commands (such as ALOC), for example to restore the originally intended total car-hours in a day.

LIST Command

LIST [DATA] [FOR] <QUALIFIER>

Action: Causes PCAM to list most of the data in CURRENT-DATA for the shifts specified by the qualifier. This command is used primarily to check that the intended DATABASE file has been read, to locate errors in the data, or to assure that changes made through the SET command are correctly reflected in the data. PCAM responds to the LIST command by displaying data for each tour, within each day, within each precinct. The values of time-invariant characteristics of each precinct are displayed first, followed by the values that apply to each day as a whole. For each day, values are displayed for each tour selected.

A sample LIST command and response are shown in Fig. 9.

This LIST command requests PCAM to display data for all TUE-WED tours in CURRENT-DATA. Since the command was issued after the READ command in Fig. 8, there are only two precincts in CURRENT-DATA, and these are the only ones shown in the output.


```
HEADR SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
READ DATA FOR PRECINCT=(WEST,CENTRAL),&
   DAY=(TUE-WED,SAT-SUN)

*** NUMBER OF CARS IN PRECINCT WEST     FOR TOUR     MIDDAY   ON DAY TUE-WED
*** INCREASED TO    14. FOR PCAM CALCULATIONS
*** 10.7 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT WEST     FOR TOUR     PM       ON DAY TUE-WED
*** INCREASED TO    15. FOR PCAM CALCULATIONS
*** 10.3 ACTUAL CARS WERE INPUT
***  8.0 TOTAL  CARS WERE ADDED IN PRECINCT WEST     ON DAY TUE-WED

*** NUMBER OF CARS IN PRECINCT WEST     FOR TOUR     MIDDAY   ON DAY SAT-SUN
*** INCREASED TO    16. FOR PCAM CALCULATIONS
***  9.2 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT WEST     FOR TOUR     PM       ON DAY SAT-SUN
*** INCREASED TO    12. FOR PCAM CALCULATIONS
*** 10.5 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT WEST     FOR TOUR     FOURTH   ON DAY SAT-SUN
*** INCREASED TO    13. FOR PCAM CALCULATIONS
***  5.7 ACTUAL CARS WERE INPUT
*** 15.1 TOTAL  CARS WERE ADDED IN PRECINCT WEST     ON DAY SAT-SUN

*** NUMBER OF CARS IN PRECINCT CENTRAL  FOR TOUR     PM       ON DAY TUE-WED
*** INCREASED TO     8. FOR PCAM CALCULATIONS
***  5.8 ACTUAL CARS WERE INPUT
***  2.2 TOTAL  CARS WERE ADDED IN PRECINCT CENTRAL  ON DAY TUE-WED

*** NUMBER OF CARS IN PRECINCT CENTRAL  FOR TOUR     PM       ON DAY SAT-SUN
*** INCREASED TO     8. FOR PCAM CALCULATIONS
***  6.3 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT CENTRAL  FOR TOUR     AM       ON DAY SAT-SUN
*** INCREASED TO     6. FOR PCAM CALCULATIONS
***  3.8 ACTUAL CARS WERE INPUT
***  3.9 TOTAL  CARS WERE ADDED IN PRECINCT CENTRAL  ON DAY SAT-SUN
```

Fig. 8 -- Sample READ command and response

LIST DATA FOR DAY=TUE-WED
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

PRECINCT: WEST ; AREA= 51.9; STREET MILES=678.5; B2=0.637; B1=-.476

DAY: TUE-WED ; CALL RATE PARM= 6.65; SERVICE TIME PARM=45.13

TOUR	ACT. CARS	AVG. EFF. CARS	SPEED RSP.	SPEED PTL.	AVG. SERV TIME	AVG. CALL RATE	FRAC. OF P1 CALLS	FRAC. OF P2 CALLS	FRAC. OF P3 CALLS
MIDDAY	14.0	7.0	15.0	7.5	36.1	6.4	0.061	0.810	0.129
PM	15.0	10.3	15.0	7.5	49.6	9.1	0.061	0.810	0.129
AM	9.1	5.4	25.0	7.5	49.6	3.4	0.061	0.810	0.129
FOURTH	4.9								

PRECINCT: CENTRAL ; AREA= 47.3; STREET MILES=498.3; B2=0.658; B1=-.746

DAY: TUE-WED ; CALL RATE PARM= 3.66; SERVICE TIME PARM=40.20

TOUR	ACT. CARS	AVG. EFF. CARS	SPEED RSP.	SPEED PTL.	AVG. SERV TIME	AVG. CALL RATE	FRAC. OF P1 CALLS	FRAC. OF P2 CALLS	FRAC. OF P3 CALLS
MIDDAY	7.6	4.3	15.0	7.5	44.2	2.9	0.067	0.810	0.123
PM	8.0	5.7	15.0	7.5	36.2	4.6	0.067	0.810	0.123
AM	4.3	2.9	25.0	7.5	36.2	2.0	0.067	0.810	0.123
FOURTH	3.5								

Fig. 9 -- Sample LIST command and response

Explanation of output: The first two lines of output give the run name and file name. The run name was specified earlier in the HEADR command (see Fig. 8). The file name is stored in the DATABASE file (see R-3087/3). The third line of output gives the precinct name (WEST), its area in square miles (51.9), and the number of miles of streets in the precinct (678.5). It also shows the values of the unavailability parameters B1 and B2 (see Sec. II). These items are identical to whatever appears in CURRENT-DATA for the West precinct.

The fourth line of output gives the name of the first day for which data are listed (TUE-WED) and also the call rate (6.65) and service time (45.13) parameters for that day. These parameters characterize the call rate and service time for the day as a whole, although PCAM does its computations using hourly data for call rates and service times. These

parameters can be changed to reflect overall changes in call rates and service times, and proportional changes will be made in the hourly data that PCAM uses (see Sec. II and the SET command description below). The items on the fourth line of printout are also identical to whatever appears in CURRENT-DATA.

The next three lines of output produce column headings to identify the data to be displayed for each of the tours. From left to right, the first column heading identifies the tour name (MIDDAY for the first tour). The second column heading identifies the number of actual cars[5] assigned to start at the beginning of the tour (14.0 for the MIDDAY tour--this is the value set by the last READ command). The third column gives the average number of effective cars (see Sec. II) on duty during the tour (7.0 for the MIDDAY tour and 10.3 for the PM tour). This figure refers to the entire eight-hour period covered by the tour and takes into account any change in the number of cars on duty during a tour due to an overlay tour. For example, during the first three hours of the PM tour there are 15 cars on duty, and during the next five hours there are 19.9 cars on duty (15.0 + 4.9 from the fourth tour). When converted to effective cars and averaged over eight hours, this results in 10.3 effective cars during the PM tour.

The fourth column gives the average speed of cars when responding to calls, in miles per hour (e.g., 15.0 for the MIDDAY tour). The fifth column gives the average speed of cars while on preventive patrol (e.g., 7.5 for the MIDDAY tour). The response and patrol speeds displayed are taken directly from CURRENT-DATA.

The sixth and seventh columns show the averages of hourly service times and call rates over the tours (these are 36.1 minutes and 6.4 calls per hour, respectively, for the MIDDAY tour). These averages will change in direct proportion to any changes the user might make in the call rate and service time parameters for the day.

The next three columns show the fractions of all calls in a tour that are of priority 1, priority 2, and priority 3, respectively (these are 0.061, 0.810, and 0.129, for the MIDDAY tour). The fractions of priority 1 and priority 2 calls were provided in DATABASE and read into

[5] Input data do not have to be integers. They can be constructed by averaging the number of actual cars over several weeks.

CURRENT-DATA. PCAM computes the fraction of priority 3 calls by subtracting the sum of the priority 1 and priority 2 fractions from 1.0.

Note that only the number of actual cars on duty is shown for the FOURTH tour because it is an overlay tour, and the information already listed for the other three tours completely describes the entire day.

The types of output described above are repeated for all days selected and for all selected precincts.

DISP Command

DISP T<NUMBERLIST> [FOR] <QUALIFIER>

or

DISP A<NUMBERLIST> [FOR] <QUALIFIER>

Action: The DISP command instructs PCAM to display output information in the tables specified by <NUMBERLIST> for the shifts specified by the qualifier. The entries in <NUMBERLIST> may be all or some of the integers 1,2,3,4,5, in any order, separated by commas. (For example, T(1,4,3).) If T is used, detailed output will be provided for every tour or precinct. If A is chosen, only the final *averages* will be shown. (These will be for days and precincts, or tours and days, depending on the order of output chosen.) The user-supplied run name and/or data file name are printed at the top of each table if you choose to have headings.

Table 1. Patrol Car Activity During Tour: If T(1) is chosen, the following output measures will be produced for each shift:

- The number of actual cars assigned to start the shift
- The number of car-hours provided by the cars starting the shift
- Call rates and service times, averaged over the hours of the shift
- The percentage of time that a patrol car on duty during the shift is busy on cfs work

- The percentage of time that a patrol car on duty during the shift is busy on non-cfs work
- The percentage of time that a patrol car on duty during the shift is busy (unavailable for dispatch)
- The average number of cars available for dispatch.

Table 2. Time Allocation: Cars Starting Each Tour. If T(2) is chosen, the following output measures will be produced for each shift:

- The number of actual cars assigned to start the shift
- The number of car-hours provided by the cars starting the shift
- The number of officer-hours provided by the cars starting the shift
- The average number of hours during the shift during which a car that started the shift is available
- The average percentage of time during the shift a car that started the shift is available

Table 3. Average Delays of Calls. If T(3) is chosen, the following output measures will be produced for each shift:

- The number of actual cars assigned to start the shift
- The number of car-hours provided by the cars starting the shift
- The expected queuing delays (in minutes) for priority 2 and priority 3 calls
- The expected total delay (i.e., queuing delay plus travel time) for priority 2 and priority 3 calls
- The expected queuing delay and total delay for any call.

Table 4. Calls Delayed and Patrol Interval. If T(4) is chosen, the following output measures will be produced for each shift:

- The number of actual cars assigned to start the shift
- The number of car-hours provided by the cars starting the shift

- The percentage of priority 1, priority 2, and priority 3 calls that will be placed in queue. (According to the model in PCAM, these will all be the same in a time block, or in a shift that is a single time block.)
- The percentage of all calls that will be placed in queue (i.e., not dispatched immediately)
- The average number of hours between successive times that a random point will be passed by a car on preventive patrol.

Table 5. Statistics from Internal PCAM Calculations. If T(5) is chosen, the following output measures will be produced for each shift:

- The number of actual cars assigned to start the shift
- The number of car-hours provided by the cars starting the shift
- The average number of cars dispatched to calls-for-service of each priority and overall
- The expected queuing delay (in minutes) for priority 1 calls
- The expected total delay (i.e., queuing delay plus travel time) for priority 1 calls. For reasons explained in Sec. II, PCAM's estimates of delays for priority 1 calls are not expected to be accurate and should generally not be used for decisionmaking.

The interpretations of these measures are explained in Sec. II.

We will refer to the five groups of output measures as output tables. Any number of tables (up to all five) can be specified in each DISP command. Output is first printed for all shifts selected by the qualifier for the first table in the list, then for all shifts for the second table on the list, etc.

Order of output: The output tables can be printed in either of two ways. One way will begin with the first precinct selected and show output measures for each tour in turn, producing summaries for each day and then for the precinct as a whole. After all output is given for the first precinct, the results will be shown for the next precinct (if any). This output mode is called "tour within day within precinct." It

is appropriate for looking at output measures as they vary from tour to tour within a particular day for a particular precinct. An example of this output order is given in Fig. 10.[6] (The interpretation of this table will be given below.)

The second output order will begin with the first tour of the first day selected and show output measures for all the precincts, producing summaries for the tour. Then it proceeds to the next tour. This mode is called "precinct within tour within day." It is more appropriate for seeing how output measures vary from precinct to precinct over the city during a particular time of a particular day. An example of output ordered by precinct within tour within day is given in Fig. 11.

PCAM determines the ordering within output tables from the ordering of qualifier phrases, as follows. The program initially assumes that you want your output in the first order described above--that is, by tour within day within precinct. However, if any phrases appear in a READ command qualifier, this default order is overridden. The rule for establishing a new default output order is that if either a TOUR or a DAY phrase is the first phrase of a READ command qualifier (as is the case in Fig. 11), then the default output order for subsequent DISP commands is by precinct within tour. If a PRECINCT or DIVISION phrase appears first in a READ command (as is the case in Fig. 8), then the default output order is the same as if no qualifier were entered, namely, tour within day within precinct. The default output order established by a READ command remains in effect only until another READ command is entered. If a subsequent READ command has no qualifier phrases, then the original default is reestablished.

If any phrases appear in a DISP command qualifier, then the default output order is overridden for that DISP command only. If a PRECINCT or DIVISION phrase is the first in a DISP command qualifier, then output is ordered as tour within day within precinct. If the first qualifier phrase is a DAY or TOUR phrase, then output will be ordered as precinct within tour within day.

[6] When only a single precinct is read from DATABASE, the output order for all tables will be tour within day within precinct. In other words, <QUALIFIER> will have no effect on the output order if only one precinct is read.

DISP T 1
RUN`NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 1. PATROL CAR ACTIVITY DURING TOUR

PRECINCT: WEST ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	CALL RATE	SERV TIME	--- DURING THE TOUR -PERCENT TIME BUSY-- CFS	NONCFS	TOTAL	---AVG. CARS AVAIL
MIDDAY	14.0	112.0	6.4	36.1	29.3	49.8	79.0	2.9
*PM	15.0	120.0	9.1	49.6	44.0	42.7	86.8	2.4
*AM	9.1	72.8	3.4	49.6	27.5	50.6	78.1	2.4
+FOURTH	4.9	39.2	7.7	49.6	38.1	45.6	83.7	2.9
AVERAGE	10.7	86.0	6.3	45.0	35.0	47.0	82.0	2.6
TOTAL	43.0	344.0						

PRECINCT: WEST ; DAY: SAT-SUN

TOUR	NO. CARS	CAR HOURS	CALL RATE	SERV TIME	--- DURING THE TOUR -PERCENT TIME BUSY-- CFS	NONCFS	TOTAL	---AVG. CARS AVAIL
MIDDAY	16.0	128.0	6.5	43.4	31.3	48.8	80.1	3.2
*PM	12.0	96.0	11.4	32.6	33.1	47.9	81.0	3.8
*AM	7.5	60.0	6.6	36.2	34.9	47.1	82.0	2.2
+FOURTH	12.5	100.0	12.4	33.9	32.6	48.2	80.8	4.4
AVERAGE	12.0	96.0	8.2	36.4	33.0	48.0	81.0	3.0
TOTAL	48.0	384.0						

PRECINCT: WEST

AVERAGE	11.4	91.0	7.2	40.2	33.9	47.6	81.5	2.8
TOTAL	91.0	728.0						

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	CALL RATE	SERV TIME	--- DURING THE TOUR -PERCENT TIME BUSY-- CFS	NONCFS	TOTAL	---AVG. CARS AVAIL
MIDDAY	7.6	60.8	2.9	44.2	30.0	43.4	73.4	2.0
*PM	8.0	64.0	4.6	36.2	29.0	44.2	73.2	2.7
*AM	4.3	34.4	2.0	36.2	23.3	48.4	71.7	1.6
+FOURTH	3.5	28.0	3.4	36.2	21.6	49.7	71.3	2.9
AVERAGE	5.8	46.8	3.2	38.6	27.9	45.0	72.9	2.1
TOTAL	23.4	187.2						

PRECINCT: CENTRAL ; DAY: SAT-SUN

TOUR	NO. CARS	CAR HOURS	CALL RATE	SERV TIME	--- DURING THE TOUR -PERCENT TIME BUSY-- CFS	NONCFS	TOTAL	---AVG. CARS AVAIL
MIDDAY	6.6	52.8	3.4	42.5	39.0	36.7	75.7	1.6
*PM	8.0	64.0	6.1	38.6	39.7	36.2	75.9	2.5
*AM	6.0	48.0	3.8	38.6	34.3	40.2	74.5	1.9
+FOURTH	4.1	32.8	6.8	38.6	41.1	35.1	76.2	2.7
AVERAGE	6.2	49.4	4.4	39.6	37.9	37.5	75.4	2.0
TOTAL	24.7	197.6						

PRECINCT: CENTRAL

AVERAGE	6.0	48.1	3.8	39.2	33.1	41.1	74.2	2.1
TOTAL	48.1	384.8						

GRAND

AVERAGE	8.7	69.5	5.5	39.8	33.6	45.3	79.0	2.4
TOTAL	139.1	1112.8						

Fig. 10 -- Sample DISP command for Table 1 ordered by tour within day within precinct


```
READ DATA FOR DAY=TUE-WED, TOUR=(MIDDAY,PM)

*** NUMBER OF CARS IN PRECINCT EAST      FOR TOUR      PM        ON DAY TUE-WED
*** INCREASED TO   16. FOR PCAM CALCULATIONS
*** 11.5 ACTUAL CARS WERE INPUT
***  4.5 TOTAL  CARS WERE ADDED IN PRECINCT EAST      ON DAY TUE-WED

*** NUMBER OF CARS IN PRECINCT WEST      FOR TOUR      MIDDAY    ON DAY TUE-WED
*** INCREASED TO   14. FOR PCAM CALCULATIONS
*** 10.7 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT WEST      FOR TOUR      PM        ON DAY TUE-WED
*** INCREASED TO   17. FOR PCAM CALCULATIONS
*** 10.3 ACTUAL CARS WERE INPUT
*** 10.0 TOTAL  CARS WERE ADDED IN PRECINCT WEST      ON DAY TUE-WED

*** NUMBER OF CARS IN PRECINCT NORTH     FOR TOUR      PM        ON DAY TUE-WED
*** INCREASED TO    9. FOR PCAM CALCULATIONS
***  7.8 ACTUAL CARS WERE INPUT
***  1.2 TOTAL  CARS WERE ADDED IN PRECINCT NORTH     ON DAY TUE-WED

*** NUMBER OF CARS IN PRECINCT SOUTH     FOR TOUR      MIDDAY    ON DAY TUE-WED
*** INCREASED TO   14. FOR PCAM CALCULATIONS
*** 12.6 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT SOUTH     FOR TOUR      PM        ON DAY TUE-WED
*** INCREASED TO   14. FOR PCAM CALCULATIONS
***  6.9 ACTUAL CARS WERE INPUT
***  8.5 TOTAL  CARS WERE ADDED IN PRECINCT SOUTH     ON DAY TUE-WED

*** NUMBER OF CARS IN PRECINCT CENTRAL   FOR TOUR      PM        ON DAY TUE-WED
*** INCREASED TO    8. FOR PCAM CALCULATIONS
***  5.8 ACTUAL CARS WERE INPUT
***  2.? TOTAL  CARS WERE ADDED IN PRECINCT CENTRAL   ON DAY TUE-WED
```

DISP T 1
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 1. PATROL CAR ACTIVITY DURING TOUR

DAY TUE-WED ; TOUR MIDDAY

PRECINCT	NO. CARS	CAR HOURS	CALL RATE	SERV TIME	--- DURING THE TOUR -PERCENT TIME BUSY-- CFS	NONCFS	TOTAL	---AVG. CARS AVAIL
EAST	13.4	107.2	6.8	48.3	43.6	31.8	75.4	3.3
WEST	14.0	112.0	6.4	36.1	29.3	49.8	79.0	2.9
NORTH	11.9	95.2	5.0	41.1	30.4	50.3	80.7	2.3
SOUTH	14.0	112.0	5.2	45.7	29.9	49.9	79.8	2.8
CENTRAL	7.6	60.8	2.9	44.2	30.0	43.4	73.4	2.0
AVERAGE	12.2	97.4	5.3	43.0	32.9	45.1	78.0	2.7
TOTAL	60.9	487.2						

DAY TUE-WED ; TOUR PM

PRECINCT	NO. CARS	CAR HOURS	CALL RATE	SERV TIME	--- DURING THE TOUR -PERCENT TIME BUSY-- CFS	NONCFS	TOTAL	---AVG. CARS AVAIL
EAST	16.0	128.0	10.1	42.6	47.5	28.5	76.1	3.8
WEST	17.0	136.0	9.1	49.6	46.8	41.4	88.2	2.0
NORTH	9.0	72.0	6.8	30.5	40.6	40.1	80.7	1.7
SOUTH	14.0	112.0	8.5	45.7	49.5	32.0	81.5	2.6
CENTRAL	8.0	64.0	4.6	36.2	36.9	38.3	75.2	2.0
AVERAGE	12.8	102.4	7.8	42.1	45.5	35.6	81.0	2.4
TOTAL	64.0	512.0						

DAY: TUE-WED

AVERAGE	12.5	99.9	6.5	42.4	39.3	40.2	79.6	2.6
TOTAL	124.9	999.2						

Fig. 11 -- Sample DISP command for Table 1 ordered by precinct within tour within day

Although the above explanation may seem somewhat complex, in practice the determination of output order works out quite naturally. For instance, the command READ DATA FOR PRECINCT=NORTH causes PCAM to read data for all days and tours in the database for precinct NORTH and establishes the default output order of tour within day for this precinct. Then a subsequent DISP command with no phrases in its qualifier will display the selected tables in this order. Conversely, the command READ DATA FOR DAY=TUE-WED, TOUR=MIDDAY causes the program to read data for all precincts in the database for the MIDDAY tour of Tuesday and establishes the default output order of precinct within tour within day. In this case, a subsequent DISP command without phrases in its qualifier will display the selected tables in this order.

The user may sometimes want to have all shifts in CURRENT-DATA printed but in the order opposite to that implied by qualifiers in the READ command. This is possible by entering null qualifiers in the DISP command. For instance, the command READ DATA causes PCAM to read data for all precincts, days, and tours in the database and establishes the default output order of tour within day within precinct. If you wish printout ordered by precinct within tour within day, you may enter a command such as DISP T(1) FOR DAY=(). This works because a <NAMELIST> in a qualifier phrase of the form () has the same effect on data selection as omitting the phrase entirely, but still produces the output order described above.

Overlay indicators: Each line of output from the DISP command corresponds to one shift (i.e., a tour of one day in one precinct). This is true regardless of the output order. To help clarify the relationships among shifts involved in overlays, each line of output values is prefixed by an indicator. If the indicator is blank, then no overlay was involved in computing the measures shown. An asterisk (*) at the beginning of any output line indicates that the measures displayed reflect the presence of an overlay shift that started or ended during the shift represented by that line of output. A plus sign (+) at the beginning of an output line indicates that the corresponding shift is an overlay shift.

Summary statistics: The DISP command output always contains averages of measures for days, tours, or precincts, depending upon the output order. Whatever order is chosen, overall averages will be displayed. If the DISP A option is used, nothing but these averages will be displayed. If an overlay tour is included in the output, all hours of the data that are of interest are included in *other tours besides the overlay tour*, so the figures displayed for the overlay tour are not used in calculating averages for the day. The summary statistics include the total number of cars assigned and the total number of car-hours. These, of course, include the cars assigned to overlay tours, if any.

Explanation of output:

Table 1. Workloads of Patrol Cars. We return to Fig. 10 for the interpretation of Table 1 output. The first line of output is the optional run name, which is supplied using the HEADR command. The second line is the optional identifier for the DATABASE that is being used as input. The third line identifies the table (TABLE 1). The next output line identifies the precinct (WEST) and day (TUE-WED) to which the tour output applies. The next two output lines are column headings that identify the output measures for tours that appear on subsequent lines. The first output column identifies the tour to which subsequent columns on the line apply (MIDDAY for the first line of output measures).

The second column shows the number of actual cars that were assigned to start the shift. This number reflects the car assignments in CURRENT-DATA, which are not necessarily the same as the assignments in the input data. CURRENT-DATA is modified by the MEET, ALOC, ADD, and SET commands. The third column shows the number of car-hours for each tour. This is the product of the number of cars assigned to start the tour and the length of the tour in hours, and does not include overlay effects. The first three columns of output are the same in all five of the output tables that PCAM produces.

The fourth and fifth columns of Table 1 give the average number of calls per hour and the average service time (in minutes) for calls in the tour. Note that the service time is averaged over calls (and not over hours, as it is in output from the LIST command).

The sixth, seventh, and eighth columns refer to the time an average car on duty during the tour spends working. The sixth column gives the percent of time cars are handling calls for service. The numbers in this table describe activity during a tour, which in the case of overlay tours is not the same as describing workload of the cars that start the tour. (Compare Table 2, described below, which refers to cars that start the tour.) For example, during the PM tour in PRECINCT WEST on Tuesday, 15 cars work 8 hours and 4.9 cars from the FOURTH tour work 5 hours, for a total of 144.5 car-hours in the PM tour. The fifth column indicates that 44 percent of this work time (or about 63.6 hours) was spent handling calls for service. The seventh column gives the percent of time that an average car will be unavailable for reasons unrelated to calls for service. Column 8 contains the sum of the percentages in columns 6 and 7. It is the percent of time during the tour that an average car on duty during the tour is busy for any reason. The ninth and last column of Table 1 gives the average number of cars on patrol and available for dispatch during the tour (2.9 for the MIDDAY tour).

One line of output is printed for each tour of TUE-WED. The lines for the PM and AM tours are flagged with asterisks to indicate that the measures displayed reflect a change in the number of cars on duty during the tour because the overlay tour was beginning or ending. The output line for the FOURTH tour is flagged with a plus to indicate that it is an overlay tour and that the measures displayed represent averages over hours of the day that are also included in other tours.

The next line of output, labeled AVERAGE, gives the values of the measures described above averaged over the hours of the tours for which output is displayed (the entire day in this case). The hours covered by the overlay tour are counted only once in the averages.[7]

[7] If you add the four lines with a hand calculator and divide by 4, you will not get the correct answers shown by PCAM. In some of the columns you will be counting the FOURTH tour twice.

The sequence of output lines described above is repeated for each day in the database. A final two lines of output for precinct WEST are then printed. The first of them identifies the next line as one displaying averages over all days selected for the precinct; the second presents the averages of the first two measures for all tours of all days selected (TOTAL). The above sequence is then repeated for precinct CENTRAL. A final line of output shows averages over both precincts.

If you compare the figures shown in Figs. 10 and 11 for the PM tour of TUE-WED in the CENTRAL precinct, you will see that they differ, while the figures for the MIDDAY tour are the same. This illustrates the fact that cars assigned to the overlay tour (FOURTH) in DATABASE are not included in CURRENT-DATA unless the overlay tour is read. The READ command at the top of Fig. 11 does not include the overlay tour, so, for example, the number of cars on duty in Central Precinct during Tuesday's PM tour is a constant 8.0 in Fig. 11. In Fig. 10, the number of cars increases from 8.0 to 11.5 when the FOURTH tour begins.

Table 2. Time Allocation: Cars Starting the Tour. Fig. 12 shows an example of Table 2 output. The first two output lines are again the (optional) user-supplied run name and file name. The third line identifies the table. The fourth output line identifies the precinct (CENTRAL) and day (TUE-WED) for which Table 2 output is displayed. The next two lines are column headings. The first column of each of the next four lines identifies the tour to which the line applies. (Remember, the precinct, day, and tour identify the shift for which output is presented.) The second and third columns show the number of actual cars that were assigned to start the shift and the number of car-hours for the shift, just as in Table 1.

The fourth column gives the number of officer-hours for each tour. This is the product of the number of cars assigned to start the tour and the average number of officers per car.

The fifth and sixth columns provide information on the availability of an average car that started the shift. Column 5 gives the uncommitted hours per car and Column 6 the percent of time that an average car is available for dispatch or patrol. For example, the average time spent uncommitted (not busy on either cfs work or

READ DATA FOR PRECINCT=CENTRAL,DAY=TUE-WED

*** NUMBER OF CARS IN PRECINCT CENTRAL FOR TOUR PM ON DAY TUE-WED
*** INCREASED TO 8. FOR PCAM CALCULATIONS
*** 5.8 ACTUAL CARS WERE INPUT
*** 2.2 TOTAL CARS WERE ADDED IN PRECINCT CENTRAL ON DAY TUE-WED
DISP T 2
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 2. TIME ALLOCATION: CARS STARTING THE TOUR

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	OFFICER HOURS	UNCOMM HRS/CAR	% TIME UNCOMM
MIDDAY	7.6	60.8	68.8	2.1	26.6
PM	8.0	64.0	75.0	2.1	26.5
AM	4.3	34.4	42.4	2.2	27.8
FOURTH	3.5	28.0	36.0	2.3	28.9
AVERAGE	5.8	46.8	55.5	2.2	27.1
TOTAL	23.4	187.2	222.2		

DISP T 3
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 3. AVERAGE DELAYS OF CALLS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	PRTY 2 DELAY		PRTY 3 DELAY		-AVERAGE	DELAY-
			QUEUE	+TRVL	QUEUE	+TRVL	QUEUE	+TRVL
MIDDAY	7.6	60.8	0:21	0:38	4:29	4:46	0:51	1:07:54
*PM	8.0	64.0	0:06	0:20	0:28	0:43	0:08	0:22:57
*AM	4.3	34.4	0:29	0:39	4:05	4:16	0:54	1:04:33
+FOURTH	3.5	28.0	0:02	0:14	0:05	0:17	0:02	0:14:16
AVERAGE	5.8	46.8	0:15	0:30	2:28	2:42	0:31	0:45:32
TOTAL	23.4	187.2						

Fig. 12 -- Sample DISP command for Tables 2-5

DISP T 4
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 4. CALLS DELAYED AND PATROL INTERVAL

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	---- PERCENT	OF CALLS	DELAYED ----		PATROL INTERVAL
			PRTY1	PRTY2	PRTY3	TOTAL	
MIDDAY	7.6	60.8	37.4	37.4	37.4	37.4	32:54
*PM	8.0	64.0	22.7	22.7	22.7	22.7	26:03
*AM	4.3	34.4	33.9	33.9	33.9	33.9	47:02
+FOURTH	3.5	28.0	12.3	12.3	12.3	12.3	23:29
AVERAGE	5.8	46.8	29.5	29.5	29.5	29.5	35:19
TOTAL	23.4	187.2					

DISP T 5
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 5. STATISTICS FROM INTERNAL PCAM CALCULATIONS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	------ AVG	CARS/CFS	------		PRTY 1 DELAY	
			PRTY1	PRTY2	PRTY3	TOTAL	QUEUE	+TRVL
MIDDAY	7.6	60.8	2.0	1.0	1.0	1.1	0:06	0:23
*PM	8.0	64.0	2.0	1.0	1.0	1.1	0:02	0:17
*AM	4.3	34.4	2.0	1.0	1.0	1.1	0:08	0:19
+FOURTH	3.5	28.0	2.0	1.0	1.0	1.1	0:01	0:13
AVERAGE	5.8	46.8	2.0	1.0	1.0	1.1	0:04	0:19
TOTAL	23.4	187.2						

Fig. 12 -- continued

CONTINUED

1 OF 2

In the first version of the ALOC command, the number of car-hours to be allocated is specified by <NUMBER>, which must be positive. In the other two versions of the ALOC command, the asterisk (*) denotes the total number of car-hours assigned to the selected shifts in CURRENT-DATA. This total is determined from the database or from preceding ALOC, MEET, SET, or ADD commands.

The second version of the ALOC command causes a reallocation of the current total number of car-hours among the selected shifts. The third version of ALOC will allocate the number currently assigned minus <NUMBER>. For example, if 320 car-hours are currently assigned, ALOC * -16 ... will allocate 304 car-hours.

The qualifier specifies the precincts, days, and tours over which car-hours will be allocated and for which car-hours are currently allocated. The <NUMBERLIST> specifies the objective function to be used for the allocation. Its first element is always a number that selects the function to be used. Other elements in the list specify parameters required for particular functions. The available objective functions are as follows:

F(1)	Average percent of calls delayed in queue
F(2)	Average length of time calls are delayed in queue
F(2,1)	Average length of time priority 1 calls are delayed in queue
F(2,2)	Average length of time priority 2 calls are delayed in queue
F(2,3)	Average length of time priority 3 calls are delayed in queue
F(3)	Average response time (queuing + travel time) to all calls
F(3,1)	Average response time (queuing + travel time) to priority 1 calls
F(3,2)	Average response time (queuing + travel time) to priority 2 calls
F(3,3)	Average response time (queuing + travel time) to priority 3 calls

As an example, the command ALOC 480 TO DAY=TUE-WED, TOUR=MIDDAY BY F(2,2) will allocate 480 car-hours (or 60 cars) among the precincts on Tuesday's MIDDAY tour in such a way as to make the citywide average delay for priority 2 calls as small as possible.

Warning message: The program's first step in carrying out an ALOC command is to assign enough cars to each shift within the command's scope to handle the call-for-service workload. If the number of car-hours required for this step is greater than the number of car-hours specified in the ALOC command, the program prints a message giving the minimum number of car-hours required, and the allocation is performed as if the user had asked to allocate that number of car-hours.

Memory: The assignment of cars resulting from the execution of an ALOC command is stored in CURRENT-DATA, replacing whatever assignments were previously stored. Therefore, the new assignment will be reflected in the output resulting from subsequent DISP, LIST, ADD, or SET commands. However, DATABASE is not changed by the ALOC command, so the user can cause the program to "forget" the assignment by executing a new READ command.

Example: Figure 13 gives an example of the use of an ALOC command. This command causes the reallocation of the current number of car-hours assigned to precinct CENTRAL on TUE-WED (specified in the previous READ command, Fig. 12) so that the probability of a call being delayed is minimized for the day as a whole. The DISP command outputs show the new assignments and, by comparison with Fig. 12, their effects on the output measures.

From Table 4, we can see that the average percent of calls delayed for precinct CENTRAL on TUE-WED is reduced from 29.5 to 27.6, so (as desired) the new allocation has improved the value of this performance measure. It happens that all the other performance measures on Tables 3 and 4 have been improved for the day as a whole by this allocation, but you may not be so lucky with your own data. Although no other allocation of 184 car-hours can have a lower average percent of calls delayed than 27.6, the use of objective functions other than F(1) will lead to lower values for their associated performance measures.

ALOC * BY F(1)
DISP T 1
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 1. PATROL CAR ACTIVITY DURING TOUR

PRECINCT: CENTRAL ; DAY: TUE-WED

					--- DURING THE TOUR	---AVG.		
	NO.	CAR	CALL	SERV	-PERCENT TIME BUSY--			CARS
TOUR	CARS	HOURS	RATE	TIME	CFS	NONCFS	TOTAL	AVAIL
MIDDAY	7.0	56.0	2.9	44.2	32.6	41.5	74.1	1.8
*PM	10.0	80.0	4.6	36.2	29.5	43.8	73.3	2.7
*AM	6.0	48.0	2.0	36.2	21.8	49.6	71.3	1.7
+FOURTH	0.0	0.0	3.4	36.2	25.7	46.6	72.3	2.4
AVERAGE	5.8	46.0	3.2	38.6	28.4	44.6	73.0	2.1
TOTAL	23.0	184.0						

DISP T 2
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 2. TIME ALLOCATION: CARS STARTING THE TOUR

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	OFFICER HOURS	UNCOMM HRS/CAR	% TIME UNCOMM
MIDDAY	7.0	56.0	63.4	2.1	25.9
PM	10.0	80.0	93.8	2.1	26.7
AM	6.0	48.0	59.1	2.3	28.7
FOURTH	0.0	0.0	0.0	0.0	0.0
AVERAGE	5.8	46.0	54.1	2.2	27.0
TOTAL	23.0	184.0	216.3		

Fig. 13 -- Sample ALOC command and response

DISP T 3
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 3. AVERAGE DELAYS OF CALLS

PRECINCT: CENTRAL ; DAY: TUE-WED

	NO.	CAR	PRTY 2 DELAY		PRTY 3 DELAY		-AVERAGE	DELAY-
TOUR	CARS	HOURS	QUEUE	+TRVL	QUEUE	+TRVL	QUEUE	+TRVL
MIDDAY	7.0	56.0	0:26	0:44	5:43	6:01	1:04	1:21:20
*PM	10.0	80.0	0:04	0:18	0:13	0:27	0:05	0:19:14
*AM	6.0	48.0	0:07	0:17	0:14	0:24	0:07	0:17:48
+FOURTH	0.0	0.0	0:05	0:18	0:12	0:26	0:05	0:18:31
AVERAGE	5.8	46.0	0:11	0:26	1:54	2:08	0:23	0:37:52
TOTAL	23.0	184.0						

DISP T 4
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 4. CALLS DELAYED AND PATROL INTERVAL

PRECINCT: CENTRAL ; DAY: TUE-WED

	NO.	CAR	---- PERCENT	OF CALLS DELAYED ----			PATROL
TOUR	CARS	HOURS	PRTY1	PRTY2	PRTY3	TOTAL	INTERVAL
MIDDAY	7.0	56.0	42.1	42.1	42.1	42.1	36:37
*PM	10.0	80.0	20.3	20.3	20.3	20.3	24:54
*AM	6.0	48.0	23.4	23.4	23.4	23.4	38:38
+FOURTH	0.0	0.0	19.9	19.9	19.9	19.9	29:43
AVERAGE	5.8	46.0	27.6	27.6	27.6	27.6	33:23
TOTAL	23.0	184.0					

DISP T 5
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 5. STATISTICS FROM INTERNAL PCAM CALCULATIONS

PRECINCT: CENTRAL ; DAY: TUE-WED

	NO.	CAR	------ AVG CARS/CFS ------				PRTY 1 DELAY	
TOUR	CARS	HOURS	PRTY1	PRTY2	PRTY3	TOTAL	QUEUE	+TRVL
MIDDAY	7.0	56.0	2.0	1.0	1.0	1.1	0:06	0:24
*PM	10.0	80.0	2.0	1.0	1.0	1.1	0:02	0:16
*AM	6.0	48.0	2.0	1.0	1.0	1.1	0:04	0:14
+FOURTH	0.0	0.0	2.0	1.0	1.0	1.1	0:02	0:15
AVERAGE	5.8	46.0	2.0	1.0	1.0	1.1	0:04	0:18
TOTAL	23.0	184.0						

Fig. 13 -- continued

These two sets of Table 4 output also indicate that the total number of car-hours for TUE-WED in precinct CENTRAL has decreased from 187.2 to 184. This is because only whole numbers of cars are assigned to shifts by the ALOC command. If another car had been assigned to any shift, it would have brought the total number of car-hours to 192, which is more than were in the original assignment.

ADD Command

ADD <NUMBER> [-*] [CAR] [HOURS] [TO] <QUALIFIER> [BY] F<NUMBERLIST>

Action: The ADD command allocates a specified number of car-hours to selected shifts in such a way as to minimize the average value of the objective function identified by F<NUMBERLIST>. The command works in a manner similar to the ALOC command, and the valid entries for F<NUMBERLIST> are the same as given above in the description of the ALOC command. The only difference between the two commands is that although the ALOC command assigns the specified total number of car-hours, the ADD command assigns cars to the selected shifts in addition to those already assigned in CURRENT-DATA. The total number of car-hours assigned to the selected shifts in CURRENT-DATA is denoted by an asterisk (*). If the optional expression [-*] is *not* used, the ADD command increases the total number of car-hours assigned to the selected shifts by <NUMBER>. If the form ADD <NUMBER> -* ... is used, the command adds the *difference* between <NUMBER> and the current total; in other words, the final total will be <NUMBER>.

The ADD command cannot be used to *subtract* cars. If the user attempts to ADD a negative number of car-hours (for example, ADD 280 -* BY F(1), when the current allocation is 310 car-hours), the program will take no action and will simply await the next command. To allocate a smaller number of car-hours, the user must start over, using the ALOC command, or the sequence of commands READ, MEET, and ADD, or the sequence ALOC 0 (zero), MEET, and ADD. (The command ALOC 0 will reinitialize the number of cars in each shift to the minimum number required to keep effective utilization under one in each hour.)

Example: The ADD command shown in Fig. 14 was given to PCAM after the commands in Fig. 13. Therefore, the ADD command increases by 40 the total number of car-hours assigned to precinct CENTRAL on TUE-WED. Exactly the same effect would be achieved by entering the command ADD 724 -* CAR HOURS BY F(3). Cars are assigned to shifts so as to achieve the greatest improvement in the average total delay for calls. Since all shifts are eight hours in length, the total number of cars assigned to CENTRAL precinct on TUE-WED has been increased by five. By comparing Table 4 in Fig. 14 with the corresponding table in Fig. 13, the user determines the improvement that could be achieved by adding five cars.

MEET Command

MEET C<NUMBERLIST>$_1$ = <NUMBERLIST>$_2$ [FOR] <QUALIFIER>

Action: The MEET command causes PCAM to assign cars to all the shifts within its scope so that a specified set of output measures meets certain constraints. The elements of <NUMBERLIST>$_1$ are codes for the measures that are to be constrained. The elements of <NUMBERLIST>$_2$ specify the limiting values on each of the output measures listed in <NUMBERLIST>$_1$. Therefore, <NUMBERLIST>$_2$ must have the same number of elements as <NUMBERLIST>$_1$, and corresponding elements of the two lists produce a pair giving (1) the measure to be constrained and (2) the value of the constraint.

The following is a list of valid entries in <NUMBERLIST>$_1$ and their meanings:

1	Percent time busy on calls-for-service	$\downarrow$
2	Average travel time (minutes)	$\downarrow$
3	Average number of cars available	$\uparrow$
5	Patrol interval (minutes between passings)	$\downarrow$
6	Minimum number of cars	$\uparrow$
7	Percent of calls delayed	$\downarrow$
8	Queuing delay for priority 2 calls (minutes)	$\downarrow$
9	Queuing delay for priority 3 calls (minutes)	$\downarrow$
10	Queuing delay for all calls (minutes)	$\downarrow$
11	Total delay (queuing + travel) for priority 2 calls (minutes)	$\downarrow$
12	Total delay (queuing + travel) for priority 3 calls (minutes)	$\downarrow$
13	Total delay (queuing + travel) for all calls (minutes)	$\downarrow$

ADD 40 CAR HOURS BY F(3)
DISP T 1
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 1. PATROL CAR ACTIVITY DURING TOUR

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	CALL RATE	SERV TIME	--- DURING THE TOUR --- -PERCENT TIME BUSY-- CFS	NONCFS	TOTAL	AVG. CARS AVAIL
MIDDAY	10.0	80.0	2.9	44.2	22.8	48.8	71.6	2.8
*PM	12.0	96.0	4.6	36.2	24.6	47.5	72.0	3.4
*AM	6.0	48.0	2.0	36.2	21.8	49.6	71.3	1.7
+FOURTH	0.0	0.0	3.4	36.2	22.4	49.1	71.5	2.8
AVERAGE	7.0	56.0	3.2	38.6	23.3	48.4	71.7	2.6
TOTAL	28.0	224.0						

DISP T 2
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 2. TIME ALLOCATION: CARS STARTING THE TCUR

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	OFFICER HOURS	UNCOMM HRS/CAR	% TIME UNCOMM
MIDDAY	10.0	80.0	90.6	2.3	28.4
PM	12.0	96.0	112.5	2.2	28.0
AM	6.0	48.0	59.1	2.3	28.7
FOURTH	0.0	0.0	0.0	0.0	0.0
AVERAGE	7.0	56.0	65.6	2.3	28.3
TOTAL	28.0	224.0	262.2		

DISP T 3
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 3. AVERAGE DELAYS OF CALLS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	PRTY 2 DELAY QUEUE	+TRVL	PRTY 3 DELAY QUEUE	+TRVL	-AVERAGE QUEUE	DELAY- +TRVL
MIDDAY	10.0	80.0	0:05	0:20	0:17	0:31	0:07	0:20:57
*PM	12.0	96.0	0:02	0:14	0:05	0:17	0:02	0:14:31
*AM	6.0	48.0	0:07	0:17	0:14	0:24	0:07	0:17:48
+FOURTH	0.0	0.0	0:03	0:15	0:06	0:18	0:03	0:14:54
AVERAGE	7.0	56.0	0:04	0:17	0:10	0:23	0:05	0:17:11
TOTAL	28.0	224.0						

Fig. 14 -- Sample ADD command and response

DISP T 4
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 4. CALLS DELAYED AND PATROL INTERVAL

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	---- PERCENT OF CALLS DELAYED ---- PRTY1	PRTY2	PRTY3	TOTAL	PATROL INTERVAL
MIDDAY	10.0	80.0	19.9	19.9	19.9	19.9	23:23
*PM	12.0	96.0	12.1	12.1	12.1	12.1	19:49
*AM	6.0	48.0	23.4	23.4	23.4	23.4	38:38
+FOURTH	0.0	0.0	13.5	13.5	13.5	13.5	26:41
AVERAGE	7.0	56.0	16.9	16.9	16.9	16.9	27:17
TOTAL	28.0	224.0					

DISP T 5
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 5. STATISTICS FROM INTERNAL PCAM CALCULATIONS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	------ AVG CARS/CFS ------ PRTY1	PRTY2	PRTY3	TOTAL	PRTY 1 DELAY QUEUE	+TRVL
MIDDAY	10.0	80.0	2.0	1.0	1.0	1.1	0:02	0:17
*PM	12.0	96.0	2.0	1.0	1.0	1.1	0:01	0:13
*AM	6.0	48.0	2.0	1.0	1.0	1.1	0:04	0:14
+FOURTH	0.0	0.0	2.0	1.0	1.0	1.1	0:02	0:13
AVERAGE	7.0	56.0	2.0	1.0	1.0	1.1	0:02	0:15
TOTAL	28.0	224.0						

Fig. 14 -- continued

The arrows indicate that the constraint is met if the measure is *lower* than the specified value for downward arrows (↓) or *higher* than the specified value for upward arrows (↑).

For example, the command MEET C(3,9)=(4,15) will assign enough cars to each shift so that the average number of cars available is 4 *or larger* and the average wait for priority 3 calls is 15 minutes *or less*.

Operation: The MEET command operates on all shifts within its scope independently but in the same manner. If a shift has not been selected in an allocation-type command (MEET, ALOC, or ADD) since the last READ command, then just enough cars are assigned to the shift to handle the call-for-service workload. Otherwise, the MEET command starts with the current assignment (based on the previous MEET, ALOC, or ADD command). Then the program adds enough cars to the initial assignment to meet all specified constraints. (See Fig. 4.)

If a shift is selected in the qualifier of a subsequent ADD command, then the specified constraints will still be met after the action of the ADD command. A subsequent ALOC command completely negates the effect of a MEET command (except that the total number of car-hours assigned by a MEET command can be reallocated).

Output: When cars have been assigned to meet all constraints for all shifts, the program prints a message giving the total number of car-hours allocated to all shifts within the MEET command scope.

Example: Figure 15 illustrates the use of the MEET command for TUE-WED in precinct CENTRAL so that the percentage of calls being delayed does not exceed 30 percent and the average wait for priority 2 calls does not exceed 8 minutes. 200 car-hours were required to meet the specified constraints.

Here the READ command reinitializes CURRENT-DATA (negating the effects of past commands). The allocation contained in CURRENT-DATA after the READ command for precinct CENTRAL on TUE-WED can be seen in the output of the DISP command in Fig. 12. Then, from Fig. 15, we can see that 12.8 additional car-hours were required to meet constraints.


```
READ DATA FOR PRECINCT=CENTRAL, DAY=TUE-WED

*** NUMBER OF CARS IN PRECINCT CENTRAL  FOR TOUR     PM        ON DAY TUE-WED
*** INCREASED TO     8. FOR PCAM CALCULATIONS
***  5.8 ACTUAL CARS WERE INPUT
***  2.2 TOTAL  CARS WERE ADDED IN PRECINCT CENTRAL  ON DAY TUE-WED
MEET C(7,8)=(30.,8)

  200 CAR HOURS ALLOCATED.
DISP T 1
RUN NAME:  SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 1. PATROL CAR ACTIVITY DURING TOUR

PRECINCT: CENTRAL ; DAY: TUE-WED
                                           --- DURING THE TOUR ---AVG.
            NO.    CAR      CALL    SERV    -PERCENT TIME BUSY--   CARS
 TOUR       CARS   HOURS    RATE    TIME    CFS    NONCFS   TOTAL  AVAIL

 MIDDAY     10.0   80.0     2.9     44.2    22.8    48.8    71.6    2.8
*PM          9.0   72.0     4.6     36.2    32.8    41.4    74.1    2.3
*AM          6.0   48.0     2.0     36.2    21.8    49.6    71.3    1.7
+FOURTH      0.0    0.0     3.4     36.2    27.7    45.1    72.8    2.1

 AVERAGE     6.3   50.0     3.2     38.6    26.1    46.3    72.4    2.3
 TOTAL      25.0  200.0


DISP T 2
RUN NAME:  SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 2. TIME ALLOCATION: CARS STARTING THE TOUR

PRECINCT: CENTRAL ; DAY: TUE-WED
                NO.        CAR      OFFICER     UNCOMM    % TIME
 TOUR          CARS       HOURS      HOURS     HRS/CAR    UNCOMM

 MIDDAY        10.0        80.0       90.6        2.3       28.4
 PM             9.0        72.0       84.4        2.1       25.9
 AM             6.0        48.0       59.1        2.3       28.7
 FOURTH         0.0         0.0        0.0        0.0        0.0

 AVERAGE        6.3        50.0       58.5        2.2       27.6
 TOTAL         25.0       200.0      234.1
```

Fig. 15 -- Sample MEET command and response

DISP T 3
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 3. AVERAGE DELAYS OF CALLS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	PRTY 2 DELAY QUEUE	PRTY 2 DELAY +TRVL	PRTY 3 DELAY QUEUE	PRTY 3 DELAY +TRVL	-AVERAGE DELAY- QUEUE	-AVERAGE DELAY- +TRVL
MIDDAY	10.0	80.0	0:05	0:20	0:17	0:31	0:07	0:20:57
*PM	9.0	72.0	0:06	0:22	0:26	0:41	0:09	0:23:45
*AM	6.0	48.0	0:07	0:17	0:14	0:24	0:07	0:17:48
+FOURTH	0.0	0.0	0:06	0:20	0:16	0:30	0:07	0:20:43
AVERAGE	6.3	50.0	0:06	0:20	0:20	0:34	0:08	0:21:38
TOTAL	25.0	200.0						

DISP T 4
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 4. CALLS DELAYED AND PATROL INTERVAL

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	---- PERCENT OF CALLS DELAYED ---- PRTY1	PRTY2	PRTY3	TOTAL	PATROL INTERVAL
MIDDAY	10.0	80.0	19.9	19.9	19.9	19.9	23:23
*PM	9.0	72.0	26.0	26.0	26.0	26.0	28:34
*AM	6.0	48.0	23.4	23.4	23.4	23.4	38:38
+FOURTH	0.0	0.0	23.3	23.3	23.3	23.3	31:53
AVERAGE	6.3	50.0	23.6	23.6	23.6	23.6	30:12
TOTAL	25.0	200.0					

DISP T 5
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 5. STATISTICS FROM INTERNAL PCAM CALCULATIONS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	------ AVG CARS/CFS ------ PRTY1	PRTY2	PRTY3	TOTAL	PRTY 1 DELAY QUEUE	PRTY 1 DELAY +TRVL
MIDDAY	10.0	80.0	2.0	1.0	1.0	1.1	0:02	0:17
*PM	9.0	72.0	2.0	1.0	1.0	1.1	0:02	0:18
*AM	6.0	48.0	2.0	1.0	1.0	1.1	0:04	0:14
+FOURTH	0.0	0.0	2.0	1.0	1.0	1.1	0:03	0:17
AVERAGE	6.3	50.0	2.0	1.0	1.0	1.1	0:03	0:17
TOTAL	25.0	200.0						

Fig. 15 -- continued

SET Command

SET P<NUMBERLIST>$_1$ = <NUMBERLIST>$_2$ [FOR] <QUALIFIER>

Action: The SET command can be used to alter certain data values. It does not change values in DATABASE but, like all other commands except READ, operates only on CURRENT-DATA. Thus, changes effected by a SET command last only until the next READ command is executed. If you want to save the changes for later runs of the PCAM program, you must use the WRITE command. Each element of <NUMBERLIST>$_1$ specifies a type of data to be altered. Corresponding elements of <NUMBERLIST>$_2$ specify the value to be assigned to each type of data for all precincts, days, and tours within the command scope.

The permitted values for <NUMBERLIST>$_1$, together with their meanings, are as follows.

1	Unavailability parameter B1	(precinct)
2	Unavailability parameter B2	(precinct)
3	Call rate parameter	(day)
4	Service time parameter	(day)
5	Actual cars assigned	(shift)
6	Response speed	(shift)
7	Patrol speed	(shift)
8	Fraction of calls that are priority 1	(shift)
9	Fraction of calls that are priority 2	(shift)
10	Officers per car	(shift)
11	Smoothing flag	(universal)

As indicated by the descriptor in parentheses, some types of data automatically refer to all days for a precinct (like unavailability parameters) or all tours of a day (like call rate parameters). Therefore, if a SET command qualifier contains a phrase that would be an "overqualification" for a type of data, then the phrase is ignored for that type of data when the command is executed. This feature is useful when altering a series of data values that require different levels of qualification. For example, the command

SET P(5,3)=(10,6.3) FOR PRECINCT=NORTH,DAY=TUE-WED,TOUR=MIDDAY

causes the number of cars assigned to precinct NORTH for the MIDDAY tour of Tuesday to be changed to 10 and the call rate parameter for TUE-WED in precinct NORTH to be changed to 6.3. The TOUR=MIDDAY phrase is ignored when the call rate parameter is set.

With the above exception, all the usual rules for command scope apply.

Warning message: Processing of the SET command always insures that all shifts within its scope end up with enough cars to handle the call-for-service workload. If a tour needs additional cars, the minimum number required is computed, printed, and assigned to the tour. Failure to meet the minimum car requirement can result not only from changes in the assignment of cars, but also from changes in other factors such as unavailability parameters, call rates, and service times.

Explanation of Output: Figure 16 gives a simple example of a SET command. Here the call rate parameter in CENTRAL precinct is changed from 3.66 to 4.10. By comparing the output with Figs. 8 and 9, we see

```
READ DATA FOR PRECINCT=CENTRAL, DAY=TUE-WED

*** NUMBER OF CARS IN PRECINCT CENTRAL  FOR TOUR     PM       ON DAY TUE-WED
*** INCREASED TO     8. FOR PCAM CALCULATIONS
***  5.8 ACTUAL CARS WERE INPUT
***  2.2 TOTAL  CARS WERE ADDED IN PRECINCT CENTRAL  ON DAY TUE-WED
SET P(3)=4.1

*** NUMBER OF CARS IN PRECINCT CENTRAL  FOR TOUR     MIDDAY   ON DAY TUE-WED
*** INCREASED TO    10. FOR PCAM CALCULATIONS

*** NUMBER OF CARS IN PRECINCT CENTRAL  FOR TOUR     AM       ON DAY TUE-WED
*** INCREASED TO     6. FOR PCAM CALCULATIONS
LIST DATA
RUN NAME:  SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

PRECINCT: CENTRAL ; AREA= 47.3; STREET MILES=498.3; B2=0.658; B1=-.746

  DAY: TUE-WED ; CALL RATE PARM= 4.10; SERVICE TIME PARM=40.20
```

TOUR	ACT. CARS	AVG. EFF. CARS	SPEED RSP.	SPEED PTL.	AVG. SERV TIME	AVG. CALL RATE	FRAC. OF P1 CALLS	FRAC. OF P2 CALLS	FRAC. OF P3 CALLS
MIDDAY	10.0	5.3	15.0	7.5	44.2	3.2	0.067	0.810	0.123
PM	8.0	5.9	15.0	7.5	36.2	5.1	0.067	0.810	0.123
AM	6.0	3.6	25.0	7.5	36.2	2.3	0.067	0.810	0.123
FOURTH	3.5								

Fig. 16 -- First sample SET command and response

that not only have the call rates been affected by the SET command, but also the minimum number of cars acceptable to PCAM has changed in the MIDDAY and AM tours, and the average number of effective cars has changed in the other tour (because the relationship between actual and effective cars depends on the call rate).

A second SET command is shown in Fig. 17. This changes the response speed to 30 mph and unavailability parameters B2 and B1 to 0.3 and 0, respectively, for both precincts (EAST and NORTH) of the HIGHLAND division on SAT-SUN. This change in the unavailability parameters results in a constant three-tenths of all cars fielded being unavailable on non-cfs work. The DAY phrase is ignored when the unavailability parameters are set, and the response speed is changed for all tours of SAT-SUN in both precincts. The message preceded by three asterisks indicates that at least 13 cars were needed in precinct EAST for the PM tour of SAT-SUN to handle the call-for-service workload, as a result of the change in unavailability parameters.

A third example SET command, shown in Fig. 18, activates the optional smoothing calculations in the PCAM program (see Sec. II). By comparison with Fig. 12, you can see that the smoothing calculation reduces the estimated delay times in this example. Rather than using the SET command, you can request smoothing in the database file (see *Program Description* R-3087/3). In this case the requirements in the READ command differ, so the error messages might not be the same as in Fig. 18.

WRITE Command

WRITE [DATA] [ON] <NUMBER> [FOR] <QUALIFIER>

Action: Writes a NEW-DATA file on FORTRAN unit <NUMBER>. This command cannot be used unless data processing personnel determine what <NUMBER> is to be used and prepare appropriate file specifications in accordance with instructions in Sec. I of *Program Description* (R-3087/3). There is no displayed output from a WRITE command.

READ DATA FOR DIVISION=HIGHLAND,DAY=SAT-SUN

*** NUMBER OF CARS IN PRECINCT NORTH FOR TOUR MIDDAY ON DAY SAT-SUN
*** INCREASED TO 8. FOR PCAM CALCULATIONS
*** 7.5 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT NORTH FOR TOUR PM ON DAY SAT-SUN
*** INCREASED TO 9. FOR PCAM CALCULATIONS
*** 7.9 ACTUAL CARS WERE INPUT

*** NUMBER OF CARS IN PRECINCT NORTH FOR TOUR AM ON DAY SAT-SUN
*** INCREASED TO 12. FOR PCAM CALCULATIONS
*** 6.3 ACTUAL CARS WERE INPUT
*** 7.3 TOTAL CARS WERE ADDED IN PRECINCT NORTH ON DAY SAT-SUN
SET P(6,2,1)=(30,.3,0)

*** NUMBER OF CARS IN PRECINCT EAST FOR TOUR PM ON DAY SAT-SUN
*** INCREASED TO 13. FOR PCAM CALCULATIONS

*** NUMBER OF CARS IN PRECINCT EAST FOR TOUR FOURTH ON DAY SAT-SUN
*** INCREASED TO 7. FOR PCAM CALCULATIONS
LIST DATA
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

PRECINCT: EAST ; AREA= 34.9; STREET MILES=503.4; B2=0.300; B1=0.000

DAY: SAT-SUN ; CALL RATE PARM= 7.71; SERVICE TIME PARM=37.91

TOUR	ACT. CARS	AVG. EFF. CARS	SPEED RSP.	SPEED PTL.	AVG. SERV TIME	AVG. CALL RATE	FRAC. OF P1 CALLS	FRAC. OF P2 CALLS	FRAC. OF P3 CALLS
MIDDAY	11.8	8.3	30.0	7.5	37.9	9.0	0.065	0.840	0.095
PM	13.0	12.2	30.0	7.5	37.9	12.1	0.065	0.840	0.095
AM	8.8	8.0	30.0	7.5	37.9	6.9	0.065	0.840	0.095
FOURTH	7.2								

PRECINCT: NORTH ; AREA= 24.1; STREET MILES=409.1; B2=0.300; B1=0.000

DAY: SAT-SUN ; CALL RATE PARM= 5.32; SERVICE TIME PARM=35.28

TOUR	ACT. CARS	AVG. EFF. CARS	SPEED RSP.	SPEED PTL.	AVG. SERV TIME	AVG. CALL RATE	FRAC. OF P1 CALLS	FRAC. OF P2 CALLS	FRAC. OF P3 CALLS
MIDDAY	8.0	5.6	30.0	7.5	42.3	4.7	0.061	0.850	0.089
PM	9.0	8.4	30.0	7.5	31.4	7.8	0.061	0.850	0.089
AM	12.0	9.7	30.0	7.5	34.2	5.1	0.061	0.850	0.089
FOURTH	4.8								

Fig. 17 -- Second sample SET command and response

HEADR SAMPLE OUTPUTS FOR RAND REPORT R-3087/2 - SMOOTHING
READ DATA FOR PRECINCT=CENTRAL,DAY=TUE-WED

*** NUMBER OF CARS IN PRECINCT CENTRAL FOR TOUR PM ON DAY TUE-WED
*** INCREASED TO 8. FOR PCAM CALCULATIONS
*** 5.8 ACTUAL CARS WERE INPUT
*** 2.2 TOTAL CARS WERE ADDED IN PRECINCT CENTRAL ON DAY TUE-WED
SET P(11)=1
DISP T 3
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2 - SMOOTHING
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 3. AVERAGE DELAYS OF CALLS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	PRTY 2 DELAY QUEUE	PRTY 2 DELAY +TRVL	PRTY 3 DELAY QUEUE	PRTY 3 DELAY +TRVL	-AVERAGE DELAY- QUEUE	-AVERAGE DELAY- +TRVL
MIDDAY	7.6	60.8	0:12	0:29	2:23	2:40	0:28	0:45:03
*PM	8.0	64.0	0:05	0:21	0:25	0:40	0:05	0:19:20
*AM	4.3	34.4	0:25	0:35	3:48	3:59	0:09	0:19:24
+FOURTH	3.5	28.0	0:01	0:13	0:03	0:15	0:01	0:12:45
AVERAGE	5.8	46.8	0:12	0:26	1:44	1:59	0:13	0:27:11
TOTAL	23.4	187.2						

DISP T 5
RUN NAME: SAMPLE OUTPUTS FOR RAND REPORT R-3087/2 - SMOOTHING
FILE NAME: DEMONSTRATION DATABASE AS LISTED IN R-3087/3

TABLE 5. STATISTICS FROM INTERNAL PCAM CALCULATIONS

PRECINCT: CENTRAL ; DAY: TUE-WED

TOUR	NO. CARS	CAR HOURS	------ AVG CARS/CFS ------ PRTY1	PRTY2	PRTY3	TOTAL	PRTY 1 DELAY QUEUE	PRTY 1 DELAY +TRVL
MIDDAY	7.6	60.8	2.0	1.0	1.0	1.1	0:03	0:20
*PM	8.0	64.0	2.0	1.0	1.0	1.1	0:02	0:17
*AM	4.3	34.4	2.0	1.0	1.0	1.1	0:06	0:17
+FOURTH	3.5	28.0	2.0	1.0	1.0	1.1	0:01	0:13
AVERAGE	5.8	46.8	2.0	1.0	1.0	1.1	0:03	0:18
TOTAL	23.4	187.2						

Fig. 18 -- Third sample SET command and response

The NEW-DATA file contains information from CURRENT-DATA for those precincts, days, and tours specified by <QUALIFIER>. The file NEW-DATA is suitable as input for subsequent runs of the PCAM program, but any READ commands issued after the WRITE command in the current session with PCAM will read data from DATABASE.

Example: Figure 19 gives an example of a WRITE command. Since this command was issued after the READ and SET commands shown in Fig. 18, the NEW-DATA file differs from DATABASE in the following ways:

- NEW-DATA contains data only for precinct CENTRAL and only for TUE-WED.
- The number of cars assigned to precinct CENTRAL is 8 for the PM tour.

END Command

END

Action: The END command causes the PCAM program to stop and return control to the operating system. This *must* be the last command for every run of the PCAM program. After the END command is issued, PCAM prints a message telling the largest amount of storage used for CURRENT-DATA during the run. This message is provided to assist data processing personnel in minimizing the cost of operating the program.

```
WRITE DATA ON 18
END

MAXIMUM SIZE OF CURRENT-DATA WAS    772 WORDS
```

Fig. 19 -- Sample WRITE command

ERROR CONDITIONS

When an error condition arises during the interpretation or execution of a command, the program indicates this by printing a message preceded by three asterisks. The error message will indicate the nature of the error and what action the program is taking and/or what action the user should take.

The three possibilities for further action when an error condition is encountered are:

- The program will terminate execution,
- The program will take corrective action and continue execution,
- The program will ignore the command just entered and accept the next command.

The error messages indicate which course of action applies to particular errors.

SELECTING AN OBJECTIVE FUNCTION

Users have a choice of nine different objective functions for the ALOC and ADD commands. We encourage experimentation with all nine of them to determine which one seems most appropriate for a particular department. As a first step, try allocating a fixed total number of car-hours, using each objective function in turn. After each ALOC command, enter a DISP command to see the results.

In many instances it will happen that the allocations suggested by PCAM are identical, no matter what objective function is used, or they differ only by one car in a few shifts. In this case, the particular objective function that you choose is immaterial, because the data are never accurate enough to permit you to decide that one allocation is better than another one when they are nearly identical.

It is especially likely that the objective functions F(2), F(2,1), F(2,2), and F(2,3) will lead to nearly identical allocations, because they all refer to the average length of time that calls are delayed in queue. Exceptions will occur only where the fraction of high priority calls varies substantially by time of day or by precinct.

If the allocations obtained using different objective functions are not similar, you should examine the grand averages of performance measures for the different allocations. (These are obtained from the DISP command.) It often happens that some of the averages are approximately the same, no matter what objective function is used, while others vary by large amounts. For example, the smallest possible percent of calls delayed might be 8.4, which is found by using F(1) as an objective function, but the percentage of calls delayed using other objective functions might be very close, say 8.9 or 9.2. However, the average delay for priority 2 calls might vary from 2.2 minutes when F(2,2) is the objective function to 12.3 minutes when F(1) is the objective function. In this example, it is clearly better to use one of the F(2)s as an objective function rather than F(1), because you are trading off a small increase in the percentage of calls delayed for a large improvement in the length of time calls are delayed. *In general, choose the objective function that produces a big improvement in its associated performance measure while not seriously impairing other performance measures.*

If these comparisons are not decisive, then we recommend using F(3) (average response time) as the objective function. This is the only objective function that blends geographical with queuing characteristics. If a department has some large precincts with few calls for service and other small precincts with many calls for service, you will find that this objective function produces allocations that appear to strike a reasonable balance among their differing requirements. In addition, total response time is the only performance measure calculated by PCAM that may be related to the chance that an offender will be apprehended at the scene of a crime.[10,19] The relationship between response time and apprehension of suspects is unclear because victims of crime often wait for a while before calling the police.

Appendix A

INFORMATION ON PCAM'S CALCULATIONS

In this appendix we present some details of the new calculations performed by PCAM85. The mathematical details of the calculation of queuing delay is given in Ref. 15. A detailed description of how PCAM allocates a specified number of car-hours across shifts is given in Appendix B of Ref. 6.

QUEUING DELAYS WITHOUT SMOOTHING

Single Hour

PCAM75 and PCAM85 both use a standard steady-state queuing formulation with a fixed number of servers to estimate the probability that a call encounters a queue and the average time spent waiting in queue by a randomly selected call. (The mathematical formulas for these performance measures are given in Appendix B of Ref. 6.)

PCAM75 used Cobham's formula [11] to estimate the average time spent waiting in queue by a priority p call. PCAM85 uses a model developed by Green [15] to estimate these measures. Cobham's model assumes that a single patrol car is dispatched to each call for service. Thus, some adjustment in the input data (e.g., an increase in the average call rate or average service time) was needed for the PCAM75 results to approximate the performance of the actual system. Green's model permits different numbers of cars to be dispatched to different calls. The number of cars assigned to each call depends on the call's priority. The mathematical formula for the average time spent on waiting in queue by a priority p call is given by Green.[15]

Averages

PCAM averages queuing statistics over time blocks, shifts, tours, precincts, days, and divisions. To describe these averages, we shall imagine that each hour-precinct combination entering into the average is indexed by j. Thus, $\lambda(j)$ is the call rate in the hour and precinct labeled j, $\mu(j)$ is the service rate, $\alpha_p(j)$ is the fraction of calls of priority p, $N_a(j)$ is the actual number of cars on duty, and N(j) is the effective number of cars. ($\alpha_p(j)$, $N_a(j)$, and N(j) do not change as j varies over hours belonging to a single time block in a single precinct.)

The *percent of calls delayed* and the *average queue delay* are calculated by weighting the hourly statistics by the call rate $\lambda(j)$. The *average queue delay for a priority p call* is calculated by weighting the hourly statistic by $\alpha_p(j)\lambda(j)$.

The *percent of time a car is busy on calls for service* (the call for service workload) is

$$100 \times \left(\sum_j \lambda(j)/\mu(j) \right) \Big/ \sum_j N_a(j)$$

and the *percent of time a car is busy on non-cfs work* is

$$100 \times \left[1.0 - \sum_j N(j) / \sum_j N_a(j) \right] .$$

AVAILABILITY AND TOTAL DELAY

The *total delay* (or *total response time*) is the sum of waiting time and travel time. Travel time is calculated as follows. Consider a single hour in a single precinct, with call rate λ, service rate μ, N effective cars, area A (square miles), and response speed v (miles per hour). The *average number of cars available* is then $M = N - \lambda/\mu$. If M => 2, the *average travel time* (in minutes) is estimated according to the square-root law

$$\bar{T} = 60 \times \frac{0.711}{v} \sqrt{\frac{A}{M}} .$$

If M <= 1,

$$\bar{T} = 60 \times \frac{0.678}{v} \sqrt{A} .$$

If 1 < M < 2, the estimate is a linear interpolation:

$$\bar{T} = \frac{60}{v} \sqrt{A} \ \ 0.080 + \frac{0.598}{\sqrt{M}} .$$

(The number 60, which converts hours into minutes, is adjusted slightly in the model to account for street density.)

These equations were developed by Peter Kolesar [24] and incorporate findings from mathematical models, [25,30] analysis of experimental data, [23,27] and analysis of data constructed by using a patrol car simulation model.[28]

Average over time blocks, precincts, etc. are constructed by weighting according to the call rate in each hour.

PATROL INTERVAL

The patrol interval in a precinct is defined to be the average number of hours that will elapse between two successive times that a patrol car on random preventive patrol passes the same point. If the number of street miles in the precinct is L, and patrol cars travel at speed s (miles per hour) while on preventive patrol, then the *patrol interval* can be shown [31] to equal

$$\bar{I} = \frac{L}{sM} ,$$

where M is the average number of cars available during the period.

When averaging the patrol interval over precincts, PCAM calculates the patrol interval in the geographical union of the precincts. (This is done by weighting each precinct's patrol interval by the number of street miles in the precinct.)

OFFICER-HOURS

The number of *officer-hours* is calculated as follows:

OFFICER HOURS = CAR HOURS × (1 + fraction of cars with 2 officers)

UNCOMMITTED TIME

The *number of hours that an average car is uncommitted during a shift* (U) is calculated from the actual number of cars on duty (N_a), the number of car-hours in the shift (H), and the fraction of time an average car is busy (B), as follows:

$$U = H(1 - B)/N_a \quad .$$

The percent of time that an average car is uncommitted during a shift (P) is then given by

$$P = (U/H) \times 100.0 \; .$$

SMOOTHING OF QUEUING PERFORMANCE MEASURES

The level of demand for police service usually varies considerably through the day. Although PCAM75 permitted call rate and service times to change every hour, its performance measures were calculated by assuming the system was in steady state in each hour, and that what happened in one hour did not affect what happened in the next hour. Thus, if the call rate were high in one hour and low in the next, PCAM75 would predict long delays in the first hour and short delays in the next. In actuality, the delays in the second hour might be as long as those in the first, because many calls would be left in queue at the beginning of the second hour.

PCAM85 includes (as a user option) routines that smooth the queuing performance measures over the day. Queues appear to build more slowly with this option than they do if it is not chosen. The smoothed results are more representative of actual performance. In addition, smoothing permits the average call rate to exceed the average service rate for short periods of time without causing the computer program to reject the input data as "impossible." When smoothing is not used, PCAM requires that enough cars be on duty in each block of each shift to handle the cfs workload in the hour with the highest workload. With smoothing, PCAM requires only enough cars to handle the average cfs workload in each block.

The smoothing algorithm used in PCAM85 is heuristic (based on several "rules of thumb" and not "optimal"). Its purpose is to produce measures of performance that are closer to those that will actually occur than are those produced by PCAM75. The quality of its estimates was verified by comparing its predictions and those produced by PCAM75 with the simulated performance of a time-dependent queue. However, the user should be aware that smoothing is a time-consuming computational process and may double the cost of making a PCAM run. It should be used only when needed (e.g. in high workload situations or when call rates exhibit considerable hour-to-hour variation).

There are two parts to the algorithm. One is used to smooth queuing measures over the hours of a single block, during which the number of cars on duty does not change. The other is used to calculate the queuing measures for the first hour of a block. A different calculation is needed, because the number of cars on duty is usually different in each block, which may lead to large differences in queuing behavior between the last hour of one block and the first hour of the next.

The following notation is used in describing the smoothing algorithm:

i	hour of the day (i=1,2,...,24)
λ_i	the number of calls for service expected to arrive during hour i
$1/\mu_i$	the average time to service a call in hour i
ρ_i	λ_i/μ_i (the call-for-service workload in hour i)
π_i	the probability that a call will be delayed in queue in hour i, as calculated by PCAM without smoothing (using the steady state model)
n_i	the effective number of servers on duty in hour i (if this is non-integer, results are combined for $[n_i]$ and $[n_i] + 1$)
P_i	the smoothed probability that a call will be delayed in queue in hour i

$\overline{W}_i$ the smoothed average time a call spends waiting in queue in hour i

W_i the average time a call spends waiting in queue in hour i, as calculated by PCAM without smoothing (using the steady state model)

$\overline{L}_i$ the smoothed expected number of calls waiting in queue at the end of hour i. $(\overline{L}_i = \lambda_i \times \overline{W}_i)$

Smoothing Within a Block

If i and i + 1 are in the same block, then PCAM calculates the probability that a call will be delayed in queue in hour i + 1 (p_{i+1}) as the average:

$$p_{i+1} = 1/2p_i + 1/2\pi_{i+1} .$$

For hours in which $\rho_i >= n_i$, PCAM makes the assumption that π_{i+1} = 1.0.

The queuing delay in hour i + 1 is directly proportional to p_{i+1}. That is,

$$\overline{W}_{i+1} = 1/2Z_{i+1}\pi_{i+1} + 1/2Z_{i+1}p_i,$$

where Z_{i+1} and π_{i+1} are calculated using the steady state model. (Z_{i+1} is the number by which π_{i+1} must be multiplied to obtain W_{i+1} in the steady state model.)

Carryover Between Blocks

The heuristic proposed above works quite well within blocks, since n_i is constant and the actual probability that all servers are busy (call this q_i) varies slowly. However, when n_{i+1} is different from n_i, q_{i+1} may be very different from q_i. To take such discontinuous behavior

into account, PCAM carries over work between blocks instead of smoothing the ps whenever the number of effective cars changes over two consecutive blocks. The algorithm for the calculation of p_{i+1} depends on the relative values of n_i and n_{i+1}. There are three cases: (1) $n_{i+1} = n_i$; (2) $n_{i+1} > n_i$; (3) $n_{i+1} < n_i$.

Case 1: $n_{i+1} = n_i$

$$p_{i+1} = 1/2p_i + 1/2\pi_{i+1}$$

Case 2: $n_{i+1} > n_i$

1. Calculate $\overline{W}_i$, the average time a call received in hour i spends waiting in queue.

   $$\overline{W}_i = p_i[1/(n_i\mu_i - \lambda_i)]$$

2. Calculate $\overline{L}_i$, the expected queue length during hour i. These calls are modeled as being "carried over" to be served in the next hour (i + 1).

   $\overline{L}_i = \lambda_i \times \overline{W}_i$, except when the expected queue length is very long.

3. Use the steady state model to calculate π^1_{i+1}.

   (π^1_{i+1} is the probability all servers are busy in hour i + 1 assuming that the call rate in hour i + 1 is

   $(\lambda_{i+1} + \overline{L}_i)$).

4. Calculate $\pi^2_{i+1} = 1/2p_i + 1/2\pi_{i+1}$.

5. Let $p_{i+1} = \min(\pi^1_{i+1}, \pi^2_{i+1})$

Case 3: $n_{i+1} < n_i$

1-4. Same as in Case 2.

5. Let $p_{i+1} = \max(\pi^1_{i+1}, \pi^2_{i+1})$.

Taking the minimum or maximum in Step 5 of Cases 2 and 3 avoids anomalies such as having p_{i+1} increase substantially when n_{i+1} is twice as large as n_i, or p_{i+1} not going up enough when n_{i+1} is substantially less than n_i.

Appendix B

PCAM REFERENCE SHEETS

GENERAL

AMPERSAND (&): At end of line, signifies command continues on the following line.

DELIMITER: Any character other than a letter, digit, parenthesis, hyphen, period, asterisk, or ampersand. Can be used freely to improve readability. Examples: blank, comma, colon, semicolon, equal sign.

FILLER WORD: FOR, CAR, CARS, HOUR, HOURS, TO, ON, BY, DATA. Ignored by program.

QUALIFIER: Any combination of
TOUR=<NAMELIST>
DIVISION=<NAMELIST>
PRECINCT=<NAMELIST>
DAY=<NAMELIST>
The words on the left of the equal sign are supplied by the user, except for DAY. The qualifier may be omitted in any command.

COMMANDS

1. HEADR [Run name]

   Reads the run name and stores it for printing at the top of all output reports.

2. READ [DATA] [FOR] <QUALIFIER>

   Reads data from DATABASE into CURRENT-DATA, establishes default output order for DISP, and increases number of cars assigned (if necessary) to assure that enough cars are on duty in every block to handle the call-for-service workload. The first command in any run of PCAM must be READ.

3. LIST [DATA] [FOR] <QUALIFIER>

   Lists data from CURRENT-DATA. Averages some data.

4. DISP T<NUMBERLIST> [FOR] <QUALIFIER>

   DISP A<NUMBERLIST> [FOR] <QUALIFIER>

   Displays the output tables specified in <NUMBERLIST>. <QUALIFIER> establishes the output order within each table as well as the scope. In the A form of the command only the average and total lines are printed.

5. ALOC <NUMBER> [CAR] [HOURS] [TO] <QUALIFIER> [BY] F<NUMBERLIST>

   ALOC * [CAR] [HOURS] [TO] <QUALIFIER> [BY] F<NUMBERLIST>

   ALOC * -<NUMBER> [CAR] [HOURS] [TO] <QUALIFIER> [BY] F<NUMBERLIST>

   Allocates the specified number of car-hours so as to minimize F<NUMBERLIST>. Asterisk (*) represents the number currently assigned. At a minimum, allocates enough cars to handle the call-for-service workload in every block.

6. ADD <NUMBER> [CAR] [HOURS] [TO] <QUALIFIER> [BY] F<NUMBERLIST>

   ADD <NUMBER> -* [CAR] [HOURS] [TO] <QUALIFIER> [BY] F<NUMBERLIST>

   Adds the specified number of car-hours to the number currently assigned so as to minimize F<NUMBERLIST>. In the second version, execution of the command will result in the total number of car-hours assigned equaling <NUMBER>.

7. MEET C<NUMBERLIST>$_1$=<NUMBERLIST>$_2$ [FOR] <QUALIFIER>

   Assigns enough car-hours to each specified shift to assure that the measures indicated in <NUMBERLIST>$_1$ meet the constraints in <NUMBERLIST>$_2$ for every time block. One constraint value must be specified for each measure.

   If no ALOC, ADD, or MEET commands have been entered since the last READ command, MEET assigns the minimum number of car-hours needed to meet constraints and keep utilization of an effective car under 1 in every hour. Otherwise, car-hours are added to those already allocated, if needed to meet the constraints.

8. SET P<NUMBERLIST>$_1$=<NUMBERLIST>$_2$ [FOR] <QUALIFIER>

   Changes specified data items. There must be a one-to-one correspondence between data items in <NUMBERLIST>$_1$ and values in <NUMBERLIST>$_2$. SET also checks that enough car-hours are assigned to each shift so as to keep the utilization of an effective car under 1 in each hour.

9. WRITE [DATA] [ON] <NUMBER> [FOR] <QUALIFIER>

   Writes a NEW-DATA file on Fortran unit <NUMBER>. NEW-DATA contains the part of CURRENT-DATA specified by <QUALIFIER>.

10. END

   Terminates program. Must be last command.

OBJECTIVE FUNCTIONS FOR ALOC AND ADD

F(1) Average fraction of calls delayed in queue

F(2) Average length of time calls are delayed in queue

F(2,N) Average length of time priority N calls are delayed in queue

F(3) Average total response time (queuing + travel time)

F(3,N) Average total response time (queuing + travel time) to priority N calls

CONSTRAINT SPECIFICATIONS FOR MEET

C(1) Percent of time an average car is busy handling calls for service

C(2) Average travel time (minutes)

C(3) Average number of cars available (same as average patrol hours per hour)

C(5) Patrol interval (minutes)

C(6) Minimum number of cars

C(7) Percent of calls delayed

C(8) Average delay, priority 2 (minutes)

C(9) Average delay, priority 3 (minutes)

C(10) Average delay for all calls (minutes)

C(11) Total delay (queuing + travel), priority 2 (minutes)

C(12) Total delay (queuing + travel), priority 3 (minutes)

C(13) Total delay (queuing + travel) for all calls (minutes)

DATA ITEMS FOR SET

P(1)	Unavailability parameter B1	(precinct)
P(2)	Unavailability parameter B2	(precinct)
P(3)	Call rate parameter	(day, in precinct)

P(4)	Service time parameter	(day, in precinct)
P(5)	Actual cars assigned	(shift)
P(6)	Response speed	(shift)
P(7)	Patrol speed	(shift)
P(8)	Fraction of calls priority 1	(shift)
P(9)	Fraction of calls priority 2	(shift)
P(10)	Officers per car	(shift)
P(11)	Smoothing flag	(universal)

SAMPLE SEQUENCE OF COMMANDS

Command	Explanation
READ DATA FOR DIVISION=HIGHLAND	Data covering an entire week in Highland Division are read into CURRENT-DATA.
SET P(3)=7.85 FOR PRECINCT=EAST SET P(3)=5.45 FOR PRECINCT=NORTH	Call rates have increased slightly since the last time PCAM was used. These commands adjust the call rates.
DISP T(1,2,3,4,5)	User wants to see what has happened to performance measures with the new call rates.
ALOC 4000 CAR HOURS BY F(2) DISP T (3)	User wants to see how to allocate the number of car-hours (4000) now planned for this division to minimize average queuing delay.
ALOC * BY F(3) DISP T (3)	Morning tours (with fast travel speed) appear to have unnecessarily low response times in the previous allocation, while most tours are too high. User attempts to minimize average response time, but finds he gets nearly the same allocation.
ADD 128 BY F(3) DISP T (2)	User wants to see how much improvement can be obtained by allocating four more patrol officers (each performing patrol car duty 32 hours a week) to this division.
MEET C(10)=21	Response times are still too high. User wants to know how many additional car-hours are needed to keep response time under 21 minutes in every shift.

MEET C(10)=21	Response times are still too high. User wants to know how many additional car-hours are needed to keep response time under 21 minutes in every shift.
READ DIVISION=HIGHLAND SET P(3)=7.85 PRECINCT=EAST SET P(3)=5.45 PRECINCT=NORTH MEET C(10)=21	Number of car-hours needed in the previous allocation is too large. User starts over, trying to meet constraints *before* allocating. He uses the short form of the commands this time.
ADD 4000-* CAR HOURS BY F(3)	The user had some car-hours left over after meeting the constraint. Now he allocates the remainder so as to minimize average travel time.
DISP T(1,2,3,4,5)	The user examines the results of this allocation.
WRITE DATA ON 18	The user thinks this is a good allocation and writes out a NEW-DATA file.
END	User terminates this session with PCAM.

Appendix C

ADDRESSES FOR FURTHER INFORMATION

1. For copies of the PCAM program on card or tape, answers to questions about the program, and information about related emergency service deployment models:

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