POLICE SYSTEMS ANALYSIS

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POLICE SYSTEMS ANALYSIS

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for the degree

DOCTOR OF PHILOSOPHY

Field of Industrial Engineering and Management Sciences

By

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Evanston, Illinois

August 1969

PLEASE NOTE: Appendix pages are not original copy. Print is indistinct on many pages. Filmed in the best possible way.

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TABLE OF CONTENTS

ABSTRACT

A systems analysis of resource allocation in the Chicago Police Department is presented. The analysis is applicable to all large metropolitan police departments.

The analysis has three major parts. The first part developes a conceptual model of the Police System and defines the resource allocation problem. Objectives and measures of effectiveness are determined.

The second part defines a Program Budget and applies it to the Chicago Police Department.

The third part consists of production models for the Response Force. The Response Force is the subsystem which responds to calls for service. Simuation models of the Communications Center and the mobile part of the field response subsystem are used to determine efficient combinations of resources. The Communications Center simulation evaluates the efficiency of the current system and the need for extensive modifications. The field response simulation evaluates the benefits from a car locator system and several administrative changes, such as interdistrict dispatching and the screening of calls.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the aid of Professor Gustave J. Rath, whose willingness to attack new problem areas and try new approaches made this dissertation possible.

Many thanks are extended to Mr Albert M. Bottoms and David G. Olson and the police members of the Operations Research Task Force. Sergeants Donald Clem and Jack Walsh spent weeks collecting the data for the Communications Center simulation and Sergeant Walter Gersch had the ardous task of determining the Program Budget costs.

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TABLE OF FIGURES

CHAPTER I

INTRODUCTION

The Problem

The problem of resource allocation for a police system is similar to that of many other public systems, namely:

1. a lack of agreement regarding the objectives of the system, and their relative importance;
2. a lack of knowledge of alternative means for accomplishing goals; either within or outside the system;
3. a lack of agreement defining the criteria of performance; and
4. a lack of knowledge of transfer functions which would enable the prediction of output from any given set of inputs.

The police system has to be studied as a distinct social system within the social structure of society. Optimizing easily quantifiable relationships is likely to obscure the important qualitative aspects.

"The legitimate point (can be made) that police systems can be understood only as institutions in interaction with the rest of the social structure."[1)]

The Police System objectives are related to Law Enforcement, Order Maintenance and Public Service. Though everyone might agree as to the desirability of the first objective, there is disagreement on what to enforce and how.[2)]

"No policeman enforces all the laws of a community. If he did, we would all be in jail before the end of the first day. The laws which are selected for enforcement are those which the power structure of the community wants enforced."[3)]

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[1]Arthur Niederhoffer, Behind the Shield: The Police in Urban Society (New York: Anchor Books, 1967), p. 13.

[2]Jerome H. Skolnick, Justice without Trial: Law Enforcement in Democratic Society (New York: John Wiley and Sons, 1966).

[3]Dan Dodson, Speech delivered at Michigan State University, May 1955, reported in Proceedings of the Institute on Police-Community Relations, May 15-20, 1955 (East Lansing: The School of Police Administration and Public Safety, Michigan State University, 1956), p. 75, as quoted in Niederhoffer, op. cit. p. 12.

The second objective, order maintenance, designates the police system as a buffer for the social system. This is bound to involve conflict situations in which there is no consensus as to what constitutes order and the propriety of the methods of enforcement employed. The function of public service is much less controversial, but constitutes a large drain on police resources. Often these service. could be more efficiently performed by other public or private organizations.

Even if an objective such as crime prevention has been agreed upon it is important to know the alternative methods which can accomplish the objective. Often the most important aspect of improving a system is the generation of good alternatives. In addition, each null alternative has to be investigated. Instead of devoting additional resources to a police system, they might produce better results if allocated to the courts or correctional agencies, or if used for social work or community building. Thus, it is necessary to consider alternatives outside the police system proper.

Criteria of performance represent the means by which a system is to be evaluated. They should provide a way of measuring how well objectives are being accomplished. For example, is an average response time to a call for service a good criterion; is the number of traffic citations issued by each office a good indicator of traffic management?

Lastly, there is a lack of quantitative descriptions of the police system. This holds true for descriptions of the system and its environment as well as transfer functions for different activities (a transfer function relates imputs to outputs for a given activity). It should permit an indication of, for example, the number of policemen needed to control a mob of 200 people or how many police cars must be in service to achieve a certain response time to high priority calls and how response time relates to the probability of arrest.

The dissertation seeks to answer the questions posed on page one. It has three objectives:

1. to define the Police System; (its objectives, its interfaces with other systems, and measures of effectiveness)
2. to develop a new structure for allocating costs (an accounting system). This structure should facilitate the development of

production models and the evaluation of benefits.

3. to develop production models for the Response Force in order to evaluate alternatives.

Chapter two meets the first objective by the presentation of a conceptual model of the Police System.

The second objective is achieved through the Program Budget discussed in chapter three. Lastly, the third objective is met by the development of simulation models in chapters four, five and six.

The dissertation proceeds from the meta system level down to models of specific activities. First the Police System, its objectives and criteria are defined. Secondly, to make the resource allocation problem manageable, a structure is developed for cost-benefit analysis. This structure is called a Program Budget and necessitates a whole new accounting system. The present allocation of resources are calc... ted for this new accounting structure. Lastly, production models are used to determine efficient combinations of resources.

CHAPTER II

SYSTEMS ANALYSIS[1)]

The Technique

The systems approach is a rational framework for complex problem solving emphasizing hierarchies of systems, and their interrelationships. Most often the problem is illstructured and the objectives not known.

"The systems approach is one in which we fit an individual action or relationship into the bigger system of which it is part, and one in which there is a tendency to represent the system in a formal model."[2)]

The Systems Approach is the methodology used to develop a conceptual model of the police system. The model specifies the objectives and the outputs of the police system and consequently permits determination of output categories (programs) for the Program Budget. The Systems Approach offers a tool for structuring the analysis, and consequently some protection against erroneous suboptimizations.

The Police System, as well as the Criminal Justice System, is a largely uncharted area. Suboptimizations are ever present hazards, in fact, the optimization of Police System performance is itself a suboptimization.

"A system may be defined as a set of objects, either fixed or mobile, and all relationships that may exist between the objects. All systems are composed of sub-systems and are members of a higher system."[3)]

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[1]The two systems models of this chapter were presented at the Operations Research Society National Meeting, Philadelphia, Nov. 7, 1968. Session on "Models of the Firm".

[2]Charles Zwick, Systems Analysis and Urban Planning (Santa Monica: Rand Corp., 1963).

[3]Kenneth Heathington and Gustave Rath, "The Systems Approach in Traffic Engineering," Traffic Engineering, June 1967.

For example, the Police System is in part a member of the Criminal Justice System, which is part of the Social System within which our society exists. The Police System, in turn, is a set of sub-systems.

For resource allocation analysis these sub-systems are a set of mission-oriented (output oriented) sub-systems. These sub-systems are usually called - programs, and the cost structure of the system, with respect to the given programs is called - The Program Budget.

The analyst tries to select a set of sub-systems which:

1. are consonants with the plan of the decision maker;
2. have operational objectives and measures of performance;
3. are as independent as possible;
4. facilitate cost-effectiveness analysis.

An environment may be defined as a set of objects that is outside the system. It is the aggregate of external conditions which affect the system.

The Systems Approach can be succinctly exhibited in a paradigm. The steps to be considered in a systems analysis are:[1] (see Figure 1)

1. define the desired goals;
2. develop alternative means for realizing the goals;
3. develop resource requirements for each alternative;
4. design a model for determining outputs of each alternative;
5. establish measurements of effectiveness for evaluating alternatives.

After a system and its environment have been specified, the analyst should consider the objectives of the system, and the resources and general constraints which are present. Resources are the total available material which can be allocated. Constraints are limitations imposed on the system.

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[1]See G. H. Fisher, "The Analytical Basis of Systems Analysis," Rand Corp., May 1966, p. 3363.
A. Hall, A Methodology of Systems Engineering (Princeton, N. J.: D. Van Nostrand Co. Inc., 1962).
Van Court Hare, Systems Analysis: A Diagnostic Approach (New York: Harcourt Brace and World, 1967).
Charles Hitch and Roland N. McKean, Economics of Defense in the Nuclear Age (Cambridge: Harvard University Press, 1963).
E. S. Quade, Analysis for Military Decisions (Chicago: Rand McNally & Co., 1964).
E. S. Quade, "Some Problems associated with Systems Analysis," Rand Corp., June 1966, P-3391.

The objectives express what the system is trying to achieve and to what end resources should be applied. An objective should be defined in such a way that an operational, quantitative measure of performance is possible. It is of little use to have an objective which cannot be quantified.

Equally important are measures of performance. They permit evaluation of how well the objective is being achieved.

Alternatives are different means of using resources to achieve objectives. Developing alternatives represents one of the more creative and crucial steps in the systems analysis process. It is here that the analyst can seek to define new alternatives that can provide increased effectiveness with respect to the previously considered alternatives.

Once alternatives have been specified, the cost of resources for each alternative has to be determined. This involves considerations of risk, time and different types of costs. To arrive at the benefits of an alternative, a model is necessary. The model determines the output to be derived from a given amount of resources.

Lastly the cost and benefit of each alternative has to be evaluated to select the optimal alternative. The criterion function relates costs and benefits to system objectives and provides the basis for selection.

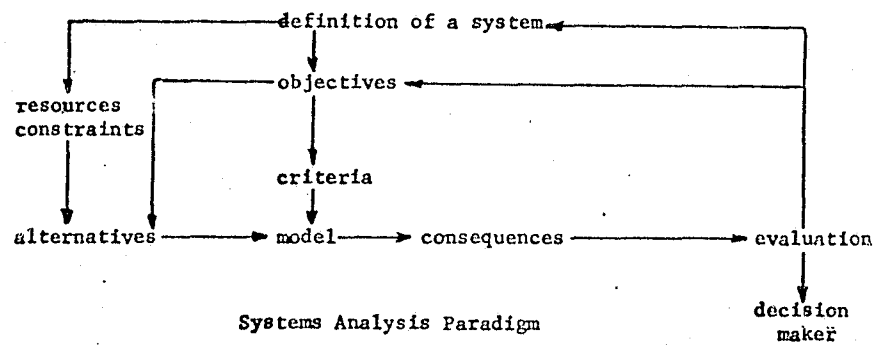
"It is my experience that the hardest problems for the systems analyst are not those of analytic techniques . . . . What distinguishes the useful and productive analyst is his ability to formulate (or design) the problem: to choose the appropriate objectives; to define the relevant, important environments or situations in which to test the alternatives, to judge the reliability of his cost and other data, and, finally, and not least, his ingenuity in inventing new systems or alternatives to evaluate."1)

1C. J. Hitch, Decision Making for Defense (Berkeley: University of California Press, 1965), p. 54.

This point cannot be emphasized enough.[1] The great danger in systems analysis lies in not spending enough effort in defining what the system under study should be, and instead seeking to optimize the effectiveness of a given system. The big payoffs are likely to come from a construction of new world views of problems, rather than optimizing current structures.

This point is illustrated in Figure 1 by the arrows drawn from the evaluation phase to the objectives and the alternatives.

This can be shown as follows:[2]



Systems Analysis Paradigm

Figure 1.

State of the Art

The current state of the art, with respect to police resource allocation optimization, is in its infancy. Most research into the Criminal Justice System has dealt exclusively with the social dimensions. Analytical contributions have appeared only during the last five years.

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[1]See Lindsey Churchill, "An Evaluation of the Task Force Report on Science and Technology," Russell Sage Foundation mimeo, 1968.

[2]Adapted from Kenneth Heathington and Gustave Rathe, "The Systems Approach in Traffic Engineering," op. cit.

A systems analysis approach was used by the President's Commission on Crime and Law Enforcement to define the scope of the Criminal Justice System problem possible research approaches and technology that could be applied.

"Because of the enormous range of research and development possibilities it is essential to begin, not with the technology, but with the problem. Technological efforts can then be concentrated in the areas most likely to be productive. Systems Analysis is a valuable method for matching the technology to the need."[1)]

Blumstein and Larson recently published an article which looks at the flow of people through the Criminal Justice System.[2)] It is not a Systems Analysis, as they do not discuss objectives or measures of effectiveness, but rather a descriptive model of the flows. This step is important, however, as it provides a quantitative description of a portion of the real world.

Description of the Police System

From a general point of view, a police system is a service organization. Its clientele are people who have broken the law as well as people in need of help. It is a twenty-four hour, citywide, dual-purpose service force.

The police system is not part of the market mechanism. Its output is not a good sold in the market in competition with other enterprises, it is a public service good. The community devotes a certain amount of resources to the system and expects an output, which never is too well defined. Even if the inputs and the outputs of the system were given, the internal process of a police system is difficult to optimize. Very little is known

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[1]The President's Commission on Law Enforcement and Administration of Justice, Task Force Report: Science and Technology (Washington, D.C.: U.S. Gov't Printing Office, 1967), p. 3.

[2]A. Blumstein and R. Larsen, "Models of a Total Criminal Justice," Operations Research, Vol. 17, No. 2 (March-April 1969).

about the transformation of inputs into outputs - the transfer functions. Consequently, tradeoffs between different methods of controlling crime (for example, more or less detectives, one or two man patrol units) are not known. This is a serious drawback in trying to allocate resources and develop a departmental budget.

The metropolitan police force is usually a paramilitary system. It is characterized by strong internal controls and centralized decision-making. Its organizational goals, as pointed out in the President's Report on Law Enforcement: Field Study San Diego[1] are primarily oriented towards the crime fighting function.

The organizational structure of the Chicago Police Department is shown in Figure 1. The Bureau of Field Services is the largest unit, both in terms of manpower and budget. It has primary responsibility for patrol and apprehension. It is sub-divided into Youth, Traffic, Patrol, Detective and Community Services Divisions.

The Youth Division is concerned with juveniles. Its missions are to establish an effective relationship with local residents and community agencies, assist in handling juveniles that have been apprehended, and suppress delinquent and criminal behavior by juveniles. The effectiveness of this division is in part measured by the incidence of juvenile crime.

The Traffic Division is responsible for traffic regulation and control, and Traffic Safety Education. The objective of traffic regulation is the safe and rapid movement of cars in the city. Officers in the Patrol Division also perform the regulation function. Hence, the responsibility for traffic law enforcement is divided between two divisions. This makes it difficult to measure the effectiveness of the Traffic Division separately.

The Detective Division's mission is to handle those crimes reported to them by the other divisions. Their responsibility is to apprehend the

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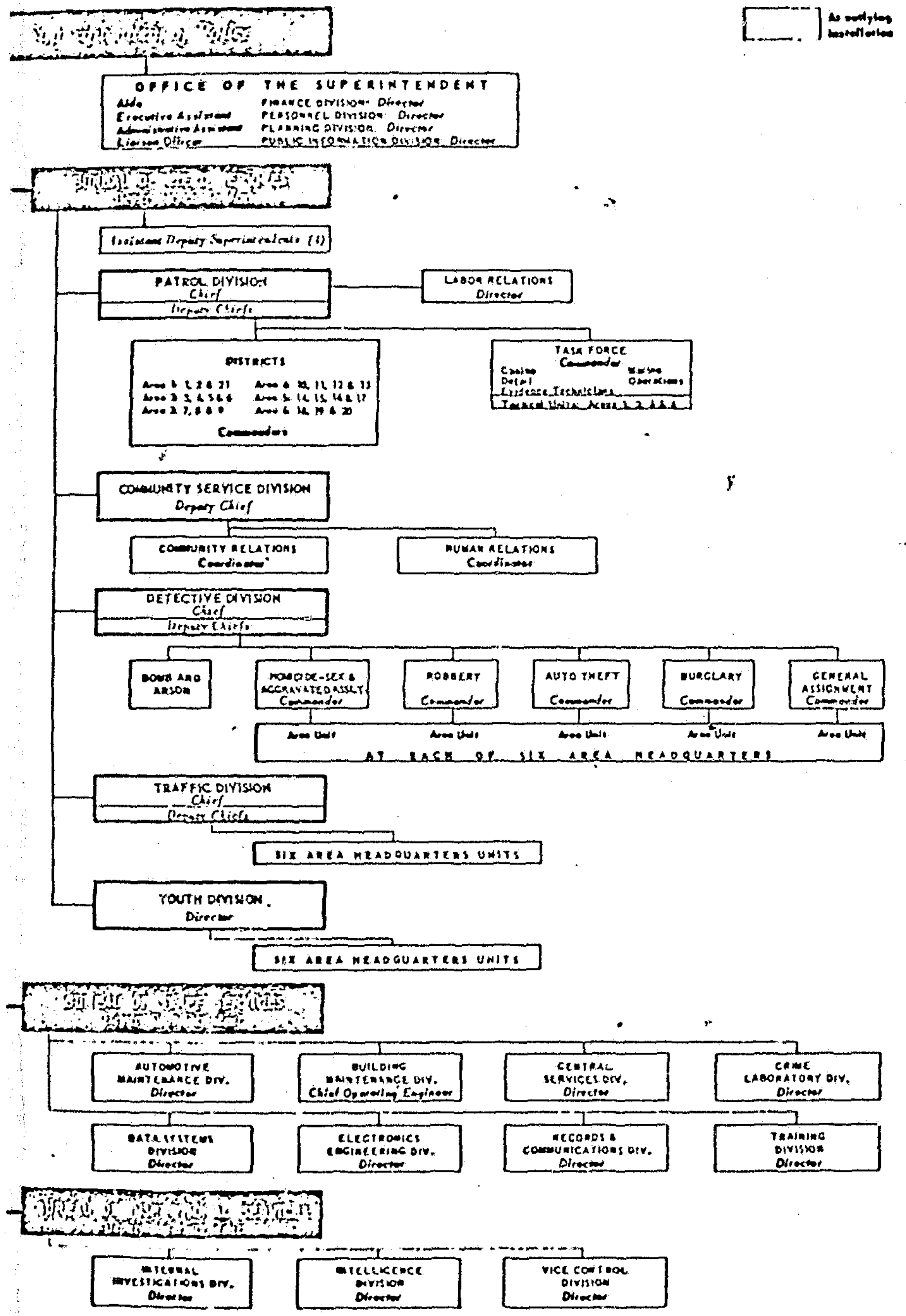
1The President's Commission on Law Enforcement, The Police and the Community (Berkeley: University of California, October 1966), Field Surveys LV, Vol. 1.

ORGANIZATION OF CHICAGO POLICE DEPARTMENT : 1967



As of 31 December 1967

criminal through investigation. A measure of their effectiveness is the ratio of cases solved to cases reported for the different index crimes.

The Patrol Division is organized into six areas, twenty-one districts and more than 400 beats. Its mission is to answer calls for service and to perform preventive patrol, usually motorized. This division includes the Task Force, an elite force attached to area headquarters, which provides additional preventive patrol. The effectiveness of the Patrol Division is measured by the number of reported crimes in the city, number of arrests, and recovery of stolen property. The lower the total level of crime, the higher the number of arrests or greater the value of recovered property, the better the Patrol Division is doing.

The Community Service Division is a reflection of the Chicago Police Department's growing concern with its social purpose: to maintain good relations and understanding with the community it serves.

The Bureau of Staff Services provides supporting services. The Bureau of Inspectional Services provides intelligence and inspectional services in addition to vice control.

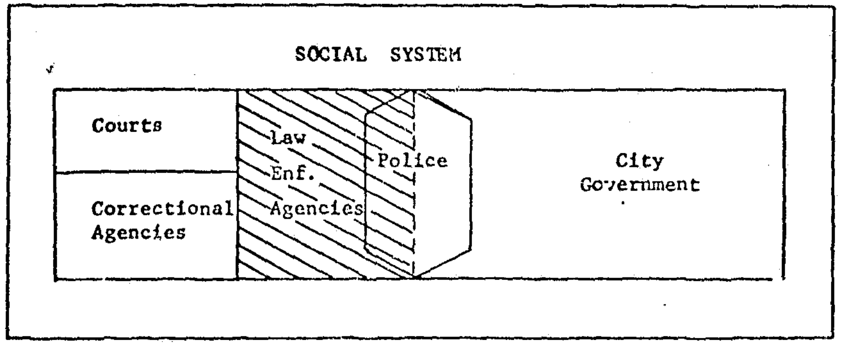
The Police System does provice two separate services: Crime Control and Public Service. The former is the main focus of activity as will be shown in the Program Budget. This crime control function is part of the efforts of the Criminal Justice System; the public service function is part of the City Government. A more precise definition of a police system will be given in the next section.

Systems Analysis of the Police System

The Police System is a set of sub-systems which are part of higher order systems. (See Figure 2). The Police System is a member of the Criminal Justice System (CJS). Its function is to prevent criminal events and failing this, to identify and apprehend the offender. There are other members of the Law Enforcement Agencies in addition to Metropolitan Police

Figure 2

Systems Analysis of the Criminal Justice System



Departments such as Federal, State, County and special police, such as Burns, Brinks, etc.

The Police System is also part of the City Government. Its Public Service mission is a function of the twenty-four hour, city-wide availability of the police force. This function could be carried out by people with no police training. This function includes actions such as animal rescue, locating missing persons, and ambulance service all of which could be performed by other city agencies or private groups.

The Police Department has another objective, Community Support. The generation process of individuals, who may choose a criminal career, is deeply rooted in social-psychological-economic variables, over which society has some control. Crime is the responsibility of society and its control cannot be delegated solely to a Police Department. The Police Department responsibility is to deter and apprehend offenders. The Criminal Justice System can effect deterrence, but this is only effective to the extent that society (or the social group to which the potential offender belongs) disapproves of criminal acts.

Community Support is the willingness of the community to fight crime, both by giving support, help, and resources to the police department, and by creating means to affect the crime generation process. Instead of actively seeking community support, police departments have often, in their desire to be professional, tended to become systems isolated from the community. This has had some detrimental effect on police effectiveness.

The investigation of the crime control problem will proceed by first analysing the Criminal Justice System and then in more detail, the Police System. This will permit the specification of objectives for the Police System.

The Criminal Justice System

To help specify the Police System, which is the focal point of the analysis, it is necessary to consider the higher order system. The Criminal Justice

System (CJS) has been charged by society to regulate and control certain classes of behavior. These classes of behavior are determined by the legislative branch of government and interpreted by the courts.

The sub-systems of the CJS are: The Police, the Courts and the Correctional Agencies. The police identify misconduct and apprehend the offenders. The courts determine the facts of the case and rule on its disposition. Correctional Agencies administer prisons and supervise the parole system.

Systems Model

How does the CJS affect the generative process of criminal events? The structure of the crime control function is exhibited by a conceptual model. It displays the pertinent sub-systems, decision points and mechanisms for change. It permits an analysis of how the CJS can affect the potential criminal's decision-making and how the impact of crime can result in community response.

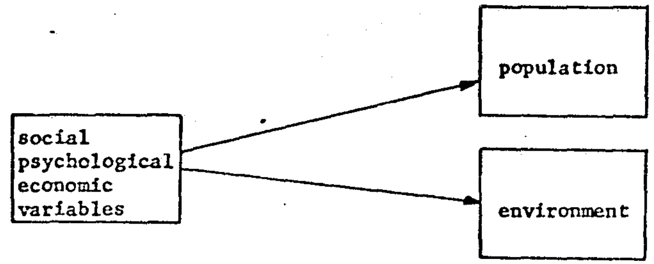
The model is only conceptual. It was developed to provide a framework for the analysis of the resource allocation problem. By emphasizing how the community and CJS influence the criminal event, it was hoped that obvious suboptimization errors might be detected and avoided.

The model postulates that the forcing function of the crime generation process is a function of social-psychological-economic variables. (See Figure 3). These variables affect the individual's utility function and consequently affect his propensity towards a criminal career. They also affect the distribution of opportunity, (for definition of opportunity, see below), by altering the mechanism for generating them. A discussion of the specific mechancisms is outside the scope of this paper.

Welfare programs provide family assistance which gives children a better start, thus reducing the likelihood of their pursuing a criminal career. Job training programs and increased employment opportunities will provide an alternative to crime for an income. For example, people might demand stricter legislation (i.e., cars must have theft proof locks) or elect

Figure 3

Conceptual Model: Forcing Function



voluntarily to lock their cars. In either case, the underlying mechanism generating opportunities has been altered.

Two factors are necessary to create a criminal event. There has to be an individual or group of individuals and a specific set of opportunities. A specific opportunity if defined as a factor of:

1. type of opportunity (theft, robbery, etc. This leaves open the question of the appropriate classification);
2. gain (usually in dollars);
3. availability (this dimension measures the probable degree of difficulty of execution associated with the specific opportunity. This permits differentiation between a car that is locked and unlocked, located in the street or in an underground garage);
4. location (in space);
5. time (interval of time when opportunity exists).

For a given type of opportunity, distributions can be generated with respect to location and time. The set of all opportunities is called Environment.

The population considered in the model is the total population of the community. It is a set of individuals characterized, for our purposes, by the following attributes:

1. the individual's perception of the environment. The model chooses to maintain an actual environment and vary the individual's knowledge

of the actual opportunities. The value of this attribute would fall between 0 and 1. That is to say he has incomplete knowledge.

2. the individual's knowledge of deterrence. Deterrence is the expected value of negatives benefits that the Criminal Justice System contributes to a given type of opportunity. It is a function of the probability of arrest for a given type of opportunity, based on past performance by the police system, the chance of being sentenced, and the length of the consequenty jailterm and amount of fine. Again the value would fall between 0 and 1. (These benefits would be pure number to which a utility transformation would be applied);
3. the individual's utility function. The coefficients of this function are determined by past social-psychological-economic effects. The utility function concept will permit an explanation of how past states of the individual will influence his present decision-making. If an offender committed a successful crime (i.e. large monetary reward, not apprehended) one day, he is not likely to attempt another crime the next day. His attitude towards the risk or estimation of his own abilities may have changed as a result of his success. The utility concept also permits analysis of "crimes of passion." The individual puts a low estimation on negative benefits or the positive benefits are very large. That is, the utility function encompasses, among other things, past experience, needs and behavior towards risk.

The decision-making process, resulting in a criminal event, can be viewed as a two-step decision-process. This allows distinguishing between inputs, which are a function of the past performance of the CJS, and inputs at the moment of execution.

First, the individual is permitted to contemplate the opportunities known to him and make an apriori decision to actually commit a specific crime. The relevant input from the CJS is deterrence, as defined above, of which the individual has varying degrees of knowledge. Knowing the individual's utility function, the opportunity having the greatest utility can be determined and a "go-no go" decision made.

The second decision point is present immediately prior to the execution of the planned criminal event. The potential offender evaluates the actual circumstances of the opportunity and makes a go-no go decision.

The first stage was an apriori decision based on the probable circumstances surrounding the event. The second state becomes the actual sample reflecting:

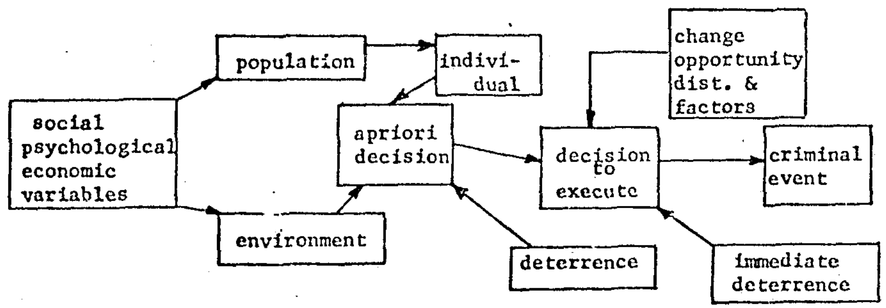
1. the juncture of the probable circumstances
2. action taken either by private groups, (persons) altering the generation of opportunity distributions and/or their factors, or police actions affecting deterrence or opportunity distributions. For example a person might decide to break his habit of not locking his car, or the police department may employ a new tactic against CTA bus robberies.

For many events, commonly called "crimes of opportunity," the time interval between the decision points is very small. However, the interval could be measured in days.[1]

Summarizing the above discussion:

Figure 4

Conceptual Model: Decision Phase



1"It has been said that there is a formula for crime: Desire plus opportunity equal crime." Allen P. Bristow, Effective Police Manpower Utilization (Springfield: Thomas Press, 1969).

Criminal Justice System Response

What is the CJS reaction to the criminal event and how can it affect the crime generation process?

The Police sub-system responds to the criminal event seeking to identify and apprehend the offender. Police strategy and tactics can influence the decision to execute (see page 30).

The generation process of crime is affected by deterrence. Deterrence was defined as the expected value of negative benefits, which are a function of the risk of arrest, chance of sentencing, length of jailterm, and fines for different classes of criminal events.

The Courts and Correctional Agencies may either emphasize deterrence or rehabilitation. Rehabilitation is the effect the CJS has on the individual as he is processed through the CJS, resulting in a change in his utility function. The Police contribute through special handling of juvenile offenders, the courts by the sentence they provide and the Correctional Agencies by programs which seek to integrate the individual into society.

There is a tradeoff between deterrence and rehabilitation. By rehabilitating the offender the CJS lowers the deterrence effect. The negative payoffs cannot be as large with a satisfactory rehabilitation program.

Community Response

There are usually two parties to a criminal event: the offender and the victim. (The exception is "crimes without victims" such as gambling). We have considered the offender and now turn to the victim. The set of victims represents the impact of crime on the community. This becomes input for private and civic action. Citizens may arm themselves, private groups might hire special police to react to criminal events.

The community (individuals, civic groups, businesses) may decide to react through the democratic process. That is, have government legislate new programs to alter social-psychological-economic variables or commit more resources to the CJS. They may, in addition, affect the opportunity distributions through laws (cars shall be locked, banks must have detection cameras) or by their own behavior. (The discussion is summarized in Figure 5).

Police System Model

This section focuses in more detail on the police contribution to the crime control function (see Figure 4). Police system impact on the crime process occurs at four points:

1. forcing function
2. apriori decision
3. decision to execute
4. criminal event

It will be convenient to analyze the major activities of the police system in terms of three sub-systems:

1. Reactive Force
2. Preventive Force
3. Follow-up Force

Police response to a criminal event can be differentiated with respect to the detection process. Detection is defined as the identification of a criminal event. The criminal event detected by a person or by the police. In the model all non-police detection will be considered as person originating. When a person detects a crime, he initiates a call for service to the police department. If the police, through offensive tactical patrol, detect a crime-in-progress, the person feedback loop need not be actuated.[1)]

The Reactive Force is defined as the police sub-system which responds to calls for service. These calls for service are generated by criminal events, public service demands and reports of suspicious activities. Public service demands consists of calls such as sick and injured transport, animal rescue and locating missing persons. Reports on suspicious activities are

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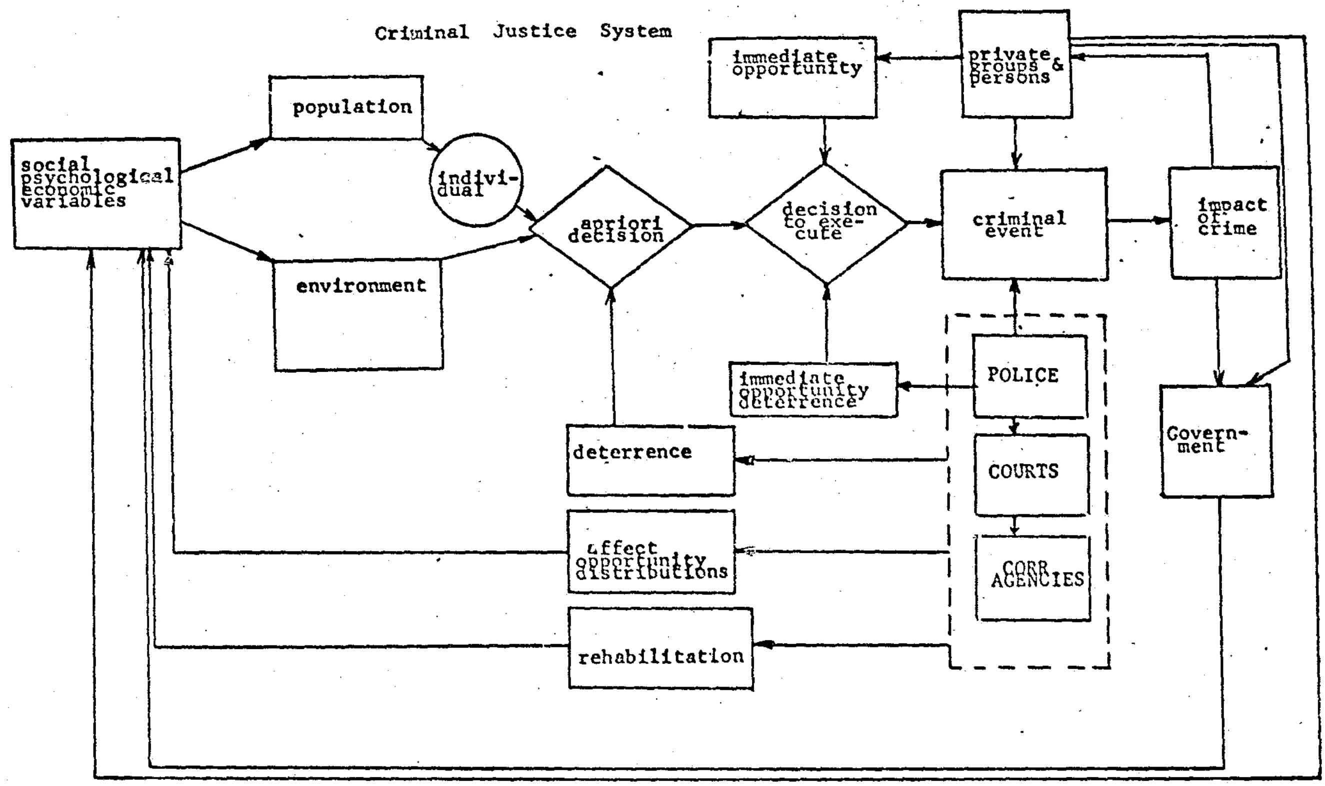
[1]For "crimes without victims" the detection process is carried out by specialized police units.

Figure 5

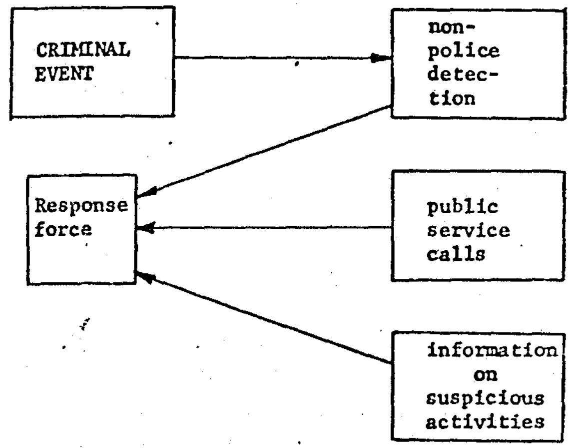
Criminal Justice System



an important factor in being able to detect crime-in-progress. It also is an indicator of community cooperation in fighting crime.[1)]

Figure 6

Inputs To The Response Force



The probability that the Response Force will apprehend the offender is a function of the time elapsed since the crime was committed and the tactic used. The elapsed time consists of:

1. time until citizen detects event and initiates a call to the police department;
2. processing time by the Communications Center;
3. travel time for the assigned cars.

It has been shown that the apprehension probability is a decreasing function with respect to elapsed time.[2)]

It is possible to initiate campaigns, which stimulate citizens to be

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[1]Chicago has a campaign "Operation Crime Stop" to this effect.

[2]See President's Commission on Law Enforcement: Task Force Report: Science and Technology.

sensors for the police department, and impress upon them the necessity of transmitting the information in a timely manner. This activity might very well have a larger potential payoff than optimization of police detection or response.

Analysis of the effectiveness of the Reactive Force is of great importance. Police departments are being offered hardware such as car locators and computerized communications centers, buy have presently no mean to evaluate the benefits. How much will the proposed hardware decrease response time, and how will this affect the probability of apprehension? Finally, how much is an increase of the probability of apprehension worth?

The Preventive Force is the offensive force in the combat against crime. It interacts with the crime process in two ways. It seeks to detect misconduct and apprehend the offender. It also influences the decision to execute a criminal event by affecting the perceived presence of police: for example, having policemen in uniform and marked cars or by giving the potential offender an impression of police omnipresence. This can come about through actual presence as a result of successful positioning of forces in time and space or through propaganda. The Preventive Force may also affect the decision to execute by restricting actual opportunity, either by removing it completely or changing the factor of availability. This would be done through premise check, checking parked cars for valuables, removing drunks from the street, etc.

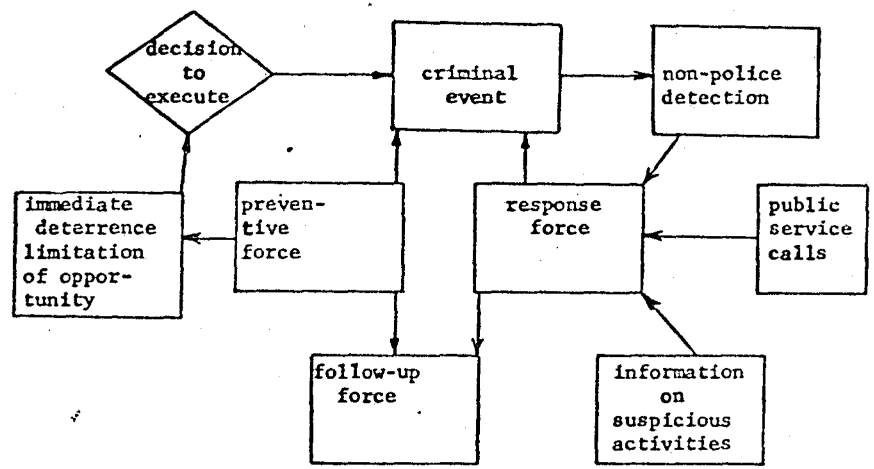
The third sub-system is the Follow-up Force. Its function is to apprehend criminals through the investigative process. It also includes the actions on a case following the booking of an offender. The above is summarized in Figure 7.

Police System Outputs

The outputs of the Reactive Force are arrest and public service. The probability of arrest was expressed as a function of elapsed time and tactics used. The Preventive Force outputs are arrests and impact on the

Figure 7

Further Development of Police Systems Inputs and Outputs



decision to execute. The probability of apprehension is a function of elapsed time, probability of detection (i.e. being at the scene of the event, and recognizing that an event did in fact occur) and tactics used. Follow-up can be characterized by the probability of arrest through investigation. It is dependent on elapsed time and methods used. All of the above functions are also dependent on the type of crime. The trade-off between the Response and Preventive Forces, given a criminal event, is that the latter may detect an event with a low probability, but may have a higher probability of apprehension (due to shorter elapsed time).

Deterrence is an input to the apriori decision point. The Police System variable is the probability of arrest for the system (i.e. the combined efforts of all three sub-systems).

The Police System does affect the forcing function by changing the mechanisms generating opportunities. It can also affect an individual's utility functions through rehabilitation measures. This is mainly with respect to juveniles. This group of offenders is given special attention in order to influence their propensity towards a criminal career. For example, special youth officers handle the cases, and often a station adjustment is made.

The conceptual model is able to account for Community Relations programs. The Police System can influence the crime generation process by devoting resources to communication with private groups and individuals. These measures would influence community support and hopefully encourage the community to assist the police in the apprehension process and even more importantly, affect the generative process of crime. These communication links can be called Human Relations, with respect to individuals; and Community Relations with regard to groups.[1)]

An effective Community Relations program seeks to explain the crime generation process to the community, what the police role is, what it can be expected to do, and what the community can do.

There is also a link to Government, for the sake of completeness, to emphasize that police departments have to make city, state and federal officials cognizant of Police problems, results and limitations.

In summary, the outputs of the Police System are:

1. apprehension of offenders
2. impact on immediate environment on the criminal event
3. impact on apriori decision
4. rehabilitation measures
5. changing opportunity distributions
6. public service
7. community support.

The discussion is summarized in Figure 8.

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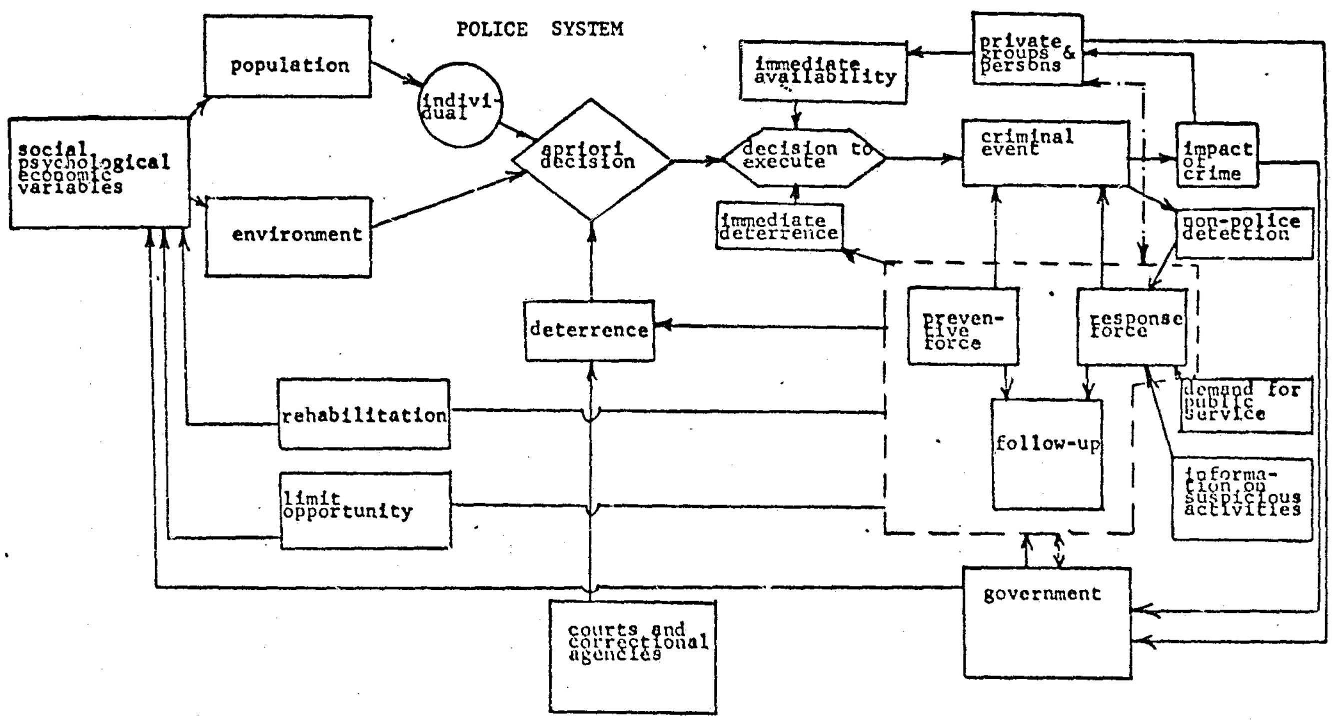
[1]For further discussion see James Q. Wilson, "Dilemmas of Police Administration", Public Administration Review, September/October, 1968.

Figure 8

POLICE SYSTEM



—·—·—·— = COMMUNICATION LINKS

Police System Objectives

Three missions and specific outputs have been identified for the Police System. It remains to specify the objectives of the system.

The first mission is Protection of Life and Property and maintenance of Peace and Order. It becomes convenient to subdivide the broad notion of crime control into two classes of events as criminal events differ in degree of seriousness and the nature of police response. Crime will be defined as index crimes and hit-and-run accidents. A second category of misconduct can be called Quasi-Criminal, whose objective contains activities devoted to the enforcement of city ordinances to a large degree. That is, crimes of lesser seriousness than index crimes, and for which the maximum sentence is a year in jail and/or a fine. The main offenses are disorderly conduct and drunkeness.

Maintenance of Peace and Order can be subdivided into an objective called Public Peace and one called Traffic Regulation. The Public Service and Community Support objectives conclude the list.

Mission	Objective
Protection of Life and Property	1. Crime control 2. Quasi-criminal control
Maintenance of Peace and Order	3. Public Peace 4. Traffic Regulation
Public Service	5. Public Service
Community Support	6. Community Support

These objectives can be compared with lists of objectives found in the literature.

The International City Managers Association listed five police objectives:[1)]

1. Prevention of Criminality
2. Repressions of Crime
3. Apprehension of Offenders

[1] Municipal Police Administration, Chicago International City Managers Association, 1961.

4. Recovery of Property
5. Regulation of Non-criminal Conduct

Another list is:[1]

1. Prevention of Crime
2. Investigation of Crimes
3. Apprehension of Violators
4. Presentation of Criminals for Adjudication
5. Services to the Public
6. Enforcement of Non-criminal Ordinances
7. Regulation of Activity within the Public Way

Peter Szanton defined the following objectives:[2]

1. Control and reduction of crime
2. Movement and control of traffic
3. Maintenance of Public Order
4. Provision of Public Service

The first two lists are not output oriented in an independent manner and consequently would be difficult to use in a resource allocation analysis. Szanton's list is excellent but neglects the goodwill aspect. It has been said that a bulldozer is an effective crimefighter. This proposition would be a feasible alternative if there were no objective to represent the social system. For example, repressive police measures might prevent crime, but if individual's rights are destroyed in the process there should be a way of indicating this.

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[1] Budgeting workshop. Florida Institute for Law Enforcement, 1966. Both as quoted in F. Leahy, Planning-Programming-Budgeting for Police Departments. Travelers Research Center, Inc., April 1968.

[2] Peter Szanton, Program Budgeting for Criminal Justice Systems, Appendix A. Task Force Report: Science and Technology, op. cit.

CHAPTER III

PROGRAM BUDGET

The Technique

The Program Budget is a structuring of organizational activities into output categories. These categories should:

1. establish total money costs of achieving defined objectives;
2. facilitate evaluation of alternative ways of achieving an objective;
3. consider total costs for extended periods of time;
4. facilitate cost-effectiveness analysis.

The complete Program Budget provides a rational, coherent structure for analyzing resource allocation problems. It encompasses efficiency measures within programs and effectiveness measures between programs.

Planning-Programming-Budgeting System (PPBS) is a modern budgeting system for planning, management and control.

The PPBS ideas were developed at Rand in the early 50's. Secretary Robert McNamara and Charles Hitch applied the technique to the Department of Defense with such success that in August 1965, President Johnson directed all other government agencies to use PPBS.[1])

PPBS is usually compared with a line budget (i.e. government appropriations type budget) and a performance type budget and found to be clearly superior. A budget is a very versatile tool serving many purposes, and the difference among the different budgets lies in their emphasis.

The line budget emphasizes control over inputs and usually follows the organizational structure. This type of budget is sufficient if one is not

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[1]See D. Novick, Program Budgeting (Cambridge: Harvard University Press, 1965).

too concerned with the output of the organization and the production process is relatively uncomplicated. The Performance budget is management oriented. It provides control and planning information for functional evaluation of organizational performance. It assesses work-efficiency of operating units permitting cost control and estimation of resources needed to achieve a given output.

This opens the question of what the output of the organization should be. The PPBS is an output oriented budget which emphasizes planning. It seeks to provide a forum for resolving competing claims on the resources of the organization.[1])

With Planning is meant the systematic consideration of objectives and alternatives. Programming incorporates the reduction of plans to specific resource requirements for an extended period of time. Budgeting consists of taking a one-year slice of the program budget.

Program budgeting characteristics are usually given as:[2])

1. Structural
2. Analytical
3. Information system

At the heart of the PPBS is the structural or conceptual problem of what the end objectives are for the system, and what grouping of activities into programs constitutes a logical and a helpful structure for decision making

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[1]The obvious conclusion is rather that all these types of budgets are important in managing an organization. See: Kenneth Heathington and Gustave Rath, "The Systems Approach in Traffic Engineering," Traffic Engineering, June 1967.
T.A. Struve and Gustave Rath, "Planning-Programming-Budgeting in Education," Educational Technology, Saddle Brook, N.J. 1966.
Gustave Rath, "PPBS is more than a budget: It is a Total Planning Process," Nation's Schools, Nov. 1968, vol. 82, No. 5.

[2]For example see:
Roland N. McKean and Melvin Anshen, Problems, Limitations and Risks of the Program Budget (Rand Corp., 1965) RM 4377-RC.
David Novick, Program Budgeting: Long Range Planning in the Department of Defense (Rand Corp., Nov. 1962) RM 3359-ASDC.
E.S. Quade, Systems Analysis Techniques for Planning-Programming-Budgeting (Rand Corp., March 1966) P-3322.

and analysis.

By analytical characteristics is meant the necessity for analysis of objectives and alternatives to develop a relevant decision space for the decision maker. Intuition is not sufficient for analysing complex alternatives or devising new ones.

Lastly the PPBS functions as an information system for control (how well program costs are following budgeted costs) and for building a data base.

The PPBS is no panacea. By projecting a structure onto a system it emphasizes certain aspects and neglects others. A continual review of the world view of the system is necessary. The analysis of alternatives tends to emphasize the quantitative aspects and neglects the qualitative ones. However, the argument can be made, that good quantitative information is better than none if the cedision maker keeps the qualitative dimension in mind.

State of the Art

A few program budgets exist in the literature. Dr. Riggs[1] defines only two major objectives for the police system, (i) control of criminal behavior and (ii) public service activities (see Table 1). The program budget that ensues is somewhat simplistic and difficult to use as a structure for analysis as the programs follow the functional organization of a police department. These programs have very little relevance to analytical output categories.

Peter Szanton[2] offers another program structure which is extremely detailed. Again it is deficient in that it separates output into functional categories. His budget also lacks a program to indicate relations with the environment.

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[1] Robert Riggs, "A Planning-Programming-Budgeting System for Law Enforcement," Law Enforcement Science and Technology (Chicago: Academic Press, 1967), Vol. 1.

[2] Peter Szanton, "Program budgeting for criminal justice systems," Appendix A of Task Force Report: Science and Technology, op. cit.

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UNIVERSITY MICROFILMS.

It is difficult to devise a structure which is output oriented and provides a structure that is amenable to analysis. A functional structure is the obvious first step, but as has been pointed out, it really leads to a performance type budget. The hallmark of the Program Budget is its insistence on systematic analysis.

Table 1

Rigg's simplified police structure:

1. Control of Criminal Behavior
    A. Vice (Liquor, Narcotics, Prostitution, Gambling)
    B. Rackets (Larceny, Loan Sharking, Organized Crime)
    C. Crime Against Property
    D. Crimes of Violence to Persons
        1. For profit
        2. Non-for-profit
    E. Youth or Juvenile Crime

II. Public Service Activities
    A. Emergency Medical Services
    B. Security in Public Buildings
    C. Traffic (Safety and Movement of Goods and Services)
    D. Crowd Control
    E. Inspection & Licenses
    F. Control & Support

Figure

Szanton's Program Budget

I. CONTROL AND REDUCTION OF CRIME PROGRAM
- A. Prevention/Suppression
  1. General Purpose Patrol
  2. Special Purpose Patrol (by type of offense)
  3. Intelligence
  4. Community Relations
- B. Investigation/Apprehension
  1. Crimes Involving Major Risk of Personal Injury
     - a. Murder
     - b. Assault
     - c. Rape
     - d. Armed Robbery
     - e. Burglary—Homes
     - f. Arson
     - g. Etc.
  2. Crimes Not Involving Major Risk of Personal Injury
     - a. Theft
     - b. Unarmed Robbery
     - c. Auto Theft
     - d. Burglary—Commercial
     - e. Fraud
     - f. Forgery
     - g. Etc.
  3. Vice
     - a. Narcotics
     - b. Prostitution
     - c. Gambling
     - d. Etc.
- C. Prosecution
  1. Interrogation
  2. Preparation for Trial
  3. Trial
- D. Recovery of Property
  1. Autos
  2. Other Personal Property
  3. Commercial Property
- E. General Support
  1. Communications
  2. Records and Data Processing
  3. Technical Services
     - a. Fingerprint
     - b. Ballistics
     - c. Polygraph
     - d. Laboratory Analysis

II. MOVEMENT AND CONTROL OF TRAFFIC PROGRAM
- A. Traffic Movement
  1. Direction of Traffic
  2. Enforcement of Traffic-oriented Parking Rules
  3. Emergency Road Services
  4. Weather Emergency Procedures
  5. Identification and Reporting of Congestion Points
- B. Traffic Safety
  1. Enforcement of Regulations
     - a. Patrol/Apprehension of Moving Violations
     - b. Enforcement of Safety-oriented Parking Rules
  2. Driver Training
  3. Educational Programs
  4. Vehicle Inspections
- C. Accident Investigation

III. MAINTENANCE OF PUBLIC ORDER PROGRAM
- A. Public Events
  1. Sporting Events
  2. Public Ceremonies
     - a. Parades and Receptions
     - b. Public Meetings
     - c. Cornerstones, etc.
- B. Minor Disturbances
  1. Private Quarrels
  2. Parties
  3. Drunkenness
  4. Derelicts
  5. Miscellaneous Nuisances
- C. Civil Disorder
  1. Prevention
  2. Suppression

IV. PROVISION OF PUBLIC SERVICES PROGRAM
- A. Emergency Services
  1. Fire
  2. Medical
  3. Power Failure
  4. Flood
  5. Civil Defense
  6. Miscellaneous
- B. Missing Persons
- C. Lost Property
- D. Miscellaneous

V. ADMINISTRATION AND SUPPORT PROGRAM
- A. Direction and Control
  1. Direction
  2. Planning and Development
  3. Internal Inspection and Review
- B. Training and Personnel
  1. Recruitment
  2. Training
     - a. Basic
     - b. Advanced

V. ADMINISTRATION AND SUPPORT PROGRAM—Continued
- B. Training and Personnel—Continued
  3. Testing, Evaluation, Promotion
- C. Public Relations
- D. Supporting Services
  1. Records (noncrime) and Data Processing
  2. Communications
  3. Budget
  4. Property

Program Budget

The conceptual model has investigated Police System activities and outputs with respect to Crime Control, Quasi-Criminal Control, Public Peace, Traffic, Public Service and Community Support. It remains to specify the program structure. It is convenient to define six major programs, which contribute to the six objectives. The difficulty then is transferred to the sub-program structure. The key to the ensuing analysis is the Police System model presented in chapter two.

Crime Control is influenced by social-behavioral-psychological factors, opportunity distributions and risk.

The police have activities directed to all of the above factors as discussed above.

Objective: Crime Control
Program: Crime Control
Sub-Program: 1. social-psychological-behavioral conditions;
2. opportunity;
3. risk.

However, police contribution to risk arises from the deployment of its three main forces, namely the preventive, response and follow-up forces.

Different types of crime call for a different mix of police response. For example, burglary is best handled through a mix of preventive patrol and detective follow-up of stolen goods. There is very little that the response force can do. Consequently it is logical to provide sub-sub-programs, with one program for each crime. At the present time very little has been done in determining the productivity of different forces with respect to index crimes.[1)]

Quasi-criminal activity mainly includes disorderly conduct and drunkeness and needs no subdivision at the current state of knowledge. One of the main

[1]R. Larson and A. Blumstein have analysed the sector patrol effectiveness of a preventive force for data from Los Angeles. Operations Research for Public Systems, ed. Morse, (Cambridge: MIT Press, 1967).

reasons for keeping it separate is to emphasize the need to consider other forms for handling these activities, such as hospital care and rehabilitation for drunks, and social care for destitute persons. In other words is the police department and jail the "best" way to handle these demands for social response?

Traffic regulation is often a separate entity within the police department. If this is the case it will be convenient to consider it a separate program, with the contributions of the Beat car force added to those of the Traffic Division.

The program Public Peace serves to highlight the following issues: should the police department provide resources for peaceful crowd control, such as parades and sporting events; what is the police role in a civil disturbance, that is - what commitment need the local police force make?

Public Service can be divided into three categories. Again the purpose is to highlight the commitment of resources and force a consideration of the opportunity cost of providing these services. The police department provides emergency services, such as sick transport. Why should it have this function? The fire department, or a special division in a public safety program or a private firm could provide these as well. Specialized services became a separate program to include large activities such as marine patrol, animal care, auto pounds, license investigators, etc.

Lastly, community support represents unilateral and bilateral efforts by the Police Department to foster goodwill. Community Relations represent efforts directed towards reaching groups, and Human Relations are activities towards contacting individuals. Public Relations would represent the costs of developing an unilateral image.

Support is a traditional category which includes general overhead and support activities such as the Superintendent's staff, the Communications Center, Records, Data Processing, maintenance of departmental vehicles, buildings, and radios, etc.

Table 3

PROGRAM BUDGET [1]
for the
CHICAGO POLICE DEPARTMENT
(for 1968 budget)

I CRIME CONTROL	
SOCIAL PSYCHOLOGICAL ECONOMIC COND.	$ 912 748
OPPORTUNITY	0
RISK	
PREVENTION	30 271 342
RESPONSE	3 037 876
FOLLOW-UP	23 873 127
II QUASI-CRIMINAL	5 182 802
III TRAFFIC REGULATION	11 220 397
IV PUBLIC PEACE	7 737 896
V PUBLIC SERVICE	
EMERGENCY	3 263 72[illegible]
SPECIALIZED	8 423 900
OTHER	3 195 571
VI COMMUNITY SUPPORT	
COMMUNITY RELATIONS	455 425
HUMAN RELATIONS	127 944
PUBLIC RELATIONS	4 435 579
VII SUPPORT	27 973 365
TOTAL	$130 161 692

[1] The cost figures for the Program Budget were developed by Sergeant Walter P. Gersch at the Chicago Police Department.

The Program Budget, as presented here, is being applied to the Boston and St. Louis Police Departments. Several other departments have indicated strong interests.

Measures of Effectiveness

A knowledge of the objectives of a system is not enough. In order to evaluate alternatives it is necessary to have criteria or measures of effectiveness.

What is needed are measures that permit an evaluation of how well each objective is being achieved and how each objective contributes to the achievement of department goals.

The first problem to be broached is for whom is the system being optimized; the citizen or the police administrator? The police department, as a public system, should optimize allocation of resources from the citizen's point of view. However, as shown below, there is not necessarily a conflict between the two views.

The citizen in evaluating police system output is interested in crime control and the amount of public service he receives. He, in turn, will indicate his satisfaction for the quantitative and qualitative aspects of police output in terms of support of the department, both in terms of resources and individual help. In the aggregate this support can be called community support.

The police administrator is concerned with crime control and with providing a certain level of public service and generating goodwill for the department.[1] Public service, public relations, human relations and community relations are all means of achieving goodwill. Crime control will contribute to goodwill, however, there may be certain instances where police activities do not result in goodwill. For example, though traffic management

[1]See Skolnick, op. cit.

is necessary, people do not appreciate getting tickets and often focus this resentment on the police department.[1]

The citizen is postulated to have a utility function with respect to police services:

$$V = \sum_{i=1}^{6} u_i \, O_i$$

where: V= total utility of individual
ui= utility derived from i - th program activity
O_i= output generated by i - th program activity
(by program is meant a program of the Program Budget)

Not enough is known about the contributions of the different programs to total utility. As a first order approximation to the resource allocation problem the analysis should focus on those programs absorbing most of the department resources and which are most important to the individual citizen.

Approximately 80% of department resources are devoted to crime control and public service. Citizens are concerned with the threat of criminal activity, expecially crimes against persons. It would seem reasonable then to look closer at crime control and public service.

The citizen is interested in optimizing:

$$V = \sum_{i=1}^{13} u_{1i} \, (1-p_i) + \sum_{j=1} u_{2j} \cdot PS_j$$

where: V= total utility
u_{1i}= utility derived from not being subjected to i - th type of index crime
p_i = threat of being subjected to a crime of type i
u_{2j}= utility derived from j - th type of Public Service activity
PS_j= output of public service activities.

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[1] President's Commission on Law Enforcement, The Police and the Community (Berkeley: University of California, October 1966), Field Surveys IV, Vol. 2.

The police administrator is concerned with crime control and generating goodwill for the department.

$$F = \sum_i u_{1i}\, c_i\, P_i + \sum_j u_{2j}\, PS_j + u_3\, CS$$

where: F= total utility of the police decision-maker
u_3= utility derived from community support
CS= amount of community support (goodwill) for the police department
the others as previously defined

The level of public service is determined by the number of public service type calls responded to and the quality of service, and the provision of specialized functions such as licensing, dog pounds, etc. The service level should ideally be considered in competition for resources with the crime control and community support programs. However, in many large police departments, the public service function is a set enstraint. Orlando Wilson set the policy in Chicago, that anyone with a dime for a telephone call should be able to have a patrolcar arrive within six minutes. This represents a very large drain on police resources. The Detroit and St. Louis Police Departments use a screening procedure where less "important" calls are not responded to. At a minimum, the determination of the opportunity cost of providing a given level of public service, should be an input to the decision-making process.

At present it is impossible to make a tradeoff between the crime control, public service and community support programs. The production functions for the police system and the utility functions of the citizens with respect to the services are not known.

This section has provided the structure of the resource allocation problem. The next chapter will provide production models for a sub-program, the Response Force.

CONTINUED

1 OF 4

CHAPTER IV

ANALYSIS OF THE RESPONSE FORCE: THE PROBLEM

Definition

When a citizen dials the police number, a sequence of events is initiated. It is the purpose of this chapter to examine these events from a resource allocation point of view.

The response force is defined as those police resources which are committed to handling calls for service. This response can be divided into two main parts, the communications center response and field response.

The objectives of the police system were:

1. Protection of Life and Property
   Maintenance of Peace and Order
2. Public Service
3. Community Support

The response force contributes to all three objectives. By responding to calls for service of a criminal or public service nature, the response force contributes to the first objective. Approximately 70% of calls for service are Public Service related. Consequently this category represents the largest drain on response force resources. Lastly, through the quality of service, the third objective is affected.

The organizational structure of the Chicago Police Department was discussed in Chapter II. The response force, a conceptual force, is a posture of the District Law Enforcement force. This latter force belongs to the Patrol Division and comprises approximately 60% of total department manpower. As the name would suggest, this force is divided among districts of which there are twenty-one in Chicago. These districts are in turn divided into beats which are patrolled by a patrol car. There are apporximately 430 beats in the city, of which all are manned on the third watch.

The beat car receives its assignments from the communications center. When not answering calls, the patrol car is either doing preventive patrol or down for an administrative call such as lunch or car service.

The Problem

The resource allocation problem of the response force has two dimensions:

1. How to allocate resources within the response force so that the efficiency of carrying out crime control and public service activities is optimized?
2. How to allocate resources among the three forces, so that the effectiveness of the department with respect to crime control and public service activities is optimized?

The current state of the art is not advanced enough to permit evaluation of force mixes. There do not exist models of the effectiveness of each force with respect to different crimes.[1)]

The analysis of the response force will present models of the communications center and field response in an effort to evaluate combinations of resources and their effectiveness.

The efficiency of the response force is a function of:

1. demands for service in space/time;
2. positioning of forces in space/time;
3. assignment rules;
4. organizational variables (such as supervision, car maintenance policies, etc.);
5. communications center response time.

These are discussed later in this section.

Measures of effectiveness

What should the measures of effectiveness for the response force be?

The police department seeks to minimize the threat of crime disutility to

[1]The methodology and initial models are presented in the final report of the Chicago Police Department Operations Research Task Force, OLEA Grant #102, Sept. 1969.

an individual in the city. It is impossible to determine the number of crimes prevented as a consequence of a certain allocation of resources. The only observable values are the total number of criminal events for each crime type (the level of crime) and the ratio of responses when there was an arrest to total number of responses to criminal events. The only way that the response force can affect the level of crime is by arrests.[1] To be consistent with the overall department objectives, the response force objective should be to maximize the crime disutility represented by the offenders arrested.

A refinement to this measure of effectiveness should, if possible, be included. The quality of arrests is an important factor. That is, did the court dismiss the case because of incorrect behavior by the arresting policeman? The measure of effectiveness then becomes to maximize the crime disutility represented by the cases of offenders not dismissed by the court for "incorrect" police action. This measure would permit a more realistic qualitative evaluation of performance than is possible at present. Both the type of crime and the quality of police performance are represented.

Examples of tradeoffs to be evaluated are:

1. How many police units should be used for a trapping procedure versus having them available to respond to a call for service?
2. Should stacking of calls be permitted (tradeoff between public service and probability of apprehension)?

A partial measure of effectiveness of the Response and Preventive forces is the probability of apprehension.

The probability of apprehension (P_a) can be defined in terms of:

1. the conditional probability of identification (P_1) given detection of the event, and
2. the conditional probability of detection (P_d) given space/time coincidence, and

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[1]We will disregard the deterrence effect, if any, of the presence of a police car responding to a call for service.

3. the conditional probability of space/time coincidence (P_{st}) for the preventive force, given an event, and
4. the elapsed time between the occurrence of an event and the arrival of the police (Δt).

Thus, the probabilities of apprehension for the preventive force and the response force can be expressed as follows:[1)]

1. Preventive force.

   $P_a = f\ (P_I, P_d, P_{st}, \Delta t)$
2. Response force[1)]

   $P_a = g\ (P_I, \Delta t)$

Comparing the two forces, the Preventive Force has a low probability of being at the scene and a low probability of detection of the event. However, the elapsed time will be less than had the Response Force responded and for certain types of events the probability of apprehension may consequently be higher for the preventive force.

The probability of detection for the Response Force is by definition equal to unity and the probability of identification should be identical for the two forces. The elapsed time is likely to be longer for the Response force.

The important question is how should the two forces be deployed? That is, what the tradeoff functions with respect to different types of activity?

Central to the study of the Response Force is the concept of elapsed time. The elapsed time between the occurrence of an event and the arrival of police at the scene is influenced by three factors:

1. The interval between the time of occurrence and the time the Communications Center is notified.
2. Elapsed time between the arrival of a call in the Communications Center and the assignment of a beat car.
3. Travel time of a beat car to the scene.

The police can influence the first factor by active publicity campaigns

[1]Implicit in this measure is the assumption that an "adequate" number of vehicles are available and are assigned for an efficient response.

soliciting citizen cooperation in the detection of crime and timely reporting. "Operation Crime-Stop" is a good example. The other two factors are under the direct control of the Department. This section will concentrate on the second factor enumerated above.

A special study was carried out at the Chicago Police Department to determine the different time intervals. The study focused on robbery calls for service in the second district. Partly because robbery is a large volume crime, partly because it is one crime for which the time of occurrence is more likely to be known and the incident reported as soon as possible.

The average response time for each interval and its mode were:

	Average	Mode
Time of occurrence to communications center notification	18.09 min.	1.0 min.
Communications Center response time	3.18	1.5
Field response	5.77	2.0
Total police response	8.80	3.5

At the Chicago Police Department public service is presently a completely exogenous demand on police resources. In St. Louis calls are screened by a police officer in an effort to determine the utility of the police service that would be rendered. Note that the police department has an objective called goodwill, so that it is in the department's interest to attempt a balance between the drain of public service calls on police availability and the goodwill that it generates.

The measure of effectiveness of public service should be the amount of goodwill generated for the department. Approximate measure would be the number of calls for service and the quality of service given. By quality is meant dimensions such as: Was the officer courteous, was the service time appropriate?

This could perhaps be measured by attitudinal surveys, or as done in a research project conducted by the British Home office, Police Research and Planning Branch.[1]

The objective was to determine the impact that a public relations crime prevention campaign would have on the public and on the crime rate. Four criteria were used to measure public response:

1. were parked cars locked with no valuables in open sight;
2. volume and quality of suspicious person and activity calls;
3. sales of security devices;
4. flow of criminal intelligence to the police.

To measure the effect on crime statistics were gathered on:

1. burglaries of homes
2. burglaries of businesses
3. larcenies from autos
4. auto thefts

The campaign was measured for three distinct time periods.

	Pre-campaign period (4 wks)	Campaign period (6 wks)	Post-campaign period (6 wks)
# of calls from public	1996	2340	2205
Ratio of arrests to "other calls"	.085	.064	.062
# crimes committed (includes house & business establishments, larcenies from autos and theft of autos.	769	550	552
Ratio of arrest to crime	.065	.111	.140
Larcenies from vehicles	182	137	157
Stolen autos	146	139	138

Table 4

Demands for Service

In order to optimally allocate patrol manpower in space and time with respect to future demand, it is necessary to be able to forecast demands for

[1] J.A. Bright, "An Evaluation of Crime Cut Sheffield," Home Office Police Research and Planning Branch (London, September 1967), No. 14/67. (See Table 4).
As presented in Frank J. Leahy, Jr., "A Literature Review of Police Planning and Research," The Travelers Research Center, Inc., Hartford, Conn., pp. 9-10.

service. Various techniques are available to do this.

The Philadelphia Police Department has tried to use multi-dimensional analysis and multiple regression techniques.[1] The former technique assumes that crime occurrances can be predicted from factors which co-occur with crimes. The objective would be to input values of crime factors and determine a probability of a certain crime type occuring at a given space/time. The factors used were:[2]

Table 4.
Crime Prediction Factors

Day of week	Percent married
Month	Percent foreign-born
Day	Percent growth
Hour	Percent decline
Phase of moon	Percent moved
Snow	Percent families, 1 or more under 6 years
Visibility	Percent non-white
Precipitation	Percent enrolled in school
Wind speed	
Temperature	
Relative humidity	Average income
Pressure	Average persons/house
Age percent 15-34	Average rent
Age percent 60 and over	Average school years completed
Percent males unemployed	Number of transit interchanges
Percent wage and salary workers changes	
Percent owner-occupied housing	
Percent sound housing	Number of Elementary school(s)
Percent with 1.01 or more persons per room	Number of Junior Highs
	Number of Senior Highs

However, to estimate the likelihood of a criminal event occurring in space/time, it is necessary to know in how many instances a specific occurance of factors did not result in a crime. This information is not available. Consequently, the use of this technique for predictive purposes for response force allocation is not recommended.

Another difficulty is that though multi-dimensional analysis is a very powerful technique, it can only be as good as its input data. It is

[1] Donald P. Stein, Jay-Louise Crawshaw and Captain James C. Herron, "Crime prediction by computer - does it work and is it useful?" Law Enforcement Science and Technology II (Chicago: IIT Research Institute, 1968).

[2] Ibid, page 543.

extremely difficult to get up-to-date socio-economic information and accurate weather predictions. The weather is often an important explanatory factor.

Even with the above limitations the analysis should yeild valuable inputs to a crime prevention program. The most likely locations and time of occurrance could be pinpointed so as to receive increased attention. The problem of preventive patrol is mainly one of space/time coincidence between a police unit and a misconduct.

The St. Louis Police Department[1] uses an exponential smoothing technique to forecast calls for service. The smoothing process incorporates seasonal, daily and hourly adjustment factors to generate hourly calls for service.

The model is:

$$S_t = \frac{a\, x_t}{w_{t-L}\, H_{k-m}} + (1 - a)\, S_{t-1}$$

$$w_t = \beta \frac{x_t}{S_t} + (1 - \beta)\, w_{t-L}$$

$$H_k = \gamma \frac{Y_k}{Y} + (1 - \gamma)\, H_{k-m}$$

where: S_t = estimated calls per period

S_{t-1} = previous estimate of calls

x_t = observed number of calls

w_{t-1} = seasonal adjustment factor

L = periodicity of seasonal adjustment (L=53)

H_{k-m} = hourly adjustment factor

m = periodicity

k = hour of week ($1 \leq k \leq 168$)

Y_k = actual calls curing k-th hour

Y = average number of calls per hour

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[1] Allocation of Patrol Manpower Resources in the St. Louis Police Department, (St. Louis Police Department), vol. II, 1968, page 30.

The St. Louis Project reports that the variation in the predicted number of calls for service accounts for approximately 90% of the total variation.

A linear prediction model has been tried at the Chicago Police Department. Adjustment factors were calculated for hourly, weekly and trend effects. The predictions were surprisingly accurate, providing that demands for service are generated by a stable system.[1)]

Positioning Problem

The positioning problem (or manpower distribution problem) has two dimensions. One is the assingment of police units to sectors (in Chicago called districts), the second their initial positioning within the sector (the beat structure).

There exist several possible criteria for assignment:[2)]

1. equalize workload
2. equalize weighted workload
3. minimize response time
4. minimize weighted response time.

Equalizing workload usually means determining a workload such as four calls/watch/car and then dividing total number of calls over a given period by four to determine the number of units needed.

The current method of allocating personnel at the Chicago Police Department is a somewhat simplified version of Wilson's distribution method as developed in his book Police Administration.[3)]

The objective function of his method is to equalize, as far as possible,

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[1]See Chicago Police Department Final Report, op. cit.

[2]For additional criteria see Allen P. Bristow. Effective Police Manpower Utilization (Springfield, Ill: Thomas Press, 1969).

[3]Orlando Wilson, Police Administration (New York: McGraw-Hill, 1963 ed.).

the weighted workload for each beat car. The workload is a function of calls for service, required premise checks, and preventive patrol. Preventive patrol is a function of misconduct hazards, which are assumed to be reflected in the volume of calls for service.

1. The Total Number of Beats
   This is determined by dividing the total number of calls for service (CFS) for the last identical season. This will provide the average daily number of CFS. It is assumed that four calls per watch per beat car with one hour devoted to each call would be an appropriate workload leaving "approximately four hours for preventing patrol during a tour of duty" (from the official document on Assignment Method).[1] The premise checks would be included in the preventive patrol time.

The total number of beats for three watches is arrived at by dividing average calls for service by four, as each beat car handles four calls.

2. Weighted workload
   The weighted workload is calculated for each district by weighting the calls for service as follows:

Part I	crimes	by 4 [2]
Part II	crimes	by 3
Other		by 1

   The weights are supposed to reflect the seriousness and the service time required of the different categories.
3. Number of District Beats
   The number of district beats is determined by multiplying the district share of citywide weighted workload (CWW) by the number of beats.

$$\text{District beats} = \frac{\text{district weighted workload}}{\text{CWW}} \times \text{no. of beats}$$

[1] Chicago Police Department, Planning Division, "Manpower Distribution," 29 December, 1965.

[2] Part I crimes consist of index crimes such as homocide, serious assault and theft. Part II crimes are less serious such as disorderly conduct and unlawful use of weapons. Other includes public service events like family disturbances.

The above statistic is subject to the following constraints:

(a) the district weighted workload (DWW)/CWW ratio is compared with the District CFS/city-wide CFS ratio. If the difference is great, the reasons are determined. The object is to maintain a reasonable mix of Part I, Part II and other of CFS for the patrolman.

(b) Beats in a pheripheral, residential district may become too large for adequate response time and preventive patrol. Therefore, extra beats may have to be authorized.

4. Beats per Watch

The district beats are apportioned to the three watches by multiplying the watch weighted workload/DWW ratio by the district number of beats. The beat structure layout is given by the third watch, as it has the greatest relative workload. During the other two watches, when the total number of beats in service is reduced, each of the eliminated beats is covered by an adjacent car.

5. Extensions

(a) In some districts (nine to be exact) overlapping watches (powershifts) are employed to more closely match the actual demand for CFS with available resources.

(b) Lastly, the two-man and one-man car assignments are made. Attention is given to the number of incidents of resistance to police, multiple arrestees, deadly weapon involved and geographical factors affecting ready access by neighboring squad cars. A ranked list is produced showing two-man cars are allocated subject to available manpower.

The criterion for judging a police system should, at least in part, be its impact on crime. It is not possible, at this state, to relate manpower allocation to criminal activity. One can, however, determine how well the system accomodates the functions of patrol with respect to the given objective function.

The present system is designed to equalize workload. Workload is defined as a function of calls for service, premise checks, and preventive patrol. The question we will address is: How well does the present distribution method achieve this objective? The specific distributions to be scrutinized are:

1. between days of the week
2. among watches
3. between districts

The week of August 16 - August 22 was exhaustively investigated. The total amount of time spent on calls for service and assist-calls was tabulated for each car.

Minutes spent on CFS for the third watch averaged forty minutes per call. Assist-calls were approximately ten minutes shorter. The number of CFS per beat car per watch exceeded the target of four calls in most instances.

Assists, in many cases, amounted to one additional call per beat per watch. To be able to evaluate the time spent on the CFS and Assist function, a "utilization" index was defined.

$$\text{Utilization Index} = \frac{\text{total time on CFS and Assists}}{\text{total time on duty}} \times 100$$

This index was determined for both the whole system and the individual districts by watch.

The desired utilization index (target index) of the present assignment system depends on the assumptions made. If four hours should be spent on CFS and Assists, and total working hours is eight hours, then 50% represents the target index.

Of the total eight hours available per tour of duty, one half hour is lost for lunch and there are usually two fifteen minute coffeebreaks. Premise checks, absorb approximately five minutes per beat car per watch. Therefore the target index become 40%.

There exists another time consuming factor, travel time. The above index is calculated from the Time-out and Time-in stamp on the radio dispatch cards. The beat car still has to return to his beat if the assignment was outside his beat. Only 23% of CFS are answered by the beat car assigned to the beat of occurrance. A car outside the district will respond to approximately 13% of the CFS. (See Table 5).

The demand for police service fluctuates in a regular pattern with respect to the days of the week, as can be seen in Table 6. Friday, Saturday and Sunday represent the busiest days. Department policy, however, is to allocate an equal number of men to each week day.

The result of this can be seen in the "indices." Friday and Saturday, on a total system basis, exhibit a greater proportion of time spent on CFS. The difference is not great. This should be expected from a system-wide point of view, where many districts are residential.

Table 6 also reflects some discrepancies with respect to allocation on a system basis between watches. Most preventive patrol is performed in the early morning when it probably is needed the least. The representative figures seem to be 20-30-40 percent for weekdays. This identifies a discrepancy since the CFS workload is twice as large on the third watch.

Between districts, the utilization factors vary widely, as can be seen in Table 7. Only the third watch has been shown as it has the highest workload. It is quite evident that districts 2, 3, 5, 7, 10, 11 and 13 need more manpower during peak points.

The main critique of the present method would have to be levied against the objective function. The stated objective is to equalize workload, assuming that four CFS per beat car per watch is the goal. Even this limited goal is not achieved as has been shown in the previous sections.

The more relevant objective should be to minimize some function of response time and maximize the probability of halting or preventing a crime through selective preventive or tactical patrol. This should determine the number of men in Patrol and how they should be deployed.

It has been shown that the actual time a patrol unit is available, when lunch, personals, administrative calls and increased travel time are considered, is less than seven hours per watch. Table 5 supports the view that the beat car structure is only a good repositioning device and a very rough positioning tool. Soon after the beginning of the watch, the beat car will be off his beat and the value of knowing a certain area becomes lost. "Magnet beats" pull cars into their areas so that the density-space distribution of beat cars approximate the real demand.

It is perhaps evident from the discussion so far that very little preventive patrol is carried out at a time when it is needed the most. For example, the Task Force (a flexible tactical unit) works from 1800 hours to 0200 hours. Indeed, it seems that the beat car force is in practice only responding to CFS and doing minor premise checks. The Detective tactical units and the Task Force are responsible for tactical preventive patrol. When this state of affairs is realized, the step to deploying a Force A and Force B to respectively carry out CFS, and preventive patrol as in St. Louis, becomes obvious. The current approach results in a waste of resources due to deficiencies in the assignment method and the difficulty of control.

The most serious problem is the use of an average figure for CFS per day for the system for a period of half a year. This is really too great an aggregation. Too much information which is relevant to the peaking of demands in the system is lost in the process. Even though the inclusion of assists will not change the system demands as between days, it does change the needs markedly for beatcars in specific districts.

Other deficiencies center around the critical assumptions made. The average service time is forty minutes, not an hour. Calls for service per beatcar is not a representative number of workload, as assists often amount to an additional call per watch per beatcar. The weights 4-3-1 are supposed to reflect service time, and seriousness of the call. Instead, there is often an inverse relationship between seriousness of a crime and service time. A patrolman will only write a preliminary report on a homocide and leave when the detectives arrive, while in a burglary case he would have to carry out a more thorough investigation.

The workload criterion is a rough assignment guide. Optimally it results in an equal workload but in unequal service level of CFS.

Further refinements are possible by using response time as a criterion. The appropriate analytical technique is queuing theory. The advantage is that instead of only using averages, as the previous method, it views demands for service and police response as a stochastic process. The interrelationships of demand and service times are modeled so as to minimize response time.

The queuing theory approach focuses on the availability of cars. To minimize response time one seeks to minimize the expected average delay before a car is available for dispatch within a given sector.

The St. Louis Project used a Poisson input, negative exponential service time, multiserver queuing model (m/m/M). Each district is considered as having M parallel channels, where M represents the number of b... c cars.

λ = mean arrival rate (number of calls per unit time)

μ = mean service rate per channel (is the mean time difference between Time Out and Time In on the RD card)

c = numbers of cars for answering calls

n = number of calls in the district system

ρ = utilization factor for the district; $\rho = \frac{\lambda}{c\mu}$

P_n = the steady state (time independent) probability that there are n calls in the district, both receiving service and waiting for a service car.

P(o) = the probability of no waiting

P(>o) = the probability of any waiting

P(>τ) = the probability of waiting greater than time

L_q = the average number of calls in the queue awaiting service

W = the average waiting time in the system

Then the following formulas give the probability of a delay in finding an available car.

$$P(>0) = \frac{(c\rho)^c}{c!\,(1-\rho)} P_0$$

where:

$$P_0 = \frac{1}{\sum_{n=0}^{c-1} \frac{(c\rho)^n}{n!} + \frac{(c\rho)^c}{c!\,(1-\rho)}}$$

and the expected waiting $W = L_q/\lambda$

$$\text{where } L_q = \frac{(c\rho)^c}{c!\,(1-\rho)^2} P_0$$

It is possible to refine this analysis to include priority queues. This is a very realistic step as it is important that emergency calls be answered quickly, while certain calls can wait.

A two priority queue[1)] was used with Chicago data. Defining a no-wait-policy as a 10-second, mean waiting time, with 30% of total calls in the high priority category, it was shown that a priority system did not result in great savings under normal circumstances. The most important factor was the average service time. However, under circumstances when half the response force would be mobilized for civil disorders, the two priority system is a necessity.

Richard Larson[2)] uses a weighted response time criterion. He assumes interdistrict dispatching and minimizes travel time. His model will be discussed later.

The difficulty with the queuing theory applications lie with the assumptions

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[1]Commission on Violence Report: Task Force and Civil Disorder Appendix B D. Olson and E. Nilsson, "Application of Queuing Theory to the Chicago Police Beat Structure."

[2]Richard C. Larson, Operational Study of the Police Response System (Cambridge: MIT, December 1967), Technical Report No. 26.

that have to be made to make the mathematical models tractable. Larson showed, that for Boston[1] the assumption of Poisson input was a good approximation. In most cases the Chi square test for the Poisson hypothesis was significant at the 0.05 level. His exponential service times did not fit the real world data very well. In Chicago both empirical distributions are significantly different from théir theoretical equivalents. (See Table 8).

How should a response force be positioned and what assignment rules should be used for selecting a car to service a call?

There exist no models for evaluating the initial positioning of police units once the sector assignment has been made. The beat structure provides a rough positioning tool.

The assignment rule is usually left to the individual dispatcher. Most often, with a beatcar structure it entails a center of mass dispatching strategy. That means, that if the beatcar is not busy, he is assumed to be positioned at the center of his beat. This is erroneous, of course, but no other information is available with a beat structure. There are complications. For administrative reasons interdistrict dispatching is not allowed except for emergencies, or if the district is out of cars. Another difficulty is the judgement of how many men/cars to send in on the call.

Organizational variable are a very important factor of system efficiency. Due to the nature of police work, it is very difficult to maintain effective supervision.[2] If supervision is lacking, service times tend to increase and the availability of cars is decreased. Most queues are very sensitive to the service time variable. It was found that a 10 minute decrease in service time amounted to a saving of six cars out of thirty assigned to a

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[1] Ibid., page 150.

[2] In New York, policemen would sleep in their cars during the first watch sometimes.

district.[1] A car locator system offers a great opportunity in supervision.

[1]D. Olson and E. Nilsson, op. cit.

Table 5

Percent of Calls for Service

Answered by Beat Car

Day		16	17	18	19	20	21	22
By Beat Car	W1	23%	22	20	19	24	23	25
	W2	23	21	23	24	23	24	22
	W3	21	22	23	24	25	26	24
By Non-District Car	W1	13%	13	11	9	9	8	8
	W2	21	18	14	17	15	16	15
	W3	20	15	15	12	12	12	13

W1 = Watch 1 = 0001-0800 hours
W2 = Watch 2 = 0801-1600 hours
W3 = Watch 3 = 1601-2400 hours

Table 6

Total System Statistics

		Fri.	Sat.	Sun.	Mon.	Tues.	Wed.	Thurs.
Utilization Factors	Watch 1	28%	32	33	26	21	24	24
	2	43	34	28	34	30	33	31
	3	55	45	40	43	42	39	40
Calls for Service answered by beat cars	Watch 1	1151	1232	1408	925	860	1013	898
	2	1849	1455	1303	1481	1379	1415	1402
	3	2616	2356	2031	2158	2279	2123	2205
	Totals	5616	5043	4742	4564	4518	4551	4505
Assists answered by beat cars	Watch 1	348	207	303	280	220	258	263
	2	153	194	241	140	161	181	175
	3	272	362	428	314	290	321	311
	Totals	773	763	972	734	671	760	749
Average time (min.) per calls for Service	Watch 1	44	43	40	46	41	39	43
	2	46	45	41	45	43	46	42
	3	43	40	41	42	38	39	38

Table 7

Utilization Indices for Third Watch (in Percent)

August		16	17	18	19	20	21	22
Districts	1	71%	31	26	27	31	28	27
	2	53	59	54	54	52	47	39
	3	53	63	42	44	48	45	45
	4	42	50	47	39	35	31	26
	5	62	60	41	41	51	43	40
	6	57	34	40	41	39	43	34
	7	58	63	44	49	52	46	49
	8	57	31	24	42	36	24	27
	9	41	23	29	32	25	31	37
	10	72	70	56	56	56	47	63
	11	57	52	52	55	46	48	44
	12	65	52	36	50	31	41	33
	13	73	52	40	43	45	54	48
	14	60	38	32	47	34	46	40
	15	56	40	33	50	41	33	42
	16	64	29	35	31	42	29	28
	17	50	36	53	40	46	31	45
	18	52	42	31	35	51	55	35
	19	37	31	40	49	41	34	42
	20	57	45	36	37	39	35	33
	21	45	31	34	22	30	32	30
System factors		55%	44%	40%	42%	42%	40%	39%

Table 8

Test for
Exponential service time distribution
by district
(for 17 degrees of freedom)

District	Average Service Time (hours)	2
1	.70	31.1
2	.70	113.0
3	.66	67.1
4	.55	30.8
5	.57	76.8
6	.57	47.1
7	.67	78.0
8	.56	48.1
9	.52	41.3
10	.65	111.6
11	.68	73.2
12	.60	60.6
13	.58	51.0
14	.56	32.7
15	.53	40.6
16	.60	37.1
17	.57	39.0
18	.66	52.4
19	.56	86.6
20	.57	60.3
21	.67	36.1

CHAPTER V

ANALYSIS OF THE RESPONSE FORCE: THE COMMUNICATIONS CENTER

Description

There exists three different types of communication centers (cc). One is the old conveyor belt type, where calls are answered by a telephone operator, a card filled out and sent on a conveyor belt to the dispatcher(s). This system was introduced with the use of police radios over forty years ago. In fact, the Cleveland Police Department still has the original communications center in operation.

In 1961 Motorola designed a communications center for the Chicago Police Department. It is still at the state of the art. It will be described later.

The third type is represented by the SPRINT system being designed by IBM for the New York Police Department. It will include a car locator, computerized dispatching and teleprinters in cars.

Richard Larson[1)] modeled the first type of system using data from the Boston Police Department. Surkis et al have developed a simulation model of the New York Police Department communications center using GPSS.[2)] Rath and Braun[3)] presented an initial systems analysis and the structure of a Simscript model for the Chicago Police Department communications center.

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[1]Richard C. Larson, Operational Study of the Police Response System, op. cit.

[2]Surkis et al, Digest of the Second Conference on Applications of Simulation, Dec. 2-4, 1968, New York, Share/ACM/IEEE/SCi.

[3]G.J. Rath and W. Braun, "Systems analysis of a police communications center," Law Enforcement Science and Technology II (Chicago: IIT Research Institute, 1968).

The communications center at the Chicago Police Department is a facility for processing information. Information inputs include demands for service, and information requests from citizens and policemen. Outputs consist of car assignments and information.

When a citizen dials PO 5-1313, the call is automatically routed to a console which handles the area covered by the telephone exchange through which the call was received. There are approximately sixty telephone exchanges in the city. Each console is staffed by one or more console operators who answer calls and a dispatcher who assigns police units.

In addition to answering calls, one of the console operators is in charge of a computer on-line inquiry unit which processes inquiries from the field regarding stolen cars and persons wanted on warrants. The console operators can also query the "hot desk". This is a facility in a separate room providing 24-hour access to files on missing persons and information stored in Springfield, Illinois and in national files.

The dispatcher is in charge of radio communications with beat cars in the area assigned to his console. He receives requests for and transmits information, assigns cars and maintains a status map of car availability. Car status is indicated on a beat map of the relevant area. On the console each beat has a small light, which when illuminated indicates the car is available for assignment; if off, the beat car is busy.

There are seven telephone lines from the telephone exchange to the console. When the call reaches the communications center, a timer is actuated. If the console has not answered the call within twelve seconds, an overload facility is actuated. The incoming call can now be answered at either the console or the overload facility. The overload facility consists of seven desks which can monitor all 56 (8 consoles x 7 lines) incoming telephone lines. The overload operator takes the call and fills out an IBM card. If the call is high-priority, the overload operator takes it to the correct console for dispatching; otherwise he actuates a yellow light requesting a messenger to relay the card.

If the incoming call has not been answered within thirty seconds, the call is permitted to ring at the auxiliary desk, which has four operators. The call is handled the same way as at the overload desks.

The different zones (exchanges) generate approximately the same number of calls. The ratios among console, overload and auxiliary is approximately 50: 35: 15. (See Table 9). The distribution of calls during the twenty-four hour period is about 0001-0800 (15%), 0800-1600 (35%) and 1600-2400 (50%). The volume of incoming calls varies between seasons. It is lower in the winter than in the summer.

When calls are received relating to traffic accidents or vice they are delivered to the Traffic Division console or the Vice Control desk respectively.

In addition to the above functions, the communications center has desks for maintaining radio communications with the Preventive Force. If a call is of an emergency nature, such as a crime-in-progress or a policeman in need of help, the dispatchers can send out a call to all cars on a city-wide frequency.

Interesting statistics abound. For example, 3,261,738 calls were answered during 1968. Total calls which a car was dispatched amounted to 1,942,599. In addition, there were 1,723,597 administrative and miscellaneous calls which were handled. All in all 837,943 inquiries were made on the on-line real time computer inquiry system. (See Table 9 for more data).

During the 4th of July, 1969, over 15,000 calls were answered, about half of them from four o'clock until midnight. A normal summer day generates approximately 10,000 calls.

The Problem

The communications center represents a complex system as is evident from its description. It is difficult to convey the magnitude of this complexity.

Table 9

ANSWERING STATISTICS FOR CHIEAGO POLICE DEPARTMENT

COMMUNICATIONS CENTER FOR 13th PERIOD - FROM 5 DECEMBER 1968 TO 1 JANUARY 1969

ZONES	TOTAL NO. OF CALLS	UNDER 12	PER-CENTAGE	TO 12-30	PER-CENTAGE	OVER 30	PER-CENTAGE
1	30360	10461	34.44	14048	46.26	5851	19.26
2	29963	12234	40.82	12809	42.74	4920	16.41
3	25222	17986	71.29	4887	19.37	2349	09.31
4	24858	13961	56.15	9262	37.25	1635	06.57
5	24223	14657	60.50	7156	29.53	2410	09.94
6	28314	16023	56.57	9219	32.55	3072	10.84
7	29856	15298	51.23	11457	38.36	3101	10.38
8	25488	13383	52.50	9444	37.04	2661	10.43

ZONES	GRAND TOTAL	UNDER 12	PER-CENTAGE	TO 12-30	PER-CENTAGE	OVER 30	PER-CENTAGE
1 thru 8	218,284	114,003	52.21	78,282	35.85	25,999	11.90

An enormous amount of short transactions of many different types are continuously being carried out.

The problem can be stated:

1. What is the present response time distribution?
2. Is the system operating efficiently?
3. Can performance be improved by changing the use of resources?
4. Is a completely new system necessary?

Proposed changes include:

1. the assignment of manpower to consoles and overload positions;
2. handling of computer inquiry at a separate facility;
3. increase the number of incoming trunk lines;
4. setting the step-up intervals for letting calls ring at the overload and auxiliary desks.

The Model

Model structure and complexity are determined by the system being modeled and the output that is desired.

The previous section identified some of the questions that the model should be able to answer. In addition to the response time distribution, it is necessary to know the average time to process a call and the percentage of calls answered at the three different levels respectively for validation purposes. Operational data of interest include:

1. Airtime per console
2. Operator working time
3. Dispatcher working time
4. Overload and auxiliary operators working time
5. Size of different queues within the system.

The modeling technique chosen was simulation. Simulation was used because the physical structure of the communications center made it difficult to apply queuing theory and the necessary distributions were not well behaved as was shown in the previous chapter.

The model is first discussed in terms of its scope, level of detail and input demanded. Then the structure will be presented.

What should the scope of the model be? Should it include field response activities; be limited to the communications center; or be limited to a specific communications center activity?

The analysis of the Response Force has been divided into two parts: the communications center response and the field response. However, the distinction is not clearcut. Car assignment by the dispatcher is a function of field response characteristics.

Within the communications center, a useful distinction can be made between the handling of telephone inputs to the system and radio transmissions. The average time that a call spends in the telephone input and handling stage of the process until it reaches the dispatcher amounts to 85% of the total average call handling time for the communications center. Queues form infrequently at the dispatcher.

Consequently it was decided to concentrate on the processing of telephone calls. The total time span considered ends with the call (IBM card) being put in the dispatcher's queue.

The level of detail for the simulation model turned out to be a crucial factor. The Simscript model, mentioned earlier, was modeled at too high a level. It proved impossible to generate internal queues. The main difficulty with the analysis of the Chicago Police Department communications center is the interaction of a great number of events of very short duration, often not longer than thirty seconds.

One of the main questions to be answered by the model is the sensitivity of the system to the computer inquiry activity. This process does not consume a great deal of time, but effectively reduces the telephone input handling capacity. Consequently it was decided to model every minute transaction in the system.

The next point to consider is the generation of inputs, that is exogenous events. In a simulation model these can be generated by the program or actual events can be read in. When it is difficult or impossible to obtain data on specific events, or the events can be characterized by a theoretical distribution it is often advantageous to generate the events. However, if the events are available and cannot be approximated by a theoretical distribution, the real events should be used. The latter applies here.

The output from a simulation model depends on how realistically the real world has been modeled. Using generated events, when not necessary, introduces one more element of uncertainty as to the validity of the output.

The input to the communications center has to be characterized as to type (telephone call, Pax[1]) call) priority (emergency, non-emergency and other), space and time. The events themselves were available, and were therefore used.

Data was collected for the third watch on Friday, December 13, 1968. The data on exogenous events collected for the model include:

1. Radio dispatch calls;
2. Administrative calls;
3. Information inquiries;
4. No Service calls.

See Figure 9 for the attributes of each type of input. The different types of telephone calls are:

1. Radio dispatch (Bell or Pax)
2. Radio dispatch (radio or on view)
3. No service (information)
4. No service (referral)
5. Traffic accident

---

[1] The name of the city internal telephone system.

6. Vice Control dispatch
7. Administrative call (by radio)
8. Administrative call (by Pax)
9. License

The radio dispatch calls represent calls for which a car was dispatched. Administrative calls represent calls changing the status of a beatcar, such as lunch, personals, station assignment, etc. These come via Pax phone or by radio. The latter is included because when the operator is not busy, he will often help the dispatcher handle the administrative radio messages.

Information inquiry events consist of demands for information regarding cars and people, such as was the car stolen, was a person wanted on a warrant? This information may come from the on-line computer inquiry system, or via the Hot Desk. The Hot Desk is a separate facility, where communication is maintained with State of Illinois files in Springfield and FBI files in Washington.

No service calls are either calls which do not result in a beatcar being dispatched (the IBM card is instead routed to the Traffic or Vice Control desks) or are simply information requests from citizens or wrong numbers.

Data was also collected to determine the distributions for performing the different unit operations.

1. Time to complete information inquiry for stolen cars;
2. Time to complete information inquiry for warrants;
3. Both of the above;
4. Time to give information request to Hot Desk;
5. Time to handle return of information from Hot Desk;
6. Service time for a normal call;
7. Service time for a non-dispatch call;
8. Waiting time until a messenger arrives to carry the IBM card from overload desks to console;

Figure 9

ATTRIBUTES OF EXOGENOUS EVENT TYPES

Telephone calls

1. Type (see pages 68 and 69);
2. Scheduled time (in seconds from 3:00 o'clock);
3. Service time;
4. Beatcar;
5. Zone;
6. Beat of Occurance;
7. Verified Incidence Code.

Administrative calls

1. Type (7 or 8);
2. Timeout;
3. Timein;
4. Beatcar;
5. Zone.

Information inquiry

1. Type (9);
2. Timeout;
3. Timein;
4. Zone;
5. Type (1, 2, 3, 4, 5).

9. Time for IBM card ti be walked back from overload to console;
10. Time to walk from auxiliary desk to console;

See Appendix A for the respective time distributions.

Another difficulty in constructing a simulation model involves the choice of clock routine. The analyst may either use a fixed step increment or a next event type of increment. The second alternative is often faster than the former and permits an accurate specification of when an event should occur. With the fixed increment alternative the increment determines the resolution of the system.

In this simulation a fixed increment of one second was chosen. Because of the necessity of checking the status of each queue for the twelve and thirty second intervals and the short duration of each event, a fixed increment seemed justified. As the input data was only accurate to the nearest second, additional accuracy would have been illusory.

The language used for the simulation is Fortran with SPURT[1)] subroutines. GPSS was not available at the Northwestern University Computing Center and the Simscript compiler was not entirely reliable.

A simulation done in Fortran has several advantages. The language is easy and its semantics are well defined, though it does not have a rigorous grammar. It compiles very fast in comparison to Simscript, and several subroutine packages are available for inclusion in the simulation.

SPURT is a set of Fortran based subroutine, which provide:

1. generators for statistical distributions;
2. list processing capability;
3. statistical summary macro-routines;
4. special output packages;
5. clock routine.

---

[1]See Martin Goldberg and Benjamin Mittman, "SPURT - A Simulation Package for University Research and Teaching," Digest of the Second Conference on Applications of Simulation, op. cit.

Model Structure

It is hard to convey the complexity of the realistic simulation model of the communications center.[1]

A flowchart of the model is shown in Figure 10. The program is initialized by a separate subroutine. It initializes relevant lists, reads in parameters, and the initial events to be used in the timing routine. The timing routine causes the events, both exogenous and endogenous. The exogenous events have been mentioned earlier in the section on inputs. Endogenous events include the following event types which are necessary for the time sequencing of events. These events are scheduled separately for each console.

Endogenous event types:

1. Operator one return;
2. Operator two return;
3. Overload operator return;
4. Auxiliary operator return;
5. Administrative-Pax queue to be answered by operator;
6. Information returning from Hot Desk to operator one;
7. Completed information card put in radio out queue;
8. Radio dispatch card assigned to dispatch queue;
9. Administrative card put in administrative queue for dispatcher.

Each call has twelve attributes as it is processed through the system:

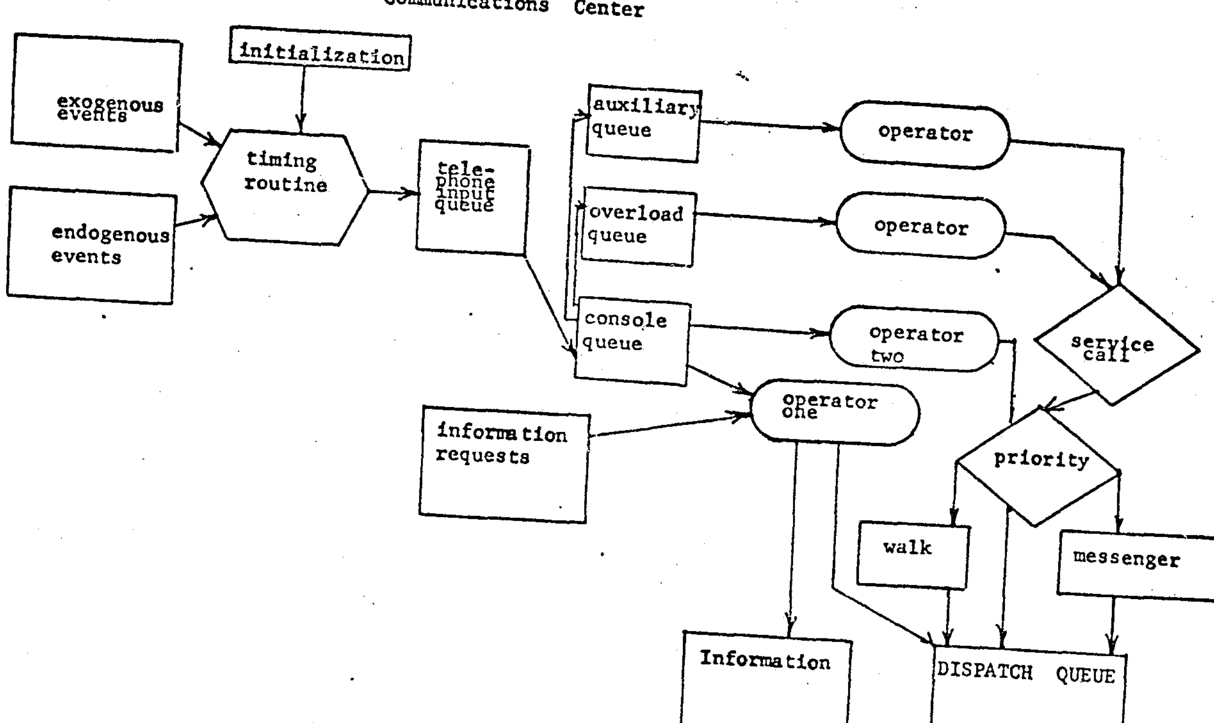
1. Type;
2. Time scheduled (final time for statistic);
3. Time on service;
4. Beatcar;
5. Zone;
6. Beat of occurance;
7. Verified incidence code;
8. Time call entered system;

---

[1] The program is 2000 cards long, needs a core of 120,000 (octal) words, and takes eleven minutes to simulate eight hours of real time.

Figure 10

Flowchart of Simulation Model of Communications Center



9. Priority for assignment;
10. Time entering console;
11. Presence of call console, overload or auxiliary queues, for purging purposes;
12. Sequential number of call for purging purposes.

The Timing routine is simply a Fortran array as discusses.

Incoming telephone calls are assigned to the telephone input queue. This permits loading of the system (more demand, more trunk lines). If a trunk line is available, the call rings at the appropriate console. After twelve seconds, if not answered, the call rings at the overload position, after thirty seconds at the auxiliary position.

One of the console operators (here called operator one) handles information requests which are of five different types. An important question to be answered is the sensitivity of the system to performing this function in a separate facility. Calls are answered and if handled at the zone level are put directly into the dispatch queue. If the overload facility has answered, the priority of the call determines if the operator or a messenger will carry the IBM card to the dispatch queue.

The model includes several behavioristic parameters. These include:

1. Number of seconds after handling a call until the operator is ready to handle the next call.
2. Answering characteristic. The operator does not answer the call immediately, but may wait a couple of seconds. This is modeled with a uniform distribution.
3. Operator availability. Operators leave their position for short intervals to coordinate response with another zone or for personal reasons.
4. Proportion of administrative radio messages handled by operators. The operators often help the dispatcher by taking the information and filling out the appropriate card.
5. Time distribution for answering calls. These differ between consoles reflecting the type of calls and clientele demanding

service. An operator may work different consoles on different nights, thus the difference in call-handling time is a zone characteristic.

Validation

The most difficult phase of constructing a simulation model is the validation stage. A theory of validation does not exist and guidelines are almost nonexistent.

The validation process can be subdivided into the following parts:

1. Validation criteria;
2. Exogenous event generation;
3. Probability distributions;
4. Model structure;
5. Initialization;
6. Parameters.

The criteria for validating the model are:

1. Average time to process a call;
2. Percentage of calls answered at console, overload, and auxiliary desks.

The communications center maintains daily records of where calls are answered. The results indicate:

	Dec. 13	Dec. (total)	Year (total) 1968
Console	53%	53.25%	53.3%
Overload	31%	35.85%	35.6%
Auxiliary	16%	11.90%	11.1%

It is noteworthy that the percentages do not vary. The total volume of communications processed differs greatly between summer and winter. A linear regression was used to determine the relationship between number of incoming calls and percentage of calls answered at the console level.

As can be seen in Table 10, the regression coefficients are all significant at the 95% level of significance. However, the correlation coefficient is not very high. It is apparent that the load factor is not the only significant variable for explaining the percentage of calls answered at the console level. Other factors would be computer inquiry handling, and behavioral factors as mentioned above.

The difference between consoles (as shown in the table) can be explained by differing nature of the calls and resultant service times.

The average time for service calls to be processed can be calculated. The mean duration of the different unit operations and the percentage of calls answered at the console overload and at the auxiliary desks are known. The average time was 81.9 seconds. This was arrived at as shown in Table 11.

The exogenous events consist of all the actual events for a given time period. Therefore this part of the simulation model did not pose any difficulties. The probability distributions for completing the unit operations were determined by taking samples of their duration. These distributions were then used to specify cumulative probability distributions which were validated against the original data by Chisquare tests.

An important consideration for simulation models is the start-up interval. How long should the model run before the influence of the starting conditions are not significant? By investigating the status of the different queues in the model, an hour of simulated time was determined to be adequate.

The model would not provide reasonable values until the behavioristic parameters, mentioned earlier, were introduced. It was assumed that the operator would need a five second "breather" between calls and that fifty of the administrative calls were handled by the operator when he was not busy.

The sensitivity of the model to the behavioristic parameters was determined

Table 10

Linear Regression of Incoming Calls/3rd Watch Versus Percentage of Calls Answered at the Console Level

Tone	$\bar{X}$	$\bar{Y}$	Y-Intercept	Regression Coeff.	T-value	Core Coeff.
1	477	.40	.67	-.00056	-4.36	-.49
2	452	.47	.72	-.00056	-4.16	-.47
3	401	.73	.87	-.00035	-2.42	-.30
4	385	.58	.71	-.00033	-2.28	-.28
5	378	.67	.87	-.00054	-2.65	-.32
6	454	.60	.80	-.00044	-2.97	-.36
7	463	.60	.89	-.00062	-3.19	-.38
8	403	.58	.69	-.00027	-1.87	-.23

Sample size per Zone = 63

$\bar{X}$ = average number of calls during third watch

$\bar{Y}$ = average percentage of calls answered at console

Table 11

Determination of Average Time for Calls

To Reach the Dispatch Queue

Desk	t1	t2	t3	t4	t5	Proportion	t6	t7
Console	36.2	25	2	0	0	53%	63.2	33.5
Overload	36.2	25	2	13	21	31%	97.2	30.13
Auxiliary	36.2	25	2	30	21	16%	114.2	18.27
						System Average		81.90

t1 = time to take a call, seconds

t2 = time to fill out the IBM card, seconds

t3 = time interval in which the operator decides to answer the call, seconds

t4 = step-up interval

t5 = time to transport IBM-card to console

t6 = average time at this level

t7 = weighted average

(See Table 12). The answering characteristic and downtime for the different operators gave the best fit to real world statistics for:

1. answering characteristic equal to two seconds;
2. console operators away from their positions for two minutes each per hour;
3. overload operators were not available for seven minutes each per hour. This is realistic as the overload operators also have other duties to perform.

The random number generator was initialized with different values to indicate the variance due to pseudo-random numbers. This variance had approximately a two second effect on the average.

Results

The questions to be investigated were:

1. priority classes;
2. number of trunk lines;
3. step-up intervals;
4. computer inquiry at consoles;
5. assignment of manpower.

The validated model, which becomes the reference point had an average of 83.1 seconds and a standard deviation of 32.9 seconds.

A two-priority system will have a shorter response time for priority one calls. The time-saving is realized where the overload or auxiliary operator walks the IBM card over to the appropriate console instead of waiting for the messenger to arrive. Since half of the calls are not answered at consoles, and the waiting time is eight seconds, the saving is four seconds plus the shorter wait in the dispatch queue.

The current number of trunk lines is not a limiting factor. Statistics are collected on the number of occurrences when all seven lines are busy and an eighth tries to enter. It is infrequent in the real world during winter season.

Figure 11

Service Time

Distibution For Communications Center
(until call reaches dispatch queue)

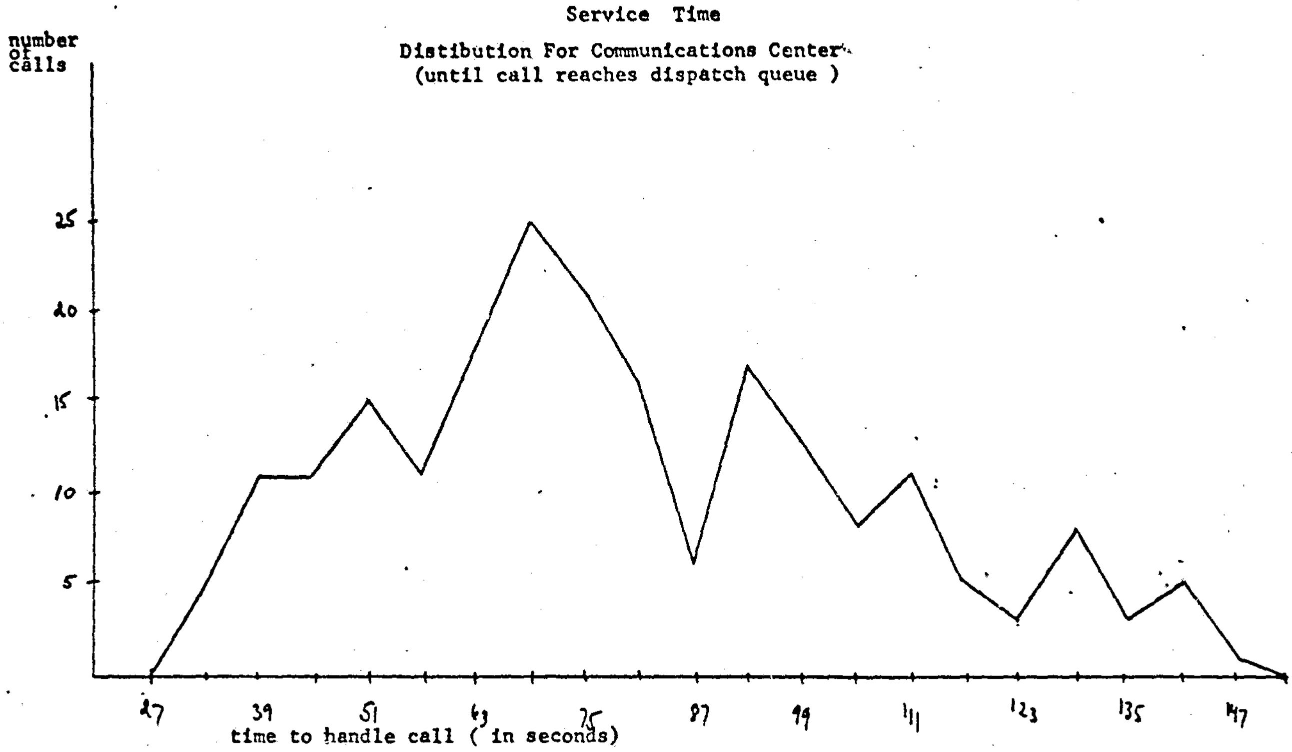


Table 12

Sensitivity Analysis of
Behavioristic Parameters

A	B	C	D	E	F	G	H
2	2	240	400	94.5	53	41	6
2	4	400	600	88.0	55	40	5
2	2	60	420	93.3	57	40	5
2	2	120	420	83.1	54	41	5
2	4	300	300	88.9	57	39	4
2	2	120	500	88.1	55	39	6
2	2	300	600	91.3	55	40	4
2	2	120	300	88.6	53	43	5
2	2	120	600	91.2	53	42	6
2	2	120	300	85.8	52	44	5
Actual performance 12/13/68				81.9	53	31	16

A= answering characteristic in seconds at console
B= answering characteristic in seconds at overload
C= seconds that operators are not available at console
D= seconds that operators are not available at overload
E= average throughput time
F= percentage of calls answered at console
G= percentage of calls answered at overload
H= percentage of calls answered at auxiliary

Table 12

Sensitivity Analysis of
Behavioristic Parameters

A	B	C	D	E	F	G	H
2	2	240	400	94.5	53	41	6
2	4	400	600	88.0	55	40	5
2	2	60	420	93.3	57	40	5
2	2	120	420	83.1	54	41	5
2	4	300	300	88.9	57	39	4
2	2	120	500	88.1	55	39	6
2	2	300	600	91.3	55	40	4
2	2	120	300	88.6	53	43	5
2	2	120	600	91.2	53	42	6
2	2	120	300	85.8	52	44	5
Actual performance 12/13/68				81.9	53	31	16

A= answering characteristic in seconds at console
B= answering characteristic in seconds at overload
C= seconds that operators are not available at console
D= seconds that operators are not available at overload
E= average throughput time
F= percentage of calls answered at console
G= percentage of calls answered at overload
H= percentage of calls answered at auxiliary

The step-up intervals are currently set at twelve and thirty seconds. By lowering the step-up interval, more calls will be answered at the overload. The time before a call is answered will be less, but the twenty-one seconds average for being transported back to the console would have to be added. The results were:[1)]

Step-up interval (seconds) 1	2	Average (seconds)	St. Dev.
5	30	84.7	36.3
10	30	86.5	35.1
13	30	83.1	32.4

Step-up interval #1 = from console to overload desks
Step-up interval #2 = from console to auxiliary desks

As can be seen, the current intervals are well chosen for the kind of load experienced on December 13.

How important is the computer inquiry activity at the console? The Sanders activity was deleted from the model and there was no significant change.

Step-up interval (seconds) 1	2	Average (seconds)	St. Dev.
13	30	83.69	38.57
5	30	82.85	30.20

The deletion of the Computer Inquiry activity did not have a significant influence on the average throughput time.

Lastly manpower levels are considered. The second position at the console was augmented by one man and the overload to its full strength of nine.

Step-up interval 1	2	Men at Position Two	Men at Overload	Average (seconds)	St. Dev.	Comment
13	30	2	6	77.76	31.7	No
5	30	2	6	74.70	33.2	Sander's
5	30	2	9	73.40	30.34	Inquiry

1 Assuming our reference point to be the true population estimate a t-test can be used to determine how large a difference of means is necessary for the sample mean to be significant. At the 95% level of significance, a difference between means of four seconds is necessary.

<u>Conclusion</u>

Current Communications Center operations are efficient. Its operations can be improved by adding another man at the console level and setting the overload step-up interval at five seconds.

The minimum throughput time for the current system is 61.2 seconds. It is, at a maximum, possible to lower the average throughput time by twenty seconds. Response time is important only for priority one calls for service. These calls constitute less than five percent of total communications.

It would seem valuable at this time to build a model of dispatch and field response time (travel time) to investigate what savings can be made at this later stage of the response process. A twenty second reduction at the Communications Center compares with one block of travel time for a motorized beat.

CHAPTER VI

ANALYSIS OF THE RESPONSE FORCE: FIELD RESPONSE

Definition

By field response is meant the activities performed by a police unit after it has been assigned and until it has completed the assignment.

The total response time consists of communications center response time and field response. It was pointed out in the previous chapter that the waiting time of a call in the dispatch queue, until a car becomes available, is dependent on assignment policies and the availability of cars. It becomes convenient to consider the impact of stacking and screening policies in the context of the field response model.

The measures of effectiveness of the Response Force were defined to be: (i) the level of service for Public Service type calls. This would include the rapid response needed for sick and injured transport and the less urgent calls that could be stacked or screened; and (ii) the crime disutility represented by the cases not dismissed by the court for incorrect police behavior. This measure includes the probability of apprehension and its qualitative aspects. It was noted earlier that the probability of apprehension is a function of the number of police units responding within a given number of minutes. This refers to the use of trapping and search procedures to capture an offender. Police units would be assigned from those available, including the Preventive and Follow-up forces. However, it is very likely that the availability of Response Force proper in an area will be an important variable.

The analysis of the field response activities entails a complex analysis of the effect of the following variables on Response Force efficiency.

1. demand;
2. service time;
3. travel time;
4. dispatch queue waiting time;

5. number of police units in Response Force;
6. total number of police units in the field.

The outline of this chapter is as follows. The first section discusses the field response model developed by Richard Larson.[1)] The next section presents a simulation model of field response and the last section uses the simulation model to evaluate a number of alternatives.

The Larson Model

The Larson model is still the state of the art with respect to field response models. It is an analytical model which determines the mean value and the density function of the response time distribution.

The model development is too long to be presented here. Only its assumptions and results will be discussed.

Assumptions:[2)]

1. patrol sector geometry is described by a rectangular grid of equidistant streets;
2. the positions of patrol and the incident are statistically independent;
3. all points on the grid are equally probable;
4. the patrolcar follows a shortest route to the scene of the reported incident;
5. a patrolcar is available to service a call with probability ≥ 0.3;
6. the city is large enough so that no queue of dispatches ever forms;
7. the dispatcher uses a "closest center-of-mass" dispatching strategy in which the exact positions of the patrol units are either not known or not considered;
8. the expected travel time is equal to a "start-up time" and expected travel distance divided by the speed of the vehicle.

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[1] Richard C. Larson, Operations Study of the Police Response System, Op. cit.

[2] ibid, page 208.

The first assumption was necessary because the model was developed for Boston, which is known for its absence of a rectangular street grid. The next assumption permits him to ignore the deterrrence effect of police presence on calls for service. The third assumption is a convenient one and he shows that his result is insensitive to it.

Larson assumes an availability of cars greater or equal to 0.3. This assumption implies that at least one car is always available in one of the four adjacent beats.

Assumption six and seven imply that interdistrict dispatching is permitted and no stacking of calls is allowed. The dispatching strategy is the same as the one used in Chicago. If a car is available he is assumed to be in the center of his beat. This is of course not true. The police officer may decide that an adjacent beat warrents more preventive patrol than his own. In addition, when returning back to his beat after assignemtn to another beat, it is physically impossible for the assumption to be true.

This is probably the most crucial assumption and involves the organizational variables of the system.

Lastly, to use a continuous approximation to his originally derived discreet formulation of expected travel distance function he adds a constant term called "start-up" time. It can also be used as a linear factor when fitting the curve to real data.

For the expected travel time Larson gets:

$$E_{tt} = \tilde{t}_s + \frac{2}{3 \cdot S}\sqrt{\frac{A}{K}}\,(2 - \rho)$$

where:

tt = travel time

t_s = start-up time

S = speed

A = area for which cars are dispatched

K = number of police units

ρ = availability

Larson also derives an expression for the density function of the

CONTINUED

2 OF 4

response time distribution.

$$f_{d_r}(d) = Pr(E_1)\ f_{d_r/E_1}(d/E_1) + \sum_{k=1}^{\infty} Pr[E_{2k}]\ f_{d_r/E_{2k}}(d/E_{2k}) + \sum_{\ell=2}^{\infty} Pr[E_3]\ f_{d_r/E_{3\ell}}(d/E_{3\ell})$$

where

$$P_r(E_1) = \rho$$

$$P_r(E_{2k}) = (1-\rho)^{2k(k+1)-3}(1-(1-\rho)^4) \qquad k = 1, 2, \ldots$$

$$P_r(E_{3\ell}) = (1-\rho)^{2\ell^2-2\ell+1}(1-(1-\rho)^{4\ell-4}) \qquad \ell = 2, 3 \ldots$$

There are essentially three different cases we must consider to derive the probability density function of d_r:

E_1 - Patrol car (0,0) assigned to service the call

E_2 - A patrol car (0,i) or (i,0) assigned to service the call (i - non-zero integer)

E_{3ij} - A patrol car (i,j) assigned to service the call (i,j - non-zero integers).

He shows that:

$$f_{d_r/E_1}(d/E_1) = \begin{cases} 4d - 4d^2 + \frac{2}{3}d^3 & 0 \le d \le 1 \\ 16/3 - 8d + 4d^2 - 2d^3/3 & 1 \le d \le 2 \\ 0 & \text{otherwise} \end{cases}$$

$$f_{d_r/E_{2i}}(d'/E_{2i}) = \begin{cases} d'^2 - d'^3/3 & |i|-1 \le d \le |i| \\ 2d'^3/3 - 4d'^2 + 7d' - 3 & |i| \le d \le |i|+1 \\ -d'^3/3 + 3d'^2 - 9d' + 9 & |i|+1 \le d \le |i|+2 \\ 0 & \text{otherwise} \end{cases}$$

where $d' = d - |i|$

$$f_{d_r/E3ij}(d'/E_{3ij}) = \begin{cases} d'^3/6 & |i| + |j| - 2 \le d \le |i| + |j| - 1 \\ (-3d'^3 + 12d'^2 - 12d' + 4)/6 & |i| + |j| - 1 \le d \le |i| + |j| \\ (3d'^3 - 24d'^2 + 60d' - 44)/6 & |i| + |j| \le d \le |i| + |j| + 1 \\ 9 - d'^3 + 12d'^2 - 48d' + 64)/6 & |i| + |j| + 1 \le d \le |i| + |j| + 2 \\ 0 & \text{otherwise} \end{cases}$$

where $d' = d - |i| - |j|$

d = travel distance in terms of sector lengths

To fit his functions to Boston data, Larson was forced to assume a multiplicative delay factor. In effect he is reducing the average speed at which the police unit is responding to a call for service. This is realistic, because if a car is not on his beat, where he should be, the travel distance will be longer; or to fit the model the effective travel speed would be slower.

The only response time data available at the Chicago Police Department was collected for an experiment conducted in the fourteenth district. As the Larson model assumes interdistrict dispatching over the area concerned, and this is not the dispatch policy in Chicago, it would be logical to apply it to a single district. Interdistrict dispatching is allowed only for emergencies and when the district is out of cars. Checking the Radio Dispatch tapes revealed that 20% of all calls for service in a district are answered by a non-district car.

The Larson model was fitted to the response curve shown in figure 12. The best fit (lowest Chi-square value) occurred at a speed of 12 mph and an availability of 40%. The Chi-square value was 42.28 (for 9 degrees of freedom) indicating a high likelihood of no fit at all.

This is probably due to (i) the 20% of interdistrict dispatching which does not permit us to view the fourteenth district as a self-contained area and (ii) the fact that the availability assumption is violated. On a Friday night as shown by the simulation model availability drops below 0.3.

Simulation Model

Introduction

We have seen that the Larson model does not exhibit a close fit with Chicago data. In addition, the model is very restricted. It can only evaluate a very limited set of alternatives.

The application of a simulation approach is ideal. It is very difficult to carry out the experiments in the real world; partly because of the undesirability of ill effects if the experiment failed, partly because of the difficulty of collecting data on system performance. A simulation model becomes a very convenient tool when evaluating a large set of alternatives. Once the better alternatives have been found, they can be tested in the real world.

It was pointed out on page 41 that a model should permit evaluation of:

1. demands for service in space/time (i.e. stacking);
2. positioning of forces in space/time (i.e. beat structure);
3. assignment rules (i.e. center of mass versus car locator system, interdistrict dispatching);
4. organizational variables (for example a decrease in service time, more on-beat patrol, less car down time for repairs on the third shift etc).

The Model

The simulation model has a modular structure developed to accommodate all of the above alternatives.

What outputs are desired from the model? The model should permit an evaluation of center of mass and car locator dispatching strategies[1)] for different alternatives. The evaluation of the benefits of a car locator system is important, because it is a fashionable hardware itme for police departments. The system represents a great commitment of resources and its possible benefits are not too well understood.

Each output from the model includes response time distributions for both strategies for the alternative being evaluated. This has the advantage of facilitating comparison as all stochastic

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[1] By a car locator strategy is meant the existence of a system that will provide the dispatcher with actual car positions; and the closest car is chosen given the assignment rules.

elements will have the same value. In addition, the travel distance saved by the car locator system is exhibited.

For validation purposes, the model provides operationsl information such as:

1. percentage of calls answered by beatcar or districtcar respectively;
2. average number of calls/car/district;
3. minutes spent on calls for service and administrative calls;
4. number of car services, car repairs, lunches, and personnals taken.

To judge system performance (i) average availability (for the system as well as district fourteen) and (ii) the probability of choosing the closest car using center-of-mass dispatching strategy is also computed.

The scope of the model has two dimensions; the number of districts and the set of activities to be included.

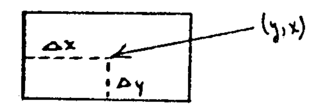
The focal point of the simulation model is the fourteenth district and its surrounding districts (eight districts in all). The reasons being the availability of data for the fourteenth district and extreme difficulty of collecting data on other districts.

The scope of activities includes the handling of calls for service and administrative down time. In addition, preventive patrol activities are modeled, so that car position can be determined when the car is considered for assignment. It is convenient to include the extra waiting time in the dispatch queue as a result of stacking procedures. Screening is easily handled by reducing the exogenous events.

There are two types of entities in the system. The first one is the beatcar. Its thirteen attributes are:

1. reference point x
2. reference point y
3. delta x for rectangle specification
4. delta y for rectangle specification
5. number of officers in car
6. availability, 0=busy, 1=available, 2=not in service
7. car is 0=outside beat, 1=inside (uniform), 2=inside (constrained uniform)
8. current location x
9. current location y
10. district
11. beat
12. time of last computation of location
13. car lunch.

Attributes one through four define the beat. It is assumed to be rectangular. The reference points x and y represent the center-of-



mass of the beat. Delta x and Delta y are the distances from the center to the beat boundaries.

The next attribute refers to how many men are assigned to the car. This is necessary as input to the car assignment subroutine. Availability provides information on car status. If equal to two, the car is not in service that evening. Attributes number 7, 8, 9 and 12 are r.cessary for determining the position of availagle cars in the sy These will be discussed further in the positioning subroutin .. Attributes 10 and 11 permit the program to gather statistics ar performance and relatethis to the administrative structure of district and beat numbers. The last item is a control variable to keep track of how many personnals a car has had and if he has had lunch. This is done conveniently through the following coding:

		Personnals No	Yes(1)	Yes(2)
Car	No	0	2	5
Lunch	Yes	1	3	4

Calls for service have the following attributes:

Input format of exogenous events

1. type of event radio dispatch 1-89;
2. timeout;
3. timein;
4. beat of occurence;
5. arreast, 1=arrest; 0=no arrest;
6. quadrant;
7. x location;
8. y location;
9. day;
10. number of cars;
11. number of men needed (1, 2, 3, 4).

By type of event is meant the thirteen category coding used by the Police Department for index crimes, miscellaneous noncriminal cases etc. The timeout and timein items schedule the event and provide the service time for handling the call. The arrest variable is necessary so the car is taken out of service for handling the arrest, which usually amounts to one hour and one half. The next three itmes determine the location of the event. The ninth item is included to permit simulation of more than one day at a time. The last two factors represent the actual number of cars and the number of men assigned to the call. This is used in the assignment routine to determine the number of cars to send in.

The structure of the program can be seen in figure 12.

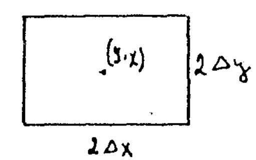
The initialization routine sets parameters and zeros out the necessary lists. It reads in the car attributes. The advantage of this arrangement is that alternative positioning methods can easily be specified. The clock routine schedules the events, either calls for service or administrative calls. If, the former, screening or stacking may be employed before the call is assigned to a car.

The subroutine assigns calls to the subroutine Center which generates the center-of-mass location of all available cars in the system and ranks them on distance away from the event location. The ranked list includes the distance, district, beat and manning for each available car.

Assign next calls subroutine Cars. Given the number of men needed, Cars chooses a car (or cars) according to the assignment rule specified.

To generate the actual travel distance for the assigned car. Assign calls Position, which generates the actual location of all available cars. This routine is really the heart of the whole simulation.

Assume a rectangular beat with its center at (x,y) and sides 2 Delta y and 2 Delta x.



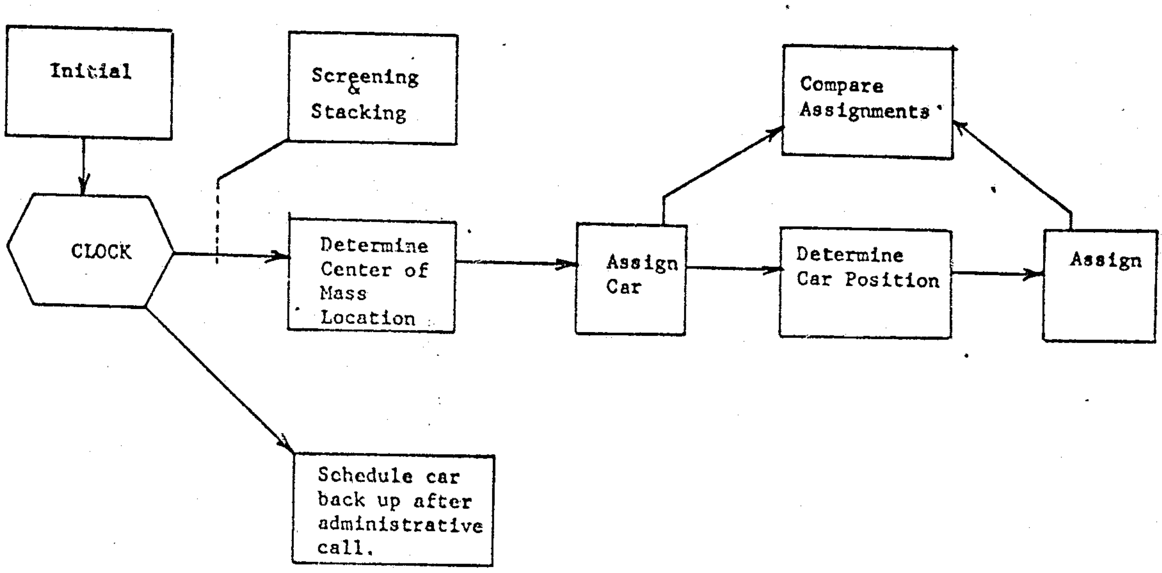
Three main cases can be distinguished for generating a car's location.

Case I: the uniform case. If item seven of the car attributes is equal to one, the car is patrolling inside his beat. His location can be determined by a drawing from a uniform distribution (Randin).

$$xloc = Randin\ (x - \Delta x,\ x + \Delta x)$$
$$yloc = Randin\ (y - \Delta y,\ y + \Delta y)$$

Figure 12

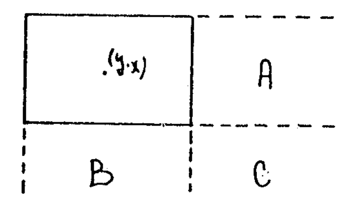
Flowchart for Simulation Model
of Field Response



<u>Case II</u>; <u>the constrained uniform case</u>. If a car is assigned to a call inside his beat item seven is set to 2, item 12 to the time when he comes back up and items 8 and 9 to the coordinates of the event. Naturally the cars position after he becomes available is a function of the time that has passed since he came back up. His location can be generated by determining the union of the beat rectangle and the rectangle, the sides of which are equal to time elapsed since his last known location times speed of travel. It is now possible to generate his location with a uniform distribution.as before.

<u>Case III</u>: <u>Outside beat</u>. The more difficult case appears when the car is assigned outside his beat. Item seven of the car attributes is set equal to 0. As before the coordinates of the event are stored and the time is entered in item 12.

Three distvinct alternatives are apparent:



The car may be in the general direction of A, B. or C[1]. We assume that the car returns by the shortest route to his beat and that there is a rectangular street grid.

<u>Alternative I</u>. From point A the car will proceed along the same y-coordinate until the boundary of the beat is reached. If not enough time has elapsed to reach the beat boundary ,his location will be: $(x + \Delta \text{time} \cdot \text{speed}, y)$. If there is additional time, item seven is set equal to two, item 12 is set equal to the travel time needed to reach the boundary plus the original time and transfer to case II is made.

---

[1] The argument is symmetrical.

Alternative II. The same calculations are performed for the y coordinate for an initial position of B.

Alternative III. For the third alternative C, some simplifying assumptions are made. The car is assumed to travel north/south or east/west until his extended beat boundary is reached, at which he follows the boundary to the beat corner. The initial direction is determined by a random function with 50% chance for either direction. As before the distance to be covered is determined from the time and speed. When the car reaches the beat boundary proper transfer is made to Case II.

After the actual locations of the cars have been determined a ranked list, like before, is generated. The same assignment routine with the same assignment rules is called (though the cars are not actually assigned). The position of the center-of-mass assigned cars are used to compare travel distances between the two strategies; as the actual locations of the center-of-mass dispatched cars are now known.

Administrative calls are events such as:

1. car service (gas);
2. car repair (radio, tires, engine);
3. personnals;
4. lunch.

The initialization routine takes 25% of the cars out of service, as soon as the watch begins, to fill their tanks. The rest of the car services are taken during the watch. When each car becomes available after a call for service or administrative call, a uniform random number between one and sixty is drawn to determine when the car should try to take a personnal, lunch or car service.

The distribution of lunches (see figure 13) as a function of time, were used to determine cumulative probability functions for taking a car out of service. The service time was a uniform number between 10 and 20 for personnals and car service and a empirical distribution for lunches (see figure 14).

Validation

Ideally, the simulation model should be compared with actual response times and key characteristics of the real world for all eight districts. However, data is only available for the Fourteenth district on response times.

The model must therefore be validated against Fourteenth district data. A great obstacle is the fact that there are too many unknown parameters.

1. return speed;
2. return route;
3. response speed;
4. start-up time.

When a beatcar has been assigned outside his beat, his position, on returning to his beat, is a function of return speed and the route taken. The beatcar is supposed to return by the shortest route and carry out preventive patrol inside his beat.

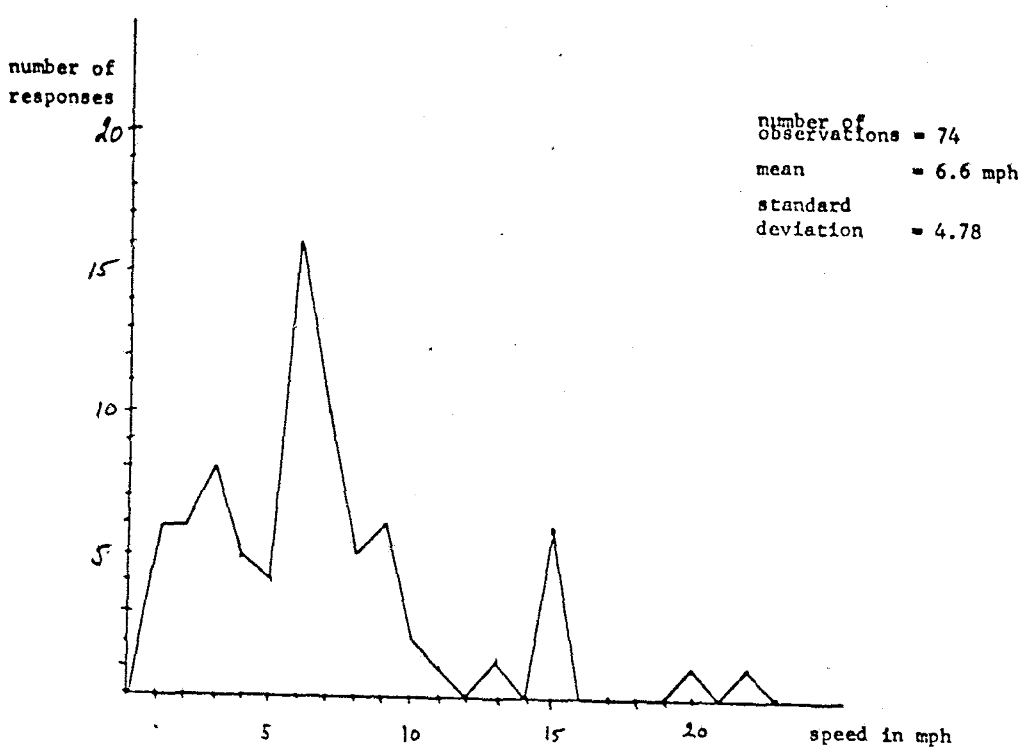
The patrol speed of a Task Force patrol unit is 9.2 mph.[1)] To determine the actual speed of Response Force cars, patrol cars were asked to give their location when assigned. Knowing the response time permitted the determination of the response speed (see figure 15). The average speed was 6.5 mph. This clearly indicates that a location was given which represented where the officer thought he ought to have been. In fact, both the response speed and the distance covered were higher. The conclusion must be that the shortest route back to the beat is not taken.

Neither the response speed not the start-up time are known. The start-up time represents the time for receiving the assignment and reporting time of arrival to the dispatcher.

[1] David Olson, Final Report: Operations Research Task Force, Chicago Police Department, 1969

Figure 13

Response Speed Distribution



It is necessary to include this so that comparisons can be made with actual response times. The start-up time is set equal to 30 seconds. Fixing the return speed at 9.2 mph. and determining the response speed which yields the best response distribution fit to real data, yields 9.6 mph. and a start-up time of one minute (Chi-square is 6.00 for 15 degrees of freedom, which is significant at 2.5% level).

The dilemma is resolved by assuming that department policy is followed. After completing an assignment, the beatcar will proceed at preventive patrol speed following the shortest route to his beat. The response speed is assumed to be twelve mph. Larson used this speed in his model, and experienced police officers felt that it was a good estimate.

The simulation model therefore is a picture of what the real world would be like under department policy and the assumed speeds. This is a valid problem formulation for the following reason. The beat structure functions as a rough positioning tool and car locator mechanism. It is this system, working as it should, which is compared with a car locator system.

The model is validated against the following criteria:

1. percent of calls for service answered by beatcar or district car;
2. minutes spent on administrative calls;
3. number of car services, car repairs, lunches, and personnals.

The average percent of calls answered by the beatcar is approximately 23% and 63% for district cars. However, these figures are for August of last year.

Demand has increased approximately 10% so that the figures are closer to 20% and 60% respectively. The simulation model gets 17% and 55% respectively.

The simulation model generates the administrative downtime. Two weeks of data on administrative calls were collected in February.

Figure 14.

DISTRIBUTION OF LUNCHES
FOR 24 HOURS

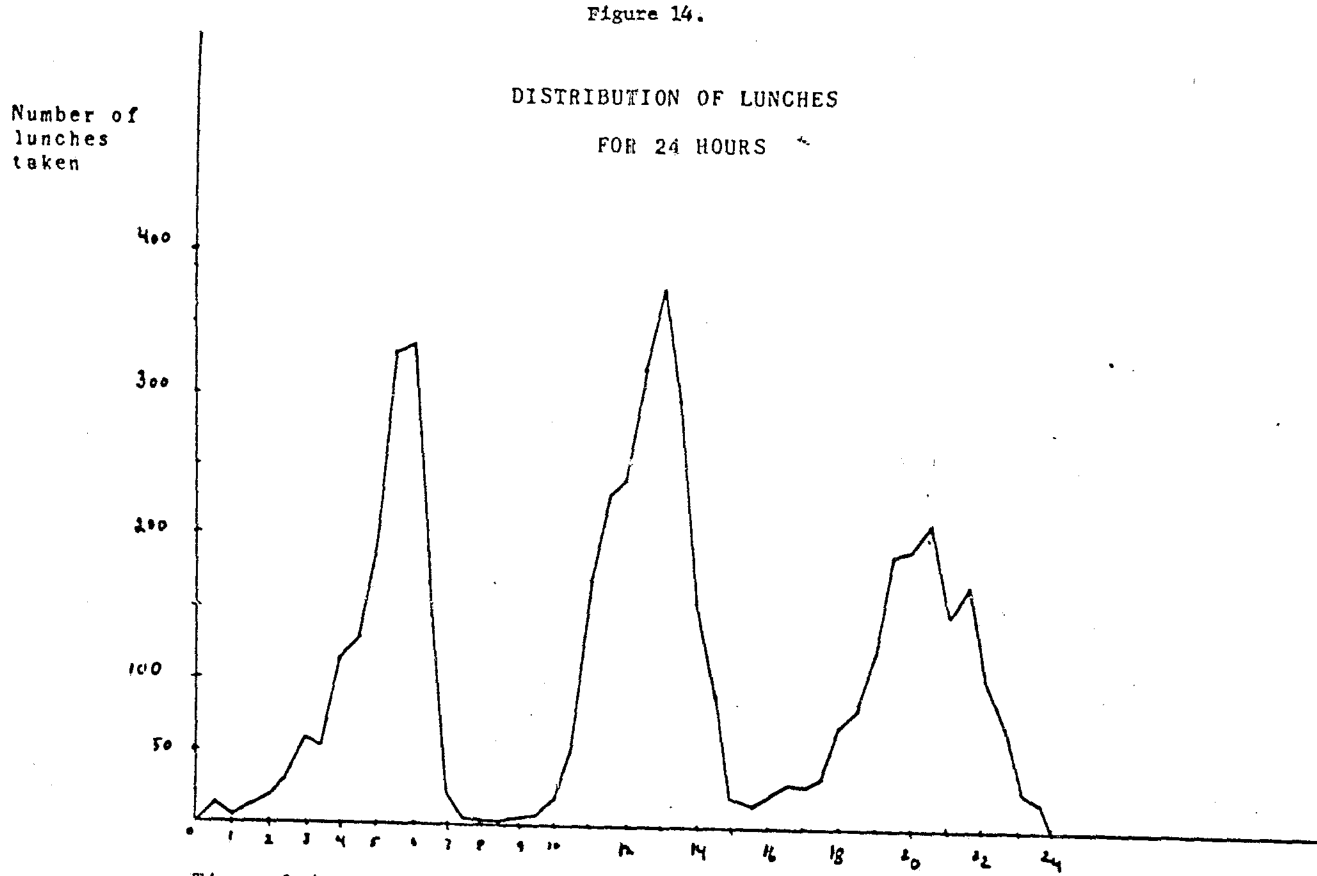
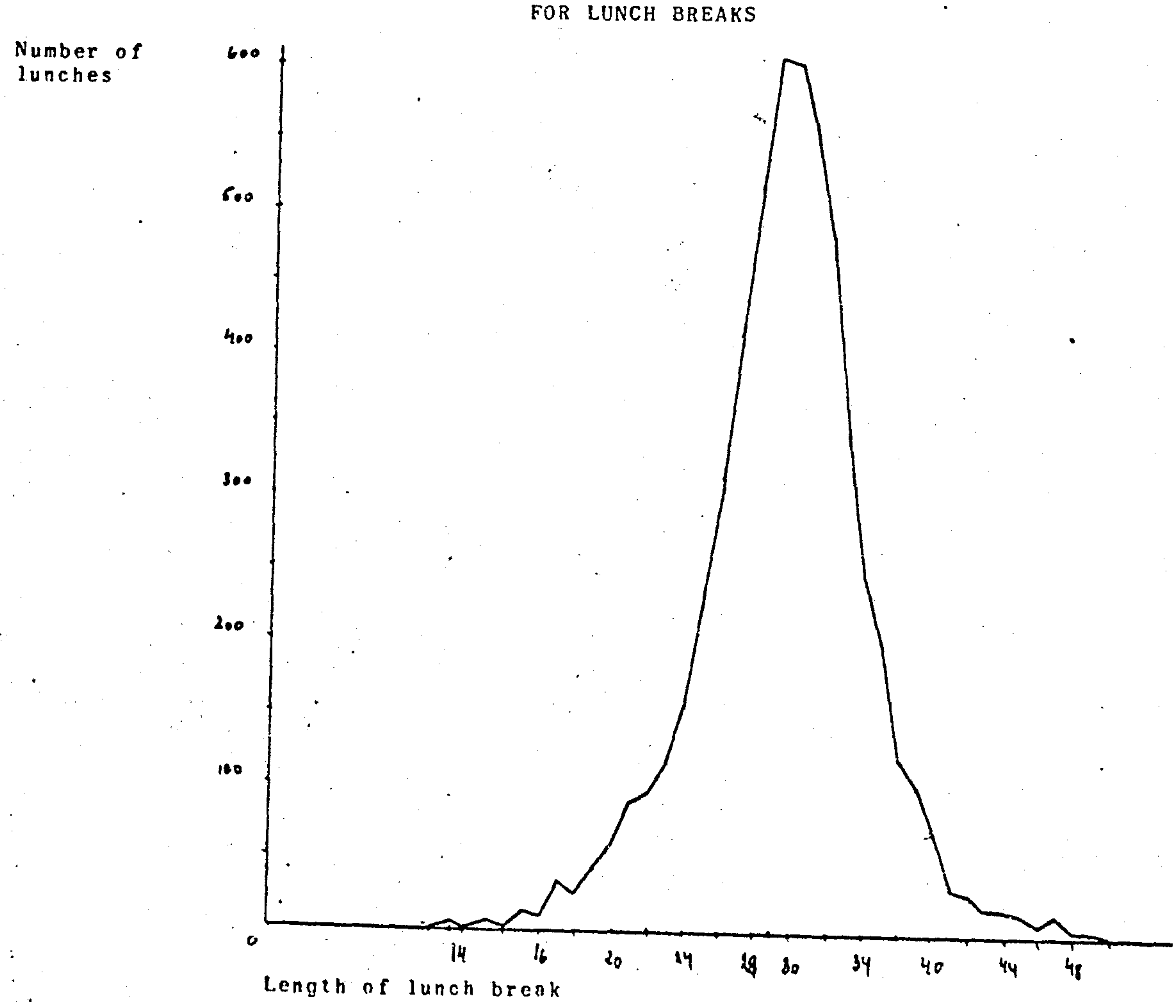


Figure 15: SERVICE TIME DISTRIBUTION

FOR LUNCH BREAKS



Downtime is related to behavioristic parameters, so that it is safe to assume that these data will be representative. Approximately 69 minutes were spent on administrative calls per car/watch. The simulation model generates 64.3 minutes during eight hours of simulated time. The number of administrative events were:

121 car services
1 car repairs
127 lunches
162 personnals.

There are 132 cars in the system that is simulated and almost all need service during an eight hour tour. Just about every unit had lunch, and got at least one personnal each.

It is not necessary that all cars get two personnals or lunch. Sometimes an officer skips lunch and personnals have to be permitted by the dispatcher. If availability is low, permission is not granted.

Different initialization periods were used; one half hour, one hour and one and one half hour. A one hour initialization period was sufficient to load the system.

Real world response times for the fourteenth district are shown in figure 16. The mean is 7.68 minutes and the standard deviation 5.65 minutes.

The statistics generated by the simulation model are random variates. An important question is the change that may be attributed to a different random number seed. Values are given for the key characteristics; (i) mean and standard deviation of the response time distribution and (ii) availability of cars for all eight districts and the fourteenth district in particular.

Figure 16.

FOURTEENTH DISTRICT

RESPONSE TIMES

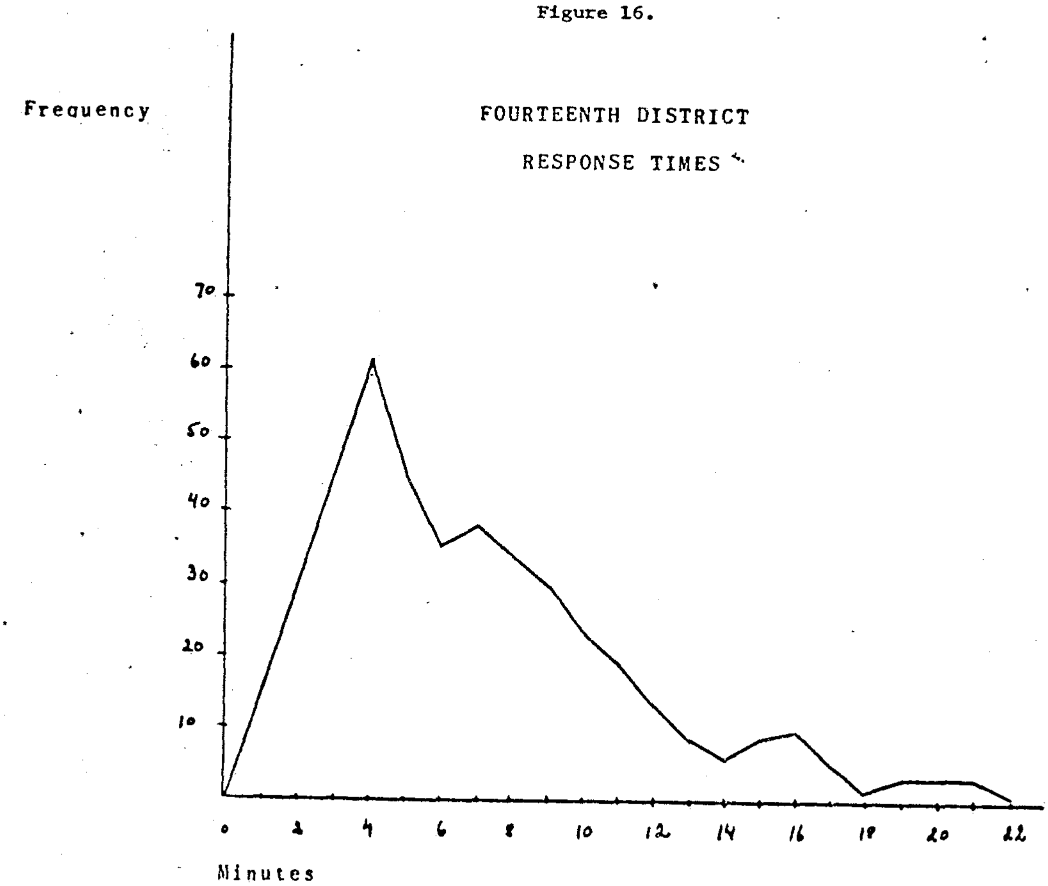


Figure 17.

Test of Random Number Seeds

	System Variable		Fourteenth District	
	Test 1	Test 2	Test 1	Test 2
Mean Response Time	8.50 min.	7.37 min.	6.44 min.	6.13 min.
Standard Deviation	10.32	7.59	5.81	4.99
Availability	35%	35%	33%	38%

Results

First a comparison will be made between actual system (eight districts) performance and that predicted by the simulation model following department policies.

Figure 18.

Comparison Between Real World Performance
and
Simulated Performance Following Department Policy

	Real World	Simulation
Mean Response Time	7.68 min.	6.44 min.
Standard Deviation	5.65	5.81
Mode	4.00	4.00
Number of Observations	454	84
Availability	35%	35%
Percent of calls answered:		
a. by beatcar	20%	17%
b. by district car	60%	55%

The distributions are remarkably similar. Given the scope of the response distribution curve and relatively low number of observations the mode is a better characteristic for comparison than the mean.

The alternatives to be investigated are center-of-mass (CM) and car locator (CL) strategies with respect to:

1. Present assignment rules
   a. normal workload
   b. reduced workload
2. Interdistrict dispatching
   a. normal workload
   b. reduced workload

Case 1a: Present Assignment rules, normal workload.
The statistics for the present system following department policy under a center-of-mass dispatching strategy is compared with a car locator system. The important characteristics are the average response time, its standard deviation and availability. Availability is related to the ability to carry out trapping and search maneuvers. The only difference between the two alternatives evaluated is the knowledge of the exact location of the car using a car locator (see figures 20 and 21 for graphic representation).

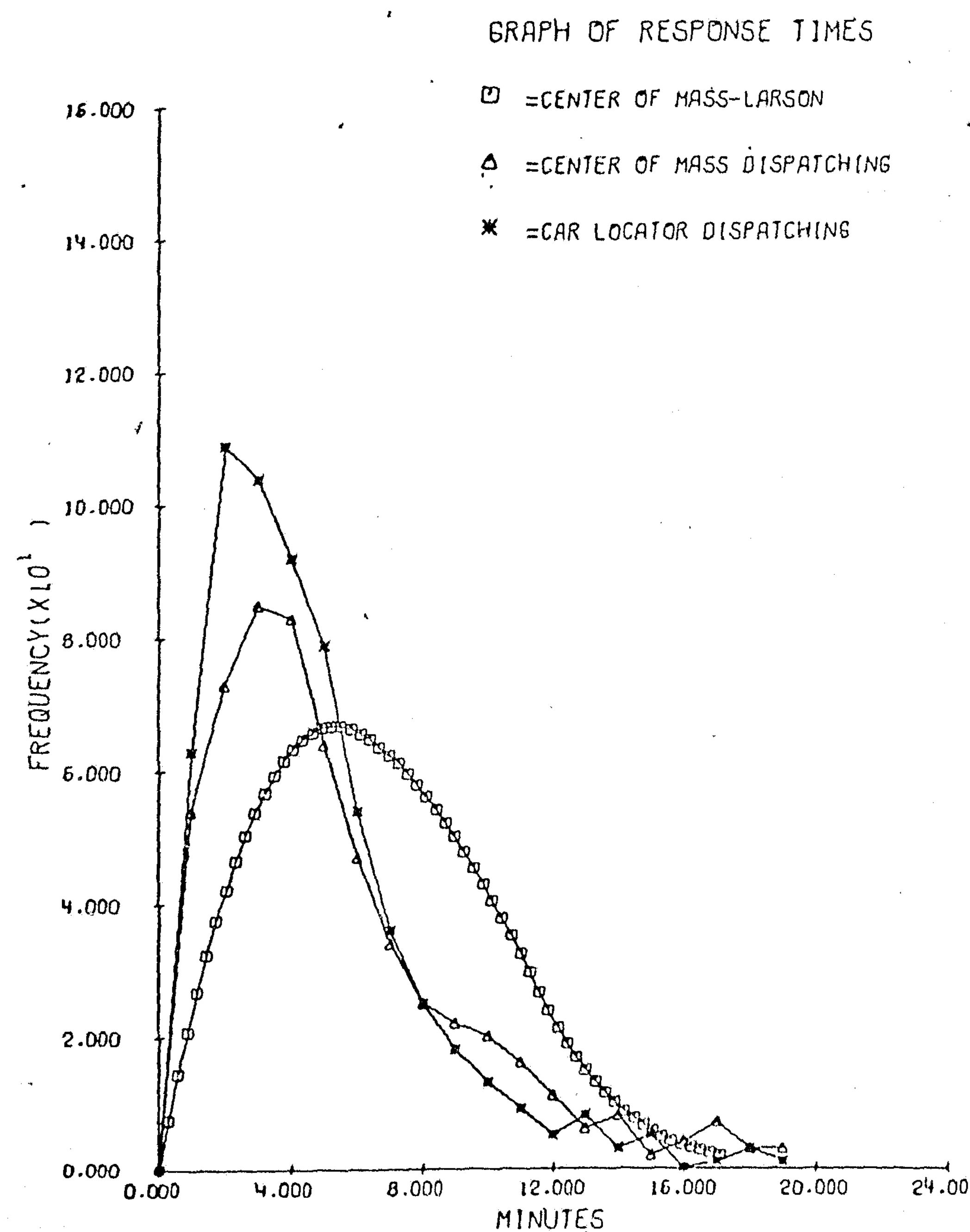
Figure 19.

Comparison of Two Dispatching Strategies
with
Normal Assignment Rules and Workload

	Mean	Standard Deviation	Mode	Availability
CM: System	8.50 min.	10.3	3.0 min.	35%
Fourteenth District	6.44 min.	5.81	4.0 min.	33%
CL: System	4.82 min.	3.73	-	-

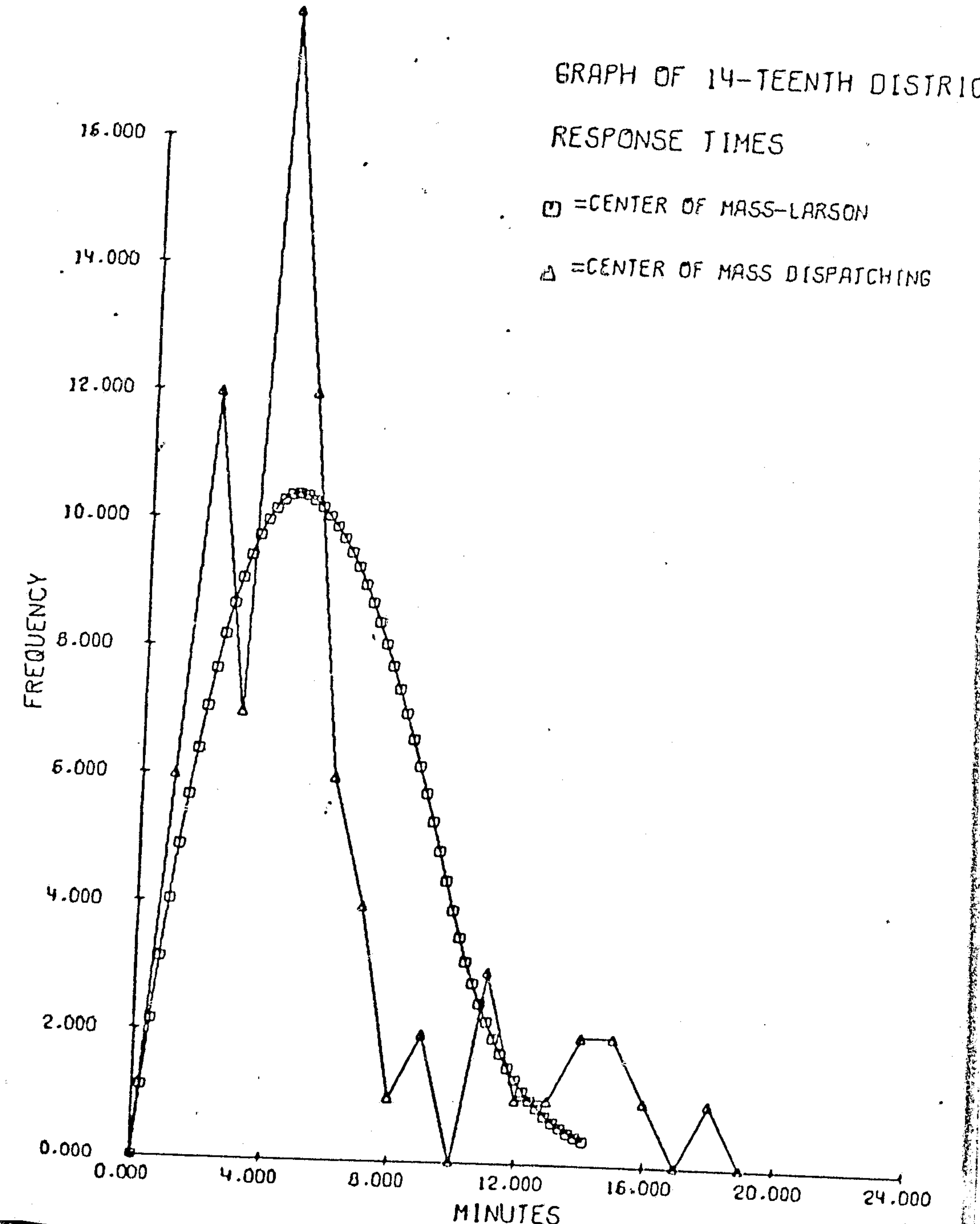
The car loactor reduces the mean response time substantially.

FIGURE 20.



GRAPH OF RESPONSE TIMES
=CENTER OF MASS-LARSON
=CENTER OF MASS DISPATCHING
=CAR LOCATOR DISPATCHING
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
FREQUENCY(X10^1)
0.000
4.000
8.000
12.000
16.000
20.000
24.000
MINUTES

FIGURE 21.


GRAPH OF 14-TEENTH DISTRIC
RESPONSE TIMES
=CENTER OF MASS-LARSON
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FREQUENCY
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4.000
8.000
12.000
16.000
20.000
24.000
MINUTES

Case 1b: Present assignment rules, reduced workload
One effective way of increasing availability and decreasing response times, is to decrease the number of calls responded to. This policy has been instituted in St. Louis and Detroit. Incoming calls are evaluated by an experienced police officer to determine if police service really is needed. A thirty percent reduction of miscellaneous-other calls is assumed. This would probably represent an upper limit of call screening (see figures 23 and 24 for graphs).

Figure 22.

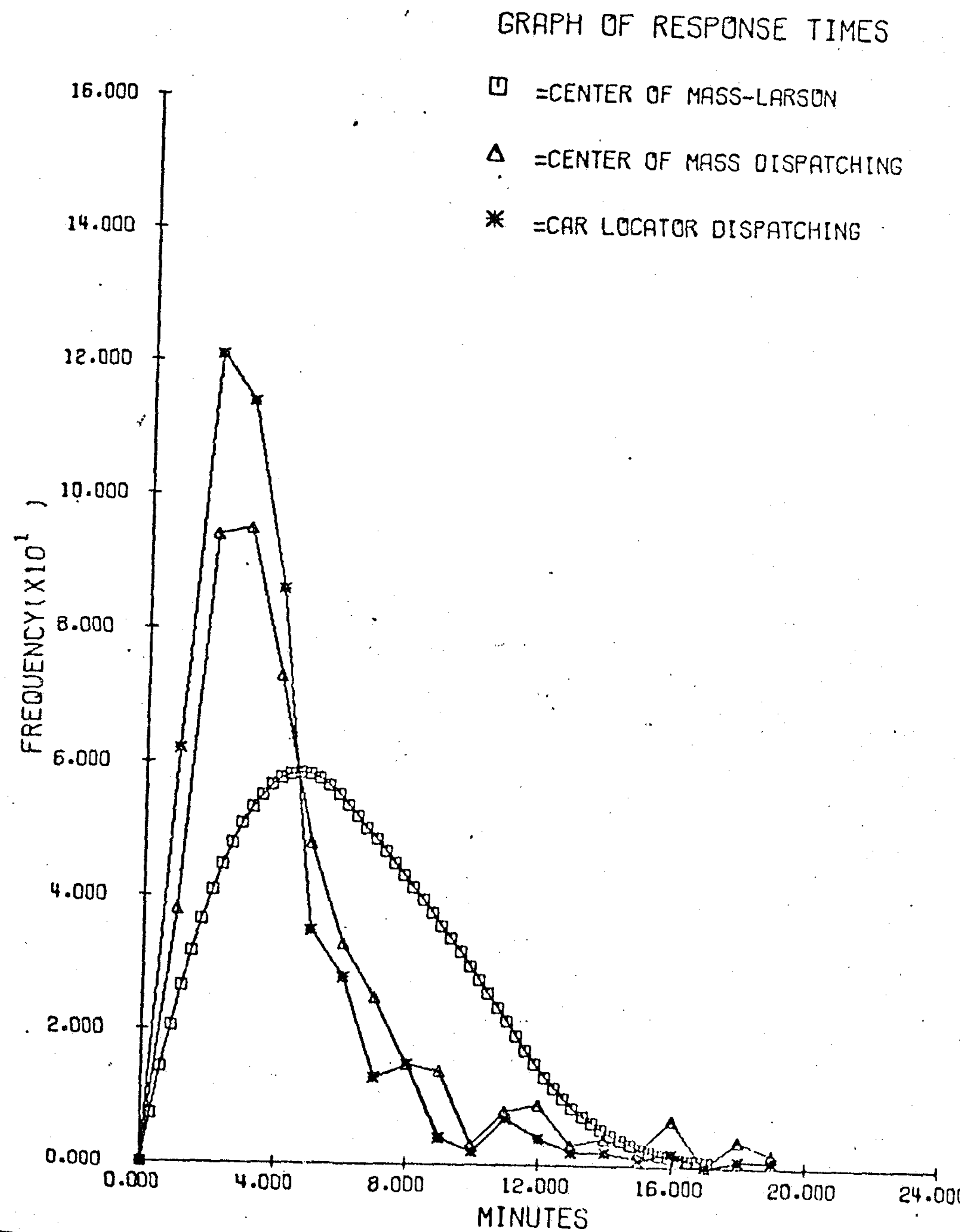
Comparison of Two Dispatching Strategies
with Reduced Workload

	Mean	Standard Deviation	Mode	Availability
CM: System	5.92 min.	6.98	3.0 min.	45%
Fourteenth District	4.68	2.24	4.0	48%
CL: System	3.77	2.87	2.0	

The outcome is a reduction in response time which is greater than that shown by using a car locator in the previous case.

Case 2a: Interdistrict dispatching, normal workload.
Interdistrict dispatching means that the nearest car is dispatched, even if the car belongs to a district different from the location of the call for service. Current department policy for reasons of administrative efficiency does not permit this alternative (see figures 26 and 27 for graphs).

FIGURE 23.



GRAPH OF RESPONSE TIMES
=CENTER OF MASS-LARSON
=CENTER OF MASS DISPATCHING
=CAR LOCATOR DISPATCHING
16.000
14.000
12.000
10.000
8.000
6.000
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0.000
FREQUENCY(X10^1)
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4.000
8.000
12.000
16.000
20.000
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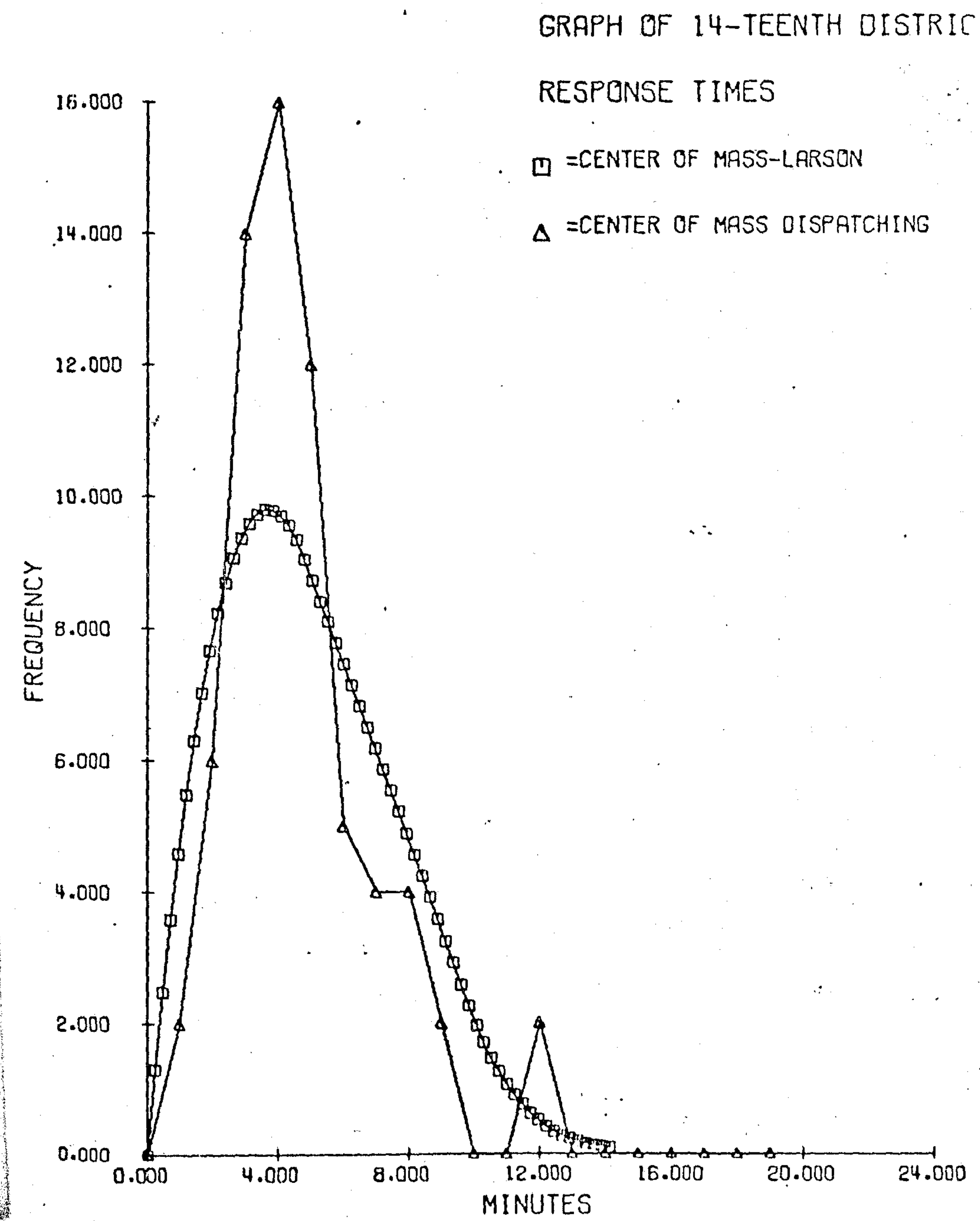
MINUTES

FIGURE 24.


GRAPH OF 14-TEENTH DISTRICT
RESPONSE TIMES
=CENTER OF MASS-LARSON
=CENTER OF MASS DISPATCHING
FREQUENCY
16.000
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0.000
4.000
8.000
12.000
16.000
20.000
24.000
MINUTES

Figure 25.

Comparison of Two Dispatching Strategies
with Interdistrict Dispatching

	Mean	Standard Deviation	Mode	Availability
CM: System	5.89	7.47	3.0	39%
Fourteenth District	6.16	9.97	5.0	39%
CL: System	4.37	3.90	3.0	

Comparing these results with the previous case, it is clear that reduced workload has a larger effect (the availability factor is much greater) than simply allowing interdistrict dispatching.

Case 2b: Interdistrict dispatching and reduced workload
The possibility certainly exists to combine the two alternatives (see figure 29).

Figure 28.

Comparison of Two Dispatching Strategies
with Interdistrict Dispatching and Reduced Workload

	Mean	Standard Deviation	Mode	Availability
CM:System	4.53	4.37	2.0	48%
Fourteenth District	3.86	1.85	4.0	47%
CL:System	3.66	3.10	2.0	

It is clear that still more improvement in response time occurred. Availability did not change much from example 1b. The above examples have evaluated two systems. However, cars were dispatched using the center-of-mass strategy. What bias is introduced into the car locator strategy results by not actually dispatching according to this strategy?

To determine this, cars were dispatched using the car locator assignment criteria for the interdistrict, reduced workload case.

Figure 30.

Comparison of Two Dispatching Strategies with Interdistrict Dispatching and Reduced Workload with Car Locator Assignment

	Mean	Standard Deviation	Mode	Availability
CM: System	4.43	4.36	2.0	
Fourteenth District	3.69	1.97	2.0	50%
CL: System	3.69	2.96	2.0	48%

It is evident that the error introduced by evaluating a car locator system, when cars are actually dispatched according to the center-of-mass strategy, is negligeable.

Summary

It is clear that the car locator system does not improve system efficiency greatly by itself. At most two minutes are saved. When interdistrict dispatching or screening are allowed the average value falls by approximately 2.5 minutes. When both policies are used the saving is 4 minutes.

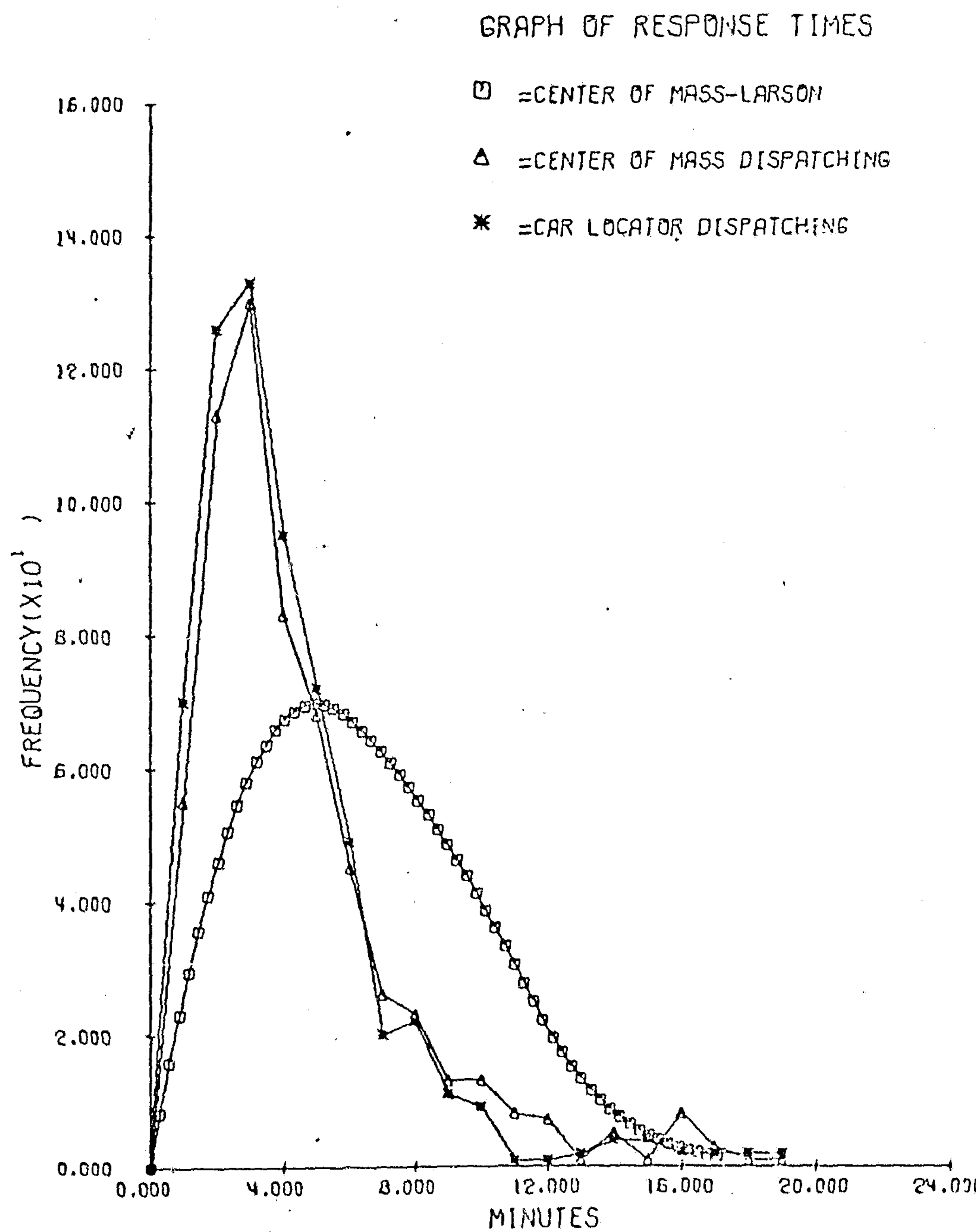
By making an administrative change interdistrict dispatching will increase the average availability from 35% to 39%. This saving is realized solely from less cross travel as everything else remains the same for the two alternatives.

The most spectacular result is a combination of the two major alternatives. The average response time and standard deviation drops in half and the modal value drops by a full minute, and the availability factor increases from 29% to 48%. The car locator offers a saving of an additional minute.

The conclusion must be that the greatest savings lie in policy changes rather than hardware. However, the car locator system might be worthwhile given the other changes.

In addition, the car locator offers great opportunities for supervision. This would probably result in shorter service times, more time on beat patrol, and release of supervisory personnel for other duties.

FIGURE 26.


GRAPH OF RESPONSE TIMES
=CENTER OF MASS-LARSON
=CENTER OF MASS DISPATCHING
=CAR LOCATOR DISPATCHING
FREQUENCY(X10¹)
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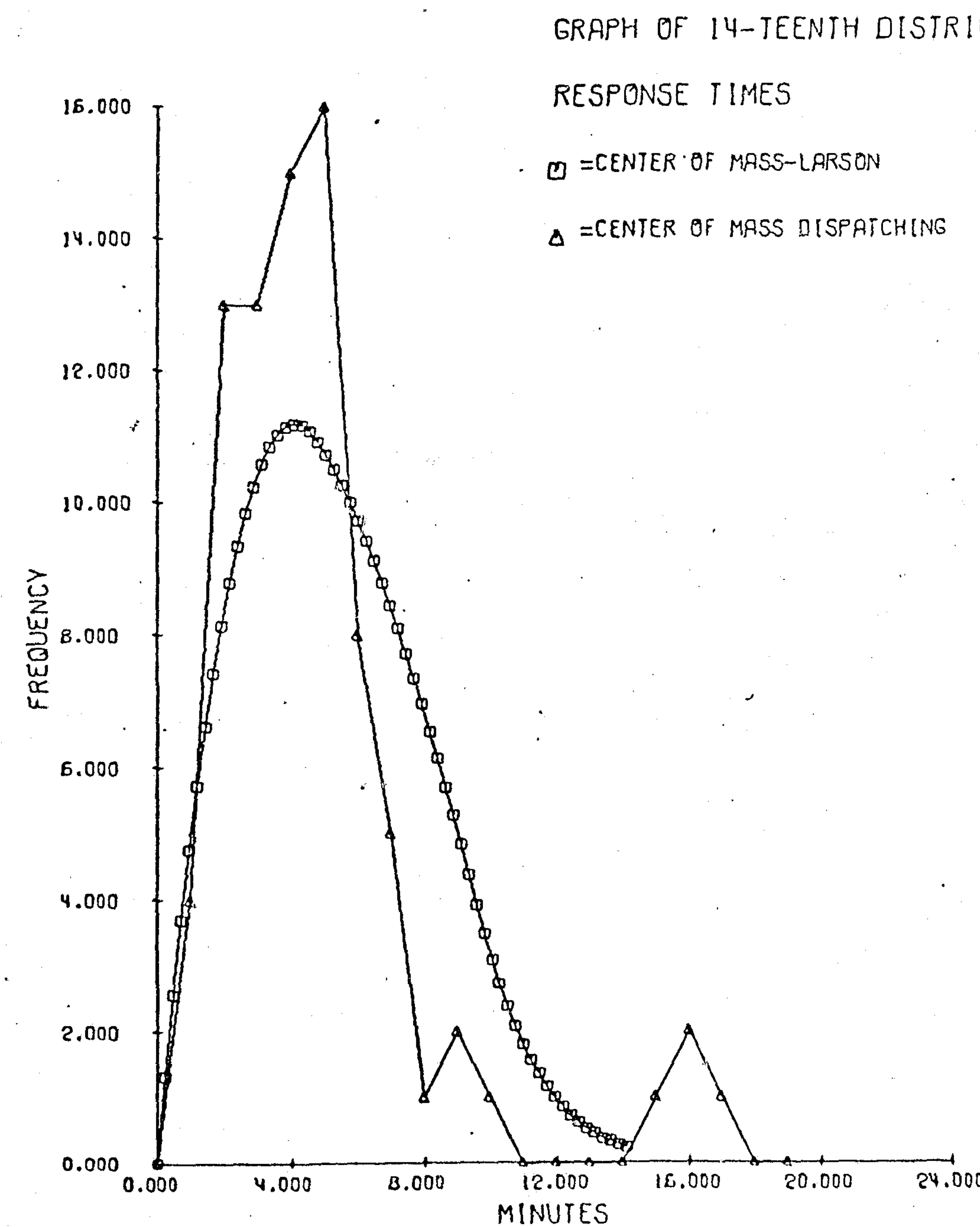
MINUTES

FIGURE 27.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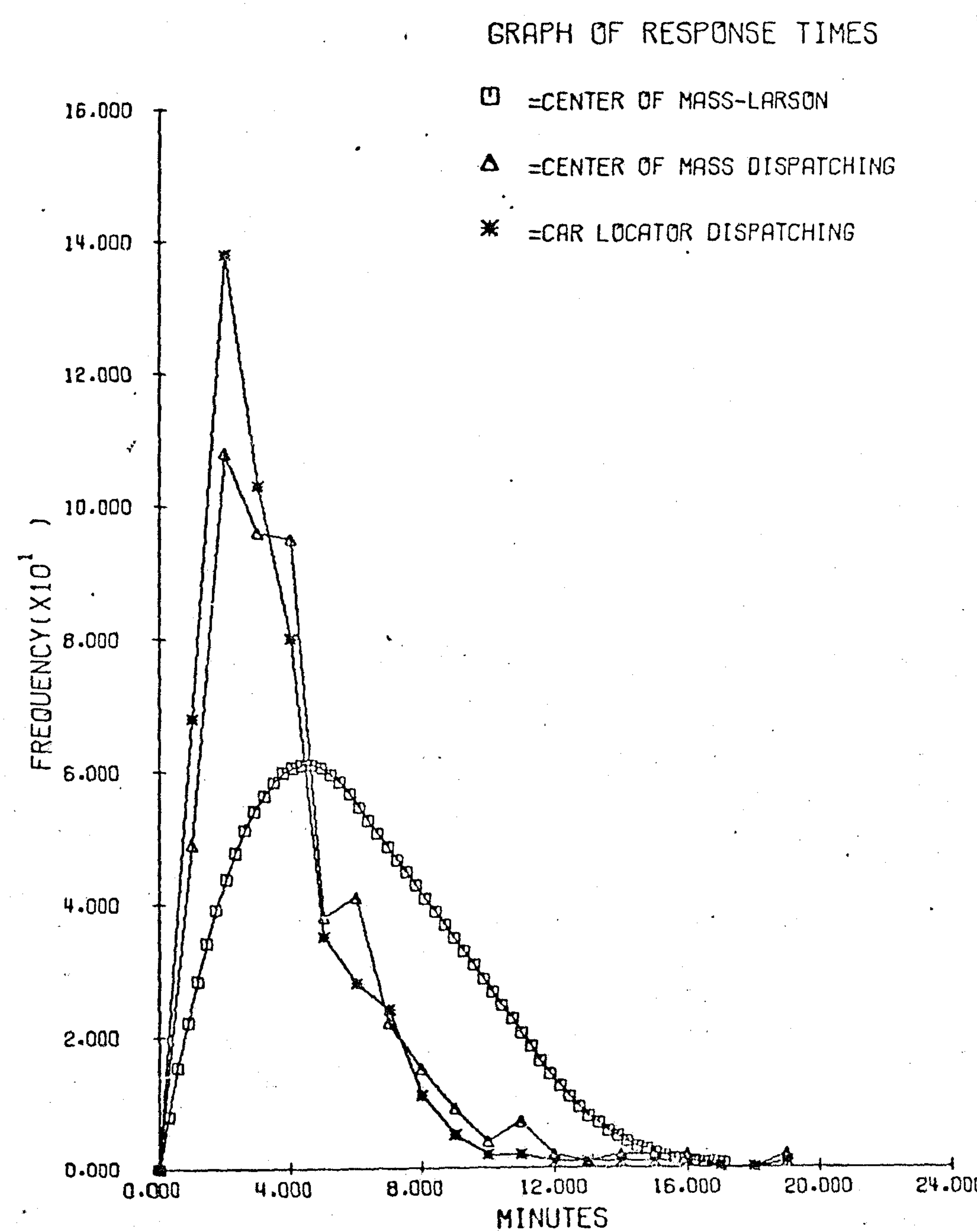
MINUTES

FIGURE 29.


GRAPH OF RESPONSE TIMES
=CENTER OF MASS-LARSON
=CENTER OF MASS DISPATCHING
=CAR LOCATOR DISPATCHING
FREQUENCY(X10^1)
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4.000
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MINUTES

CHAPTER VII

CONCLUSION

The foremost conclusion is that quantitative analysis can contribute to the understanding and improvement of police systems.

The program budget is the first to be defined and applied to a police department.[1)] It establishes, without doubt, that most police resources are devoted to the prevention and control of crime.

The Communications Center was shown to be efficient. The removal of the on-line computer inquiry activity from the consoles did not decrease communications center response time. It was shown that the most effective change in response time would be realised from adding a third man to answering telephone calls at the console.

It is not likely that great improvements can be realized at the Chicago Police Department by installing a computerized dispatching system. The most logical extension of center capacity would come from the addition of extra consoles.

The analysis of the field response force found that administrative changes, such as interdistrict dispatching and screening of calls would have a greater effect on systems efficiency than a car locator per se.

<u>Future Research</u>

The need for future analysis in the police system is great. Profitable areas include:

1. determine the functions of response time versus probability of arrest for different types of crime;
2. analysis of Response Force strategies and tactics;
3. analysis of the Preventive Force;
4. analysis of Follow-up Force;
5. analysis of Public Service function;
6. analysis of Police-Community relations.

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[1]This program budget is being implemented in Boston and St. Louis

Moving to the higher level system, the Criminal Justice System, it is evident that the interfaces between the criminal justice system sub-systems need be investigated as well as the sub-systems proper.

However, there is no need to stop at this level. The social system itself should be analyzed as to why individuals commit criminal acts. That is, what are the dynamics of the forcing function referred to in the conceptual model. It is very likely that changing the socio-economic-behavioral variables will have a greater effect on criminality than increasing the effectiveness of the Criminal Justice System and its sub-systems.

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APPENDIX A

COMMUNICATIONS CENTER

SIMULATION: TIME DISTRIBUTION

FREQUENCY DISTRIBUTION

OF STOLEN CAR INQUIRIES

ON SANDERS UNIT

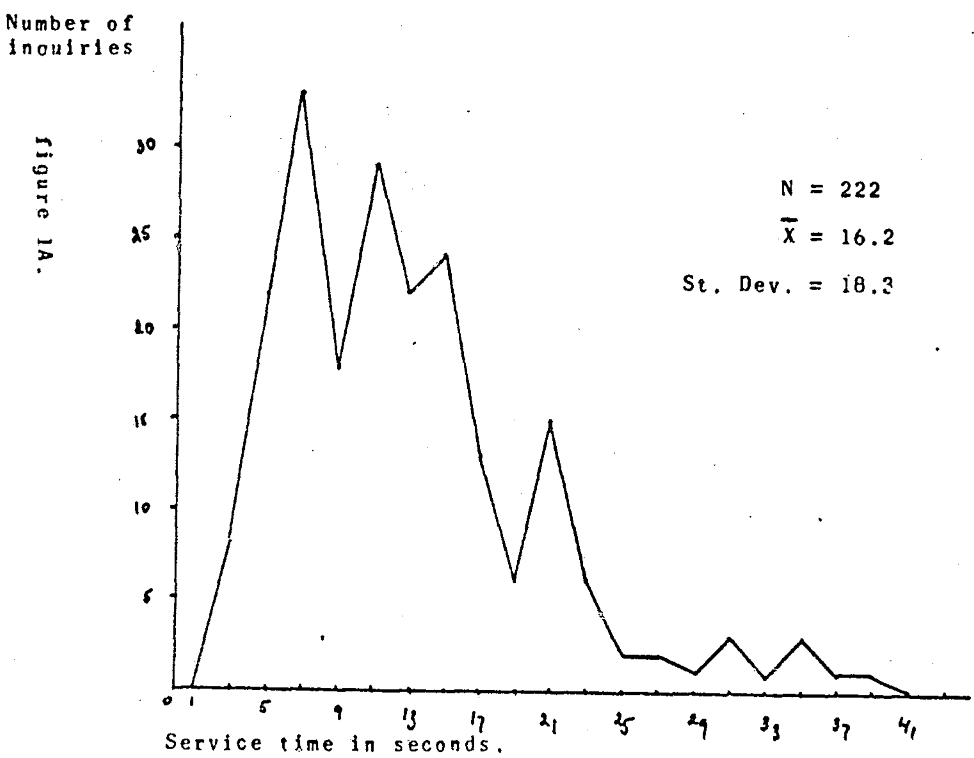


figure 1A.

FREQUENCY DISTRIBUTION

OF NAME INQUIRIES

ON SANDERS UNIT

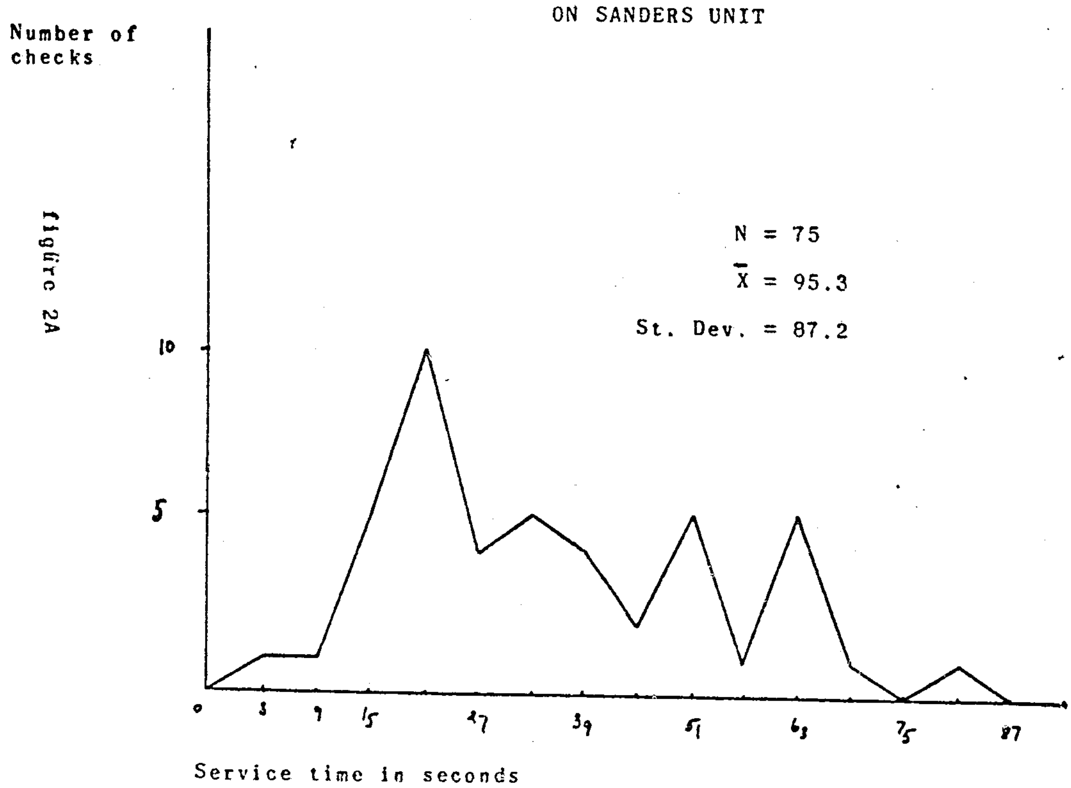


figure 2A

HOT DESK

FREQUENCY DISTRIBUTION

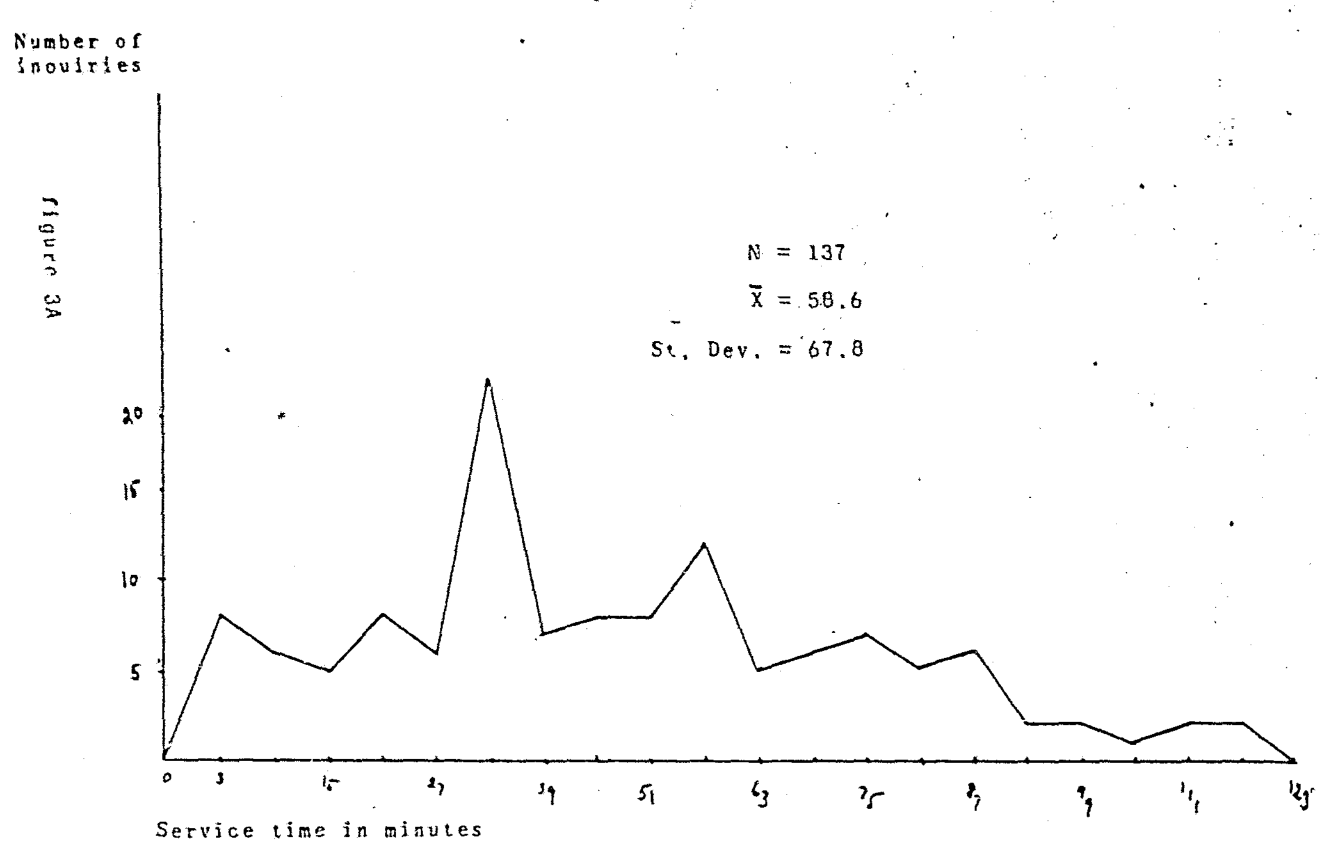


figure 3A

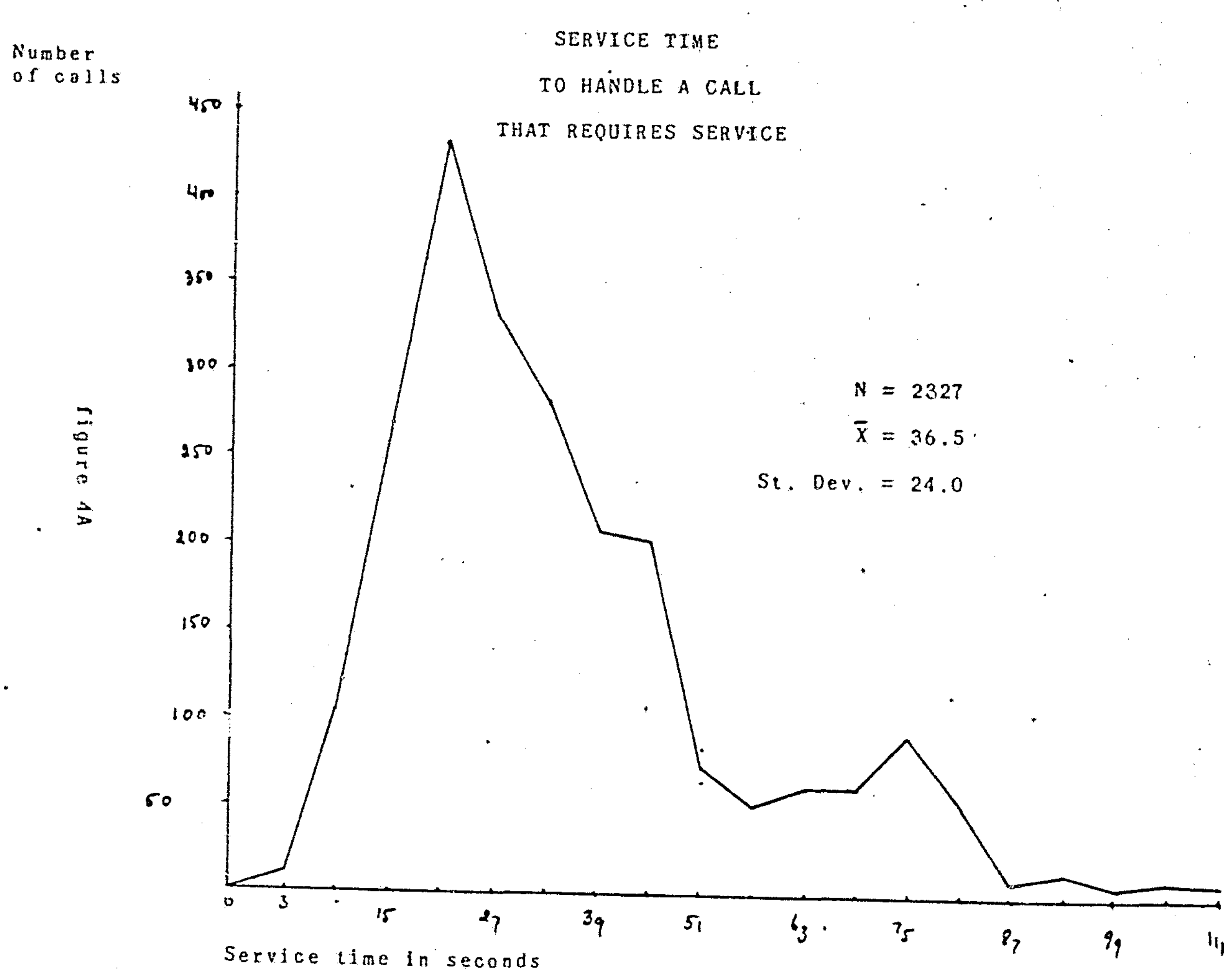

SERVICE TIME
TO HANDLE A CALL
THAT REQUIRES SERVICE
Number of calls
450
400
350
300
250
200
150
100
50
N = 2327
$\bar{X}$ = 36.5
St. Dev. = 24.0
0
3
15
27
39
51
63
75
87
99
111
Service time in seconds

figure 4A

SERVICE TIME

FOR NON-DISPATCH CALLS

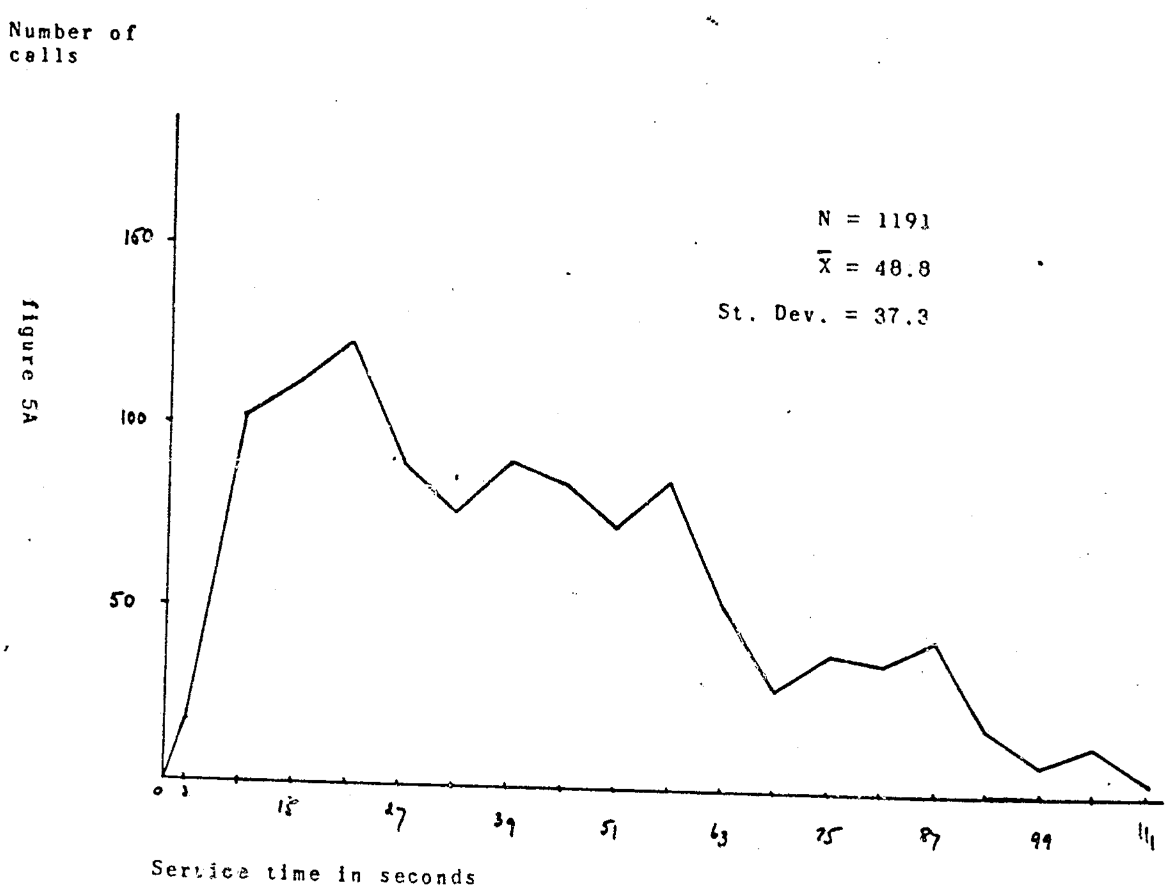
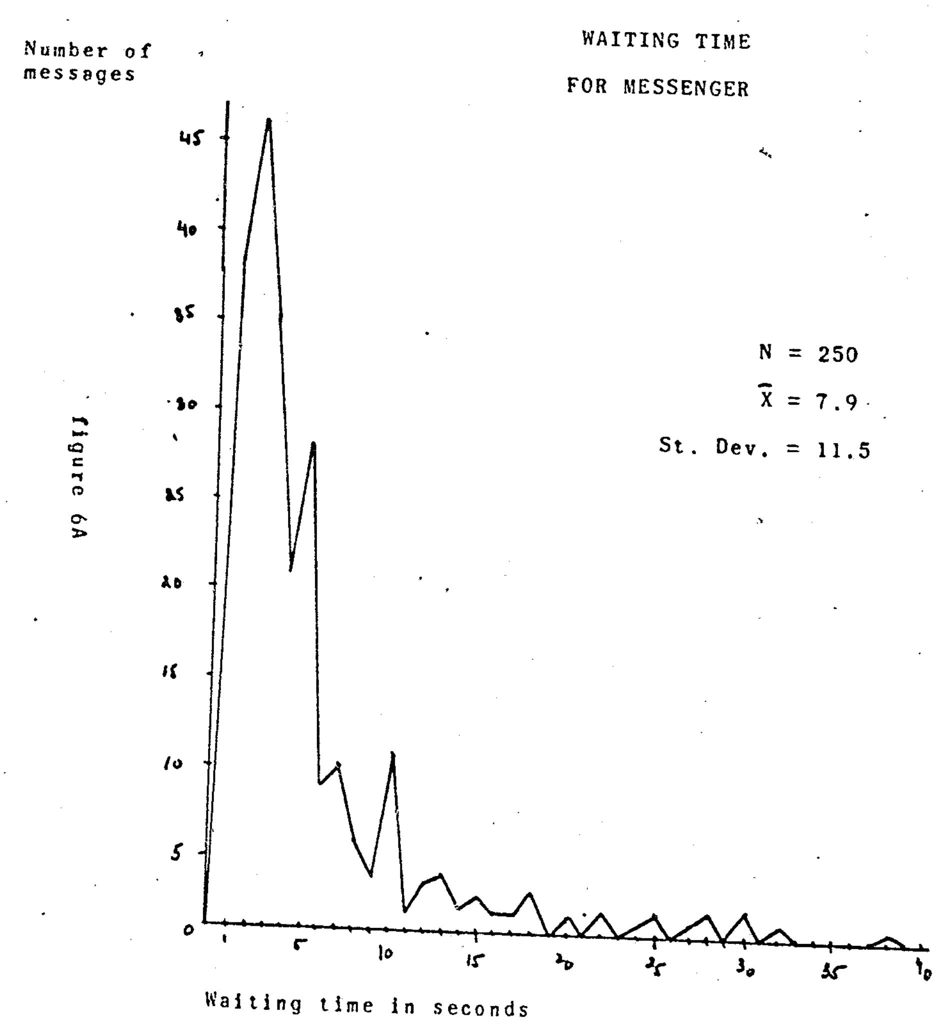


figure 5A



Number of messages
WAITING TIME
FOR MESSENGER
45
40
35
30
25
20
15
10
5
0
10
15
20
25
30
35
40
N = 250
$\bar{X}$ = 7.9
St. Dev. = 11.5
Waiting time in seconds

figure 6A

MESSENGER WALKING TIME

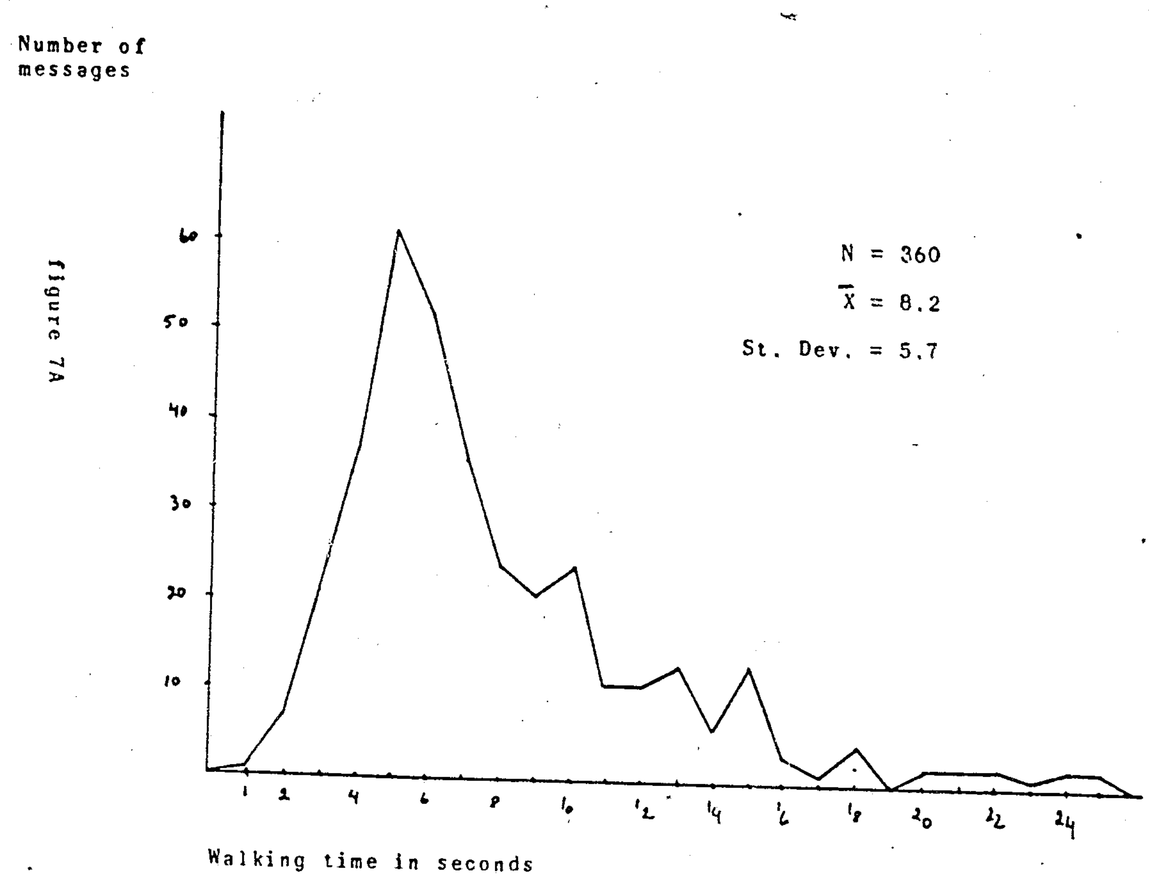


figure 7A

APPENDIX B

COMMUNICATIONS CENTER SIMULATION MODEL

CONTINUED

3 OF 4

```
VTEST,CHNA9000-3305,CM120000,T600.
RUN(S)
ASSIGN(AC,PLOT,GP,F6)
LIBRARY( SPURT1, SPURT2, SPURT4, SPURT6)
LGO.
'  END OF RECORD
      PROGRAM SIMULA  ( INPUT,OUTPUT, TAPE60=INPUT, TAPE61=OUTPUT,
     1 TAPE5=TAPE60, TAPE6= TAPE61,PLOT, TAPE99=PLOT,PUNCH)
C
*******************************************************************************
C
C
C          DISTRICT 14 IS SURROUNDED BY DISTRICTS 11,13,15,16,17,18,19
C          CONSEQUENTLY IT IS NECESSARY TO MODEL ALL OF THEM AS A SYSTEM
C          HOWEVER DISTRICT 14 IS THE FOCAL POINT OF THE SIMULATION
C
*******************************************************************************
*
*
*
*          BEAT CHARACTERISTICS
*
*          WORD       CONTENT
*
*           1          REFERENCE POINT  X
*           2          REFERENCE POINT  Y
*           3          DELTA X FOR RECTANGLE SPECIFICATION
*           4          DELTA Y FOR RECTANGLE SPECIFICATION
*           5          MANCAR
*           6          AVAILABILITY, 0=BUSY, 1=AVAIL,2= NOT IN SERVICE
*           7          CAR IS 0= OUTSIDE BEAT 1= INSIDE(UNIFORM) 2= INSIDE(CONST)
*           8          CURRENT LOCATION X
*           9          CURRENT LOCATION Y
*          10          DISTRICT
*          11          BEAT
*          12          TIME OF LAST COMPUTATION OF LOCATION
*          13          CAR LUNCH
*
*
*
*                                    PERSONNALS
*                              NO    YES(1)    YES(2)
*              CAR   NO        0      2          5
*            LUNCH   YES       1      3          4
*
*
*
*
*******************************************************************************
*
*         INPUT FORMAT OF EXOGENOUS EVENTS
*
*
*
*         WORD       CONTENT
*
*          1          TYPE OF EVENT RADIO DISPATCH 1-89, ADM(200-203)
*          2          TIMEOUT
*          3          TIMEIN
*          4          BEAT OF OCCURENCE
*          5          ARREST, 1= ARREST
```

```
*        6          QUADRANT
*        7          X  LOCATION
*        8          Y  LOCATION
*        9          DAY
*       10          NUMBER OF CARS
*       11          NUMBER OF MEN NEEDED (1,2,3,4)
*
*        ENDOGENOUS EVENTS
*        ADMINISTRATIVE CALLS ARE READ AS EXOGENOUS EVENTS, BUT THERE IS
*        THE POSSIBILITY IN THE MODEL TO GENERATE THEM STOCHASTICALLY
*
*        ALGORITHM FOR CODING
*
*       50000 + UNIT ASSIGNED          CAR COMING BACK UP
*       60000 + UNIT ASSIGNED          TRANSFER TO TIMEOUT FOR ASSIGNMENT
*       70000  END OF DAY FOR ENDOGENOUS EVENTS
*
*        100       JUMP TO SUBROUTINE AVAIL TO DETERMINE CAR AVAILABILITY
*
*
**************************************************************************

      COMMON/A/ INDEX, TOTAL
      COMMON/CLOCK1/DUM1,NEVEN,DUM2,NEVEQ,LUN
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/TIME/ ITIME,IDAY
       COMMON/NILSSON/ XAVAIL(19)
      DIMENSION IAUTOS(19)
      INTEGER RANDIN
      INTEGER CAR
      DATA IZEND/0/
      DATA IDAY/4/
      DATA KSWITCH/0/

      KZ=60
      IEND=1440
      ILUNCH=960
      JLUNCH=1440
 2    CONTINUE
      CALL INITIAL
 1    CONTINUE
      CALL CLOCK(4,NEWT,NEWJ)
 3    CONTINUE



      IF( EXOGEN(NUM,2).LT.NEWT) 10,20

C        HANDLE CALLS FOR SERVICE

 10   ITIME= EXOGEN(NUM,2)
      IF( ICOUNT2 .GT. 695) GO TO 9002
      IF( ITIME .GT.IEND) GO TO 9002
 6    CALL ASSIGN
```

```
8     NUM=NUM-1
      IF( NUM.EQ.IZEND) 11,5


11    IF(KSWITCH.EQ.1) GO TO 9002
      DO 12 I=1,100
      READ 13,(EXOGEN(101-I,J),J=1,11)
      IF(EOF(60)) 4,14
13    FORMAT( 11F5.0)
14    CONTINUE
      IK1=EXOGEN(101-I,2)
      IK2=EXOGEN(101-I,3)
      IK1=IK1/100
      IK2=IK2/100
      EXOGEN(101-I,2)= EXOGEN(101-I,2)-IK1*40
      EXOGEN(101-I,3)= EXOGEN(101-I,3) -IK2*40
      IF(EXOGEN(101-I,3).LE.EXOGEN(101-I,2))EXOGEN(101-I,3)=EXOGEN(101-I,3)
     1,2) + RANDIN(20,50)
12    CONTINUE
      NUM=100
      GO TO 5
4     NUM=100
      IZEND=101-I
      KSWITCH=1
      GO TO 5
C
C        HANDLE ENDOGENOUS EVENTS
C
20    ITIME= NEWT
      IF( ITIME .GT.IEND) GO TO 9002
      IF( NEWJ.EQ.100) 104,105
104   CALL AVAIL
      GO TO 1
105   IF( NEWJ.EQ.90000) GO TO 9000
      KK= (NEWJ/10000)*10000
      IDIST= (NEWJ-KK)/100
      NUMBER= NEWJ-KK-IDIST *100
      IF( KK.EQ.60000) GO TO 126

C        CAR COMING BACK UP

120    CAR(IDIST,NUMBER,6)= 1
      CAR(IDIST,NUMBER,12)= ITIME
       IF( XAVAIL(IDIST).LT.0.25) GO TO 125
      IF( CAR(IDIST,NUMBER,13).EQ.0 .OR. CAR(IDIST,NUMBER,13).EQ.2.OR.CAR
     1R(IDIST,NUMBER,13).EQ.5) 130,125
130    CALL LUNCH( IDIST,NUMBER)
      GO TO 1
125   CALL CLOCK(2,ITIME+RANDIN(1,KZ ), 60000+IDIST *100+NUMBER)
      GO TO 1

C       IF HERE THERE ARE ADMINISTRATIVE EVENTS (STOCHASTIC)

126    CONTINUE
      IF(CAR(IDIST,NUMBER,6).EQ.0) GO TO 1
       IF( XAVAIL(IDIST).LT.0.25) GO TO 125
      CALL TIMEOUT( IDIST,NUMBER)
      GO TO 1
```

```
C        END OF SIMULATED DAY

C        END OF SIMULATION RUN

9000  CONTINUE
9002   CALL DAYSTAT
      CALL NAMPLT
      CALL LARSON
      CALL LARSON
      CALL ENDPLT
      PRINT 9001
9001  FORMAT(10X,*END OF SIMULATION*)
      END


      SUBROUTINE INITIAL
C
      COMMON/CLOCK1/DUM1,NEVEN,DUM2,NEVEQ,LUN
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/A/ INDEX, TOTAL
      COMMON/C/ TRAVDIS(700), ICOUN
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON MTL(500),JUMP(500),MTQ(10),JUMQ(10)
      COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
      COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
      DIMENSION ITYPE(7)
      INTEGER RANDIN
      INTEGER CAR


      CALL RANSET(555.5)
      CALL SETCLK(MTL,JUMP,500,MTQ,JUMQ,10)

      IBE=1020
      KZ=60
C        DETERMINE END OF DAY

      CALL CLOCK( 2,IBE,100)
      CALL CLOCK(2,1440,90000)
      ITIME=960
      NUMX=0
      NUM=1
       INDEX=0
      TOTAL=0
      ICOUN=0
      ISUM1=ISUM2=ISUM3=ISUM4=0
       ICOUNT=0
      ICOUNT2=0
      ICOUNT3=0
      ICOUNT4=0
      ICOUNT5=0
      DO6I=1,22
      ISTAT(I)=0
      KSTAT(I)=0
```

```
6     JSTAT(I)=0
      DO 5 I=11,19
      DO 5 J=1,30
      IADMIN(I,J)=0
      MINUTE(I,J)=0
5     CAR(I,J,6)= 2
C        READ IN REFERENCE POINTS
9     CONTINUE
      READ1,I,J,CAR(I,J,1),CAR(I,J,2),CAR(I,J,3),CAR(I,J,4)
1     FORMAT( 2I2,2I4,2I3)
      IF(I.EQ.99) GO TO 100
      PRINT 2,I,J,(CAR(I,J,K),K=1,4)
2     FORMAT( 10X, 2I2,4I5)
      CAR(I,J,5)= 2
      TOTAL= TOTAL+1
      CAR(I,J,6)=1
      CAR(I,J,7)= 1
      CAR(I,J,8)= 0
      CAR(I,J,9)= 0
      CAR(I,J,10)= I
      CAR(I,J,11)= J
      CAR(I,J,12)= 960
      CAR(I,J,13)= 0
      GO TO 9
C        READ IN MANNING PER CAR
100   CONTINUE
      READ 20,I,JJ,(CAR(I,J,5),J=1,JJ)
20    FORMAT( 8X, 2I2, 30I1)
      IF( I.EQ.0) 120,101
101   CONTINUE
      PRINT 20,I,JJ,(CAR(I,J,5),J=1,JJ)
      GO TO 100
120   CONTINUE
200   READ 300, (EXOGEN(I),I=1,11)
300   FORMAT( 11F5.0)
      IK1= EXOGEN(NUM,2)
      IK2=EXOGEN(NUM,3)
      IK1=IK1/100
      IK2=IK2/100
      EXOGEN(NUM,2)= EXOGEN(NUM,2)-IK1*40
      EXOGEN(NUM,3)= EXOGEN(NUM,3)-IK2*40
      DO 401 I=11,19
      IF( I.EQ.12) GO TO 401
      DO 400 J=1,30
      IF( CAR(I,J,6).EQ.2) GO TO 400
      IF( RANDIN(1,6).EQ.1) GO TO 350
      CALL CLOCK( 2, ITIME+ RANDIN( 1,KZ), 60000+100*I+J)
      GO TO 400
C        CAR RECEIVES CAR SERVICE RIGHT AWAY
350   CONTINUE
      IVALUE= RANDIN(10,30)
      CALL CLOCK(2,ITIME+ IVALUE, 50000+100*I+J)
      IADMIN(I,J) = IADMIN(I,J)+IVALUE
```

```
      CAR(I,J,6)=0
      ISUM1=ISUM1+1
400   CONTINUE
401   CONTINUE
      RETURN
      END

      SUBROUTINE TIMEOUT(I,J)
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
      DIMENSION XX(17)
      DATA XX/0.0, 0.14,0.25,0.37,0.5,0.37,0.25,0.14,0.0,0.14, 0.25,0.37
     1, 0.5,0.37,0.25,0.14,0.0/
      INTEGER CAR
      INTEGER RANDIN
      LOGICAL DRAW
      KZ=60
      IPERIOD= (ITIME-960)/30+1
      IF( DRAW(XX(IPERIOD)))2,5
2     ISUM4=ISUM4+1
      IF( CAR(I,J,13).LT.2) 10,20
10    IVALUE=RANDIN(10,20)
C
C        PERSONNALS
C
      CALL CLOCK(2,ITIME+IVALUE,50000+I*100+J)
      IADMIN(I,J)= IADMIN(I,J)+IVALUE
       CAR(I,J,6)=0
      CAR(I,J,12)= CAR(I,J,12) + IVALUE
      IF(CAR(I,J,13).EQ.0)30,40
30    CAR(I,J,13)=2
      GO TO 50
40    CAR(I,J,13)=3
      GO TO 50
20    IF( CAR(I,J,13).NE.4 .AND. ITIME .GT.1200) 60,201
60    IVALUE=RANDIN(10,20)
      IADMIN(I,J)= IADMIN(I,J)+IVALUE
      CALL CLOCK(2,ITIME+IVALUE,50000+I*100+J)
      CAR(I,J,6)= 0
      CAR(I,J,12)= CAR(I,J,12)+IVALUE
       IF(CAR(I,J,13).EQ.3) 80,90
80    CAR(I,J,13)= 4
      GO TO 50
90     CAR(I,J,13)= 5
50    CONTINUE
      RETURN
C
C        CAR SERVICE
C
5     IF( DRAW(0.20))200,201
200   IF( DRAW(0.015)) GO TO 202
      ISUM1=ISUM1+1
      IVALUE= RANDIN(10,20)
203   CONTINUE
      IADMIN(I,J)= IADMIN(I,J)+IVALUE
      CALL CLOCK(2,ITIME+IVALUE       ,50000+I*100+J)
```

```
      CAR(I,J,12)= CAR(I,J,12)+ IVALUE
       CAR(I,J,6)=0
      RETURN
 201   CONTINUE
      CALL CLOCK(2,ITIME+RANDIN(1,KZ),60000+I*100+J)
      RETURN
C        CAR REPAIR
 202  IVALUE= RANDIN(60,240)
      ISUM2= ISUM2+1
      GO TO 203
      END

      SUBROUTINE LUNCH( IDIST,NUMBER)
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
      DIMENSION DATUM(16)
      DIMENSION XX(7),XXX(1,7),OR(7),ORD(1,7)
      DATA DATUM/24.0,57.0,87.0,121.0,192.0,279.0,399.0,588.0,779.0,
     1 986.0,1134.0,1298.0,1402.0,1469.0,1494.0,1518.0/
      DATA XX/0,0.092,0.22,0.5,0.61,0.98,1.0/
      DATA OR/18.0,23.0,26.0,29.0,30.0,37.0,39.0/
      LOGICAL DRAW
      INTEGER RANDIN
      INTEGER CAR
      INTEGER TIN

C        DETERMINE IF CAR GETS LUNCH

      KZ=60
      IA= 960
      TOTAL=1518
      IPERIOD= (ITIME-IA)/30 +1
      XK=DATUM(IPERIOD)
      IF(DRAW(XK/TOTAL))101,901
 101  TIN= IDIST*100 + NUMBER + 50000
      DO 100 I=1,7
       XXX(1,I)= XX(I)
 100  ORD(1,I)= OR(I)

C        DETERMINE FOR HOW LONG THE CAR WILL STAY DOWN

      IVALUE= STOGN2 (7,XXX,ORD,1)
      ISUM3=ISUM3+1
      CALL CLOCK(2,ITIME+ IVALUE,TIN)
      IADMIN(IDIST,NUMBER)=IADMIN(IDIST,NUMBER)+IVALUE

      IF( CAR(IDIST,NUMBER,13).EQ.0) 105,106
 105   CAR(IDIST,NUMBER,13)= 1
      GO TO 110
 106  IF( CAR(IDIST,NUMBER,13).EQ.2) 107,108
 107  CAR(IDIST,NUMBER,13)=3
      GO TO 110
 108   CAR(IDIST,NUMBER,13)= 4
 110  CONTINUE
      CAR(IDIST,NUMBER,6)= 0
      CAR(IDIST,NUMBER,12)= CAR(IDIST,NUMBER,12)+IVALUE
```

```
      RETURN
901   CONTINUE
      CALL CLOCK(2,ITIME+RANDIN(1,KZ ),60000+IDIST*100+NUMBER)
      RETURN
      END

      SUBROUTINE ASSIGN
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(70C
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/A/ INDEX, TOTAL
      COMMON/B/ LIST(200,4), LENGTH
      COMMON/C/ TRAVDIS(700), ICOUN
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
      COMMON/CARS/ KK1,KK2,YDISTAN
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
      DIMENSION KK(3), KL(3)
      DIMENSION IAUTOS(19)
      INTEGER OPTION
      INTEGER CAR
      INTEGER RANDIN
      DATA IAUTOS/10*0, 15,0,17,19,13,11,13,22,23/
      OPTION =1
      IBE=1020
      SPEED=12.0
      BETA=0.5
      SPEED= SPEED*800.0/60.0

C        WHEN OPTION = 0 , CENTER OF MASS DISPATCHING IS USED

C        THIS SUBROUTINE HAS FIVE PARTS
C          1.  DETERMINE EVENT LOCATION
C          2.  DETERMINE LOCATION OF ALL CARS
C          3.  DETERMINE MEN NEEDED
C          4.  FIND CLOSEST AVAILABLE CAR(GIVEN RESOLUTION OF INFORMATIO
C          5.  ASSIGN CAR

      IF(RANDIN(1,3).EQ.1 .AND. EXOGEN(NUM,1).GT.89) GO TO 700
      IF( EXOGEN(NUM,6).EQ.1) GO TO 10
3     CONTINUE
      RETURN

10    CONTINUE

      IXZ=EXOGEN(NUM,4)
      IXZZ=IXZ/100
      IF(IXZ.GT.IXZZ*100+IAUTOS(IXZZ))GO TO 3

C        DETERMINE RESPONSE DISTANCE WITH CENTER OF MASS DISPATCHING

      CALL CENTER
      CALL CARS(KL(1),KL(2),KL(3))
```

```
      II=KL(1)
      KK1=LIST(II,2)
       KK2=LIST (II,3)
      CALL POSITON
      DO 200 I=1,3
      IF( KL(I).LT..1) KL(1)= RANDIN(1,10)
      IF( KL(I).EQ.0) GO TO 210
      II=KL(I)
      K1=LIST(II,2)
      K2=LIST(II,3)
      IF(OPTION .EQ.1) GO TO 200
      CAR(K1,K2,6)=0
      CAR(K1,K2,7)=0
      IEXOG= EXOGEN(NUM,4)+ 0.0001
      IF( IEXOG.EQ.K1*100+K2) 51,52
51    CONTINUE
      CAR(K1,K2,7)=2
      IF( I.GT.1) GO TO 54
      IF( ITIME .LT.IBE)GO TO 54

C        ISTAT= SAME BEAT
C        JSTAT= SAME DISTRICT
C        KSTAT= NUMBER OF CALLS

      ISTAT(K1)=ISTAT(K1)+1
      GO TO 53
52    CONTINUE
      IF( I.GT.1) GO TO 54
      IF( ITIME .LT.IBE)GO TO 54
      IDOUBT=EXOGEN(NUM,4)/100
      IF(K1.EQ.IDOUBT)JSTAT(K1)=JSTAT(K1)+1
53    KSTAT(K1)=KSTAT(K1)+1


54    CONTINUE
      CAR(K1,K2,8)= EXOGEN(NUM,7)
      CAR(K1,K2,9)= EXOGEN(NUM,8)
      NEXT=EXOGEN(NUM,3)
      IF(EXOGEN(NUM,5).EQ.1) NEXT=NEXT+RANDIN(60,120)
      NEWJ=50000+K1*100 +K2
      CALL CLOCK(2,NEXT,NEWJ)
200   CONTINUE
210   CONTINUE

C        CAR LOCATOR INFORMATION AVAILABLE

C

       IF( OPTION .NE.1) GO TO 110
      CALL CARS(KK(1),KK(2),KK(3))
      DO 100 I1=1,3
      IF( KK(I1).EQ.0) GO TO 110
      K1= LIST(I1,2)
      K2= LIST(I1,3)

C        ASSIGN CAR

50    CONTINUE
```

```
      CAR(K1,K2,6)=0
      CAR(K1,K2,7)=0
      IEXOG= EXOGEN(NUM,4)+0.0001
      IF( IEXOG.EQ.K1*100+K2)61,62
61    CONTINUE
      CAR(K1,K2,7)= 2
      IF( I.GT.1) GO TO 64
      IF(ITIME.LT.IBE) GO TO 64
      ISTAT(K1)= ISTAT(K1)+1
       GO TO 63
62    CONTINUE
      IF( I.GT.1) GO TO 64
        IF( ITIME.LT.IBE) GO TO 64
      IDOUBT= EXOGEN(NUM,4)/100
      IF( K1.EQ.IDOUBT) JSTAT(K1)= JSTAT(K1)+1
63    KSTAT(K1)= KSTAT(K1)+1
64    CONTINUE
C
C        YDISTAN = CM DISTANCE
C        XDISTAN= CL DISTANCE
C
      CAR(K1,K2,8)= EXOGEN(NUM,7)
      CAR(K1,K2,9)= EXOGEN(NUM,8)
      NEXT=  EXOGEN(NUM,3)
       IF( EXOGEN(NUM,5).EQ.1) NEXT=NEXT+ RANDIN(60,120)
      NEWJ= 50000+K1*100+K2
      CALL CLOCK(2,NEXT,NEWJ)

      XDISTAN= LIST(I1,1)
100    CONTINUE
110    CONTINUE
      IF( ITIME .LT.IBE)GO TO 700

C        CALCULATE STATISTICS

C          1.  WAS THE SAME ASSIGNMENT MADE BY DISPATCHER
C              THAT IS WAS THE NEAREST CAR CHOSEN
C          3.  TRAVEL DISTANCE


C          TRAVEL DISTANCE SAVED
      IF(OPTION.EQ.0) XDISTAN=LIST(1,1)
      ICOUNT2=ICOUNT2+1
      CARRSP2(ICOUNT2)= YDISTAN/SPEED       + BETA
      ICOUNT3=ICOUNT3+ 1
      CARRSP3(ICOUNT3)= XDISTAN/SPEED        +BETA
      ITRIP= IEXOG
       IF( ITRIP/100 .EQ.14) 500,310
500   ICOUNT5=ICOUNT5+1
      PUNCH 600,YDISTAN
600   FORMAT( F10.2)
      CARRSP5(ICOUNT5)= YDISTAN/SPEED       +BETA
310   CONTINUE
      ICOUN= ICOUN+1
      TRAVDIS(ICOUN)= YDISTAN- XDISTAN
      IF(TRAVDIS(ICOUN ).LT.0) TRAVDIS(ICOUN )=0


C        CALCULATE PROBABILITY OF NOT ASSIGNING THE CLOSEST CAR
```

```
      ICOUNT4=ICOUNT4+1
      IF(KK1*100+KK2.EQ.LIST(1,2)*100+LIST(1,3))NUMX=NUMX+1
      IX1= EXOGEN(NUM,2)/100
      IX2= EXOGEN(NUM,3)/100
      MINUTE(K1,K2)= MINUTE(K1,K2)+ EXOGEN(NUM,3)-EXOGEN(NUM,2)

700   CONTINUE
       RETURN
      END


      SUBROUTINE SORT( LIST,N,M, INDEX,NUMBER)
      DIMENSION LIST(N,M)
      NUM=NUMBER
      DO 30 I2=1,NUM
      I3=I2+1
      IF(NUM.LT.I3) GO TO 30
      DO 20 I=I3,NUM
      IF( LIST(I,INDEX).GE. LIST(I2,INDEX) )GO TO 20
      DO 10 K=1,M
      ITEMP= LIST(I,K)
      LIST(I,K)= LIST(I2,K)
10    LIST(I2,K)= ITEMP
20    CONTINUE
30    CONTINUE
      RETURN
      END


      SUBROUTINE CENTER
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/TIME/ ITIME,IDAY
      COMMON/B/ LIST(200,4), LENGTH
      INTEGER CAR
      XLOC= EXOGEN(NUM,7)
      YLOC= EXOGEN(NUM,8)
      NU =0
      DO 11 I=11,19
      IF( I.EQ.12) GO TO 11
      DO 10 J=1,30
      IF( CAR(I,J,6) -1) 10,30,10
30    IDISTAN= ABS(CAR(I,J,1)-XLOC) + ABS(CAR(I,J,2)-YLOC)
      NU=NU+1
      LIST(NU ,1)= IDISTAN
      LIST(NU ,2)= CAR(I,J,10)
      LIST(NU ,3)= CAR(I,J,11)
      LIST(NU ,4)= CAR(I,J,5)
10    CONTINUE
11    CONTINUE
      IF( NU .GT.200) PRINT 40
40    FORMAT( 10X,* TROUBLE IN SORT*)
      LENGTH= NU
      CALL SORT(LIST,200,4,1,NU )
      RETURN
      END

      SUBROUTINE AVAIL
```

```
      COMMON/NILSSON/ XAVAIL(19)
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/A/ INDEX, TOTAL
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/TIME/ ITIME,IDAY
      COMMON/CLOCK1/DUM1,NEVEN,DUM2,NEVEQ,LUN
      COMMON/KAJSA/ FOURTEN(120)
      COMMON MTL(500),JUMP(500),MTQ(10),JUMQ(10)
      DIMENSION IAUTOS(19)
      DATA IAUTOS/10*0,15,0,17,19,13,11,13,22,23/
      INTEGER CAR
      XAVAIL(12)= 0
      NU =0
      ICOUNT=ICOUNT+1
      DO 6 I=11,19
      XZ=0
      IF( I.EQ.12) GO TO 6
      DO 5 J= 1,30
      IF( CAR(I,J,6).EQ. 1) NU =NU +1
      IF(CAR(I,J,6).EQ.1) XZ=XZ+1
5     CONTINUE
      XAVAIL(I)=XZ/IAUTOS(I)
6     CONTINUE
      CARBUSY(ICOUNT)= NU/132.0
      PRINT 10,CARBUSY(ICOUNT),ITIME,(XAVAIL(I),I=11,19)
10    FORMAT(   X,   *CARBUSY*F10.3,* ITIME*I5, 10F8.3)
      FOURTEN(ICOUNT)=XAVAIL(14)
      NEWT= ITIME +  5
      NEWJ= 100
      CALL CLOCK(2,NEWT,NEWJ)


      GO TO 50
      LENGTH=NEVEN
      DO 20 I=1,LENGTH
      PRINT 25,MTL(I),JUMP(I)
25    FORMAT( 10X,*TIME*I6,* TYPE*I10)
20    CONTINUE
      DO 40 I=11,19
      IF( I.EQ.12) GO TO 40
      DO 40 J=1,30
      IF( CAR(I,J,6).EQ.2) GO TO 40
      PRINT 30,(CAR(I,J,K),K=1,13)
30    FORMAT( 10X,13I8)
40    CONTINUE
 50   CONTINUE
      RETURN
      END

      SUBROUTINE POSITON
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/B/ LIST(200,4), LENGTH
      COMMON/CARS/ KK1,KK2,YDISTAN
      COMMON/TIME/ ITIME,IDAY
```

```
      INTEGER XLOC,YLOC
      INTEGER CAR,RANDIN
      INTEGER DELTAX, DELTAY
C
C
C        IX= X LOCATION OF EVENT
C        IY = YLOCATION OF EVENT
C        LIST = MATRIX OF CARS RANKED ON DISTANCE
C
C
C        WORD      CONTENT
C
C          1       DISTANCE
C          2       DISTRICT
C          3       BEAT
C          4       MANCAR
C                                      I
C                                      I
C                                      I
C                                      I        *CASE 3
C                                      I
C                                      I
C                  *********************----------
C                  *                   *
C                  *                   *
C                  *                   *
C                  *       * BEAT      *         *CASE 2
C                  *    REF POINT      *
C                  *                   *
C                  *                   *
C                  *********************----------
C                  I                   I
C                  I                   I
C                  I         *CASE 1   I
C                  I                   I
C                  I                   I
C                  I                   I
C
C
C
      SPEED=9.2
      SPEED= SPEED *800/60.0
      IX= EXOGEN(NUM,7)
      IY= EXOGEN(NUM,8)
      NOM=0
      DO 1002 I=11,19
      IF( I.EQ.12) GO TO 1002
      DO 1001 J=1,30
      IF( CAR(I,J,6).NE. 1) GO TO 1001
      DELTAX= CAR(I,J,3)
      DELTAY= CAR(I,J,4)
      INDEX=CAR(I,J,7)+1
      IF( INDEX.LT.1 .OR. INDEX.GT.3) 1030,1031
1030    INDEX=2
      PRINT 1032, CAR(I,J,7),I,J
1032   FORMAT(10X,* INDEX IN  POSITION IS BAD*,3I6)
1031  CONTINUE
      GO TO (100,200,300) INDEX
```

```
C          100= OUTSIDE BEAT
C          200= INSIDE BEAT (UNIFORM)
C          300= INSIDE(CONSTRAINED UNIFORM)

C          ASSUMPTION THAT CAR RETURNS BY SHORTEST ROUTE

100     IB=CAR(I,J,8)
        IA= DELTAX
        IC=CAR(I,J,1)
        IF(IB.GE.IC-IA.AND.IB.LE.IC+IA)10,20

C          WE HAVE CASE NUMBER ONE

10      IN=2
        IF(CAR(I,J,9).GT.CAR(I,J,2))IN=1
11      IDISTAN=IABS(CAR(I,J,9)-CAR(I,J,2)+(-1)**IN*CAR(I,J,4))

C          THIS IS THE DISTANCE TO THE BORDER OF THE BEAT. NOW NEED TO
C          DETERMINE IF CAR IS STILL OUTSIDE

         IRANGE=SPEED*(ITIME-CAR(I,J,12))
        IF(IDISTAN.LT.IRANGE) GO TO 50
        NOM=NOM+1
        CAR(I,J,9)=CAR(I,J,9) +(-1)**IN*IRANGE
        CAR(I,J,12)=ITIME
49      LIST( NOM,1)=IABS(IX-CAR(I,J,8))+IABS(IY-CAR(I,J,9))
        LIST(NOM,2)= I
        LIST( NOM,3)= J
        LIST(NOM,4)= CAR(I,J,5)
         GO TO 1000
50      CAR(I,J,12)=CAR(I,J,12)+ IDISTAN/SPEED
        CAR(I,J,9)= CAR(I,J,2)+(-1)**IN*DELTAY      *(-1)
        GO TO 300

C          CASE NUMBER 2. THE CAR IS EAST OR WEST OF ITS REFERENCE POINT

20       IB=CAR(I,J,9)
        IA= DELTAY
        IC=CAR(I,J,2)
        IF(IB .GE.IC-IA.AND.IB.LE.IC+IA)30,40
30      IN=2
         IF(CAR(I,J,8).GT.CAR(I,J,1))IN=1
        IDISTAN=IABS(CAR(I,J,8)- CAR(I,J,1)+(-1)**IN*DELTAX)
        IRANGE=SPEED*(ITIME-CAR(I,J,12))
        IF( IDISTAN.LT.IRANGE) 60,49
60      CAR(I,J,12)=CAR(I,J,12)+ IDISTAN/SPEED
        CAR(I,J,8)= CAR(I,J,1)+(-1)**IN*DELTAX      *(-1)
        GO TO300

C       THE CAR IS AT A DIAGONAL FROM ITS REFERENCE POINT

40      CONTINUE
        IF( RANDIN(1,2).EQ.2) GO TO 1010
        IN=2
        IF(CAR(I,J,8).GT.CAR(I,J,1))IN=1
        IRANGE= SPEED*(ITIME-CAR(I,J,12) )
        IF(IN.EQ.2) GO TO 1005
        IF(CAR(I,J,8)-IRANGE.LT.CAR(I,J,1)+DELTAX     )1003,1004
```

```
1003    CAR(I,J,8)=CAR(I,J,1)+DELTAX
      CAR(I,J,12)=CAR(I,J,12) +IABS(CAR(I,J,1)+DELTAX     -CAR(I,J,8))/S
     1EED
      GO TO 100
1004   NOM=NOM+1
      CAR(I,J,8)= CAR(I,J,8) + IRANGE
      LIST(NOM,1)= IABS(CAR(I,J,8)-IX) + IABS(CAR(I,J,9)-IY)
      LIST( NOM,2)= I
      LIST( NOM,3)= J
      LIST(NOM,4)= CAR(I,J,5)
      GO TO 1000
1005    IF( CAR(I,J,8)+IRANGE.GT. CAR(I,J,1)-DELTAX     )1006,1004
1006    CAR(I,J,8)= CAR(I,J,1)-DELTAX
      CAR(I,J,12)= CAR(I,J,12)+IABS(CAR(I,J,1)-DELTAX     -CAR(I,J,8))/S
     1EED
      GO TO 100
1010   CONTINUE

C         IF HERE IS MEANS THAT THE Y DIMENSION OF CASE 3 IS BEING EXPLO

      IN=2
      IF( CAR(I,J,9).GT.CAR(I,J,2))IN=1
      IRANGE=(ITIME-CAR(I,J,12))*SPEED
      IF( IN.EQ.2) GO TO 1020
      IF( CAR(I,J,9)-IRANGE.LT.CAR(I,J,2)+DELTAY     )1013,1014
1013    CAR(I,J,12)=CAR(I,J,12)+IABS(CAR(I,J,2)+DELTAY     -CAR(I,J,9))/S
     1PEED
      CAR(I,J,9)= CAR(I,J,2)+ DELTAY
      GO TO 100
1014  CAR(I,J,9)=CAR(I,J,9)-IRANGE
1015  CONTINUE
      LIST(NOM,1)= IABS(CAR(I,J,8)-IX) + IABS(CAR(I,J,9)-IY)
      LIST( NOM,2)= I
      LIST( NOM,3)= J
      LIST(NOM,4)= CAR(I,J,5)
      GO TO 1000

C         CAR IS SOUTH OF REFERENCE POINT

1020   IF(CAR(I,J,9)+IRANGE.GT.CAR(I,J,2)-DELTAY     )1021,1024
1021    CAR(I,J,12)=CAR(I,J,12)+IABS(CAR(I,J,2)-DELTAY     -CAR(I,J,9))/
     1SPEED
      CAR(I,J,9)= CAR( I,J,2)-DELTAY
      GO TO 100
1024   CAR(I,J,9)= CAR(I,J,9) + IRANGE
      GO TO 1015


C         UNIFORM DISTRIBUTION CASE

200   CONTINUE
      IBEGIN= CAR(I,J,1) - DELTAX
      IF( IBEGIN.LT.0) IBEGIN=0
      IEND= CAR(I,J,1) + DELTAX
      IF( IEND.LE. IBEGIN) 4000,4002
4000   PRINT 4051
4051   FORMAT(10X,* TROUBLE WITH JX*)
      IEND= IBEGIN+1
4002   CONTINUE
```

```
      JX= RANDIN( IBEGIN, IEND)
      IBEGIN= CAR(I,J,2)- DELTAY
      IF( IBEGIN.LT.0) IBEGIN=0
      IFND= CAR(I,J,2) +   DELTAY
      IF( IEND.LE. IBEGIN) 4600, 4610
4600  PRINT 4601
4601  FORMAT( 10X,* TROUBLE WITH JY    *)
      IEND= IBEGIN+1
4610  CONTINUE
      JY= RANDIN( IBEGIN,IEND)
      NOM=NOM+1
      LIST(NOM,1)= IABS(JX-IX) + IABS(JY-IY)
      LIST(NOM,2)= I
      LIST(NOM,3)=J
      LIST(NOM,4)= CAR(I,J,5)
      CAR(I,J,7)= 1
      GO TO 1000

300    CONTINUE

C          THE CONSTRAINED UNIFORM CASE

      IRANGE=(ITIME -CAR(I,J,12))*SPEED
      IF( IRANGE.LT.1) IRANGE =1
      IF( IRANGE.GT.2*DELTAY.AND.IRANGE.GT. 2*DELTAX)2001,2002
2001  CAR(I,J,7)= 1
      GO TO 200



2002   CONTINUE
       IYMIN= CAR( I,J,9)-IRANGE
      IF(IYMIN.LT.0) IYMIN=0
      MINY= CAR(I,J,2)-DELTAY
      IF( MINY.LT.0) MINY=0
      IF( IYMIN.LT.MINY) IYMIN=MINY

      IYMAX=CAR(I,J,9)+IRANGE
      MAXY=CAR(I,J,2)+CAR(I,J,4)
      IF( IYMAX.GT.MAX ) IYMAX=MAXY
      IF( IYMIN.GE. IYMAX) 4010,4012
4010  PRINT 4001, IYMIN, IYMAX
4001  FORMAT(10X,*IYMIN* I5,* IYMAX* I5)
      IYMIN= IYMAX-1
4012  CONTINUE
      YLOC=RANDIN(IYMIN,IYMAX)

      IXMIN=CAR(I,J,8)-IRANGE
      IF( IXMIN.LT.0) IXMIN=0
      MINX=CAR(I,J,1)-DELTAX
      IF( MINX.LT.0) MINX=0
      IF( IXMIN.LT.MINX) IXMIN=MINX

      IXMAX=CAR(I,J,8)+IRANGE
      MAXX=CAR(I,J,1)+DELTAX
      IF(IXMAX.GT.MAXX) IXMAX=MAXX
      IF(IXMIN.GE.IXMAX) 4003,4005
4003  PRINT 4004, IXMIN, IXMAX
4004  FORMAT( 10X,* IXMIN* I5, * IXMAX* I5)
```

```
      IXMAX= IXMIN+1
4005   CONTINUE
      XLOC= RANDIN(IXMIN,IXMAX)

3000  NOM=NOM+1
      LIST(NOM,1)= IABS(IX-XLOC)+IABS(IY-YLOC)
      LIST(NOM,2)= I
      LIST( NOM,3)= J
      LIST(NOM,4)= CAR(I,J,5)
      CAR(I,J,7)=2
1000  IF( KK1.EQ.I.AND.KK2.EQ.J) 9001,1001
9001   YDISTAN=LIST(NOM,1)
1001  CONTINUE
1002   CONTINUE
      IF( NOM.GT.200) PRINT 7000
7000  FORMAT( 10X,*  NOM IS TOO LARGE*)
      LENGTH=NOM
      CALL SORT(LIST,200,4,1,NOM)
      RETURN
      END


      SUBROUTINE CARS(IANS1,IANS2,IANS3)
      COMMON/B/ LIST(200,4), LENGTH
      COMMON/INPUT/EXOGEN(101,11), CAR(19,30,13),NUM
      INTEGER RANDIN
C
C
C        THIS SUBROUTINE DETERMINES WHICH CARS ARE TO BE ASSIGNED BASED (
C        MINIMUM TRAVEL DISTANCE AND NUMBER OF MEN NEEDED
C        AND RETURNS THE LOCATION OF THE LIST TO BE ASSIGNED
C
      IANS1=0
      IANS2=0
      IANS3=0
      ICODE= EXOGEN(NUM,1)
      ICARS=EXOGEN(NUM,10)
      IMEN=EXOGEN(NUM,11)
      IF( IMEN .LT.1 .OR.IMEN.GT. 4) IMEN=2
      IDIST= EXOGEN(NUM,4)/100
      IF( LENGTH.GT.20) LENGTH=20
      GO TO (100,200,300,400) IMEN
100   CONTINUE
C
C        NOW IT ASSIGNS THE CLOSEST CAR
C        CLOSEST THAT IS WITHIN THE DISTRICT TO BEGIN WITH
C
      DO 101 I=1,LENGTH
      GO TO 104
      IF(ICODE.LT.86.AND. RANDIN(1,4).EQ.1) GO TO 104
      IF( I.EQ.20)    GO TO 103
       IF( LIST(I,2).EQ.IDIST) 102,101
 102   CONTINUE
104   IANS1=I
      GO TO 105
103     IANS1= RANDIN(1,5)
      GO TO 105
101   CONTINUE
105   CONTINUE
```

```
      RETURN
C
C        FIND CLOSEST TWO MAN CAR OR TWO ONE-MAN CARS AND ASSIGN
C        CLOSEST COMBINATION
C
200   DO 201 I=1,LENGTH
      GO TO 202
--    IF( ICODE.LT.86.AND.RANDIN(1,4).EQ.1) GO TO 202
      IF( LIST(I,4).EQ.2 .AND. LIST(I,2).EQ.IDIST) GO TO 196
       IF( I.EQ.20) GO TO199
201   CONTINUE
196   ICAR1=I
      GC TO 198
199   ICAR1= RANDIN(1,5)
      GO TO 198
202   CONTINUE
      ICAR1=1
198   CONTINUE
      ISWITCH=0
      DO 203 I=1,LENGTH
      GO TO 205
       IF( ICODE.LT.86.AND.RANDIN(1,4).EQ.1) GO TO 205
      IF( LIST(I,4).EQ.1.AND.LIST(I,2).EQ.IDIST)204,210
204   IF(ISWITCH.EQ.0) 205,206
205   ICAR2=I
      ISWITCH=1
      GO TO 203
206   ICAR3=I
      GO TO 207
210    IF( I.EQ.20) GO TO 208
      ISWITCH=1
203   CONTINUE
207   IF(MAX0(LIST(ICAR2,1),LIST(ICAR3,1)).GT.LIST(ICAR1,1))208,209
208    IANS1=ICAR1
      RETURN
209   IANS1=ICAR2
      IANS2=ICAR3
      RETURN
300   IANS1=1
      NEED=IMEN-LIST(1,4)
      IF( NEED.GT.2) NEED=2
      DO 301 I=2,LENGTH
      IF( NEED.EQ.LIST(I,4))GO TO 302
301   CONTINUE
302   IANS2=I
      RETURN
400    CONTINUE
      ISWITCH=0
      DO 401 I=1,LENGTH
       IF(LIST(I,4).EQ. 2) 402,401
402   IF( ISWITCH) 405,403,404
403    ICAR1=I
      GO TO 401
404   CAR2=I
      ISWITCH=-1
      GO TO 401
405   ICAR3=I
      GO TO 407
401    CONTINUE
```

```
407    CONTINUE
       RETURN
       END


       SUBROUTINE DAYSTAT
C
       COMMON/C/ TRAVDIS(700), ICOUN
       COMMON/D/ MINUTE(19,30), IADMIN(19,30)
       COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
       COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(70(
      1),ICOUNT3,ICOUNT4,NUMX
       COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
       COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
       DIMENSION IAUTOS(19)
       DIMENSION SAVE(19)
       DATA IAUTOS/10*0,15,0,17,19,13,11,13,22,23/
C
C         STATISTICS FOR....
C               1.  AVAILABILITY OF CARS
C               2.  RESPONSE TIMES  A. FOR CENTER OF MASS
C                                   B.  CAR LOCATOR SYSTEM
C         3.  PERCENTAGE OF BEATCAR ANSWERING CFS ON HIS BEAT
C         4.  PROBABILITY OF NOT ASSIGNING THE CLOSEST CAR


       PRINT 1
 1     FORMAT( 30X,* STATISTICAL DAILY SUMMARY*,////)
       IF( ICOUNT2.LT.2) GO TO 10
       CALL STIX7(CARRSP2,ICOUNT2,0.5,50.0,1.0,7HMINUTES,1,0,1,42HTRAVEL
      1TIME FOR CENTER OF MASS DISPATCHING    ,42)
10     CONTINUE
       IF( ICOUNT3.LT.2) GO TO 20
       CALL STIX7(CARRSP3,ICOUNT3,0.5,50.0,1.0,7HMINUTES,1,0,1,39HTRAVEL
      1TIME FOR CAR LOCATOR DISPATCHING   , 39)
20     CONTINUE
       IF( ICOUNT.LT.2) GO TO 30
       CALL STIX7(TRAVDIS,ICOUN ,0.0,500.0,50.0,7HNUMBERS,1,0,1,21HTRAVEL
      1 DISTANCE SAVED   ,21)
30     CONTINUE
        IF( ICOUNT5.LT.2) GO TO 40
       CALL STIX7(CARRSP5,ICOUNT5,0.5,50.0,1.0,7HMINUTES,1,0,1,34HTRAVEL
      1 TIME FOR 14TEENTH DISTRICT   , 34)
40     CONTINUE

       SUM3=0
        SUM4=0
        SUM5=0
       PRINT 100
100    FORMAT( 1H1,9X,*PERCENT OF CALLS ANSWERED BY BEAT OR DISTRICT CAR*
      1///,10X,*DISTRICT* 5X,*BEATCAR* 5X,*DISTRICT CAR*,5X,*NUMBER OF CA
      1LLS*5X,*AVERAGE NUMBER OF CALLS/CAR*//)
       DO 5I=11,19
       IF( I.EQ.12) GO TO 5
       XX=KSTAT(I)
       SUM3=SUM3+XX
       P1= ISTAT(I)/XX
       SUM4=SUM4+ISTAT(I)
       P2= JSTAT(I)/XX
```

```
      SUM5=SUM5+JSTAT(I)
      AVE= XX/IAUTOS(I)
      SAVE(I)=AVE
      PRINT 101, I,P1,P2,XX,AVE
101   FORMAT( 10X,I4, 7X,F5.2,10X,F5.2,10X,F7.2,15X,F7.2)
5      CONTINUE
      SUM4=SUM4/SUM3
      SUM5=SUM5/SUM3
      SUM6=SUM3/132.0
      PRINT 102,SUM4, SUM5,SUM3,SUM6
102   FORMAT(/,9X,*AVERAGES*4X,F5.2,10X,F5.2,10X,F7.2,15X,F7.2)


      PRINT 105
105   FORMAT( ////,10X,*MINUTES SPENT ON CALLS  FOR SERVICE AND ADMIN CA
     1LLS*,//,10X,*DISTRICT* 5X,* MIN ON CFS*,5X,*MIN ON ADMIN*,
     110X,*MIN/CALL*,//)
      SUM7=0
      SUM8=0
      DO 202 I=11,19
      IF( I.EQ.12) GO TO 202
      SUM1=0
      SUM2=0
      DO 201 J=1,30
       SUM7=SUM7+MINUTE(I,J)
      SUM1=SUM1 +MINUTE(I,J)
      SUM8=SUM8+ IADMIN(I,J)
201   SUM2= SUM2 + IADMIN(I,J)
       SUM1=SUM1/IAUTOS(I)
      SUM2=SUM2/IAUTOS(I)
      SUM9=SUM1/SAVE(I)
      PRINT 200,I,SUM1, SUM2 ,SUM9
200   FORMAT( 10X, I5,10X,F7.1,10X, F7.1,10X,F7.1)
202    CONTINUE
      SUM7=SUM7/132.0
      SUM8=SUM8/132.0
      PRINT 205,SUM7,SUM8
205   FORMAT(10X,*AVERAGES*7X,F7.1,11X,F7.2)
      PP= NUMX/SUM3
      PRINT110,PP
110   FORMAT(///,10X,*THE PROBABILITY OF ASSIGNING THE CLOSEST CAR*,/,
     1 10X,* USING CENTER OF MASS DISPATCHING STRATEGY IS* F7.2)
      SUMMA= 0
      DO 300 I= 1,ICOUNT
300   SUMMA= SUMMA+ CARBUSY(I)
      SUMMA= SUMMA/ ICOUNT
      PRINT 301,SUMMA
301   FORMAT( ////, 10X,* AVERAGE AVAILABILITY = * F6,2)
      PRINT 310,ISUM1,ISUM2 ,ISUM3 ,ISUM4
310   FORMAT(///,10X,*THERE WERE*I5,* CAR SERVICES*,/,10X,*AND*I4* CAR
     1REPAIRS*,/,10X,* AND* I5,* LUNCHES TAKEN*,10X,*AND*I6* PERSONNALS*
     1)
      RETURN
      END


      SUBROUTINE LARSON
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
```

```
      COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/A/ INDEX,TOTAL
      COMMON/KAJSA/ FOURTEN(120)
      COMMON/N/ RHO3
       DIMENSION F(102), E(102)
      INTEGER OPTION
      DATA OPTION/-1/
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)

C        OPTION = 0 MEANS THAT 14TH DISTRICT ONLY IS PLOTTED

C
      OPTION=OPTION+1
      SPEED=12.0

      IF(OPTION .EQ.0) GO TO 40
C     DETERMINE AVAILABILITY
C      THAT IS FIND RHO3 FOR DISTRICT 14
      SUM=0
      DO 1 I=1,ICOUNT
1     SUM=SUM+FOURTEN(I)
      RHO3=SUM/ICOUNT
      PRINT 3, RHO3
3     FORMAT(//,10X,*14-TEENTH DISTRICT RHO=*F6.3,//)
      AA=ICOUNT5
      K=19
      CONST= SQRT(7.752/K)*90.0/SPEED

C        CALCULATE THE MEAN RESPONSE TIME FOR LARSON SETUP

      XMEAN=0.5 +2.0*60.0/(3.0*12.0) *SQRT(7.752/19)*(2 -RHO3)
      PRINT 10,XMEAN
10    FORMAT( //,10X,*THE LARSON PREDICTED MEAN IS*F8.2)
      GO TO 45
C

40    CONST= 90.0 * SQRT(78.513/TOTAL)/ SPEED
      DO 2 I=1,ICOUNT
2     SUM=SUM+CARBUSY(I)
      RHO3=SUM/ICOUNT

C        CALCULATE THE MEAN RESPONSE TIME FOR LARSON SETUP

      XMEAN= 0.5 +2.0*60.0/(3.0*12.0)*SQRT(78.513/132.0)*(2-RHO3)
      PRINT 10,XMEAN
      AA= ICOUNT4
45    CONTINUE
      PRINT 20,TOTAL,CONST,AA,SPEED
20    FORMAT(10X,*TOTAL*F10.3,* CONST*F6.2,* AA*F6.2,* SPEED* F6.2)
      DRO=-0.05
      DO 50 J=1,60
      DRO= DRO + 0.05
      E(J)= DRO*CONST
      SUM1=RESULT1(DRO)
      X1=SUM1*RHO3
      X2=RESULT2 (DRO)
      X3=RESULT3(DRO)
```

```
      F(J)=(X1 + X2 + X3 )/CONST *AA
      PRINT 200,F(J),E(J)
200   FORMAT(10X, F10.2,F20.2)
50    CONTINUE
100   CONTINUE
      CALL PLOTTER(F,E)
      RETURN
      END
      FUNCTION RESULT1(DRO)
      COMMON/N/ RHO3
      IF(DRO.LE.1) 10,20
10    RESULT1= 4*DRO -4*DRO**2 +2.0/3.0 *DRO**3
      RETURN
20    IF(DRO.GT.2)GO TO 30
      RESULT1= 16.0/3.0-8*DRO+4*DRO**2-2.0/3.0*DRO**3
      RETURN
30     RESULT1=0
      RETURN
      END
      FUNCTION RESULT2(DRO)
      COMMON/N/ RHO3
      SUM=0
      DO 100 K=1,1
      IF( DRO.GE. K-1 .AND. DRO.LE. K) 10,20
10    DELTA= DRO**2- 1.0/3.0*DRO**3
      GO TO 80
20    IF( DRO.GT.K.AND.DRO.LE.K+1)30,40
30    DELTA= 2.0/3 *DRO**3-4*DRO**2+7*DRO-3
      GO TO 80
40     IF(DRO.GT.K+1.AND.DRO.LE.K+2)50,60
50    DELTA= -1.0/3.0*DRO**3+3*DRO**2-9*DRO+9
      GO TO 80
60     DELTA=0
80    CONTINUE
      SUM=SUM +DELTA*( (1-RHO3)**   (2*K*(K+1)-3)*(1-(1-RHO3)**4))
100   CONTINUE
      RESULT2=SUM
      RETURN
      END
      FUNCTION RESULT3(DRO)
      COMMON/N/ RHO3
      SUM=0
      DO 100 L=2,2
      IF( DRO.GE. L-2 .AND. DRO.LE. L-1) 10,20
10    DELTA= 1.0/6.0 *DRO**3
      GO TO 80
20    IF(DRO.GT.L-1.AND.DRO.LE.L)30,40
30    DELTA= 1.0/6.0*(-3*DRO**3+12*DRO**2-12*DRO+4)
      GO TO 80
40    IF(DRO.GE.L.AND.DRO.LT.L+1)50,60
50    DELTA= 1.0/6 *(3*DRO**3-24*DRO**2+60*DRO-44)
      GO TO 80
60    IF(DRO.GE.L+1.AND.DRO.LT.L+2)70,75
70    DELTA= ( -DRO**3+12*DRO**2-48*DRO+64)/6.0
      GO TO 80
75     DELTA=0
80    SUM=SUM+DELTA*((1-RHO3)**(2*L**2-2*L+1)*(1-(1-RHO3)**(4*L-4)))
100   CONTINUE
      RESULT3=SUM
```

```
      RETURN
      END


      SUBROUTINE PLOTTER(F,E)

      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
      DIMENSION ZZ(100)
      DIMENSION NUMBER(40)
      DIMENSION CENTM(102), CARLOC(102)
       DIMENSION F(102), E(102)
      REAL IVAL2
      REAL NUMBER
      DATA ISWITCH/0/
      DO 2 I=1,21
2     NUMBER(I)=I-1

      CALL SCALE(F, 8.0, 60,1)
      CALL SCALE(E, 6.0, 60,1)
      F(61)= 0
      E(61)= 0
       IF( ISWITCH.EQ.1) GO TO 100


      ISWITCH=ISWITCH+1
      DO 1 I=1,100
      CENTM(I)=0
1     CARLOC(I)= 0
       DO 10 I=1,ICOUNT2
      IX= (CARRSP2(I)+0.5)+1
10    CENTM(IX)= CENTM(IX)+1
      DO 20 I=1,ICOUNT3
      IX= (CARRSP3(I)+0.5)+1
20    CARLOC(IX)= CARLOC(IX)+1


       CALL SCALE(CENTM, 8.0,20,1)
      CALL SCALE(CARLOC, 8.0,20,1   )


      CENTM(21)= 0
      CARLOC(21)=0
      NUMBER( 21)=0
      IVAL2 = MAX1(F( 62), CENTM(22), CARLOC(22))

      F(62)= IVAL2
      CENTM(22)= IVAL2
      CARLOC( 22)= IVAL2
      NUMBER(22)= E( 62)


      CALL LINE(E,F,60,1,1,0)
      CALL LINE( NUMBER,CENTM, 20,1,1,2)
      CALL LINE( NUMBER, CARLOC,20,1,1,11)

      CALL AXIS( 0.0,0.0,9HFREQUENCY ,9, 8.0,90.0,0.0, IVAL2)
```

```
      CALL AXIS(0.0,0.0,7HMINUTES,-7, 6.0,0.0,0.0,E( 62))

      CALL SYMBOL(2.5,8.5,0.15,23HGRAPH OF RESPONSE TIMES ,0.0,23)
      CALL SYMBOL( 2.5,8.1,0.12,0,0.0,-1)
      CALL SYMBOL (2.8,8.0,0.12,22H=CENTER OF MASS-LARSON  ,0.0,22)
      CALL SYMBOL(2.5,7.6,0.12,2,0.0,-1)
      CALL SYMBOL(2.8, 7.5,0.12,27H=CENTER OF MASS DISPATCHING ,0.0,27)
      CALL SYMBOL(2.5,7.1,0.12,11,0.0,-1)
      CALL SYMBOL(2.8,7.0,0.12,24H=CAR LOCATOR DISPATCHING ,0.0,24)

      CALL PLOT(20.0,0.0,-3)
      RETURN

C        PRINT RESULTS OF 14 TEENTH DISTRICT

100    CONTINUE
      DO 50 I=1,ICOUNT5
      IX=CARRSP5(I)+1.5
50    ZZ(IX)=ZZ(IX)+1
      ZZ(21)=0
      NUMBER(21) =0
      NUMBER(22)= E(62)
      ZZ(22)= F(62)
      CALL LINE(NUMBER,ZZ,20,1,1,2)
      CALL LINE(E,F,60,1,1,0)
      CALL AXIS(0.0,0.0,9HFREQUENCY,9, 8.0,90.0,0.0,ZZ(22))
      CALL AXIS(0.0,0.0,7HMINUTES,-7,6.0,0.0,0.0,E(62))

      CALL SYMBOL(3.0,8.5,0.15,27HGRAPH OF 14-TEENTH DISTRICT,0.0,27)
      CALL SYMBOL(3.0,8.0,0.15,14HRESPONSE TIMES,0.0,14)
      CALL SYMBOL(3.0,7.5,0.12,0,0.0,-1)
      CALL SYMBOL(3.2,7.5,0.12,22H=CENTER OF MASS-LARSON,0.0,22)
      CALL SYMBOL(3.0,7.0,0.12,2,0.0,-1)
      CALL SYMBOL(3.2,7.0,0.12,27H=CENTER OF MASS DISPATCHING ,0.0,27)

      CALL PLOT(20.0,0.0,-3)
      RETURN
      END
    END OF RECORD
```

APPENDIX C

FIELD RESPONSE SIMULATION MODEL

```
VTEST,CHNA9000-3305,CM4C000,T50.
REWIND(INPUT)
COPYSCF(INPUT,TAPEX)
REWIND(TAPEX)
COPYCF(TAPEX,OUTPUT)
REWIND(TAPEX)
COPYCF(TAPEX,OUTPUT)
REWIND(TAPEX)
COPYCF(TAPEX,OUTPUT)
COPYCF(TAPEX,OUTPUT)
REWIND(TAPEX)
COPYCF(TAPEX,OUTPUT)
REWIND(TAPEX)
COPYCF(TAPEX,OUTPUT)
      PROGRAM SIMULA   ( INPUT,OUTPUT, TAPE60=INPUT, TAPE61=OUTPUT,
     1 TAPE5=TAPE60, TAPE6= TAPE61,PLOT, TAPE99=PLOT,PUNCH)
C
**************************************************************************
C
C
C         DISTRICT 14 IS SURROUNDED BY DISTRICTS 11,13,15,16,17,18,19
C         CONSEQUENTLY IT IS NECESSARY TO MODEL ALL OF THEM AS A SYSTEM
C         HOWEVER DISTRICT 14 IS THE FOCAL POINT OF THE SIMULATION
C
**************************************************************************
*
*
*
*         BEAT CHARACTERISTICS
*
*         WORD        CONTENT
*
*          1          REFERENCE POINT  X
*          2          REFERENCE POINT  Y
*          3          DELTA X FOR RECTANGLE SPECIFICATION
*          4          DELTA Y FOR RECTANGLE SPECIFICATION
*          5          MANCAR
*          6          AVAILABILITY, 0=BUSY, 1=AVAIL,2= NOT IN SERVICE
*          7          CAR IS 0= OUTSIDE BEAT 1= INSIDE(UNIFORM) 2= INSIDE(CONST)
*          8          CURRENT LOCATION X
*          9          CURRENT LOCATION Y
*         10          DISTRICT
*         11          BEAT
*         12          TIME OF LAST COMPUTATION OF LOCATION
*         13          CAR LUNCH
*
*
*                              PERSONNALS
*                          NO   YES(1)    YES(2)
*              CAR   NO    0     2         5
*            LUNCH   YES   1     3         4
*
*
*
**************************************************************************
*
*         INPUT FORMAT OF EXOGENOUS EVENTS
*
*
*
*         WORD        CONTENT
*
*          1          TYPE OF EVENT RADIO DISPATCH 1-89, ADM(200-203)
*          2          TIMEOUT
```

```
*        4          HEAT OF OCCURENCE
*        5          ARREST, 1= ARREST
*        6          QUADRANT
*        7          X  LOCATION
*        8          Y  LOCATION
*        9          DAY
*       10          NUMBER OF CARS
*       11          NUMBER OF MEN NEEDED (1,2,3,4)
*
*      ENDOGENOUS EVENTS
*      ADMINISTRATIVE CALLS ARE READ AS EXOGENOUS EVENTS, BUT THERE IS
*      THE POSSIBILITY IN THE MODEL TO GENERATE THEM STOCHASTICALLY
*
*      ALGORITHM FOR CODING
*
*     50000 + UNIT ASSIGNED          CAR COMING BACK UP
*     60000 + UNIT ASSIGNED          TRANSFER TO TIMEOUT FOR ASSIGNMENT
*     90000  END OF DAY FOR ENDOGENOUS EVENTS
*
*      100        JUMP TO SUBROUTINE AVAIL TO DETERMINE CAR AVAILABILITY
*
*
**********************************************************************

      COMMON/A/ INDEX, TOTAL
      COMMON/CLOCK1/DUM1,NEVEN,DUM2,NEVEQ,LUN
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/TIME/ ITIME,IDAY
       COMMON/NILSSON/ XAVAIL(19)
      DIMENSION IAUTOS(19)
      INTEGER RANDIN
      INTEGER CAR
      DATA IZEND/0/
      DATA IDAY/4/
      DATA KSWITCH/0/

      KZ=60
      IEND=1440
      ILUNCH=960
      JLUNCH=1440
 2    CONTINUE
      CALL INITIAL
 1    CONTINUE
      CALL CLOCK(4,NEWT,NEWJ)
 5    CONTINUE



      IF( EXOGEN(NUM,2).LT.NEXT) 10,20

C        HANDLE CALLS FOR SERVICE

10    ITIME= EXOGEN(NUM,2)
      IF( ICOUNT2 .GT. 695) GO TO 9002
      IF( ITIME .GT.IEND) GO TO 9002
 6    CALL ASSIGN
 8    NUM=NUM-1
      IF( NUM.EQ.IZEND) 11,5
```

```
      DO 12 I=1,100
      READ 13,(EXOGEN(101-I,J),J=1,11)
      IF(EOF(60)) 4,14
13    FORMAT( 11F5.0)
14    CONTINUE
      IK1=EXOGEN(101-I,2)
      IK2=EXOGEN(101-I,3)
      IK1=IK1/100
      IK2=IK2/100
      EXOGEN(101-I,2)= EXOGEN(101-I,2)-IK1*40
      EXOGEN(101-I,3)= EXOGEN(101-I,3) -IK2*40
      IF(EXOGEN(101-I,3).LE.EXOGEN(101-I,2))EXOGEN(101-I,3)=EXOGEN(101-I,3)
     1,2) + RANDIN(20,50)
12    CONTINUE
      NUM=100
      GO TO 5
4     NUM=100
      IZEND=101-I
      KSWITCH=1
      GO TO 5
C
C        HANDLE ENDOGENOUS EVENTS
C
20    ITIME= NEWT
      IF( ITIME .GT.IEND) GO TO 9002
      IF( NEWJ.EQ.100) 104,105
104   CALL AVAIL
      GO TO 1
105   IF( NEWJ.EQ.90000) GO TO 9000
      KK= (NEWJ/10000)*10000
      IDIST= (NEWJ-KK)/100
      NUMBER= NEWJ-KK-IDIST *100
      IF( KK.EQ.60000) GO TO 126

C        CAR COMING BACK UP          CAR(IDIST,Number,12) = ITime

120    CAR(IDIST,NUMBER,6)= 1
      IF( CAR(IDIST,NUMBER,13).EQ.0 .OR. CAR(IDIST,NUMBER,13).EQ.2.OR.CAR
     1R(IDIST,NUMBER,13).EQ.5) 130,125
130    CALL LUNCH( IDIST,NUMBER)
      GO TO 1
125   CALL CLOCK(2,ITIME+RANDIN(1,KZ ), 60000+IDIST *100+NUMBER)
      GO TO 1

C       IF HERE THERE ARE ADMINISTRATIVE EVENTS (STOCHASTIC)

126    CONTINUE
      IF(CAR(IDIST,NUMBER,6).EQ.0) GO TO 1
      IF(XAVAIL(IDIST).LT.0.2) GO TO 125
      CALL TIMEOUT( IDIST,NUMBER)
      GO TO 1

C        END OF SIMULATED DAY


C        END OF SIMULATION RUN

9000  CONTINUE
9002   CALL DAYSTAT
      CALL NAMPLT
      CALL LARSON
      CALL LARSON
      CALL ENDPLT
      PRINT 9001
9001  FORMAT(10/,*END OF SIMULATION*)
```

```
      SUBROUTINE INITIAL
C
      COMMON/CLOCK1/DUM1,NEVEN,DUM2,NEVEQ,LUN
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXOGEN(10),11),CAR(19,30,13),NUM
      COMMON/A/ INDEX, TOTAL
      COMMON/C/ TRAVDIS(700), ICOUN
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON MTL(500),JUMP(500),MTQ(10),JUMQ(10)
      COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
      COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
      DIMENSION ITYPE(7)
      INTEGER RANDIN
      INTEGER CAR


      CALL RANSET(17,0)
      CALL SETCLK(MTL,JUMP,500,MTQ,JUMQ,10)

      IBE=1020
      KZ=60
C        DETERMINE END OF DAY

      CALL CLOCK( 2,IBE,100)
      CALL CLOCK(2,1440,90000)
      ITIME=960
      NUMX=0
      NUM=1
       INDEX=0
      TOTAL=0
      ICOUN=0
      ISUM1=ISUM2=ISUM3=ISUM4=0
       ICOUNT=0
      ICOUNT2=0
      ICOUNT3=0
      ICOUNT4=0
      ICOUNT5=0
      DO6I=1,22
      ISTAT(I)=0
      KSTAT(I)=0
6     JSTAT(I)=0
      DO 5 I=11,19
      DO 5 J=1,30
      IADMIN(I,J)=0
      MINUTE(I,J)=0
5     CAR(I,J,6)= 2

C        READ IN REFERENCE POINTS

9     CONTINUE
      READ1,I,J,CAR(I,J,1),CAR(I,J,2),CAR(I,J,3),CAR(I,J,4)
1     FORMAT( 2I2,2I4,2I3)
      IF(I.EQ.99) GO TO 100
      PRINT 2,I,J,(CAR(I,J,K),K=1,4)
2     FORMAT( 10X, 2I2,4I5)
      CAR(I,J,5)= 2
      TOTAL= TOTAL+1
      CAR(I,J,6)=1
      CAR(I,J,7)= 1
      CAR(I,J,8)= 0
```

```
      CAR(I,J,10)= I
      CAR(I,J,11)= J
      CAR(I,J,12)= 960
      CAR(I,J,13)= 0
      GO TO 9

C         READ IN MANNING PER CAR

100   CONTINUE
      READ 20,I,JJ,(CAR(I,J,5),J=1,JJ)
20    FORMAT( 8X, 2I2, 30I1)
      IF( I.EQ.0) 120,101
101   CONTINUE
      PRINT 20,I,JJ,(CAR(I,J,5),J=1,JJ)
      GO TO 100
120   CONTINUE
200   READ 300, (EXOGEN(I),I=1,11)
300   FORMAT( 11F5.0)
      IK1= EXOGEN(NUM,2)
      IK2=EXOGEN(NUM,3)
      IK1=IK1/100
      IK2=IK2/100
      EXOGEN(NUM,2)= EXOGEN(NUM,2)-IK1*40
      EXOGEN(NUM,3)= EXOGEN(NUM,3)-IK2*40
      DO 401 I=11,19
      IF( I.EQ.12) GO TO 401
      DO 400 J=1,30
      IF( CAR(I,J,6).EQ.2) GO TO 400
      IF( RANDIN(1,6).EQ.1) GO TO 350
      CALL CLOCK( 2, ITIME+ RANDIN( 1,KZ), 60000+100*I+J)
      GO TO 400

C         CAR RECEIVES CAR SERVICE RIGHT AWAY

350   CONTINUE
      IVALUE= RANDIN(10,30)
      CALL CLOCK(2,ITIME+ IVALUE, 50000+100*I+J)
      IADMIN(I,J) = IADMIN(I,J)+IVALUE
      CAR(I,J,6)=0
      ISUM1=ISUM1+1
400   CONTINUE
401   CONTINUE
      RETURN
      END


      SUBROUTINE TIMEOUT(I,J)
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
      DIMENSION XX(17)
      DATA XX/0.0, 0.14,0.25,0.37,0.5,0.37,0.25,0.14,0.0,0.14, 0.25,0.37,
     1, 0.5,0.37,0.25,0.14,0.0/
      INTEGER CAR
      INTEGER RANDIN
      LOGICAL DRAW
      KZ=60
      IPERIOD= (ITIME-960)/30+1
      IF( DRAW(XX(IPERIOD)))2,5
2     ISUM4=ISUM4+1
      IF( CAR(I,J,13).LT.2) 10,20
10    IVALUE=RANDIN(10,20)
C
C         PERSONNALS
```

```
      CALL CLOCK(2,ITIME+IVALUE,50000+I*100+J)
      IADMIN(I,J)= IADMIN(I,J)+IVALUE
       CAR(I,J,6)=0
      CAR(I,J,12)= CAR(I,J,12) + IVALUE
      IF(CAR(I,J,13).EQ.0)30,40
30    CAR(I,J,13)=2
      GO TO 50
40    CAR(I,J,13)=3
      GO TO 50
20    IF( CAR(I,J,13).NE.4 .AND. ITIME .GT.1200) 60,201
60    IVALUE=RANDIN(10,20)
      IADMIN(I,J)= IADMIN(I,J)+IVALUE
      CALL CLOCK(2,ITIME+IVALUE,50000+I*100+J)
      CAR(I,J,6)= 0
      CAR(I,J,12)= CAR(I,J,12)+IVALUE
       IF(CAR(I,J,13).EQ.3) 80,90
80    CAR(I,J,13)= 4
      GO TO 50
90     CAR(I,J,13)= 5
50    CONTINUE
      RETURN
C
C        CAR SERVICE
C
5     IF( DRAW(0.20))200,201
200   IF( DRAW(0.015)) GO TO 202
      ISUM1=ISUM1+1
      IVALUE= RANDIN(10,20)
203   CONTINUE
      IADMIN(I,J)= IADMIN(I,J)+IVALUE
      CALL CLOCK(2,ITIME+IVALUE          ,50000+I*100+J)
      CAR(I,J,12)= CAR(I,J,12)+ IVALUE
       CAR(I,J,6)=0
      RETURN
201    CONTINUE
      CALL CLOCK(2,ITIME+RANDIN(1,KZ),60000+I*100+J)
      RETURN
C        CAR REPAIR
202   IVALUE= RANDIN(60,240)
      ISUM2= ISUM2+1
      GO TO 203
      END


      SUBROUTINE LUNCH( IDIST,NUMBER)
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXGGEN(101,11),CAR(19,30,13),NUM
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
      DIMENSION DATUM(16)
      DIMENSION XX(7),AXX(1,7),OR(7),ORD(1,7)
      DATA DATUM/24.0,57.0,87.0,121.0,192.0,279.0,399.0,588.0,779.0,
     1 986.0,1134.0,1298.0,1402.0,1469.0,1494.0,1518.0/
      DATA XX/0,0.092,0.22,0.5,0.61,0.98,1.0/
      DATA OR/18.0,23.0,26.0,29.0,30.0,37.0,39.0/
      LOGICAL DRAW
      INTEGER RANDIN
      INTEGER CAR
      INTEGER TIN

C        DETERMINE IF CAR GETS LUNCH

      KZ=60
      IA= 960
      TOTAL=1518
```

```
      XK=DATUM(IPERIOD)
       IF(DRAW(XK/TOTAL))101,901
 101  TIN= IDIST*100 + NUMBER + 50000
      DO 100 I=1,7
       XXX(1,I)= XX(I)
 100  ORD(1,I)= OR(I)

C         DETERMINE FOR HOW LONG THE CAR WILL STAY DOWN

      IVALUE= STOGN2 (7,XXX,ORD,1)
      ISUM3=ISUM3+1
      CALL CLOCK(2,ITIME+ IVALUE,TIN)
      IADMIN(IDIST,NUMBER)=IADMIN(IDIST,NUMBER)+IVALUE

      IF( CAR(IDIST,NUMBER, 3).EQ.0) 105,106
 105   CAR(IDIST,NUMBER,13)= 1
      GO TO 110
 106  IF( CAR(IDIST,NUMBER,13).EQ.2) 107,108
 107  CAR(IDIST,NUMBER,13)=3
      GO TO 110
 108   CAR(IDIST,NUMBER,13)= 4
 110  CONTINUE
      CAR(IDIST,NUMBER,5)= 0
      CAR(IDIST,NUMBER,12)= CAR(IDIST,NUMBER,12)+IVALUE
      RETURN
 901  CONTINUE
      CALL CLOCK(2,ITIME+RANDIN(1,KZ ),60000+IDIST*100+NUMBER)
      RETURN
      END


      SUBROUTINE ASSIGN
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/TIME/ ITIME,IDAY
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/A/ INDEX, TOTAL
      COMMON/B/ LIST(200,4), LENGTH
      COMMON/C/ TRAVDIS(700), ICOUN
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
      COMMON/CARS/ KK1,KK2,YDISTAN
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
      DIMENSION KK(3), KL(3)
      DIMENSION IAUTOS(19)
      INTEGER OPTION
      INTEGER CAR
      INTEGER RANDIN
      DATA IAUTOS/10*0, 15,0,17,19,13,11,13,22,23/
      DATA OPTION/0/
      IBE=1020
      SPEED= 8.6
      BETA=0.70
      SPEED= SPEED*800.0/60.0
       IF(EXOGEN(NUM,1).GT.66.AND. RANDIN(1,3).EQ.1)GOTO 700

C         WHEN OPTION = 0 , CENTER OF MASS DISPATCHING IS USED


C         THIS SUBROUTINE HAS FIVE PARTS
C            1.  DETERMINE EVENT LOCATION
C            2.  DETERMINE LOCATION OF ALL CARS
C            3.  DETERMINE MEN NEEDED
C            4.  FIND CLOSEST AVAILABLE CAR(GIVEN RESOLUTION OF INFORMATION)
C            5.  ASSIGN CAR
```

```
      IF( EXOGEN(NUM,6).EQ.1) GO TO 10
 3    CONTINUE
      RETURN

 10   CONTINUE

      IXZ=EXOGEN(NUM,4)
       IXZZ=IXZ/100
      IF(IXZ.GT.IXZZ*100+IAUTOS(IXZZ))GO TO 3


C        DETERMINE RESPONSE DISTANCE WITH CENTER OF MASS DISPATCHING

      CALL CENTER
      CALL CARS(KL(1),KL(2),KL(3))
      II=KL(1)
      KK1=LIST(II,2)
       KK2=LIST (II,3)
      CALL POSITON
      DO 200 I=1,3
      IF( KL(I).LT. 1) KL(I)= RANDIN(1,10)
      IF( KL(I).EQ.0) GO TO 210
      II=KL(I)
      K1=LIST(II,2)
      K2=LIST(II,3)
      IF(OPTION .EQ.1) GO TO 200
      CAR(K1,K2,6)=0
      CAR(K1,K2,7)=0
      IEXOG= EXOGEN(NUM,4)+ 0.0001
      IF( IEXOG.EQ.K1*100+K2) 51,52
 51   CONTINUE
      CAR(K1,K2,7)=2
      IF( I.GT.1) GO TO 54
      IF( ITIME .LT.IBE)GO TO 54

C        ISTAT= SAME BEAT
C        JSTAT= SAME DISTRICT
C        KSTAT= NUMBER OF CALLS

      ISTAT(K1)=ISTAT(K1)+1
      GO TO 53
 52   CONTINUE
      IF( I.GT.1) GO TO 54
      IF( ITIME .LT.IBE)GO TO 54
      IDOUBT=EXOGEN(NUM,4)/100
      IF(K1.EQ.IDOUBT)JSTAT(K1)=JSTAT(K1)+1
 53   KSTAT(K1)=KSTAT(K1)+1


 54   CONTINUE
      CAR(K1,K2,8)= EXOGEN(NUM,7)
      CAR(K1,K2,9)= EXOGEN(NUM,8)
      NEXT=EXOGEN(NUM,3)
      IF(EXOGEN(NUM,5).EQ.1) NEXT=NEXT+RANDIN(60,120)
      NEWJ=50000+K1*100 +K2
      CALL CLOCK(2,NEXT,NEWJ)
 200  CONTINUE
 210  CONTINUE

C        CAR LOCATOR INFORMATION AVAILABLE

C
```

```
      CALL CARS(KK(1),KK(2),KK(3))
      DO 100 I1=1,3
      IF( KK(I1).EQ.0) GO TO 110
      K1= LIST(I1,2)
      K2= LIST(I1,3)

C        ASSIGN CAR

50    CONTINUE

      CAR(K1,K2,6)=0
      CAR(K1,K2,7)=0
      IF(EXOGEN(NUM,4).EQ.K1*100+K2) CAR(K1,K2,7)=2
      CAR(K1,K2,8)= EXOGEN(NUM,7)
      CAR(K1,K2,9)= EXOGEN(NUM,8)
      NEXT=  EXOGEN(NUM,3)
       IF( EXOGEN(NUM,5).EQ.1) NEXT=NEXT+ RANDIN(60,120)
      NEWJ= 50000+K1*100+K2
      CALL CLOCK(2,NEXT,NEWJ)

      XDISTAN= LIST(I1,1)
100    CONTINUE
110    CONTINUE
      IF( ITIME .LT.IBE)GO TO 700

C        CALCULATE STATISTICS

C           1.  WAS THE SAME ASSIGNMENT MADE BY DISPATCHER
C               THAT IS WAS THE NEAREST CAR CHOSEN
C           3.  TRAVEL DISTANCE


C           TRAVEL DISTANCE SAVED
      IF(OPTION.EQ.0) XDISTAN=LIST(1,1)
      ICOUNT2=ICOUNT2+1
      CARRSP2(ICOUNT2)= YDISTAN/SPEED        + BETA
      ICOUNT3=ICOUNT3+ 1
      CARRSP3(ICOUNT3)= XDISTAN/SPEED         +BETA
      ITRIP= IEXOG
       IF( ITRIP/100 .EQ.14) 500,310
500   ICOUNT5=ICOUNT5+1
      PUNCH 600,YDISTAN
600   FORMAT( F10.2)
      CARRSP5(ICOUNT5)= YDISTAN/SPEED        +BETA
310   CONTINUE
      ICOUN= ICOUN+1
      TRAVDIS(ICOUN)= YDISTAN- XDISTAN
      IF(TRAVDIS(ICOUN ).LT.0) TRAVDIS(ICOUN )=0


C        CALCULATE PROBABILITY OF NOT ASSIGNING THE CLOSEST CAR

      ICOUNT4=ICOUNT4+1
      IF(KK1*100+KK2.EQ.LIST(1,2)*100+LIST(1,3))NUMX=NUMX+1
      IX1= EXOGEN(NUM,2)/100
      IX2= EXOGEN(NUM,3)/100
      MINUTE(K1,K2)= MINUTE(K1,K2)+ EXOGEN(NUM,3)-EXOGEN(NUM,2)

700   CONTINUE
       RETURN
      END


      SUBROUTINE SORT( LIST,N,M, INDEX,NUMBER)
      DIMENSION LIST(N,M)
```

```
      DO 30 I2=1,NUM
      I3=I2+1
      IF(NUM.LT.I3) GO TO 30
      DO 20 I=I3,NUM
      IF( LIST(I,INDEX).GE. LIST(I2,INDEX) )GO TO 20
      DO 10 K=1,M
      ITEMP= LIST(I,K)
      LIST(I,K)= LIST(I2,K)
 10   LIST(I2,K)= ITEMP
 20   CONTINUE
 30   CONTINUE
      RETURN
      END


      SUBROUTINE CENTER
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/TIME/ ITIME,IDAY
      COMMON/B/ LIST(200,4), LENGTH
      INTEGER CAR
      XLOC= EXOGEN(NUM,7)
      YLOC= EXOGEN(NUM,8)
      NU =0
      DO 11 I=11,19
      IF( I.EQ.12) GO TO 11
      DO 10 J=1,30
      IF( CAR(I,J,6) -1) 10,30,10
 30   IDISTAN= ABS(CAR(I,J,1)-XLOC) + ABS(CAR(I,J,2)-YLOC)
      NU=NU+1
      LIST(NU ,1)= IDISTAN
      LIST(NU ,2)= CAR(I,J,10)
      LIST(NU ,3)= CAR(I,J,11)
      LIST(NU ,4)= CAR(I,J,5)
 10   CONTINUE
 11   CONTINUE
      IF( NU .GT.200) PRINT 40
 40   FORMAT( 10X,* TROUBLE IN SORT*)
      LENGTH= NU
      CALL SORT(LIST,200,4,1,NU )
      RETURN
      END


      SUBROUTINE AVAIL
       COMMON/NILSSON/ XAVAIL(19)
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/A/ INDEX, TOTAL
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/TIME/ ITIME,IDAY
      COMMON/CLOCK1/DUM1,NEVEN,DUM2,NEVEQ,LUN
      COMMON/KAJSA/ FOURTEN(120)
      COMMON MTL(500),JUMP(500),MTQ(10),JUMQ(10)
       DIMENSION IAUTOS(19)
      DATA IAUTOS/10*0,15,0,17,19,13,11,13,22,23/
      INTEGER CAR
      XAVAIL(12)= 0
      NU =0
      ICOUNT=ICOUNT+1
      DO 6 I=11,19
       XZ=0
      IF( I.EQ.12) GO TO 6
      DO 5 J= 1,30
      IF( CAR(I,J,6).EQ. 1) NU =NU +1
      IF(CAR(I,J,6).EQ.1) XZ=XZ+1
```

```
      XAVAIL(I)=XZ/IAUTOS(I)
6     CONTINUE
      CARBUSY(ICOUNT)= NU/132.0
      PRINT 10,CARBUSY(ICOUNT),ITIME,(XAVAIL(I),I=11,19)
10    FORMAT(   X,  *CARBUSY*F10.3,* ITIME*I5, 10F8.3)
      FOURTEN(ICOUNT)=XAVAIL(14)
      NEWT= ITIME +  5
      NEWJ= 100
      CALL CLOCK(2,NEWT,NEWJ)



      GO TO 50
      LENGTH=NEVEN
      DO 20 I=1,LENGTH
      PRINT 25,MTL(I),JUMP(I)
25    FORMAT( 10X,*TIME*I6,* TYPE*I10)
20    CONTINUE
      DO 40 I=11,19
      IF( I.EQ.12) GO TO 40
      DO 40 J=1,30
      IF( CAR(I,J,6).EQ.2) GO TO 40
      PRINT 30,(CAR(I,J,K),K=1,13)
30    FORMAT( 10X,13I8)
40    CONTINUE
 50   CONTINUE
      RETURN
      END


      SUBROUTINE POSITON
      COMMON/INPUT/ EXOGEN(101,11),CAR(19,30,13),NUM
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/B/ LIST(200,4), LENGTH
      COMMON/CARS/ KK1,KK2,YDISTAN
      COMMON/TIME/ ITIME,IDAY
      INTEGER XLOC,YLOC
      INTEGER CAR,RANDIN
      INTEGER DELTAX, DELTAY
C
C
C        IX= X LOCATION OF EVENT
C        IY = YLOCATION OF EVENT
C        LIST = MATRIX OF CARS RANKED ON DISTANCE
C
C
C        WORD      CONTENT
C
C          1       DISTANCE
C          2       DISTRICT
C          3       BEAT
C          4       MANCAR
C                                    I
C                                    I
C                                    I
C                                    I           *CASE 3
C                                    I
C                                    I
C                  *******************----------
C                  *                 *
C                  *                 *
C                  *                 *
C                  *       * BEAT    *           *CASE 2
C                  *    REF POINT    *
```

```
C                          o                 o
C                          ********************----------
C                          I                 I
C                          I                 I
C                          I        *CASE 1  I
C                          I                 I
C                          I                 I
C                          I                 I
C
C
C
      SPEED= 7.0
      SPEED= SPEED *800/60.0
      IX= EXOGEN(NUM,7)
      IY= EXOGEN(NUM,8)
      NOM=0
      DO 1002 I=11,19
      IF( I.EQ.12) GO TO 1002
      DO 1001 J=1,30
      IF( CAR(I,J,6).NE. 1) GO TO 1001
      DELTAX= CAR(I,J,3)
      DELTAY= CAR(I,J,4)
      INDEX=CAR(I,J,7)+1
      IF( INDEX.LT.1 .OR. INDEX.GT.3) 1030,1031
1030   INDEX=2
      PRINT 1032, CAR(I,J,7),I,J
1032   FORMAT(10X,* INDEX IN  POSITION IS BAD*,3I6)
1031  CONTINUE
      GO TO (100,200,300) INDEX

C       100= OUTSIDE BEAT
C       200= INSIDE BEAT (UNIFORM)
C       300= INSIDE(CONSTRAINED UNIFORM)

C       ASSUMPTION THAT CAR RETURNS BY SHORTEST ROUTE

100   IB=CAR(I,J,8)
      IA= DELTAX
      IC=CAR(I,J,1)
      IF(IB.GE.IC-IA.AND.IB.LE.IC+IA)10,20

C       WE HAVE CASE NUMBER ONE

10    IN=2
      IF(CAR(I,J,9).GT.CAR(I,J,2))IN=1
11    IDISTAN=IABS(CAR(I,J,9)-CAR(I,J,2)+(-1)**IN*CAR(I,J,4))

C       THIS IS THE DISTANCE TO THE BORDER OF THE BEAT. NOW NEED TO
C       DETERMINE IF CAR IS STILL OUTSIDE

       IRANGE=SPEED*(ITIME-CAR(I,J,12))
      IF(IDISTAN.LT.IRANGE) GO TO 50
      NOM=NOM+1
      CAR(I,J,9)=CAR(I,J,9) +(-1)**IN*IRANGE
      CAR(I,J,12)=ITIME
49    LIST( NOM,1)=IABS(IX-CAR(I,J,8))+IABS(IY-CAR(I,J,9))
      LIST(NOM,2)= I
      LIST( NOM,3)= J
      LIST(NOM,4)= CAR(I,J,5)
       GO TO 1000
50    CAR(I,J,12)=CAR(I,J,12)+ IDISTAN/SPEED
      CAR(I,J,9)= CAR(I,J,2)+(-1)**IN*DELTAY     *(-1)
      GO TO 300
```

```
20     IB=CAR(I,J,9)
       IA= DELTAY
       IC=CAR(I,J,2)
       IF(IB .GE.IC-IA.AND.IB.LE.IC+IA)30,40
30     IN=2
       IF(CAR(I,J,8).GT.CAR(I,J,1))IN=1
       IDISTAN=IABS(CAR(I,J,8)- CAR(I,J,1)+(-1)**IN*DELTAX)
       IRANGE=SPEED*(ITIME-CAR(I,J,12))
       IF( IDISTAN.LT.IRANGE) 60,49
60     CAR(I,J,12)=CAR(I,J,12)+ IDISTAN/SPEED
       CAR(I,J,8)= CAR(I,J,1)+(-1)**IN*DELTAX     *(-1)
       GO TO300
C      THE CAR IS AT A DIAGONAL FROM ITS REFERENCE POINT
40     CONTINUE
       IF( RANDIN(1,2).EQ.2) GO TO 1010
       IN=2
       IF(CAR(I,J,8).GT.CAR(I,J,1))IN=1
       IRANGE= SPEED*(ITIME-CAR(I,J,12) )
       IF(IN.EQ.2) GO TO 1005
       IF(CAR(I,J,8)-IRANGE.LT.CAR(I,J,1)+DELTAX    )1003,1004
1003   CAR(I,J,8)=CAR(I,J,1)+DELTAX
       CAR(I,J,12)=CAR(I,J,12) +IABS(CAR(I,J,1)+DELTAX     -CAR(I,J,8))/SP
      1EED
       GO TO 100
1004   NOM=NOM+1
       CAR(I,J,8)= CAR(I,J,8) + IRANGE
       LIST(NOM,1)= IABS(CAR(I,J,8)-IX) + IABS(CAR(I,J,9)-IY)
       LIST( NOM,2)= I
       LIST( NOM,3)= J
       LIST(NOM,4)= CAR(I,J,5)
       GO TO 1000
1005   IF( CAR(I,J,8)+IRANGE.GT. CAR(I,J,1)-DELTAX     )1006,1004
1006   CAR(I,J,8)= CAR(I,J,1)-DELTAX
       CAR(I,J,12)= CAR(I,J,12)+IABS(CAR(I,J,1)-DELTAX     -CAR(I,J,8))/SPEED
      1EED
       GO TO 100
1010   CONTINUE
C      IF HERE IS MEANS THAT THE Y DIMENSION OF CASE 3 IS BEING EXPLORED
       IN=2
       IF( CAR(I,J,9).GT.CAR(I,J,2))IN=1
       IRANGE=(ITIME-CAR(I,J,12))*SPEED
       IF( IN.EQ.2) GO TO 1020
       IF( CAR(I,J,9)-IRANGE.LT.CAR(I,J,2)+DELTAY     )1013,1014
1013   CAR(I,J,12)=CAR(I,J,12)+IABS(CAR(I,J,2)+DELTAY     -CAR(I,J,9))/S
      1PEED
       CAR(I,J,9)= CAR(I,J,2)+ DELTAY
       GO TO 100
1014   CAR(I,J,9)=CAR(I,J,9)-IRANGE
1015   CONTINUE
       LIST(NOM,1)= IABS(CAR(I,J,8)-IX) + IABS(CAR(I,J,9)-IY)
       LIST( NOM,2)= I
       LIST( NOM,3)= J
       LIST(NOM,4)= CAR(I,J,5)
       GO TO 1000
C      CAR IS SOUTH OF REFERENCE POINT
1020   IF(CAR(I,J,9)+IRANGE.GT.CAR(I,J,2)-DELTAY     )1021,1024
1021   CAR(I,J,12)=CAR(I,J,12)+IABS(CAR(I,J,2)-DELTAY     -CAR(I,J,9))/
      1SPEED
```

```
      GO TO 100
1024   CAR(I,J,9)= CAR(I,J,9) + IRANGE
      GO TO 1015

C         UNIFORM DISTRIBUTION CASE

200   CONTINUE
      IBEGIN= CAR(I,J,1) - DELTAX
      IEND= CAR(I,J,1) + DELTAX
      IF( IEND.LE. IBEGIN) 4000,4002
4000   PRINT 4051
4051   FORMAT(10X,* TROUBLE WITH JX*)
      IEND= IBEGIN+1
4002   CONTINUE
      JX= RANDIN( IBEGIN, IEND)
      IBEGIN= CAR(I,J,2)- DELTAY
      IEND= CAR(I,J,2) +   DELTAY
      IF( IEND.LE. IBEGIN) 4600, 4610
4600  PRINT 4601
4601  FORMAT( 10X,* TROUBLE WITH JY    *)
      IEND= IBEGIN+1
4610  CONTINUE
      JY= RANDIN( IBEGIN,IEND)
      NOM=NOM+1
      LIST(NOM,1)= IABS(JX-IX) + IABS(JY-IY)
      LIST(NOM,2)= I
      LIST(NOM,3)=J
      LIST(NOM,4)= CAR(I,J,5)
      CAR(I,J,7)= 1
      GO TO 1000

300    CONTINUE

C         THE CONSTRAINED UNIFORM CASE

      IRANGE=(ITIME -CAR(I,J,12))*SPEED
      IF( IRANGE.GT.2*DELTAY.AND.IRANGE.GT. 2*DELTAX)2001,2002
2001  CAR(I,J,7)= 1
      GO TO 200



2002   CONTINUE
       IYMIN= CAR( I,J,9)-IRANGE
      MINY= CAR(I,J,2)-DELTAY
      IF( IYMIN.LT.MINY) IYMIN=MINY

      IYMAX=CAR(I,J,9)+IRANGE
      MAXY=CAR(I,J,2)+CAR(I,J,4)
      IF( IYMAX.GT.MAXY) IYMAX=MAXY
      IF( IYMIN.GE. IYMAX) 4010,4012
4010  PRINT 4001, IYMIN, IYMAX
4001  FORMAT(10X,*IYMIN* I5,* IYMAX* I5)
      IYMIN= IYMAX-1
4012  CONTINUE
      YLOC=RANDIN(IYMIN,IYMAX)

      IXMIN=CAR(I,J,8)-IRANGE
      MINX=CAR(I,J,1)-DELTAX
      IF( IXMIN.LT.MINX) IXMIN=MINX

      IXMAX=CAR(I,J,8)+IRANGE
      MAXX=CAR(I,J,1)+DELTAX
      IF(IXMAX.GT.MAXX) IXMAX=MAXX
```

```
4003  PRINT 4004, IXMIN, IXMAX
4004  FORMAT( 10X,* IXMIN* I5, * IXMAX* I5)
      IXMAX= IXMIN+1
4005   CONTINUE
      XLOC= RANDIN(IXMIN,IXMAX)

3000  NOM=NOM+1
      LIST(NOM,1)= IABS(IX-XLOC)+IABS(IY-YLOC)
      LIST(NOM,2)= I
      LIST( NOM,3)= J
      LIST(NOM,4)= CAR(I,J,5)
      CAR(I,J,7)=2
1000  IF( KK1.EQ.I.AND.KK2.EQ.J) 9001,1001
9001   YDISTAN=LIST(NOM,1)
1001  CONTINUE
1002   CONTINUE
      IF( NOM.GT.200) PRINT 7000
7000  FORMAT( 10X,*  NOM IS TOO LARGE*)
      LENGTH=NOM
      CALL SORT(LIST,200,4,1,NOM)
      RETURN
      END


      SUBROUTINE CARS(IANS1,IANS2,IANS3)
      COMMON/B/ LIST(200,4), LENGTH
      COMMON/INPUT/EXOGEN(101,11), CAR(19,30,13),NUM
      INTEGER RANDIN
C
C
C        THIS SUBROUTINE DETERMINES WHICH CARS ARE TO BE ASSIGNED BASED ON
C        MINIMUM TRAVEL DISTANCE AND NUMBER OF MEN NEEDED
C        AND RETURNS THE LOCATION OF THE LIST TO BE ASSIGNED
C
      IANS1=0
      IANS2=0
      IANS3=0
      ICODE= EXOGEN(NUM,1)
      ICARS=EXOGEN(NUM,10)
      IMEN=EXOGEN(NUM,11)
      IF( IMEN .LT.1 .OR.IMEN.GT. 4) IMEN=2
      IDIST= EXOGEN(NUM,4)/100
      IF( LENGTH.GT.30) LENGTH =30
      GO TO (100,200,300,400) IMEN
100   CONTINUE
C
C        NOW IT ASSIGNS THE CLOSEST CAR
C        CLOSEST THAT IS WITHIN THE DISTRICT TO BEGIN WITH
C
      DO 101 I=1,LENGTH
      IF( ICODE.LT.86 .AND.RANDIN(1,4).EQ.1) GO TO 104
      IF( I.EQ.30) GO TO 103
       IF( LIST(I,2).EQ.IDIST) 102,101
 102   CONTINUE
104   IANS1=I
      GO TO 105
103   IVAL= RANDIN(1,I)
      IANS1=IVAL
      GO TO 105
101   CONTINUE
105   CONTINUE
      RETURN
C
C        FIND CLOSEST TWO MAN CAR OR TWO ONE-MAN CARS AND ASSIGN
C        CLOSEST COMBINATION
```

```
200   DO 201 I=1,LENGTH
      IF( ICODE.LT.86 .AND. RANDIN(1,4) .EQ.1) GO TO 202
      IF( LIST(I,4).EQ.2 .AND. LIST(I,2).EQ.IDIST) GO TO 202
      IF( I.EQ.30) GO TO 202
201   CONTINUE
202   CONTINUE
      ICAR1=I
      ISWITCH=0
      DO 203 I=1,LENGTH
      GO TO 204
      IF( ICODE.LT.86 .AND.RANDIN(1,4).EQ.1) GO TO 205
      IF( LIST(I,4).EQ.1.AND.LIST(I,2).EQ.IDIST)204,210
204   IF(ISWITCH.EQ.0) 205,206
205   ICAR2=I
      ISWITCH=1
      GO TO 203
206   ICAR3=I
      GO TO 207
210    IF( I.EQ.30) GO TO 208
      ISWITCH=1
203   CONTINUE
207   IF(MAX0(LIST(ICAR2,1),LIST(ICAR3,1)).GT.LIST(ICAR1,1))208,209
208    IANS1=ICAR1
      RETURN
209   IANS1=ICAR2
      IANS2=ICAR3
      RETURN
300   IANS1=1
      NEED=IMEN-LIST(1,4)
      DO 301 I=2,LENGTH
      IF( NEED.EQ.LIST(I,4))GO TO 302
301   CONTINUE
302   IANS2=I
      RETURN
400    CONTINUE
      ISWITCH=0
      DO 401 I=1,LENGTH
       IF(LIST(I,4).EQ. 2) 402,401
402   IF( ISWITCH) 405,403,404
403    ICAR1=I
      GO TO 401
404   CAR2=I
      ISWITCH=-1
      GO TO 401
405   ICAR3=I
      GO TO 407
401    CONTINUE
407    CONTINUE
      RETURN
      END


      SUBROUTINE DAYSTAT
C
      COMMON/C/ TRAVDIS(700), ICOUN
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMA
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
      COMMON/K/ISUM1,ISUM2,ISUM3,ISUM4
      DIMENSION IAUTOS(19)
      DIMENSION SAVE(19)
      DATA IAUTOS/1980,15,0,17,19,13,11,13,22,23/
C
```

```
C          STATISTICS FOR...
C              1.  AVAILABILITY OF CARS
C              2.  RESPONSE TIMES  A. FOR CENTER OF MASS
C                                  B.  CAR LOCATOR SYSTEM
C         3.  PERCENTAGE OF BEATCAR ANSWERING CFS ON HIS BEAT
C         4.  PROBABILITY OF NOT ASSIGNING THE CLOSEST CAR


      PRINT 1
 1    FORMAT( 30X,* STATISTICAL DAILY SUMMARY*,////)
      IF( ICOUNT2.LT.2) GO TO 10
      CALL STIX7(CARRSP2,ICOUNT2,0.5,50.0,1.0,7HMINUTES,1,0,1,42HTRAVEL
     1TIME FOR CENTER OF MASS DISPATCHING    ,42)
10    CONTINUE
      IF( ICOUNT3.LT.2) GO TO 20
      CALL STIX7(CARRSP3,ICOUNT3,0.5,50.0,1.0,7HMINUTES,1,0,1,39HTRAVEL
     1TIME FOR CAR LOCATOR DISPATCHING  , 39)
20    CONTINUE
      IF( ICOUNT.LT.2) GO TO 30
      CALL STIX7(TRAVDIS,ICOUN ,0.0,500.0,50.0,7HNUMBERS,1,0,1,21HTRAVEL DIS
     1 DISTANCE SAVED  ,21)
30    CONTINUE
       IF( ICOUNT5.LT.2) GO TO 40
      CALL STIX7(CARRSP5,ICOUNT5,0.5,50.0,1.0,7HMINUTES,1,0,1,34HTRAVEL
     1 TIME FOR 14TEENTH DISTRICT  , 34)
40    CONTINUE

      SUM3=0
       SUM4=0
       SUM5=0
      PRINT 100
100   FORMAT( 1H1,9X,*PERCENT OF CALLS ANSWERED BY BEAT OR DISTRICT CAR*
     1///,10X,*DISTRICT* 5X,*BEATCAR* 5X,*DISTRICT CAR*,5X,*NUMBER OF CA
     1LLS*5X,*AVERAGE NUMBER OF CALLS/CAR*//)
      DO 5I=11,19
      IF( I.EQ.12) GO TO 5
      XX=KSTAT(I)
      SUM3=SUM3+XX
      P1= ISTAT(I)/XX
      SUM4=SUM4+ISTAT(I)
      P2= JSTAT(I)/XX
      SUM5=SUM5+JSTAT(I)
      AVE= XX/IAUTOS(I)
      SAVE(I)=AVE
      PRINT 101, I,P1,P2,XX,AVE
101   FORMAT( 10X,I4, 7X,F5.2,10X,F5.2,10X,F7.2,15X,F7.2)
5      CONTINUE
      SUM4=SUM4/SUM3
      SUM5=SUM5/SUM3
      SUM6=SUM3/132.0
      PRINT 102,SUM4, SUM5,SUM3,SUM6
102   FORMAT(/,9X,*AVERAGES*4X,F5.2,10X,F5.2,10X,F7.2,15X,F7.2)


      PRINT 105
105   FORMAT( ///,10X,*MINUTES SPENT ON CALLS  FOR SERVICE AND ADMIN CALLS
     1LLS*,//,10X,*DISTRICT* 5X,* MIN ON CFS*,5X,*MIN ON ADMIN*,
     110X,*MIN/CALL*,//)
      SUM7=0
      SUM8=0
      DO 202 I=11,19
      IF( I.EQ.12) GO TO 202
      SUM1=0
      SUM2=0
      DO 201 J=1,30
       SUM7=SUM7+...
```

```
      SUM8=SUM8+ IADMIN(I,J)
201   SUM2= SUM2 + IADMIN(I,J)
       SUM1=SUM1/IAUTOS(I)
      SUM2=SUM2/IAUTOS(I)
      SUM9=SUM1/SAVE(I)
      PRINT 200,I,SUM1, SUM2 ,SUM9
200   FORMAT( 10X, I5,10X,F7.1,10X, F7.1,10X,F7.1)
202    CONTINUE
      SUM7=SUM7/132.0
      SUM8=SUM8/132.0
      PRINT 205,SUM7,SUM8
205   FORMAT(10X,*AVERAGES*7X,F7.1,11X,F7.2)
      PP= NUMX/SUM3
      PRINT110,PP
110   FORMAT(///,10X,*THE PROBABILITY OF ASSIGNING THE CLOSEST CAR*,/,
     1 10X,* USING CENTER OF MASS DISPATCHING STRATEGY IS* F7.2)
      SUMMA= 0
      DO 300 I= 1,ICOUNT
300   SUMMA= SUMMA+ CARBUSY(I)
      SUMMA= SUMMA/ ICOUNT
      PRINT 301,SUMMA
301   FORMAT( ////, 10X,* AVERAGE AVAILABILITY = * F6.2)
      PRINT 310,ISUM1,ISUM2 ,ISUM3 ,ISUM4
310   FORMAT(///,10X,*THERE WERE*I5,* CAR SERVICES*,/,10X,*AND*I4* CAR
     1REPAIRS*,/,10X,* AND* I5,* LUNCHES TAKEN*,10X,*AND*I6* PERSONNALS*
     1)
      RETURN
      END



      SUBROUTINE LARSON
      COMMON/D/ MINUTE(19,30), IADMIN(19,30)
      COMMON/E/ ISTAT(22),JSTAT(22),KSTAT(22)
      COMMON/OUTPUT/CARBUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/A/ INDEX,TOTAL
      COMMON/KAJSA/ FOURTEN(120)
      COMMON/N/ RHO3
       DIMENSION F(102), F(102)
      INTEGER OPTION
      DATA OPTION/-1/
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)

C         OPTION = 0 MEANS THAT 14TH DISTRICT ONLY IS PLOTTED

C
      OPTION=OPTION+1
      SPEED=15.0

      IF(OPTION .EQ.0) GO TO 40
C     DETERMINE AVAILABILITY
C      THAT IS FIND RHO3 FOR DISTRICT 14
      SUM=0
      DO 1 I=1,ICOUNT
1     SUM=SUM+FOURTEN(I)
      RHO3=SUM/ICOUNT
      PRINT 3, RHO3
3     FORMAT(//,10X,*14-TEENTH DISTRICT RHO=*F6.3,//)
      AA=ICOUNT5
      K=19
      CONST= SQRT(7.752/K)*90.0/SPEED

C         CALCULATE THE MEAN RESPONSE TIME FOR LARSON SETUP
```

```
      PRINT 10,AMEAN
10    FORMAT( //,10X,*THE LARSON PREDICTED MEAN IS*F8.2)
      GO TO 45
C
40    CONST= 90.0 * SORT(78.513/TOTAL)/ SPEED
      DO 2 I=1,ICOUNT
2     SUM=SUM+CARBUSY(I)
      RHO3=SUM/ICOUNT
C        CALCULATE THE MEAN RESPONSE TIME FOR LARSON SETUP
      AMEAN= 0.5 +2.0*60.0/(3.0*12.0)*SORT(78.513/132.0)*(2-RHO3)
      PRINT 10,AMEAN
      AA= ICOUNT4
45    CONTINUE
      PRINT 20,TOTAL,CONST,AA,SPEED
20    FORMAT(10X,*TOTAL*F10.3,* CONST*F6.2,* AA*F6.2,* SPEED* F6.2)
      DRO=-0.05
      DO 50 J=1,60
      DRO= DRO + 0.05
      E(J)= DRO*CONST
      SUM1=RESULT1(DRO)
      X1=SUM1*RHO3
      X2=RESULT2 (DRO)
      X3=RESULT3(DRO)
      F(J)=(X1 + X2 + X3 )/CONST *AA
      PRINT 200,F(J),E(J)
200   FORMAT(10X, F10.2,F20.2)
50    CONTINUE
100   CONTINUE
      CALL PLOTTER(F,E)
      RETURN
      END
      FUNCTION RESULT1(DRO)
      COMMON/N/ RHO3
      IF(DRO.LE.1) 10,20
10    RESULT1= 4*DRO -4*DRO**2 +2.0/3.0 *DRO**3
      RETURN
20    IF(DRO.GT.2)GO TO 30
      RESULT1= 16.0/3.0-8*DRO+4*DRO**2-2.0/3.0*DRO**3
      RETURN
30     RESULT1=0
      RETURN
      END
      FUNCTION RESULT2(DRO)
      COMMON/N/ RHO3
      SUM=0
      DO 100 K=1,1
      IF( DRO.GE. K-1..AND. DRO.LE. K) 10,20
10    DELTA= DRO**2- 1.0/3.0*DRO**3
      GO TO 80
20    IF( DRO.GT.K.AND.DRO.LE.K+1)30,40
30    DELTA= 2.0/3 *DRO**3-4*DRO**2+7*DRO-3
      GO TO 80
40     IF(DRO.GT.K+1.AND.DRO.LE.K+2)50,60
50    DELTA= -1.0/3.0*DRO**3+3*DRO**2-9*DRO+9
      GO TO 80
60     DELTA=0
80    CONTINUE
      SUM=SUM +DELTA*( (1-RHO3)**   (2*K*(K+1)-3)*(1-(1-RHO3)**4))
100   CONTINUE
      RESULT2=SUM
      RETURN
      END
```

```
      COMMON/N/ RHO
      SUM=0
      DO 100 L=2,2
      IF( DRO.GE. L-2 .AND. DRO.LE. L-1) 10,20
10    DELTA= 1.0/6.0 *DRO**3
      GO TO 80
20    IF(DRO.GT.L-1.AND.DRO.LE.L)30,40
30    DELTA= 1.0/6.0*(-3*DRO**3+12*DRO**2-12*DRO+4)
      GO TO 80
40    IF(DRO.GE.L.AND.DRO.LT.L+1)50,60
50    DELTA= 1.0/6 *(3*DRO**3-24*DRO**2+60*DRO-44)
      GO TO 80
60    IF(DRO.GE.L+1.AND.DRO.LT.L+2)70,75
70    DELTA= ( -DRO**3+12*DRO**2-48*DRO+64)/6.0
      GO TO 80
75     DELTA=0
80    SUM=SUM+DELTA*((1-RHO3)**(2*L**2-2*L+1)*(1-(1-RHO3)**(4*L-4)))
100   CONTINUE
      RESULT3=SUM
      RETURN
      END


      SUBROUTINE PLOTTER(F,E)

      COMMON/OUTPUT/CARRUSY(120),ICOUNT,CARRSP2(700),ICOUNT2,CARRSP3(700)
     1),ICOUNT3,ICOUNT4,NUMX
      COMMON/EXTRA/ ICOUNT5,CARRSP5(100)
      DIMENSION ZZ(100)
      DIMENSION NUMBER(40)
      DIMENSION CENTM(102), CARLOC(102)
       DIMENSION F(102), E(102)
      REAL IVAL2
      REAL NUMBER
      DATA ISWITCH/0/
      DO 2 I=1,21
2     NUMBER(I)=I-1

      CALL SCALE(F,10.0, 60,1)
      CALL SCALE(E, 8.0, 60,1)
      F(61)= 0
      E(61)= 0
       IF( ISWITCH.EQ.1) GO TO 100


       ISWITCH=ISWITCH+1
      DO 1 I=1,100
      CENTM(I)=0
1     CARLOC(I)= 0
       DO 10 I=1,ICOUNT2
      IX= (CARRSP2(I)+0.5)+1
10    CENTM(IX)= CENTM(IX)+1
      DO 20 I=1,ICOUNT3
      IX= (CARRSP3(I)+0.5)+1
20    CARLOC(IX)= CARLOC(IX)+1


       CALL SCALE(CENTM, 8.0,20,1)
      CALL SCALE(CARLOC, 8.0,20,1  )
      PRINT 30, F(62), CENTM(22),CARLOC(22),E(62),NUMBER(22)
30    FORMAT (5X,*F(62)*F6.2,* CENTM(22)*F6.2,* CARLOC(22)*F6.2,* E(62)* F6.2
     1,F6.2,* NUMBER(22)* F6.2)
```

```
      CARLOC(21)=0
      NUMBER( 21)=0
      IVAL2 = MAX1(F( 62), CENTM(22), CARLOC(22))

      F(62)= IVAL2
      CENTM(22)= IVAL2
      CARLOC( 22)= IVAL2
      NUMBER(22)= E( 62)
      PRINT 30, F(62), CENTM(22),CARLOC(22),E(62),NUMBER(22)


      CALL LINE(F,F,60,1,1,0)
      CALL LINE( NUMBER,CENTM, 20,1,1,2)
      CALL LINE( NUMBER, CARLOC,20,1,1,11)
      PRINT 30, F(62), CENTM(22),CARLOC(22),E(62),NUMBER(22)

      CALL AXIS( 0.0,0.0,9HFREQUENCY ,9,10.0,90.0,0.0, IVAL2)
      CALL AXIS(0.0,0.0,7HMINUTES,-7, 8.0,0.0,0.0,E( 62))


      CALL SYMBOL(4.0,8.5,0.15,23HGRAPH OF RESPONSE TIMES ,0.0,23)
      CALL SYMBOL( 4.0,8.1,0.12,0,0.0,-1)
      CALL SYMBOL (4.3,8.0,0.12,22H=CENTER OF MASS-LARSON  ,0.0,22)
      CALL SYMBOL(4.0,7.6,0.12,2,0.0,-1)
      CALL SYMBOL(4.3, 7.5,0.12,27H=CENTER OF MASS DISPATCHING ,0.0,27)
      CALL SYMBOL(4.0,7.1,0.12,11,0.0,-1)
      CALL SYMBOL(4.3,7.0,0.12,24H=CAR LOCATOR DISPATCHING ,0.0,24)

      CALL PLOT(20.0,0.0,-3)
      RETURN

C        PRINT RESULTS OF 14 TEENTH DISTRICT

100    CONTINUE
      DO 50 I=1,ICOUNT5
      IX=CARRSP5(I)+1.5
50    ZZ(IX)=ZZ(IX)+1
      ZZ(21)=0
      NUMBER(21) =0
      NUMBER(22)= E(62)
      ZZ(22)= F(62)
      CALL LINE(NUMBER,ZZ,20,1,1,2)
      CALL LINE(F,F,60,1,1,0)
      CALL AXIS(0.0,0.0,9HFREQUENCY,9,10.0,90.0,0.0,ZZ(22))
      CALL AXIS(0.0,0.0,7HMINUTES,-7,8.0,0.0,0.0,E(62))

      CALL SYMBOL(4.0,8.5,0.15,27HGRAPH OF 14-TEENTH DISTRICT,0.0,27)
      CALL SYMBOL(5.0,8.0,0.15,14HRESPONSE TIMES,0.0,14)
      CALL SYMBOL(4.0,7.5,0.12,0,0.0,-1)
      CALL SYMBOL(4.2,7.5,0.12,22H=CENTER OF MASS-LARSON,0.0,22)
      CALL SYMBOL(4.0,7.0,0.12,2,0.0,-1)
      CALL SYMBOL(4.2,7.0,0.12,27H=CENTER OF MASS DISPATCHING ,0.0,27)


      CALL PLOT(20.0,0.0,-3)
      RETURN
      END
```

VITA

Ernst Nilsson was born September 5, 1942 in Minneapolis,Minnesota. He received his bachelor's degree in economics from Northwestern University, Evanston ,Illinois in 1964 and was awarded an M.B.A. by the University of Chicago in 1966. He entered the systems synthesis and design doctoral program of the Industrial Engineering and Management Sciences Department of Northwestern University in 1966.

Mr Nilsson spent one and a half years as a member of the Operations Research Task Force at the Chicago Police Department.

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