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MANAGEMENT PLANNING

for

FORENSIC SCIENCE LABORATORIES

Ezra S. Krendel
R. Michael Dummer
Leonard R. Freifelder

Department of Statistics and Operations Research
University of Pennsylvania

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ABSTRACT

This study was undertaken as a practical exercise in Operations Research problem formulation and solution by a graduate seminar at the University of Pennsylvania. The study goal was to devise methods for determining the best forensic science service for a particular catchment area. In order to accomplish this the demands placed upon this service by the pattern of criminal activity and the requirements of the judicial system were analyzed for the City of Philadelphia and the laboratories serving the states of Pennsylvania and New Jersey. On the basis of these analyses a simulation model of a laboratory, as a production facility subject to constraints of time, and a capital budgeting model were developed to assist management decisions. Interpretations of various factors of the simulation model as they apply to forensic laboratories were also made. Several surveys of crime laboratories were conducted and the data used in the models have been presented.

FOREWORD

This study was carried out with the support of grant NI 71-070-6 from the National Institute for Law Enforcement and Criminal Justice of the LEAA to Professor Ezra S. Krendel, Department of Statistics and Operations Research, University of Pennsylvania, with the administrative support of the University City Science Center. The study began as a project in a University of Pennsylvania graduate seminar as partial fulfillment of the requirements of the degree, Master of Science in Operations Research. The seminar was led by Professor Ezra S. Krendel and Professor Sidney W. Hess and the students were Messrs. John L. Boyle, II; R. Michael Dummer; Leonard R. Freifelder; Dev K. Ghandi; David M. Hill; Josephino Ligaya; Ravi Metre; Jack Nickell; Suchin Phongsak; and John F. Schank. These students contributed the content of the ten technical appendices to this report.

One of the objectives of the grant was to give students in operations research an opportunity to work on criminal justice problems, and hopefully, out of this exposure and after graduation, to develop an interest and capability of applying the techniques and thinking of operations research to the Criminal Justice System.

Many people involved in the Criminal Justice System were extremely generous with their time, assistance and advice, and we gratefully acknowledge this help. The active cooperation of Mr. Vincent Cordova and his staff at the Philadelphia City Police Crime Laboratory was especially invaluable. The work on this project would have been impossible without their assistance. Others whose assistance we are pleased to acknowledge are: Lt. Zanerelli, Sgt. Vander Berghe, Dr. Richard Saferstein, Forensic Science Bureau, New Jersey State Police; Capt. Lodwick Jenkins, Sgt. James Sagans, Crime Laboratory, Pennsylvania State Police; Mr. Taras M. Wochok, Assistant District Attorney, City of Philadelphia; Mr. Larry Polanski, Director of Computer Operations, Court of Common Pleas, City of Philadelphia; Inspector James Herron, Computer Unit Philadelphia Police Department; Sgts. Edward McKenna and John Devlin, Records Control, Philadelphia Police Department, Inspector Raymond Capper and Chief Inspector Joseph Golden, Detective Division, Philadelphia Police Department.

Finally, it is our pleasure to acknowledge the support, the comments and the encouragement of Dr. E. I. Golding and Miss Sheila Perlaky of the National Institute of Law Enforcement and Criminal Justice.

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CHAPTER 1. INTRODUCTION

As part of the general trend towards greater use of technology in numerous areas of industry and government, almost every law enforcement agency and judicial system has a forensic science service or crime laboratory at its disposal [1, 2, 3, 4]. These facilities were provided in the belief that modern scientific analysis of physical material will enable more accurate reconstruction of certain aspects of a criminal incident. This, in turn, will result in more accurate and efficient dispensing of justice. Such qualitative conjectures are undoubtedly true. However, in order to make a meaningful evaluation of the role of forensic science within the criminal justice system, quantitative information reflecting the degree to which justice is affected is necessary.

The role of a department within a larger organization is determined not only by its explicit function but also by the traditions which derive from its origin and position within the larger organization. The origins of forensic laboratories in the Northeastern United States are relatively diverse. Some began by adding a chemist to a Fingerprint or Ballistics File Bureau. Others originated as a result of some notorious or spectacular crime. The Philadelphia Police Laboratory began with the need to analyze bootleg liquor for alcoholic content during prohibition. Many others were a result of general trends and "me too" feelings on the part of local agencies. Their precise positions within the local justice systems differ somewhat as well. Almost without exception, the forensic laboratories in Northeastern United States are connected with some law enforcement agency, either state, county or city police. However, many laboratories in California are connected with the District Attorney's Office.

It is not obvious what effect, if any, these organizational differences have on the operating characteristics of a crime laboratory. Regional differences in the organization of the criminal justice system may have necessitated the various laboratory organizations. Thus, an important part of the research has been a systems study of the Philadelphia City Police Department and the Philadelphia County Criminal Court System. The objectives of this study were to determine the responsibilities of these agencies and how they are now fulfilled. This study did give considerable insight into the effects of organizational differences in the Criminal Justice System, and suggested important organizational implications for new laboratories. The system was analyzed both functionally and structurally. The laboratory position is described from both aspects. Further, the role forensic science is playing, could possibly play and ought to play is considered. This is the subject matter of Chapter Two.

In the Third Chapter, an intensive study of forensic science itself is taken. This work includes a complete system study of three particular laboratories. Philadelphia City Police Laboratory,

New Jersey State Police Forensic Science Bureau in West Trenton, New Jersey and the Pennsylvania State Police Laboratory in Harrisburg, Pennsylvania. An in-depth survey was taken at each of the laboratories to determine various operating characteristics. A more general questionnaire was mailed to a cross section of laboratories throughout the United States. This work determined three important characteristics of crime laboratories: firstly, basic configurations, both of equipment and personnel; secondly, methods of operation; and thirdly, what type of analysis forensic science is capable of performing.

Using the information derived from these systems studies, a mathematical model of a forensic laboratory within the criminal justice system has been constructed. The work is described in Chapter Four. This model consists of a series of filtered queues. The filtering devices are determined by requirements of the justice system, methods of operation and professional standards within the laboratory. Further requirements of the justice system provide minimum performance criteria for the model. The decision variable is total cost required to meet these performance criteria. A simulation program has been written to evaluate various laboratory configurations in terms of total cost. Using inputs from this simulation, a dynamic programming model has been constructed to make marginal capital equipment decisions on the basis of cost effectiveness for existing facilities.

In the Fifth Chapter, use of the model in making funding and grant decisions is described. Suggestions for laboratory grant procedures are made. Also, methods of collecting and assimilating input data for the model are delineated. The Sixth Chapter deals with general suggestions and recommendations for improving laboratory performance. Some of these suggestions are already in operation in at least one laboratory.

The above research was carried out in an attempt to attack a simply stated but difficult to approach problem: that is, given a particular criminal justice organization and crime pattern in a particular area, what is the optimal forensic science service. This study indicates how this problem could be solved. It has presented reasonable criteria for defining performance variables and for comparing various laboratory configurations. There is a clear need for the National Institute of Law Enforcement and Criminal Justice to fill the role of providing evaluation technique, information exchange, and managerial assistance to the various crime laboratories throughout the country. This report presents a preliminary version of how the Institute might proceed. Reorganization in the criminal justice system designed to improve the role of forensic science was not considered, although changes within the present system outside of the laboratory were suggested.

CHAPTER 2. THE CRIMINAL JUSTICE SYSTEM

The organizations in our cities, states and federal government charged with the responsibilities of protecting individual and corporate rights, maintaining behavior within social norms and supervising civil order is a collection of agencies loosely combined into what may be called the criminal justice system. These agencies include all law enforcement agencies as well as official court systems. By expending part of their resources in patrols and by being a visible public presence, law enforcement agencies discourage infringement on individual rights and property. Deployment of resources in this way also puts law enforcement officers close to scenes of abnormal situations which do arise. The officer at such a scene has the authority and responsibility to take charge and resolve the situation, if possible. Finally, patrols are charged with the responsibility for public service and assistance. (See Figure 1.) The magnitude of this function cannot be overemphasized. In the City of Philadelphia in 1970, 1,548,829 of 1,657,000 calls to the Police Department were of a noncriminal nature.

When a situation arises which is abnormal enough to be declared criminal, a second phase, that of investigation, begins. Laboratory analysis is an integral part of this phase. An investigation is basically a reconstruction of the incident designed to determine what occurred, whether it was criminal,

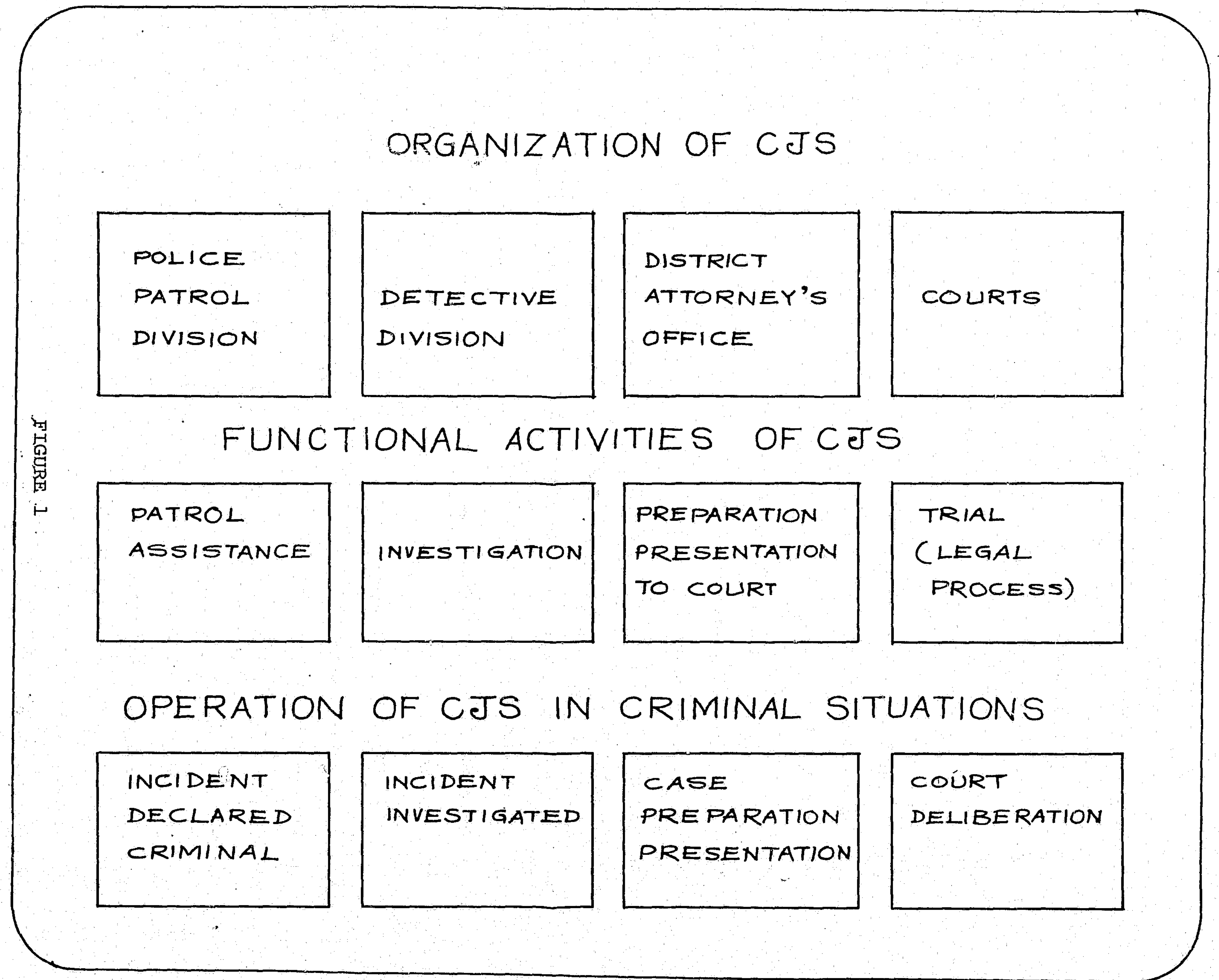
ORGANIZATION OF CJS
POLICE PATROL DIVISION
DETECTIVE DIVISION
DISTRICT ATTORNEY'S OFFICE
COURTS
FUNCTIONAL ACTIVITIES OF CJS
PATROL ASSISTANCE
INVESTIGATION
PREPARATION PRESENTATION TO COURT
TRIAL (LEGAL PROCESS)
OPERATION OF CJS IN CRIMINAL SITUATIONS
INCIDENT DECLARED CRIMINAL
INCIDENT INVESTIGATED
CASE PREPARATION PRESENTATION
COURT DELIBERATION

FIGURE 1

and who was involved. The third phase is the presentation of the results of the investigation to a court for deliberation and judgment. This is usually directed by a member of the judiciary but the investigator provides assistance.

To observe the role of a forensic laboratory in a major metropolitan area, the criminal justice system comprised of the Philadelphia Police Department and the criminal section of the Philadelphia Court of Common Pleas was studied. There are no formal organizational links between the police department and the courts. The police department is a city agency responsible through the police commissioner to the mayor. The courts and District Attorney's Office are headed by elected officials responsible to the people. The lack of formal communication links results in some overlap in responsibility. Rather than being redundant, however, this overlap is necessary for proper operation of the system as presently organized. Further, this casual overlap of responsibilities has important implications regarding the crime laboratory's position in the system.

Once an incident has been declared criminal, the reason for investigating or reconstructing the event is twofold. Firstly, the investigation and eventually the court must determine if the incident was actually criminal. Secondly, the individual responsible for the incident must be identified. The two court proceedings in which these matters are considered are the preliminary hearing and the trial. The hearing acts as a screening device. At this proceeding two things must be established: first, that a crime was committed, second, that the defendant probably committed it. As a matter of practice, laboratory analysis incriminating the defendant is almost never presented at the hearing. It is only if scientific analysis is necessary to classify an incident as criminal that the laboratory becomes involved at this point. Narcotics cases are a prime example. Thus, the production-type constraints placed on the laboratory by the court is that the report be completed by hearing or trial date, depending on the function of the report.

To convict a defendant at trial, guilt beyond a reasonable doubt must be established. A weight of evidence type of argument is often sufficient in this regard. Collaborating physical evidence can be extremely important in this role. It is important to note that reports of laboratory personnel in court are treated in the same manner as witness testimony, with the qualification that it is expert testimony. Since any case, which comes to trial has been screened into a probable guilt category, the result which is most favorable within the current organization of criminal justice is a conviction. Naturally, the more physical evidence which can be brought to bear on a case, the better the laboratory is serving the aims

of the justice system.

It is generally believed that, as well as linking known suspects to a particular crime, a forensic laboratory provides a good deal of assistance to investigations in actually identifying suspects. In fact, physical evidence is almost never used in this regard. Organizationally, the crime laboratory in Philadelphia is a service department to the investigating arm. However, functionally, the two departments operate almost in parallel. Evidence is received by the laboratory through the investigating divisions and submitted to the District Attorney's Office through these same divisions. But there is almost no interchange between these two types of analysis. Both groups are analyzing different types of information with the purpose of presentation in court. When the limitations of laboratory analysis is considered, it is not surprising to discover it rarely aids in identifying an actual suspect.

The criminal justice system presently demands the following things from a forensic laboratory facility:

1. a sufficient quantity of analysis to have a significant effect on court proceedings, and for less formal plea bargaining between the prosecutor and the defense;
2. accurate analysis with accepted standards,
3. completion of the analysis in time for the required court proceedings,
4. chain of evidence must be maintained,
5. providing personnel for expert testimony as required.

Appendices I and II provide more detailed descriptions of the processes described above.

CHAPTER 3. THE FORENSIC LABORATORY

A forensic laboratory is a configuration of men and equipment capable of analyzing certain physical material with the purpose of classifying the physical and chemical properties of the material. The physical material analyzed has some connection with a criminal incident and the analysis is done at the request of the agency investigating the incident. This classification can play a very important role in criminal justice. Firstly, possession, sale or consumption of certain chemicals is illegal. Certain drugs, narcotics, and hallucinogens are typical examples. Explosives, flammables, and bombs are becoming increasingly important in laboratory analysis. In this case, as in the case of weapons and firearms analysis, the intent is to determine whether the material is dangerous. Making determinations of this type are instrumental in, and very often tantamount to, classifying an incident as criminal. Another use of analyzing physical material connected with a crime is to compare the analysis to analysis of physical material connected with a suspect. Examples of this are clothing particles, physiological fluid samples and paint chips. Comparisons of this type of material collected from different crime scenes may also be compared. In fact, such comparisons between crimes are rarely made as a matter of course. However, in September 1971, such a program is scheduled to begin in Suffolk County, New York under the direction of laboratory director Bernard Newman. In addition, the ballistic section of the New Jersey State Police Bureau of Identification regularly compares all weapons received with a reasonable sampling of weapons from outstanding unsolved cases.

The general organization of forensic science bureaus is quite standard and is determined by the analysis techniques used. The three main sections of any laboratory are ballistics, documents, and chemistry with the latter generally being the largest. Depending on the size of the staff and the equipment configurations, each of these basic sections may have well-defined organizational structures. Detailed organization and systems flowcharts of three area laboratories: Philadelphia City Police, New Jersey State Police, Pennsylvania State Police, are included in Appendix X.

The processing of physical evidence follows well-defined stages. Firstly, material is collected at the scene of a crime and submitted to the laboratory. There are several systems of submission all of which take care to preserve the chain of evidence. In Philadelphia, evidence may be collected directly by the mobile crime laboratory or submitted in person by the officer in charge at the crime scene. Most commonly, evidence

is submitted to the Pennsylvania State Police Laboratory by registered mail. In New York City, off-hours submissions are secured in lockers which are emptied the following day by laboratory personnel. Information submitted with the evidence may vary from just a listing of what is submitted to a description of the case and the circumstances of the evidence, to a request for specific analysis to be performed.

Submissions to a forensic science bureau may be made either to a single receiving office or directly to the individual units, that is ballistics, documents or chemistry. Once submitted, the evidence is logged in to preserve the chain of evidence, classified by analysis and secured in a tamper-proof area to await processing. The classification of evidence by general type of analysis required is generally routine. A quick visual test may be involved; for example, distinguishing between marijuana and heroin samples. Any non-routine analysis decisions are usually made by analysts or supervisory personnel.

The specificity of classification will depend on the size and organization of the laboratory. In the ballistics and documents sections, each analyst is generally prepared to do all types of analysis which may be required. The chemistry section, however, is usually broken down into chemistry, toxicology and criminalistics subunits. The subunit performs analysis to identify chemical properties of substances. It is generally staffed by the most highly trained personnel. The toxicology unit performs chemical and biological analysis of physiological or bodily fluids. The criminalistics unit identifies physical properties and does comparison analysis.

In any event, no matter how the laboratory itself is organized once evidence is received, it waits in storage until the required analysis facility is free. The queueing priority is by earliest submission date. There are cases which will preempt these priorities. These are generally homicides or narcotics cases in which the hearing date has been advanced, or cases which have gained notoriety. Once the analysis is completed a report is made to the submitting agency and the evidence is either returned to the submitting agency or stored at the laboratory.

Physical evidence if it is presented at a preliminary hearing is done so by stipulation, that is only the laboratory report is presented. However, at the trial, the analyst must appear as a witness. Court testimony is a very important part of an analyst's function and operationally this means time spent on a case equals analysis time plus court time. If the laboratory serves a wide geographic area, travel time and, thus, court time is considerable. This results in an increase in time per case and a decrease in

cases per analyst.

An important observation generally to be made about crime laboratories is that narcotics offenses presently make up the largest single crime classification handled by the laboratory. In fact, it commonly makes up thirty per cent of the total caseload. Further, the cases for which the analysis is required by the court at the time of the hearing are almost always narcotics cases for it is these cases that require chemical analysis to establish that a crime has been committed. The lab report for most other cases is required only by the laboratory date. This fact provides a convenient method of segregating cases according to urgency and analysis simultaneously and apportioning resources accordingly.

CHAPTER 4. A MATHEMATICAL MODEL OF A FORENSIC LABORATORY

On the basis of the systems studies of the criminal justice system and the forensic laboratories described previously, the logical genre of model to consider is a queueing model. The logic is twofold. First, the functioning of the laboratory definitely does have a queueing aspect to it, and second, an important factor because of the nature of the justice system's constraint, the distribution of time in the system, is a basic result of a queueing theory type analysis.

The actual queueing system is quite intricate but not irreducibly complex. It consists of a sequence of service facilities or types of analysis which are all unique but may consist of more than one server. Demands are placed on each service facility by a common arrival phenomenon, the occurrence of a criminal incident. Actual demands are filtered responses to these criminal incidents and the filtering device for each service facility differs.

The filtering occurs in two stages. The type of crime has an important bearing on whether and what type of evidence is collected. Some types of crime are more likely to yield useful physical evidence. Seriousness of the crime and general police practice with respect to collecting physical evidence are clearly important factors.

To determine the absolute arrival discipline for a particular type of analysis, several probabilistic quantities must be defined.

Let: $f(t)$ .... be the probability density function of the occurrence of criminal incidents over time;

c_i ...... be the probability that a given incident is a crime of type i; (standard reporting classifications are used and in the case of multiple charges, the most serious charge is used)

e_{ij} ..... be the probability that evidence of types j is obtained at the scene of a crime of type i;

a_{jk} ..... be the probability that analysis of type k is used to analyze evidence of type j;

p_k ...... be the probability that analysis of type k will be required given a criminal incident has occurred.

Then the filtered device is binomial in character with filter probability p_k for analysis of type k. Further,

p_k ...... $\sum_i \sum_j a_{jk} e_{ij} c_i$.

Now is defined:

$s_k(t)$.... to be the probability density function of service time for analysis of type k;

$w_k(t)$.... to be the probability density function of total time in the system if analysis of type k is required;

$g_i(t)$.... to be the probability density function of the time at which analysis is needed in court for a crime of type i.

$q_{ik} = \sum_j a_{jk} e_{ij}$ to be the probability that analysis of type k will be required given a crime of type i has been committed.

Then,

$$h_i(t) = \frac{d}{dt}\left[\int_{\max t_k} \Pi_k \, q_{ik} \, w_k (t_k) \, d\, t_k \right]$$

is the probability density function of time to completion of total laboratory report.

Furthermore,

$$T_i = \int_{t_1 > t_2} g_i(t_1) h_i(t_2) \, d_{t_1} \, d_{t_2} .$$

is the probability that the laboratory analysis is done by the time the court requires it for a crime of type i.

Finally,

$T = \sum_i c_i T_i$ is the probability that the laboratory analysis for a given criminal incident will be done in time.

As a by-product of this analysis, if the number of criminal incidents for a fixed period, say R, can be predicted, then the demand for analysis of type K can be predicted as:

$A_k = p_k R$.

In the formulation of the model, the configurations of equipment and manpower determine the service densities and precise system of queueing. For example, certain equipment will reduce the time for certain types of analysis. Also, because of the training of the personnel, several types of analysis may be performed by one analyst. Then the filter probability for that analyst will be $p = \sum_{k \varepsilon G} p_k$ where G is the set of analysis types he performs. This means the effective arrival rate increases.

The value T acts as a constraint on the system. There is a minimum acceptable value for T and only those configurations of equipment and personnel providing at least this acceptable value of T are feasible. Naturally, of these feasible configurations, the minimum cost configuration would be "optimal". The values of $\{e_{ij}\}$ or evidence matrix, and $\{a_{jk}\}$ or analysis matrix provide further constraints. Sufficiently high values in the evidence matrix insure reasonable use is being made of the facilities. Quality of analysis and professional standards are embodied in the analysis matrix. These matrices are useful criteria for drawing comparisons between laboratories <u>independent</u> of the crime structure in the respective areas.

To obtain estimates of the probabilistic quantities associated with the model, pilot surveys of fourteen days duration were carried out at the Philadelphia City Police Laboratory and the New Jersey State Police Laboratory. Applicable data from 1970 was supplied by the Pennsylvania State Police Laboratory and was used as well. The values c_i, e_{ij}, and a_{jk} were estimated by relative frequency estimators. The density functions $f(t)$ and $s_k(t)$ were estimated by the sample cumulative distribution functions. A description of the structure of the survey and the complete results are presented

in Appendix III. Further, a simulation program of the queueing system has been developed to obtain estimates of T for various laboratory configurations. The simulation model is described in Appendix IV.

Using the output of the queueing model of the laboratory, a method for making capital budgeting decisions in an existing laboratory has been developed. The method is most applicable in the situation where the laboratory has a fixed amount available for capital expenditures and is considering only new or improved versions of existing equipment. First, we define:

- B — to be the total capital budget for the period;
- OC — to be the present annual operating budget of the laboratory
- OC_i — to be the annual reduction in operating budget if capital expenditure i is made; (of course OC_i could be negative indicating an increase in operating budget)
- C_i — to be the cost of capital expenditure i.

Then

$$B_i = \frac{OC_i}{C_i} \text{ is the cost benefit of capital expenditure i.}$$

The budgeting decision problem then becomes:

$$\text{Max } \sum_i d_i B_i$$

$$\text{subject to } \sum_i d_i C_i \leq B$$

where the sum is taken over all capital expenditures which are feasible in terms of the time constraints generated by the queueing model. The laboratory configuration including this expenditure still yields an acceptable value of T. This problem can be formulated as a "knapsack" problem and solved using the dynamic programming algorithm. A computer program has been developed to perform this algorithm, and is described in Appendix VII, and a sensitivity analysis is presented in Appendix VIII.

If there is no fixed budget or the capital expenditure decisions are not being made solely on the basis of cost effectiveness as is quite reasonable and most likely, calculation of the B_i's will at least order the prospective expenditures by decreasing cost effectiveness. Thus at least one factor in the decision process can be successfully quantified.

CHAPTER 5. FUNDING DECISIONS IN THE FORENSIC LABORATORY

In making funding decisions for a forensic laboratory, cost effectiveness of the proposed expenditure should not be the sole criteria. Expenditures which cannot be justified on the basis of improved laboratory performance should be considered in some cases. Forensic science is not merely a collection of technical procedures, and to retain vitality as a science, continuing research is essential. Funding decisions must consider this possibility.

Some research in the forensic sciences is being done at the university level at John Jay College & the University of California (Berkeley), in particular. Some federal laboratories such as the Bureau of Narcotics and Dangerous Drugs and the Federal Bureau of Investigation also do research and development work. Decentralized research work in the various regional laboratories, however, is beneficial from several standpoints. If a laboratory is to be staffed by well trained professional personnel some non-routine work is essential for the maintenance of skills and for morale purposes. If morale is good, better, more imaginative work results. Further, the adoption of new equipment or the development of new techniques may improve the quality of analysis or allow the analysis of previously unusable types of evidence. This will result in more effective testimony in court cases and enable the laboratory to better serve the objectives of the criminal justice system.

In supporting the notion of encouraging some decentralized forensic research, LEAA would do well to exploit an existing loose organization of forensic laboratories, particularly in the Northeastern United States. The National Association of Criminal Laboratories centered mainly in the Northeast, is a mechanism for communication between laboratory personnel in this area. Information about a new technique or procedure in use at one laboratory is circulated to the other. This is accomplished through the publication of a newsletter and through periodic conferences. Some work is undertaken jointly, using various facilities of several laboratories. There has been a proposal to initiate a program of temporary exchange of personnel. This could be instrumental in unifying laboratory procedures and in trying new ones; such as described in Appendices V and VI.

There presently exists no central laboratory or research agency devoted to forensic science research. It is, therefore, proposed that this existing organization and such other similar groups as may exist be exploited for this purpose and that grants be awarded to laboratories through this organization on the basis of a particular proposal's attributes as a research project. If such grants are given the prestige of national projects, large manufacturers may give discounts on equipment costs and may be persuaded to redesign equipment more specifically for forensic science use. A further benefit of well documented research program is that the data

and detailed information necessary for other laboratories to make capital budgeting decisions using the proposed model will be available.

For expenditures of a non-research nature, that is, investment in tested procedures and equipment designed to upgrade the performance of the laboratory, the budgeting model is a valuable tool. Ideally, replacement expenditures or fixed budget expenditures can be justified via the model strictly on the basis of cost benefit consideration. Attempts to progressively reduce laboratory operating costs by the introduction of more sophisticated equipment are doomed to failure. It is well documented that laboratory caseloads are increasing annually and more personnel and equipment will be required to provide the same level of service. In fact, some capital expenditure will be necessary just to maintain an acceptable value of T.

The reason laboratory work is increasing is because crime rates themselves are rising. In terms of the queueing model, this means the arrival rate or rate of occurrence of criminal incidents has increased. By using a projected crime rate in the simulation model, various expansion configurations can be evaluated to determine feasibility. The feasible configurations can then be ranked on the basis of cost effectiveness.

In addition to maintaining the present level of service, expenditures designed to upgrade laboratory services should be considered. Procedures for evidence receipt or collection may be redesigned so that evidence is more likely to be received in the event of a criminal incident. Introduction of a mobile crime facility or in-field regional laboratory would have this effect. This effect will be exhibited by changes in the evidence matrix. A change in laboratory analysis procedures would have a similar effect on the analysis matrix. The final result is a shift in the filtered probabilities. Again the simulation model embodying the new filtering matrices can be solved for feasible expenditures which will be evaluated on the basis of cost effectiveness by the dynamic programming model. Of course, both upgrade service and increasing volume of work expenditures can be evaluated simultaneously.

To aid in making projected estimates of crime rates and evidence and analysis matrices a national survey of crime laboratories was carried out. Inquiries were made into past histories of annual caseload and caseload composition by crime type. Also changing breakdowns of analysts' time was surveyed. The material was used to devise methods of making the projections needed for the budgeting analysis. A description of this work is contained in Appendix IX.

Finally, as an aid to decision-making, the robustness of the evidence and analysis matrices should be examined. These matrices characterize a laboratory, illustrate the constraints under which an individual laboratory operates and compares methods of operation independently of the crime structure in the particular catchment area served.

CHAPTER 6. RECOMMENDATIONS, IMPRESSIONS, CONCLUSIONS

Through observing the operation of forensic laboratories and analyzing the flow of evidence through these laboratories, comparisons of methods of operation can be made. Out of these comparisons some general recommendations become obvious. First of all, communication, not necessarily verbal, between the laboratory analyst and others involved in the investigation is important to the analyst's work. This statement seems obvious but it is often ignored in practice. At the very least there should be some communication between laboratory analysts working on the same case. This will be facilitated if all evidence is received and recorded centrally by the laboratory and all reports compiled on a per case basis. Further, submitting agencies should be required to supply some information about the particular case and the circumstances of the material submitted. A submission form requiring this information could be helpful.

The use of search theory in both evidence collection and laboratory analysis has been investigated. If the quantity of material available is large so that there is considerable leeway for choice, its utility in saving collection or analysis time can be demonstrated. Information about the case so that weights can be assigned to the evidence is a prerequisite. The technique along with a computer program is documented in Appendix V.

As observed earlier, laboratory analysis and work by other police investigators occurs almost independently of each other. This is partly a result of the limitations of laboratory analysis in individualizing evidence. While evidence may not be individualized readily, positive or negative comparisons can be made. This facility can be applied to comparison of physical evidence from similar crimes to determine if there is a common culprit. Thus, if one crime is solved both may be solved. This would provide the investigator with some feedback from the laboratory. Search theory may be applicable here in determining the scope to which these comparisons should economically be made.

A major portion of the laboratory's work is spent in determining whether a substance contains one of a number of prohibited drugs or narcotics. It would be worthwhile to develop a method of determining from a given set of tests with known specificity, an optimal, in the sense of minimum average number of tests per substance, series of tests with well defined stopping rules for a given level of accuracy or probability of error. Such a methodology derived from sequential testing would indicate which characteristics were most valuable in a new test for the greatest improvement in the testing routine. This would provide a means of evaluating the value of a new test under development. Further research into this area would probably be beneficial providing assistance with the crime laboratory's largest volume.

In consideration of the fact that requests for drug analyses make up such a significant part of the laboratory's workload and that this development is relatively recent, it is understandable that a great preoccupation exists among supervisory laboratory personnel with how to analyze great quantities of drugs accurately

and efficiently. Over emphasis of this aspect of laboratory work could be counter-productive. During prohibition, the major portion of the work in the Philadelphia City Police Laboratory was analysis for illegal alcohol. Today almost no alcohol analysis is done. This possibility exists with drug analysis as well. Thus, laboratories should guard against building up a large, efficient but inflexible drug analysis unit. If tests and techniques which may have wider applications are instituted, the readjustment of the laboratory to falling drug requests would be less traumatic. As an example, much of the drug facility might be redirected to making the cross-crime comparisons suggested earlier.

Forensic science has an important role in criminal justice and may in the future be instrumental in introducing more rigorous methods into other areas of the criminal justice system by serving as a scientific resource within the system. National standards and a data base on procedures and performance times are needed to make the simulation model and the budgeting model more generally applicable. The National Institute can serve an important role in collecting and disseminating such data and information.

The National Institute should take the necessary action to obtain crime laboratory surveys, such as are presented in Appendix III, on a national basis. The forms and questions should first be pretested on a larger sample than was available in preparing the report. This more widely based data should be used in developing planning models as described in this report. Assistance in planning, as well as information on administrative and technical procedures should be disseminated from the National Institute both as a generating source for new information as well as a conduit for facilitating the exchange of information among laboratories throughout the country.

The organizational position of the crime laboratory in the various state criminal justice systems has arisen by happenstance. Rationalizing the position of the laboratory in terms of its customers and the infrastructure which supports it could well be suggested following a National Institute study directed to this end.

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APPENDICES

The work summarized in the following appendices was carried out by students enrolled in graduate course, OR800, at the University of Pennsylvania, in the Spring of 1971. Although more than one student participated in several of the appendices, only the main contributors are listed in what follows. What is presented in these appendices is a much briefer version of more extensive original efforts. Much that was learned and many analyses have not been presented here because they were either peripheral to this report or data limitations made them too tentative.

In a painful, but almost fitting incident, a great deal of data bearing on the measurement of $\{e_{ij}\}$ and $\{a_{ik}\}$ matrices as described in Appendix III were stolen from one our researcher's automobiles!

Michael Dummer and Leonard Freifelder, working as research assistants after the conclusion of the semester, both augmented their academic efforts and helped to integrate many of the other student efforts.

The student contributors to the various appendices were as follows:

Appendix I..............Freifelder
II..............Ligaya
III..............Dummer and Freifelder
IV..............Freifelder and Dummer
V..............Ghandi
VI..............Freifelder
VII..............Boyle and Hill
VIII..............Shank and Hill
IX..............Nickell and Metre
X..............Freifelder

APPENDIX I

THE POLICE DEPARTMENT

Figure I-1 presents a detailed analysis of the police department and its effect upon the criminal justice system. The flows represented on the chart specify the entire range of possibilities and do not represent the actual procedures followed in any specific case. A description of the police department and how its units operate follows.

Responsibility of Patrolmen

The police department responds to all calls for aid and assistance by dispatching a patrol car to the scene of the alleged crime. The patrolmen decide whether the incident is not of a criminal nature. Of course, an affirmative decision at this stage results in termination of their responsibility and action by the police department. If, however, the response is not affirmative, investigation continues.

Moving to the second stage of the investigation requires that a detective team be assigned to the incident - now considered a crime. This team may, in important and obvious cases, be requested directly by the patrol car, or ordered through the district from which the police car was assigned.

Responsibility of Detectives

It is the job of the detective to obtain from the patrolmen a description of the crime and any information subsequently given by

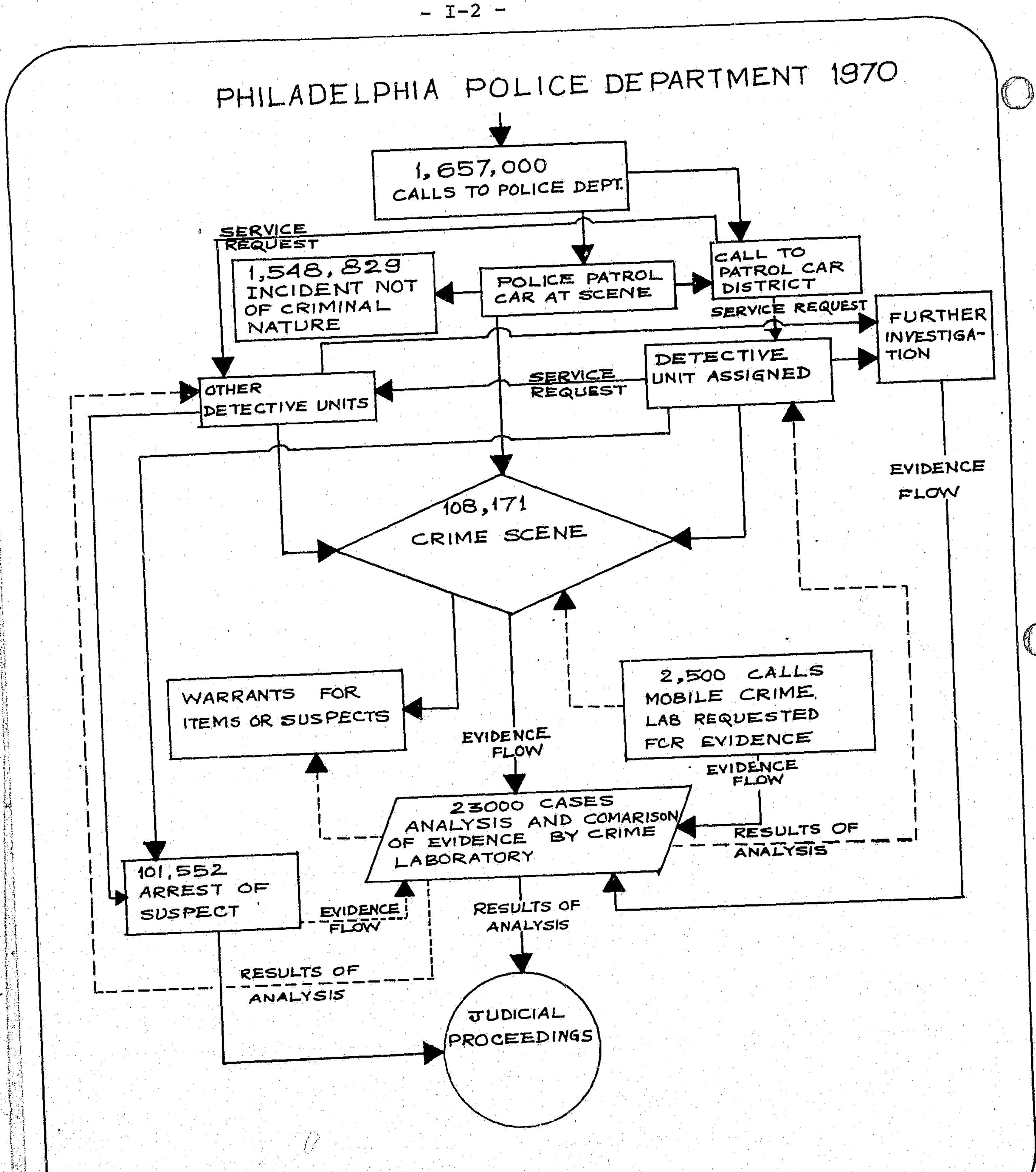


FIGURE I-1

witnesses or complaintants. The detectives then begin a search of the crime scene to ascertain if there is any physical evidence to be collected. If the detective finds evidence, or believes that useful evidence may be present, a request is made for the mobile crime laboratory. The detective will never collect evidence himself; it is his duty to request the assistance of the mobile lab.

Depending upon the severity and complexity of the incident, the assigned detective team may request additional assistance. Such aid takes the form of special detective squads - narcotics, homicide, etc. - who are specifically trained to investigate a particular class of crimes. If called, the special squad and the original team will discuss the case and continue the investigation as one unit.

Responsibility of Mobile Crime Laboratory

Upon arriving at the scene of the crime, the mobile crime laboratory begins evidence collection under the directions of the detective. The mobile unit will collect those items designated as evidence by the detectives.

Investigation

The detectives, once informed as to the nature of the crime, may release the patrol unit and continue the investigation. In cases where the patrol unit has apprehended a suspect at the scene of the crime, identifications and statements from witnesses will be obtained.

If a suspect is not immediately found, the detectives will attempt to reconstruct the crime through witnesses and any other facts of which they are aware. Such procedures will generally lead to a suspect, for whom a warrant is obtained, as well as warrants for specific articles that may link the individual to the crime.

Laboratory

It is the responsibility of the laboratory to analyze all materials and objects brought to them, by the mobile crime labs and the various police units.

There are several possible uses of laboratory findings. If there has been no arrest, the results of the laboratory's analysis may lead to arrest of the suspect. If an arrest was made, a negative finding by the laboratory may lead to release of the suspect. When analysis is positive, the results will be forwarded to the judicial branch, for possible use in court.

Further Investigation

When the laboratory findings are negative, or not sufficiently conclusive, the investigation of the crime may continue. Generally, the detective activity will be at a manpower level reduced from that utilized in the initial stages. Further evidence or suspects uncovered by such work, will, of course, be submitted to detailed analysis and examinations in an attempt to link it to the crime.

Physical Evidence in the Police Investigation Process

On an intuitive basis, one would believe a crime laboratory could be of considerable assistance in the investigation of crimes. Not only should the lab be of assistance in reconstructing the crime, but also in identifying likely suspects. The results of laboratory analysis are frequently used to reconstruct the crime in court. However, statistics show that physical evidence is almost never the basis for making an arrest. In a sample of forty(40) cases from early 1971 in the Philadelphia area, only two of the cases had the lab analysis completed before the arrest was made. In both of these instances, no arrest was made and the case was declared inactive. The sample was interesting in that it included a spectacular, violent burglary. Much police effort was expended in the investigation. The lab personnel had believed that their extensive analysis of numerous files for latent fingerprints was responsible for the arrests of the defendants. However, the facts reveal that the arrests were made four days before the lab analysis was completed. Further, to the credit of the Philadelphia crime laboratory, in all narcotics cases, the analysis was completed previous to the preliminary hearing date.

The reason laboratory analysis is rarely used in police investigations is simply because the laboratory is incapable of providing such fine analysis. The types of functions the laboratory can perform best are either identification of chemicals or comparison of physical material. To ask the laboratory to identify a particular individual on the basis of trace physical elements is unrealistic.

However, a compromise use of the laboratory is possible which is both realistic and helpful to police investigators. Since the laboratory can perform comparisons of trace elements effectively, it is suggested that a program of comparing physical evidence from two separate crimes be instituted to determine whether or not they were committed by the same individual. Naturally, making all possible comparisons over all possible crimes is again unrealistic. However, using the fact that certain types of criminals tend to commit similar type crimes repeatedly in the same area, probability estimates of getting a positive match for certain types of comparisons can be made by police investigators. In fact, this process is periodically used on an informal basis already by detectives. Once these prior probabilities are made explicit, search theory can be used to determine which comparisons are reasonable to make from a cost-benefit point of view.

APPENDIX II

COURT FLOW PROCESSES

Whether planning for a crime laboratory entails budgeting, e.g., acquisition of new instruments, or whether it entails allocation of presently available resources, e.g., sequencing of the analysis of evidences submitted to the laboratory, the specific use to which the results of the laboratory analysis will be put must be taken into consideration.

To the above ends, a flow chart of the criminal courts system has been prepared. The flow chart on Figure II-1, supported in part by Figures II-1 through II-7 provides insights that concern the following:

a) interaction of the criminal laboratory with the courts
   ---when and in what courts the results of crime laboratory analyses of physical evidences are needed
   ---when and in what courts personnel of the crime laboratory are needed as expert witnesses
b) disposition rate of cases

Preliminary Arraignment

Within twenty-four hours after arrest in Philadelphia, the defendant is brought to the Municipal Court for preliminary arraignment. It is at this initial stage in the court process that:

a) the defendant is initially informed of the charge against him, and of his right to representation by an attorney,

b) matters pertaining to bail are determined and,

c) the date for a preliminary hearing is determined, or if the sentence for the charge does not exceed two years, a date for trial at the Municipal Court level is scheduled.

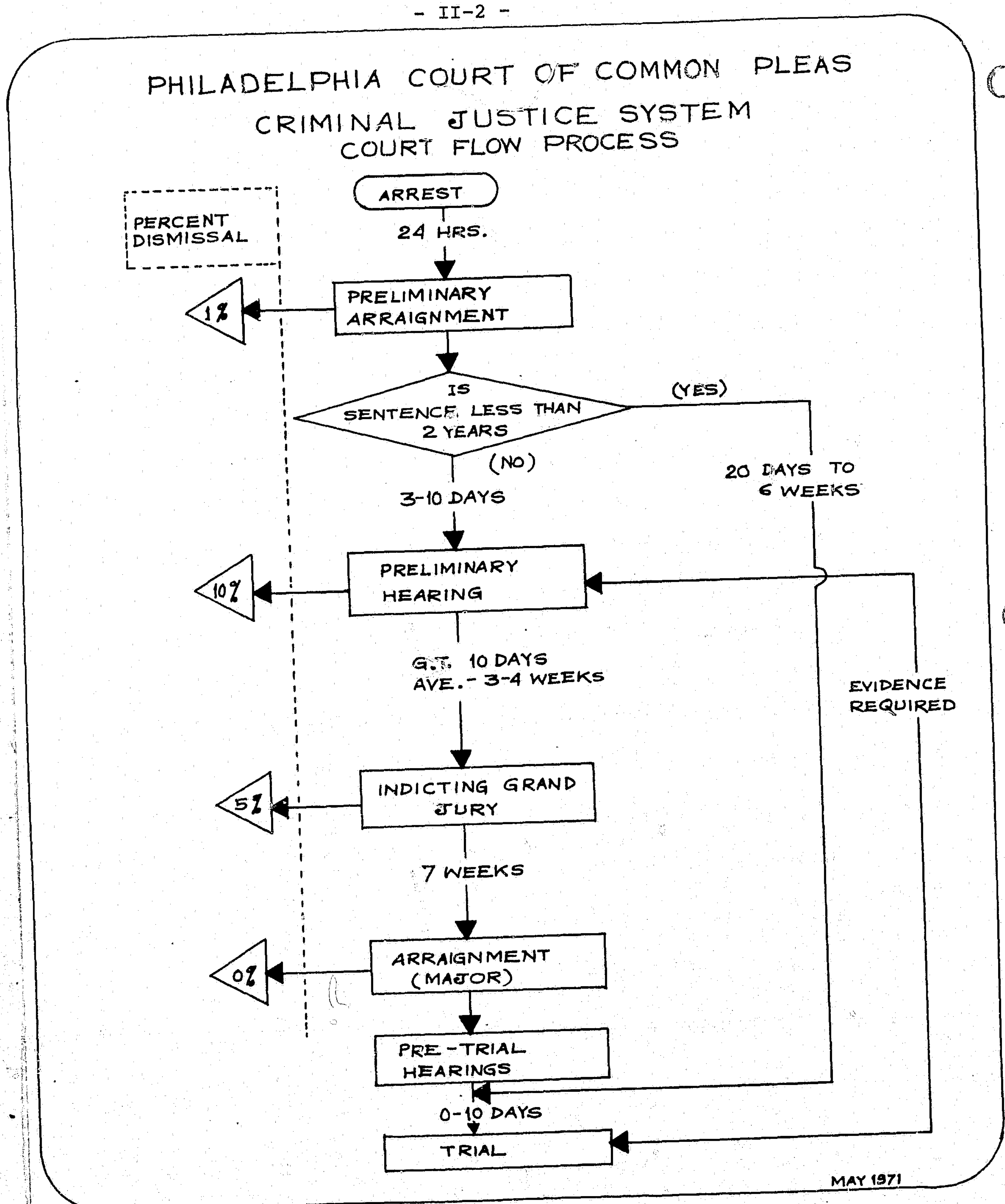


FIGURE II-1
Court Flow Process; Philadelphia Court of Common Pleas

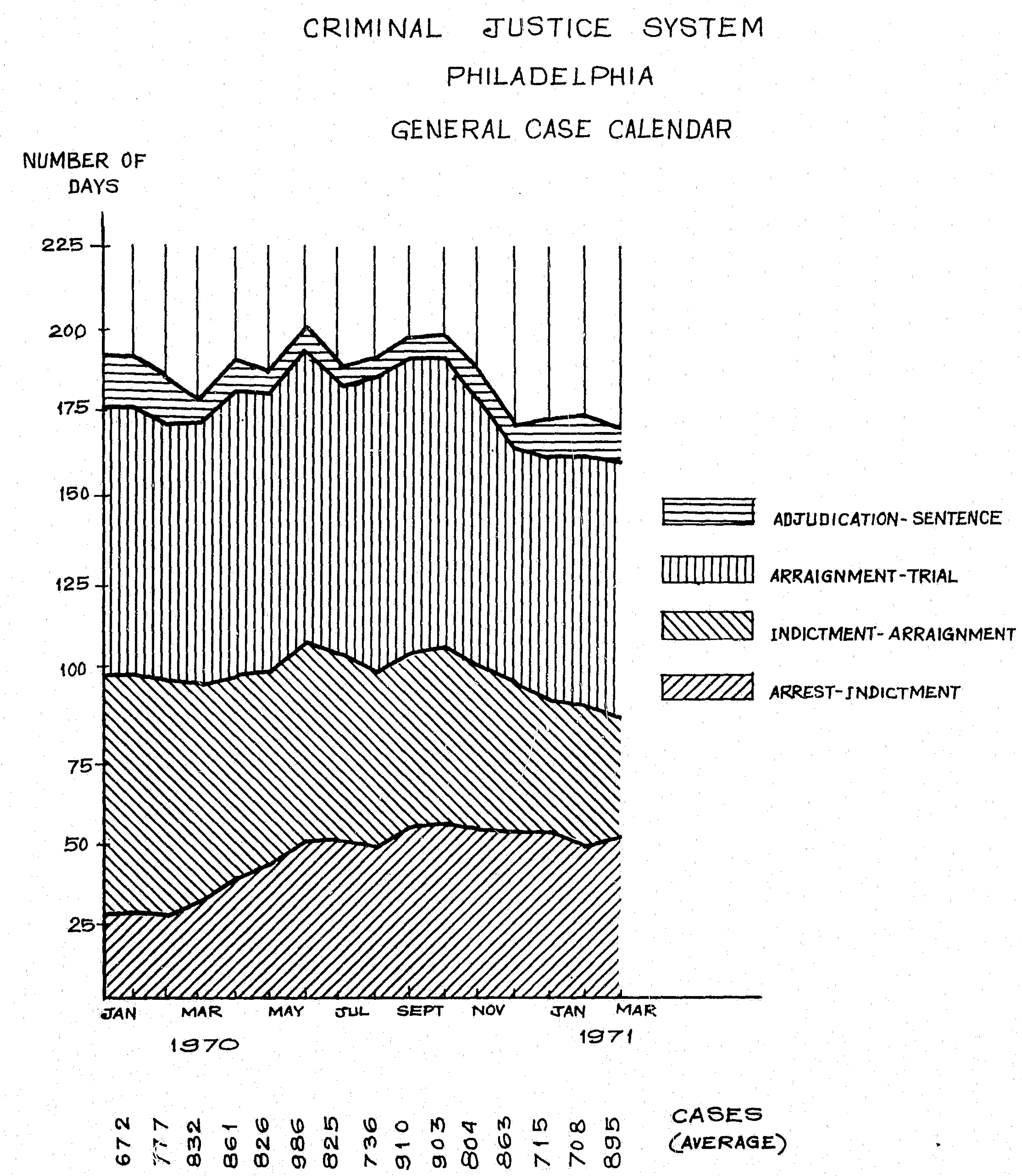


FIGURE II - 2

CRIMINAL JUSTICE SYSTEM
PHILADELPHIA

AVERAGE TIME: ARREST TO INDICTMENT

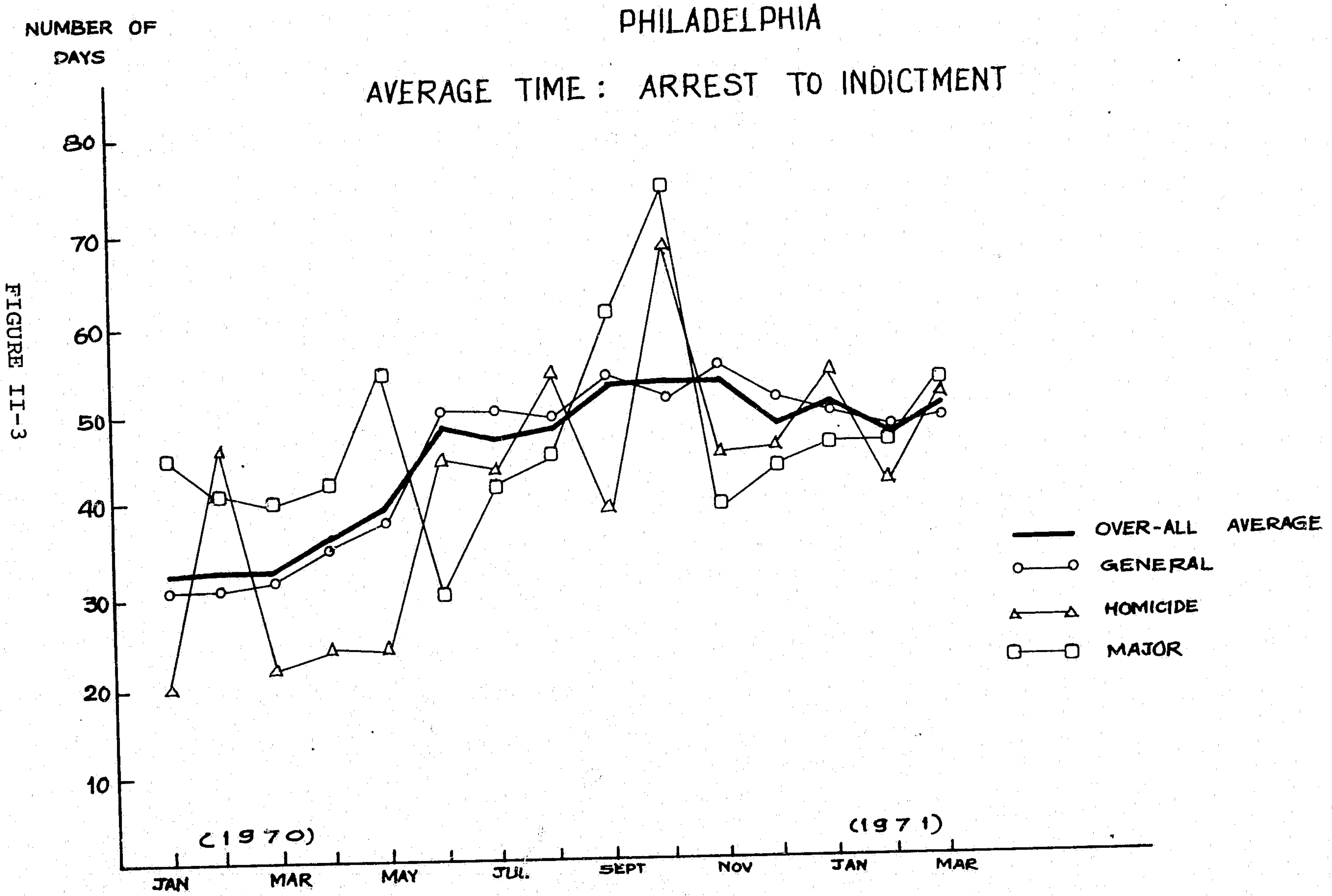


FIGURE II-3

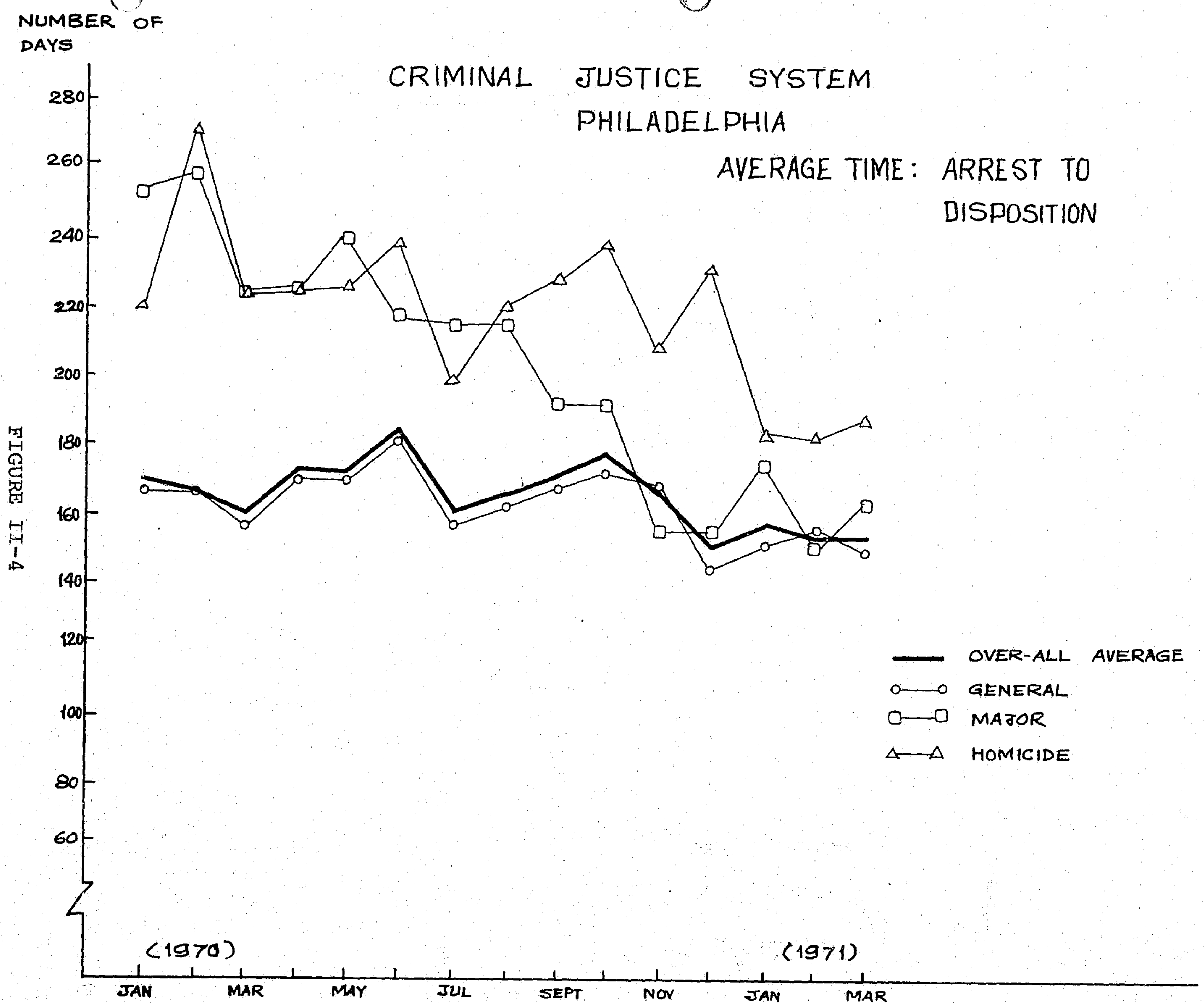
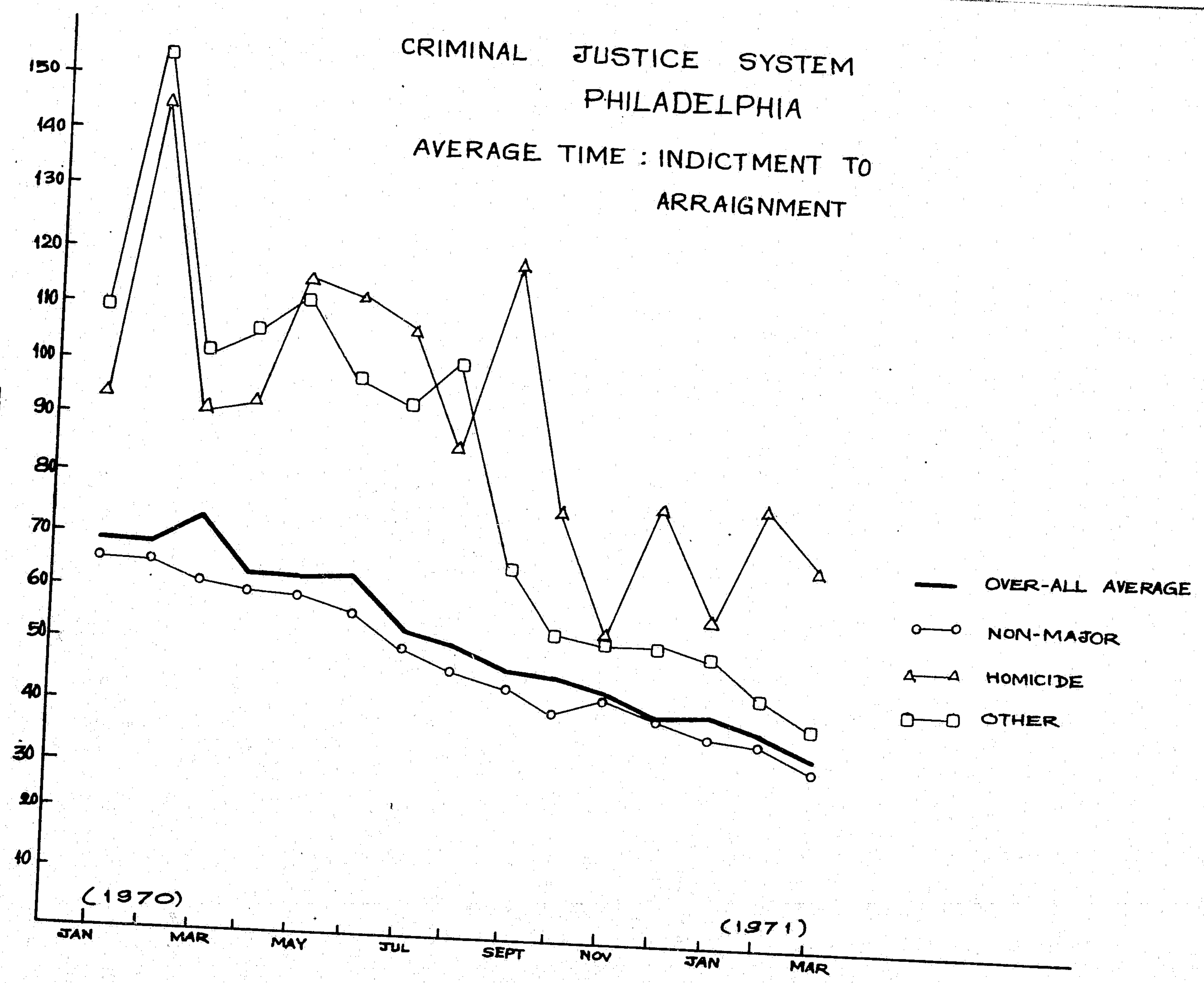
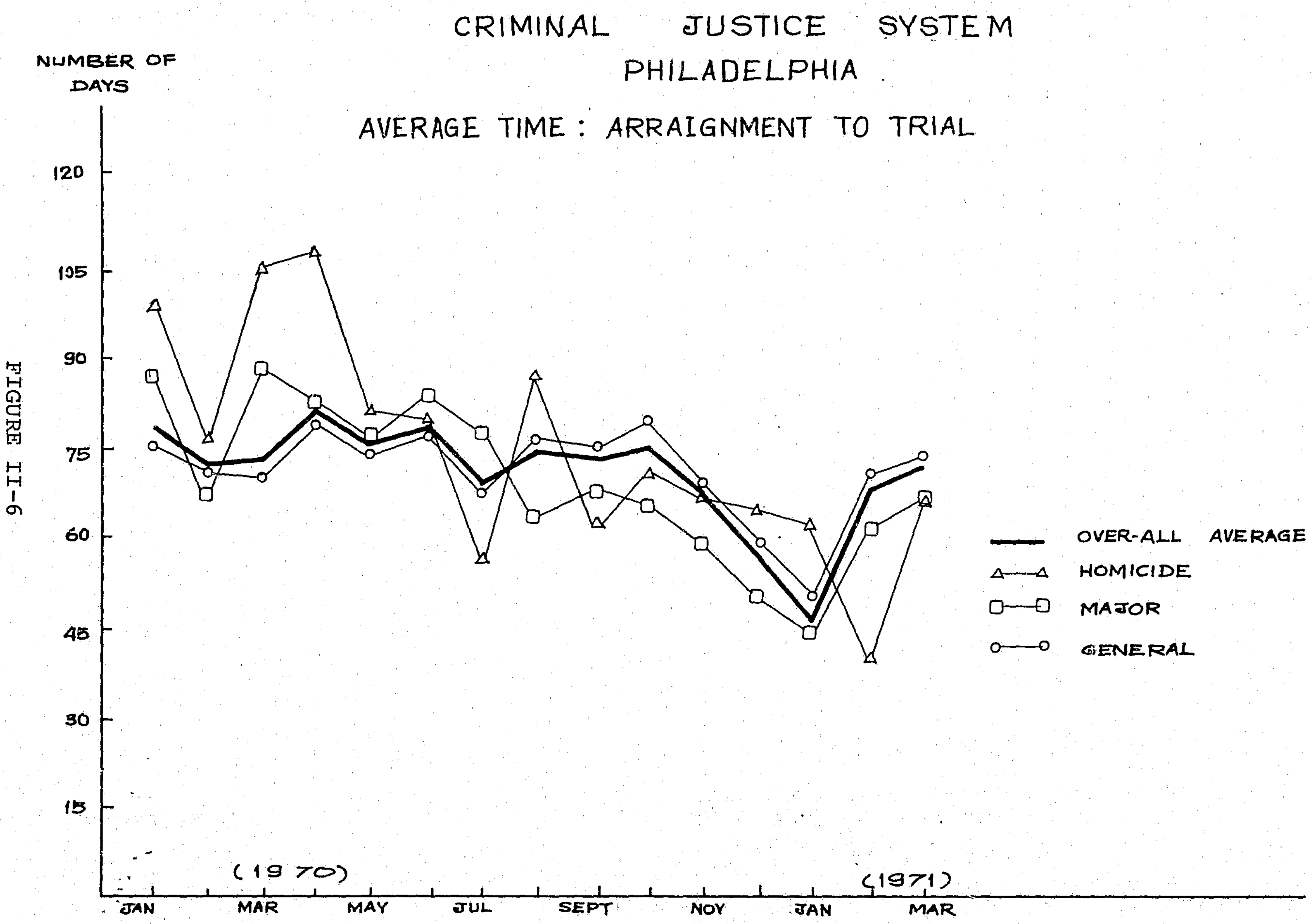

NUMBER OF DAYS
CRIMINAL JUSTICE SYSTEM
PHILADELPHIA
AVERAGE TIME: ARREST TO DISPOSITION
280
260
240
220
200
180
160
140
120
100
80
60
(1970)
(1971)
JAN
MAR
MAY
JUL
SEPT
NOV
JAN
MAR
OVER-ALL AVERAGE
GENERAL
MAJOR
HOMICIDE

FIGURE II-4

FIGURE II-5


CRIMINAL JUSTICE SYSTEM
PHILADELPHIA
AVERAGE TIME : INDICTMENT TO ARRAIGNMENT
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
(1970)
(1971)
JAN
MAR
MAY
JUL
SEPT
NOV
JAN
MAR
OVER-ALL AVERAGE
NON-MAJOR
HOMICIDE
OTHER



CRIMINAL JUSTICE SYSTEM
PHILADELPHIA
AVERAGE TIME: ARRAIGNMENT TO TRIAL
NUMBER OF DAYS
120
105
90
75
60
45
30
15
(1970)
(1971)
JAN
MAR
MAY
JUL
SEPT
NOV
JAN
MAR
OVER-ALL AVERAGE
HOMICIDE
MAJOR
GENERAL

FIGURE II-6

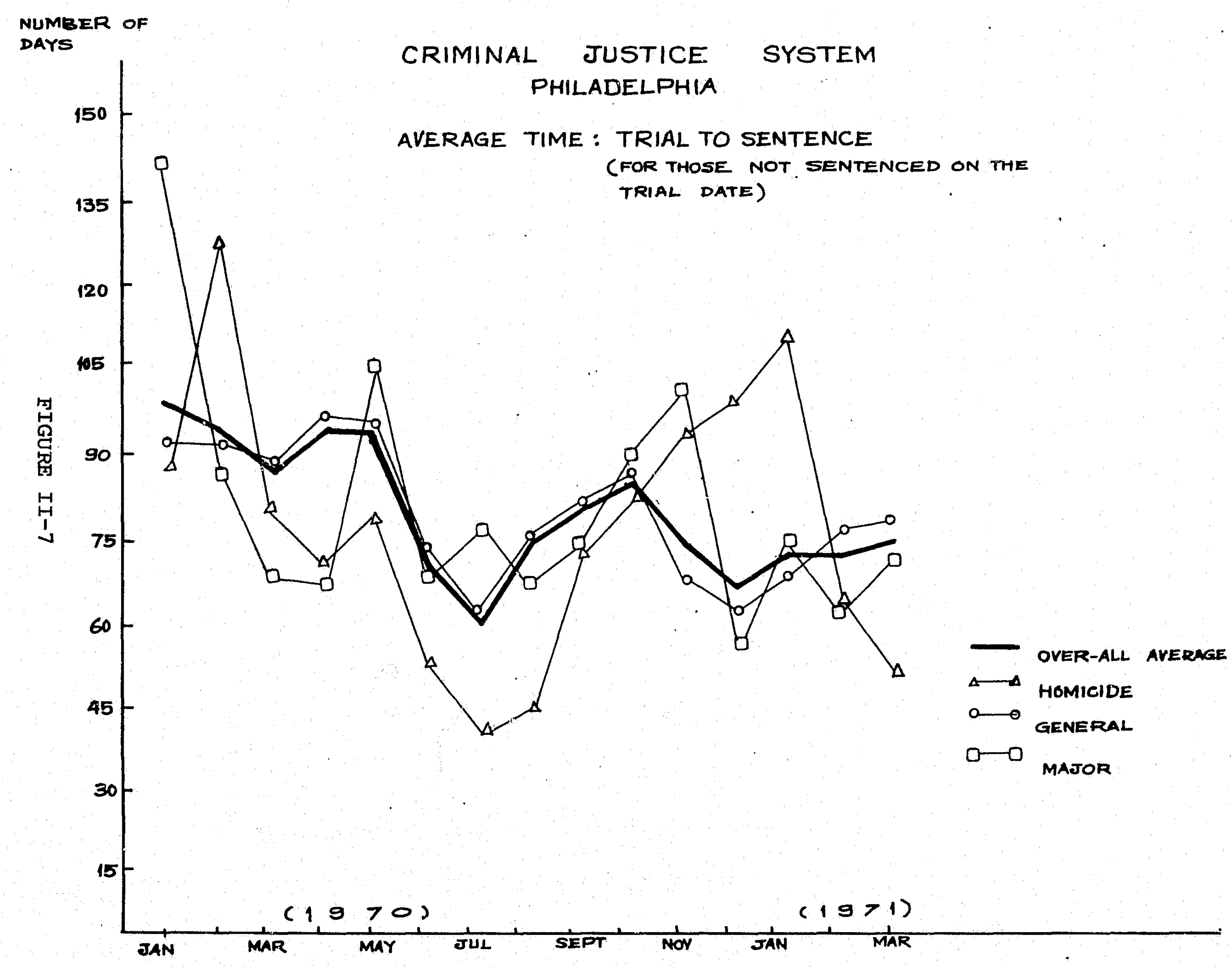

NUMBER OF DAYS
CRIMINAL JUSTICE SYSTEM
PHILADELPHIA
AVERAGE TIME : TRIAL TO SENTENCE
(FOR THOSE NOT SENTENCED ON THE TRIAL DATE)
150
135
120
105
90
75
60
45
30
15
(1970)
(1971)
JAN
MAR
MAY
JUL
SEPT
NOV
JAN
MAR
OVER-ALL AVERAGE
HOMICIDE
GENERAL
MAJOR

FIGURE II-7

Preliminary hearings are to be held three to ten days after the preliminary arraignment. If trial will be the next stage, however, it is scheduled to be held twenty days to six weeks after the preliminary arraignment.

Cases submitted before the preliminary arraignment courts are dismissed only when the District Attorney believes that the Commonwealth has no basis for a case against the defendant. This happens in very minor cases which accounts for less than one per cent of the total cases that enter preliminary arraignment.

Preliminary Hearing

The preliminary hearing is concerned with the establishment of a *prima facie* case against the defendant, i.e., it aims to determine:

a) if a crime has been committed and,

b) if the defendant may probably have committed it.

The court proceedings last from fifteen to twenty-five minutes and are attended by the defendant, the judge, a district attorney, a defense lawyer or public defender, the arresting police officer and eyewitnesses. Though the criminal laboratory personnel who have performed analysis on physical evidences that relate to the case may be called as expert witnesses, this almost never occurs; testimonies from the crime laboratory are usually done by stipulation. Use of physical evidence by the District Attorney to establish a prima facie case is maintained at a low level, evidences being cited only if they are imperative to establish a case against the defendant, e.g., in charges of possession of dangerous drugs.

Roughly ten per cent of the total cases that enter into preliminary hearings are discharged at this stage. The remaining ninety per cent are then scheduled for the indicting grand jury no sooner than ten days and usually three to four weeks after the preliminary hearing.

Indicting Grand Jury

The indicting grand jury hears cases for the same purposes as the preliminary hearing, i.e., to determine if a crime has been committed and to determine if the defendant may probably have committed it. In this stage of the court process, the District Attorney reads the case and the results of the preliminary hearing before the presiding judge and the grand jury and then leaves the court room. The grand jury decides, relying solely on the written reports of previous court stages, whether or not to dismiss the case. Dismissal of cases happen in less than five per cent of the total cases that read the indicting grand jury process. The remaining ninety-five per cent are then scheduled for the major arraignment, usually seven weeks after the indicting grand jury hearing.

Arraignment

Arraignment is set only to schedule the trial date and to decide issues of bail. The arraignment session is conducted by a court administrator with the participation of the District Attorney, the defense attorney, and the defendant. By virtue of its purpose, no cases are dismissed at this stage. There is also no legal rule as to when trial is to be held, though statistics reveal that the average time from arraignment to trial is six to eleven weeks.

If the defendant is to remain in jail either because he cannot afford to set bail or because no bail has been set for the charge against him, then he may file a "180 day" petition. If the defendant remains in jail and the trial is not conducted for longer than 180 days after the petition is filed, the defendant is released and the charge against him automatically dismissed.

Pre-Trial Hearing

At pre-trial hearings motions for suppression of evidences or testimonies are presented. Pre-trial motions are to be filed with the Clerk of Quarter Session no later than ten days before the trial date as scheduled by the arraignment session. The petition is sent to a judge at the Miscellaneous Court who then orders a hearing on the motion. For felonies, the pre-trial hearing is usually held to the date of the trial itself.

It is the policy of the District Attorney's Office to cite as few physical evidences as possible in the pre-trial stages of the criminal court process since the main concern is only to establish that the defendant may probably have committed a crime. This is generally the case for all charges except that of possession of dangerous drugs where chemical identification of the drug in question is usually needed. General court principles aim to insure, however, that each party has the chance to rebut any arguments of the opposing party. Hence, if the defense believes that there are other physical evidences available to the District Attorney but which have not been cited in previous court session, the defense may file a bill of particulars to request that the District Attorney declare all the evidences at his disposal.

Trial

Trial is held to determine if "guilt beyond reasonable doubt" may be established or not. Trial is held from six to ten weeks after arraignment and involves the defendant, the judge, the jury (if a jury trial is selected), the district attorney, the defense attorney and witnesses (eyewitnesses, expert witnesses and arresting officers). Trial sessions usually last for one day only, but special characteristics of cases extend this length to much longer sessions. Furthermore, sentence may or may not be given at the trial date itself.

At this stage in the court process the results of the analysis by the crime laboratory of the physical evidences relating to the case on trial must be available to the District Attorney for use as he sees appropriate for the proper disposition of the case. Also, though testimony by personnel of the crime laboratory can be admitted by stipulation, analysts from the crime laboratory are called to the court sessions as expert witnesses, not only to testify on the results of the analyses done on the physical evidences, but also to establish their credibility; i.e., that they have special knowledge. The value of crime laboratory personnel testimony may be fortified or denegated by examination as to his general experience, his means of knowledge in a particular case, and the facts and reasons on which he bases his conclusion.

APPENDIX III

The results of the surveys of both the Philadelphia Crime Laboratory and the New Jersey State Crime Laboratory are presented on the following figures. Both sets of data were obtained by two week surveys using forms as presented in the following pages. The data from the Philadelphia Laboratory are in the form of proportions; whereas, the data from the New Jersey State Crime Laboratory Survey are expressed in terms of entries. Not all the data have been presented here because of the small number of entries in some cases. The survey allowed the computation of processing times and queue lengths as well, and these values were helpful in establishing credible ranges for the parameters in the simulation described in Appendix IV.

Figure III-1 illustrates the approach we have taken in analyzing the crime laboratory. The data needed to describe the last two boxes, the $\{e_{ij}\}$ and the $\{a_{kj}\}$ matrices implied in Figure III-2 were generated from the crime laboratory surveys. Table III-1 presents the $\{e_{ij}\}$ matrix as obtained from the Philadelphia data and Table III-2 the $\{a_{kj}\}$ matrix as derived from the same source. Table III-3 through III-5 are similar a_{kj} matrices from the New Jersey State Laboratory. Although additional data were obtained, the size of the samples due to the limited time interval under study do not warrant their inclusion. The survey forms which are presented are suggested as prototypes for a subsequent larger survey by LEAA.

ORIGINS OF WORKLOAD FOR A CRIME LABORATORY

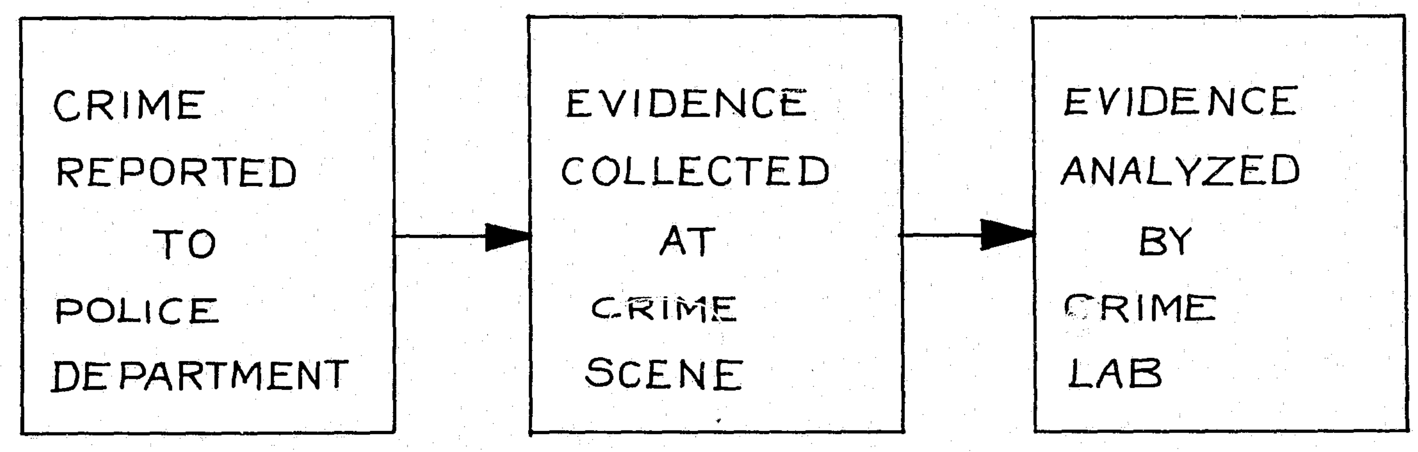


FIGURE III-1

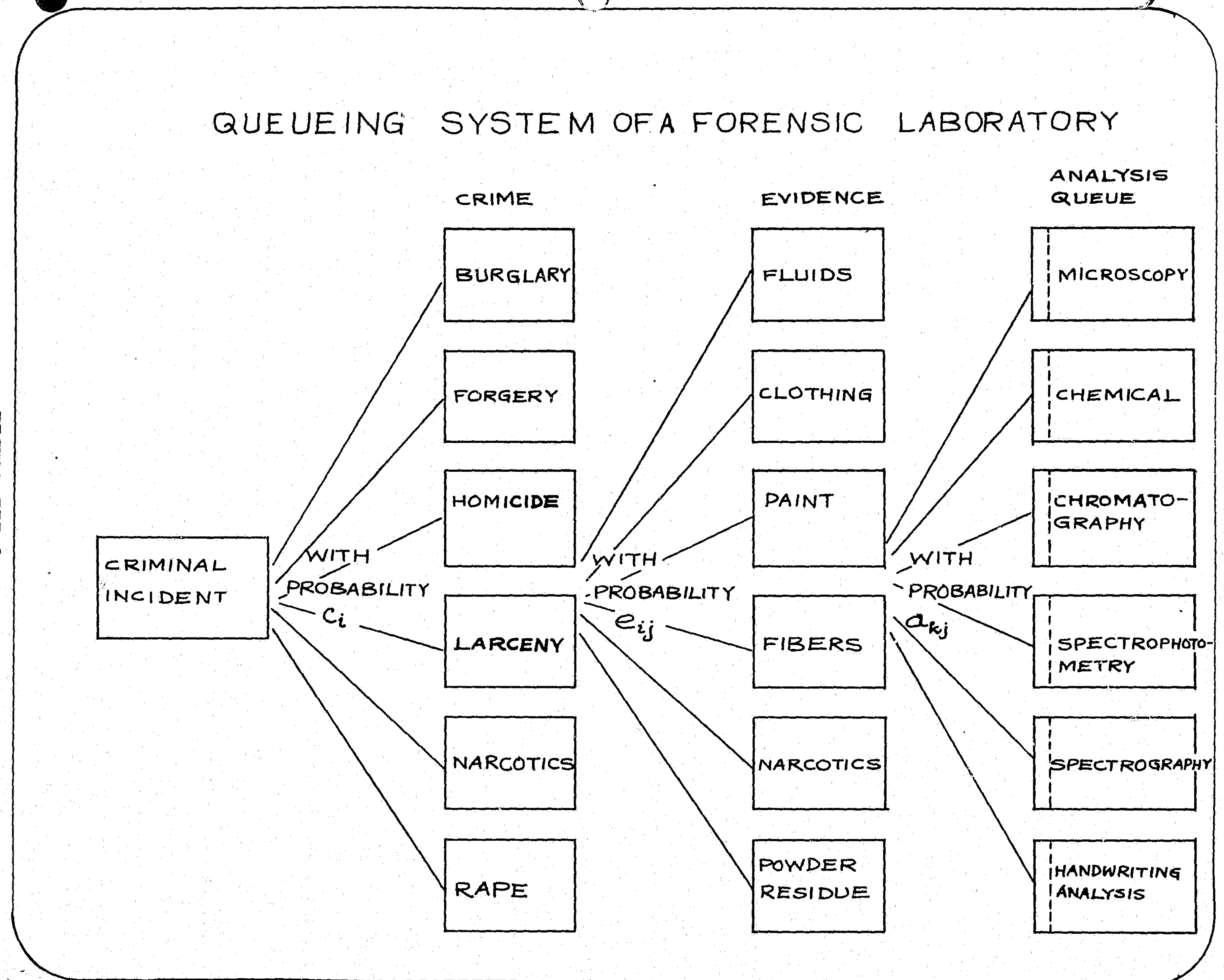

QUEUEING SYSTEM OF A FORENSIC LABORATORY
CRIME
EVIDENCE
ANALYSIS QUEUE
CRIMINAL INCIDENT
WITH PROBABILITY c_i
BURGLARY
FORGERY
HOMICIDE
LARCENY
NARCOTICS
RAPE
WITH PROBABILITY e_{ij}
FLUIDS
CLOTHING
PAINT
FIBERS
NARCOTICS
POWDER RESIDUE
WITH PROBABILITY a_{kj}
MICROSCOPY
CHEMICAL
CHROMATO-GRAPHY
SPECTROPHOTO-METRY
SPECTROGRAPHY
HANDWRITING ANALYSIS

FIGURE III-2

Table III-1

PHILADELPHIA CRIME LABORATORY

Spring 1971

Distribution of Evidence/Given Crime

Crime \ Evidence	Powder Residue	Narcotic	Alcohol	Fiber	Live Ammo	Projectile	Weapon	Documents	Paint	Impressions	Wood	Physical Material	Fingerprints	Clothing	Photos	Other Fluids	Physio Fluids	Totals
Aggravated Assault												.01	.016	.01	.032	.012	.012	250
Burglary						.01		.01	.01	.01	.01	.01	.010		.010			962
V.U.F.A.					.137	.025	.219											160
Forgery								.612										23
Gambling								.01										321
Homocide				.182				.054				1.0	.682	.454	1.0		.591	22
Larceny								.017							.01			334
Liquor			.01					.01										89
Narcotics			1.0					.01							.01		.035	319
Robbery	.01				.01		.01					.01	.015		.020		.01	405
Rape														.207		.035	.137	29
Misc.									.01				.01		.01	.01	.01	

Miscellaneous Class Consists Mainly Of: Arson, Suicide, Suspicious Death, Threatening Letters

.01 indicates some positive quantity ≤ 1%

Table III-2

PHILADELPHIA CRIME LABORATORY

Spring 1971

Distribution of Analysis/Given Evidence
(same conventions as previous chart)

Evidence \ Analysis	General	Compar. Phys. Mat.	Counterfeit Documents	Machine Ident.	Ink Paper Comparison	Handwriting Analysis	Fingerprint Analysis	Weapon Anal.	Ammo Anal.	Spectography	Spectophotometry	Microscopy	Chromotography	Chemical	Densitometry
Physio Fluids														1.0	.588
Other Fluids										.353	.681		.751	1.0	.375
Photos	1.0														
Clothing		1.0													
Fingerprints							1.0								
Physical Material		1.0													
Wood												1.0			
Impressions												1.0			
Paint												1.0			
Documents			.133	.167	.127	.523	.047								
Weapon							.079	1.0							
Projectile									1.0						
Live Ammo									1.0						
Fiber												1.0			
Alcohol														1.0	
Narcotic											.316	.862	.791	.979	
Powder Residue										.667	.333	.667		1	.333

Table III-3

NEW JERSEY STATE CRIME LABORATORY

EVIDENCE/CRIME MATRIX

Entries From Chemistry and Criminalistics Survey July 1971

Evidence / Crime	Alcohol in Blood	Building Materials	Corrosive Materials	Drugs in Urine	Explosives	Fibers	Fire Producing Material	Gunpowder Residues	Hallucinogens	Narcotics	Prescription Drugs	Impressions	Lacrymators	Liquor	Paint Chips	Physiological Fluids	Poisons	Soil Samples	Stains	Tool Marks	Other
Aggravated Assault																					
Arson		6				1												1			3
Burglary		2										1							1	2	
Carrying Concealed Deadly Weapon																					1
Forgery																					
Gambling																					
Homicide																					
Larceny															1						
Liquor Law Viol.																3					
Narcotics									57	8	20										2
Rape																					
Robbery																					
Other						2						2			14					2	2

Table III-4

NEW JERSEY STATE CRIME LABORATORY

EVIDENCE/CRIME MATRIX

Entries From Firearms, Latent Prints and Documents Survey July 1971

Evidence / Crime	Casings	Shells	Bullets	Ammo	Weapons	Fingerprints	Handwriting Iden.	Ink & Paper Comp.	Machine Iden	Other
	← Firearms				→		← Documents			→
Aggravated Assault		3	6		5	1				
Arson						3				
Burglary					1	1				
Carrying Concealed Deadly Weapon					20					
Forgery							10			
Gambling								1		1
Homicide		2	2	3	2	1				
Larceny										
Liquor Law Viol.										
Narcotics										
Rape										
Robbery	1			1	4					
Other (Specify)		3	3		11		3			

NEW JERSEY STATE CRIME LABORATORY

EVIDENCE/ANALYSIS MATRIX

Entries From Chemistry and Criminalistics Survey   July 1971

Table III-5

Analysis		Alcohol in Blood	Building Materials	Corrosive Materials	Drugs in Urine	Explosives	Fibers	Fire Producing Material	Gunpowder Residues	Hallucinogens	Narcotics	Prescription Drugs	Impressions	Lacrymators	Liquor	Paint Chips	Physiological Fluids	Poisons	Soil Samples	Stains	Tool Marks	Other
Chemical										57	7	20				14	3					3
Physical	melting point															1						
	refractive index		1																			
	density		1																			
Chromatography	gas		1								3	2					3					3
	thin layer									11			1			1						1
Microscopy			1				1	1		55	6	3	1			14	1				2	2
Spectrography--emission																4						
Spectrophotometry	infrared																					
	ultraviolet									7	2	14										2
	visible																					
	fluorescence									7		2										1
Immunology																						
Other			6						1			2	3					1		1	3	1

The data presented from the Pennsylvania State Police Laboratory were not collected through the same survey conducted at West Trenton and Philadelphia and, therefore, does not follow the same format. It is being collected as a matter of ordinary record reporting. It is a good example of the type of records now being kept which, with a little encouragement from the National Institute, could be turned into a valuable source of analysis to assist in planning for crime laboratories.

The evidence and analysis matrices for New Jersey and Pennsylvania State Police Laboratories have not been normalized because appropriate crime rates were not presently available.

Pennsylvania State Crime Laboratory, Harrisburg
Document Section - Yearly Summary, 1970

PSP = Pennsylvania State Police OA = Other Agencies

Evidence

	Anon. Comm. & Threats	Arson	Buglary & Larceny	Forgery	Fraud & Embezzlement	Gambling	Homicide	Robbery	Suspicious Death	Miscellaneous
PSP	21	0	38	45	19	17	3	1	3	22
OA	12	1	64	78	11	0	0	0	0	30

Analysis

	Comparisons					Identification			Miscellaneous				
	Handwriting	Adding Machine	Checkwriter	Typewriter	Miscellaneous	Typewriter	Paper & Water	Miscellaneous	Charred Doc.	Ident. Writing	Oblit. Restor.	Microscopic	Miscellaneous
PSP	3,110	0	13	134	55	87	697	1,235	371	578	152	2,255	13
OA	2,706	0	43	1401	43	662	1,063	1,545	50	1,618	79	3,228	9

Table III-6

Pennsylvania State Crime Laboratory, Harrisburg
Ballistics Section - Yearly Summary, 1970

PSP = Pennsylvania State Police OA = Other Agencies

Evidence

	Accidental Shooting	Assault and/or Attempted Homicide	Auto Accidents	Buglary & Larceny	Game Violations	Homicide	Robbery	Suspicious Death	Miscellaneous
PSP	13	24	3	61	0	57	8	9	50
OA	20	33	0	72	17	33	3	4	26

Analysis

	Comparisons						Identification			Firearms				Miscellaneous		
	Bullets	Shell & Ctgs.	Fingerprints	Feet & Tireprints	Toolmarks	Miscellaneous	Ammunition	Make of Weapon (from slug)	Make of Weapon	Automatics	Revolvers	Rifles	Shotguns	Shot & Powder Pattern	Fingerprints	Miscellaneous
PSP	821	823	266	40	2922	101	73	153	73	11	78	46	18	5	183	43
OA	454	621	730	11	793	71	137	50	523	259	304	143	16	2	349	40

Table III-7

Pennsylvania State Crime Laboratory, Harrisburg
Chemistry Section - Yearly Summary, 1970

PSP = Pennsylvania State Police OA = Other Agencies

Evidence

	Arson	Assault and/or Attempted Homicide	Burglary and Larceny	Fatal Accidents	Hit and Run	Homicide	Game Law	Narcotics	Rape	Robbery	Suspicious Death	Miscellaneous
PSP	30	13	30	17	48	39	0	650	10	2	10	39
OA	12	20	32	2	40	44	5	620	9	1	9	31

Analysis

	Microscopic					Chemical				Miscellaneous					Serology			Toxicology		1037	
	Glass	Hairs & Fibers	Paint	General Comparisons	Miscellaneous	Drugs & Narcotics	Powder Residue & Pattern	Blood & Urine Alcohol	Miscellaneous	Arson	General Comparisons	Serial No. Restoration	Soil Comparison	Miscellaneous	Blood	Blood Group	Seminal Stains	Body Fluids	Viscera	Blood & Urine Alcohol	Intoximeter
PSP	20	186	337	202	130	7,767	69	30	288	67	143	13	62	340	196	210	38	1	4	201	99
OA	47	110	263	133	92	4896	54	24	192	61	108	3	53	349	215	206	62	3	1	161	0

Table III-8

EVIDENCE GATHERING FORMS
for
e_{ij} and a_{kj} matrices

CONTINUED

1 OF 3

LEAA CRIME LAB SURVEY

Evidence Fact Sheet   Latent Print Analysis

A. Crime Classification of Case:

1. Aggravated Assault	7. Homicide
2. Arson	8. Larceny
3. Burglary	9. Liquor Law Viol.
4. Carrying Concealed Deadly Weapon	10. Narcotics
	11. Rape
5. Forgery	12. Robbery
6. Gambling	13. Other (Specify)

B. Type of Evidence:

1. Latent Print Analysis   2. Other (Specify)

C. Time Data:

	Date	Time	
Receipt of Evidence	/ /	________	AM PM
Analysis by Technician Begins	/ /	________	AM PM
Analysis by Technician Ends	/ /	________	AM PM

D. Results of Analysis:

An { Identification / Comparison } { Could / Could not } be made on the basis of the analysis.

E. Amount of Evidence:

The number of pieces of evidence was ____________.

LEAA CRIME LAB SURVEY

Evidence Fact Sheet Documents

A. Crime Classification of Case:

1. Aggravated Assault
2. Arson
3. Burglary
4. Carrying Concealed Deadly Weapon
5. Forgery
6. Gambling
7. Homicide
8. Larceny
9. Liquor Law Viol.
10. Narcotics
11. Rape
12. Robbery
13. Other (Specify)

B. Type of Evidence to be Analyzed:

1. Handwriting Identification
2. Ink and Paper Comparison
3. Machine Identification
4. Other

C. Type of Analysis:

1. Comparison
2. Identification

D. Results of Analysis:

An { Identification / Comparison } Could / Could not } be made on the basis of the analysis.

E. Amount of Evidence:

The number of pieces of evidence was ____________________.

F. Time Data:

	Date	Time	
Receipt of Evidence	/ /	________	AM / PM
Analysis by Technician Begins	/ /	________	AM / PM
Analysis by Technician Ends	/ /	________	AM / PM

LEAA CRIME LAB SURVEY

Evidence Fact Sheet Firearms

A. Crime Classification of Case:

1. Aggravated Assault
2. Arson
3. Burglary
4. Carrying Concealed Deadly Weapon
5. Forgery
6. Gambling
7. Homicide
8. Larceny
9. Liquor Law Viol.
10. Narcotics
11. Rape
12. Robbery
13. Other (Specify)

B. Type of Evidence to be Analyzed:

1. Casings
2. Shells
6. Bullets
4. Ammo
5. Weapons

C. Type of Analysis:

1. Comparison
2. Identification

D. Results of Analysis:

An { Identification / Comparison } Could / Could not } be made on the basis of the analysis.

E. Amount of Evidence:

The number of pieces of evidence was ____________________.

F. Time Data:

	Date	Time	
Receipt of Evidence	/ /	________	AM / PM
Analysis by Technician Begins	/ /	________	AM / PM
Analysis by Technician Ends	/ /	________	AM / PM

LEAA CRIME LAB SURVEY

Evidence Fact Sheet   Laundry & Jewelry Marks

A. Crime Classification of Case:

1. Aggravated Assault
2. Arson
3. Burglary
4. Carrying Concealed Deadly Weapon
5. Forgery
6. Gambling
7. Homicide
8. Larceny
9. Liquor Law Viol.
10. Narcotics
11. Rape
12. Robbery
13. Other (Specify)

B. Type of Evidence:

1. Laundry and Jewelry Marks   2. Other (Specify)

C. Time Data:

	Date	Time	
Receipt of Evidence	/ /	________	AM PM
Analysis by Technician Begins	/ /	________	AM PM
Analysis by Technician Ends	/ /	________	AM PM

D. Results of Analysis:

An { Identification / Comparison } Could / Could not } be made on the basis of the analysis.

E. Amount of Evidence:

The number of pieces of evidence was ____________.

LEAA CRIME LAB SURVEY

Evidence Fact Sheet   Voice Print

A. Crime Classification of Case:

1. Aggravated Assault
2. Arson
3. Burglary
4. Carrying Concealed Deadly Weapon
5. Forgery
6. Gambling
7. Homicide
8. Larceny
9. Liquor Law Viol.
10. Narcotics
11. Rape
12. Robbery
13. Other (Specify)

B. Type of Evidence:

1. Voice Print   2. Other (Specify)

C. Time Data:

	Date	Time	
Receipt of Evidence	/ /	________	AM PM
Analysis by Technician Begins	/ /	________	AM PM
Analysis by Technician Ends	/ /	________	AM PM

D. Results of Analysis:

An { Identification / Comparison } Could / Could not } be made on the basis of the analysis.

E. Amount of Evidence:

The number of piece of evidence was ____________.

LEAA CRIME LAB SURVEY

Evidence Fact Sheet   Mobile Crime Collection

A. Crime Classification of Case:

1. Aggravated Assault
2. Arson
3. Burglary
4. Carrying Concealed Deadly Weapon
5. Forgery
6. Gambling
7. Homicide
8. Larceny
9. Liquor Law Viol.
10. Narcotics
11. Rape
12. Robbery
13. Other (Specify)

B. Evidence Collected:

1. Photographs
2. Other (Specify)

C. Time Data:

	Date	Time	
Receipt of Call	/ /	______	AM PM
Call Answered	/ /	______	AM PM
Call Finished	/ /	______	AM PM

LEAA CRIME LAB SURVEY

EVIDENCE FACT SHEET — CHEMISTRY & CRIMINALISTICS

A. Crime Classifications of Case:

1. Aggravated Assault
2. Arson
3. Burglary
4. Carrying Concealed Deadly Weapon
5. Forgery
6. Gambling
7. Homicide
8. Larceny
9. Liquor Law Violations
10. Narcotics
11. Rape
12. Robbery
13. Other (Specify)

B. Type of Evidence to be Analyzed:

1. Alcohol in Blood
2. Building Materials
   ---wire ---glass
   ---insulation
3. Corrosive Materials
   ---acids ---alkalines
4. Drugs in Urine
5. Explosives
6. Fibers
   ---human ---textile
   ---animal ---vegetable
7. Fire Producing Material
8. Gunpowder Residues
9. Hallucinogens
10. Narcotics
11. Prescription Drugs
12. Impressions
    ---shoe ---tire
    ---hand
13. Lacrymators
14. Liquor
15. Paint Chips
16. Physiological Fluids
    ---blood ---semen
    ---urine ---saliva
17. Poisons
18. Soil Samples
19. Stains
    ---lipstick ---grease
    ---tar ---oil
    ---food ---gasoline
20. Tool Marks
21. Other

C. Type of Analysis

1. Comparison
2. Identification

EVIDENCE FACT SHEET CHEMISTRY (continued) & CRIMINALISTICS

D. Nature of the Analysis:

In the matrix below please record the type of evidence analyzed (by its number) in the blank spaces at the top; and in the corresponding columns, check the squares of the techniques used to analyze the evidence.

Type of Evidence / Analysis		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Chemical																						
Physical	melting point																					
	refractive index																					
	density																					
Chroma-tography	gas																					
	thin layer																					
Microscopy																						
Spectrography--emission																						
Spectro-photometry	infrared																					
	ultraviolet																					
	visible																					
	fluorescence																					
Immunology																						
Other: ____________																						

E. Results of the Analysis:

(Please indicate appropriate wording)

An { Identification / Comparison } { Could / Could not } be made on the basis of the analysis performed on this evidence.

F. Amount of Evidence:

The number of pieces of evidence analyzed ______________________________.

G. Time Data:

	Date	Time
Receipt of Evidence	/ /	____________ AM / PM
Analysis by Technician Begins	/ /	____________ AM / PM
Analysis by Technician Ends	/ /	____________ AM / PM

APPENDIX IV

SUPLAB SIMULATION

The SUPLAB simulation program is designed to simulate the operations of a crime laboratory. The program is composed of a main routine and nine subroutines, which simulate the arrival of cases to the crime laboratory, develop statistics about the type of case, the amounts and types of evidence, and the servicing each case receives. In addition, the program determines the number of arrived, but as yet unserved, cases at various points in the day, as well as determining the probability that a case involving a crime of type i is serviced before it is needed in court.

There are two major policy assumptions with which the program operates. The first is that each unit of a crime laboratory can be handled separately, simulating at one time only arrival and service for cases to the Chemistry Unit or the Ballistics Unit, for example. Second, the time is measured in minutes from 1 to 1440, which 1 represents 5 p.m. of the preceding calendar day, and 1440 represents 4:59 p.m. of the next. Of course, the simulation would operate efficiently if, represented 12:00 a.m. and 1440 11:59 p.m. However, under the first scheme, the working day of the laboratory (9 a.m. - 5 p.m.) become minutes 960 to 1440. Analysis of the output of the program will show that no service begins before 1080 (11 a.m.). Here again operation has been simplified by loading the time spent for lunch, coffee-breaks, etc. onto the front of the day (960 - 1080).

Description of the Program

The Main Program

There are three major functions performed by the main routine:

1) initialization
2) input of data
3) control

The main routine is used to set the original values of many of the program variables to zero. This function is performed to meet compiler requirements and serve as a check against error.

All data necessary to operate the SUPLAB is entered through read statements in the main routine. The nature and handling of this data will be explained in a later section entitled "Data Requirements."

The final function of the main routine is to generate the case arriving to the laboratory on a given day. Once the case is generated, the main routine calls the various subroutines to develop the characteristics of the case. At the end of the day, the main routine calls the various statistical routines included in the simulation.

CHOOS Subroutine

CHOOS is a function subroutine that determines the value of the random number generated by RANNOS. These random numbers are uniformly distributed between 0 and 1 and must be converted to their corresponding value. CHOOS performs this conversion by comparing the 0-1 random variate to the cumulative distribution function for the item being simulated. The actual value simulated is the first value of the random variable whose cumulative probability value is greater than the 0-1 variate.

EXAMPLE: ARRIV(t) = Cumulative probability for the interarrival time is t minutes

Assume the probability of arrivals 1, 2, 3 minutes apart is .05, .05, .10 respectively.

Then ARRIV(1) = .05, ARRIV(2) = .10, ARRIV(3) = .20

If the random variate is .16, then the program has simulated two arrivals three minutes apart.

CTYPE Subroutine

CTYPE determines the type of case, the number of different types of evidence submitted, and the specific types of evidence submitted on this case. It is called by the main routine immediately after each case enters the system. All simulated values are stored for the particular day of the simulation until the end of that day.

ANLTIM Subroutine

After determining the type of crime and evidence data, the program then determines the amount of time the case needs for service. For each type of evidence, a simulated service time is obtained and the time for servicing each case is then determined through summation.

BUSY Subroutine

At the end of each simulated day, the entire day's cases receive servicing in BUSY. After determining the case priority (note: only cases arriving before 1080 can be priority cases), each case is handled by the first server available at or after the case arrived. The MAXAMI subroutine is used to determine which server is available, by calculating, for each server, when his last service ended and then picking the smallest time. If all servers are busy until the end of the day, the date of service is incremented to the next calendar day.

STAT, AVGS, QUEUES Subroutines

These three routines compile statistical information about the laboratory's operation on a daily basis. The STAT routine gives the total of each type of crime the laboratory received. In addition, the information about each case - the number of types of evidence, analysis methods, etc. - are printed here.

AVGS routine determines the average time between arrivals, the average length of a service, and the average waiting time in the queue.

The QUEUES routine determines the length of the queue throughout the day and the average queue length.

SNEED Subroutine

The SNEED routine calculates the probability that a case of crime type i is serviced on or before the time at which the analysis results are needed in court. SNEED generates the date the analysis is needed through the TNEED array (time data needed) and compares this date with the date upon which the analysis was completed. The number of successful completions is compared to the total number of cases of each crime type to determine the probability that the analysis is done in time.

Data Requirements

To operate the program, nineteen different types of data are required.

The data can be divided into three major types. The first applies to all units of the laboratory. The record types varies by laboratory unit and the third varies by laboratory unit and type of crime.

(1) For all laboratory units:

ISEED must be an 8 digit odd integer, which is used to initialize the sequence of random numbers generated by RANNOS function (This data may have to change for use on another compiler with a different random number generator.).

IDAY the maximum elapsed time (in days) for a case to be needed in court. This should be a limiting value for all types of cases and should be requested from court agencies serviced by the laboratory

NDAY is the number of days being simulated. This value is under the operator's control. The choice should be large enough to assure steady-state being reached. Current array size limits NDAY to 30.

NU is the number of units to be simulated.

TNEED is the probability distribution of the number of days until the case goes to court. The operator will require court records for each type of crime classification considered.

PRIOR is the probability that a case is a priority case. Laboratory records will generally not contain information indicating this type of data. Several alternatives are possible:
1) discussions with laboratory personnel
2) request that all cases for a trial period be marked priority or non-priority
3) request a set of case histories from the laboratory. Check for all cases handled in a substantially shorter period of time than average and assume this percentage represents priority cases.

QUECHK this array contains the times at which the length of the queue is to be checked. These values are currently 9 a.m. to 5 p.m. by the hour (corresponding to minutes 960 to 1440 in increments of 60). However, they can be changed at the decision maker's discretion.

(2) Individual unit data:

NWKR the number of workers in the unit. This figure will vary from unit to unit and should be obtained from the laboratory director. Both day and night workers should be considered.

NMIN the maximum time any individual analysis takes. This data can be obtained through use of the survey forms discussed in the paper.

NTEVI the total number of distinct types of evidence. Since classification procedures vary the value for NTEVI should be obtained through direct conversation with the laboratory director.

NANAL the total number of distinct analysis methods. This data must be obtained through use of a survey. A listing of equipment that perform different functions may yield an incorrect estimate. For example, in Philadelphia, narcotics are analyzed under two methods -- one involving spectroscopy and one not -- both methods, however, use more than one technique. Hence here NANAL would be two, not three or four.

NTT is the maximum time between two successive arrivals. The value of NTT will generally be available through laboratory records, as most laboratories log the time each case arrives.

OUT is the distribution of the probability that people are out on a given day. Laboratory records of absences should be requested to obtain these values.

CRIM is the distribution of the probability that a case involves a crime of type i. Requesting laboratory records for the previous 6 to 12 months indicating the number of each type of case should provide sufficient estimates.

ARRIV is the probability distribution that the time between arrivals is K minutes. Here again the laboratory should be able to supply this information from past case records.

EVI is the probability that L different types of evidence are submitted on a case. To obtain these probabilities it may be necessary to request analysis reports and/or property receipts either of which should contain this information.

TEVI is the probability distribution that evidence received is of a specific type. If record keeping in the laboratory is sparse, analysis reports may be necessary. Otherwise, monthly or yearly analysis summaries may be used.

(3) Data for units and crime:

Often the amount of data, time of analysis, or type of analysis depends upon the particular crime, as well as the laboratory unit.

ANALTY is the distribution for the probability that an analysis for unit I, involving crime J, uses method L. It will be rare for data to be kept in such a manner, but in the interest of accuracy such data should be obtained. Use of the aforementioned survey form for a short period (one month) will generate enough data to supply this matrix.

TIM for an analysis of type L, TIM contains the probability that the analysis time is M minutes. Here again data is generally not kept in such detail, but sufficient information can be obtained through the survey.

As was stated previously, when probability data is entered into the program, it must be converted to cumulative distribution form.

<u>Use of SUPLAB Program</u>

The program should be used to test various configurations of a proposed or existing laboratory to select the most cost effective arrangement.

Once the input data has been obtained for a base or original configuration, testing other structures is relatively simple. At present there are only two changes a laboratory can make in its configuration - machines and men.

To test a change in manpower, the operator must change only two pieces of data - NWKR and OUT. Changing NWKR involves only simple addition or subtraction. To change the OUT cumulative probability distribution is more complex, but still fairly straightforward. The laboratory director and/or the program operator must discuss and decide the probability of the added (deleted) man's being absent. Application of probability rules then determines the new OUT probabilities.

An addition or replacement of a machine is equally simple. Here only the ANALTY and TIM distributions change to reflect the new probabilities of choosing each analysis method or to include a new method. Change of the TIM array is simple if the machine directly replaces an old machine. A system's analysis of the contribution (in terms of time) of the old machine determines the time to be subtracted from entries in TIM and must be replaced by the operating time of the new machine. If the machine is strictly an addition, a new method must be added to ANALTY and a new row to TIM.

The optimal configurations for each facility depends, of course, upon the cost of operating the laboratory. While the costs incurred for additional manpower and equipment can be accurately ascertained, many indirect and overhead costs are impossible to estimate. From a study of three laboratories, these costs were seen to vary widely without any recognizable pattern. For this reason, it seems inexpeditious to attempt such an evaluation in the program, and is left to the program operator.

Improvements and Extensions

As presently structured, the SUPLAB program represents, with reasonable accuracy and minimal computer costs, the operation of a crime laboratory.

In the interest of realism and accuracy, several extensions might be considered:

1) Presently all analysts are considered identical. They are all assumed to be able to perform the same functions with equal skill. Admittedly, most laboratories do not operate in this manner.

2) Presently no overtime is considered in the system. It should be possible to create overtime services if the queue backs up beyond a certain level.

3) Structuring the system to fit a 12 a.m. - 12 p.m. day. This would involve making the analyst busy in the middle of the day, etc.

These are possible areas of improvement for the simulation. While none are believed to be crucial, each one could add to the program's utility.

SUPLAB PROGRAM

Variable List*

Main Program

Symbol	Description
Constants	
NDAY	is the number of days to be simulated
NU	is the number of laboratory units simulated
NWKR	is the number of workers on the laboratory unit
NMIN	is the maximum time that any evidence analysis may take
NTEVI	is the number of possible types of evidence the unit can receive
NANAL	is the number of distinct analyses the unit can perform on a piece of evidence
NTT	is the maximum time between two successive case arrivals
NDAYP	extends the number of days the system uses in order to accommodate the service times for each case
NOVT	is the number of workers out on a given day
TARR	is the time of last arrival to laboratory unit
KCOMP	is the number of cases coming to the laboratory unit on a given day.
NAVL	is the number of workers available to process cases
INTER	is the interarrival time between cases K and (K+1)
SIM	is the random number generated by the system
Arrays	
PRIOR	contains the probability that a given case is or is not a priority case
QUECHK	designates the times at which the length of the queue is to be checked
OUT	contains the probabilities that 1, 2, 3, --- workers are out today
ARRIV	contains the probabilities that the time between two successive arrivals is 0, 1, 2, --- minutes
CRIM	the probability distribution to determine the crime represented by each case received at the laboratory

*Only those variables not previously described are listed.

Arrays

ICRR..........records the # of types of evidence involved in the case
ICRI..........records the type of case that just arrived to the laboratory
NCR..........keeps a total for the day of the number of homicides, rapes, assaults,...the lab processes
TANAL.........records the case I that the Jth type of evidence was of type K

ANLTIM Subroutine

Constants

IFAKE.........records the type of evidence that was the Kth evidence presented on the ith case
ITY...........represents the analysis method chosen for the Kth piece of evidence
NTIM..........the amount of time the above analysis takes

Variables

CTIM..........records the total analysis time consumed by the ith case
ANTY..........a dummy array used to access the correct row of the ANALTY array (depends upon the type of evidence)
IAN...........records the type of analysis for the Kth type of evidence
ATIMES........a dummy array used to obtain the correct row of the TIM array (depends upon type of analysis chosen)
ETIM..........records the time spent analyzing each piece of evidence

BUSY Subroutine

Constants

K1............day upon which case is serviced
I4............the number of cases serviced
LPRIOR........constant telling whether we are servicing priority or non-priority cases
IDENT.........an identifier to tell program whether all the day's cases have been serviced
IBUSY.........a constant which is set equal to the time when the analyst's last service finished

Arrays (continued)

EVI...........is the probability distribution that 1, 2, 3, or more distinct types of evidence were submitted on the case
TEVI..........the probability distribution describing the chances that the evidence was type 1, 2, 3,....
ANALTY........contains the probabilities that for unit I, and case type J the method of analysis used was K
TIM...........contains the probabilities that an analysis using method K took L minutes
IAVL..........contains the number of analysts available to work each day the system operates
APRIOR........contains a 1 or a z designating whether the case is non-rush or rush, respectively
TINTAR........contains the arrival time of each simulated case
ITECH.........contains the times over which the technicians are busy servicing cases
INTAR.........contains the time between each set of successive cases

CHOOS Subroutine

Constants

I.............dummy index representing maximum value of array being considered.
J.............dummy index representing value for array being simulated

Arrays

A.............dummy array which contains values of simulated array

CTYPE Subroutine

Constants

ICR...........a constant whose value (1,2...20)designates the type of case that has just arrived to the lab
NEVI..........the number of types of evidence presented by the case
IEVI..........a constant whose value (1, 2, 3...)designates each specific type of evidence for...the case that just arrived

Arrays

KTECH.........records the arrival date of the case being serviced
LTECH.........records the case number from arrival date
ATECH.........records the time that the case arrived to the laboratory
SYST..........evaluates the time that the case spent in the system (waiting plus service time)

MAXIMI Subroutine

Constants

JR............is the number of cases handled by the technician up to this point in time
KMIN..........is the minimum for which an analyst is available to service another case
JZI...........is the number of the first available analyst
I3............is the number of cases handled today by the analyst, who will handle this case

Arrays

KLARGE........is the latest until which the analyst is busy

STAT Subroutine

Constants

I7............dummy constant into which the values of ICR2 are put

AVGS Subroutine

Constants

TOTA..........sum of the interarrival times between each pair of successive cases
TOTSYS........total time spent in the system by all cases
TOTSER........total time spent in servicing all the laboratory cases

Arrays

AVGA..........average time between interarrival for day K
AVGSER........average service time for a case arriving on day K
AVGSYS........average time spent in the system by a case arriving on day K
AVGNT.........average waiting time prior to service

QUEUES

Constant

IQUE..........a counter indexing the number of times that the queue's length is checked (currently 10)
NQUE..........is the number of cases arriving to the queue between checking times
NSERV.........is the number of servicing finished between the previous and the current time at which the queue is checked
NEWQU.........is the number of additions or subtractions to the queue's length
LQUE..........is the length of the queue at the previous check
TOTQUE........is the total number of cases in the queue over the entire day
AVGQUE........is the average length of the queue for day K

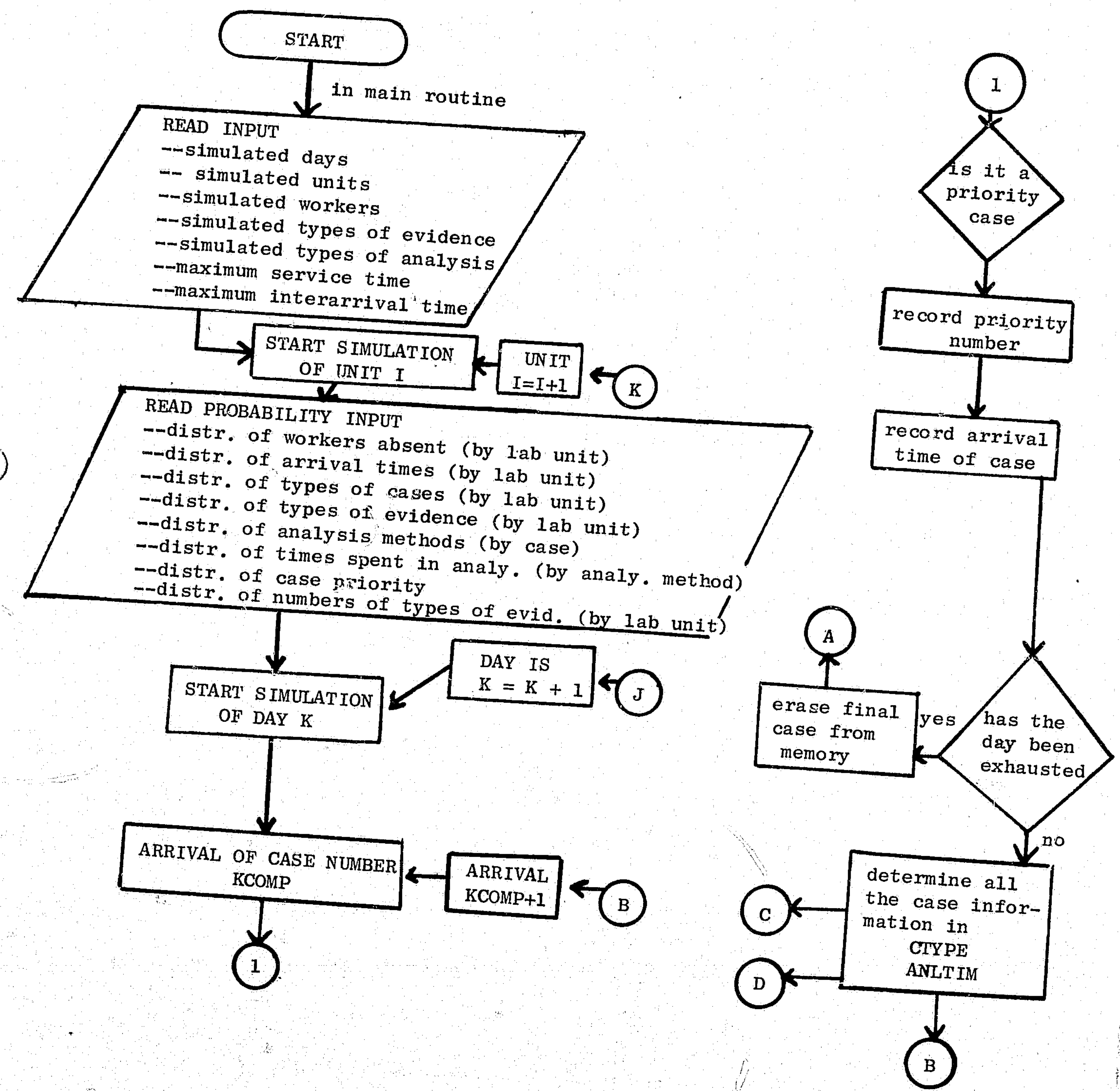
Arrays

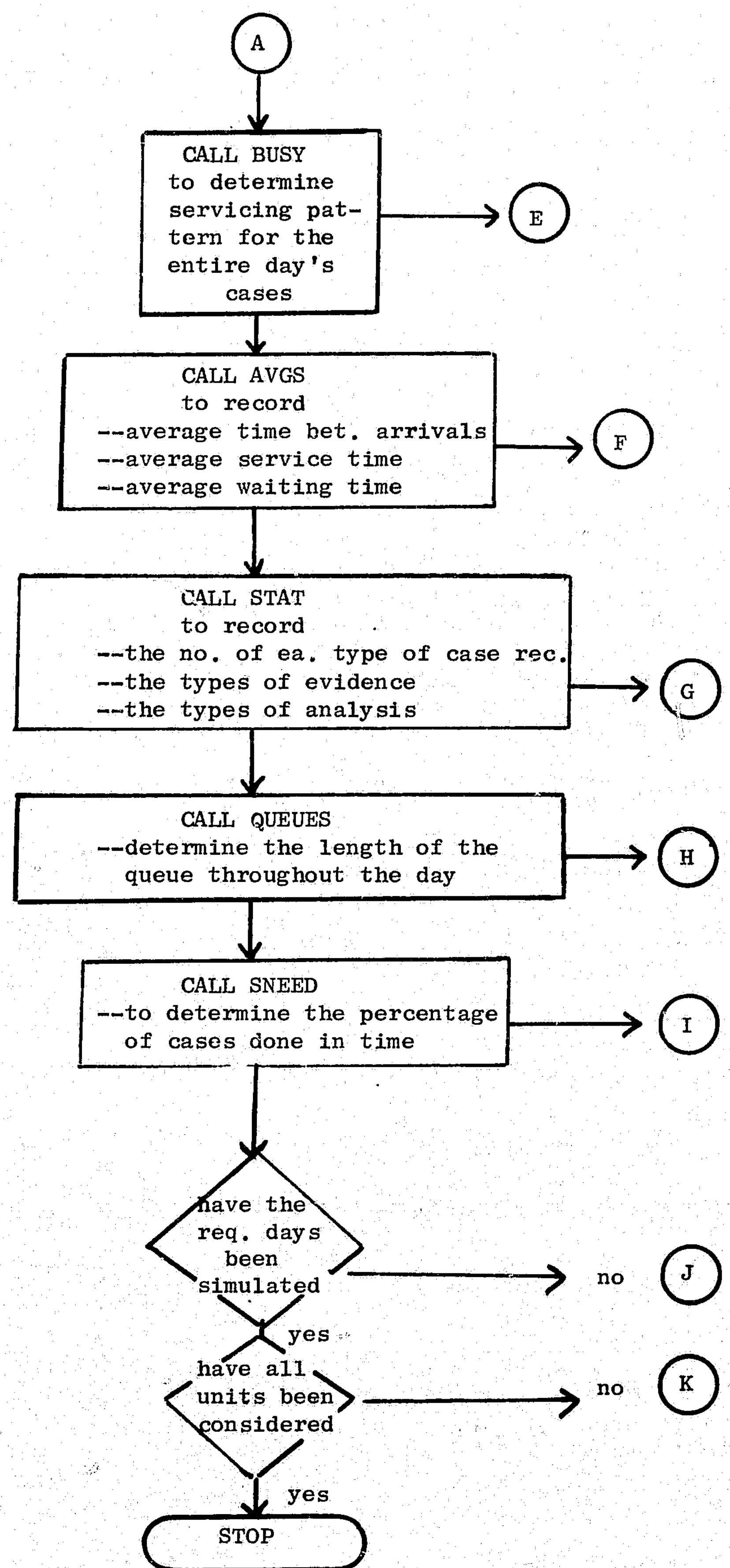
QUET..........is the actual length of the queue at various times

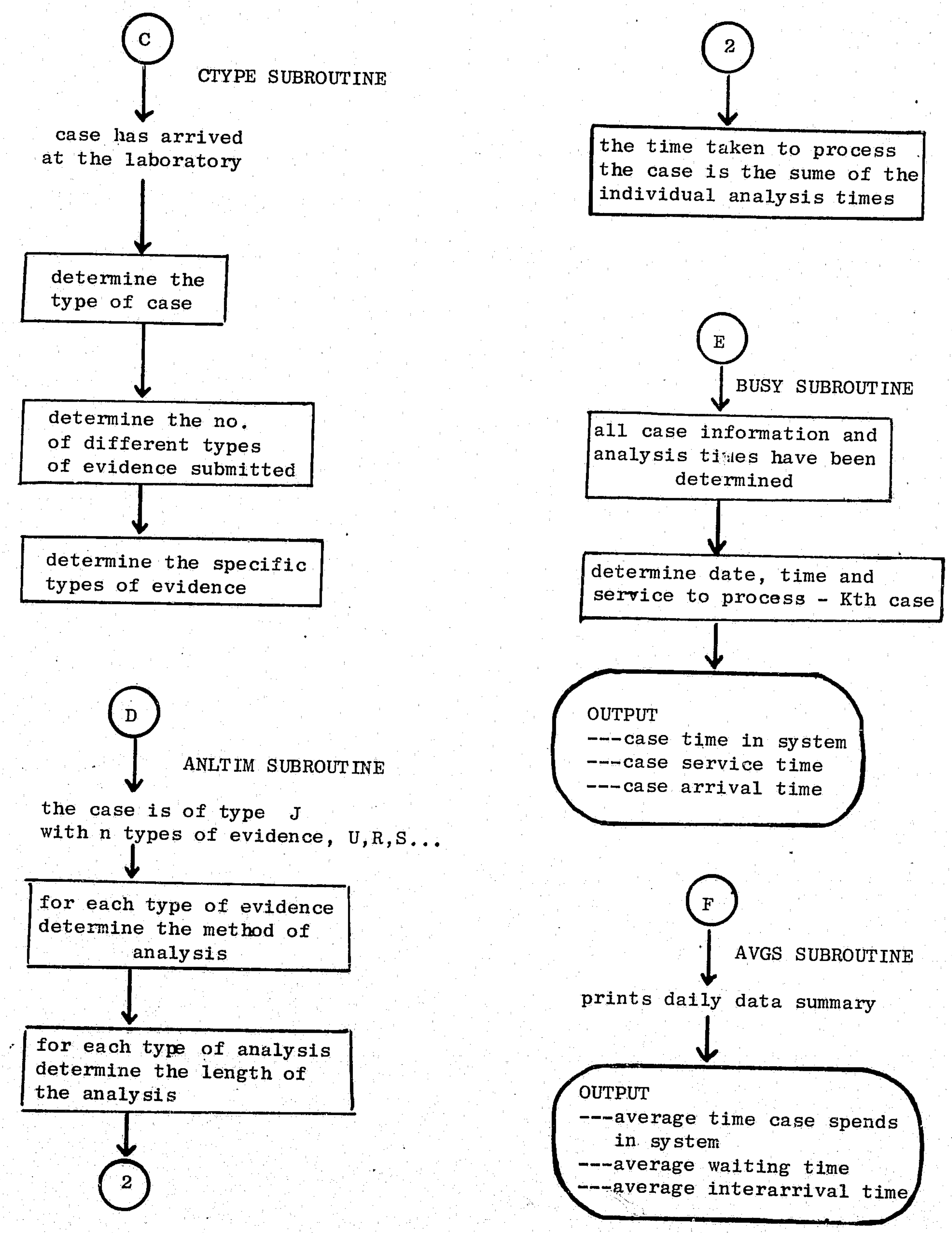
SIMPLIFIED SUPLAB PROGRAM

Flow Charts

The following is a simplified descriptive flow chart of the operation of the SUPLAB simulation program.

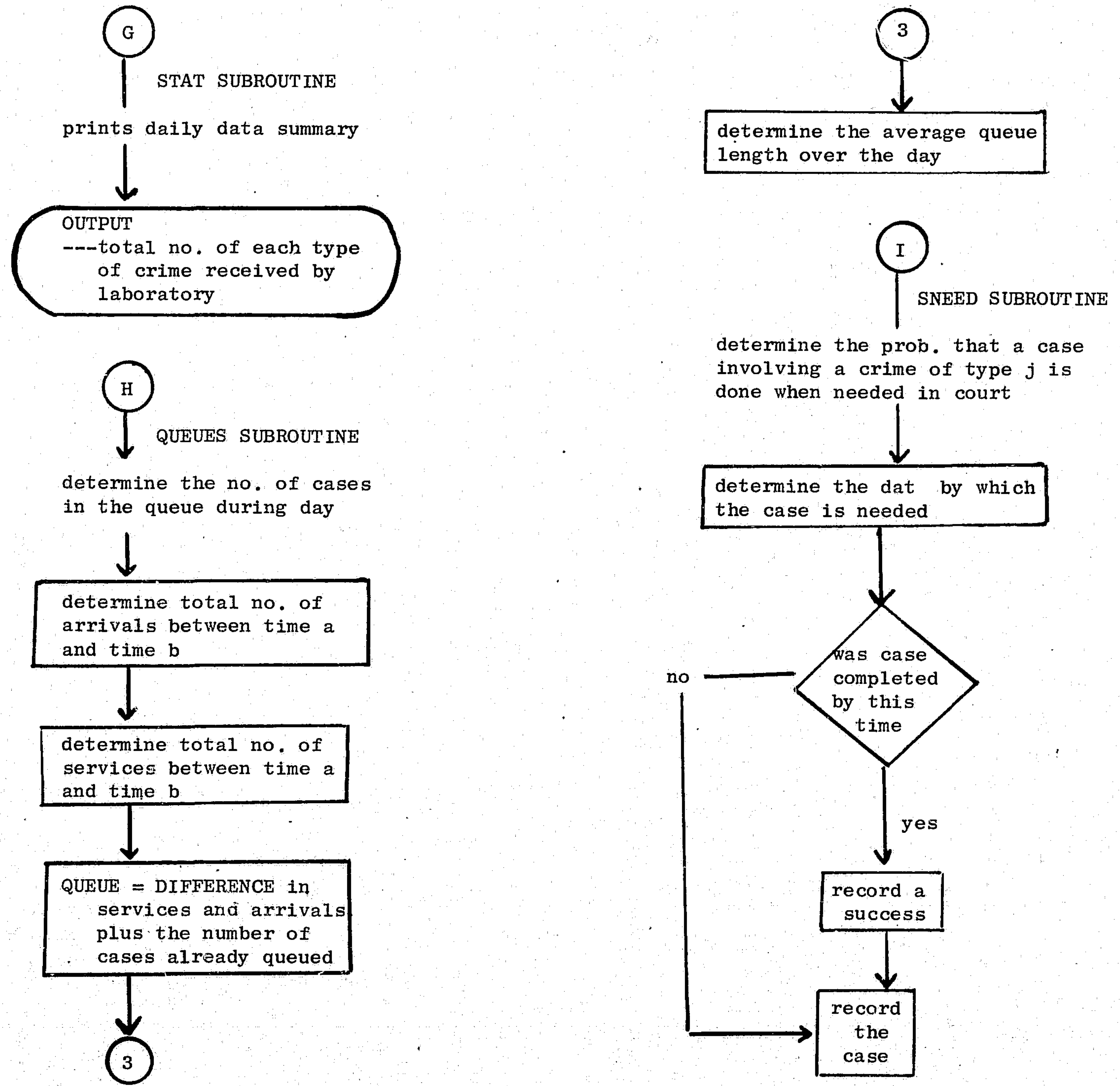



A
CALL BUSY
to determine
servicing pat-
tern for the
entire day's
cases
E
CALL AVGS
to record
--average time bet. arrivals
--average service time
--average waiting time
F
CALL STAT
to record
--the no. of ea. type of case rec.
--the types of evidence
--the types of analysis
G
CALL QUEUES
--determine the length of the
queue throughout the day
H
CALL SNEED
--to determine the percentage
of cases done in time
I
have the
req. days
been
simulated
no
J
yes
have all
units been
considered
no
K
yes
STOP


C
CTYPE SUBROUTINE
case has arrived
at the laboratory
determine the
type of case
determine the no.
of different types
of evidence submitted
determine the specific
types of evidence
D
ANLTIM SUBROUTINE
the case is of type J
with n types of evidence, U,R,S...
for each type of evidence
determine the method of
analysis
for each type of analysis
determine the length of
the analysis
2
2
the time taken to process
the case is the sume of the
individual analysis times
E
BUSY SUBROUTINE
all case information and
analysis times have been
determined
determine date, time and
service to process - Kth case
OUTPUT
---case time in system
---case service time
---case arrival time
F
AVGS SUBROUTINE
prints daily data summary
OUTPUT
---average time case spends
in system
---average waiting time
---average interarrival time

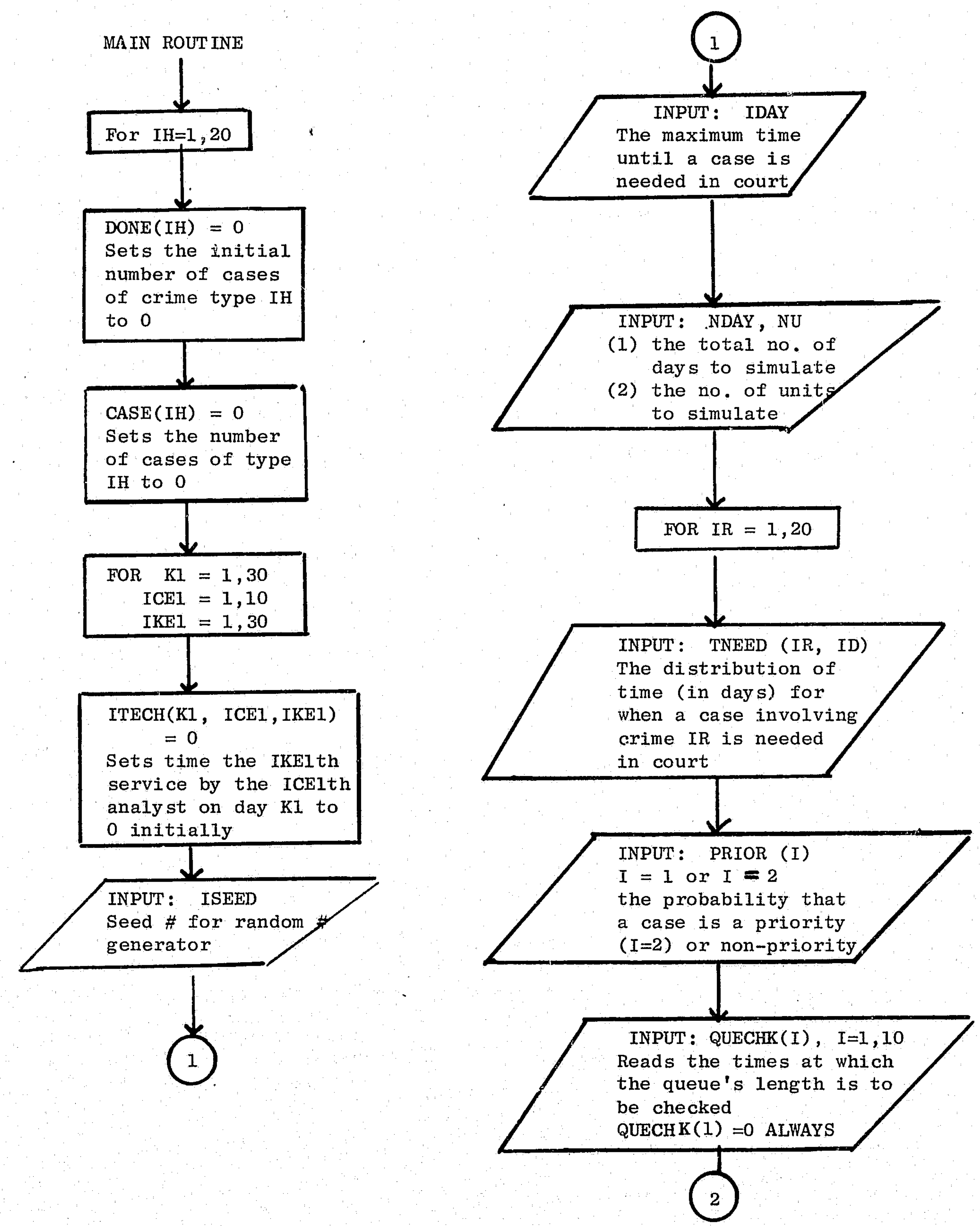
SIMPLIFIED

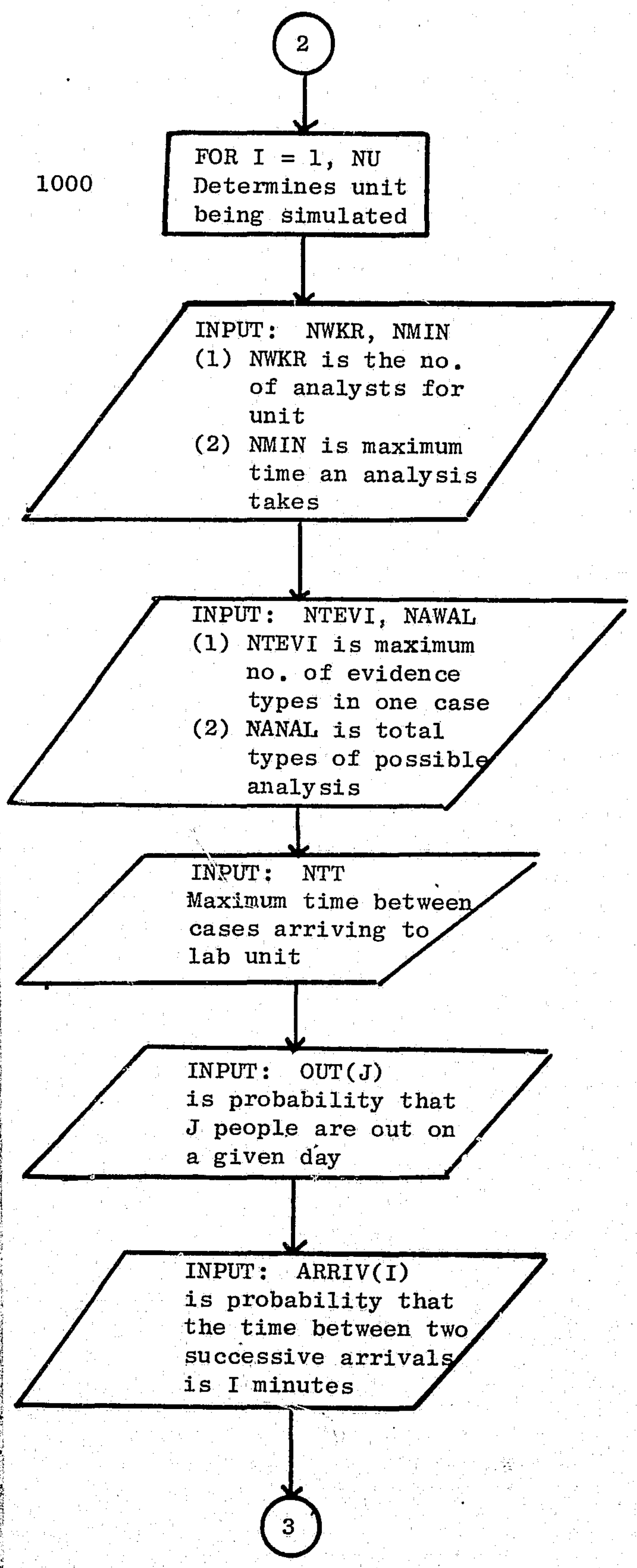
SUPLAB PROGRAM

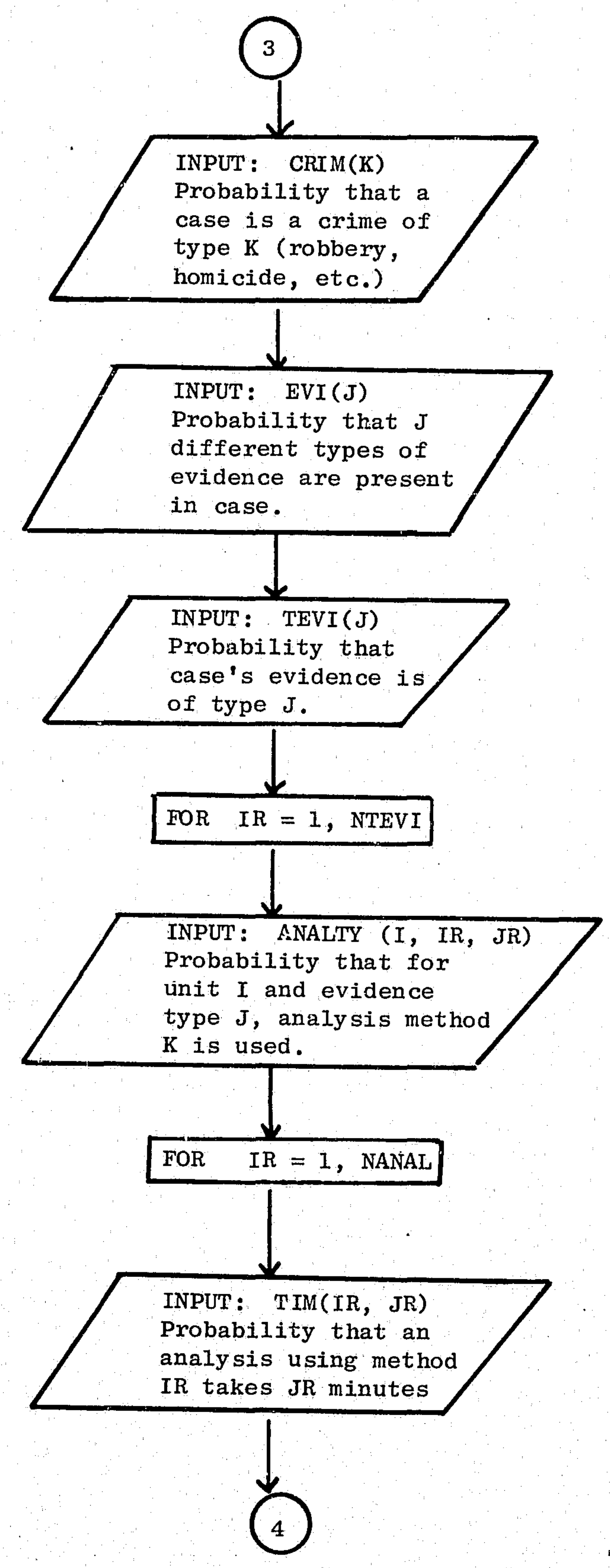


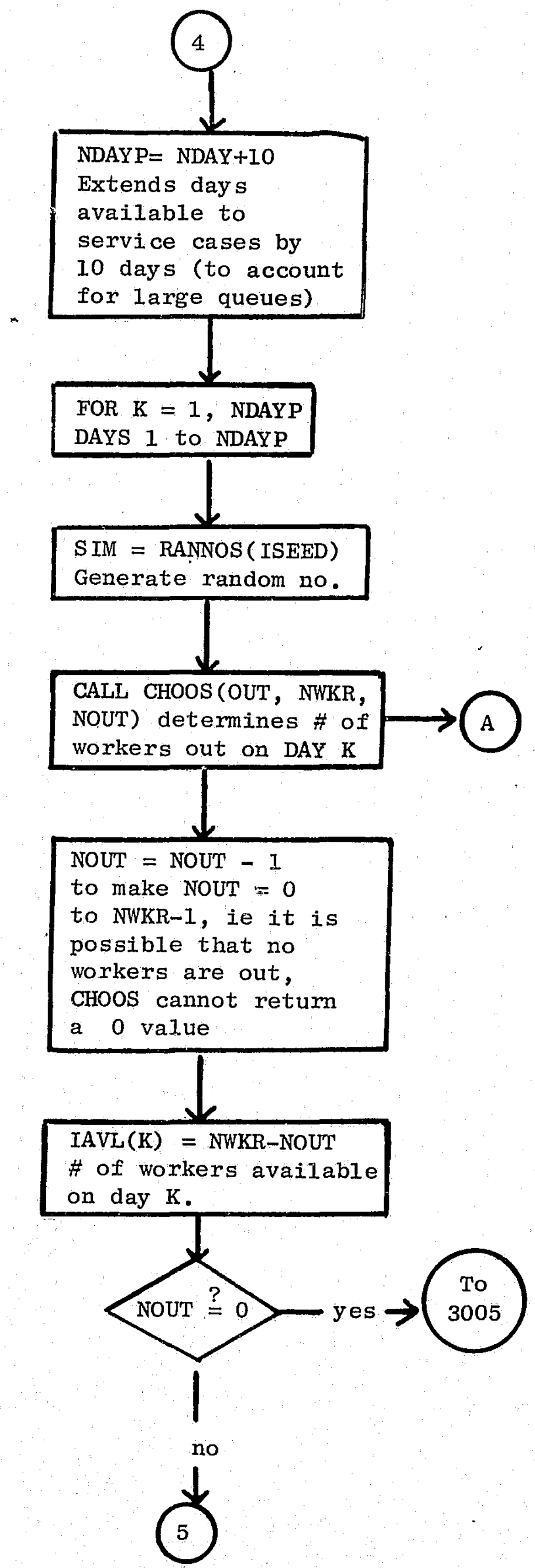
SUPLAB PROGRAM FLOWCHART

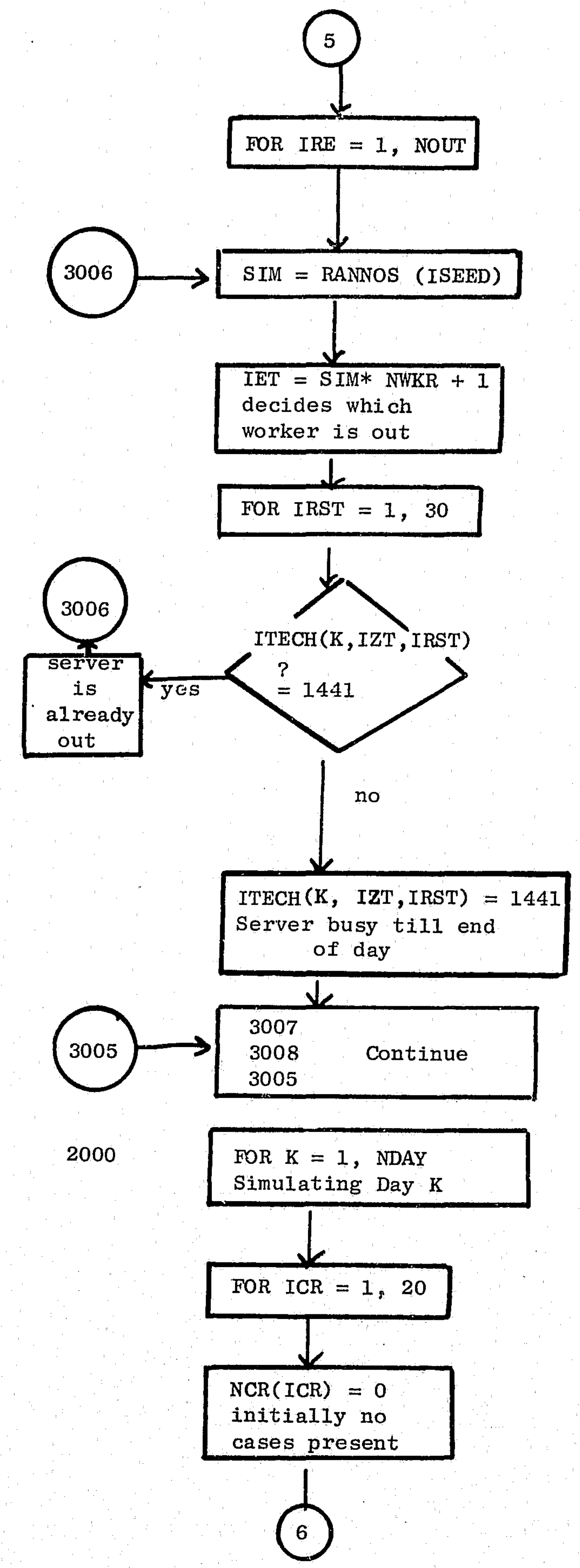
SUPLAB PROGRAM FLOWCHART

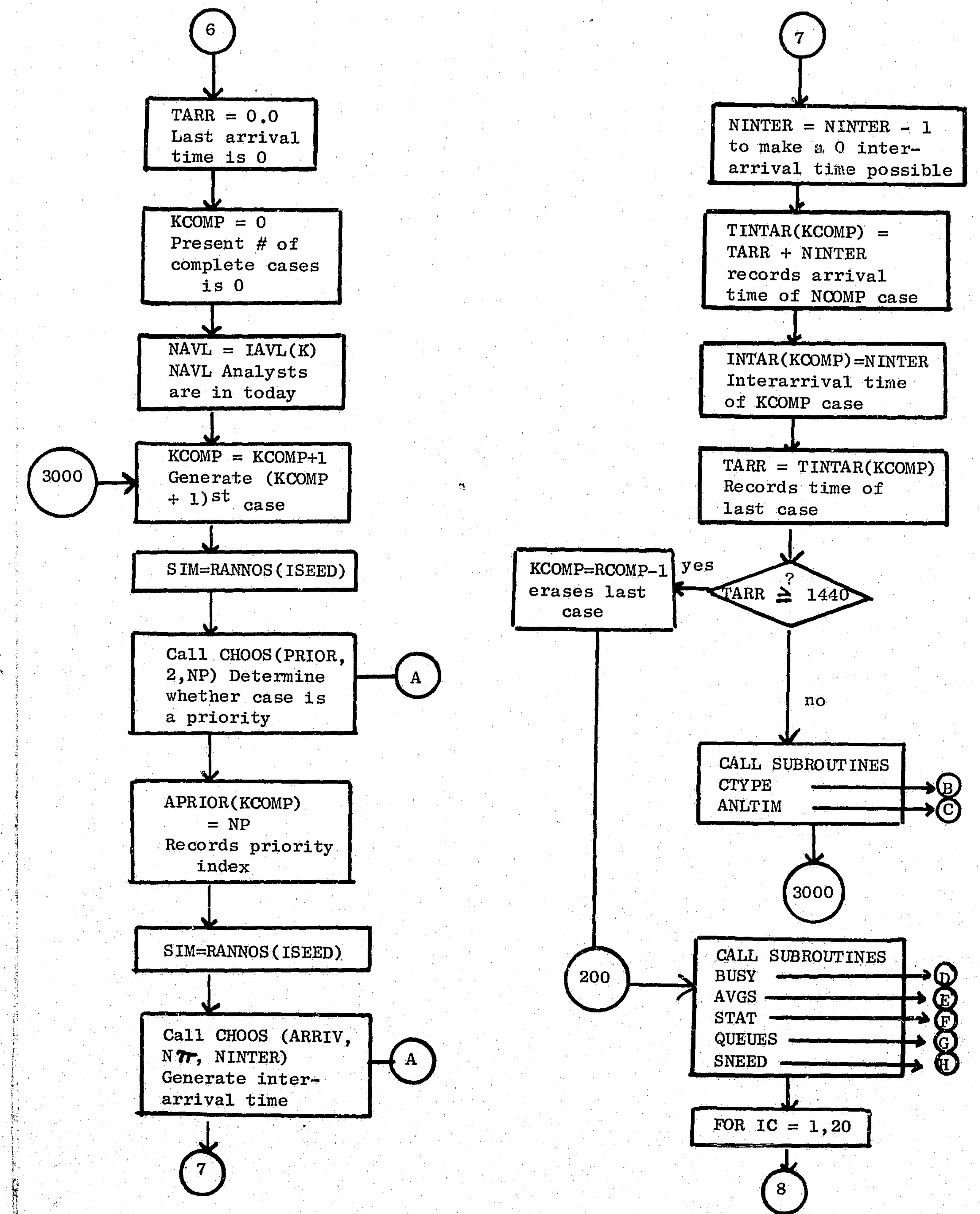


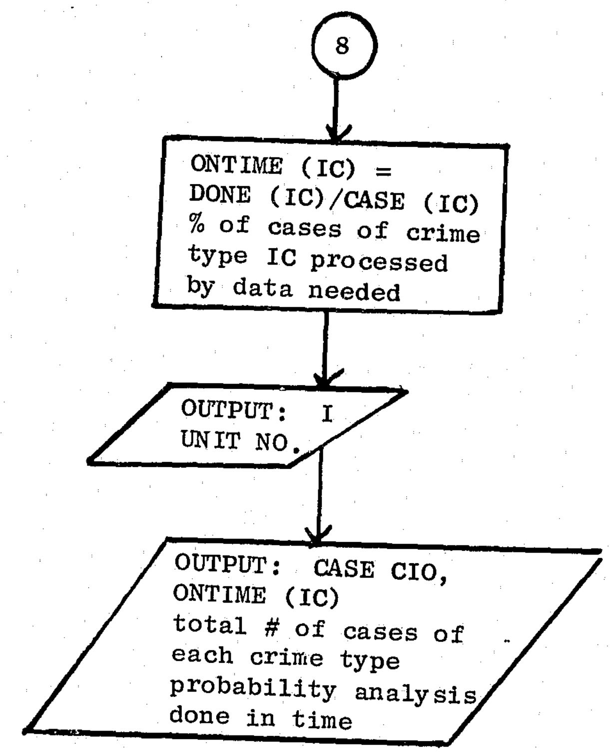

2
1000
FOR I = 1, NU
Determines unit
being simulated
INPUT: NWKR, NMIN
(1) NWKR is the no. of analysts for unit
(2) NMIN is maximum time an analysis takes
INPUT: NTEVI, NAWAL
(1) NTEVI is maximum no. of evidence types in one case
(2) NANAL is total types of possible analysis
INPUT: NTT
Maximum time between cases arriving to lab unit
INPUT: OUT(J)
is probability that J people are out on a given day
INPUT: ARRIV(I)
is probability that the time between two successive arrivals is I minutes
3

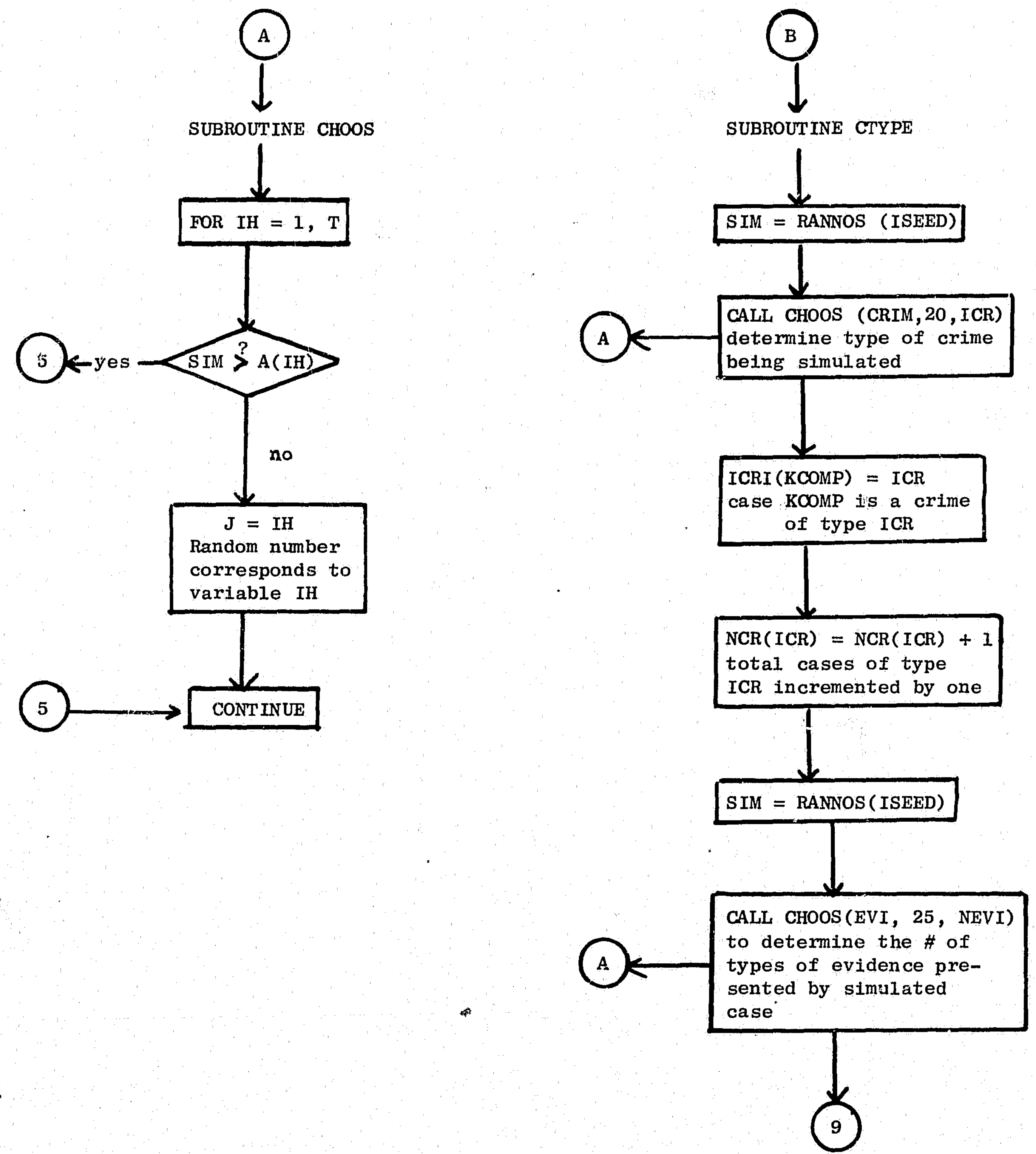

3
INPUT: CRIM(K)
Probability that a case is a crime of type K (robbery, homicide, etc.)
INPUT: EVI(J)
Probability that J different types of evidence are present in case.
INPUT: TEVI(J)
Probability that case's evidence is of type J.
FOR IR = 1, NTEVI
INPUT: ANALTY (I, IR, JR)
Probability that for unit I and evidence type J, analysis method K is used.
FOR IR = 1, NANAL
INPUT: TIM(IR, JR)
Probability that an analysis using method IR takes JR minutes
4

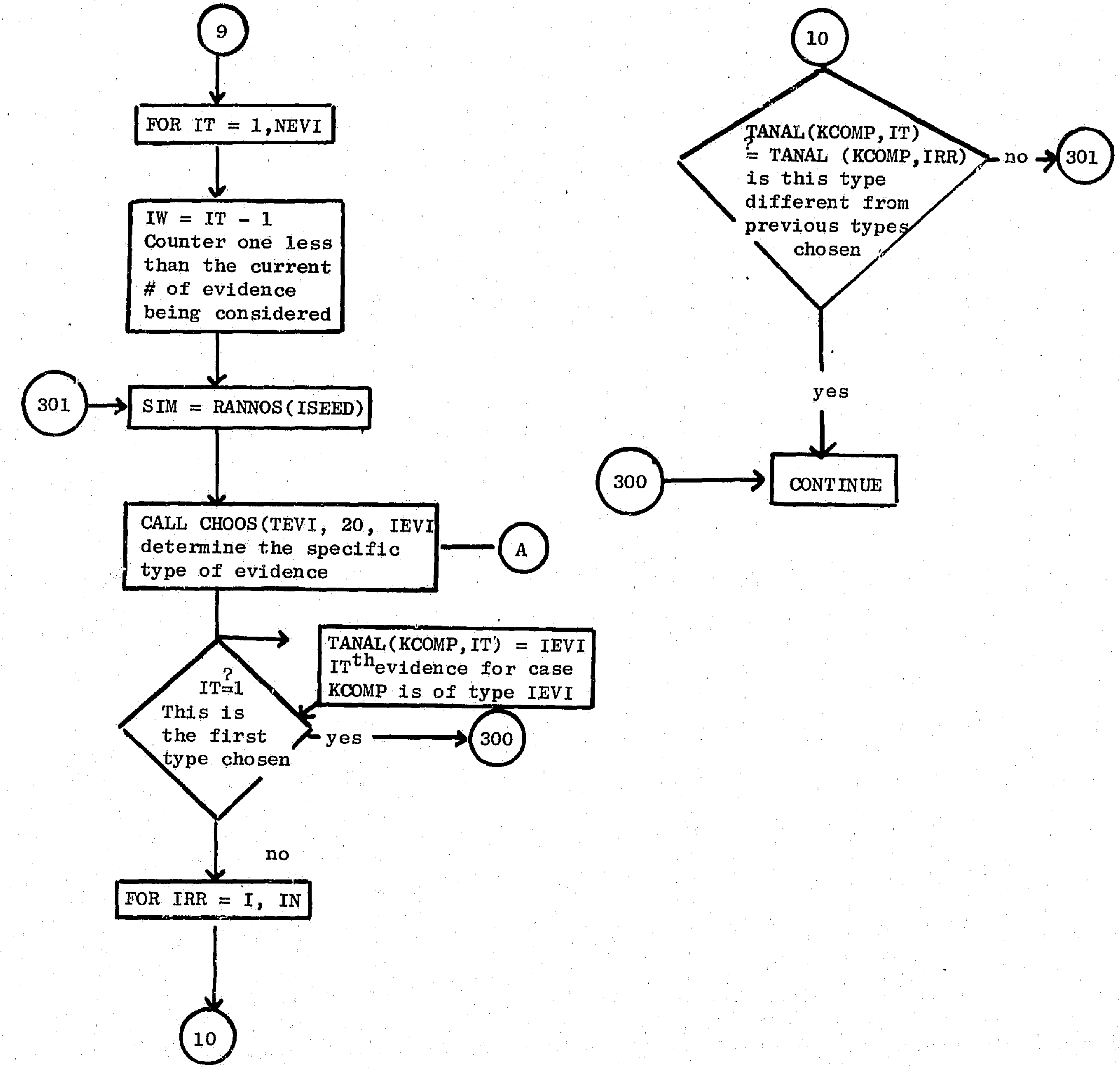

4
NDAYP= NDAY+10
Extends days available to service cases by 10 days (to account for large queues)
FOR K = 1, NDAYP
DAYS 1 to NDAYP
SIM = RANNOS(ISEED)
Generate random no.
CALL CHOOS(OUT, NWKR, NOUT) determines # of workers out on DAY K
A
NOUT = NOUT - 1
to make NOUT = 0 to NWKR-1, ie it is possible that no workers are out, CHOOS cannot return a 0 value
IAVL(K) = NWKR-NOUT
# of workers available on day K.
NOUT ? = 0
yes
To 3005
no
5

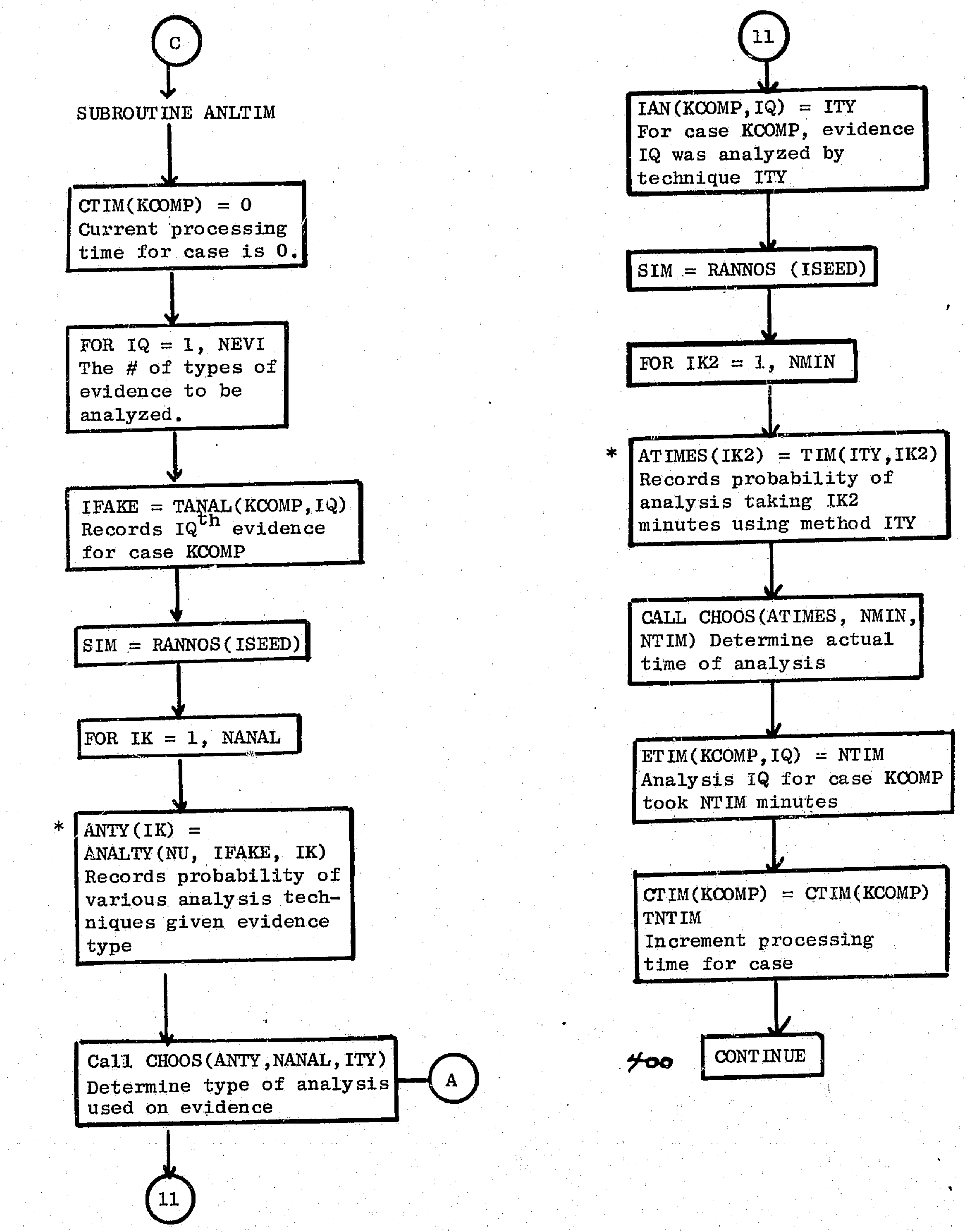

5
FOR IRE = 1, NOUT
3006
SIM = RANNOS (ISEED)
IET = SIM* NWKR + 1
decides which worker is out
FOR IRST = 1, 30
3006
server is already out
yes
ITECH(K,IZT,IRST) ? = 1441
no
ITECH(K, IZT,IRST) = 1441
Server busy till end of day
3005
3007
3008
3005
Continue
2000
FOR K = 1, NDAY
Simulating Day K
FOR ICR = 1, 20
NCR(ICR) = 0
initially no cases present
6


6
TARR = 0.0
Last arrival
time is 0
KCOMP = 0
Present # of
complete cases
is 0
NAVL = IAVL(K)
NAVL Analysts
are in today
3000
KCOMP = KCOMP+1
Generate (KCOMP
+ 1)st case
SIM=RANNOS(ISEED)
Call CHOOS(PRIOR,
2,NP) Determine
whether case is
a priority
A
APRIOR(KCOMP)
= NP
Records priority
index
SIM=RANNOS(ISEED)
Call CHOOS (ARRIV,
Nπ, NINTER)
Generate inter-
arrival time
A
7
7
NINTER = NINTER - 1
to make a 0 inter-
arrival time possible
TINTAR(KCOMP) =
TARR + NINTER
records arrival
time of NCOMP case
INTAR(KCOMP)=NINTER
Interarrival time
of KCOMP case
TARR = TINTAR(KCOMP)
Records time of
last case
?
TARR ≥ 1440
yes
KCOMP=RCOMP-1
erases last
case
no
CALL SUBROUTINES
CTYPE
ANLTIM
B
C
3000
200
CALL SUBROUTINES
BUSY
AVGS
STAT
QUEUES
SNEED
D
E
F
G
H
FOR IC = 1,20
8

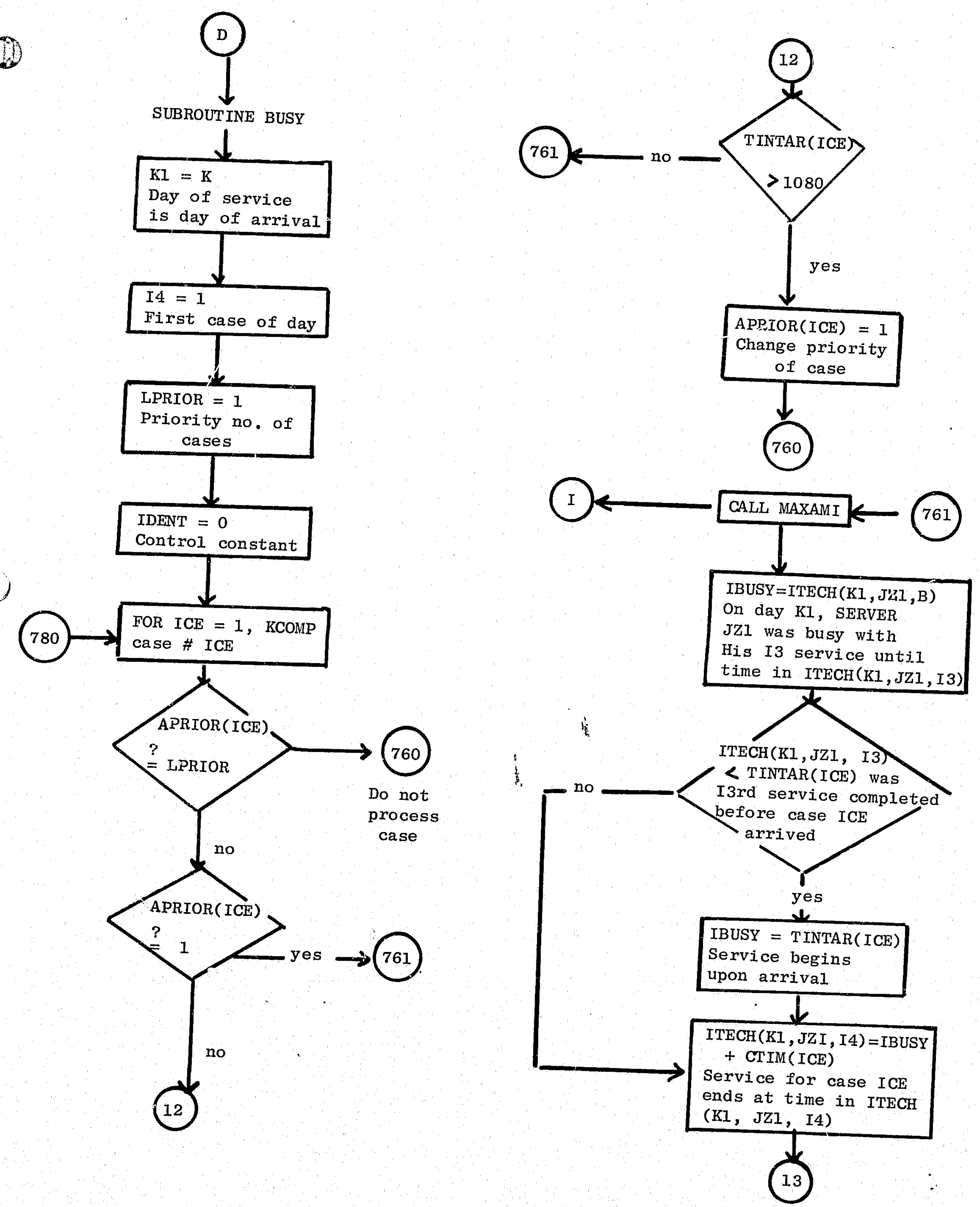

8
ONTIME (IC) =
DONE (IC)/CASE (IC)
% of cases of crime
type IC processed
by data needed
OUTPUT: I
UNIT NO.
OUTPUT: CASE CIO,
ONTIME (IC)
total # of cases of
each crime type
probability analysis
done in time

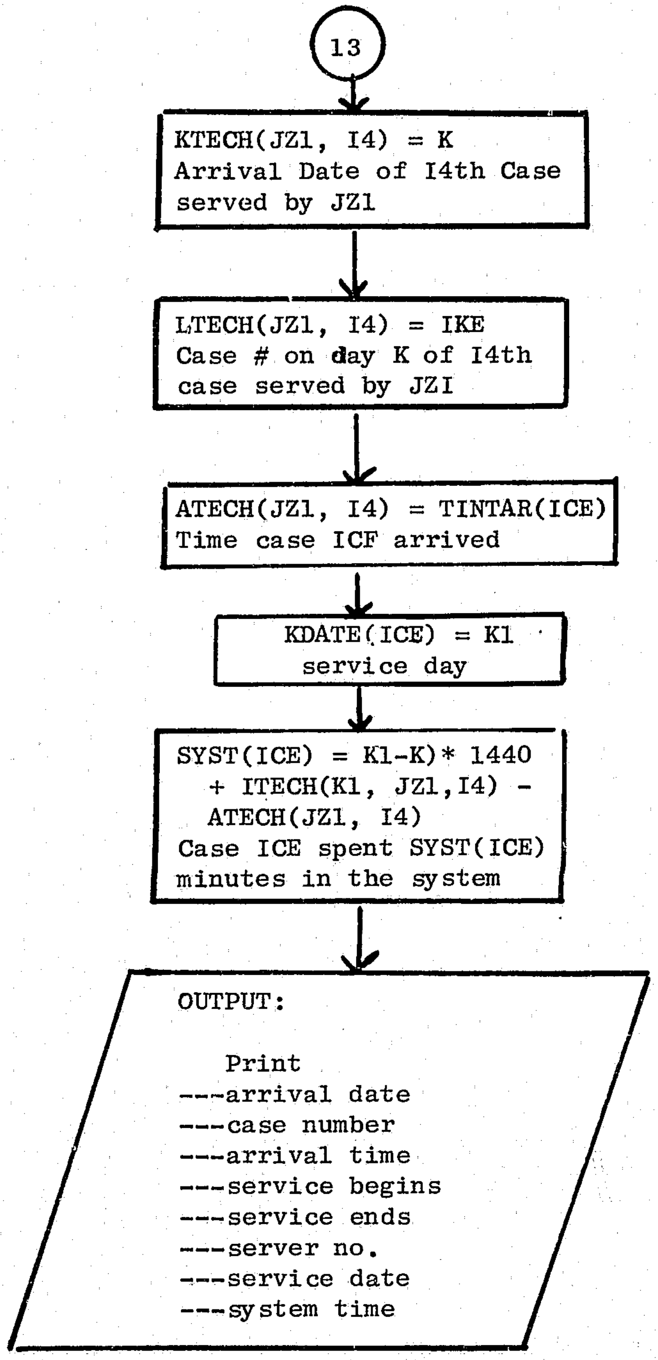

A
SUBROUTINE CHOOS
FOR IH = 1, T
SIM ? A(IH)
yes
5
no
J = IH
Random number corresponds to variable IH
5
CONTINUE
B
SUBROUTINE CTYPE
SIM = RANNOS (ISEED)
CALL CHOOS (CRIM,20,ICR)
determine type of crime being simulated
A
ICRI(KCOMP) = ICR
case KCOMP is a crime of type ICR
NCR(ICR) = NCR(ICR) + 1
total cases of type ICR incremented by one
SIM = RANNOS(ISEED)
CALL CHOOS(EVI, 25, NEVI)
to determine the # of types of evidence presented by simulated case
A
9

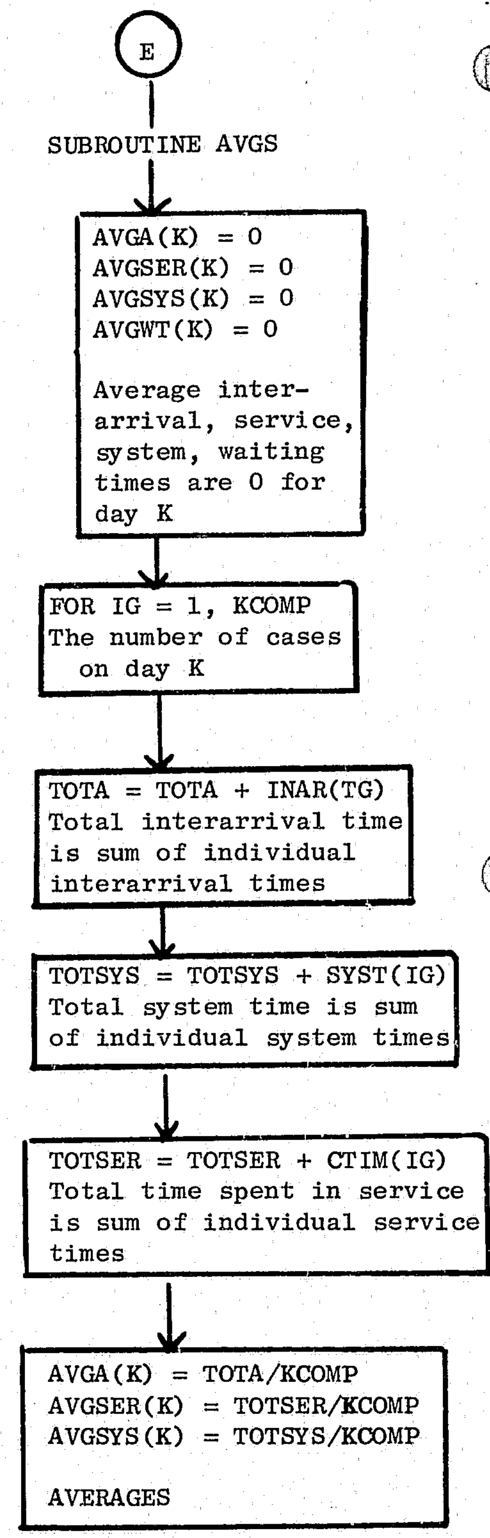

9
FOR IT = 1,NEVI
IW = IT - 1
Counter one less than the current # of evidence being considered
301
SIM = RANNOS(ISEED)
CALL CHOOS(TEVI, 20, IEVI
determine the specific type of evidence
A
TANAL(KCOMP,IT) = IEVI
IT^th evidence for case KCOMP is of type IEVI
IT ? 1
This is the first type chosen
yes
300
no
FOR IRR = I, IN
10
10
TANAL(KCOMP,IT)
? = TANAL (KCOMP,IRR)
is this type different from previous types chosen
no
301
yes
300
CONTINUE

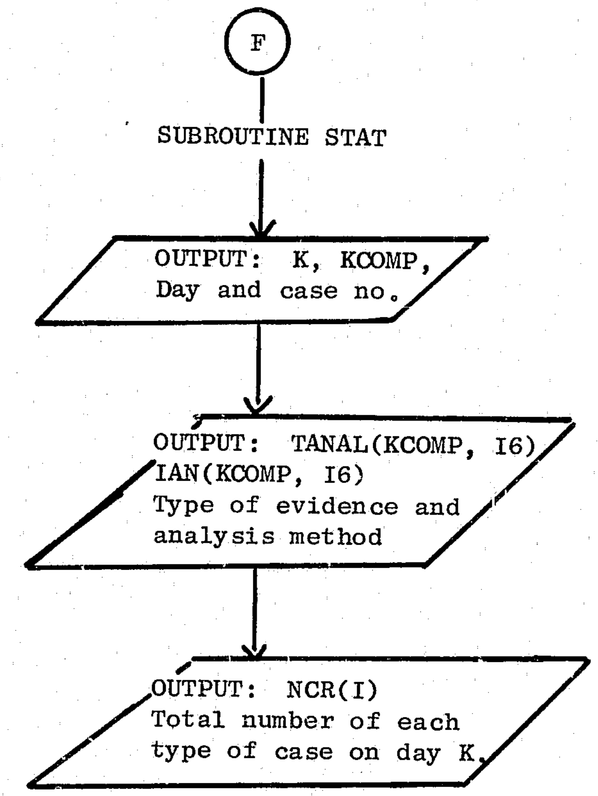


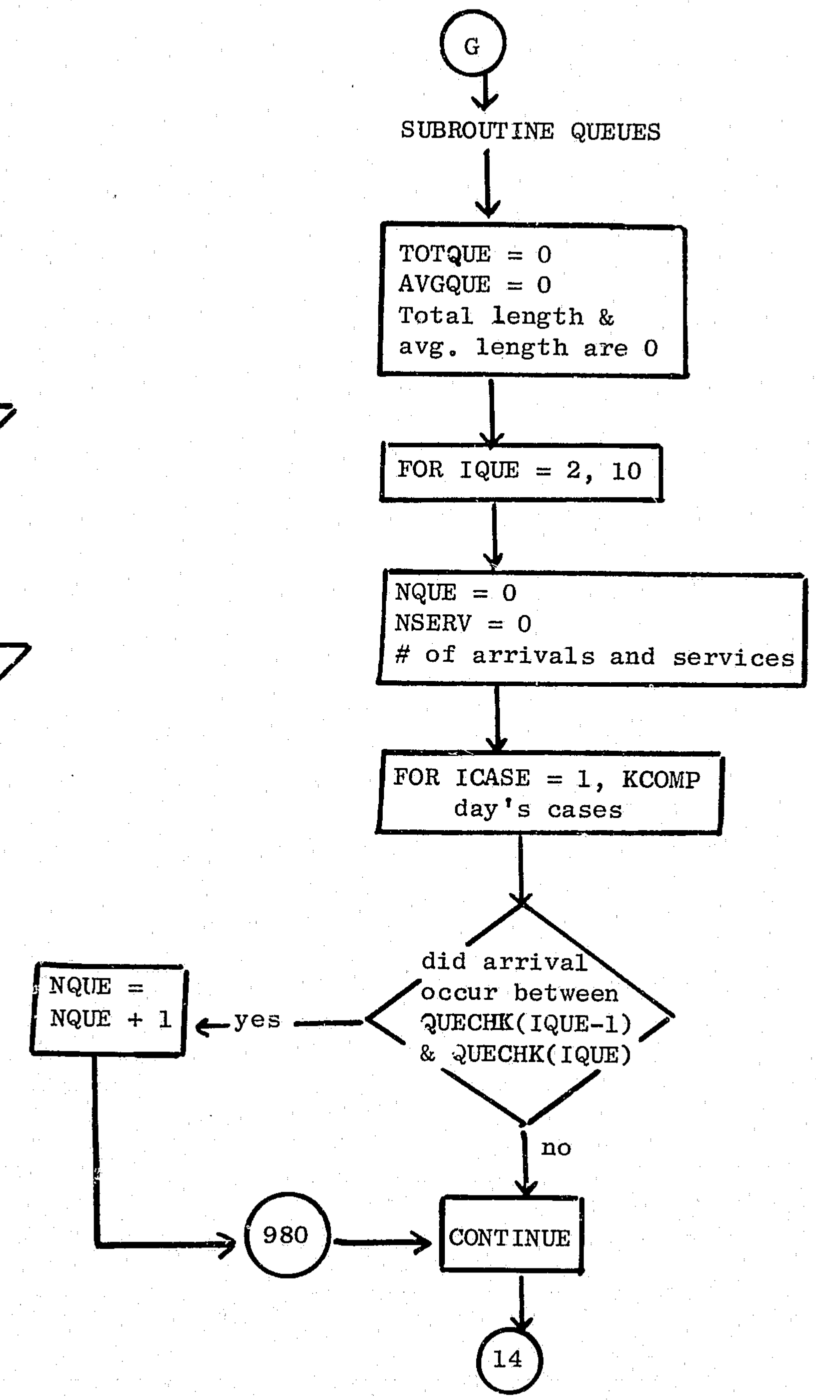
* Accesses correct row of right hand side matrix

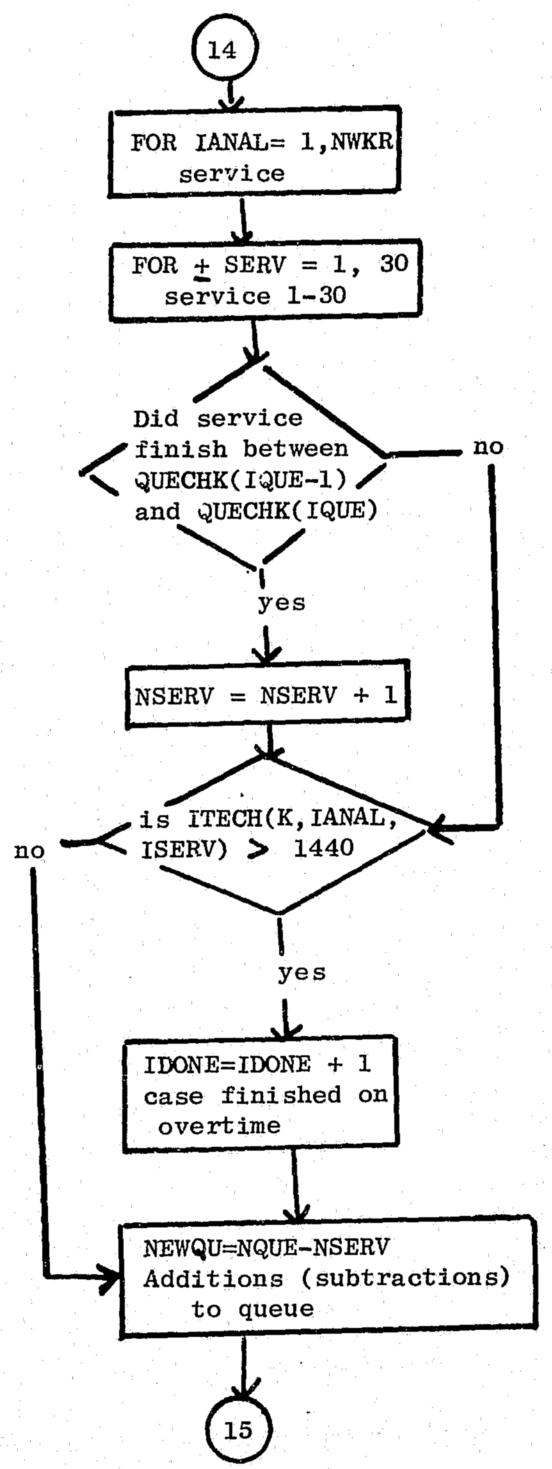


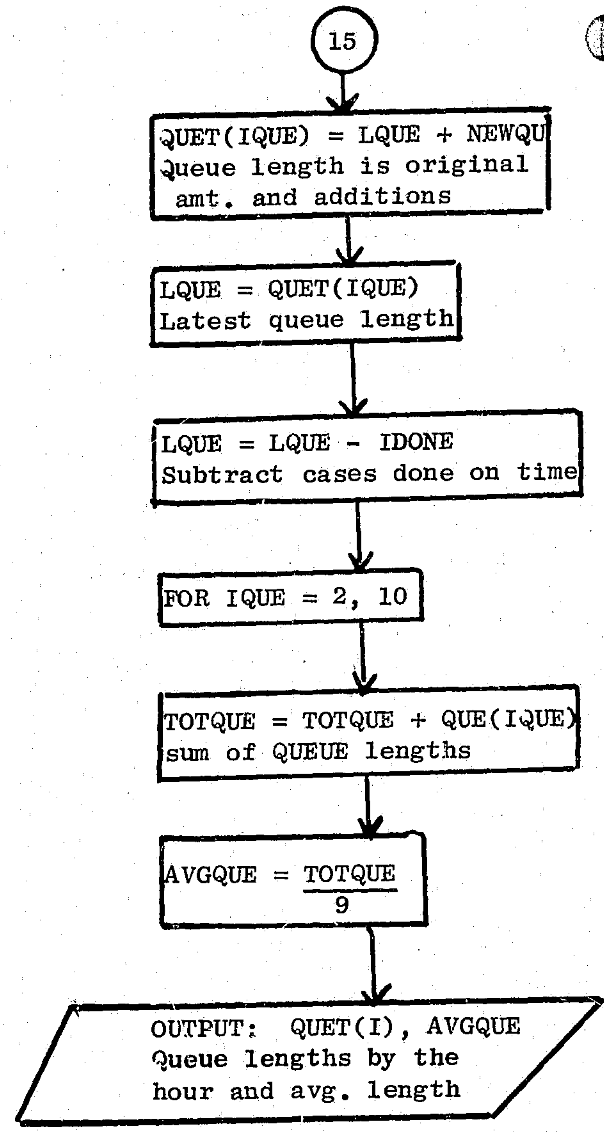

13
KTECH(JZ1, I4) = K
Arrival Date of I4th Case served by JZ1
LTECH(JZ1, I4) = IKE
Case # on day K of I4th case served by JZI
ATECH(JZ1, I4) = TINTAR(ICE)
Time case ICF arrived
KDATE(ICE) = K1
service day
SYST(ICE) = K1-K)* 1440 + ITECH(K1, JZ1,I4) - ATECH(JZ1, I4)
Case ICE spent SYST(ICE) minutes in the system
OUTPUT:
Print
---arrival date
---case number
---arrival time
---service begins
---service ends
---server no.
---service date
---system time

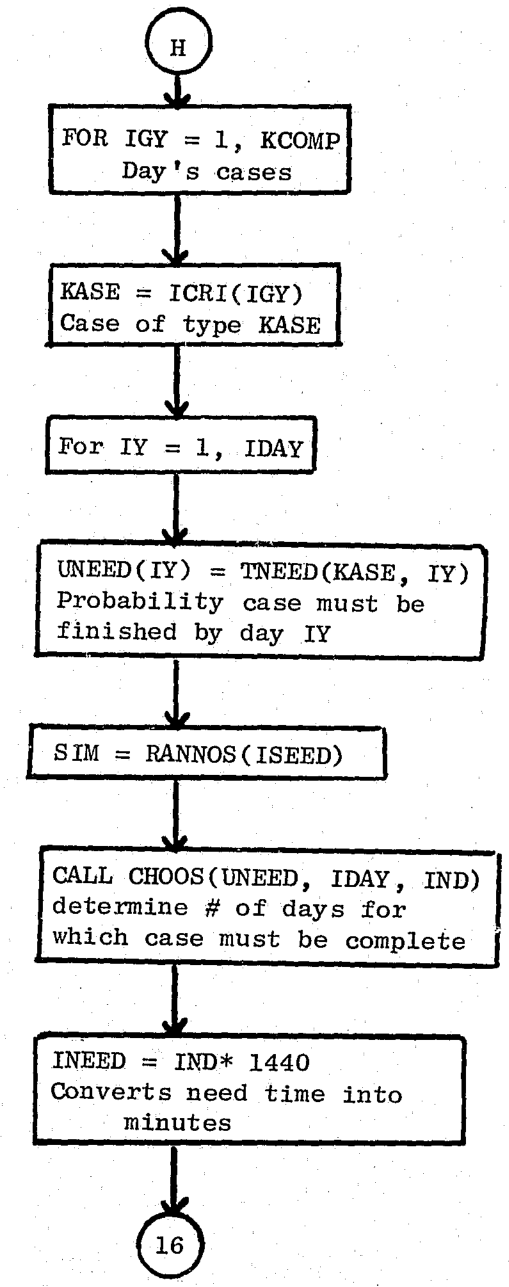

E
SUBROUTINE AVGS
AVGA(K) = 0
AVGSER(K) = 0
AVGSYS(K) = 0
AVGWT(K) = 0
Average inter-arrival, service, system, waiting times are 0 for day K
FOR IG = 1, KCOMP
The number of cases on day K
TOTA = TOTA + INAR(TG)
Total interarrival time is sum of individual interarrival times
TOTSYS = TOTSYS + SYST(IG)
Total system time is sum of individual system times
TOTSER = TOTSER + CTIM(IG)
Total time spent in service is sum of individual service times
AVGA(K) = TOTA/KCOMP
AVGSER(K) = TOTSER/KCOMP
AVGSYS(K) = TOTSYS/KCOMP
AVERAGES

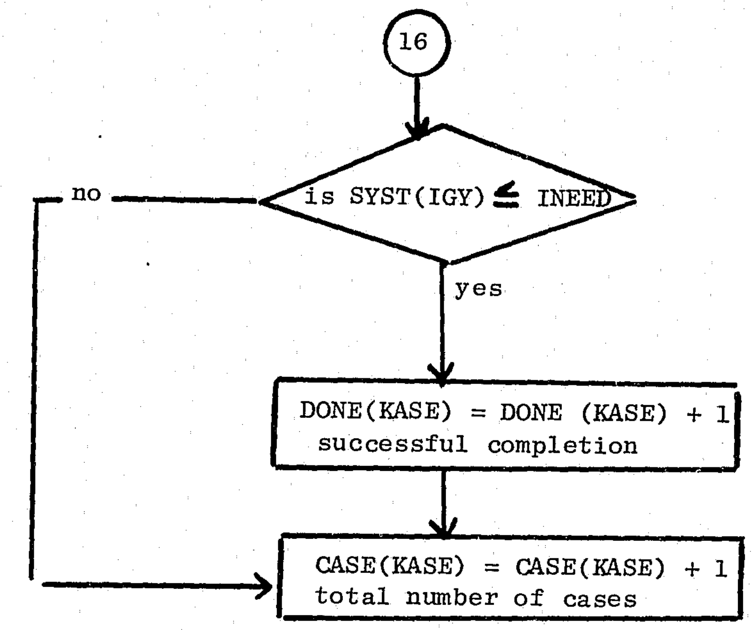

F
SUBROUTINE STAT
OUTPUT: K, KCOMP,
Day and case no.
OUTPUT: TANAL(KCOMP, I6)
IAN(KCOMP, I6)
Type of evidence and analysis method
OUTPUT: NCR(I)
Total number of each type of case on day K

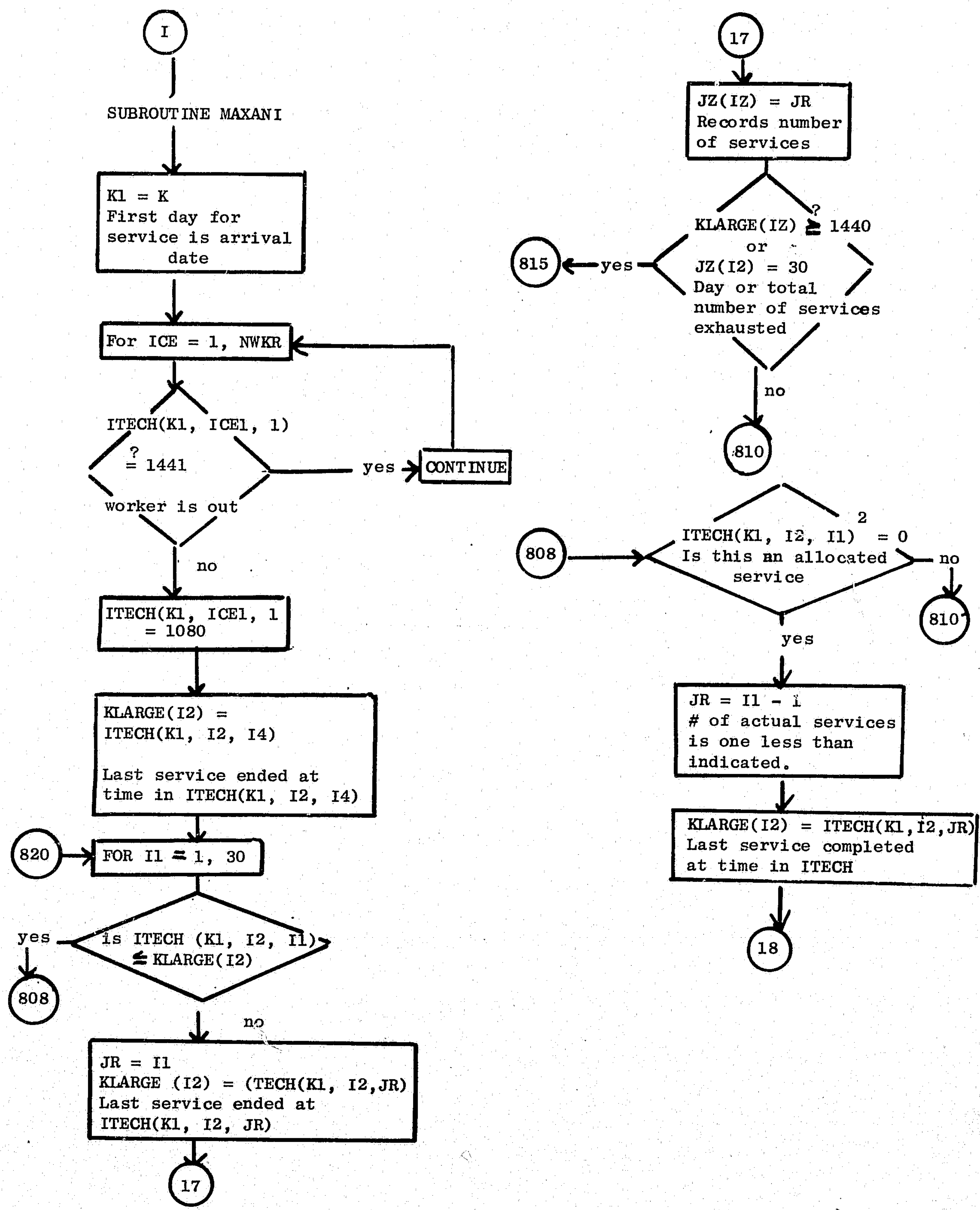

G
SUBROUTINE QUEUES
TOTQUE = 0
AVGQUE = 0
Total length & avg. length are 0
FOR IQUE = 2, 10
NQUE = 0
NSERV = 0
# of arrivals and services
FOR ICASE = 1, KCOMP
day's cases
did arrival occur between QUECHK(IQUE-1) & QUECHK(IQUE)
yes
NQUE = NQUE + 1
no
980
CONTINUE
14

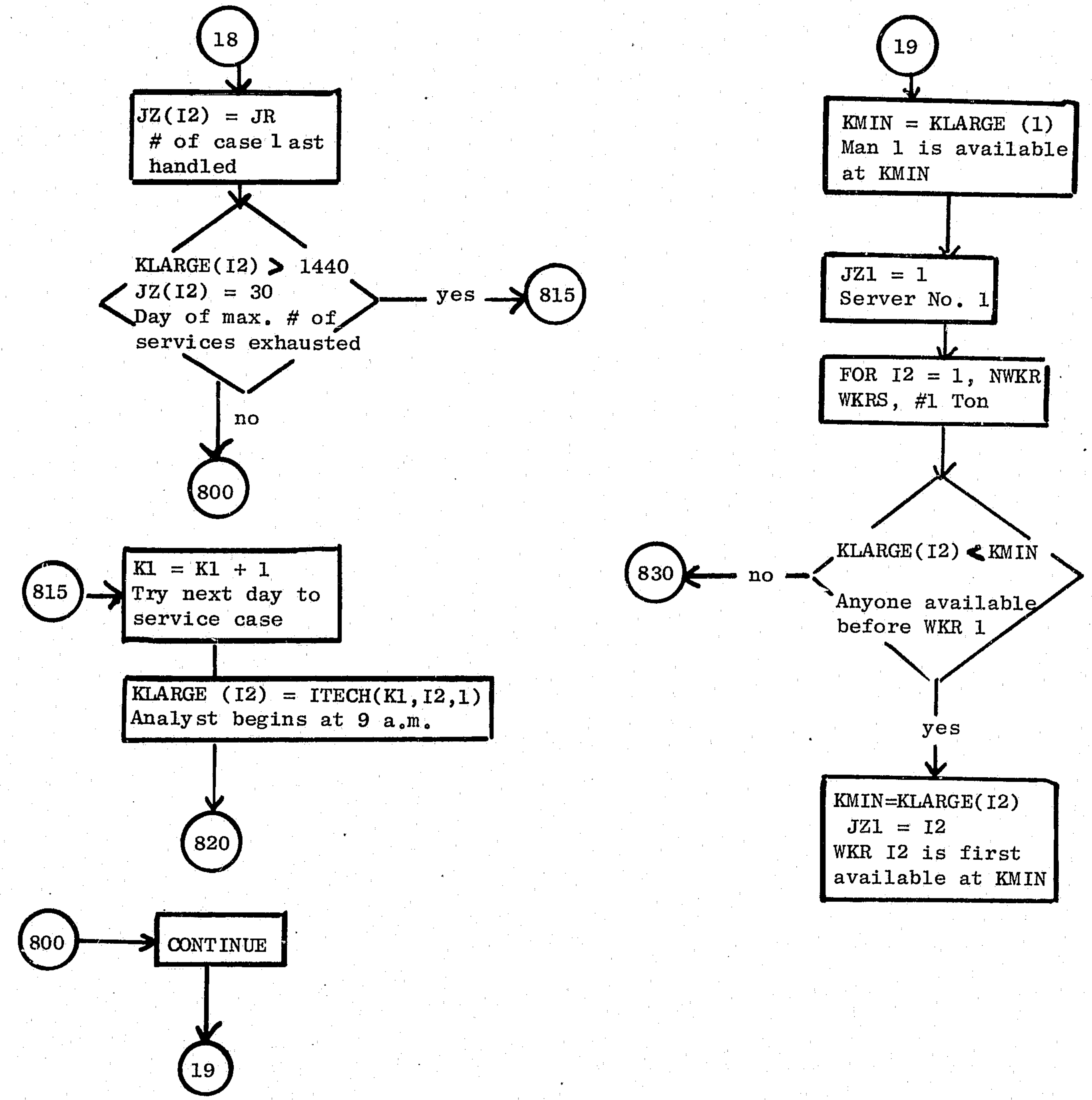

14
FOR IANAL= 1,NWKR
service
FOR ± SERV = 1, 30
service 1-30
Did service finish between QUECHK(IQUE-1) and QUECHK(IQUE)
no
yes
NSERV = NSERV + 1
is ITECH(K,IANAL, ISERV) > 1440
no
yes
IDONE=IDONE + 1
case finished on overtime
NEWQU=NQUE-NSERV
Additions (subtractions) to queue
15


15
QUET(IQUE) = LQUE + NEWQU
Queue length is original amt. and additions
LQUE = QUET(IQUE)
Latest queue length
LQUE = LQUE - IDONE
Subtract cases done on time
FOR IQUE = 2, 10
TOTQUE = TOTQUE + QUE(IQUE)
sum of QUEUE lengths
AVGQUE = TOTQUE / 9
OUTPUT: QUET(I), AVGQUE
Queue lengths by the hour and avg. length


H
FOR IGY = 1, KCOMP
Day's cases
KASE = ICRI(IGY)
Case of type KASE
For IY = 1, IDAY
UNEED(IY) = TNEED(KASE, IY)
Probability case must be finished by day IY
SIM = RANNOS(ISEED)
CALL CHOOS(UNEED, IDAY, IND)
determine # of days for which case must be complete
INEED = IND* 1440
Converts need time into minutes
16


16
is SYST(IGY) ≤ INEED
no
yes
DONE(KASE) = DONE (KASE) + 1
successful completion
CASE(KASE) = CASE(KASE) + 1
total number of cases


I
SUBROUTINE MAXANI
K1 = K
First day for service is arrival date
For ICE = 1, NWKR
ITECH(K1, ICE1, 1)
? = 1441
worker is out
yes
CONTINUE
no
ITECH(K1, ICE1, 1 = 1080
KLARGE(I2) = ITECH(K1, I2, I4)
Last service ended at time in ITECH(K1, I2, I4)
820
FOR I1 = 1, 30
yes
Is ITECH (K1, I2, I1) ≤ KLARGE(I2)
808
no
JR = I1
KLARGE (I2) = (TECH(K1, I2,JR)
Last service ended at ITECH(K1, I2, JR)
17
17
JZ(IZ) = JR
Records number of services
815
yes
KLARGE(IZ) ≧ 1440
or
JZ(I2) = 30
Day or total number of services exhausted
no
810
808
ITECH(K1, I2, I1) = 0
Is this an allocated service
no
810
yes
JR = I1 - 1
# of actual services is one less than indicated.
KLARGE(I2) = ITECH(K1,I2,JR)
Last service completed at time in ITECH
18


18
JZ(I2) = JR
# of case last handled
KLARGE(I2) > 1440
JZ(I2) = 30
Day of max. # of services exhausted
yes
815
no
800
815
K1 = K1 + 1
Try next day to service case
KLARGE (I2) = ITECH(K1,I2,1)
Analyst begins at 9 a.m.
820
800
CONTINUE
19
19
KMIN = KLARGE (1)
Man 1 is available at KMIN
JZ1 = 1
Server No. 1
FOR I2 = 1, NWKR
WKRS, #1 Ton
830
no
KLARGE(I2) < KMIN
Anyone available before WKR 1
yes
KMIN=KLARGE(I2)
JZ1 = I2
WKR I2 is first available at KMIN

SUPLAB PROGRAM AND TYPICAL PRINTOUT


```
/PROGRAM SUPLAB
      DIMENSION ICR1(500)
      DIMENSION OUT(25), ARRIV(120 )
      COMMON / ONE/ SIM, KCOMP
      COMMON /TWO/ TANAL(50,20),NCR(20), NEVI
      COMMON /THREE/ CTIM(400), K
      COMMON /FOUR/ NU
      COMMON /SIC/ CRIM(20), EVI(25) , TEVI(20)
      COMMON /SEVEN/ ANALTY(10,20,10) , TIM(20,25)
      COMMON /EIGHT/ NMIN      , NANAL
      COMMON/ELEVEN/ AVGA(30), AVGSYS(30), AVGSER(30), AVGWT(30)
      COMMON /THIRTE   / QUECHK(10)
      COMMON /RRR/ INTAR(50)
      COMMON /SSS/ IAVL(50)
      COMMON /TTT/ NWKR  , LQUE
      COMMON / UUU/ TINTAR (100), SYST(50)
      COMMON /VVV/ PRIOR(2), APRIOR(50)
      COMMON /WWW/ NAVL , JZ1
      COMMON /ZZZ/ ITECH(30,10,30)
      LQUE = 0
      DO 764 K1 = 1,30
      DO 765 ICE1= 1,10
      DO 766 IKE1 =1,30
      ITECH(K1,ICE1,IKE1) = 0
  766 CONTINUE
  765 CONTINUE
  764 CONTINUE
      READ 2010, NDAY, NU
      READ 2010, NWKR  , NMIN
      READ 2010, NTEVI ,NANAL
      READ 2011 , NTT
      READ 2020, ( PRIOR(J) , J = 1,2)
 2011 FORMAT (I10)
 2010 FORMAT ( 2I10   )
      READ 2025 , ( QUECHK(J) , J = 1, 10 )
 2025 FORMAT ( 10F7.1)
      DO 1000 I = 1, NU
      READ 2020, ( OUT(J), J = 1,25)
 2020 FORMAT ( 15F4.2)
      READ 2020, ( ARRIV(J), J =1,120 )
      READ 2020, ( CRIM(J) , J = 1,20)
      READ 2020, ( EVI(J), J = 1,25 )
      READ 2020, (TEVI(J), J = 1,20 )
      DO 800 IR = 1, NTEVI
      READ 2020, ( ANALTY(NU,IR,JR) , JR= 1,NANAL)
  800 CONTINUE
      DO 810 IR= 1, NANAL
      READ 2020, (TIM(IR, JR) , JR= 1,NMIN)
  810 CONTINUE
      IQUE = 0
      NDAYP = NDAY + 10
      DO 3005 K = 1, NDAYP
      SIM = RANNOS(69141943  )
      CALL CHOOS( OUT, NWKR, NOUT )
      NOUT = NOUT -1
      IAVL(K) = NWKR- NOUT
      IF(NOUT .EQ. 0 ) GO TO 3005
      DO 3008 IRE = 1, NOUT
      SIM = RANNOS(69141943)
      IZT = SIM*NWKR + 1
      DO 3007 IRST = 1,30
      ITECH(K, IZT, IRST) = 1440
 3007 CONTINUE

 3008 CONTINUE
 3005 CONTINUE
      DO 2000 K = 1, NDAY
      DO 120 ICR = 1,20
  120 NCR(ICR) = 0
      TARR= 0.0
      KCOMP = 0
      NAVL = IAVL(K)
 3000 KCOMP  = KCOMP  +1
      SIM = RANNOS(69141943)
      CALL CHOOS(PRIOR,2,NP)
      APRIOR(KCOMP) = NP
      SIM = RANNOS(69141943)
      CALL CHOOS(ARRIV,NTT,NINTER)
      NINTER = NINTER -1
      TINTAR( KCOMP) = TARR + NINTER
      INTAR(KCOMP) = NINTER
      TARR= TINTAR(KCOMP )
      IF ( TARR- 1440.0 ) 1,2,2
    2 KCOMP  = KCOMP  -1
      GO TO 2001
    1 CONTINUE
      CALL CTYPE
      CALL ANLTIM
      GO TO 3000
 2001 CALL BUSY
      CALL AVGS
      CALL STAT
      CALL QUEUES
 2000 CONTINUE
 1000 CONTINUE
      STOP
      END

      SUBROUTINE CHOOS(A,I,J)
      DIMENSION A(I)
      COMMON / ONE/ SIM, KCOMP
      DO 12  IH =1,I
      IF( SIM - A(IH) ) 4,4,5
    4 J = IH
      GO TO 13
    5 CONTINUE
   12 CONTINUE
   13 CONTINUE
      RETURN
      END

      SUBROUTINE CTYPE
      COMMON / ONE/ SIM, KCOMP
      COMMON /TWO/ TANAL(50,20),NCR(20), NEVI
      COMMON /FOUR/ NU
      COMMON /SIC/ CRIM(20), EVI(25) , TEVI(20)
      COMMON /TEN/ ICR1(50), IAN(50,20), ICR2(50)
      SIM = RANNOS(69141943)
      CALL CHOOS ( CRIM,20, ICR)
      ICR1(KCOMP) = ICR
      NCR(ICR) = NCR(ICR) + 1
      SIM = RANNOS(69141943)
      CALL CHOOS(EVI,25, NEVI)
      ICR2(KCOMP) = NEVI
      DO 300 IT = 1, NEVI
```

```
      IW = IT -1
  301 SIM = RANNOS(69141943)
      CALL CHOOS(TEVI,20, IEVI)
      TANAL(KCOMP,IT) = IEVI
      IF(IT .EQ. 1 ) GO TO 300
      DO 302 IRR = 1, IW
      IF(TANAL(KCOMP,IT) .EQ. TANAL(KCOMP,IRR)) GO TO 301
  302 CONTINUE
  300 CONTINUE
      RETURN
      END

      SUBROUTINE ANLTIM
      DIMENSION                         ETIM(400,20)
      DIMENSION ATIMES (25)
      DIMENSION ANTY (25)
      COMMON / ONE/ SIM, KCOMP
      COMMON /TWO/ TANAL(50,20),NCR(20), NEVI
      COMMON /THREE/ CTIM(400), K
      COMMON /FOUR/ NU
      COMMON /SEVEN/ ANALTY(10,20,10) , TIM(20,25)
      COMMON /EIGHT/ NMIN       , NANAL
      COMMON /TEN/ ICR1(50), IAN(50,20), ICR2(50)
      CTIM(KCOMP) = 0.0
      DO 400 IO= 1,NEVI
      IFAKE = TANAL(KCOMP,IO)
      SIM = RANNOS(69141943)
      DO 425 IK= 1, NANAL
  425 ANTY(IK) = ANALTY(NU,IFAKE, IK)
      CALL CHOOS(ANTY,NANAL,ITY)
      IAN(KCOMP, IO) = ITY
      SIM = RANNOS(69141943)
      DO 450 IK2=1, NMIN
  450 ATIMES(IK2) = TIM(ITY, IK2)
      CALL CHOOS(ATIMES,NMIN, NTIM)
      ETIM(KCOMP, IO) = NTIM
      CTIM(KCOMP) = CTIM(KCOMP) + NTIM
  400 CONTINUE
      RETURN
      END

      SUBROUTINE BUSY
      DIMENSION KTECH(10,30), LTECH(10,30), ATECH(10,30)
      COMMON / ONE/ SIM, KCOMP
      COMMON /THREE/ CTIM(400), K
      COMMON / UUU/ TINTAR (100), SYST(50)
      COMMON /VVV/ PPIOR(2), APRIOR(50)
      COMMON /WWW/ NAVL , JZ1
      COMMON /YYY/ I4
      COMMON /ZZZ/ ITECH(30,10,30)
      PRINT 1009
 1009 FORMAT(7X,'ARRIVAL DATE',5X,'CASE NO.',5X,'ARRIVAL TIME',5X,'SERVI
     1CE ENDS',3X,'SERVER NO.',5X,'SERVICE DATE', 10X, 'SYSTEM TIME')
      K1 = K
      I4 = 1
      LPRIOR = 1
      IDENT = 0
      DO 765 ICE1 = 1, NAVL
  765 ITECH(K1, ICE1, 1) = 1080
  780 DO 760 ICE = 1, KCOMP
      IF ( APRIOR(ICE   )  .EQ. LPRIOR) GO TO 760


      CALL MAXAMI
      I3 = I4-1
      IBUSY = ITECH(K1,JZ1, I3)
      IF(ITECH(K1,JZ1,I3) .LT. TINTAR(ICE))      IBUSY          = TINTAR(I
     1CE  )
      ITECH(K1,JZ1, I4) =         IBUSY                    + CTIM(ICE)
      KTECH(JZ1, I4) = K
      LTECH(JZ1, I4 ) = ICE
      ATECH(JZ1, I4) = TINTAR(ICE)
      SYST(ICE) =(K1-K)* 1440.0 + ITECH(K1,JZ1,I4) - ATECH(JZ1, I4)
      PRINT 1008 , KTECH(JZ1,I4),LTECH(JZ1,I4), ATECH(JZ1,I4), ITECH(K1,
     1JZ1,I4), JZ1 ,K1 , SYST(ICE)
 1008 FORMAT (10X,I5,10X,I5,10X,F10.3,10X,I5,10X, I5,10X,I5,10X,F8.3)
  760 CONTINUE
      IF(IDENT .EQ. 1) GO TO 785
      LPRIOR = 2
      IDENT = 1
      GO TO 780
  785 RETURN
      END

      SUBROUTINE MAXAMI
      DIMENSION  JZ(30)
      DIMENSION KLARGE(10)
      COMMON /THREE/ CTIM(400), K
      COMMON /SSS/ IAVL(50)
      COMMON /WWW/ NAVL , JZ1
      COMMON /YYY/ I4
      COMMON /ZZZ/ ITECH(30,10,30)
      K1 = K
      DO 800 I2=1, NAVL
      KLARGE (I2) = ITECH(K1, I2, I4)
  820 DO 810 I1= 1,30
      IF(ITECH(K1, I2, I1)  .LE. KLARGE(I2)) GO TO 808
      JR = I1
  812 KLARGE(I2) = ITECH(K1, I2, JR)
      JZ(I2) = JR
      IF((KLARGE(I2) .GE. 1440) .OR. (JZ(I2) .EQ. 30)) GO TO 815
      GO TO 810
  808 IF(ITECH(K1,I2,I1) .NE. 0) GO TO 810
      JR = I1-1
      KLARGE(I2) = ITECH(K1, I2, JR)
      JZ(I2) = JR
      IF((KLARGE(I2) .GE. 1440) .OR. (JZ(I2) .EQ. 30)) GO TO 815
      GO TO 800
  810 CONTINUE
      GO TO 800
  815 K1 = K1 + 1
      KLARGE(I2) = ITECH(K1, I2, 1)
      GO TO 820
  800 CONTINUE
      KMIN = KLARGE(1)
      JZ1 = 1
      DO 830 I2= 1, NAVL
      IF(KLARGE(I2) .GE. KMIN) GO TO 830
      KMIN = KLARGE(I2)
      JZ1 = I2
  830 CONTINUE
      I3 = JZ(JZ1)
      I4 = I3 +1
      RETURN
      END
```



```
      SUBROUTINE STAT
      COMMON / ONE/ SIM, KCOMP
      COMMON /TWO/ TANAL(50,20),NCR(20), NEVI
      COMMON /THREE/ CTIM(400), K
      COMMON /TEN/ ICR1(50), IAN(50,20), ICR2(50)
      PRINT 1012
 1012 FORMAT (1H1,10X,'DAY',5X,'CASE NO.', 5X,'TYPE OF CASE',5X,'EVIDENC
     1E TYPES',5X,'ANAL. METH.')
      DO 900 I5= 1,KCOMP
      I7 = ICR2(I5)
      PRINT 1013,K,I5,ICR1(I5)
 1013 FORMAT(1H0,10X,I3,10X,I3,15X,I3)
      DO 901 I6 = 1, I7
      PRINT 1014, TANAL(I5,I6), IAN(I5,I6)
 1014 FORMAT( 55X, F7.2, 10X, I6)
  901 CONTINUE
  900 CONTINUE
      PRINT 1016
 1016 FORMAT (1H0, 5X, 'DAY', 50X, 'TOTAL OF CASE TYPES')
      PRINT 1017
 1017 FORMAT(15X,'  1  ','  2  ','  3  ','  4  ','  5  ','  6  ','  7
     1','  8  ','  9  ','  10 ','  11  ','  12 ',' 13  ','  14 ',' 15  ',
     2'  16 ',' 17  ','  18 ',' 19  ','  20 ')
      PRINT 1018, ( NCP(IU), IU = 1,20)
 1018 FORMAT ( 15X, 20I5)
      RETURN
      END

      SUBROUTINE AVGS
      COMMON / ONE/ SIM, KCOMP
      COMMON /THREE/ CTIM(400), K
      COMMON/ELEVEN/ AVGA(30), AVGSYS(30), AVGSER(30), AVGWT(30)
      COMMON /RRR/ INTAR(50)
      COMMON / UUU/ TINTAR (100), SYST(50)
      AVGA(K) = 0.0
      AVGSYS(K) = 0.0
      AVGSER(K) =0.0
      AVGWT(K) =0.0
      TOTA =0.0
      TOTSYS= 0.0
      TOTSER =0.0
      DO 950 IG= 1, KCOMP
      TOTA = TOTA+  INTAR(IG)
      TOTSYS= TOTSYS+ SYST(IG)
      TOTSER = TOTSER + CTIM(IG)
  950 CONTINUE
      AVGA(K) = TOTA/KCOMP
      AVGSYS(K) = TOTSYS/ KCOMP
      AVGSER(K) = TOTSER/ KCOMP
      AVGWT(K) = AVGSYS(K) -AVGSER(K)
      PRINT 1015, AVGA(K), AVGSER(K), AVGWT(K)
 1015 FORMAT (1H , 'AVERAGE INTERARRIVAL TIME', 3X,F7.2, 10X, 'AVERAGE S
     1ERVICE TIME',3X,F7.2,10X,'AVERAGE QUEUE WAIT',3X,F7.2)
      RETURN
      END

      SUBROUTINE QUEUES
      DIMENSION QUET (10)
      COMMON / ONE/ SIM, KCOMP
      COMMON /THREE/ CTIM(400), K
      COMMON /THIRTE  / QUECHK(10)


      COMMON /TTT/ NWKR   , LQUE
      COMMON / UUU/ TINTAR (100), SYST(50)
      COMMON /ZZZ/ ITECH(30,10,30)
      TOTQUE = 0.0
      AVGQUE = 0.0
      PRINT 1021 , K
 1021 FORMAT (1H0, 10X, ' NUMBER OF CASES IN QUEUE ON DAY', 5X, I5)
      PRINT 1022
 1022 FORMAT ( 1H0,10X,'AT',5X,' 9 AM ',' 10 AM',' 11 AM',' 12 AM',' 1 P
     1M ',' 2 PM ',' 3 PM ',' 4 PM ',' 5 PM ')
      DO 970 IQUE = 2,10
      IQUE1 = IQUE -1
      NQUE = 0
      NSERV = 0
      DO 980 ICASE = 1, KCOMP
      IF((TINTAR(ICASE) .GT. QUECHK(IQUE1)) .AND. (TINTAR(ICASE) .LE. QU
     1ECHK(IQUE)))  NQUE = NQUE + 1
  980 CONTINUE
      DO 985 IANAL = 1, NWKR
      DO 990 ISERV = 2,30
      IF((ITECH(K,IANAL,ISERV) .GT. QUECHK(IQUE1)) .AND. (ITECH(K,IANAL,
     1ISERV) .LE. QUECHK(IQUE)))  NSERV = NSERV+1
  990 CONTINUE
  985 CONTINUE
      NEWQU = NQUE - NSERV
      QUET(IQUE) = NEWQU + LQUE
      LQUE = QUET(IQUE)
  970 CONTINUE
      DO 960 IQUE = 2,10
  960 TOTQUE = TOTQUE+ QUET(IQUE)
      AVGQUE = TOTQUE / 9
      PRINT 1020, ( QUET(IQUE), IQUE = 2,10)
 1020 FORMAT ( 17X, 9F6.1)
      PRINT 1023, AVGQUE
 1023 FORMAT ( 1H0, 40X, ' AVERAGE QUEUE LENGTH IS ', 5X, F7.2)
      RETURN
      END
```

DAY	CASE NO.	TYPE OF CASE	EVIDENCE TYPES	ANAL. METH.
1	1	2		
			2.00	2
			1.00	3
1	2	1		
			1.00	2
			3.00	2
1	3	2		
			2.00	1
			3.00	1
			1.00	1
1	4	1		
			1.00	3
			2.00	3
1	5	2		
			1.00	2
1	6	2		
			3.00	1
			1.00	1
			2.00	1
1	7	1		
			1.00	1
1	8	3		
			1.00	3
1	9	2		
			1.00	1
			2.00	1
1	10	1		
			1.00	3
1	11	2		
			2.00	3
			1.00	1
			3.00	3
1	12	1		
			3.00	2
			1.00	3
1	13	3		
			2.00	1
1	14	3		
			2.00	1
1	15	3		
			1.00	3
1	16	3		
			2.00	1
1	17	3		
			1.00	3
1	18	2		
			2.00	1
1	19	1		
			2.00	1
1	20	2		
			1.00	2
1	21	1		
			1.00	2
			3.00	1
1	22	2		
			3.00	1
1	23	3		
			1.00	1
1	24	3		
			3.00	1
			1.00	1

DAY — TOTAL OF CASE TYPES

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
7	9	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NUMBER OF CASE [illegible] QUEUE ON DAY 1

AT	9 AM	10 AM	11 AM	12 AM	1 PM	2 PM	3 PM	4 PM	5 PM
	16.0	17.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0

AVERAGE QUEUE LENGTH IS 5.67

ARRIVAL DATE	CASE NO.	ARRIVAL TIME	SERVICE ENDS	SERVER NO.	SERVICE DATE	SYSTEM TIME
2	17	1019.000	1081	1	2	62.000
2	1	98.000	1082	2	2	984.000
2	2	113.000	1085	3	2	972.000
2	3	211.000	1082	4	2	871.000
2	4	315.000	1082	5	2	767.000
2	5	412.000	1083	6	2	671.000
2	6	412.000	1083	7	2	671.000
2	7	437.000	1084	8	2	647.000
2	8	444.000	1082	1	2	638.000
2	9	556.000	1085	1	2	529.000
2	10	662.000	1087	2	2	425.000
2	11	703.000	1088	4	2	385.000
2	12	717.000	1088	5	2	371.000
2	13	790.000	1084	6	2	294.000
2	14	838.000	1084	7	2	246.000
2	15	951.000	1085	6	2	135.000
2	16	977.000	1087	7	2	110.000
2	18	1093.000	1100	8	2	7.000
2	19	1148.000	1149	1	2	1.000
2	20	1225.000	1226	3	2	1.000
2	21	1302.000	1311	6	2	9.000
2	22	1409.000	1410	2	2	1.000

AVERAGE INTERARRIVAL TIME 64.05 AVERAGE SERVICE TIME 3.09 AVERAGE QUEUE WAIT 396.73

APPENDIX V

USE OF SEARCH THEORY IN SEEKING AND IN ANALYZING PHYSICAL EVIDENCE

A basic problem in dealing with physical evidence is that of finding and properly ascribing "ownership" of the objects. Detecting blood stains in a group of items brought to the lab and identification of the set that may be ascribed to the criminal or victim illustrates the problem.

The technicians who analyze physical evidence may have intuitive notions, reinforced by their experience about the most effective search procedures. It is reasonable to assume that these analysts will be able to translate their intuition and knowledge into estimates of prior probabilities of discovery of objects sought in a space of possibilities and that they will be able to introduce effective measures to the testing procedure they employ. A reasonable estimate of prior probabilities -- not essentially the pinpoint accuracy -- is sufficient in applying the model proposed in this Appendix. There is an advantage in analysis in moving from random searches to decision rules which incorporate the probability estimates and effectiveness measures described presently together with the cost estimates (cost being man-hours of work done). The method by which such decision rules can be generated is discussed here.

Conceptual Formulation of the Proposed Model

Let S be the set of objects O_i from which the evidence is sought. For every object O_i in S, assign parameters:

p_i = probability that X is in O_i

α_i = probability that X will not be detected in O_i given that X is in O_i (this parameter is determined by the search effective probability of the series of tests and the sensitivity of instruments applied and can be estimated by analysts on the job)

e_i = cost of search in O_i (can be in terms of time spent)

Search at the Scene of a Crime

Here S may be defined to be a large area where a fleeing criminal has supposedly left an object which is sought. (The model applies even to the case when the object is not there -- it minimizes the time in winding up the search quickly.) Then, each O_i in this case is different (roughly circumscribed) subarea that could contain the object with probability p_i. A full description of the case and what took place can greatly help the estimation of p_i's. Or, again, our S may be the whole town and O_i's as different parts of the town where a criminal could be hiding. In general, detectives and other searchers have their prior p_i's as to where a criminal could be.

Search Proposed In the Crime Laboratory

Here, S is taken as the space or collection of all pieces of evidences and they can be very numerous, collected from the scene of crime. Now our parameters are translated as follows:

Let:

X be the clue being searched for, e.g., blood stain on item, etc.

O_i = the piece of evidence brought to the lab

p_i = the probability that X is in O_i

α_i = probability of nondetection of X given that X is in O_i piece

Since the search is usually to be done by analytical procedures (instruments and types of tests), α_i may fairly be estimated as a function of these analytical procedures, i.e., α_i = 1-f (analytical procedures to detect the existence of clue X in O_i).

Decision Rule for Search

Such rules apply to both cases 1 and 2.

1) Set an arbitrary upper bound M for the total number of analysis or search cycles, e.g., at the crime scene searching all the O_i's once, not finding what we are looking for and repeating the round of search again constitutes a cycle. At the crime laboratory, a cycle would be completing the search for all pieces once and then starting the second round a second time.

2) Let N be the total number of objects. All the O_i's be given a number tag with estimates of p_i's and α_i's written on them.

3) Construct a Spectrum Π of numbers Π_{ij}'s, such that

$$\Pi = \{ \Pi_{ij} = p_i \, \alpha_i^{d-1} (1-\alpha_i)_j \quad i = 1, \ldots N_i j = 1, \ldots M\}$$

and then the set of ratios

$$R = \{ \frac{\Pi_{ij}}{e_i} , i = 1, \ldots N_i j = 1, \ldots M\}$$

Arrange the elements of R into a non-increasing sequence K.

Then:

if the nth number of R is Π_{ij}/e_i, the search of ith object is the nth search or analysis in the procedure.

The procedure stated above will always be consistent, e.g., the 29th search for object 5 will never be suggested by the sequence before the 27th or 10th search of the same object.

A Proof for the Optimal Decision Procedure

Suppose our clue is in or on one of the γ possible locations ($\gamma \geq 2$), let p_i's and α_i's be as defined before. We clearly have $\sum p_i = 1$ and $0 \leq \alpha_i < 1$. The general process may be described as follows: Suppose at some stage, when one of the locations, say, j, is searched, the objects are not found. Then for i = 1, ...r, the posterior probability p_i^* that the object is in location i is by use of Bayes Theorem:

$$p_j^* = \frac{p_j \alpha_j}{p_j \alpha_j + 1-p_j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$p_i^* = \frac{p_i}{p_j d_j + 1-p_j}$$

Procedure must be determined that will minimize the expected total cost (in terms of time) of the searching process.

For any probabilities $p_1, p_2, \ldots p_\gamma$, we shall let L $(p_1, p_2, \ldots p_\gamma)$ denote the expected total cost of the searching process. The functional equation that must be satisfied by L is as follows:

Suppose that the first search is made in a certain location, say j. Then the probability is $p_j(1-\alpha_j)$ that the object will be terminated. On the other hand, the probability is $p_j\alpha_j(1-p_j)$ that the clue will not be found in the first search. If is is not found, the posterior probabilities p_1^*, p_γ^* as specified by (1), and the expected cost of the remainder of the process when an optimal procedure is adopted is $L^*(p_1, \ldots p_2^*)$. After we add the cost of c_j of the first search, the expected total cost of searching in location j first and then

continuing with an optimal procedure will be $c_j + (p_j \alpha_j + 1-p_j)L(p_1^*, \ldots p_2^*)$. Since one of the r locations must be searched first, $L(p_1, \ldots p_2)$ must satisfy the following equation:

$$L(p_1, \ldots p_\gamma) = \min_{j=1,\ldots\gamma} \{ c_j + (p_j\alpha_j + 1-p_j)L(p_1^*, \ldots p_2^*) \} \ldots (2)$$

Now, since $L(p_i, \ldots p_2)$ is the expected total cost of an optimal procedure, its value cannot be greater than the expected cost of the procedure under which locations 1 through r are searched cyclically until the clue has been found. This also gives an upper bound on the cost as follows:

Suppose first the clue is in location i. Then $\frac{1}{1-\alpha_i}$ is the expected number of searches in location i which will be needed to find the clue. Since the cost of each cycle of searches of all r locations is $c_1 + \ldots c_\gamma$, it follows the expected cost of finding the clue will not be more than $(c_1 + c_2 + \ldots c_\gamma)/(1-\alpha_i)$. Expecting over all possible locations r gives the upper bound on expected cost as

$$(c_1 + \ldots c_\gamma) \sum_{E1}^{2} \frac{p_i}{1-\alpha_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Equation (2) is difficult to solve but the following line of attack gives the same optimal procedure as (2).

For an sequential procedure and for i = 1,....r and j = 1,],..., we shall let Πij be the probability under any proceudre that the clue will be found for the first time and the search cease during the jth search of location i. Then, regardless of number of times other locations have been searched before the jth search of location i is made, the probability πij is

$$\pi ij = p_i \alpha_i^{j-1} (1-\alpha_i) \quad i = 1,....2 \quad j = 1,2,... \quad ....(4)$$

Every search procedure specifies, at each stage n(n=1,2,....) that a certain one of locations 1,....2 should be searched if the clue has not yet been found. (Note that our applications stage is equivalent to each subarea at the crime scene or each piece brought to the crime lab.) For any given procedure D, we let R_n denote the cost of the search that is made at the nth stage, and we let λ_n denote the probability that the clue will be found at the nth stage; e.g., if D specifies that the location i should be searched for the jth time at the nth stage, then $R_n = c_i$ and $\lambda_n = \pi ij$. Let M denote the total number of searches required to find the clue. Then the expected total cost p(D) of finding the clue can be written as follows:

$$P(D) = \sum_{n=1}^{\infty} (\sum_{m=1} R_m)\lambda_n = \sum_{m=1}^{\infty} (\sum_{n=m}^{\infty} \lambda_n) R_m$$

$$= \sum_{m=1}^{\infty} R_m \, p_r(M \geq m) \quad ....(5)$$

$$= R_1 + R_2 (1 - \lambda_1) + R_3 (1 - \gamma_1 - \gamma_2) + ...$$

Note: The final result in (5) is appropriate even for a procedure D under which there exists a time probability of never finding the object.

We now prove that the optimal procedure specifies that the search should be performed so that the following relation is satisfied:

$$\frac{\lambda_1}{R_1} \geq \frac{\lambda_2}{R_2} \geq \frac{\gamma_n}{R_n} \; ...... \quad ....(6)$$

In other words, if all values of the ratio πij for all values of i and j are arranged in order of decreasing magnitude, then this ordering is the sequence in which the searches should be made.

Proof of Optimality: suppose that D is a procedure for which some value of n, $\frac{\lambda_n}{R_n} < \frac{\lambda_n + 1}{R_n + 1}$ ....(7)

Suppose also that D' specifies that location i should be searched at the nth stage and location k at the (n + 1) st stage. By (7) we know $i \neq k$. Let D* be the procedure that specifies that the location k should be searched at the nth stage and i at the (n + 1) but which agrees with procedure D at all other stages. Let R_m* and r_m* be the cost and probability at the mth stage for procedure D*, then the following relations must be satisfied.

$R_n* = R_n + 1$ and $\lambda*_n = \lambda_n + 1$

$R_n + 1 = R_n$ and $\lambda*_n + 1 = \lambda_n$

$R_n = R_m$ and $\lambda_m = \lambda_m$ for $m \neq n$ and $m \neq n + 1$

We can now obtain the following result from equations (5), (7), and (8):

$$P(D') = P(D*) = R_n (1 - \lambda_1 - .... \lambda_n - 1)$$
$$+ R_n + 1 (1 - \lambda_1 .... \lambda_n - 1 - \lambda_n)$$
$$- R_n + 1 (1 - \lambda_1 .... \lambda_n - 1)$$
$$- R_n (1 - \lambda_1 - .... - \lambda_n - 1 - \lambda_n + 1)$$

Hence, the result:

$$= R_n \lambda_n + 1 - R_n + 1 \; \lambda_n > 0 \quad ....(9)$$

Note: The dynamic point of view is clearly implicit in the above procedure. Observe equations (1) and (4). The optimal procedure has the following forceful and dynamic interpretation. At any given stage of process, let p_i*, ...p_γ* be the current posterior probabilities that the clue is in each of the γ possible locations. Then the next search should be made in the location for which the value of p_i* $(1 - \alpha i)$ is the probability of actually finding the object in a single search of location i, the optimal procedure at each stage is simply to search in the location for which there is the highest probability per unit search cost of finding the clue in the next search. Also note that in case costs are equal, the optimal procedure will minimize the expected number of searches needed to find the object.

A computer program illustrating the foregoing procedure follows.

The sample runs, using data from the Philadelphia City Police Laboratory indicate that the use of search theory is clearly cost effective if twenty or more items or areas are considered.

COMMENTS ON THE SEARCH AND SEQUENCING ALGORITHM

Inputs

1. NUM = number of objects; maximum allowable is 1000.

2. MAX = number of search cycles; maximum value is 8.

3. PROB(I), I = 1, NUM; PROB(I) = prior probability measure that the item being searched for is in object I.

   NOTE: the inputted values for array PROB are automatically normalized into mathematical probability numbers using:

$$PROB(I) = \frac{\text{inputted } PROB(I)}{\Sigma(\text{inputted } PROB(I))}$$

4. EFFI(I), I = 1, NUM:
   EFFI(I) = search effectiveness probability (in %) of discovering the item searched for in object I given that it is in that object.

5. COST(I), I = 1, NUM:
   COST(I) = cost per unit search in object I.

6. KSIG = 1 means the complete P(I,J) matrix is to be printed out.

7. NOTE: All the inputted numbers must be positive numbers.

Computational Scheme

1. The array P(I,J) is calculated using:

$$P(I,J) = \frac{PROB(I) * EFFI(I) * (1 - EFFI(I))^{J-1}}{COST(I)}$$

2. The matrix P(I,J) is then sequenced in descending order to determine the analysis sequence for the individual objects.

Print - Out Of Results

1. All the raw data are printed out (for verification purposes).

2. The suggested sequence of analysis of the objects are printed out with the corresponding P(I,J) ratio.

   The sequence is valid only for positive P(I,J) = C/E ratio.

   C/E values of -1.00 are to be disregarded as they are used only for arranging P(I,J) in descending order.

PROGRAM SEARCH PRINTOUT

```
/PROGRAM SEARCH
C--------------
C  *SEARCH ALGORITHM*
C   THIS ALGORITHM SEQUENCES THE ANALYSIS OF PHYSICAL EVIDENCES USING
C   BAYES POSTERIOR PORBABILITY RULES AND COST-EFFECTIVENESS RATIOS.
C
C  ** LIMITATION ON CAPABILITY OF PROGRAM DICTATED BY DIMENSION STATEMENTS *
C        NUM = NUMBER OF OBJECTS   NO MORE THAN 1000
C        MAX = NUMBER OF SEARCH CYLES  NO MORE THAN 8
C-----------------------
      DIMENSION PROB(1000),EFFI(1000),COST(1000)
      DIMENSION P(1000,8)
      DIMENSION VAL(1000)
      DIMENSION NOBJ(20)
      EQUIVALENCE (EFFI,VAL)
C
    4 FORMAT(5I5)
    5 FORMAT(14F5.0)
C--          LAST 10 COLUMNS ARE FOR IDENTIFICATION PURPOSES.
    6 FORMAT(//1X,15HOBJECT NUMBER (,I5,19H) HAS PROB VALUE = ,F10.2/
     C    5X,50HTRANSFORMED TO ZERO FOR COMPUTATIONAL FEASIBILITY, )
    7 FORMAT(1H1,1X,31HSEARCH AND SEQUENCING ALGORITHM//1X,
     1 30HRATIOS USED TO SEQUENCE SEARCH/35X,12HCYCLE NUMBER//1X,
     2 13HOBJECT NUMBER,7X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5,9X,1H6,
     1   9X,1H7,9X,1H8//)
    8 FORMAT(4X,1H(,I5,3H  ) ,3X,6(F8.4,2X))
    9  FORMAT(1H1,//1X,19HRESULTS OF ANALYSIS//1X,19HNUMBER OF OBJECTS =
     1  I6/5X,15HSEARCH CYCLES =  ,I6//20X,20H*(GROUPS OF TWENTY)*//1X,
     2 12HGROUP NUMBER//)
   10 FORMAT(/I3,2X,6HOBJ NO,20I6)
   11 FORMAT( 5X,3HC/E,4X,20F6.3)
   12 FORMAT(1H1,37HLISTING OF DATA DECK FOR VERIFICATION ///1X,
     16H NUM =,I7,10X,6H MAX =,I7,10X,6HKSIG =,I2//1X,20HPROBABILITY MEA
     2SURES/)
   13  FORMAT(14F8.3)
   14 FORMAT(//1X,27HSEARCH-EFFECTIVENESS VALUES /)
   15 FORMAT(//1X,25HCOST OF SEARCH PER OBJECT  /)
   16 FORMAT(///1X,15HEND OF ANALYSIS  ///)
   17 FORMAT(1H1)
C---------
   99 READ 4,NUM,MAX,KSIG
      IF(NUM.EQ.0) GO TO 500
C INPUT *LOCATIONAL PROBABILITY* VALUES
      READ 5,(PROB(I),I=1,NUM)
C INPUT PERCENT VALUES OF SEARCH EFFECTIVENESS PROBABILITIES
      READ 5,(EFFI(I),I=1,NUM)
C INPUT COST PER SEARCH IN EACH OBJECT
      READ 5,(COST(I),I=1,NUM)
C
C PRINT OUT RAW DATA
      PRINT 12,NUM,MAX,KSIG
      PRINT 13,(PROB(I),I=1,NUM)
      PRINT 14
      PRINT 13,(EFFI(I),I=1,NUM)
      PRINT 15
      PRINT 13,(COST(I),I=1,NUM)
C
C  START COMPUTATIONS
C  NORMALIZE INPUTTED PROBABILITY VALUES
      VAL(1) = 0.0
      DO 100 I=1,NUM
      IF(PROB(I).LT.0.0) PRINT 6,I,PROB(I)
      IF(PROB(I).LT.0.0) PROB(I)=0.

      VAL(1) = VAL(1) + PROB(I)
  100 CONTINUE
C
      PRINT 13,VAL(1)
      DO 101 I=1,NUM
        PROB(I) = PROB(I) / VAL(1)
        EFFI(I) = EFFI(I) / 100.
  101 CONTINUE
C
      PRINT 13,PROB(1)
      PRINT 13,COST(1)
      PRINT 13,EFFI(1)
C
C
C  COMPUTE  P(I,J)
      DO 110 I=1,NUM
      DO 110 J=1,MAX
         P(I,J) = PROB(I) * EFFI(I) * ((1.0 - EFFI(I)) ** (J-1))
         P(I,J) = P(I,J) / COST(I)
  110 CONTINUE
C
      PRINT 13,P(1,1)
C
      IF(KSIG.EQ.0)GO TO 300
C  PRINT-OUT OF COST-WEIGHTED SEARCH PROBABILITIES
      PRINT 7
      NOBJ(1) = 0
      DO 205 I=1,NUM
      NOBJ(1) = NOBJ(1) + 1
      IF(NOBJ(1).GT.55) PRINT 7
      IF(NOBJ(1). GT.55) NOBJ(1) = 0
      PRINT 8,I,(P(I,J),J=1,MAX)
  205 CONTINUE
C
  300 CONTINUE
      PRINT 9,NUM,MAX
      KKK = 0
      KOUNT=0
  301 CONTINUE
      DO 360 K=1,20
      HIGH = -1.
      DO 350 I=1,NUM
      DO 350 J=1,MAX
      IF(P(I,J).LE.HIGH) GO TO 349
      HIGH = P(I,J)
      NROW = I
      NCOL = J
  349 CONTINUE
  350 CONTINUE
      VAL(K) = HIGH
      NOBJ(K) = NROW
      P(NROW,NCOL) = -2.
  360 CONTINUE
      KOUNT = KOUNT + 1
      LIM = NUM * MAX - (KOUNT-1) * 20
      IF(LIM.GT.20) LXM = 20
      PRINT 10,KOUNT,(NOBJ(K),K=1,LXM)
      PRINT 11,(VAL(K),K=1,LXM)
      KKK = KKK + 1
      IF(KKK.GT.14) PRINT 9,NUM,MAX
      IF(KKK.GT.14) KKK = 0
      IF((LIM-20).GT.0) GO TO 301
C
```

E N D   O F   A N A L Y S I S

LISTING OF DATA DECK FOR VERIFICATION

NUM = 20 MAX = 6 KSIG = 1

PROBABILITY MEASURES

1.000 2.000 2.000 4.000 1.000 7.000 8.000 3.000 1.000 1.000 1.000 2.000 1.000 3.000
2.000 2.000 5.000 5.000 1.000 1.000

SEARCH-EFFECTIVENESS VALUES

89.000 89.000 85.000 91.000 90.000 92.000 88.000 92.000 94.000 90.000 87.000 89.000 97.000 92.000
89.000 79.000 86.000 82.000 94.000 80.000

COST OF SEARCH PER OBJECT

10.000 10.000 10.000 20.000 15.000 14.000 10.000 14.000 14.000 14.000 13.000 10.000 28.000 21.000
10.000 11.000 11.000 15.000 15.000 13.000
53.000
0.019
10.000
0.530
0.001

SEARCH AND SEQUENCING ALGORITHM

RATIOS USED TO SEQUENCE SEARCH

OBJECT NUMBER	CYCLE NUMBER 1	2	3	4	5	6	7	8
(1)	0.0010	0.0005	0.0002	0.0001	0.0000	0.0000		
(2)	0.3358	0.0369	0.0041	0.0004	0.0000	0.0000		
(3)	0.3208	0.0481	0.0072	0.0011	0.0002	0.0000		
(4)	0.3434	0.0309	0.0028	0.0003	0.0000	0.0000		
(5)	0.1132	0.0113	0.0011	0.0001	0.0000	0.0000		
(6)	0.8679	0.0694	0.0056	0.0004	0.0000	0.0000		
(7)	1.3283	0.1594	0.0191	0.0023	0.0003	0.0000		
(8)	0.3120	0.0298	0.0024	0.0002	0.0000	0.0000		
(9)	0.1267	0.0076	0.0005	0.0000	0.0000	0.0000		
(10)	0.1213	0.0121	0.0012	0.0001	0.0000	0.0000		
(11)	0.1263	0.0164	0.0021	0.0003	0.0000	0.0000		
(12)	0.3358	0.0369	0.0041	0.0004	0.0000	0.0000		
(13)	0.3586	0.0076	0.0010	0.0001	0.0000	0.0000		
(14)	0.2480	0.0198	0.0016	0.0001	0.0000	0.0000		
(15)	0.3358	0.0369	0.0041	0.0004	0.0000	0.0000		
(16)	0.2710	0.0569	0.0120	0.0025	0.0005	0.0001		
(17)	0.7376	0.1033	0.0145	0.0020	0.0003	0.0000		
(18)	0.5157	0.0928	0.0167	0.0030	0.0005	0.0001		
(19)	0.1182	0.0071	0.0004	0.0000	0.0000	0.0000		
(20)	0.1161	0.0232	0.0046	0.0009	0.0002	0.0000		

RESULTS OF ANALYSIS

NUMBER OF OBJECTS = 20
SEARCH CYCLES = 6

(GROUPS OF TWENTY)

GROUP NUMBER

1	OBJ NO	7	6	17	18	8	4	2	12	15	3	16	14	7	9	11	10	19	20	5	17
	C/E	1.328	0.868	0.738	0.516	0.372	0.343	0.336	0.336	0.336	0.321	0.271	0.248	0.159	0.127	0.125	0.121	0.118	0.116	0.113	0.103
2	OBJ NO	18	6	13	16	3	2	12	15	4	8	20	14	7	18	11	17	10	16	5	13
	C/E	0.093	0.069	0.059	0.057	0.042	0.037	0.037	0.037	0.031	0.030	0.023	0.020	0.019	0.017	0.015	0.014	0.012	0.012	0.011	0.008
3	OBJ NO	9	3	19	6	20	2	12	15	18	4	16	8	7	11	17	14	10	5	3	1
	C/E	0.008	0.007	0.007	0.006	0.005	0.004	0.004	0.004	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
4	OBJ NO	13	20	18	16	1	9	2	12	15	6	19	17	11	7	4	1	8	20	3	13
	C/E	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	OBJ NO	14	10	5	16	1	18	2	12	15	1	17	20	11	6	7	9	19	3	1	4
	C/E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	OBJ NO	13	8	10	5	14	2	12	15	11	6	13	4	9	19	8	10	5	14	9	19
	C/E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

LISTING OF DATA DECK FOR VERIFICATION

NUM = 42 MAX = 5 KSIG = 1

PROBABILITY MEASURES

1.000 2.000 3.000 1.000 9.000 9.000 3.000 7.000 3.000 2.000 4.000 6.000 8.000 1.000
2.000 2.000 2.000 4.000 3.000 1.000 2.000 3.000 5.000 1.000 2.000 3.000 4.000 1.000
2.000 5.000 5.000 1.000 3.000 4.000 2.000 1.000 5.000 1.000 2.000 3.000 4.000 1.000

SEARCH-EFFECTIVENESS VALUES

89.000 89.000 92.000 93.000 90.000 91.000 95.000 98.000 97.000 92.000 92.000 90.000 94.000 96.000
92.000 94.000 89.000 85.000 89.000 85.000 94.000 90.000 91.000 92.000 93.000 93.000 92.000 95.000
91.000 90.000 90.000 92.000 94.000 97.000 93.000 92.000 91.000 95.000 94.000 96.000 98.000 99.000

COST OF SEARCH PER OBJECT

10.000 20.000 10.000 15.000 14.000 13.000 10.000 16.000 28.000 20.000 13.000 24.000 15.000 18.000
15.000 15.000 14.000 13.000 10.000 28.000 27.000 28.000 23.000 26.000 19.000 19.000 21.000 18.000
10.000 24.000 28.000 35.000 34.000 36.000 26.000 19.000 19.000 37.000 18.000 19.000 21.000 18.000
135.000
0.007
10.000
1.150
0.001

SEARCH AND SEQUENCING ALGORITHM

RATIOS USED TO SEQUENCE SEARCH

OBJECT NUMBER	CYCLE NUMBER 1	2	3	4	5	6	7	8
(1)	0.0010	-0.0003	0.0001	-0.0000	0.0000			
(2)	0.0654	0.0074	0.0008	0.0001	0.0000			
(3)	0.2044	0.0164	0.0013	0.0001	0.0000			
(4)	0.0459	0.0032	0.0002	0.0000	0.0000			
(5)	0.4296	0.0429	0.0043	0.0004	0.0000			
(6)	0.4667	0.0420	0.0038	0.0003	0.0000			
(7)	0.3519	0.0176	0.0009	0.0000	0.0000			
(8)	0.3176	0.0064	0.0001	0.0000	0.0000			
(9)	0.0770	0.0023	0.0001	0.0000	0.0000			
(10)	0.0681	0.0055	0.0004	0.0000	0.0000			
(11)	0.2726	0.0218	0.0017	0.0001	0.0000			
(12)	0.1667	0.0167	0.0017	0.0002	0.0000			
(13)	0.3714	0.0223	0.0013	0.0001	0.0000			
(14)	0.0395	0.0016	0.0001	0.0000	0.0000			
(15)	0.0909	0.0073	0.0006	0.0000	0.0000			
(16)	0.0968	0.0019	0.0000	0.0000	0.0000			
(17)	0.0942	0.0104	0.0011	0.0001	0.0000			
(18)	0.1937	0.0291	0.0044	0.0007	0.0001			
(19)	0.1978	0.0218	0.0024	0.0003	0.0000			
(20)	0.0225	0.0034	0.0005	0.0001	0.0000			
(21)	0.0516	0.0031	0.0002	0.0000	0.0000			
(22)	0.0714	0.0071	0.0007	0.0001	0.0000			
(23)	0.1465	0.0132	0.0012	0.0001	0.0000			
(24)	0.0262	0.0021	0.0002	0.0000	0.0000			
(25)	0.0765	0.0054	0.0004	0.0000	0.0000			
(26)	0.1088	0.0076	0.0005	0.0000	0.0000			
(27)	0.1298	0.0104	0.0008	0.0001	0.0000			
(28)	0.0395	0.0016	0.0001	0.0000	0.0000			
(29)	0.1348	0.0121	0.0011	0.0001	0.0000			
(30)	0.1389	0.0139	0.0014	0.0001	0.0000			
(31)	0.1190	0.0119	0.0012	0.0001	0.0000			
(32)	0.0195	0.0016	0.0001	0.0000	0.0000			
(33)	0.0614	0.0037	0.0002	0.0000	0.0000			
(34)	0.0798	0.0024	0.0001	0.0000	0.0000			
(35)	0.0530	0.0037	0.0003	0.0000	0.0000			
(36)	0.0379	0.0030	0.0002	0.0000	0.0000			
(37)	0.1774	0.0160	0.0014	0.0001	0.0000			
(38)	0.0190	0.0019	0.0000	0.0000	0.0000			
(39)	0.0774	0.0046	0.0003	0.0000	0.0000			
(40)	0.1123	0.0045	0.0002	0.0000	0.0000			
(41)	0.1383	0.0028	0.0001	0.0000	0.0000			
(42)	0.0407	0.0004	0.0000	0.0000	0.0000			

RESULTS OF ANALYSIS

NUMBER OF OBJECTS = 42
SEARCH CYCLES = 5

(GROUPS OF TWENTY)

GROUP NUMBER

1	OBJ NO	6	5	13	7	8	11	3	19	18	37	12	23	30	41	29	27	31	40	26	16
	C/E	0.467	0.429	0.371	0.352	0.318	0.273	0.204	0.198	0.194	0.177	0.167	0.147	0.139	0.138	0.135	0.130	0.119	0.112	0.109	0.097
2	OBJ NO	17	15	34	39	9	25	22	10	2	33	35	21	4	5	6	42	14	28	36	18
	C/E	0.094	0.091	0.080	0.077	0.077	0.077	0.071	0.068	0.065	0.061	0.053	0.052	0.045	0.043	0.042	0.041	0.040	0.040	0.038	0.029
3	OBJ NO	24	20	13	11	19	32	38	7	12	3	37	30	23	29	31	27	17	26	15	2
	C/E	0.026	0.022	0.022	0.022	0.022	0.019	0.019	0.018	0.017	0.016	0.016	0.014	0.013	0.012	0.012	0.010	0.010	0.008	0.007	0.007
4	OBJ NO	22	8	10	25	39	40	18	5	6	35	33	20	4	21	36	41	34	19	9	24
	C/E	0.007	0.006	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
5	OBJ NO	16	11	12	14	28	32	37	30	13	3	31	23	17	29	1	38	7	27	2	22
	C/E	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
6	OBJ NO	18	15	26	20	10	5	42	25	6	39	19	35	36	4	33	21	40	24	12	11
	C/E	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	OBJ NO	30	37	8	17	32	1	31	23	3	29	18	2	13	20	34	22	9	27	14	28
	C/E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	OBJ NO	41	38	15	7	5	16	26	10	6	19	25	36	35	39	12	4	1	30	17	24
	C/E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	OBJ NO	33	31	37	20	11	21	32	2	23	29	3	40	22	27	13	42	15	10	26	8
	C/E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	OBJ NO	14	28	38	7	34	9	25	36	35	41	4	24	39	32	33	16	21	40	38	14
	C/E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	OBJ NO	28	34	9	8	42	41	16	42	1	1	1	1	1	1	1	1	1	1	1	1
	C/E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.000	-0.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

END OF ANALYSIS

APPENDIX VI

CENTRAL LABORATORY RECEIVING OFFICE

Analysis has shown that the investigative arm of the Philadelphia Police Department, which of course includes the several divisions of the crime laboratory, actually operates as several independent investigating agencies when viewed macroscopically. Each unit effectively collects, analyzes, and reports results to the court system in their own specialized province of responsibility, in ignorance of other investigations being done on the same case. Operating under such conditions of ignorance, the lab analyst is severely restricted in scope of analysis; and the effectiveness of his work falls far below its potential. Having little or no knowledge of the circumstances of the crime or of the physical evidence received, the analyst will often be compelled by circumstances to perform a cursory, standardized analysis since the complete procedure of using every possible test is infeasible and inefficient, if not impossible.

A more integrated approach to the investigation of crimes is the logical solution to this dilemma. The problem is to introduce an inter-communication procedure which will not be so time consuming as to reduce the effectiveness of the primary function of investigation and which will still leave clearly defined areas of responsibility. Since the detective divisions are likely to view such inter-communication schemes as interference and extension of influence by the lab, the second consideration is especially important. At the very least, however, the various activities of the lab should be coordinated on a per case basis.

The first step in coordinating the internal lab activities is to have all physical evidence received centrally by the lab at least conceptually. To perform this, a Central Laboratory Receiving Office (CLRO) is proposed. This CLRO would receive all evidence and information relating to a particular crime, 1) determine the analysis advisable for each piece of evidence, 2) receive the results of the analysis, and assemble 3) a complete report based on the total analysis for each case. Most of the clerical and administrative staff would be concentrated in this unit. Some experienced analysts should also be attached to the CLRO to make decisions regarding the routing of evidence. Much of this routing will of course be routine. Furthermore, the CLRO should have the ability to re-direct analysis on the basis of interim results. This schema will force such interaction between the various units of the laboratory. Knowledge of the results of other analyses should result in more purposeful testing by each analyst.

The CLRO would also be invested with the responsibility of obtaining necessary information about the case and circumstances of the evidence submitted. Thus, it would act as the communications link between the detective divisions and the lab.

Further, the CLRO would be instrumental in implementing the use of search theory in lab analysis. This technique imposes the discipline of certain data requirements. The needed data would be collected or requested through this agency.

Thus, a Central Laboratory Receiving Office will be a mechanism for coordinating investigation effort and improving communication both within the lab and between lab and police investigators.

Further, it will provide the capability to introduce other proposals relating to the internal lab operations, and create a more unified records system.

APPENDIX VII

CAPITAL BUDGETING MODEL

Allocating budgetary resources in some optimal fashion is a management problem of long standing and general concern. Predicting future demands, determining incremental costs and benefits, and selecting and ranking from among alternatives are all actions which have been performed in a variety of production and marketing centers. In the case of a crime laboratory, the selection and ranking of expenditures subject to a fixed capital budget is often quite simple. If the set of possible expenditures is small, the optimal combination can be found by enumerating the measures of performance for each budgetarily possible combination. The number of iterations will be small and easily carried out by paper and pencil techniques. As the set of possible expenditures expands, more sophisticated techniques are needed to specify optimal combinations of capital expenditures. The problem can be formulated as a "knapsack" problem and dynamic programming used to solve for a set on optimal allocation of resources. This appendix illustrates this process.

A Dynamic Programming Formulation

Consider the situation in which the effects of new capital purchases on our measures of performance are independent. Thus, when our value function is $\sum_i c_i T_i$ then a project raises the value to $\sum_i c_i T_i'$ no matter what other projects might be added. Let us consider a set of J possible pieces of capital equipment to be added, where the decision at each of the J stages is to add 0 or 1 unit of that project. (This is a reasonable assumption when considering major project expenditures. But for a situation in which the decision maker is willing to add m units of a project $m = 0, 1, \ldots, M$, he need only to include M identical categories (stages) within the set of J possible expenditures.)

Let us now assume we have a set of J possible purchases about which to make 0 or 1 decisions. First we define:

- B — to be the total capital budget for the period
- Oc — to be the present annual operating budget of the laboratory
- Oc_i — to be the annual reduction in operating budget if capital expenditure i is made (of course, Oc_i could be negative indicating an increase in operating budget).
- c_i — to be the cost of capital expenditure i

Then $B_i = \frac{Oc_i}{c_i}$ is the cost benefit of capital expenditure i.

The budgeting decision problem then becomes:

Max $\sum_i d_i B_i$, where $d_i = 0$ or 1 is in number of units of equipment j added, subject to $\sum_i d_i c_i \leq B$, where the sum is taken over all capital expenditures judged feasible by the queueing model; that is, the laboratory configuration including this expenditure still yields an acceptable value of T.

We now rank the J projects in order of increasing cost. (This is done purely for convenience in working the problem.) Then as a dynamic program,

stage 1 is the decision to buy d_1 units (0 or 1) project 1
stage 2 is the decision to buy d_2 units (0 or 1) project 2
.
.
.
stage J is the decision to buy d_J units (0 or 1) project J.

The stage j input: remaining funds available = k_j

The stage j return: $r_j(d_j) = d_j B_j$

The stage transformation: $k_{j-1} = k_j - d_j a_j$

Let $\left[\frac{k_j}{a_j}\right]$ mean the largest integer less than or equal to $\frac{k_j}{a_j}$.

Then the recursion relation is:

$$f_j(k_j) = \underset{0 \leq d_j \leq \min\{1, [\frac{k_j}{a_j}]\}}{\text{MAX}} \{d_j B_j + f_{j-1}(k_j - d_j a_j)\}$$

$$j = 1, 2, \ldots, J$$

$$f_o(-) = 0$$

$$k_j = B$$

Where $f_j(k_j)$ is the optimal incremental value from j stages when k_j is the amount of funding available at the jth stage.

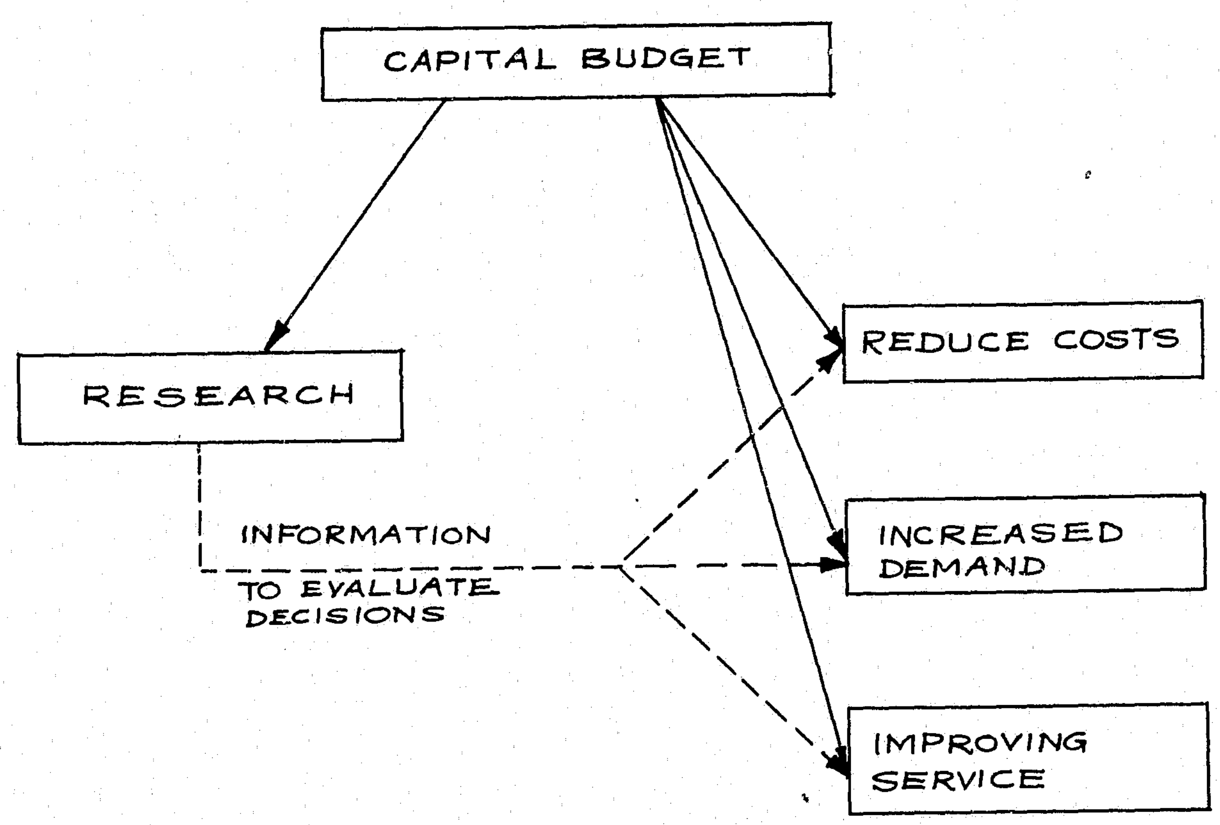
Or, equivalently,

$$f_j(k_j) = \begin{cases} f_{j-1}(k_j), \text{ implying } d_j = 0 \text{ for } k_j < a_j \\ \text{MAX} \{f_{j-1}(k_j), \text{ implying } d_j = 0; \\ \quad B_j + f_{j-1}(k_j - a_j), \text{ implying } d_j = 1\} \\ \quad \text{for } k_j \geq a_j \end{cases}$$

$$f_o(-) = 0$$

$$k_j = B.$$

A program for accomplishing this has been written and is presented in Appendix VIII.



APPENDIX VIII

SENSITIVITY ANALYSIS

Once a combination of projects is outlined by the cost benefit model as being the best selections under the prevailing situation, a further step is required. This is to perform a sensitivity analysis of the model; i.e., how sensitive or critical the answers are to changes in the parameters of the model. Some of the parameters inputed to the model are predictions or approximations of what is expected to happen. It is quite possible that these predictions may be slightly higher or lower than what will ultimately be realized. If we rank the possible combinations of the projects by their total cost benefit and find that the top two or three combinations are fairly close together, we can see that a slight change in the parameters may alter the ranking. Therefore, one must consider the range of the parameters over which the solution remains optimal so as to understand the solution better as well as to determine what efforts should be expended in further refining the estimates of the parameters.

The three parameters that directly come into the model are the predicted caseloads for the coming year, the cost of the projects, and the incremental economies associated with adding a piece of equipment. We shall consider the effects of changes on each of these, outline the purpose of the attached computer program and make suggestions for future studies in this area. The equipment and numbers referred to are derived from those used in the examples in Appendix VII, but the statements are general and should be considered as such.

Effects of Perturbing the Predicted Economies

The predicted economies for expenditure i, OC_i, represents the estimate of the cost saving expected for the coming year. These numbers may be obtained by considering the data available from other laboratories or research reports. Therefore, the figures may be overestimated or underestimated for all the expenditures, or the estimate for only one or two sections may be affected.

Since the OC_i's are used in the numerators of the cost benefit ratio for every piece of equipment, an overestimate or underestimate should produce a proportionate rise or fall in all the cost benefits. An increase in OC_i may change the cost benefit ratios for the two projects in such a way that previously excluded projects may provide higher cost-benefit ratios than some that were previously included in the optimal answer. That is, the proportion that the excluded project's cost benefit increases may be greater than the proportion that the included project's cost benefit increases by enough to overcome the difference in the two projects cost benefit ratios. The same situation could happen in the opposite sense where a decrease in C_i may force a previously higher ranked project to become lower. The program is designed to test the sensitivity of a particular solution through a series of perturbations of the input parameters.

Effects of Perturbing the Costs of the Expenditures

When considering the cost of a piece of equipment, one may not always be able to arrive at an exact figure. The actual cost may be

somewhat higher or lower than anticipated when employing the model. This situation could conceivably exist in those crime labs where most of the purchases are undertaken on a lowest bid basis. The question comes up then of how a change in cost will affect the model.

Unlike the prior situation of the predicted caseload, a change in cost for a certain expenditure will affect only that piece of equipment's cost benefit ratio. Since the cost enters in the denominator of the cost benefit ratio, an increase in cost will mean a decrease in cost benefit ratio and vice versa. Therefore, if the cost of a project that is in the optimal solution has been underestimated, it is possible that the revised cost may lower the cost benefit ratio by enough to force a new entry into the optimal solution. The opposite may also occur, where a project not in the final solution may be able to enter the optimal solution because its cost was overestimated.

We can calculate the new cost benefit ratio that will come about by a change in cost from C_j to C'_j as:

$$\text{new cost benefit } j = \text{initial cost benefit } j \times \frac{C_j}{C'_j}$$

If we look at the perturbations on the costs in the computer program, we can see that the optimal solution remains the same even when changing costs by 10% in each direction. This should not be taken to mean that the model is fairly insensitive to changes in cost, however. If we again look at the computer program, we can see that for the base case the total cost benefit for combination 456 is slightly higher than that for combination 356. If we increase the cost of project 4 by 1%, however, the order of these two combinations are reversed. This reversal will also occur for a decrease in cost of 1% for project 3. This occurs because the two combinations have total cost benefits that are very similar.

Therefore, when talking of the sensitivity of the model to changes in cost, we can only say that if the total cost benefits are fairly dissimilar, the model is insensitive, and if the total cost benefits are similar, the model is sensitive. What should be done then is to determine if the optimal combination has a total cost benefit close to that of another combination; and, if so, then try to determine if the ordering will change for increases or decreases in costs.

<u>The Computer Program and Suggested Changes</u>

The computer program that follows does the following:

1. Finds all combinations of expenditures that satisfy the budget.
2. Finds the optimal combination for the base case.
3. Finds the optimal combinations by perturbing three variables for the base case.

What is done in effect is to provide the solution of a number of slightly different situations. It would appear to be more beneficial if ranges could be found over which the base case holds as optimal. That is, what would be desired is the optimal solution and the values of the variables over which this solution remains optimal. It would then be known what degree of accuracy is required in supplying the variables.

COMPUTER PROGRAM PRINTOUT

```
FORTRAN IV G LEVEL  19              MAIN              DATE = 71126          09/36/46               PAGE 0001

              C*****************************************************************
              C**                                                              *
              C** THIS PROGRAM WILL DETERMINE THE OPTIMAL SELECTION OF A NUMBER   *
              C** OF POSSIBLE PROJECTS BY THE PROPOSED COST BENEFIT MODEL       *
              C** OF THE PROJECT RESEARCH GROUP (OR 800) OF THE UNIVERSITY OF   *
              C** PENNSYLVANIA,SPRING TERM 1971.
              C** WHAT IS REQUIRED IS FOR THE USER TO ARRIVE AT A LIST OF POSSIBLE  *
              C** PROJECTS FOR THE COMING BUDGET PERIOD AND TO ORDER THIS LIST BY   *
              C** DECREASING COSTS.THE PROGRAM WILL THEN CALCULATE THE COST BENEFIT *
              C** RATIOS FOR THESE EXPENDITURES AND THEN FIND THAT COMBINATION OF   *
              C** PROJECTS WHICH YIELD THE HIGHEST SUM. SENSITIVITY ANALYSIS WILL
              C** THEN BE DONE TO DETERMINE THE RANGE FOR WHICH THIS SOLUTION    *
              C** REMAINS OPTIMAL.                                             *
              C**                                                              *
              C** VARIBLES:                                                    *
              C**   J           NUMBER OF POSSIBLE PROJECTS                     *
              C**   I           NUMBER OF SECTIONS OF CRIME LAB BEING CONSIDERED *
              C**   CASE(I)     PREDICTED CASELOAD OF SECTION I FOR COMING YEAR *
              C**   COST(J)     COST OF EXPENDITURE J (DECREASING ORDER )       *
              C**   PRIOR(I)    PROBABILITY OF SECTION I COMPLETING ALL THE CASES FOR
              C**               THE COMING YEAR IF NO PROJECTS ARE BOUGHT       *
              C**   PROB(I,J)   INCREMENT INCREASE ON I OF ADDING PROJECT J     *
              C**   BUDGET      BUDGET FOR COMING YEAR                          *
              C**   COSBEN(J)   COST BENEFIT RATIO OF PROJECT J                 *
              C**                                                              *
              C** THE EQUATION FOR THE COST BENEFIT RATIO FOR PROJECT 4 IS      *
              C**         COSBEN(J)=(SUM OVER I  CASE(I)*PROB(I,J))/COST(J)     *
              C**                                                              *
              C** AN ADDITIONAL VARIABLE IS COMB(K) WHICH REPRESENTS THE POSSIBLE  *
              C** COMBINATIONS UNDER THE BUDGET.IT IS A THREE DIGIT NUMBER WHERE   *
              C** EACH DIGIT REPRESENTS A PROJECT.THEREFORE. 123 WOULD BE THW     *
              C** COMBINATION OF PROJECTS 1,2,3.IF IT IS POSSIBLE THAT THERE MAY   *
              C** BE MORE THAN 3 PROJECTS IN A COMBINATION,COMB(K) CAN BE CHANGED TO*
              C** A FOUR(OR MORE) DIGIT NUMBER AND ADDITIONAL STATEMENTS ARE ADDED  *
              C** AT THE PROPER PLACES.                                        *
              C**                                                              *
              C** INPUT:                                                       *
              C**   CARD A      COLS1-5      J                                 *
              C**               COLS6-10     I                                 *
              C**               COLS11-20    BUDGET                            *
              C**   CARD B      CASE(I)      COLS1,11,21,...                   *
              C**   CARD C      COST(J)      COLS1,11,21,...                   *
              C**   CARD D      PRIOR(I)     COLS1,6,11,...                    *
              C**   CARD E      PROB(I,J)    COLS1,6,11,... INCREMENT BY I FIRST  *
              C**                                                              *
              C*****************************************************************
 0001               DIMENSION CASE(6),COST(20),PRIOR(6),PROB(6,20),COSBEN(20)
 0002               DIMENSION S(6),ALLOW(6),B(6,20),C(20)
 0003               INTEGER*4 COMB(50),FLAG(50)
              C**
              C** READ IN THE VARIABLES
              C**
 0004               READ(5,100)J,I,BUDGET
 0005               READ(5,110)(CASE(N),N=1,I)
 0006               READ(5,120)(COST(N),N=1,J)
 0007               READ(5,130)(PRIOR(N),N=1,I)
 0008               READ(5,130)((PROB(N,M),N=1,I),M=1,J)
              C**
              C** CALCULATE THE COMBINATIONS
              C**
 0009               DO 1 K=1,50

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 0010               COMB(K)=0
 0011             1 CONTINUE
 0012               K=0
 0013               DO 25 N=1,J
 0014               K=K+1
 0015               DO 2 L=N,J
 0016               FLAG(L)=0
 0017             2 CONTINUE
 0018               FLAG(N)=1
 0019             3 COMB(K)=COMB(K)+N*100
 0020               ALEFT=BUDGET-COST(N)
 0021               NN=N+1
 0022               IF(NN.GT.J)GO TO 30
 0023               DO 5 M=NN,J
 0024               IF(FLAG(M).EQ.1)GO TO 5
 0025               IF(ALEFT.LT.COST(M))GO TO 4
 0026               COMB(K)=COMB(K)+M*10
 0027               BLEFT=ALEFT-COST(M)
 0028               FLAG(M)=1
 0029               GO TO 6
 0030             4 CONTINUE
 0031               FLAG(M)=1
 0032             5 CONTINUE
 0033               COMB(K)=0
 0034               K=K-1
 0035               GO TO 30
 0036             6 CONTINUE
 0037               IF(M.EQ.J)GO TO 10
 0038               MM=M+1
 0039            12 IF(MM.EQ.J)GO TO 8
 0040               DO 7 LL=MM,J
 0041               IF(BLEFT.LT.COST(LL))GO TO 7
 0042               COMB(K)=COMB(K)+LL
 0043               GO TO 11
 0044             7 CONTINUE
 0045               GO TO 9
 0046             8 CONTINUE
 0047               IF(FLAG(J).EQ.1)GO TO 10
 0048               IF(COST(J).GT.BLEFT) GO TO 9
 0049               COMB(K)=COMB(K)+J
 0050               MMM=M+1
 0051               IF(MMM.EQ.J)GO TO 10
 0052               IF(FLAG(MMM).NE.1)GO TO 9
 0053               GO TO 10
 0054             9 CONTINUE
 0055               K=K+1
 0056               GO TO 3
 0057            11 CONTINUE
 0058               IF(LL.EQ.J)GO TO 9
 0059               K=K+1
 0060               COMB(K)=COMB(K)+N*100+M*10
 0061               MM=LL+1
 0062               GO TO 12
 0063            10 CONTINUE
 0064               NO1=COMB(K)/100
 0065               NO2=(COMB(K)-(NO1*100))/10
 0066               NO3=(COMB(K)-(NO1*100)-(NO2*10))
 0067               IF(NO3.EQ.0)GO TO 14
 0068               TOTAL=COST(NO1)+COST(NO2)+COST(NO3)
 0069               GO TO 15
 0070            14 IF(NO2.EQ.0)GO TO 15
```

```
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                  TOTAL=COST(NO1)+COST(NO2)
                  GO TO 16
               15 TOTAL=COST(NO1)
               16 DIFF=BUDGET-TOTAL
                  DO 20 II=1,J
                  IF(COST(II).LE.DIFF)GO TO 3000
               20 CONTINUE
                  GO TO 25
             3000 CONTINUE
                  IF(II.EQ.NO1.OR.II.EQ.NO2.OR.II.EQ.NO3)GO TO 25
                  GO TO 30
               25 CONTINUE
               30 CONTINUE
                  COMB(K)=0
                  K=K-1
            C**
            C** THE TOTAL INCREASE IN PROB FOR SECTION I PLUS THE PROB IF NO
            C** PROJECTS ARE BOUGHT MUST BE LESS THAN OR EQUAL TO 1
            C**
                  DO 32 N=1,I
                  TOTAL=0.0
                  DO 31 M=1,J
                  TOTAL=TOTAL+PROB(N,M)
               31 CONTINUE
                  IF(TOTAL.GT.1.0)GO TO 33
                  ALLOW(N)=1.0-TOTAL
               32 CONTINUE
                  GO TO 34
            C**
            C** WRITE OUT AN ERROR MESSAGE FOR INCORRECT PROB(I,J)
            C**
               33 CONTINUE
                  WRITE(6,505)I
                  GO TO 900
            C**
            C** CALCULATE THE COST BENEFIT RATIOS FOR ALL PROJECTS
            C**
               34 CONTINUE
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,CASE,PRIOR,J,COST,PROB)
            C**
            C** PERTURB CASE UPWARDS,ONE AT A TIME
            C**
                  DO 55 M=1,I
                  DO 50 L=1,I
                  A(L)=CASE(L)
               50 CONTINUE
                  DO 51 N=1,5
                  A(M)=A(M)+.02*CASE(M)
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,A,PRIOR,J,COST,PROB)
               51 CONTINUE
               55 CONTINUE
            C**
            C** PERTURB CASE DOWNWARDS,ONE AT A TIME
            C**
                  DO 60 M=1,I
                  DO 56 L=1,I
                  A(L)=CASE(L)
               56 CONTINUE
                  DO 57 N=1,5
                  A(M)=A(M)-.02*CASE(M)
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,A,PRIOR,J,COST,PROB)
```

```
FORTRAN IV G LEVEL  19                MAIN              DATE = 71126          09/36/46             PAGE 0004

               57 CONTINUE
               60 CONTINUE
            C**
            C** PERTURB ALL CASES UPWARDS
            C**
                  DO 61 M=1,I
                  A(M)=CASE(M)
               61 CONTINUE
                  DO 63 L=1,5
                  DO 62 M=1,I
                  A(M)=A(M)+.02*CASE(M)
               62 CONTINUE
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,A,PRIOR,J,COST,PROB)
               63 CONTINUE
            C**
            C** PERTURB ALL CASES DOWNWARDS
            C**
                  DO 66 M=1,I
                  A(M)=CASE(M)
               66 CONTINUE
                  DO 65 L=1,5
                  DO 64 M=1,I
                  A(M)=A(M)-.02*CASE(M)
               64 CONTINUE
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,A,PRIOR,J,COST,PROB)
               65 CONTINUE
            C**
            C** PERTURB PROB UPWARDS ONE AT A TIME
            C** MAKING SURE TOTAL PROB DOES NOT EXCEED 1
            C**
                  DO 85 N=1,I
                  DO 82 M=1,J
                  SUM=0.0
                  DO 80 L=1,I
                  DO 79 LL=1,J
                  B(L,LL)=PROB(L,LL)
               79 CONTINUE
               80 CONTINUE
                  DO 81 MM=1,4
                  SUM=SUM+.01
                  IF(SUM.GT.ALLOW(N))GO TO 82
                  B(N,M)=B(N,M)+.01
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,CASE,PRIOR,J,COST,B)
               81 CONTINUE
               82 CONTINUE
               85 CONTINUE
            C**
            C** PERTURB PROB DOWNWARDS ONE AT A TIME
            C** MAKING SURE NOT TO GO BELOW PRIOR
            C**
                  DO 95 N=1,I
                  DO 92 M=1,J
                  SUM=0.0
                  DO 90 L=1,I
                  DO 89 LL=1,J
                  B(L,LL)=PROB(L,LL)
               89 CONTINUE
               90 CONTINUE
                  DO 91 MM=1,4
                  SUM=SUM+.01
                  IF(SUM.GT.PROB(N,M))GO TO 92
```



```
FORTRAN IV G LEVEL  19                MAIN              DATE = 71126          09/36/46             PAGE 0005

                  B(N,M)=B(N,M)-.01
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,CASE,PRIOR,J,COST,B)
               91 CONTINUE
               92 CONTINUE
               95 CONTINUE
            C**
            C** PERTURB COSTS UPWARDS
            C**
                  DO 42 M=1,J
                  DO 40 L=1,J
                  C(L)=COST(L)
               40 CONTINUE
                  DO 41 N=1,5
                  C(M)=C(M)+.02*COST(M)
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,CASE,PRIOR,J,C,PROB)
               41 CONTINUE
               42 CONTINUE
            C**
            C** PERTURB COSTS DOWNWARDS
            C**
                  DO 45 M=1,J
                  DO 43 L=1,J
                  C(L)=COST(L)
               43 CONTINUE
                  DO 44 N=1,5
                  C(M)=C(M)-.02*COST(M)
                  CALL CALC(COSBEN,K,COMB,BUDGET,I,CASE,PRIOR,J,C,PROB)
               44 CONTINUE
               45 CONTINUE
              100 FORMAT(2I5,F8.0)
              110 FORMAT(6F10.0)
              120 FORMAT(8F10.0)
              130 FORMAT(16F5.3)
              505 FORMAT('1','THE INCREMENT PROBABILITIES IN SECTION',I4,
                 1       ' ARE TOO LARGE')
              900 CONTINUE
                  STOP
                  END
```

THE SOLUTION FOR THE FOLLOWING CASE
****

BUDGET= 27500.

SECTION	CASELOAD	PROBABILITY(NO PROJECTS)
1	10000.	0.730
2	1000.	0.300

EXPENDITURE	COST	PROBABILITIES		COST BENEFIT RATIO
1	23000.	0.020	0.150	0.01565
2	15000.	0.040	0.040	0.02933
3	12000.	0.070	0.060	0.06333
4	10000.	0.050	0.140	0.06400
5	3500.	0.030	0.100	0.11429
6	2500.	0.0	0.050	0.02000

COMBINATION	TOTAL COST BENEFIT
150	0.1299
160	0.0357
230	0.0927
246	0.1133
256	0.1636
345	0.2416
346	0.1473
356	0.1976
456	0.1983

THE OPTIMAL COMBINATION IS   345
WITH A TOTAL COST BENEFIT OF   0.2416

APPENDIX IX

CRIME LABORATORY SURVEY ANALYSIS

This appendix contains sample questionnaire forms from a nation-wide survey of Forensic science laboratories designed to compile statistics regarding case distribution, manpower allocation costs and historical trends over the past ten years. Results of the 35 responses from the 106 laboratories surveyed and possible projections using the data are presented. The purpose of this section of the overall study was to assist in both long term and projections for a specific laboratory as well as to relate a specific laboratory to the performance standards of laboratories nation-wide.

Five years ago the John Jay College of Criminal Justice, City University of New York, conducted a national survey of crime laboratories. That survey resulted in a compilation of basic statistics on ninety-two crime laboratories and an appendix (dated April 1967) containing a list of 106 crime laboratories in the United States (and four labs in Canada), (4). The seven member Advisory Board of consultants for the John Jay College study "set a criterion that a laboratory which did not at least do wet chemistry was not to be included in the data analysis." (1) "One hundred and forty (140) replies to the John Jay College questionnaire were received; from the remaining, 55 letters were received indicating that there was no such laboratory, and five laboratories known to exist did not reply to the questionnaire."

The results of the John Jay survey have served as a basis for subsequent studies on crime laboratories, including the recent Midwest Research Institute report. This latter report together with the John Jay study provide the most comprehensive collection of crime lab statistics presently available. However, there are certain deficiencies in the existing data base which limit analyses of crime lab operations and funding. First, the John Jay study reflects laboratory conditions in the mid-Sixties, the survey having been conducted in 1966. Second, the survey does not provide historical data to show changing trends in laboratory demands and capabilities. Third, the John Jay survey data is not homogeneous. For example, lab budgets shown may or may not include salaries. Also, case load data includes a mixture of various types of cases depending on the definition of case load to the individual crime laboratory. Problems then arise in trying to analyze changes in the data base over time.

To establish a consistent data base which could serve as a basis for analysis of crime laboratory systems and to aid in understanding organizational considerations affecting funding of crime laboratories, a criminalistics laboratory survey was designed and distributed to the 106 crime laboratories in the United States, listed in Appendix No. 2 of the John Jay College Report. (4)

The results of this University of Pennsylvania survey and comparison with John Jay results are interesting not only from the standpoint of describing some of the basic features of crime laboratories but also for the questions that are raised as a result of analysis of the data.

The University of Pennsylvania crime lab survey was designed to obtain operational and funding data for the past ten years. The questions were designed to gather sufficient data to gain an understanding of crime lab funding and operations and to provide a basis for analysis of changes in basic crime lab variables over time. Unfortunately, the information requested could not be provided by many of the crime laboratories. Responses were received from thirty-five laboratories, or roughly one-third of those surveyed. Though few labs were able to complete the survey fully, nevertheless, the information that was provided does provide some insights into the significant changes taking place in crime labs. In this respect the survey has been a help in the major effort of this study, describing and explaining funding and decision processes relating to crime laboratories.

SURVEY FORMS FOR THE NATIONAL CRIME LABORATORY SURVEY

Criminalistics Laboratory Survey

1. What has been the total case load handled by your crime laboratory during each of the past ten years?

Year	Total Cases	Drugs	Index Crimes	Other
1961				
1962				
1963				
1964				
1965				
1966				
1967				
1968				
1969				
1970				

If further breakdown of cases under the "others" heading is available, please indicate on separate sheet.

2. It is generally true that the average effort differs widely from one crime type to another. Some crime labs keep data on manhour utilization by crime types. Do you keep such records? Yes ______ No ______

In any case an intelligent guess of this would be helpful.

Please indicate the distribution of manhour percentages in the following table. If the data is readily available you may break down the "others" category in further detail. You may go back as many years in the table as are conveniently available.

Crime Type	1970	1969	1968	1967	1966	1965	1964	1963	1962	1961
Drugs										
Index										
Others										

3. The geographical area under your jurisdiction may or may not be strictly defined.

Do you have a well defined jurisdiction? Yes _____ No _____

If so, is the jurisdiction defined by Law ___ Past Practice _____?

Is your jurisdiction defined by Municipality _____, City _____, County _____, State _____, Other _____? If "other" please explain.

Any further clarifications?

On the basis of your judgement and any data available, what would be the current percentage breakdown of number of cases and manhours originating from within your jurisdiction as opposed to those referred from outside?

	% Cases	% Man power
Within Jurisdiction		
Outside Jurisdiction (other labs or other authorities)		

4. What type of crime index do you use in relation to your area of operation? What is the geographical area covered?

Please give data on the Crime Index for the area you mention. Please give indices by crime type, if data is available; otherwise, give the single index you may use.

	1970	1969	1968	1967	1966	1965	1964	1963	1962	1961
Drugs										
Index										
Others										

If you have your own separate classification of crime type, please attach similar data on that basis.

5. Please give the breakdown by number of personnel and total salary * expenses under the following categories:

	No. of Personnel	Total Salary Costs
Lab Professionals		
Clerical		

* Total salaries include salary, fringe benefits, traveling, overtime, etc.

6. What is the vary approximate total value at current replacement prices of the equipment that you have at present?

7. Please provide a breakdown of your expenses for the past years and the current year's budget under the following headings (in thousands of dollars).

	1971 Budget	1970	1969	1968	1967	1966	1965	1964
Total Salaries								
Total Equipment								
Payments to Other labs								
Payments to Public Agencies								
Others								

8. Please show the percentage breakdown of your source of funds in the table below. You may give dollar figures instead of percentages, if it is more convenient.

	Untied	Tied to Salaries	Tied to Equipment in general	Tied to Specific Equipment	Total
Municipal					
City					
County in which lab is situated					
Counties for which lab handles cases					
State					
Federal					

In addition you may have some funds generated by the work you have done for other crime labs. Please mention the current level of this source.

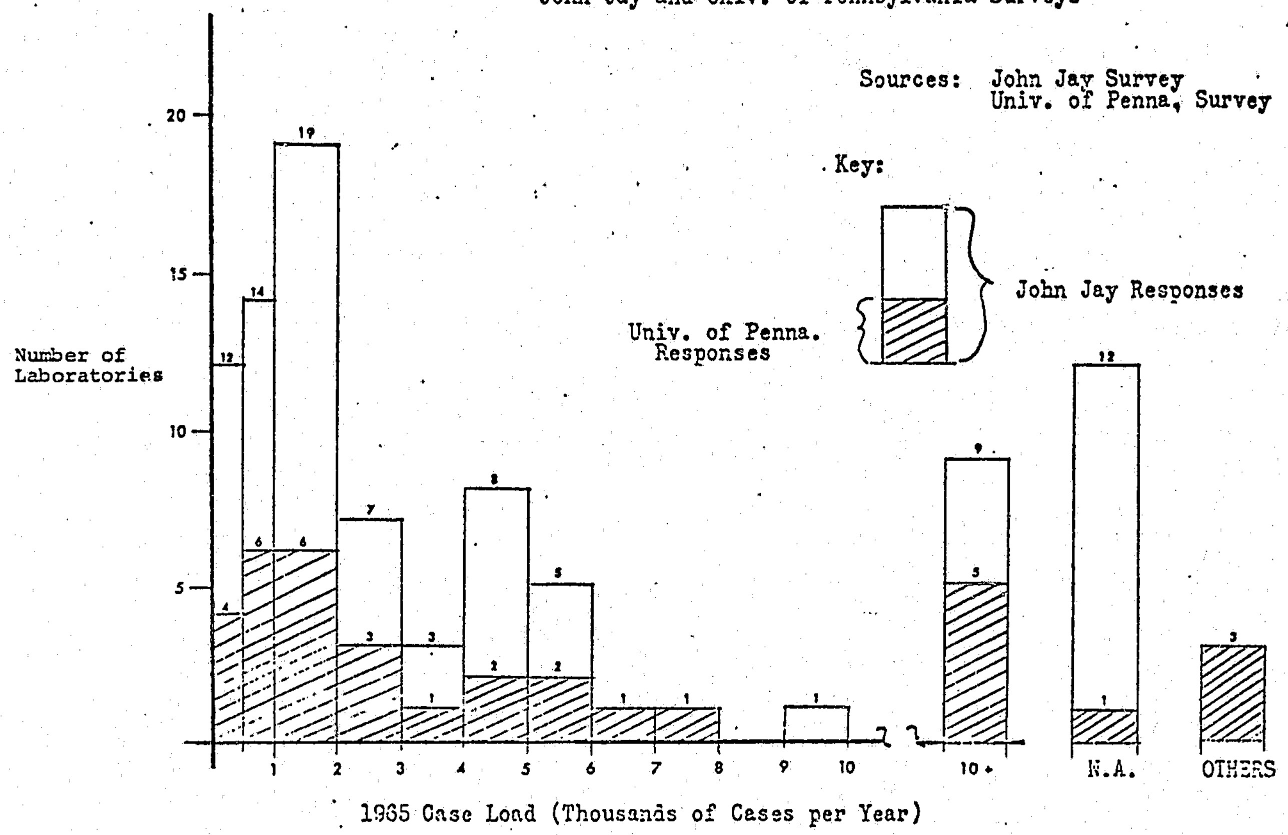
Do you exercise any control on the choice of cases that you work on?

RESULTS AND ANALYSIS OF THE QUESTIONNAIRE

CRIME LAB RATIOS : COMPOSITE OF JOHN JAY AND UNIV. OF PENNA. SURVEYS

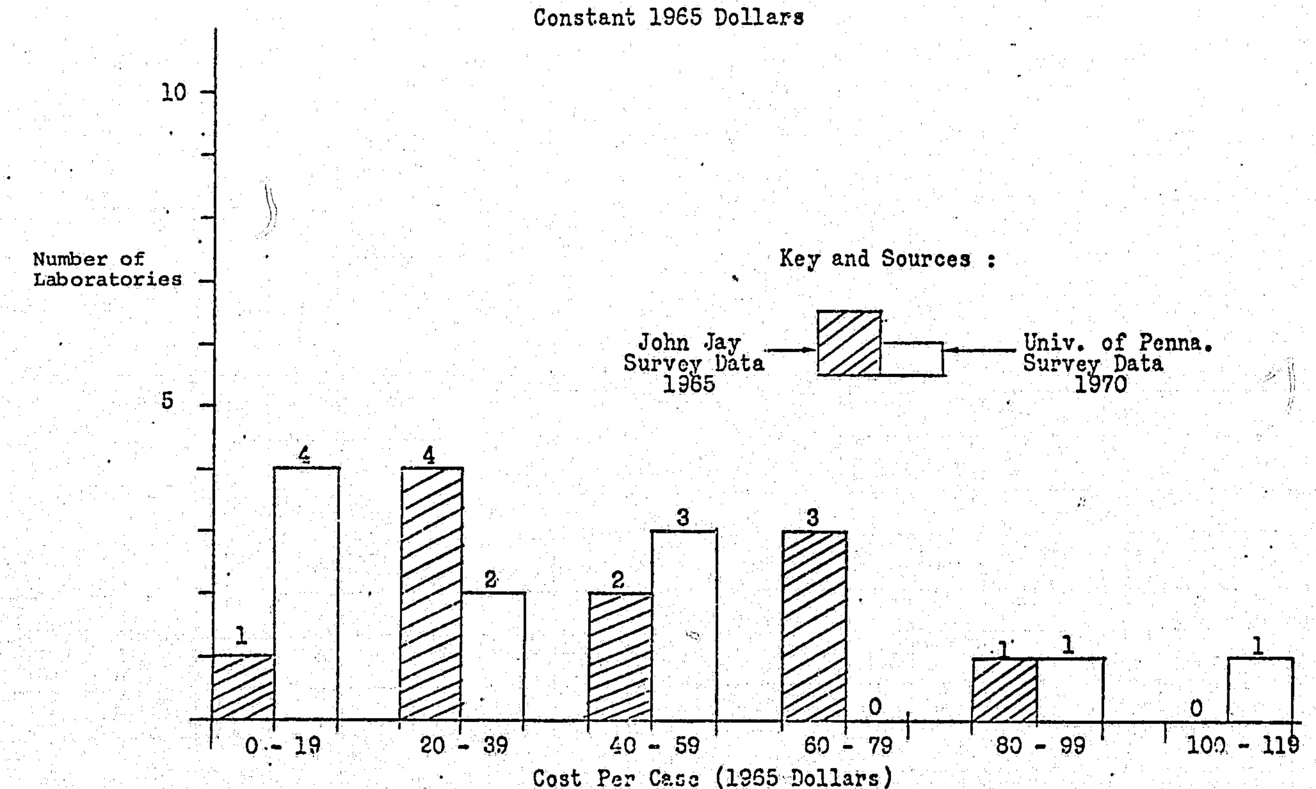
Laboratory	(1) Cost Per Case (Dollars)		(2) Cases Per Examiner		(3) Cases Per Capita X 10^3		(4) Cost Per Employee		(5) Examiners Per Capita X10^6		(6) Percent Clerks		(7) Percent Police		(8) Cases Per Officer	
	J.J.	U.P.	J.J.	U.P.	J.J	U.P	J.J.	U.P.	J.J.	U.P.	J.J.	U.P.	J.J.	U.P.	J.J.	U.P.
1. Kern County, Cal.			252	816				20.3			0%	0%	0%			
2. Los Angeles, Cal.	19		482	1180	2.6		8.1		5.4		13	14	41			
3. San Bernadino, Cal.		16	575	955	.3			11.3	5.7		33	27	0			
4. Contra Costa, Cal.	20	51	1045	457	7.0		15.4	16.6	6.7		25	29	33			
5. San Mateo, Cal.	1	48	875	333			1.3	13.8			0	14	0			
6. Monroe County, N.Y.	89	62	200	1600	1.3		11.9	21.3	6.4		33	25	0			
7. Suffolk County, N.Y.		56	179	300	1.6			15.7	9.0		10	7	89			
8. Auburn, Alabama	50	102	190	234	1.2	1.7	7.2	17.1	6.0	7.3	28	29	0			
9. Sacramento, Cal.	66	126	382	189	3.3	5.9	25.0	17.3	8.6	31.2	0	27	0			
10. Des Moines, Iowa	New Laboratory									3.2		25				
11. Boston, Mass.	14	61	1114	236	1.6	.5	13.8	12.2	1.4	2.1	13	14	0			
12. Lansing, Mich.	13	124	792	154	3.2	1.0	8.8	16.8	4.0	6.8	14	12	83			
13. Detroit, Mich.	27	21	258	650	.6	1.9	6.9	13.6	2.5	3.2	0	0	0			
14. St. Paul, Minn.		198	99	95	.2	.5		15.4	2.0	4.7	13	13	0			
15. Albany, N.Y.	99		314		.7	.6	25.0		2.3		20		50			
16. Richmond, Va.	32	8	1143	2150	2.3	3.2	30.0	11.5	2.0	1.5	18	30	0			
17. Tuscon, Arizona	40	39	300	346	1.7	4.0	12.0	13.6	5.7	11.6	0	0	50			
18. Glendale, Cal.		40	122	261	3.8	7.9		10.4	30.8	30.2	0	0	75			
19. San Francisco, Cal.	20	18	490	790	8.5	18.0	8.1	11.8	17.3	22.7	19	16	77			
20. Santa Ana, Cal.		23	125	930	3.6	12.7		15.0	2.9	12.9		33	100			
21. Chicago, Illinois			637		6.9						11		85			
22. New Orleans, La.		93	50	207	.1	3.5		20.3		17.0						
23. Grand Rapids, Mich.								33.0	6.0		100	50				
24. Duluth, Minn.	71				3.2											
25. Kansas City, Mo.	38		132		2.9		6.1	10.5	16.0		11	7	50			
26. St. Louis, Mo.	9	55	252	417	1.3	3.3	2.1	15.3	4.0	20.0	17	33	60			
27. New York City, N.Y.	1	30	228		2.3	6.5	.3		10.2		3		96			
28. Dayton, Ohio	60	23	210	525	3.8	13.0	12.5	9.1	13.0			25	91			
29. Phila. Pa.	70	45	149		1.5		9.4				10		43			
30. Alexandria, Va.	2	80	109	210	5.4		.2	14.5	50.0		14	14	100			
31. Seattle, Wash		71														
32. Hartford, Conn.																
33. Trenton, N.J.																
34. Harrisburg, Pa.	87		130		.2		10.4		1.5		8		67			

Comparison of Survey Responses
1965 Case Load Rankings of Laboratories
John Jay and Univ. of Pennsylvania Surveys

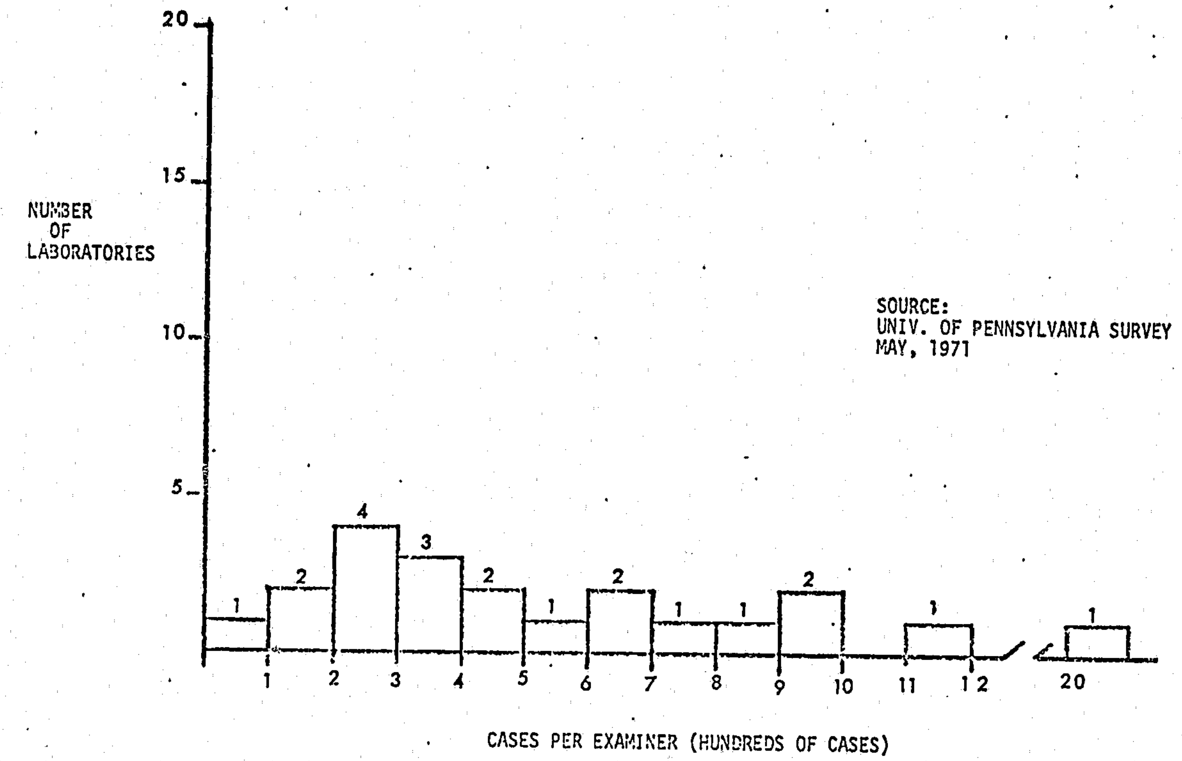


Comparison of Cost Per Case
John Jay vs. Univ. of Penna. Surveys
1965 vs. 1970

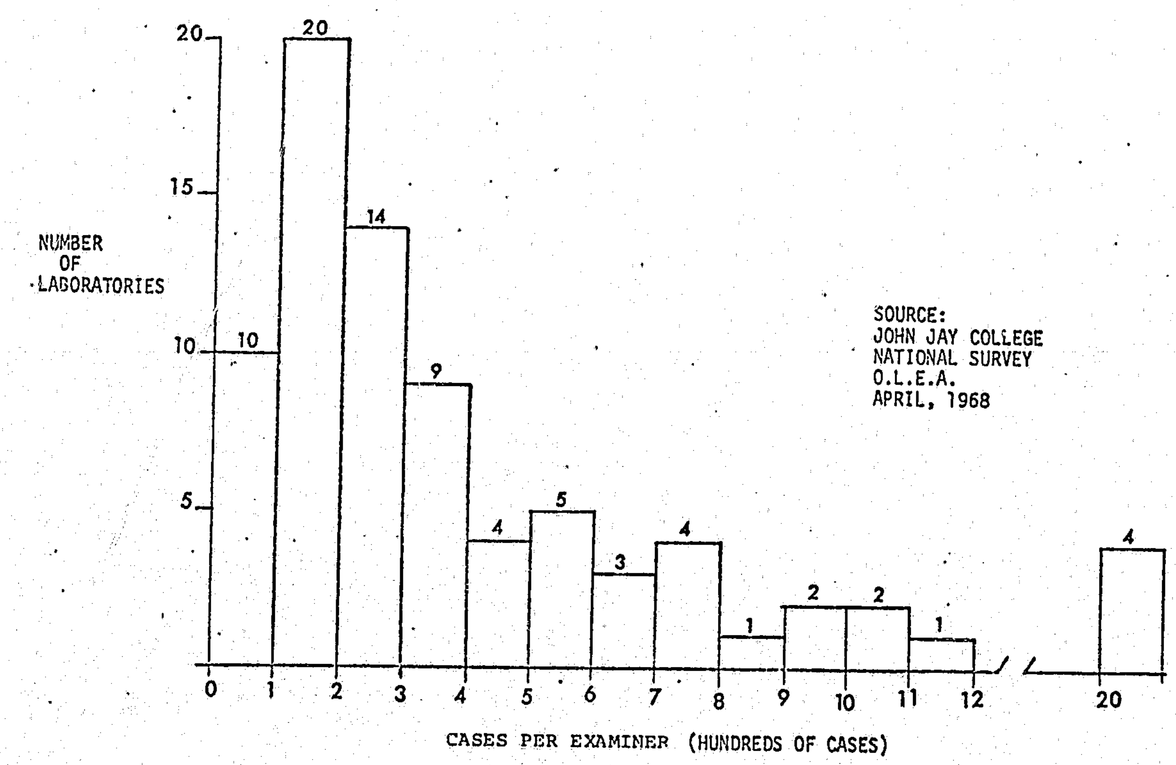
Constant 1965 Dollars



FREQUENCY DISTRIBUTION
CASE LOAD PER EXAMINER
(UNIVERSITY OF PENNSYLVANIA SURVEY)

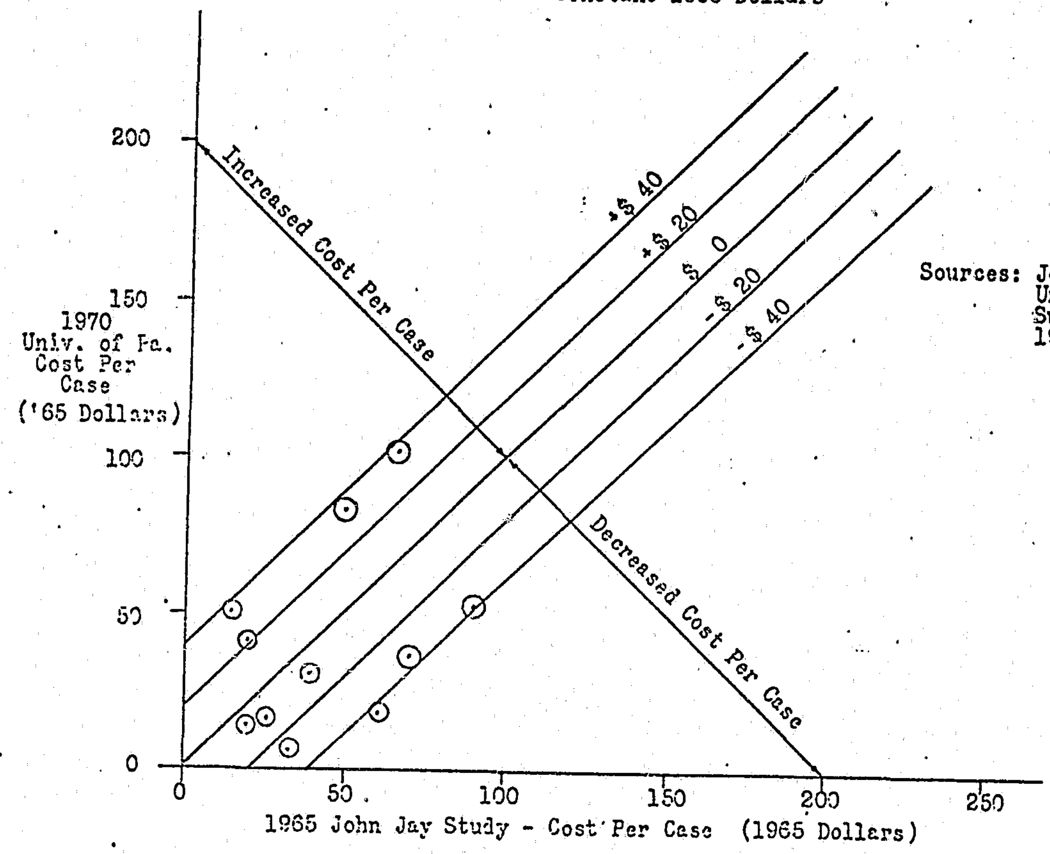


FREQUENCY DISTRIBUTION
CASE LOAD PER EXAMINER
(JOHN JAY STUDY)



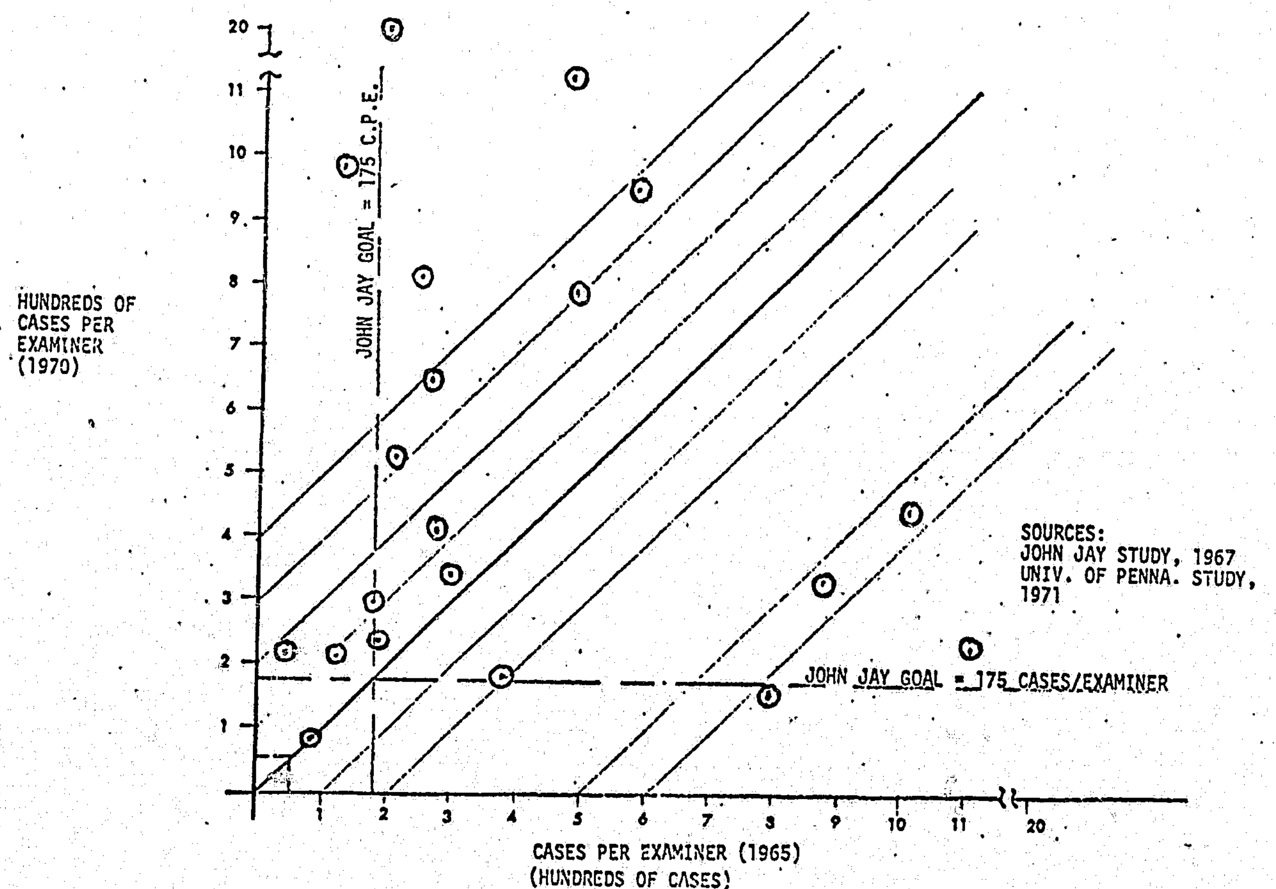
Cost Per Case : 1970 vs. 1965

Constant 1965 Dollars

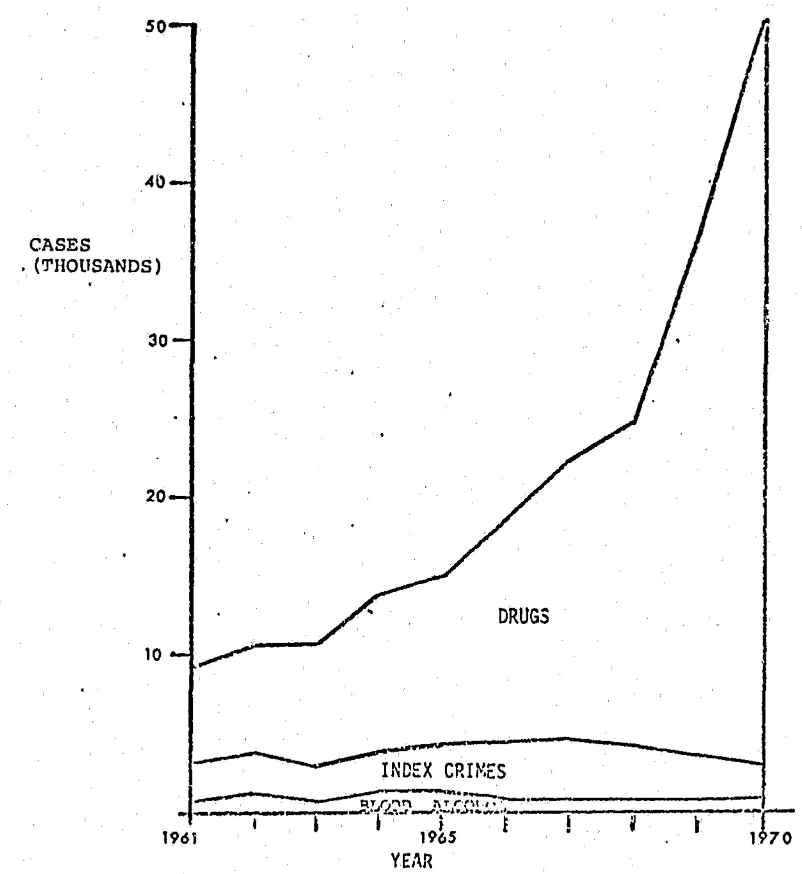


Sources: John Jay Survey
Univ. of Penna. Survey
Survey of Current Business
1965 and 1970 for C.P.I.

CASES PER EXAMINER: 1970 VS. 1965

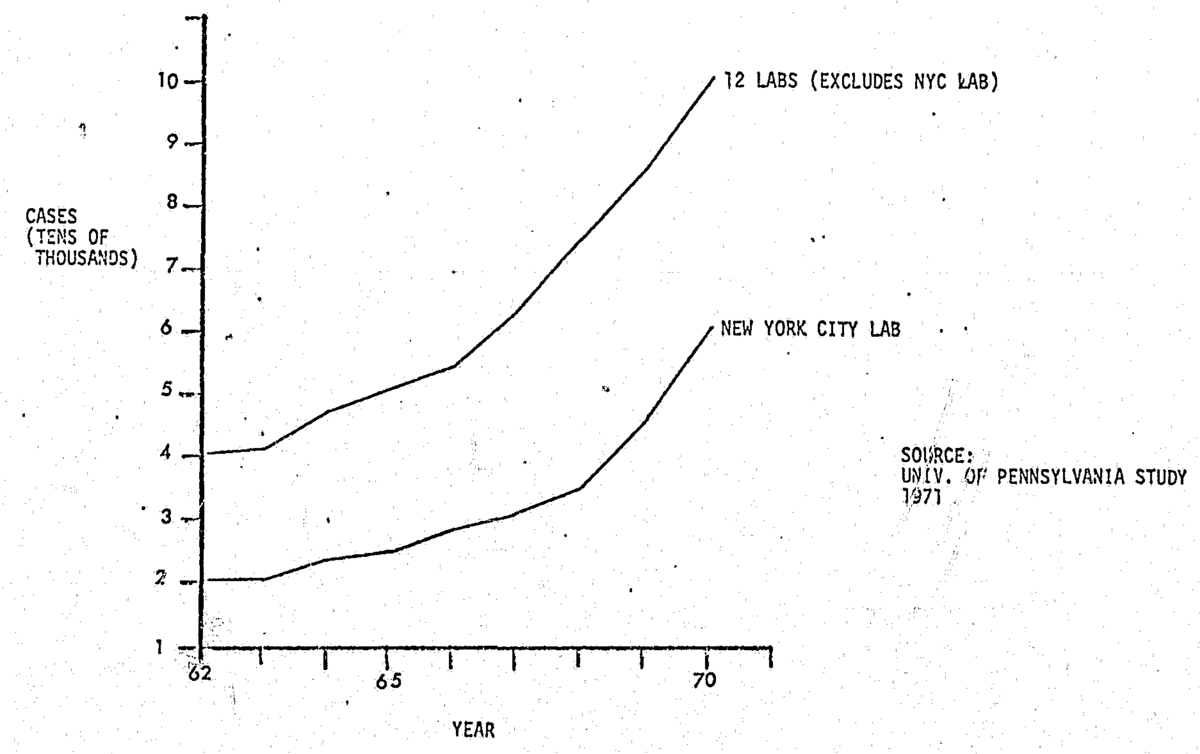


CASE MIX BY YEAR
NEW YORK CITY CRIME LAB



SOURCE:
UNIV. OF PENNSYLVANIA
SURVEY, MAY, 1971

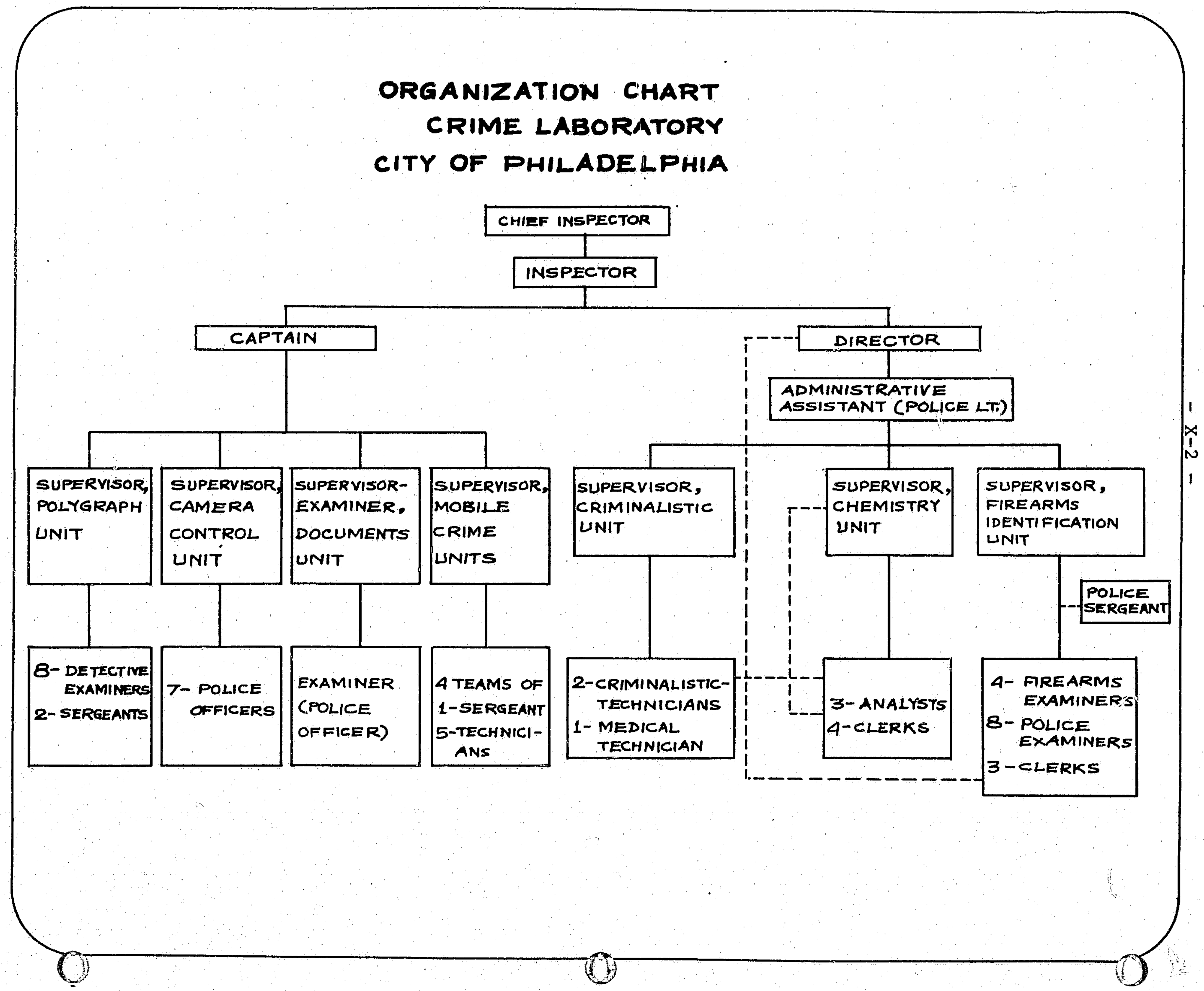
CASE LOAD GROWTH
1961 - 1970



APPENDIX X

This Appendix presents detailed organizational charts of the Philadelphia Crime Laboratory, the New Jersey Criminal Justice System and Crime Laboratory, and less detailed charts and a sample Laboratory Analysis Form from the Pennsylvania Crime Laboratory. The purpose of presenting this archival material is to aid the reader in placing the crime laboratory in perspective with the overall organization it serves.

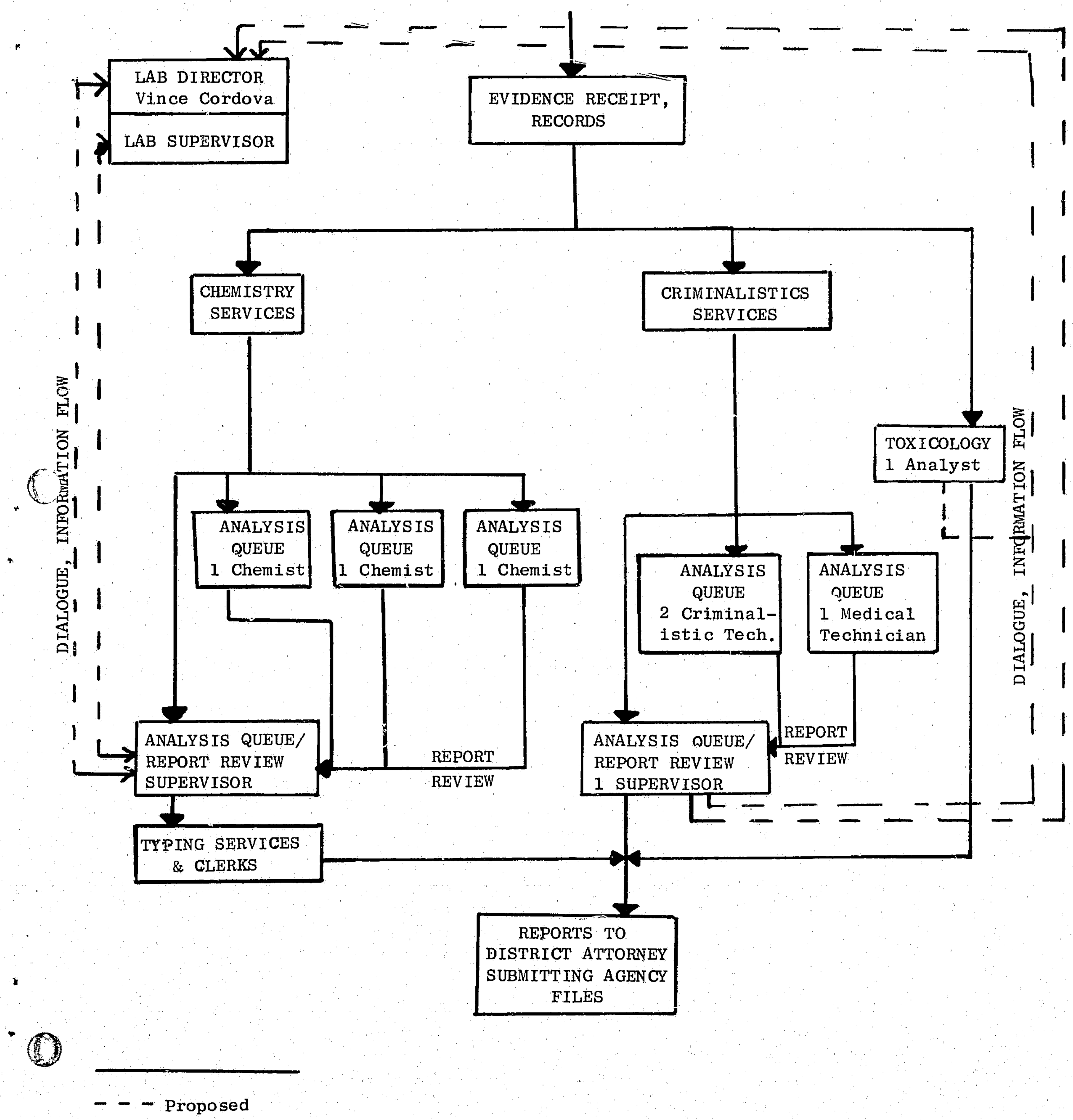
The Philadelphia Crime Laboratory organization charts follow. The Criminal Justice System flow charts for Philadelphia have been presented previously.


ORGANIZATION CHART
CRIME LABORATORY
CITY OF PHILADELPHIA
CHIEF INSPECTOR
INSPECTOR
CAPTAIN
DIRECTOR
ADMINISTRATIVE ASSISTANT (POLICE LT.)
SUPERVISOR, POLYGRAPH UNIT
SUPERVISOR, CAMERA CONTROL UNIT
SUPERVISOR-EXAMINER, DOCUMENTS UNIT
SUPERVISOR, MOBILE CRIME UNITS
SUPERVISOR, CRIMINALISTIC UNIT
SUPERVISOR, CHEMISTRY UNIT
SUPERVISOR, FIREARMS IDENTIFICATION UNIT
POLICE SERGEANT
8- DETECTIVE EXAMINERS
2- SERGEANTS
7- POLICE OFFICERS
EXAMINER (POLICE OFFICER)
4 TEAMS OF 1-SERGEANT 5-TECHNICIANS
2-CRIMINALISTIC-TECHNICIANS
1- MEDICAL TECHNICIAN
3- ANALYSTS
4-CLERKS
4- FIREARMS EXAMINERS
8- POLICE EXAMINERS
3-CLERKS

PHILADELPHIA CRIME LABORATORY

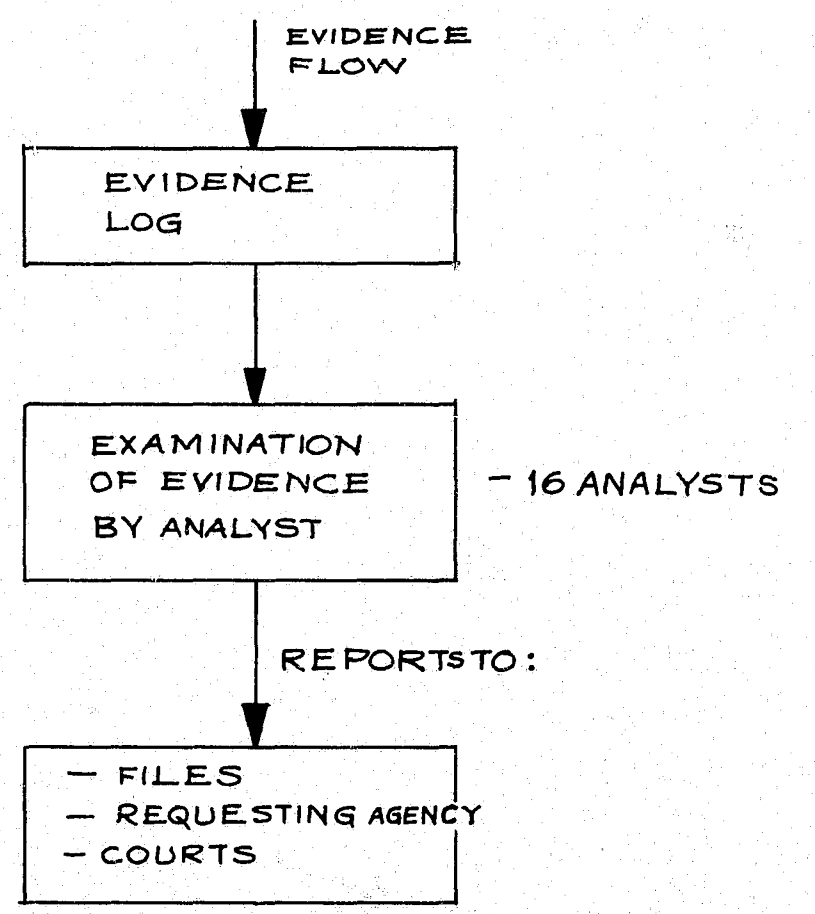
JUNE 1971

CHEMISTRY - CRIMINALISTICS



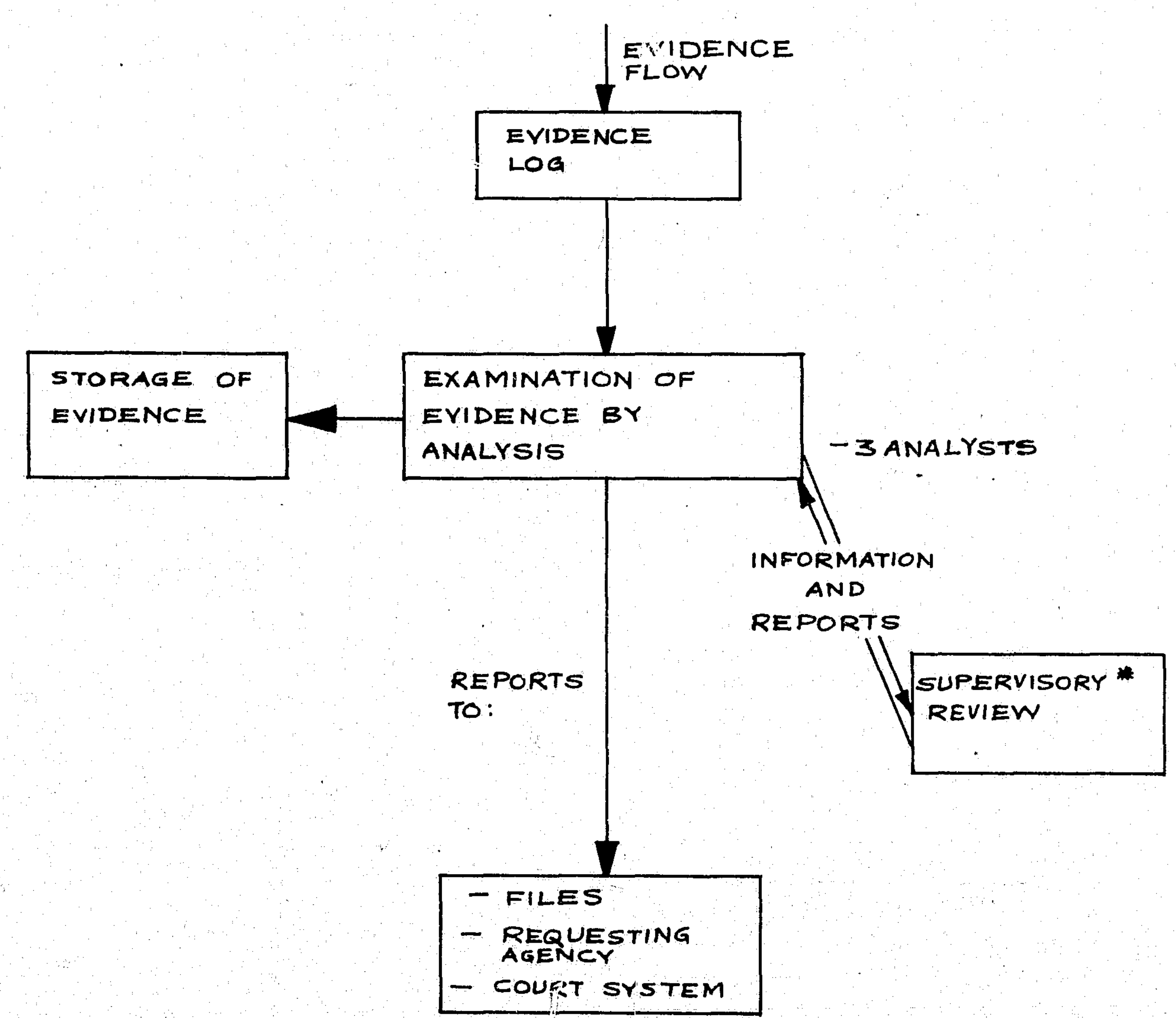
PHILADELPHIA CRIME LABORATORY

FIREARMS IDENTIFICATION (JUNE 1971)

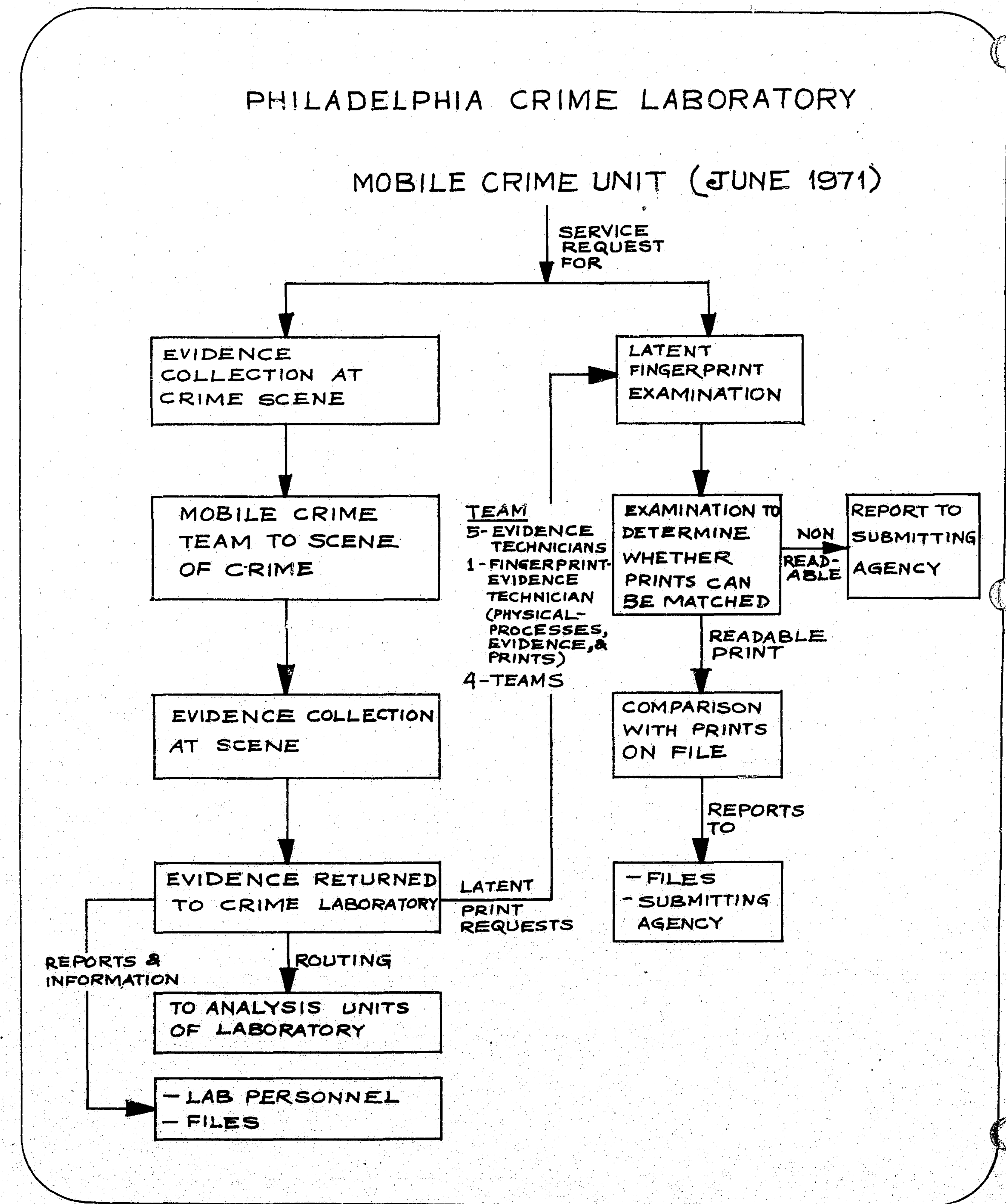


PHILADELPHIA CRIME LABORATORY

DOCUMENT ANALYSIS UNIT (JUNE 1971)

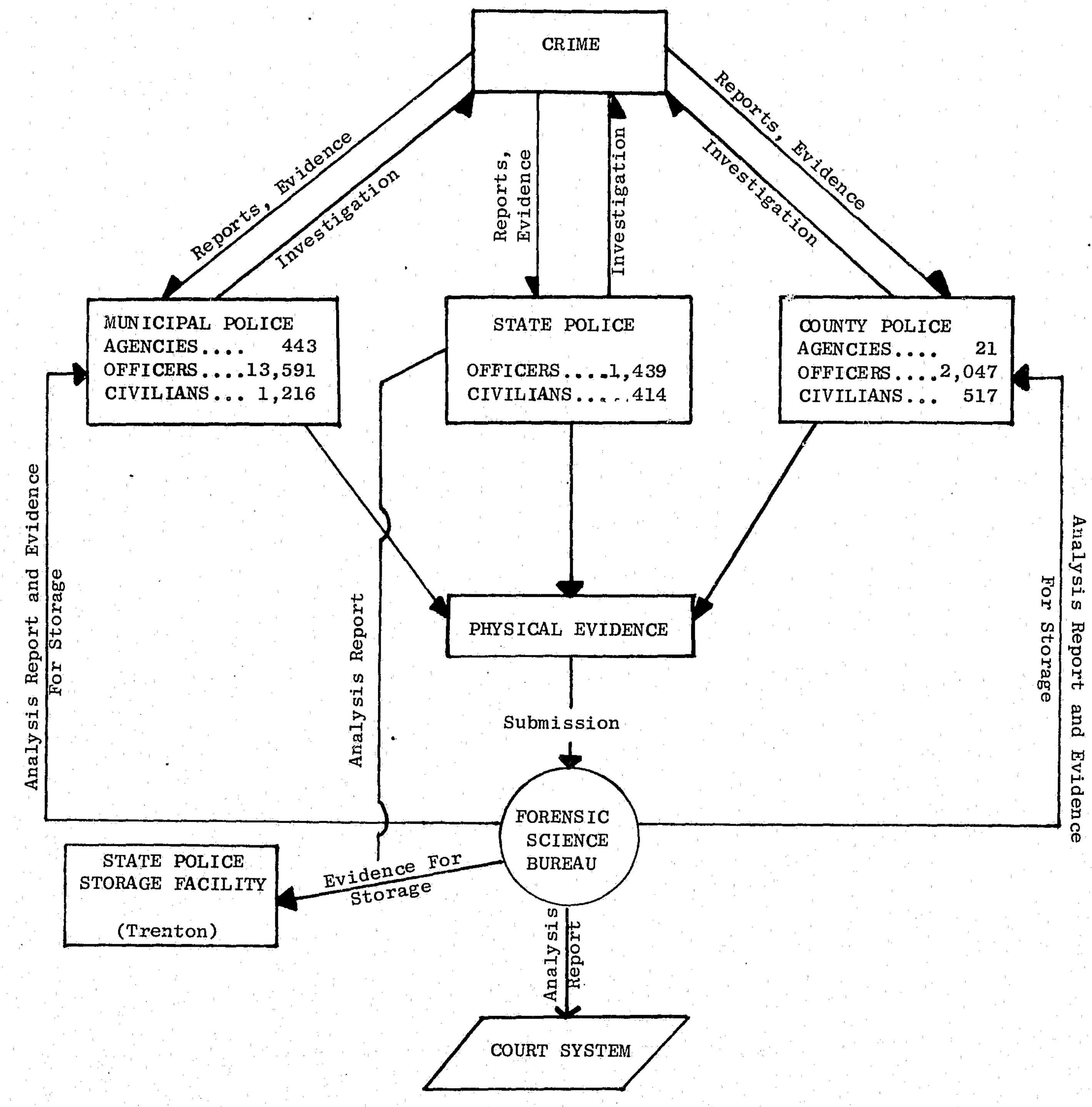


* IN THE DOCUMENTS UNIT, THE SUPERVISOR IS AN ANALYST AS WELL



THE NEW JERSEY CRIMINAL JUSTICE SYSTEM AND CRIME LABORATORY

NEW JERSEY CRIMINAL JUSTICE SYSTEM



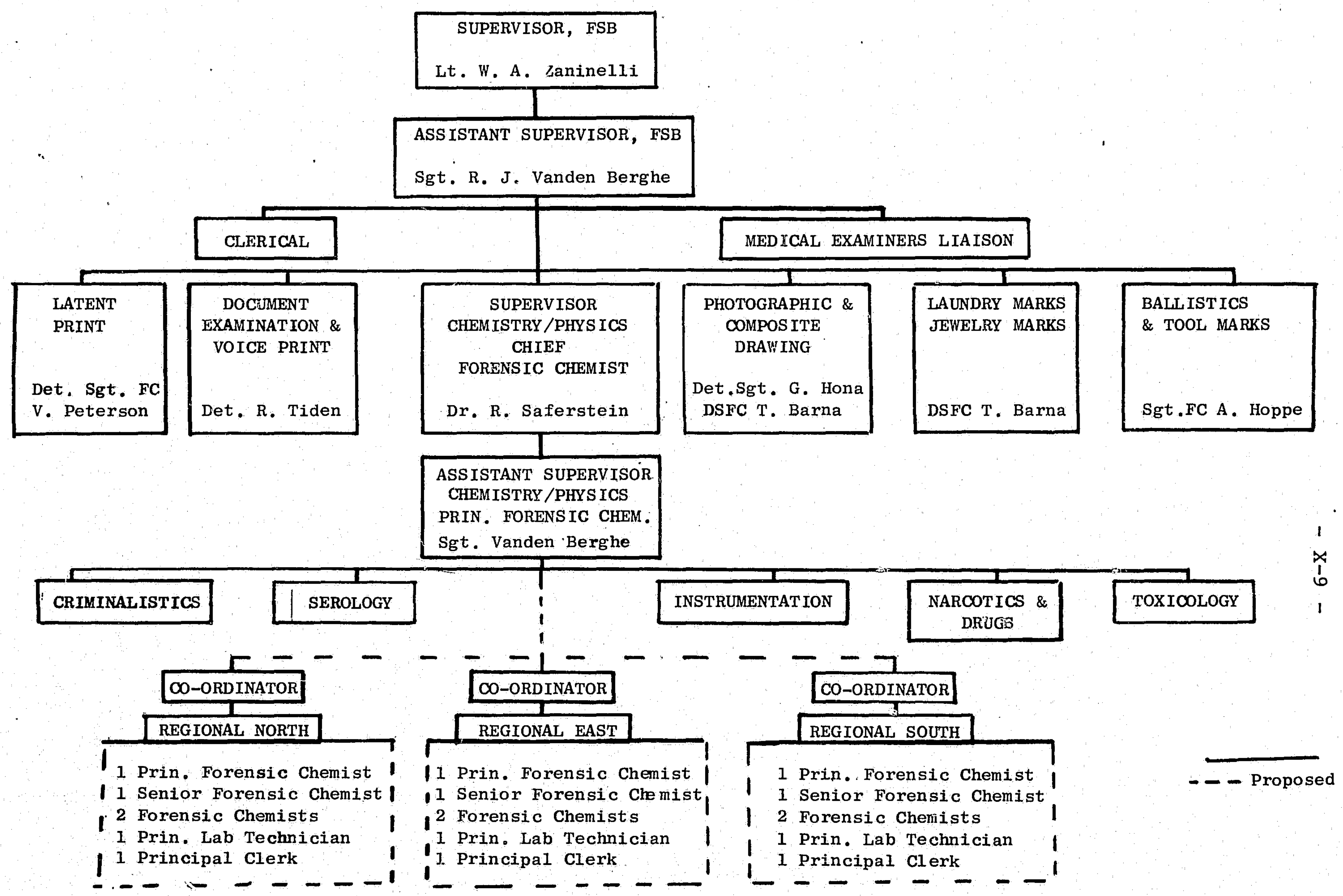
1969 Figures

State Population (est.)	7,283,440
Total Index Crimes	175,554

*Total Non-Index Crimes
**Cases Completed by F.S.B.

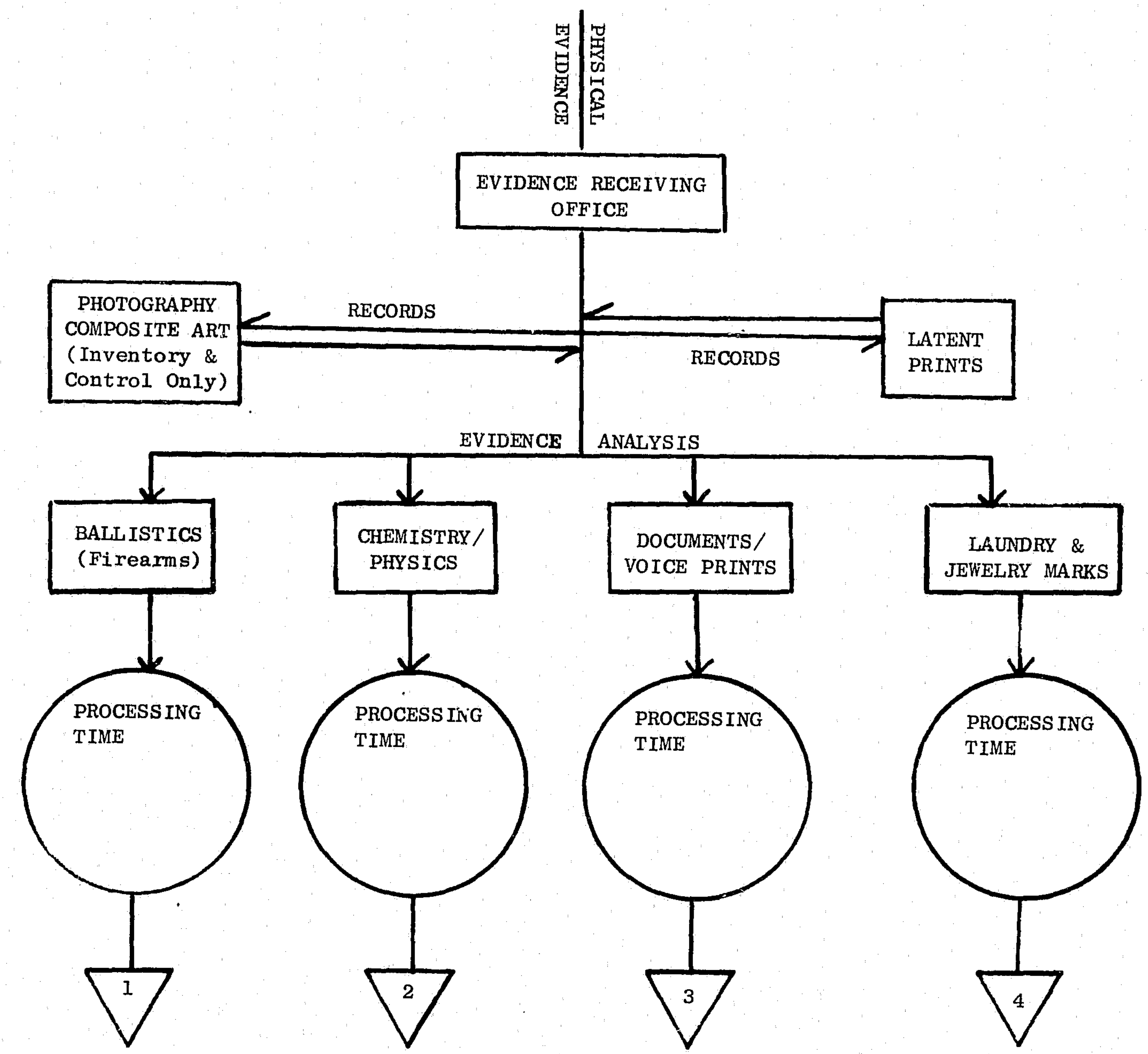
FORENSIC SCIENCE BUREAU (FSB) OF THE STATE OF NEW JERSEY

JUNE 1971



FORENSIC SCIENCE BUREAU (FSB) OF THE STATE OF NEW JERSEY

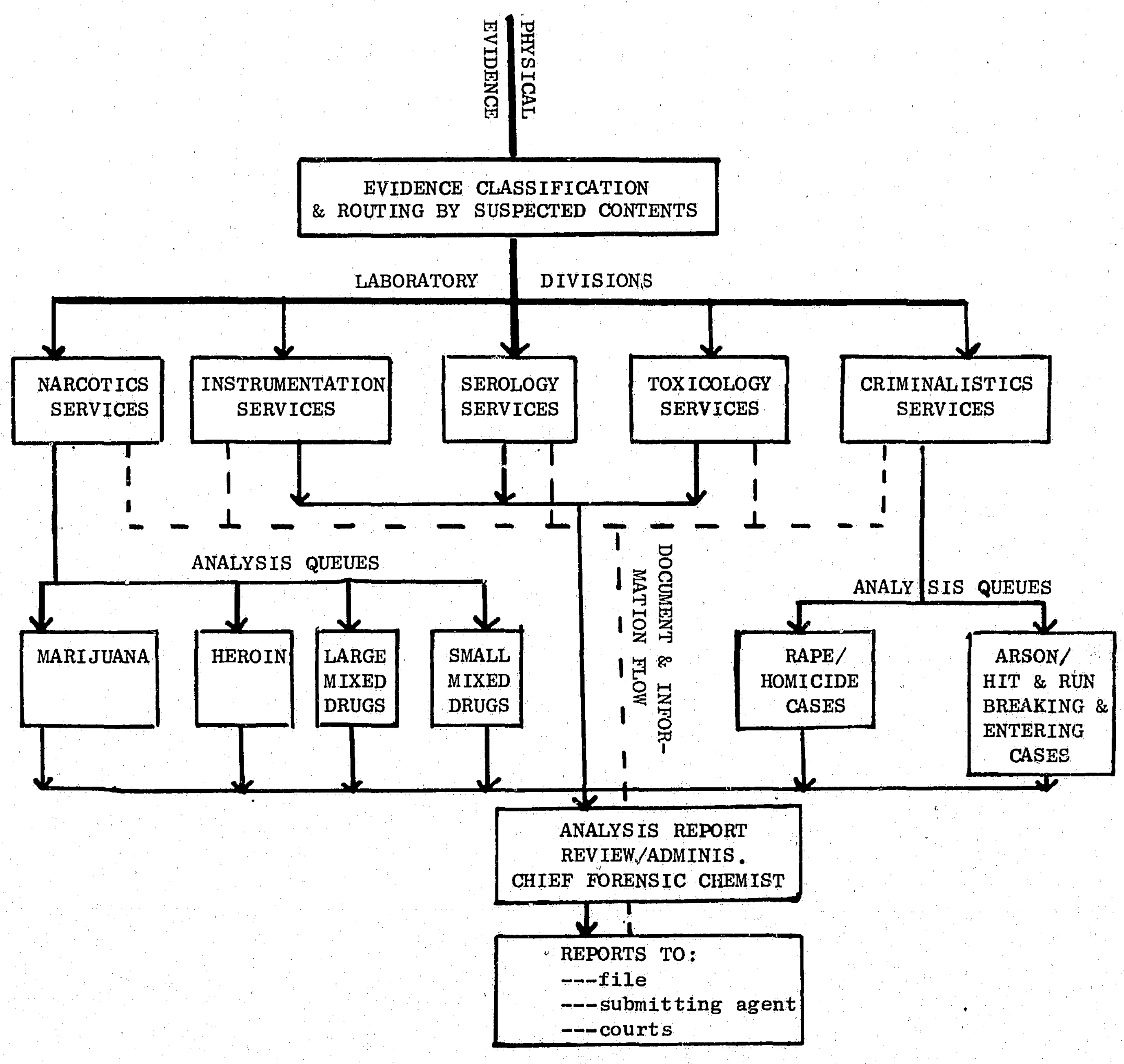
JUNE 1971



FORENSIC SCIENCE BUREAU OF THE STATE OF NEW JERSEY

JUNE 1971

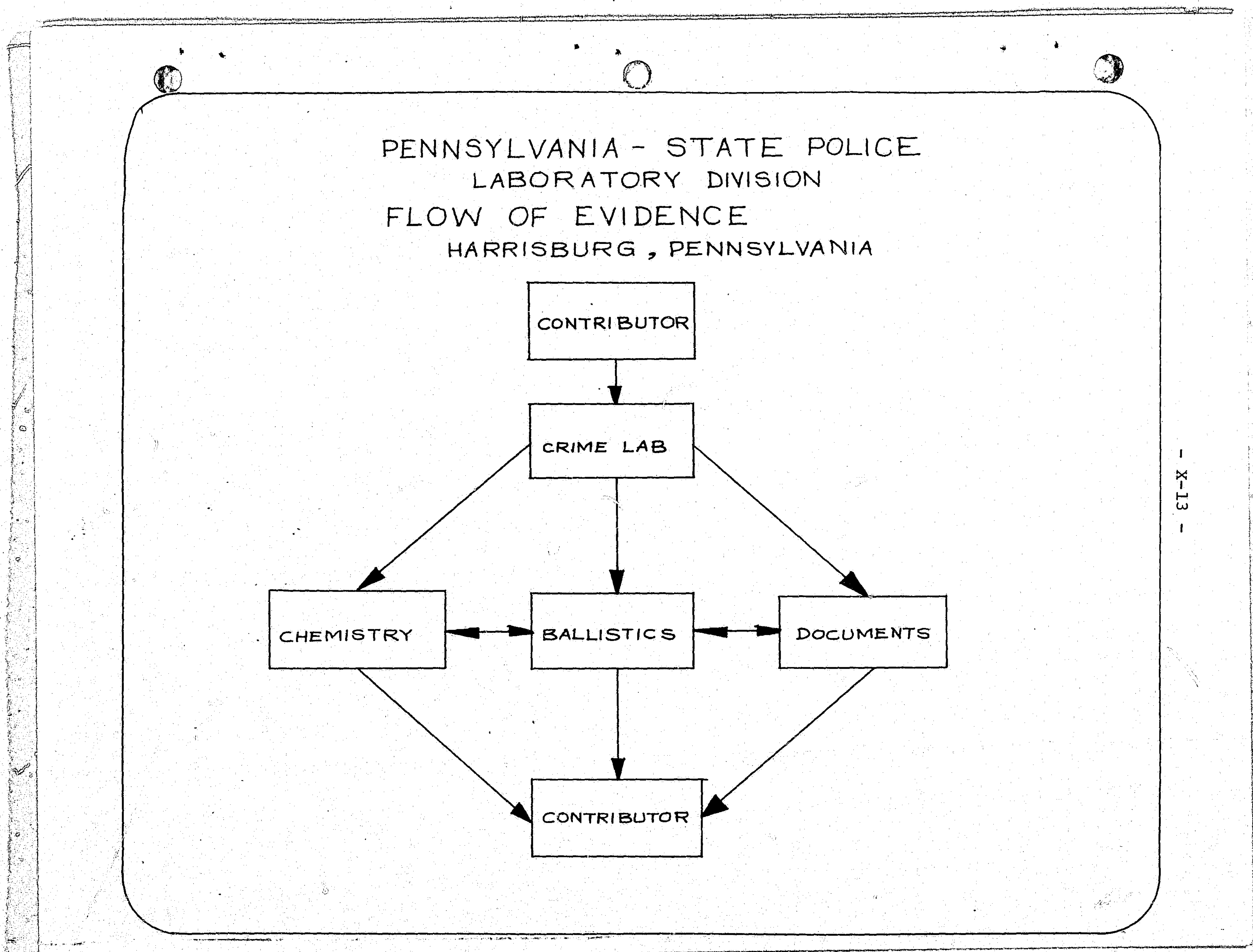
CHEMISTRY/PHYSICS LABORATORY



__________ Proposed

- - - Proposed

THE PENNSYLVANIA CRIME LABORATORY


PENNSYLVANIA - STATE POLICE
LABORATORY DIVISION
FLOW OF EVIDENCE
HARRISBURG, PENNSYLVANIA
CONTRIBUTOR
CRIME LAB
CHEMISTRY
BALLISTICS
DOCUMENTS
CONTRIBUTOR

SP 4 - 212 (5 - 69)

PENNSYLVANIA STATE POLICE
LABORATORY DIVISION
21st. & HERR STS., HARRISBURG, PA. 17103 TEL: 717-234-4051

REQUEST FOR LABORATORY ANALYSIS

FOR CRIME LABORATORY USE	
DATE RECEIVED	LABORATORY NO.
SECTION	

1. OFFENSE	2. LOCATION (CITY-BOROUGH-TOWNSHIP-COUNTY)	3. INCIDENT NO.	4. DATE OCCURRED

5. VICTIM	6. ACCUSED	7. SUSPECT

8. TYPE OF EXAMINATION REQUESTED	9. SUBMIT REPORT TO (NAME AND ADDRESS OF AGENCY)

10. QUANTITY	ITEM NO.	DESCRIPTION

- X-14 -

11. REMARKS

12. IF LABORATORY RESULTS ARE NEGATIVE, THE LISTED EVIDENCE MAY BE DESTROYED ☐ YES ☐ NO	13. SIGNATURE OF REQUESTER	14. DATE

PENNSYLVANIA STATE POLICE
LABORATORY DIVISION
TABLE OF ORGANIZATION
HARRISBURG, PENNSYLVANIA