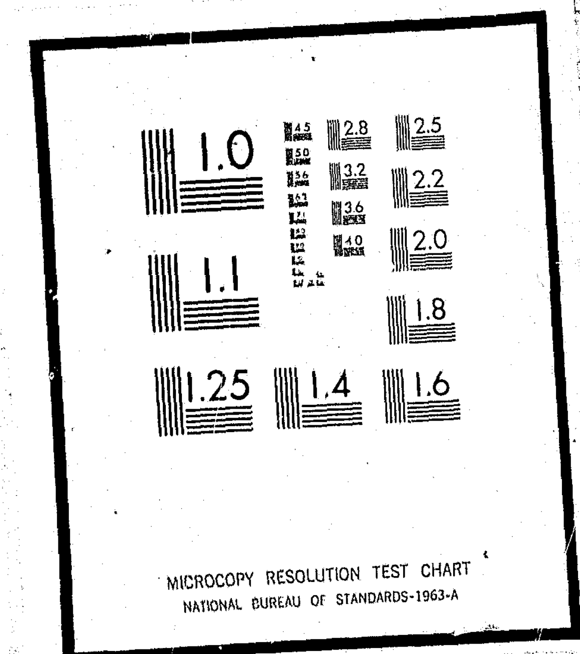

Report No.
ATR-74(7912)-2

EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM

EQUIPMENT OPTIONS AND COST IN 911 EMERGENCY PHONE SYSTEMS

Law Enforcement Development Group
THE AEROSPACE CORPORATION
El Segundo, California

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EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM

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Approved

John O. Eylar, Jr., General Manager
Law Enforcement and Telecommunications Division

ABSTRACT

"911" is expected to become the universal emergency telephone number throughout the United States. Numerous studies have been conducted and reported on the social, economic, and technical questions relating to 911 emergency phone systems. The present report focuses on one particular facet of 911: the system and equipment options available or which could be made available, their typical cost, and their performance. This effort was sponsored by the Law Enforcement Assistance Administration, U. S. Department of Justice. Specific tasks undertaken by Aerospace included technical analyses of 911 equipment options and synthesis of new configurations, identification and analyses of "buy-or-provide" options, statistical analyses and modeling of traffic, system vulnerability analyses, and assessment of response time. Some of these tasks are reported in detail in this document.

A basic problem of practically all 911 systems arises because telephone company wire boundaries often do not coincide with specific municipal boundaries and, consequently, there is no way to tell where the 911 calls are to be routed. Essentially all solutions to this problem are based on callers' automatic number identification (ANI) which enables selective routing. An alternative to selective routing is a technique, referred to in this document as selective answering, which is based on the idea that all 911 calls are routed simultaneously to the two or three municipalities served by a specific central office; and only the proper municipality answers a call automatically based on a computer reverse directory look-up. Relative advantages and disadvantages of selective routing and selective answering are discussed. The concept of a centralized voice/data (CVD) system is also described.

The document reports on a study of problems telephone companies face in providing automatic number identification (ANI). Findings include the following: (a) approximately 80 percent of all telephone subscribers presently terminate in central offices which are already equipped with ANI for accounting purposes, (b) central offices which do not now have ANI are in low population areas where ANI and selective routing of 911 calls is not a pressing need, and (c) ANI could be provided to public safety answering points fairly easily and at relatively modest costs.

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ACKNOWLEDGMENTS

Appreciation is acknowledged for the valuable advice and criticism furnished by other investigators who are studying 911 systems, potential users, and equipment manufacturers. Particular thanks are due Mr. Scott Hovey, Project Director of the Alameda County Study for 911.

The following technical personnel of The Aerospace Corporation made valuable contributions to this study performed under the direction of Mr. Louis Martinez, Program Manager in the Law Enforcement Development Group.

H. Anderson M. Feliciano	-	Line Cost Analyses
H. Bender	-	Minicomputer Subsystem Costs

Principal consultants supporting Mr. Martinez in this study were Mr. Jackson T. Witherspoon and Mr. Victor Krueger.

SUMMARY

The Aerospace Corporation has provided technical consultant services and guidance to the Law Enforcement Assistance Administration (LEAA) funded Alameda County 911 Emergency Telephone System Study and conducted general studies of 911 questions. A principal goal of the Alameda study is to determine the utility and cost effectiveness of providing public safety answering points (PSAP) with selective call routing and automatic location identification (ALI) using automatic number identification (ANI).

Specific tasks undertaken by Aerospace and reported on here included the following:

- Technical analysis of 911 equipment options and synthesis of new configurations
- Identification and analysis of "buy-or provide" options
- Statistical analysis and modeling of traffic
- Vulnerability analysis - false reports, security, saturation, catastrophies
- Response time assessment

The Aerospace effort resulted in several interim reports, including a more detailed automatic number identification (ANI) study, which are summarized in this report. An alternative 911 system concept called centralized voice/data (CVD) system is also described.

1. Background. The Alameda County area comprises a population of approximately one million people and contains 500,000 telephone sets. The existing telephone plant consists of 19 central office locations in which 32 wire centers are installalled. The Alameda County 911 User's Group, together with the 911 Project Office at Oakland, have determined that they need 56 telephone answerers, supported by cathode-ray tube (CRT) terminals, at 23 locations.

In actuality there are only 17 municipalities and/or service centers; however, several of these municipalities have multiple terminals. For example, Oakland Police Department is proposing to install eight CRT terminals and their Fire Department (at another location) requires two more.

The anticipated county-wide 911 emergency telephone traffic is estimated at approximately 3,000 calls per day, and about 250 to 300 of these calls are expected to occur during the busiest hour. Consequently, on the average one would expect about five to six emergency calls per CRT terminal per hour during the busy hour. Each call lasts about a minute and consequently a typical terminal sees fairly light incoming traffic loads.

The so-called advanced 911 system is basically designed to provide the following three progressive levels of sophistication:

- Selective routing of calls
- Automatic location identification (ALI)
- Optional supplementary dispatch support data (SDSD)

All of these levels require that the existing telephone equipment provide the caller's number automatically.

When a citizen picks up his phone and dials a number, his call goes directly to the nearest central office which routes his call directly to the called person, or indirectly via other central offices, on the basis of the number dialed by the caller. For accounting and billing purposes, as well as for other services (e.g., for supervisory telephone operators) the telephone company needs to know the caller's number. Years ago they would simply do this by asking the caller for his number; today automatic number identification (ANI) is performed at most locations. Automatic number identification (ANI) information is vital to 911 systems providing such features as selective routing and automatic location identification (ALI). We should note however that in areas in which only selective routing is desired, the routing of the call could be done in a bulk fashion by using only the first three or four digits of the caller's number, consequently maintaining caller anonymity in most cases; the exceptions are those citizens living directly on the boundary of municipalities and telephone wire service areas. In the present instance the advanced systems that are being investigated could provide all three levels of sophistication described earlier in this section and, consequently, all the digits in the caller's number (full ANI) are required.

Among the most important factors in the system design problem are reliability, user privacy, cost, and compatibility with existing communications equipment and procedures. We will discuss a few of these points in the following narrative.

2. Traffic load. An analysis of expected traffic has revealed the interesting fact that, for Alameda County at least, the number of telephone lines and answering stations required is governed more by the nature of the existing telephone system and public safety offices than it is by traffic considerations. Estimates were made of the number of answering points required to provide busy signal probabilities as a function of call volume rate for calls lasting 50 seconds on the average. To provide a grade of service yielding less than 0.1 percent probability of a busy signal for the entire county would (optimally) require from 12 to 15 call answering stations and perhaps twice this number of lines to enable call transfers.

A cost study was made to estimate the necessary number of phone lines, mileages, and required cost as a function of the location of the principal answering points in Alameda County. From a practical standpoint it is concluded that:

- About 65 to 70 phone lines would be adequate.
- The automatic location identification (ALI) computer should be located in Oakland.
- Perhaps a secondary phone line concentrating device should be located in the southern part of the county.

3. Automatic number identification (ANI) availability and cost. A careful study was also performed to determine the nature of the problems involved on the part of the telephone company to provide automatic number identification (ANI), since ANI capability is essential to all advanced 911

systems. The details of this study will be presented in Chapter IV; however, the following are highlights:

- Prevalence of automatic number identification (ANI). Approximately 80 percent of the subscriber lines which terminate in central offices in the United States are equipped with ANI for automatic message accounting (AMA). ANI is not available to certain classes of service even though the subscriber line terminates in a central office equippped with ANI (e.g., certain private automatic branch exchange (PABX) installations and coin telephones). ANI equipment is available for all major types of central office equipment in use today. Stand-alone systems are available for adding ANI to older panels.
- Automatic number identification (ANI) for 911. ANI can be provided with 911 calls using techniques and equipment identical to that which is used today to provide ANI for automatic message accounting (AMA). In offices already equipped with ANI for AMA, existing elements can be used to provide both services. The volume of ANI traffic for 911 would be less than 0.1 percent of the current ANI traffic for AMA. Therefore, the addition of this function to existing office equipment would have a negligible effect on traffic loading.

- Cost of Modifications for 911 automatic number identification (ANI). The cost of modifications to central offices to provide ANI with outgoing 911 calls will range from $2700 to $5900 per office depending on the size and type of office.
- Cost Versus Office Size. The cost of central office modifications will depend principally on the number of trunks required between the office and the central public safety answering point (PSAP). Modern automatic number identification (ANI) systems are designed to handle multiple (up to 10) prefixes per office, i.e., offices with up to 100,000 equipped lines. Separate trunks are not required for each prefix.
- Telephone Company (Telco)/PSAP Interfaces. A Telco-provided voice connection arrangement (VCA) is required at the public safety answering point (PSAP). The PSAP voice switching and distribution system must be equipped with multifrequency (MF) signaling and trunk supervision circuits capable of interfacing with all local central offices connected to it. These interfaces are similar to those required in a Telco tandem office with central automatic message accounting (AMA), and can be implemented with equipment available from several manufacturers.

- Trends. Electronic switching systems (ESS) are rapidly replacing older central office equipment. By the year 2000 virtually all central offices will be converted to ESSs. These systems can be arranged to provide 911 automatic number identification (ANI) with minor program modifications. Automatic location identification (ALI) could also be provided by these systems but with some increase in memory.

4. Recommendations. The equipment requirements of advanced 911 systems are unique and also involve services which presently are not offered or tariffed by telephone companies. The cost for such equipment and services is not clear at this time; therefore,

- A cost study should be initiated by the Law Enforcement Assistance Administration to develop preliminary tariff charges for a leased telephone line which includes ANI.* The study should be undertaken in cooperation with the Federal Communications Commission (FCC) and/or the Public Utilities Commissions (PUC). The study should include development of costs to provide updated telephone directory data on a daily and weekly basis for automated use by public safety agencies.

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*This service is a fundamental building block for all advanced 911 systems and is a regulated service under FCC/PUC jurisdiction.

- All hardware required for 911 implementation on an operational or test basis, with the exception of the leased line with automatic number identification (ANI), are available from a number of independent sources.
- The Law Enforcement Assistance Administration should commission preparation of a document on the subject of "Requirements, Specifications, and Guidelines for Purchasing 911 Equipment" for use by state and municipal planning agencies.

CHAPTER I. INTRODUCTION

Implementing a 911 system involves many factors beside technical ones. Municipal and County Administrators, the people who must directly confront these problems, face decisions ranging from the consolidation of dispatching operations with neighboring communities to the interpretation of the need for such things as caller automatic location identification and related caller privacy issues. In addition, these administrators must assess the significance of technical equipment limitations and their impact on equipment and operational options.

Existing or pending legislation, for example, California's Assembly Bill 515, provides the legislative driving force for implementing 911 systems. As a minimum, this legislation requires the designation of the telephone number 911 solely for emergency telephone communication to public safety answering agencies and generally dictates that this answering agency must respond affirmatively and rapidly. Unfortunately, preparation and passage of legislation is easier to accomplish than are the results which the legislation is designed to attain.

A. Goals

The principal goal of this study was to provide on-going technical consultant services and guidance to the federally sponsored Alameda County 911 study. The general goal of this report is therefore to provide a broad description of the equipment and techniques which are available or which can be made available to public safety agencies interested in this problem.

The report is consequently aimed at Municipal and County Administrators and their communications advisors and planners, as well as the using public safety agencies. Hopefully, potential equipment suppliers will also find here sufficient description of the 911 problem to enable them to review their own equipment capabilities and its applicability to these problems.

Two broad categories of 911 systems are under consideration in the United States: Basic and Advanced 911. Basic 911, which relies on manual rerouting of calls (when necessary) received at a central location, is presently serving about 25 million people in Omaha, Seattle, Denver, New York City, and many other municipalities. While the Basic 911 systems are feasible where there is a general correspondence between wire center service areas and municipal jurisdiction areas, there are many areas which require some type of call routing. This is provided for in the Advanced 911 system which includes automatic number and location identification (ANI and ALI), the subject of this study.

The President's Office of Telecommunications Policy (OTP) is on record endorsing Basic 911. However, it, in conjunction with the Law Enforcement Assistance Administration, is interested in studying the utility and cost-effectiveness of selective call routing (SCR) and automatic location identification (ALI) prior to endorsing use of these techniques in Advanced 911 systems. The federally sponsored Alameda County 911 study has as one of its main goals the determination of the cost-effectiveness of these two features. If they prove desirable, the federal government will consider funding

development and evaluation programs leading to the establishment of a standard national telephone tariff, thereby saving these expenses for the individual communities. While the Alameda study is involved with the social and operational factors as well, this study considers only the technical aspects of the problem.

In this report, the population and characteristics of Alameda County are used as a specific example and case application; however, the discussion and concepts are intended to be general and applicable to other cities in the United States, even though their population and make-up may differ substantially. Our studies have shown that the volume of emergency calls is not significantly different in various parts of the country and probably has greater seasonal than geographical variation. The make-up of telephone equipment and general level of public safety facilities, at least as far as the design of advanced 911 systems are concerned, is generally the same throughout the United States.

One may accept at the outset that the main technical problem is to get the emergency caller in contact with the right public safety answering point (PSAP) in the most expeditious manner possible. Broadly speaking, there is one telephone for every two citizens in the United States. Later in this report we will show that the cost to install a so-called advanced 911 system is in the range of \$1.00 per citizen (\$2.00 per phone); and the annual costs for operation and maintenance are probably equal or less than the present on-going costs. With these economics in mind, one can quickly dispense with technical solutions which cost substantially more than this.

For example, some consideration was given by other investigators[1] to the use of special signalling modules which could be installed in each telephone subscriber phone instrument which would automatically transmit a coded message when the digits 911 were dialed. Thus the subscriber originates automatic number identification (ANI). However, when one considers that this special circuit module must be designed, built, and installed in over one hundred million telephone sets at less than $2.00 each, the economic feasibility must be seriously questioned.

At the present time the only feasible solution is to have the telephone company central office equipment automatically ascertain the caller's number. This approach is made more attractive when one realizes that most telephone companies already determine a caller's number automatically during toll calls for the purpose of automatic message accounting (AMA) (i.e., customer billing).

The question which then remains is to determine what problems are involved in providing this automatic number identification (ANI) information to public safety agencies and to determine what equipment is required and available to these agencies to interface with the telephone equipment. These points are discussed in detail in Chapter IV.

Leased lines including ANI are not a customary service offering of the telephone company, though as pointed out here there is no technical reason why this cannot be made available. There is, however, a question in the willingness of telephone companies to provide this automatic number

identification (ANI) so that public safety agencies can utilize it to service their own needs. This is a question which is not addressed here.

We have already noted that the volume of 911 emergency traffic anticipated is in the same general magnitude throughout the United States, but of course varies with time of day, day of the week, and season. For estimating purposes, Hill and Johnson[2] suggest a call volume of 2.5 emergency calls per thousand of population per day as a typical average. About 10 percent of these calls will occur during the "busy hour." These figures are supported by other investigators in Omaha and by our own investigations and measurements in Oakland, California. These questions and the related equipment implications will be discussed in Chapter II.

We see now that for a typical populated area of one million citizens, one could expect an emergency traffic volume of approximately 2500 calls per day of which approximately 250 will occur during the busiest hour. Consequently we would expect one emergency call every 15 seconds during a typical busy hour. Obviously, an unusual catastrophe such as an earthquake or a large aircraft accident would substantially change this traffic volume. Unfortunately, it appears economically impossible to provide communication facilities that would adequately handle all possible traffic conditions, including major catastrophies. On the other hand, many catastrophies involve considerable redundant telephone traffic (e.g., an airline crash) and in such cases one would like to minimize the number of redundant callers.

With knowledge of the volume of telephone traffic involved and the fact that the telephone company could probably provide automatic number information almost instantaneously, one is left with the question of determining the type of system to employ to get the call to the right answerer — the right answerer in this case being the person assigned to particular geographic areas for specific types of service. Note that one can never know beforehand whether a caller is asking for police, fire, medical, or other emergency services; this can only be determined by listening to the caller. Obviously, provision for automatically determining the services needed, for example by providing a fourth digit (e.g., 911F) could be implemented but, by definition, such techniques are not a consideration in this 911 study.

B. System Concepts

There are at least two fundamental approaches to getting the call to the right person. One technique is called selective routing and the second selective answering. In the first, all 911 calls are routed to a single point where the automatic number identification (ANI) is used in a reverse telephone directory, thereby yielding the caller's location and consequently determining where the call should be routed. In the second technique, all 911 calls reaching a particular telephone company central office are automatically and simultaneously routed to the several municipalities whose citizens are served by the same telephone wire center. Each municipality is then equipped with a device which automatically responds to the automatic

number identification (ANI) information accompanying the call and only the proper municipality answers, somewhat like a party line. Each municipality is autonomous and may include any level of service [e.g., automatic location identification (ALI)] or none at all. More telephone lines between central offices and municipalities are required in the selective answering concept, however, the phone lines required in the selective answering concept are shorter than in selective routing and the result is that the total line-miles, consequently the total telephone line cost, is not significantly different for the two.

A significant advantage of the selective answering concept, since it has more phone lines to start with, is much greater capacity to sustain telephone volume overloads. A second advantage is that mutual aid can be provided between neighboring communities, particularly for citizens near the boundary of the two communities. Since this is where the telephone companies wire center boundaries generally overlap and where call routing is most important, this is an important advantage. A third advantage is reduced vulnerability to detrimental effects of problems in adjacent communities.

The concept of selective answering is relatively unique, and it appears that not many investigators have given thought to this possibility. Nevertheless, the selective answering concept has many attractive features which should be investigated; some thoughts along these lines are discussed in Chapter III. It is also important to note that in the selective answering concept, not all calls are routed to all municipalities. Only the calls that lie in the overlapping region are routed to the several municipalities responsible for citizens in this overlap region, which comprises perhaps 20 to 30 percent of the citizens. Generally, the calls associated with any specific telephone wire center (i.e., the first three digits in the caller's number) can often be uniquely identified with citizens of one community; and consequently these calls could be routed directly to their proper municipality without any automatic number identification (ANI).

C. Automatic Number Identification (ANI) Study

Because of the importance of automatic number identification (ANI) in advanced 911 systems, a study was initiated to identify the modifications to telephone central offices which would be required to provide ANI data to public safety answering points. Specific tasks addressed in this study were:

- Prepare a description of telephone central office modifications required to provide ANI for 911 application, including a brief description of the various types of central office equipment in use in the United States with estimates of the prevalence of each of these types of equipment and a statement as to whether or not these equipments can now provide ANI, including a description of the form of this ANI.
- Estimate the cost to modify central office equipment when necessary and determine the availability of off-the-shelf equipment which could be provided for this purpose.

- Prepare preliminary interface specifications for equipment designed to mate with various telephone company central offices so that they may receive ANI.

The ANI study results are presented in Chapter IV and are based on technical reports of the Bell Telephone Laboratories and other open technical literature listed here in the bibliography, plus information and cost estimates provided by various independent manufacturing companies* who market ANI and automatic message accounting (AMA) equipment.

The principal conclusions derived from this ANI study were that approximately 80 percent of all telephone subscribers today are connected to telephone central offices which are already equipped with ANI for use in automatic message accounting. For those cases where ANI is not now available, equipment can generally be installed at modest cost. One should recall, however, that those areas where ANI is not available are generally of low population density and the problem of call routing is not a pressing one there since Basic 911 is often satisfactory. It is concluded that the ANI which is presently available at telephone central offices could be provided for 911 purposes using techniques and equipment essentially equivalent to that which is now used for automatic message accounting. However, the public safety equipment required to interface with this telephone automatic number identification (ANI) equipment has not yet been tried in the 911 application, although this equipment does exist and is being used in other areas.

*Microdata; GTE Automatic Electric; ITT Telecommunications Division; GD/Stromberg-Carlson; Continental TEL/VITEL; Northern TELECOM, etc.

The increased volume of ANI traffic because of 911* would be less than 0.1 percent of the current ANI traffic for automatic message accounting. This is negligible and probably undetectable; therefore, 911 calls would not present significant loading of existing central office ANI equipment.

It is also concluded that the cost to modify central offices to provide ANI with outgoing 911 calls would range from $2700 to $5900 per office depending on the size and type of office. A telephone company provided voice connect arrangement (VCA) would be required at the public safety agency in order to receive 911 calls with ANI and the public agency would also have to install ANI receiving equipment so as to decode it and enter it into their own minicomputer and subsequently reroute the call to the proper answering point. These costs are not included in the above estimates.

D. Privacy

There are some social issues which have important technical connotations. Caller privacy is probably the most important. Automatically determining and presenting a caller's telephone number, address, and name might represent an invasion of privacy which the caller may not wish to provide. The telephone company indicates that on the order of 25 percent of all telephone subscribers have unlisted telephone numbers. Surveys conducted for the Alameda County 911 project by the Pacific Telephone and Telegraph Company indicate that most telephone subscribers, both with listed and unlisted phone numbers, would be willing to have their phone

*Based on 911 rule of thumb: 2.5 calls/1000/day; compared to published Direct Distance Dialing (DDD) traffic.

numbers registered in a public safety computer for emergency service use. Nevertheless, it is implicit that these files would be carefully safeguarded to ensure confidentiality. One way to ensure this is to provide physically isolated 911 systems with restricted and controlled access, as suggested in Chapter IIID.

Another way to ensure system security is to employ techniques within the system itself (e.g., employing coding methods which scramble the phone number in a manner that prevents linking phone number and identifying information). This could be done by incorporating the phone number into a computer algorithm that requires a key value to unscramble and determine the caller's location. If the value is changed frequently and is sufficiently large, the probability of an unauthorized person picking the right value would be quite small. Another possibility is to have the telephone company code files provided to public safety agencies in such a way that phone number and address files cannot be easily matched by unauthorized persons.

CHAPTER II. TRAFFIC VOLUME

A knowledge of the anticipated call volume is a fundamental parameter required for design of 911 systems. This section discusses these and related questions about phone line requirements.

A. Answering Requirements

The number of answering stations [e.g., cathode-ray tube (CRT) consoles] is determined by the volume of traffic anticipated and the percentage of busy signals which can be tolerated. A typical telephone system criterion is to provide no more than one busy signal per 1000 incoming calls. This is considered a good class of service. On the other hand, systems are often designed to provide for busy signals as frequently as one out of every 100 calls, or even two busy signals per hundred calls. In a public safety system such as 911 one would probably want a system which would generally provide a busy signal probability of less than one per 1000 calls. Obviously, in certain natural catastrophy situations even these systems could be saturated.

Figure 1 shows the theoretical[3] number of answering stations required as a function of the average "busy hour" traffic anticipated. Note that three solid curves are shown for cases of: one-tenth-, one-, and two-percent busy signal probability. These curves are computed using the Erlang B equation[3] commonly employed in telephone traffic analysis and an average call

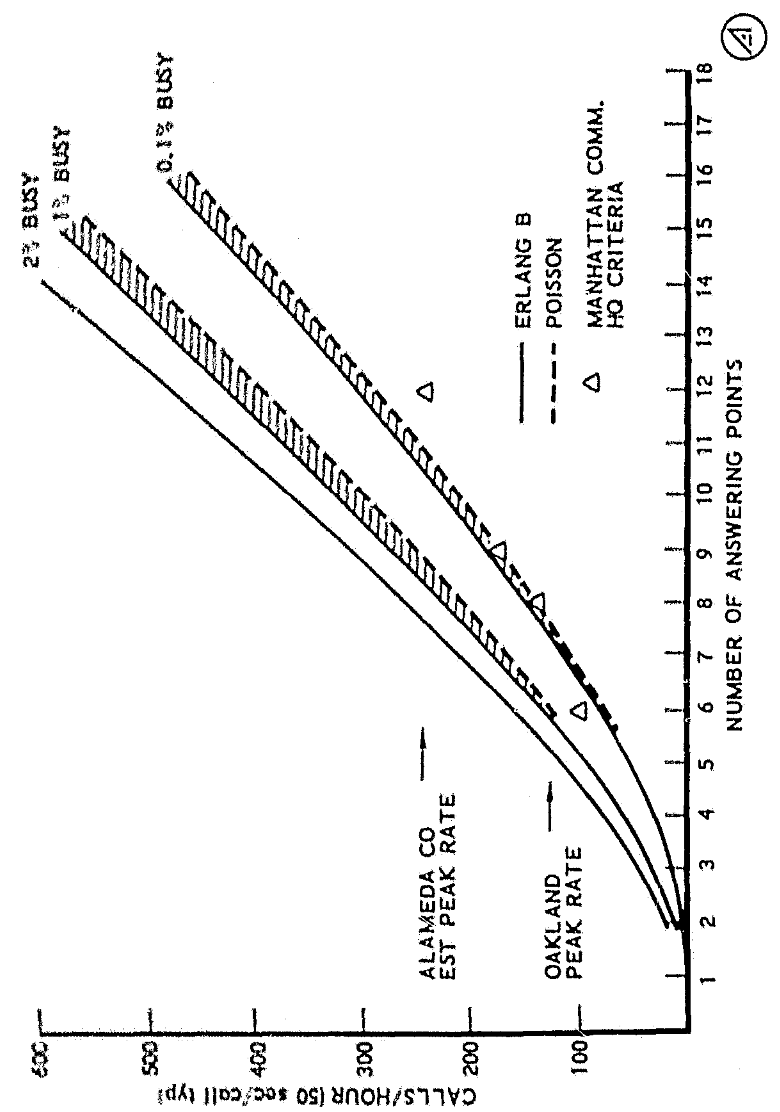

Figure 1. Required Answering Points as a Function of Traffic

duration of 50 seconds.* The dotted curves shown in Figure 1 represent the one-tenth-percent and one-percent busy signal probabilities using the alternate Poisson equation, which is also commonly employed in telephone traffic analysis. Note there is relatively little difference between the Erlang and Poisson equations.

One could use the curves of Figure 1 in the following manner. Assume a traffic of 300 calls per hour during the busy period. In this case if one wishes to maintain a probability of busy signal of less than one-tenth percent [this is referred to as P(001) grade of service] during the "busy hour," then 12 or 13 answering stations would be necessary; nine or ten stations would provide a busy signal probability of one percent [P(01)]. As an example, the total traffic in Alameda County is estimated at approximately four calls per minute during the busy hour (240 calls per hour) and consequently, one would estimate that approximately ten or eleven answering stations could adequately handle this traffic and provide a busy signal probability of about one busy signal per 1000 calls; this is about one busy signal every four hours. Since the "busy hour" traffic load lasts for about four hours each evening, one would expect about one or two busy signals per day if eleven answering stations are used for all of Alameda County.

The Figure 1 curves are plotted on the basis of a typical signal call duration of 50 seconds -- the average call length experienced in Oakland during a three-day observation period.

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*Subsequently a 60-second standard is introduced; this change has no significant effect on the results or conclusions of this task.

It is interesting to compare Figure 1 to the recommended number of answering stations found experimentally by the Manhattan communications headquarters[4]. These data points are plotted in Figure 1 as triangles and are as follows:

Traffic Volume Calls/Hour	Recommended Number of Answering Stations
100	6
150	8
180	9
240	12

Note that the Manhattan criterion is rather conservative for the case where 12 stations are used (well under one busy signal per 100 calls). The Manhattan criterion agree with the one-tenth percent criterion when eight or nine answering stations are used. On the other hand, when only six answering stations are used, the busy signal probability increases to about five-tenths percent (i.e., one busy signal out of every 200 calls).

B. Measured Time Between Calls

In order to obtain direct information regarding actual traffic statistics, a call measurement project was initiated by The Aerospace Corporation and carried out in cooperation with the Oakland Police Department. An individual was stationed at the Oakland Police Department dispatching room where the telephone answering stations are located. A reel-to-reel tape recorder and a tone generator actuated by a telegraph key were provided. Each measurement period lasted seven to eight hours. The operator of this equipment was

placed in a position where she could see the signal lights on each of the answerer's telephone sets and could therefore determine when either an administrative or an emergency telephone call arrived by virtue of the different color of these signal lamps. Each time a telephone call arrived the operator would press the telegraph key and record a brief tone blip on the tape recorder. This procedure was carried out for both emergency calls only and for emergency plus administrative calls. A record of the dates on which these measurements were taken are as follows:

Friday, 25 January 1974, 2-10 P.M., emergency lines only

Wednesday, 18 February 1974, 8 A.M. - 4 P.M., emergency and administrative calls

Thursday, 19 February 1974, 4-12 P.M., emergency and administrative calls

Friday, 20 February 1974, 4-12 P.M. emergency calls only

Later, the tape recordings were played back onto a strip chart recorder at The Aerospace Corporation and were analyzed visually by taking a ruler and measuring the distance between calls and converting this into the equivalent time. The results of this experiment are believed to be accurate to within one or two seconds. Unfortunately the data taken on Friday, 20 February, was not readable, apparently because of a tape recorder malfunction.

The results of these measurements are shown in the following six graphs (Figures 2 through 7). Two types of graphs are presented for each of the three days on which usable data was recorded. The first type of graph is a cumulative distribution indicating the percent of calls which occurred within

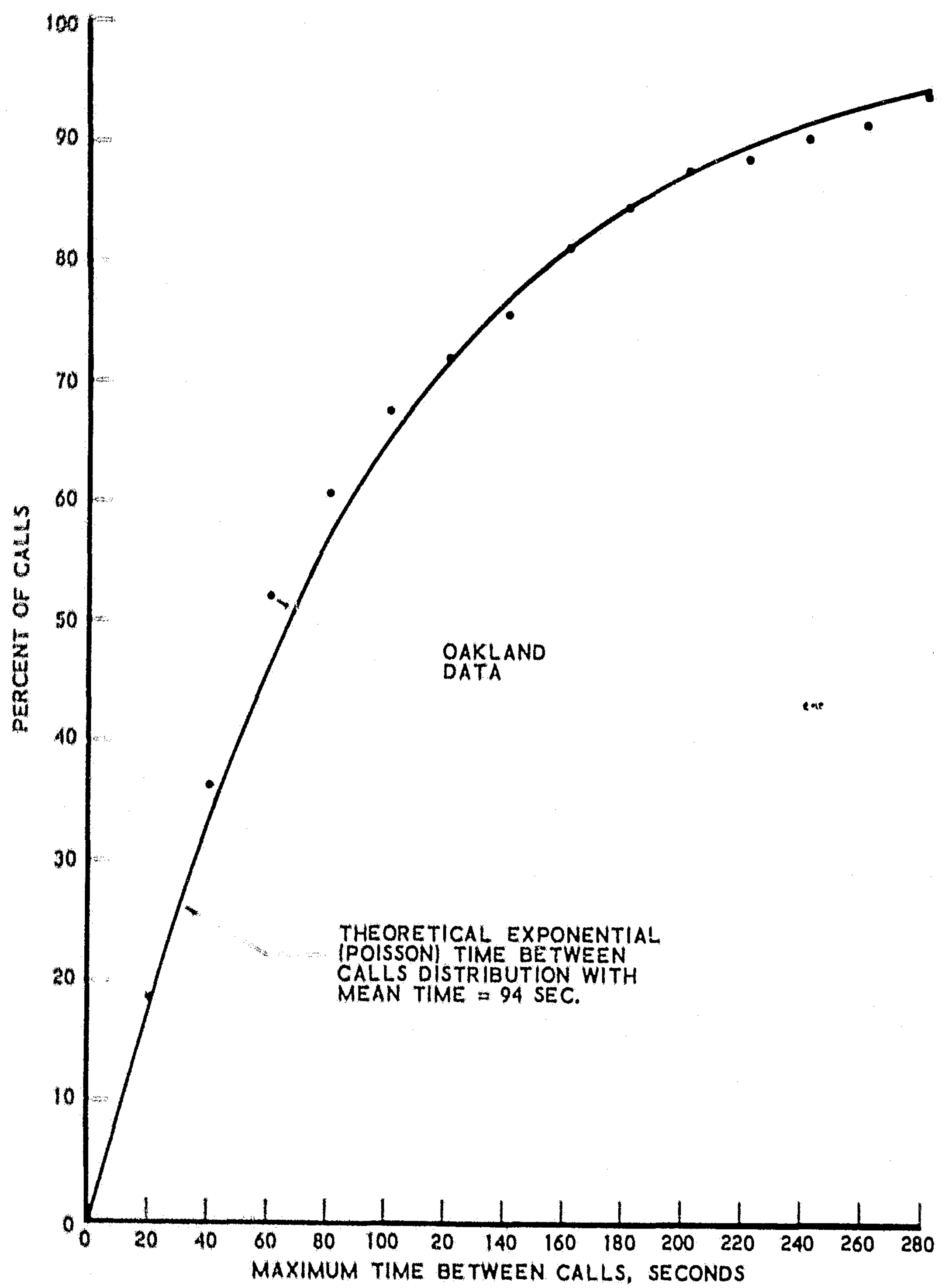

Figure 2. Time Between Calls, Oakland Police Department Emergency Telephone Traffic,
2 to 10 P. M. Friday, 25 January 1974,
257 Minute Data, 164 Calls,
Average 0.0638 Calls per Minute

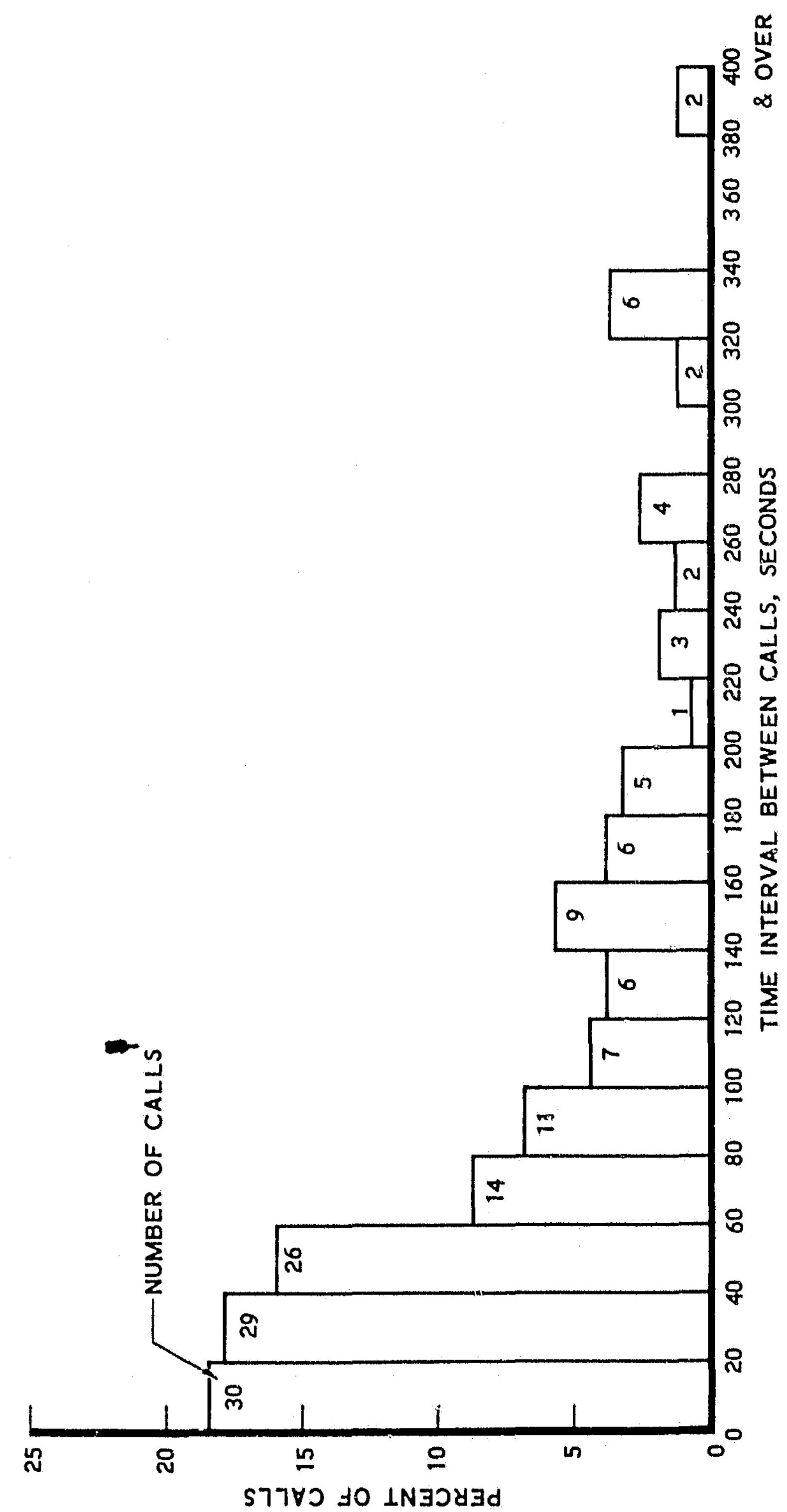

Figure 3. Frequency Histogram of Time Interval Between Calls,
Oakland Police Department,
2 to 10 P. M. Friday, 25 January 1974,
257 Minute Data, 164 Calls

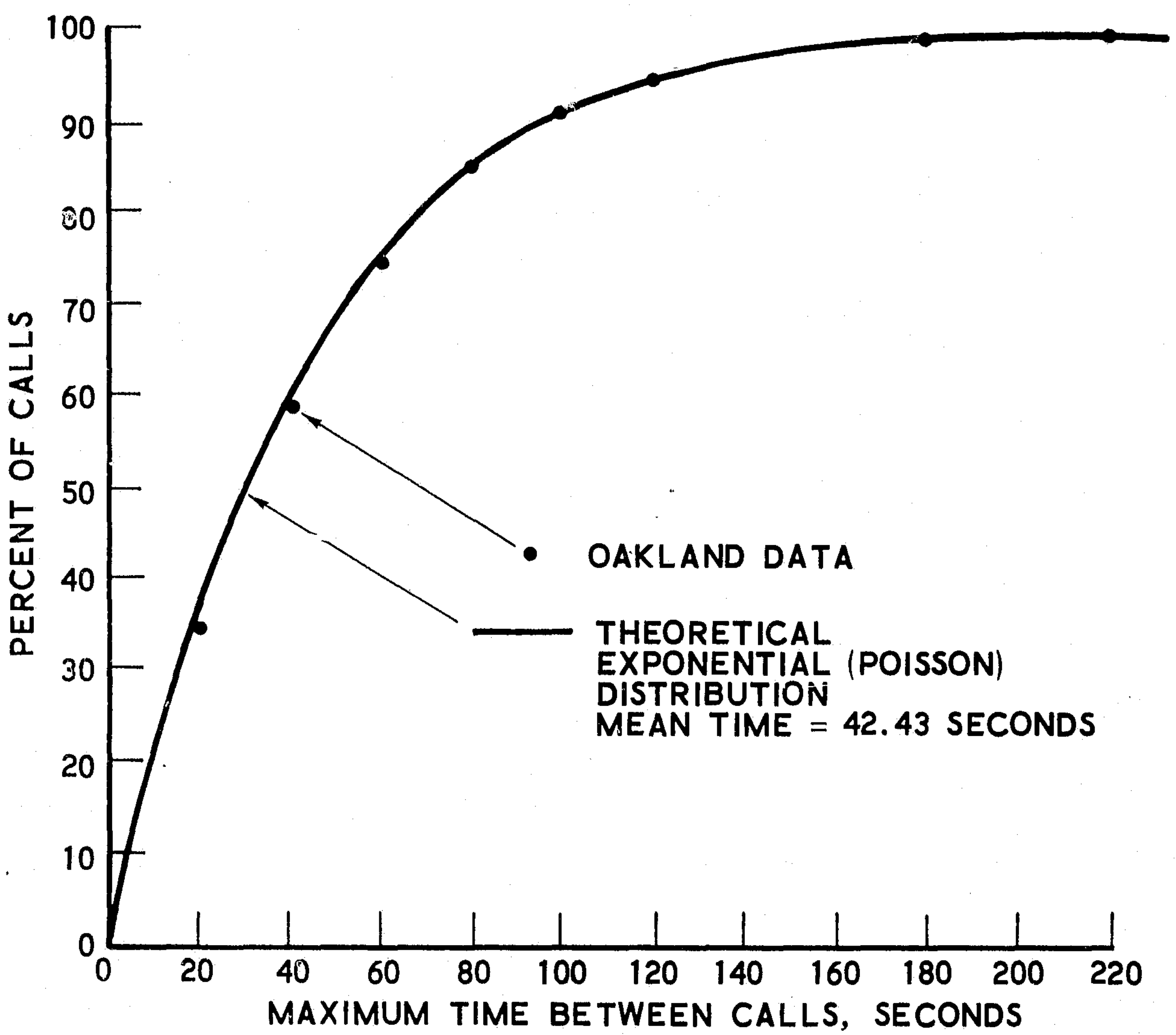

Figure 4. Time Between Calls, Oakland Police Department Emergency and Administrative Calls, 8 A. M. to 4 P. M., Wednesday, 18 February 1974, Total 574 Calls

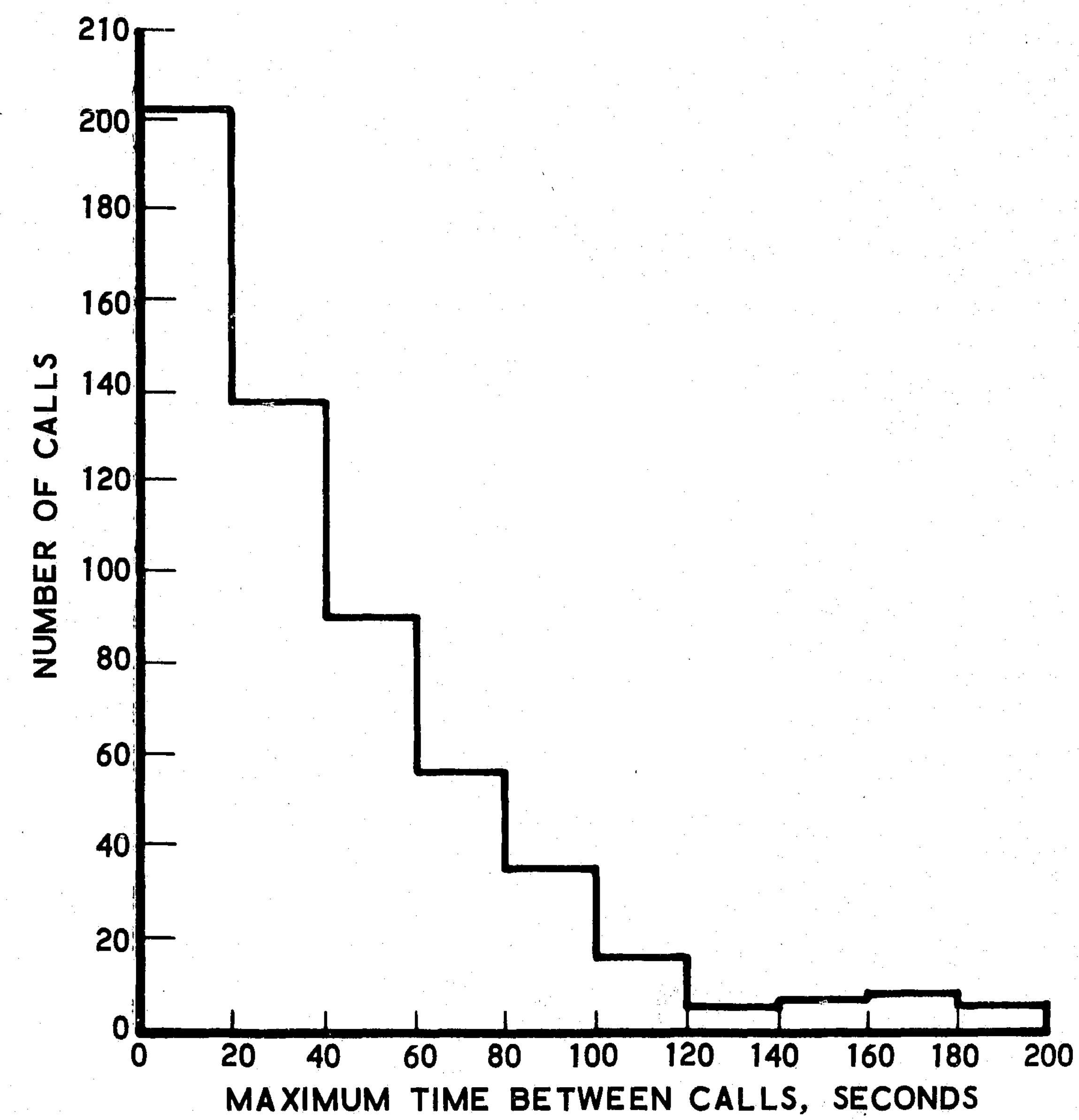

Figure 5. Frequency Histogram of Calls in 20-Second Intervals, Oakland Police Department, Emergency and Administrative, 8 A. M. to 4 P. M., Wednesday, 18 February 1974

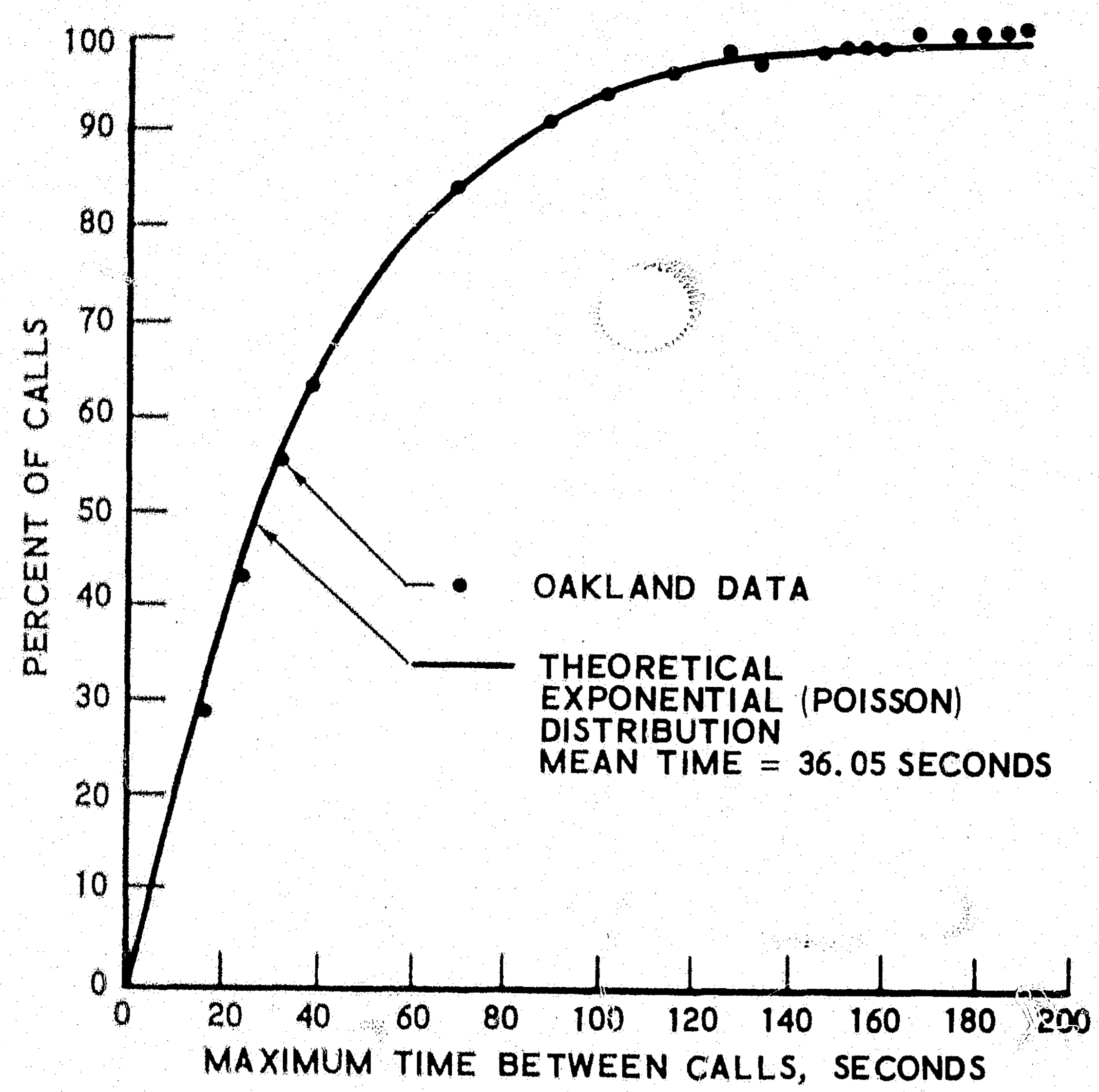

Figure 6. Time Between Calls, Oakland Police Department Emergency and Administrative Calls, 4 to 12 P.M., Thursday, 19 February 1974

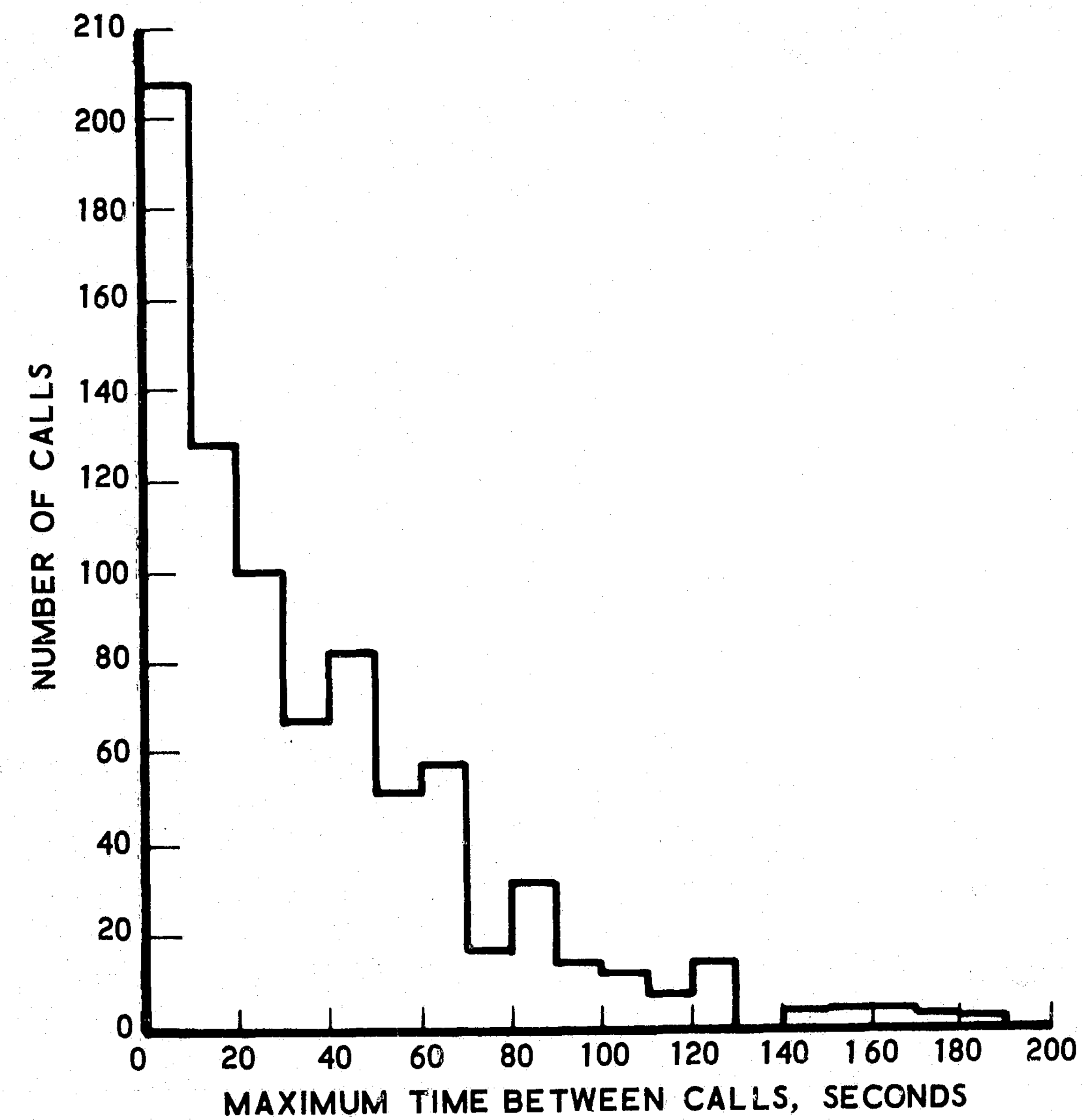

Figure 7. Frequency Histogram of Calls in 10-Second Intervals, Oakland Police Department, Emergency and Administrative Calls, 4 to 12 P.M., Thursday, 19 February 1974

a time interval equal or less than the time indicated on the horizontal axis. For example, for Friday, 25 January, (Figure 2) 50 percent of the calls occurred within 63 seconds or less of each other. Stated another way, and using this same figure, less than 35 percent of the calls were spaced more than 100 seconds apart.

The dotted points on the graphs in Figures 2, 4, and 6 represent actual data, and the solid line is the theoretical curve that would best describe the actual data, if a Poisson distribution was assumed. Note that for all practical purposes the assumptions made in the previous discussion regarding the theoretical number of phone answering stations required, based on a Poisson statistical distribution, should be valid.

The second type of graph (Figures 3, 5, and 7) is a frequency histogram of the distribution of time interval between calls. The histogram is constructed by sorting out the time between calls for calls that lie between a certain interval, for example, between 0 and 20 seconds apart, between 20 seconds and 40 seconds apart, etc. The main conclusion one can reach from these data is that the use of a theoretical Poisson statistical distribution is justifiable, at least during the preliminary equipment design phase. Secondly, these data indicate typical call arrival rates for both emergency and emergency plus administrative calls.

The population of Oakland, according to the 1970 census, was 361,500. At the present time the population is probably closer to 380,000. Data in Figure 2 for Friday, 25 January, cover a time interval of slightly over four

hours (164 calls) and are fairly representative of the statistical distribution of time interval between emergency calls. During the entire eight hour measurement period (actually about 7.5 hours), a total of approximately 285 emergency calls were recorded. Projecting these average figures for the entire 24-hour day would result in slightly over 900 calls. This results in approximately 2.4 calls per thousand of population per day, which is within the expected volume predicted by the rule of thumb figure of 2.5 calls per day per thousand suggested earlier in this report.

Table 1 summarizes the total number of emergency and administrative calls received during the days on which these measurements were taken, as registered by mechanical call counting devices installed by the telephone

Table 1. Summary of Emergency and Administrative Telephone Calls to Oakland Police Department (1974)

Parameters	2-10 P.M. Friday, 25 Jan.		8 A.M. - 4 P.M. Wed. 18 Feb.	
	Emergency	Administrative	Emergency	Administrative
Total Number of Calls	303	515	213	409
Calls Per Minute	0.63	1.07	0.44	0.85
Average Time Between Calls (Seconds)	95	56	136	70
	4-12 P.M. Thurs. 19 Feb.		4-12 P.M. Friday, 20 Feb.	
	Emergency	Administrative	Emergency	Administrative
Total Number of Calls	295	541	311	466
Calls Per Minute	0.64	1.13	0.64	0.97
Average Time Between Calls (Seconds)	94	53	94	62

company. In some cases the total figures shown in Table 1 do not agree with the figures obtained by the measurement equipment described above. The discrepancy could have been due to the fact that for some unknown reason the mechanical counters would occasionally miscount (compared to counters at the Central Office). There is also the possibility of slight errors in counting calls using the aparatus described above, particularly during the busy periods when several calls would be arriving almost simultaneously.

Some other interesting data along these lines were provided to us by the Communications Division of the Omaha Public Safety Department*. These data are plotted in Figures 8, 9, 10, and 11 and represent the number of 911 calls received by Omaha on each of the seven days of the week from 28 July 1973 through 3 August 1973, sorted out by time of day. An average for the week is on Figure 11. The information actually presented to us by Omaha was in the form of tables, and we have taken the liberty of plotting this information in the form of graphs. The actual table of data is included here in Appendix B. Note that these data represent actual calls dialed 911.

C. Telephone Lines, Citizen to PSAP†

With respect to telephone service, an area such as Alameda County is broken up into regions, each served by a central office which provides the switching for all calls between phones located in that region. Calls involving telephones in different central office regions are routed via interoffice trunks

*Provided at a 911 briefing in Oakland on November 5, 1973 and herein gratefully acknowledged.

†The remaining discussion in this chapter illustrates a methodology of analysis as well as a specific case application, which case may differ significantly depending on city and 911 System plan.

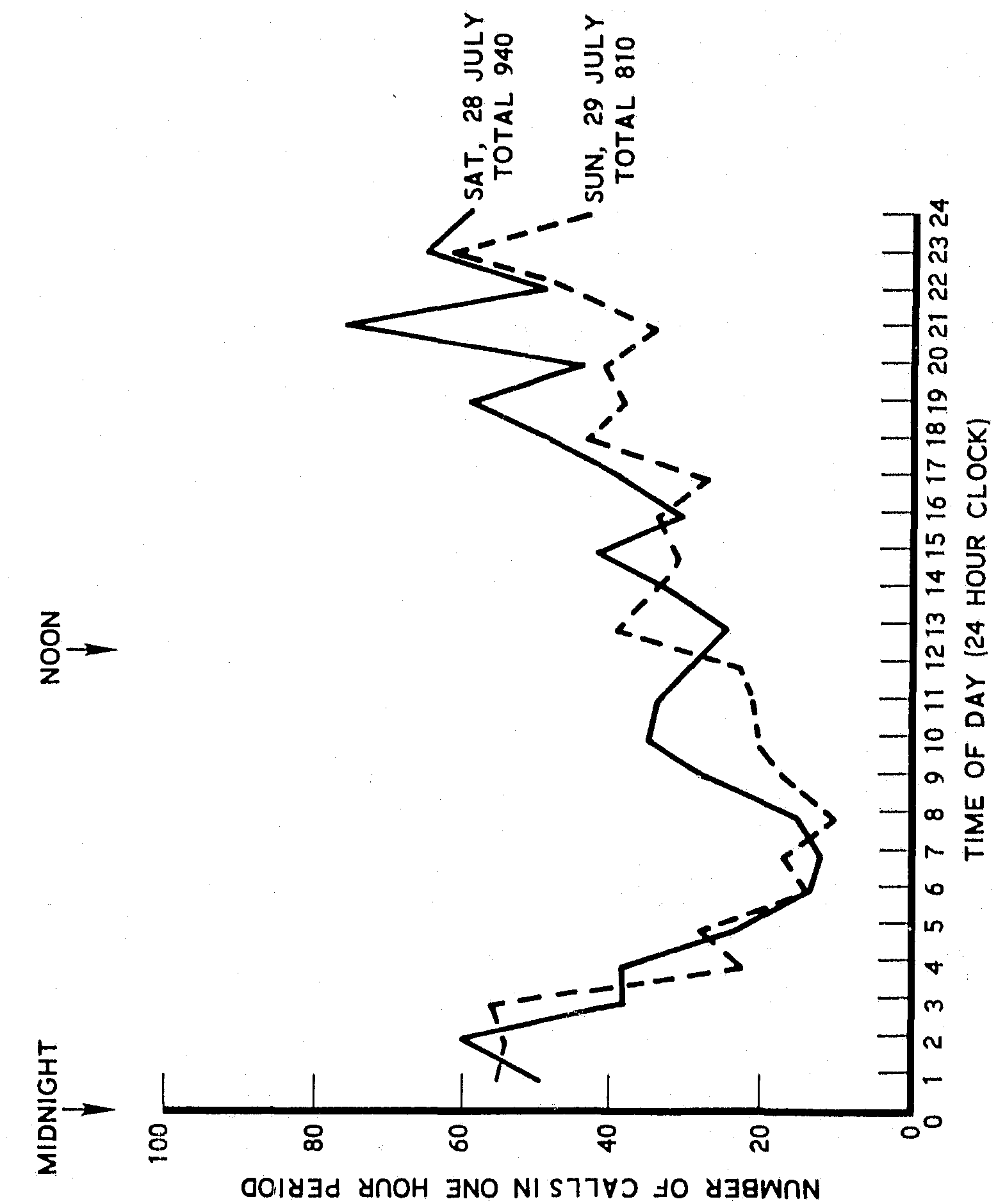

Figure 8. Omaha 911 Telephone Traffic Volume by Time of Day, Saturday and Sunday, 28 and 29 July 1973

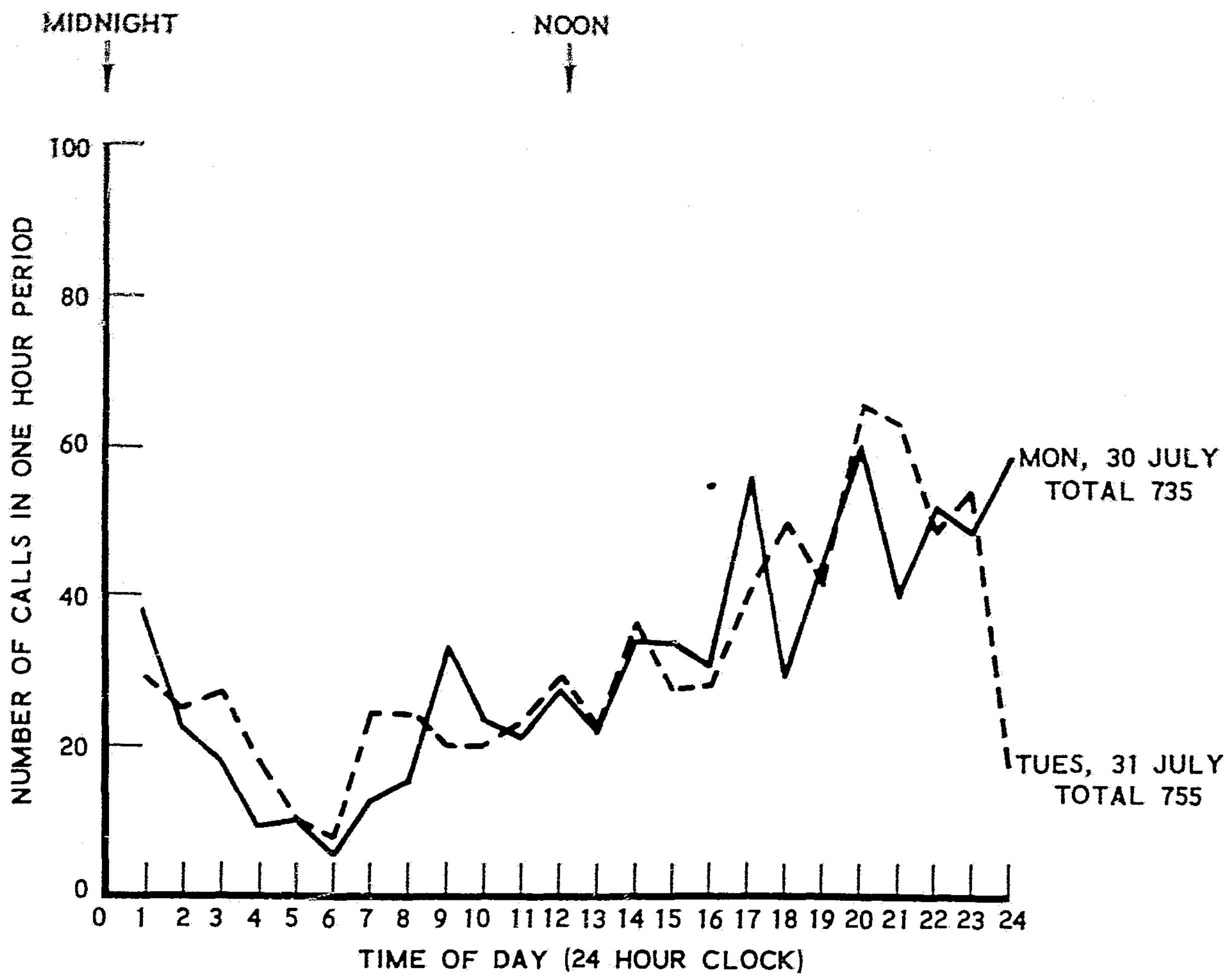

Figure 9. Omaha 911 Telephone Traffic Volume by Time of Day, Monday and Tuesday, 30 and 31 July 1973

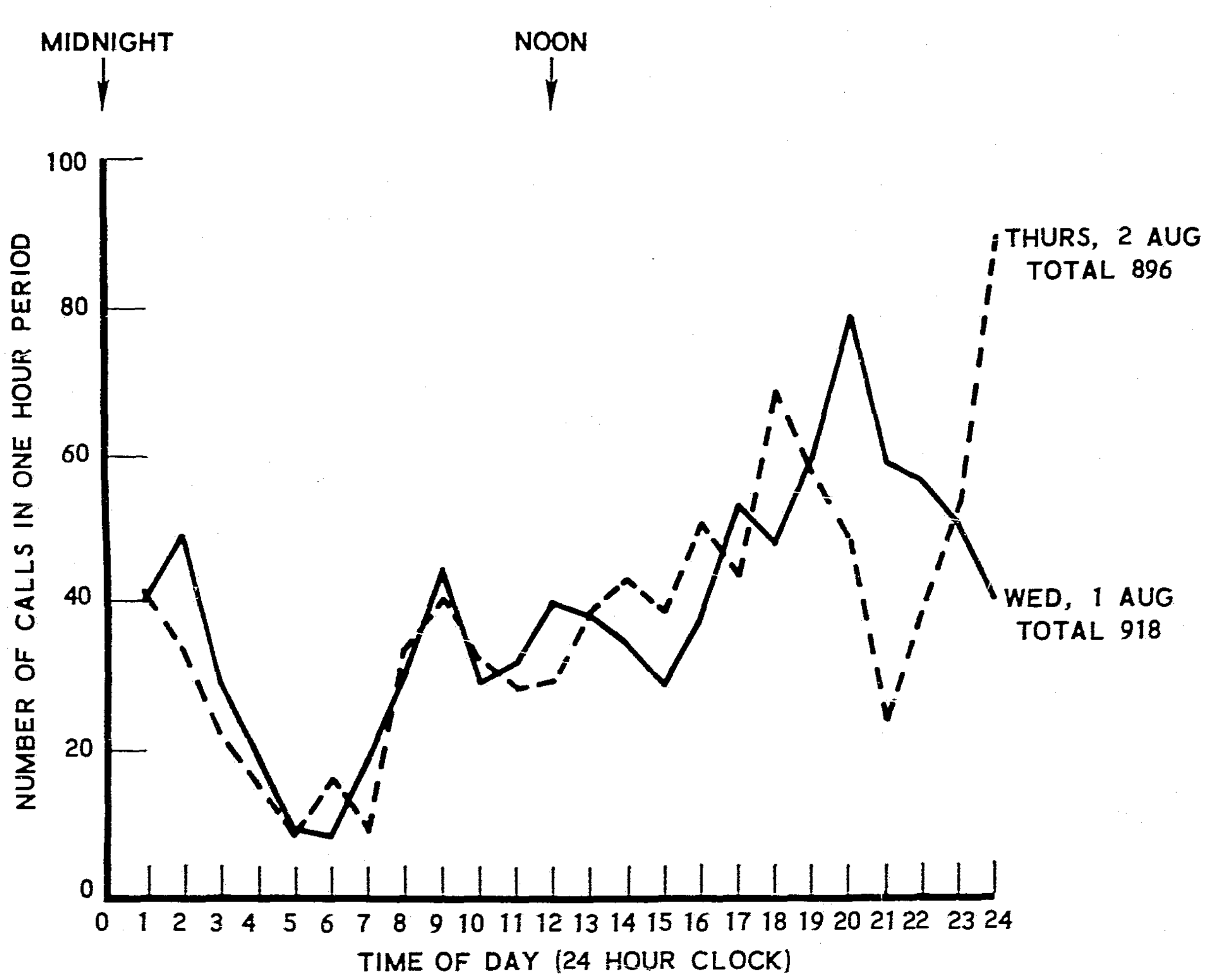

Figure 10. Omaha 911 Telephone Traffic Volume by Time of Day, Wednesday and Thursday, 1 and 2 August 1973

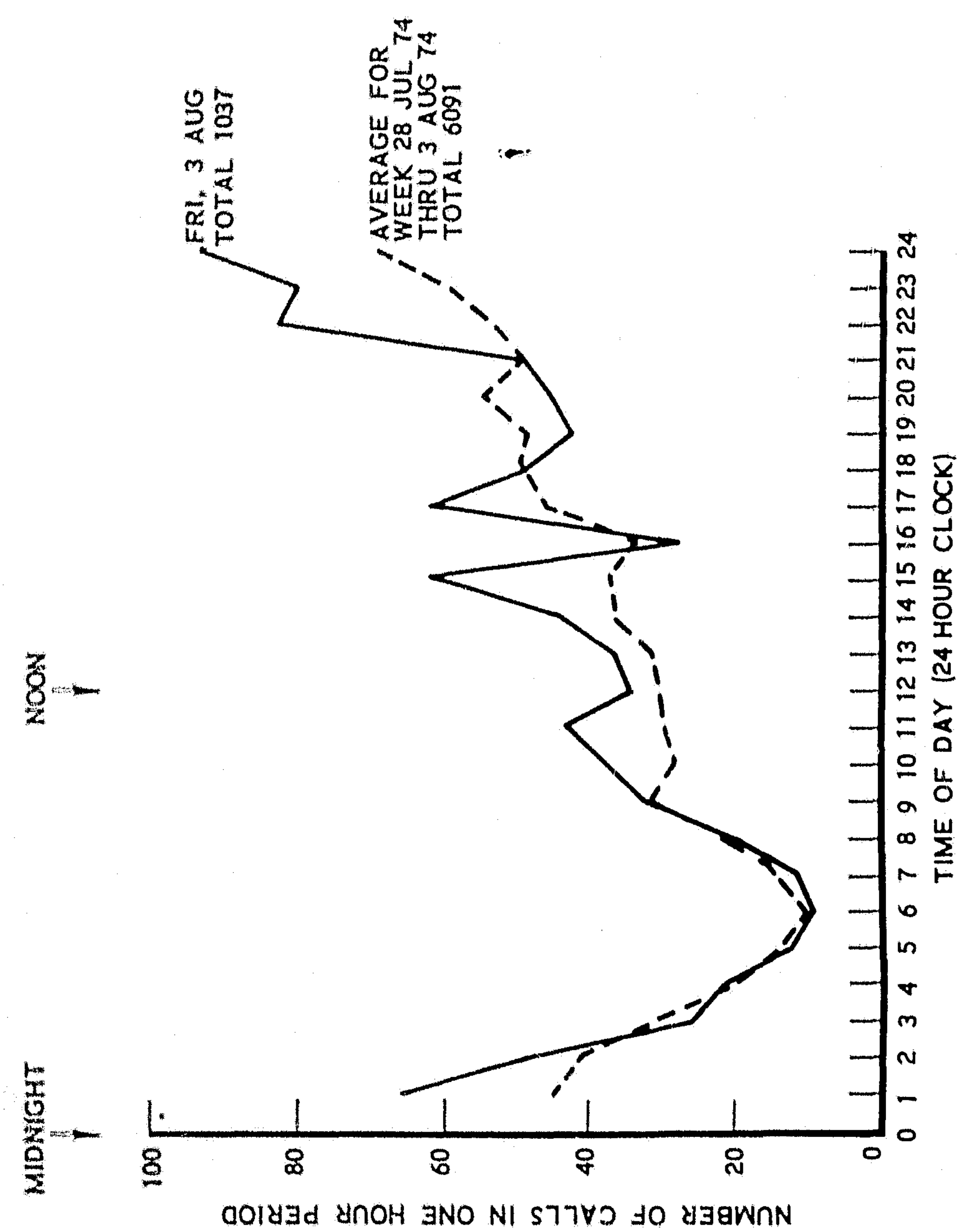

Figure 11. Omaha 911 Telephone Traffic Volume by Time of Day, Friday, 3 August 1973 and Average

and may incur a toll charge. Alameda County contains 19 central offices as shown by the attached map supplied by Pacific Telephone (Figure 12). The majority of the telephones in Alameda County are concentrated in Oakland and the surrounding communities.

The center where 911 calls are answered is called a public safety answering point (PSAP). Because political and central office region boundaries do not coincide and because of efficiency and cost considerations, a PSAP would normally receive the calls from several central office regions. Therefore, a charge for a line between the central office in the region where the call originates and the central office in the region where the receiving PSAP is located may be incurred. This cost may be a toll charge if the public switched network is used or a cost for leased lines, microwave links, etc. The total of these charges for Alameda County depends on the number of PSAPs established and the central office regions where the PSAPs are located.

In this section, phone line charges are estimated two ways: using toll charges of the public switched network (i. e., the present approach available to citizens) and using the rate of $3.60 per mile per month for leased lines.

Telephone company data indicating the percent of county telephones served by each central office were applied to the total projected 911 call volume for the county to obtain the volume estimates shown in Tables 3 and 8. Two methods of estimating 911 call volume can be used. One is based on current emergency call levels plus projected increases after 911 becomes available;

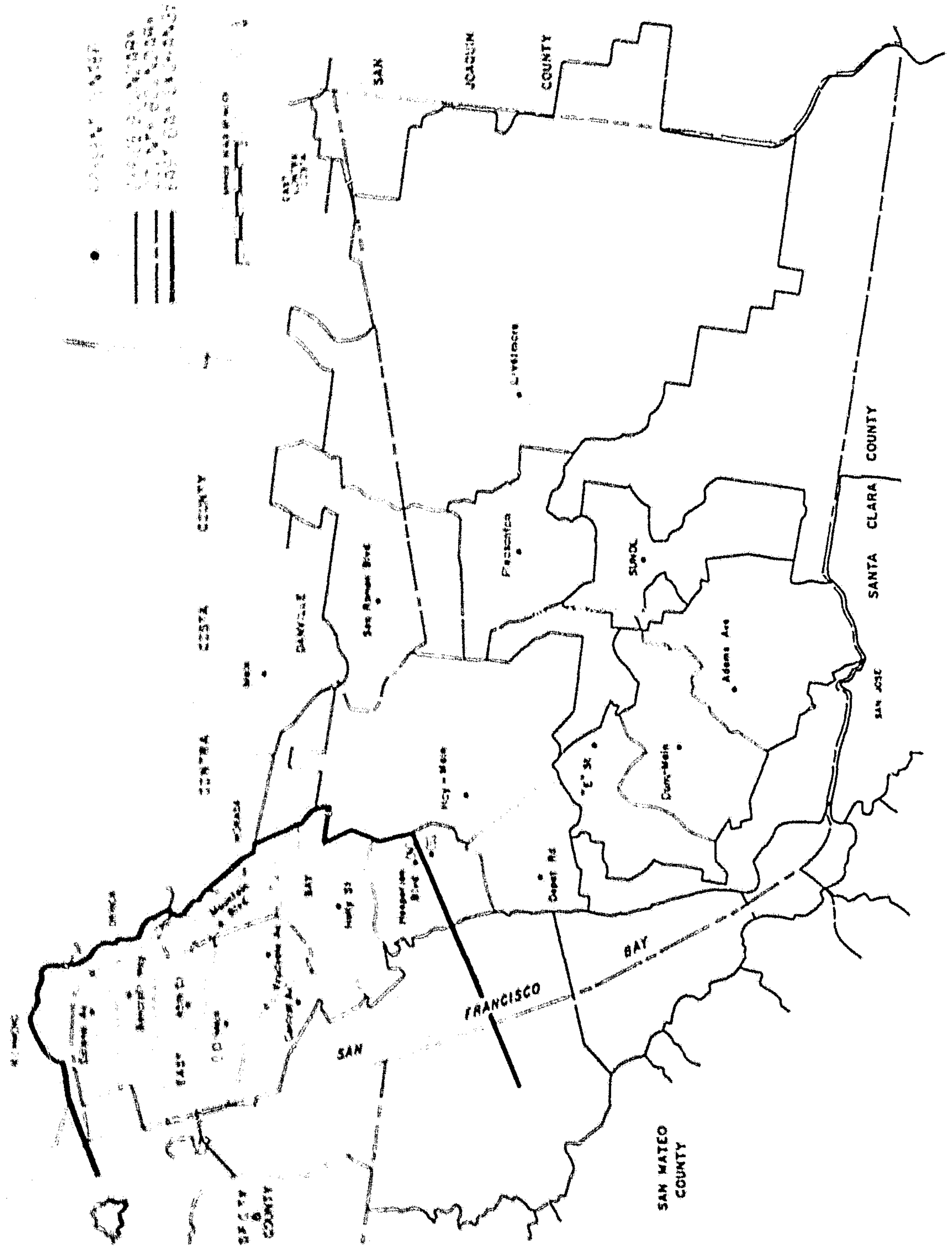

Figure 12. Alameda County and East Bay Exchange (supplied by Pacific Telephone)

the other is based on 2.5 calls per 1000 population. The two estimates for the entire county agree within ten percent. The figure used here, 2740 calls per day in the county, was based on the assumption of 2.5 calls per 1000 population.

The volume of calls determines the number of toll calls or the number of leased lines required to provide a given grade of service. The grade of service required was assumed to be P(001), that is, an average of one busy signal per thousand calls based on the Poisson tables for lost-calls-held conditions. Since the number of lines must be based on peak conditions, the assumption was made that the number of calls per day is ten times the number of calls in the busiest hour. Finally, the average duration of a call was assumed to be 60 seconds. Call volume data and line requirements obtained from standard Poisson tables are summarized in Table 2.

In the first part of Section C, the method is described for computing the total toll cost for 911 calls using the public switched network. In the second part, the method is described for computing the cost of leased lines to handle 911 call traffic.

1. Toll Costs. Information about the toll call structure in Alameda County can be found in the rate pages of the appropriate Pacific Telephone Directories. Basically, the County includes 13 toll zones which in some cases include more than one central office. There may be toll charges for calls between zones, whereas calls within a zone are free. Furthermore, the local

Table 2. Line Loading Capacity From Reference 3 Converted to Number of Calls Per Day

Number of Lines	Call Capacity Per Day
1	2
2	30
3	120
4	240
5	450
6	660
7	930
8	1170
9	1470
10	1770

NOTES: a) The average call is of 60 seconds duration.

b) The number of calls per day is ten times the number of calls in the busy hour.[2]

c) Grade of service is P(001), lost-calls-held conditions.

Example: Three lines are capable of handling 12 calls of an average duration of 60 seconds during the busy hour. This allows a maximum of 120 calls per day.

calling area of a toll zone is usually extended to include adjacent or nearby zones so that calls between two different zones do not always involve a toll charge. In Table 3 and Figure 13, the structure of the toll zones and the cost matrix assuming a 3 minute, daytime, station-to-station call are shown. The submatrices of 0's in Figure 13 indicate the presence of several large free zones. Table 3 also shows the free calling zones from each zone and volume data for zones.

Let V_i be the number of 911 calls originating in Zone i per day and let C_i be the toll charge per call (may be zero). Then, the total toll cost per day is given by

$$C = \sum_{i=1}^{13} C_i V_i .$$

The value of C_i is determined as follows. For only one PSAP, the value of C_i is the toll charge to call from zone i to the zone where the PSAP is located. For several PSAPs, the value of C_i is the minimum of the toll charges from Zone i to each of the zones where a PSAP is located. The effect of this procedure is that, when there are several PSAPs, a toll call is always routed to the PSAP which is cheapest to call.

The cost was computed for each of the 13 possible locations of one PSAP and for each of the $\binom{13}{2} = 78$ possible locations for two PSAPs. These results are summarized in Tables 4, 5, and 6. In Table 4, the values below the dotted line are one PSAP only; the remaining values are for two PSAPs.

Table 3. Structure of Toll Zones and Daily 911 Call Volume Estimates by Toll Zone for Alameda County

Toll Zone	Percent of Total Main Stations		Number of 911 Calls		Calling Zones
East Bay Exchange	64.9		1778		
1 Central Ave.		5.8		159	1, 2, 3, 4, 5
2 North		15.1		413	1, 2, 3, 4, 5
Solano Ave.		6.4		175	
Bancroft Way		8.7		238	
3 North Central		20.0		549	1, 2, 3, 4, 5
Oakland 49th St.		8.2		225	
Oakland Main		11.5		315	
20% of Mt. Blvd.		0.3		9	
4 South Central		8.2		224	1, 2, 3, 4, 5
Fruitvale Ave.		6.8		186	
80% of Mt. Blvd.		1.4		38	
5 South		15.8		433	1, 2, 3, 4, 5, 6
Holly St		9.5		260	
Hesperian North		6.3		173	
6 Hayward Exchange	15.5		425		5, 6, 7, 13
Hesperian South		3.2		88	
Depot Rd.		4.5		123	
Hayward Main		7.8		214	
Fremont-Newark Exchange	12.1		332		
7 "E" St.		2.5		69	6, 7, 8, 9, 10
8 Fremont Main (Dumbarton)		5.9		162	7, 8, 9, 10
9 Alamo Ave		3.7		101	7, 8, 9, 10
Other Exchanges	7.5		207		
10 Sunol Exchange		0.1		3	7, 8, 9, 10, 11, 12
11 Pleasanton Exchange		2.1		58	10, 11, 12, 13
12 Livermore Exchange		3.5		96	10, 11, 12, 13
13 San Ramon Exchange		1.8		50	6, 11, 12, 13
County Totals	100.0		2742		

Number of Toll Zone (See Table 3 for Key)

Number of Toll Zone	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	0	0	18	23	27	35	30*	30	35*	23
2	0	0	0	0	0	23	27	35	35	35*	35	40*	27
3	0	0	0	0	0	18	23	27	35	30*	30	35*	23
4	0	0	0	0	0	18	23	27	35	30*	30	35*	23
5	0	0	0	0	0	0	18	23	27	25	25	30	18
6	18	23	18	18	0	0	0	14	18	15	15	25	0
7	23	27	23	23	18	0	0	0	0	0	15	20	14
8	27	35	27	27	23	14	0	0	0	0	15	25	18
9	35	35	35	35	27	18	0	0	0	0	15	20	18
10	30*	35*	30*	30*	25	15	0	0	0	0	0	0	15
11	30	35	30	30	25	15	15	15	15	0	0	0	0
12	35*	40*	35*	35*	30	25	20	25	30	0	0	0	0
13	23	27	23	23	18	0	14	18	18	15	0	0	0

*Estimated; data not available.

Rate for call between zones i and j is found in ith row and jth column. (Note that matrix is symmetric.)

Example: Rate between zones 3 and 8 is 27 cents.

Figure 13. Cost Matrix for Alameda County Toll Calls (3 Minute, Daytime, Station-to-Station, in Cents)

Table 4. Summary of Results for One and Two PSAPs Using Public Switched Network (Entries are monthly cost in dollars)

Entries are monthly cost in dollars[a]

Number of Toll Zone See Table 3 for Key

Number of Toll Zone	1	2	3	4	5	6	7	8	9
1	7143.66	7143.66	7143.66	7143.66	3954.17	2251.14	1061.54	3078.17	3449.25
(2)		8567.77	7143.66	7143.66	3954.17	2251.14	1061.54	3078.17	3449.25
(3)			7143.66	7143.66	3954.17	2251.14	1061.54	3078.17	3449.25
(4)				7143.66	3954.17	2251.14	1061.54	3078.17	3449.25
(5)					3954.17	2251.14	1061.54	1268.38	1122.38
(6)						10243.12	8840.60	8986.60	8840.60
(7)							13344.10	13344.10	13344.10
(8)								18158.14	18012.14
(9)									21323.91

Find results for 2 PSAPs above dotted line.
Find results for 1 PSAP below dotted line.

Number of Toll Zone	10	11	12	13
1	2167.19	3453.81	4592.92	1747.44
2	2167.19	3453.81	5239.27	1747.44
3	2167.19	3453.81	4592.92	1747.44
4	2167.19	3453.81	4592.92	1747.44
5	228.13	1514.75	2125.52	1747.44
6	7091.98	9142.64	9234.80	9248.49
7	12495.47	12282.55	12282.55	12282.55
8	17117.89	16889.77	16889.77	12282.55
9	18361.02	18132.90	20201.53	12282.55
10	18361.02	18132.90	18132.90	12282.55
(11)		19647.65	19647.65	13776.32
(12)			24395.69	14016.30
(13)				14029.99

Example (2 PSAPs)

Find monthly cost when PSAPs are located in zones 3 and 8 in 3rd row, 8th column.

Cost = $3, 078.17

Example (1 PSAP)

Find monthly cost when PSAP is located in zone 5 in 5th row, 5th column.

Cost = $3, 954.17

[a]PSAP - public safety answering point

Table 5. Cost Using Public Switched Network with One PSAP[a] as a Function of PSAP Location (ordered by Increasing Cost)

PSAP Location (Toll Zone)	Cost per Month, Dollars
5. South Holly St. Hesperian North	3, 954.17
1. Central Ave.	7, 143.66
3. North Central Oakland 45th St. Oakland Main 20% of Mt. Blvd.	7, 143.66
4. South Central Fruitvale Ave. 80% of Mt. Blvd.	7, 143.66
2. North Solano Ave. Bancroft Way	8, 567.77
6. Hayward Exchange Hesperian South Depot Rd. Hayward Main	10, 243. 12
7. "E" Street	13, 344. 10
13. San Ramon Exchange	14, 029. 99
8. Fremont Main (Dumbarton)	18, 158. 14
10. Sunol Exchange	18, 361. 02
11. Pleasanton Exchange	19, 647. 65
9. Adams Ave.	21, 323. 91
12. Livermore Exchange	24, 395. 69

[a]PSAP - Public Safety Answering Point

Table 5. Summary Information for Two PSAPs Using Public Switched Network (Ordered by Increasing Cost)

Monthly Cost, $	PSAP[a] Locations (Toll Zones)		Zone of PSAP to be Called Based on Least Cost[b] Number of Toll Zone (See Table 3 for Key)													No. of Calls Per Day		
			1	2	3	4	5	6	7	8	9	10	11	12	13	1st PSAP	2nd PSAP	Either at = Cost
22[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1061.[illegible]	1	7	1	1	1	1	1	7	7	7	7	7	7	7	7	1778	964	0
1061.54	2	7	2	2	2	2	2	7	7	7	7	7	7	7	7	1778	964	[illegible]
1061.54	3	7	3	3	3	3	3	7	7	7	7	7	7	7	7	1778	964	[illegible]
1061.54	4	7	4	4	4	4	4	7	7	7	7	7	7	7	7	1778	964	0
1061.54	5	7	5	5	5	5	5	[illegible]	7	7	7	7	7	7	7	1778	539	425
1122.38	5	9	5	5	5	5	5	5	9	9	9	9	9	9	0	2203	489	50
1268.38	5	8	5	5	5	5	5	5	8	8	8	8	8	8	0	2203	489	50
1514.75	5	11	5	5	5	5	5	5	11	11	11	11	11	11	11	2203	539	0
1747.44	1	13	1	1	1	1	1	13	13	13	13	13	13	13	13	1778	964	0
1747.44	2	13	2	2	2	2	2	13	13	13	13	13	13	13	13	1778	964	0
1747.44	3	13	3	3	3	3	3	13	13	13	13	13	13	13	13	1778	964	0
1747.44	4	13	4	4	4	4	4	13	13	13	13	13	13	13	13	1778	964	0
1747.44	5	13	5	5	5	5	5	0	13	13	13	13	13	13	13	1778	539	425
2125.52	5	12	5	5	5	5	5	5	5	5	12	12	12	12	12	2434	308	0
2167.19	1	10	1	1	1	1	1	10	10	10	10	10	10	10	10	1778	964	0
2167.19	2	10	2	2	2	2	2	10	10	10	10	10	10	10	10	1778	964	0

[a]PSAP - Public Safety Answering Point.

[b]0 - Implies equal cost when assigned to either PSAP

Table 6. Summary Information for Two PSAPs Using Public Switched Network (Ordered by Increasing Cost) (Continued)

Monthly Cost, $	PSAP[a] Locations (Toll Zones)		Zone of PSAP to be Called Based on Least Cost[b] Number of Toll Zone (See Table 3 for Key)													No. of Calls Per Day		
			1	2	3	4	5	6	7	8	9	10	11	12	13	1st PSAP	2nd PSAP	Either at = Cost
2167.19	3	10	3	3	3	3	3	10	10	10	10	10	10	10	10	1778	964	0
2167.19	4	10	4	4	4	4	4	10	10	10	10	10	10	10	10	1778	964	0
2251.14	1	6	1	1	1	1	0	6	6	6	6	6	6	6	6	1345	964	433
2251.14	2	6	2	2	2	2	0	6	6	6	6	6	6	6	6	1345	964	433
2251.14	3	6	3	3	3	3	0	6	6	6	6	6	6	6	6	1345	964	433
2251.14	4	6	4	4	4	4	0	6	6	6	6	6	6	6	6	1345	964	433
2251.14	5	6	5	5	5	5	0	0	6	6	6	6	6	6	6	1345	539	858
3078.17	1	8	1	1	1	1	1	8	8	8	8	8	8	8	8	1778	964	0
3078.17	2	8	2	2	2	2	2	8	8	8	8	8	8	8	8	1778	964	0
3078.17	3	8	3	3	3	3	3	8	8	8	8	8	8	8	8	1778	964	0
3078.17	4	8	4	4	4	4	4	8	8	8	8	8	8	8	8	1778	964	0
3449.25	1	9	1	1	1	1	1	0	9	9	9	9	9	9	9	1778	539	425
3449.25	2	9	2	2	2	2	2	9	9	9	9	9	9	9	9	1778	964	0
3449.25	3	9	3	3	3	3	3	0	9	9	9	9	9	9	9	1778	539	425
3449.25	4	9	4	4	4	4	4	0	9	9	9	9	9	9	9	1778	539	425
3453.81	1	11	1	1	1	1	1	11	11	11	11	11	11	11	11	1778	964	0
3458.81	2	11	2	2	2	2	2	11	11	11	11	11	11	11	11	1778	964	0

[a]PSAP - Public Safety Answering Point

[b]0 - Implies equal cost when assigned to either PSAP

Table 6. Summary Information for Two PSAPs Using Public Switched Network Ordered by Increasing Cost (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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3954.17	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3954.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3954.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4592.92	1	12	1	1	1	1	1	1	12	12	12	12	12	12	12	2203	539	0
4592.92	3	12	3	3	3	3	3	3	12	12	12	12	12	12	12	2203	539	0
4592.92	4	12	4	4	4	4	4	4	12	12	12	12	12	12	12	2203	539	0
6239.27	2	12	2	2	2	2	2	2	12	12	12	12	12	12	12	2203	539	0
7143.66	1	2	0	0	0	0	0	1	1	1	0	1	1	1	1	863	0	1879
7143.66	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2742
7143.66	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2742
7143.66	2	3	0	0	0	0	0	3	3	3	0	3	3	3	3	0	863	1879
7143.66	2	4	0	0	0	0	0	4	4	4	0	4	4	4	4	0	863	1879
7143.66	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2742
7991.98	6	10	6	6	6	6	6	6	0	10	10	10	10	10	6	2253	420	69
8840.60	6	7	6	6	6	6	6	0	0	7	7	7	0	7	6	1828	362	552

[a]PSAP - Public Safety Answering Point

[b]0 - Implies equal cost when assigned to either PSAP

In Table 5 the results for one PSAP are shown, ordered by increasing cost. The least cost location for one PSAP is Zone 5 (South) with a monthly cost of $3,954.17.

In Table 6 the results for two PSAPs are shown, again ordered by increasing cost. The least cost locations are Zones 5 (South) and 10 (Sunol Exchange) with a monthly cost of $228.13. Additional information is also shown. Indicated for each zone is the PSAP to which it is assigned. Entries of 0 indicate cases where either assignment results in the same cost. Finally, the volume of calls which would be received by each PSAP with the indicated assignment is shown. The third column of volume figures indicates the number of calls which could be routed to either PSAP at the same cost.

In Table 7, a detailed breakdown of the cost computation is shown for one PSAP located in the South toll zone. In Table 8, similar computations are shown for two PSAPs located in the South toll zone and the Sunol Exchange toll zone. These two cases give the least cost for one and two PSAPs, respectively.

2. Leased Lines. The cost of using leased lines for 911 calls depends on the level of service required and on the distance between calling points. The level of service desired for this application is assumed to be P(001); that is, an average of one busy signal in one thousand calls.

The distance between two points can be calculated by imposing coordinates on the points and applying to the coordinates the Euclidean distance formula. The coordinates of the 19 central offices were estimated from a map supplied by Pacific Telephone (Figure 12). The distance matrix is

Table 7. Detailed Cost Breakdown for One PSAP[a] Located in South Toll Zone (Holly St. or Hesperian North)

(Least cost location of one PSAP based on public network toll call charges)

Toll Zone	Toll Charge to Call Zone of PSAP[b], $	Expected No. of Calls/Day[c]	Cost per Day, $	Cost per Month, $
1. Central Ave.	0	159	0	0
2. North Solano Ave. Bancroft Way	0	413	0	0
3. North Central Oakland 45th St. Oakland Main 20% of Mt. Blvd.	0	549	0	0
4. South Central Fruitvale Ave. 80% of Mt. Blvd.	0	224	0	0
5. South (PSAP) Holly St. Hesperian North	0	433	0	0
6. Hayward Exchange Hesperian South Depot Rd. Hayward Main	0	425	0	0
7. "E" St.	0.18	69	12.42	377.78
8. Fremont Main	0.23	162	37.26	1133.33
9. Adams Ave.	0.27	101	27.27	829.46
10. Sunol Exch.	0.25	3	0.75	22.81
11. Pleasanton Exch.	0.25	58	14.50	441.04
12. Livermore Exch.	0.30	96	28.80	876.00
13. San Ramon Exch.	0.18	50	9.00	273.75
COUNTY TOTALS	-	2742	130.00	3954.17

[a]PSAP - Public Safety Answering Point

[b]From Figure 13

[c]From Table 3, based on 2.5 calls per 1000 population

Table 8. Detailed Cost Breakdown for Two PSAPs[a] Located in South Toll Zone (Holly St. or Hesperian North) and Sunol Exchange

(Least Cost Locations of Two PSAPs Based on Public Network Toll Call Charges)

Toll Zone	Toll Charge to Call Zone of PSAP[b], $	Expected No. of Calls/Day[c]	Cost per Day, $	Cost per Month, $
South:				
1. Central Ave.	0	159	0	0
2. North Solano Ave. Bancroft Way	0	413	0	0
3. North Central Oakland 45th St. Oakland Main 20% of Mt. Blvd.	0	549	0	0
4. South Central Fruitvale Ave. 80% of Mt. Blvd.	0	224	0	0
5. South Holly St. Hesperian North	0	433	0	0
6. Hayward Exchange Hesperian South Depot Rd. Hayward Main	0	425	0	0
PSAP TOTALS	-	2203	0	0
Sunol Exchange:				
7. "E" St.	0	69	0	0
8. Fremont Main (Dumbarton)	0	162	0	0
9. Adams Ave.	0	101	0	0
10. Sunol Exch.	0	3	0	0
11. Pleasanton Exch.	0	58	0	0
12. Livermore Exch.	0	96	0	0
13. San Ramon Exch.	0.15	50	7.50	228.13
PSAP TOTALS	-	539	7.50	228.13
COUNTY TOTALS	-	2742	7.50	228.13

[a]PSAP - Public Safety Answering Point

[b]From Figure 13

[c]From Table 3, based on 2.5 calls per 1000 population

shown in Table 9. It gives the distance in miles between any pair of central offices. To compute the cost, it is first necessary to obtain the line distance by multiplying distances by the number of lines required to provide the desired level of service. The number of lines required is based on the number of calls in the busiest hour as was discussed in Section C and is conservative; however, this excess capacity could permit some expansion in the number of calls handled with no increase in line requirements. Traffic tables which show the number of lines needed for various line loading capabilities were used[3]. Table 10 shows the number of lines estimated for each central office. It also shows the maximum number of calls per day that can be accommodated for the desired grade of service.

The total cost of using leased lines is directly proportional to the total line distance. The cost of one mile of leased line is assumed to be $3.60 per month. If one PSAP is used, then the total line distance is the sum of the line distances between the central office servicing the PSAP and each of the other central offices.

The procedure can be extended to more than one PSAP. Connections are assumed between the central office servicing a PSAP and neighboring central offices with the restriction that no central office is connected to more than one central office servicing a PSAP. The question of which central offices are connected to which PSAPs was decided on the basis of least cost.

Typical figure quoted by PT&T for leased two-wire line.

Table 9. Mileage Between Central Offices in Alameda County

Row i and column j contains mileage between central offices i and j.

Number of Central Office (See Table 10 for Key)

	2	3	4	5	6	7	8	9	10	11	12	13
1	8.51	7.19	4.58	4.43	3.20	3.41	4.22	7.47	8.02	20.45	26.27	10.85
	(2)	1.53	3.94	6.42	5.47	7.66	11.02	14.66	15.25	25.70	30.62	17.72
		(3)	2.63	4.88	4.34	6.16	9.50	13.13	13.72	24.23	29.23	16.19
			(4)	3.46	1.78	3.93	7.36	11.01	11.60	22.88	28.22	14.22
				(5)	4.08	2.17	4.85	8.37	8.95	19.51	24.77	11.33
					(6)	3.52	6.76	10.32	10.89	22.79	28.35	13.64
						(7)	3.43	7.09	7.67	19.28	24.85	10.31
							(8)	3.66	4.24	16.24	22.06	6.90
								(9)	0.59	13.31	19.41	3.38
									(10)	12.91	19.04	2.86
										(11)	6.32	10.18
											(12)	16.41

Number of Central Office

Number of Central Office

Number of Central Office	14	15	16	17	18	19
1	11.07	16.05	18.55	21.89	22.97	16.63
2	19.13	23.37	26.20	29.42	29.26	20.45
3	17.64	21.83	24.68	27.89	27.75	19.06
4	15.28	19.77	22.51	25.78	26.07	18.13
5	13.11	17.00	19.89	23.07	22.89	14.67
6	14.23	19.04	21.64	24.95	25.68	18.89
7	11.48	15.84	18.60	21.85	22.24	14.95
8	8.26	12.41	15.18	18.43	13.93	12.52
9	5.03	8.76	11.54	14.78	15.50	10.70
10	4.55	8.17	10.96	14.19	14.93	10.53
11	13.23	8.50	10.11	10.48	5.14	6.14
12	19.54	14.56	15.55	14.37	8.34	10.18
13	4.40	5.70	8.72	11.78	12.12	8.68
	(14)	5.82	7.67	11.02	13.66	12.95
		(15)	3.16	6.08	7.83	10.69
			(16)	3.35	7.72	13.44
				(17)	6.53	15.04
					(18)	11.07

Example

Find mileage between central offices 6 and 11 in 6th row, 11th column.

Mileage = 22.79

Table 10. Daily 911 Call Volume Estimates and Line Requirements for Alameda County

(Table based on 2.5 calls per 1000 population, a 60-second average call length, and P(001) grade of service)

Central Office	% of Total Main Stations	Estimated Number of 911 Calls	Number of Lines	Daily Call Capacity
1. Central Ave.	5.8	159	4	240
2. Solano Ave.	6.4	175	4	240
3. Bancroft Way	8.7	238	5	450
4. Oakland 45th St.	8.2	225	5	450
5. Mountain Blvd.	1.7	47	3	120
6. Oakland Main	11.5	315	5	450
7. Fruitvale Ave.	6.8	186	4	240
8. Holly St.	9.5	260	5	450
9. Hesperian North	6.3	173	4	240
10. Hesperian South	3.2	88	3	120
11. Pleasanton Exch.	2.1	58	3	120
12. Livermore Exch.	3.5	96	3	120
13. Hayward Main	7.8	214	4	240
14. Depot Rd.	4.5	123	4	240
15. "E" St.	2.5	69	3	120
16. Fremont Main (Dumbarton)	5.9	162	4	240
17. Adams Ave.	3.7	101	3	120
18. Sunol Exch.	0.1	3	2	30
19. San Ramon Exch.	1.8	50	3	120
County Totals	100.0	2742	71	4350

The cost was computed for each of the 19 possible locations of one PSAP and each of the $\binom{19}{2} = 171$ possible locations of two PSAPs. These results are summarized in Tables 11, 12, and 13, in a fashion similar to Section C.1. In Table 11, the values below the dotted line are for one PSAP; the values above the line are for two PSAPs. In Table 12, results for one PSAP are shown, ordered by increasing cost. The least cost location is Holly Street at a monthly cost of $2,300.11. In Table 13, results for two PSAPs are shown ordered by increasing cost. In addition, the assignment of each central office to a PSAP and the number of calls that would be received by each PSAP with the indicated assignment are shown. The least cost locations are Oakland 45th Street and "E" Street with a monthly cost of $1,341.30, but there are a number of other choices which have only a slightly greater cost.

In Table 14, a detailed breakdown of the cost computations is shown for one PSAP located in the Holly Street Central Office Region; this is the least cost location. Similar computations are shown in Table 15 for two PSAPs located in the Oakland 45th Street and Hayward Central Office Regions. This choice of locations costs only $4.50 per month more than the minimum and provides a much more equal call load on each PSAP.

D. Telephone Lines, PSAP to Dispatching Location

In the previous section, the toll cost and leased lines cost to connect the citizen telephones through the central offices to the public safety answering points (PSAPs) was analyzed. In this section, the cost for leased lines between a centralized PSAP and dispatching centers is is analyzed for Alameda County. If the existing dispatching centers are retained as part of a 911 system, it must be possible

Table 11. Summary of Results for One and Two PSAPs Using Leased Lines

(Entries are monthly cost in dollars)

Find results for two PSAPs above dotted line.

Find results for one PSAP below dotted line.

Number of Central Office (See Table 10 for Key)

	1	2	3	4	5	6	7	8	9	10
1	2586.93	2351.03	2322.00	2320.63	2395.57	2379.98	2399.86	2028.26	1668.91	1631.77
(2)		3591.17	3241.40	2312.25	2435.41	2712.37	2253.17	1913.28	1670.25	1648.50
(3)			3263.50	2806.78	2414.98	2706.84	2224.38	1363.80	1586.88	1550.10
(4)				2383.31	2408.27	2745.95	2227.83	1837.47	1490.41	1453.63
(5)					2588.07	2443.32	2370.12	1961.67	1605.29	1568.51
(6)						2841.60	2280.51	1882.15	1524.02	1487.24
(7)							2446.74	1966.88	1603.49	1556.14
(8)								2300.11	1874.96	1827.61
(9)									2325.79	2269.97
(10)										2351.47

Number of Central Office

Example (1 PSAP)

Find monthly cost when PSAP is located in C. O. region 6 in 6th row, 6th column.

Cost = $2, 841.60

Number of Central Office

Number of Central Office	11	12	13	14	15	16	17	18	19
1	1572.38	1840.37	1476.14	1620.14	1448.12	1529.08	1657.05	1592.47	1756.69
2	1887.94	2864.94	1548.87	1717.23	1610.26	1766.33	1987.49	1973.60	2004.33
3	1751.45	2168.09	1442.33	1610.69	1476.39	1632.47	1826.62	1804.23	1870.46
4	1571.72	1917.28	1345.86	1498.09	1341.30	1489.74	1623.09	1615.69	1735.37
5	1573.12	1847.45	1423.89	1567.89	1405.51	1498.90	1630.62	1599.56	1754.69
6	1576.90	1898.98	1376.85	1520.85	1364.06	1501.37	1643.27	1620.87	1752.73
7	1493.94	1753.62	1400.51	1544.51	1358.19	1444.16	1563.29	1505.72	1677.75
8	1585.35	1814.73	1671.99	1788.14	1543.24	1593.11	1633.25	1595.28	1790.61
9	1848.95	1983.43	2049.60	2111.06	1857.24	1843.45	1875.13	1852.87	2001.17
10	1004.18	2023.07	2124.75	2169.45	1916.31	1902.41	1934.10	1911.83	2040.31
11	3893.79	3825.58	2214.00	2382.05	2957.31	3382.20	3625.39	3773.14	3168.42
(12)		5163.79	2278.71	2454.59	3020.63	3463.79	4083.13	4279.64	3308.62
(13)			2524.81	2438.14	2253.07	2239.16	2263.48	2224.99	2312.49
(14)				2308.60	2456.50	2467.03	2495.91	2433.05	2472.32
(15)					3206.98	3130.88	3131.55	3046.78	2347.41
(16)						3707.98	3655.32	3495.29	2938.73
(17)							4341.21	4116.29	3022.13
(18)								4379.37	3125.16
(19)									3440.01

Example (2 PSAPs)

Find monthly cost when PSAPs are located in Central Office regions 5 and 12 in 5th row, 12th column.

Cost = $1, 847.45

Table 12. Cost Using Leased Lines with One PSAP as a Function of PSAP Location (Ordered by Increasing Cost)

PSAP Location (Central Office)	Cost per Month, Dollars
8. Holly St.	2, 300.11
9. Hesperian North	2, 325.79
10. Hesperian South	2, 351.47
7. Fruitvale Ave.	2, 446.74
13. Hayward Main	2, 524.81
1. Central Ave.	2, 586.93
5. Mountain Blvd.	2, 588.07
14. Depot Rd.	2, 808.60
6. Oakland Main	2, 841.60
4. Oakland 45th St.	2, 888.81
15. "E" St.	3, 206.98
3. Bancroft Way	3, 263.50
19. San Ramon Exchange	3, 440.01
2. Solano Ave.	3, 591.17
16. Fremont Main (Dumbarton)	3, 707.98
11. Pleasanton Exchange	3, 893.79
17. Adams Ave.	4, 341.21
18. Sunol Exchange	4, 379.37
12. Livermore Exchange	5, 168.79

Table 13. Summary Information for 50 Lowest Cost Locations for Two PSAPs Using Leased Lines (Ordered by Increasing Cost)

Monthly Cost, $	PSAP[a] Locations (C.O.)	Central Office of PSAP to be Called Based on Least Cost Number of Central Office (See Table 10 for Key)																			No. of Calls/Day		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1st PSAP	2nd PSAP	Either
1341.83	4 15	4	4	4	4	4	4	4	4	15	15	15	15	15	15	15	15	15	15	15	1605	1137	0
1345.86	4 13	4	4	4	4	4	4	4	13	13	13	13	13	13	13	13	13	13	13	13	1345	1887	0
1358.19	7 15	7	7	7	7	7	7	7	7	7	7	15	15	15	15	15	15	15	15	15	1866	876	0
1364.06	6 15	6	6	6	6	6	6	6	6	15	15	15	15	15	15	15	15	15	15	15	1605	1137	0
1376.85	6 13	6	6	6	6	6	6	6	6	13	13	13	13	13	13	13	13	13	13	13	1605	1137	0
1400.51	7 13	7	7	7	7	7	7	7	7	13	13	13	13	13	13	13	13	13	13	13	1605	1137	0
1405.51	5 15	5	5	5	5	5	5	5	5	5	15	15	15	15	15	15	15	15	15	15	1778	964	0
1423.89	5 13	5	5	5	5	5	5	5	5	13	13	13	13	13	13	13	13	13	13	13	1605	1137	0
1442.33	3 13	3	3	3	3	3	3	3	13	13	13	13	13	13	13	13	13	13	13	13	1345	1397	0
1443.12	1 15	1	1	1	1	1	1	1	1	1	1	15	15	15	15	15	15	15	15	15	1866	876	0
1444.16	7 16	7	7	7	7	7	7	7	7	7	7	16	16	16	16	16	16	16	16	16	1866	876	0
1453.63	4 10	4	4	4	4	4	4	4	10	10	10	10	10	10	10	10	10	10	10	10	1345	1397	0
1476.14	1 13	1	1	1	1	1	1	1	1	13	13	13	13	13	13	13	13	13	13	13	1605	1137	0
1476.39	3 15	3	3	3	3	3	3	3	3	15	15	15	15	15	15	15	15	15	15	15	1605	1137	0
1487.24	6 10	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10	10	10	10	10	1345	1397	0
1489.74	4 16	4	4	4	4	4	4	4	4	4	16	16	16	16	16	16	16	16	16	16	1778	964	0
1490.41	4 9	4	4	4	4	4	4	4	9	9	9	9	9	9	9	9	9	9	9	9	1345	1397	0
1498.94	7 11	7	7	7	7	7	7	7	7	7	7	11	11	11	7	11	11	11	11	11	1989	753	0
1498.09	4 14	4	4	4	4	4	4	4	4	14	14	14	14	14	14	14	14	14	14	14	1605	1137	0
1499.80	5 16	5	5	5	5	5	5	5	5	5	5	16	16	16	16	16	16	16	16	16	1866	876	0
1501.87	6 16	6	6	6	6	6	6	6	6	6	6	16	16	16	16	16	16	16	16	16	1866	876	0
1505.72	7 18	7	7	7	7	7	7	7	7	7	7	18	18	7	7	18	18	18	18	18	2203	539	0

[a]PSAP - Public Safety Answering Point

Table 13. Summary Information for 50 Lowest Cost Locations for Two PSAPs Using Leased Lines (Ordered by Increasing Cost) (Continued)

Monthly Cost, $	PSAP[a] Locations (C.O.)	Central Office of PSAP to be Called Based on Least Cost Number of Central Office (See Table 10 for Key)																			No. of Calls/Day		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1st PSAP	2nd PSAP	Either
1520.85	6 14	6	6	6	6	6	6	6	6	14	14	14	14	14	14	14	14	14	14	14	1605	1137	0
1524.02	6 9	6	6	6	6	6	6	6	9	9	9	9	9	9	9	9	9	9	9	9	1345	1397	0
1529.08	1 16	1	1	1	1	1	1	1	1	1	1	16	16	16	16	16	16	16	16	16	1866	876	0
1543.24	8 15	8	8	8	8	8	8	8	8	8	8	15	15	15	15	15	15	15	15	15	1866	876	0
1544.51	7 14	7	7	7	7	7	7	7	7	14	14	14	14	14	14	14	14	14	14	14	1605	1137	0
1548.87	2 13	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	13	13	13	13	1345	1397	0
1550.10	3 10	3	3	3	3	3	3	3	10	10	10	10	10	10	10	10	10	10	10	10	1345	1397	0
1556.14	7 10	7	7	7	7	7	7	7	7	10	10	10	10	10	10	10	10	10	10	10	1605	1137	0
1563.29	7 17	7	7	7	7	7	7	7	7	7	7	17	17	7	17	17	17	17	17	7	2130	612	0
1567.89	5 14	5	5	5	5	5	5	5	5	14	14	14	14	14	14	14	14	14	14	14	1605	1137	0
1568.51	5 10	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10	10	10	10	10	1345	1397	0
1571.72	4 11	4	4	4	4	4	4	4	4	4	4	11	11	11	11	11	11	11	11	11	1866	876	0
1572.88	1 11	1	1	1	1	1	1	1	1	1	11	11	11	11	1	11	11	11	11	11	1889	753	0
1573.12	5 11	5	5	5	5	5	5	5	5	5	5	11	11	11	5	11	11	11	11	11	1889	753	0
1576.90	6 11	6	6	6	6	6	6	6	6	6	6	11	11	11	11	11	11	11	11	11	1866	876	0
1585.35	8 11	8	8	8	8	8	8	8	8	8	8	11	11	8	8	11	11	11	11	11	2203	589	0
1586.88	3 9	3	3	3	3	3	3	3	9	9	9	9	9	9	9	9	9	9	9	9	1345	1397	0
1592.47	1 18	1	1	1	1	1	1	1	1	1	1	18	18	1	1	18	18	18	18	18	2203	539	0
1593.11	8 16	8	8	8	8	8	8	8	8	8	8	16	16	8	16	16	16	16	16	8	2130	612	0
1595.28	8 18	8	8	8	8	8	8	8	8	8	8	18	18	8	8	18	18	18	18	18	2203	539	0
1599.56	5 18	5	5	5	5	5	5	5	5	5	5	18	18	5	5	18	18	18	18	18	2203	539	0
1603.49	7 9	7	7	7	7	7	7	7	7	9	9	9	9	9	9	9	9	9	9	9	1605	1137	0

[a]PSAP - Public Safety Answering Point

Table 13. Summary Information for 50 Lowest Cost Locations for Two PSAPs Using Leased Lines (Ordered by Increasing Cost) (Continued)

Monthly Cost, $	PSAP[a] Locations (Central Office)	Central Office of PSAP to be Called Based on Least Cost Number of Central Office (See Table 10 for Key)																			No. of Calls/Day		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1st PSAP	2nd PSAP	Either
1605.29	5 9	5	5	5	5	5	5	5	9	9	9	9	9	9	9	9	9	9	9	9	1345	1397	0
1610.26	2 15	2	2	2	2	2	2	2	2	15	15	15	15	15	15	15	15	15	15	15	1605	1137	0
1610.69	3 14	3	3	3	3	3	3	3	14	14	14	14	14	14	14	14	14	14	14	14	1345	1397	0
1615.69	4 18	4	4	4	4	4	4	4	4	4	4	18	18	18	18	18	18	18	18	18	1866	876	0
1620.14	1 14	1	1	1	1	1	1	1	1	14	14	14	14	14	14	14	14	14	14	14	1605	1137	0
1620.87	6 18	6	6	6	6	6	6	6	6	6	6	18	18	18	18	18	18	18	18	18	1866	876	0

[a]PSAP - Public Safety Answering Point

Table 14. Detailed Cost Breakdown for One PSAP Located in Holly St. Central Office Region

(Least Cost Location of One PSAP with Leased Lines)

Central Office	Mileage to Holly St.[a]	No. of Lines[b]	Line Mileage	Line Cost $/Month[c]	Expected No. of Calls/Day[d]	Call Capacity Per Day[b]
1. Central Ave.	4.22	4	16.88	60.77	159	240
2. Solano Ave.	11.02	4	44.08	158.69	175	240
3. Bancroft Way	9.50	5	47.50	171.00	238	450
4. Oakland 45th St.	7.36	5	36.80	132.48	225	450
5. Mountain Blvd.	4.85	3	14.55	52.38	47	120
6. Oakland Main	6.76	5	33.80	121.68	315	450
7. Fruitvale Ave.	3.43	4	13.72	49.39	186	240
8. Holly St.	-----	-	------	-------	260	450
9. Hesperian North	3.66	4	14.64	52.70	173	240
10. Hesperian South	4.24	3	12.72	45.79	88	120
11. Pleasanton Exch.	16.24	3	48.72	175.39	58	120
12. Livermore Exch.	22.06	3	66.18	238.25	96	120
13. Hayward Main	6.90	4	27.60	99.36	214	240
14. Depot Rd.	8.26	4	33.04	118.94	123	240
15. "E" St.	12.41	3	37.23	134.03	69	120
16. Fremont Main (Dumbarton)	15.18	4	60.72	218.59	162	240
17. Adams Ave.	18.43	3	55.29	199.04	101	120
18. Sunol Exch.	18.93	2	37.86	136.30	3	30
19. San Ramon Exch.	12.52	3	37.56	135.22	50	120
COUNTY TOTALS	-----	66	638.89	2300.00	2742	4350

[a]From Table 9
[b]P(001) grade of service, average call duration 60 seconds, see Table 2
[c]Cost of lines - $3.60 per mile per month
[d]From Table 2, based on 2.5 calls per 1000 population

Table 15. Detailed Cost Breakdown for Two PSAPs Located in Oakland 45th St. and Hayward Central Office Regions

(Least Cost Locations of Two PSAPs[a] with Leased Lines and Equal Division of Call Load)[b]

Central Office	Mileage to Central Office of PSAP[c]	No. of Lines[d]	Line Mileage	Line Cost $/Month[e]	Expected No. of Calls/Day[f]	Call Capacity Per Day
Oakland 45th St.:						
1. Central Ave.	4.58	4	18.32	65.95	159	240
2. Solano Ave.	3.94	4	15.76	56.74	175	240
3. Bancroft Way	2.63	5	13.15	47.34	238	450
4. Oakland 45th St.	(g)	-	-----	------	225	450
5. Mountain Blvd.	3.46	3	10.38	37.37	47	120
6. Oakland Main	1.78	5	8.90	32.04	315	450
7. Fruitvale Ave.	3.93	4	15.72	56.59	186	240
PSAP Totals	----	25	82.23	296.03	1345	2190
Hayward:						
8. Holly St.	6.90	5	34.50	124.20	260	450
9. Hesperian North	3.38	4	13.52	48.67	173	240
10. Hesperian South	2.86	3	8.58	30.89	88	120
11. Pleasanton Exch.	10.18	3	30.54	109.94	58	120
12. Livermore Exch.	16.41	3	49.23	177.23	96	120
13. Hayward Main	(g)	-	-----	------	214	240
14. Depot Rd.	4.40	4	17.60	63.36	123	240
15. "E" St.	5.70	3	17.10	61.56	69	120
16. Fremont Main (Dumbarton)	8.72	4	34.88	125.57	162	240
17. Adams Ave.	11.78	3	35.34	127.22	101	120
18. Sunol Exch.	12.12	2	24.24	87.26	3	30
19. San Ramon Exch.	8.69	3	26.07	93.85	50	120
PSAP Totals	----	37	291.60	1049.75	1397	2160
County Totals	----	62	373.83	1345.78	2742	4350

[a] PSAP - Public Safety Answering Point

[b] Locating the 2nd PSAP in the "E" St. Region instead of the Hayward Region costs $4.50 less per month but the call load is not equally distributed.

[c] From Table 9

[d] P(001) grade of service, average call duration 60 seconds, see Table 2

[e] Cost of lines - $3.60 per mile per month

[f] From Table 2, based on 2.5 calls per 1000 population

[g] Distance between Oakland 45th and Hayward is 14.22 miles.

to transfer calls from the answering PSAP to the appropriate dispatcher. The cost of the needed lines depends on the number and location of the PSAPs. In this report, the following assumptions are made:

- One centralized PSAP
- PSAP located in Alameda County Sheriff's Office
- An individual group of lines to each distinct dispatching location

The choice of these particular assumptions does not mean that this particular type of PSAP was found to be most desirable. Which type of PSAP would minimize the line costs analyzed in this report was not investigated, since sufficient data were not available and could not be obtained in the time available for completion of the report. The assumptions made apply to the data which were available. The effect of these assumptions is discussed later.

1. Computations. The breakdown of line costs is shown in Table 16. Estimates of call volume in each municipality based on 2.5 calls per day per 1000 population, the same basis applied before, were used to obtain line requirements based on P(001) grade of service from Table 17. Experience has shown that fire calls are about 10 percent of the total; therefore, in those municipalities where police and fire dispatching are separate, this conservative number was used. A minimum of two lines was assumed in all cases.

Mileage and individual line cost data were supplied by the Oakland 911 Project Office. The costs are indicated separately for the required voice lines only and the voice lines plus one data line to each dispatching center. The data lines would be used in a 911 system incorporating ANI or ALI. Certain lines also incur termination charges of $20.00 per month; this total is listed separately.

Table 16. Cost Breakdown for Leased Lines Between 911 Answering Point at Alameda County Sheriff's Office and Dispatching Stations

Dispatching Station	No. of Lines (Voice)	Mileage	Mileage Charge, $/month One Line	Total Voice	Voice + 1 Data	Call Capacity Per Day
Alameda Police	4	8.0	33.00	132.00	165.00	240
Alameda Fire	2	7.5	31.00	62.00	93.00	30
Albany Police & Fire	3	16.0	65.00	195.00	260.00	120
Berkeley Police	5	14.0	57.00	285.00	342.00	450
Berkeley Fire	2	14.0	57.00	114.00	171.00	30
U. C. Berkely Police	2	13.5	55.00	110.00	165.00	30
Emeryville Police	2	13.5	55.00	110.00	165.00	30
Emeryville Fire	2	12.5	51.00	102.00	153.00	30
Oakland Police	7	10.5	43.00	301.00	344.00	930
Oakland Fire	3	10.0	41.00	123.00	164.00	120
Piedmont Police & Fire	2	10.0	41.00	82.00	123.00	30
San Leandro Police & Fire	4	2.5	11.00	44.00	55.00	240
Hayward Police*	4	8.0	29.20	116.80	146.00	240
Hayward Fire*	2	8.0	29.20	58.40	87.60	30
Union City Police & Fire*	3	14.0	51.10	153.30	204.40	120
Newark Police & Fire*	3	17.0	62.05	186.15	248.20	120
Fremont Police*	5	17.0	62.05	310.25	372.30	450
Fremont Fire*	2	17.0	62.05	124.10	186.15	30
Pleasanton Police & Fire*	3	18.0	65.70	197.10	262.80	120
Livermore Police & Fire*	3	23.0	83.95	251.85	335.80	120
Alameda County Sheriff	5	--	2.00	10.00	12.00	450
Valley C. S. D.*	2	13.0	47.45	94.90	142.35	30
Consolidated Fire District*	2	8.0	29.20	58.40	87.60	30
East Bay Reg. Parks	2	6.5	27.00	54.00	81.00	30
Fairview Fire District*	2	8.0	29.20	58.40	87.60	30
Alameda County Fire Patrol*	2	23.0	83.95	167.90	251.85	30
Division of Forestry	2	na	na	na	na	30
California Highway Patrol	2	na	na	na	na	30
MILEAGE TOTALS		--	1204.10	3501.55	4705.65	
TERMINATION CHARGES ($20 per line for 12[illegible]d stations with 33 lines)			--	660.00	900.00	
TOTALS	82			4161.55	5605.65	4170

Table 17. Daily 911 Call Volume Projections

Jurisdiction	Current Emergency Telephone Call Volumes[a]	Seattle Recommended Planning Figures of 2.5/1000 Pop.
Oakland	773	905
Berkeley	216	292
Fremont	154	286
Uninc. Alameda Co.	148	280
Hayward	145	242
Alameda	77	186
San Leandro	84	176
Livermore	53	109
Newark	24	74
Pleasanton	20	68
Union City	22	50
Albany	14	37
Piedmont	9	27
Emeryville	15	8
Totals	--	2,740

[a] As supplied by 911 Project Office

The total cost for voice lines would be $4161.55 per month. With an additional data line to each dispatching center, the cost becomes $5605.65 per month. To provide a comparison with the previous section, the mileage costs are $3501.55 and $4161.55 per month, respectively.

2. Discussion of Assumptions. With one centralized PSAP, some of the lines may be quite long. Decentralization of answering would tend to reduce the average length of the lines and therefore the cost. On the other hand, with decentralization it is possible that the same dispatching center would have to be linked to several PSAPs. This would tend to increase line mileage. Linking together of PSAPs would also increase line mileage. The exact effect of decentralization on cost would therefore depend on the particular system design.

Although only one PSAP location was analyzed, the Alameda County Sheriff's Office is representative since the Oakland area contains the majority of the county population. In addition, computations in the previous section have shown that the cost for leased lines is insensitive to PSAP location.

Instead of maintaining a separate group of lines to each dispatching location, it is possible to provide a transfer capability from the police station to where the fire calls are answered. While this approach tends to reduce the line requirements (costs) between the PSAP and the main dispatching location, there is an additional expense for the secondary transfer capability. The tradeoff among these costs would depend on the specific situation under consideration.

E. Conclusions

Conclusions about the desirable number and location of PSAPs based solely on these results should be avoided since several important components of the total 911 system cost are not analyzed. These include the cost of lines between a PSAP and its central office, the cost of links between multiple PSAPs, and the cost of equipping and operating the PSAP. With this qualification, these results can be used to help decide on the number of PSAPs, their locations in an Alameda County 911 system, and what type of communications links to use. The methodology used to obtain these cost figures should also be applicable in the design of other 911 systems.

The cost figures calculated in this study are summarized in Table 18. For the portion of the 911 calls from the citizen to the PSAP, the results for the public switched network show a much greater cost spread than do the results for leased lines. With a single PSAP, the monthly cost for leased lines is less than the monthly cost for the public network. With two PSAPs, there are a number of location choices for which the public network cost is less than the cost of leased lines. The sets of location choices giving the lower costs are different for the two cases. The portion of the calls from PSAP to dispatching location was less extensively analyzed, but representative cost figures for a centralized PSAP located in the Alameda County Sheriff's Office were obtained. The mileage charge for the required lines runs somewhat higher than for the first portion of the call.

The validity of costs for both approaches is limited primarily by the accuracy of the call volume estimates and, for the leased lines costs, the accuracy (about 10 percent) of the distance measurements. The leased lines costs are upper bounds* because the estimate of necessary lines is high; this results in some excess capacity; however, increased traffic could be absorbed without increased line requirements.

Because of demographic considerations and the concentration of telephones in the eastern part of the county, the lowest cost PSAP locations are those in the East Bay area. Since the entire East Bay exchange, which contains 65 percent of the county telephones, is a toll free zone, the benefits of locating a PSAP in this area are apparent. A further cost savings would accrue if it were located in the southern part of this exchange so it would be closer to the rest of the county.

As the number of PSAPs increases, the telephone costs analyzed in this study are reduced since the average distance from a central office to a PSAP goes down. Of course, other costs, such as the cost of operating the PSAPs, may go up. In the case of the public network, exploratory calculations for three PSAPs indicate a number of choices with no cost for the portion of the call between citizen and PSAP. This occurs when the PSAPs are located so as to take advantage of the large toll free zones found in Alameda County.

*Based on traffic considerations, as noted in the summary, the required number of lines is governed more by telephone plant design than by traffic.

Table 18. Summary of Line Cost Analysis for Alameda County 911 System

Citizen to Public Safety Answering Point (PSAP)

Number of PSAPs	Cost per Month	
	Leased Lines	Public Network
One	$2300	$3954
Two	$1341	$ 228

Public Safety Answering Point (PSAP) to Dispatcher

Number of PSAPs	Cost per Month	
	No Data Lines	With Data Lines
One	$4162	$5607

Total Cost for One PSAP

System	Cost per Month	
	No Data Lines	With Data Lines
Leased Lines	$6462 (2300 + 4162)	$7907 (2300 + 5607)
Public Network	$8116 (3954 + 4162)	$9561 (3954 + 5607)

CHAPTER III. SYSTEM OPTIONS

A. Selective Routing and Selective Answering

We have noted in the Introduction that there are two basic advanced 911 approaches designated as selective routing (SR) and selective answering (SA). These concepts are illustrated in Figure 14.

In selective routing, all calls dialed 911 are routed to one or two specific locations where they are subsequently rerouted, usually automatically, to the proper answering point. Note that to do this, a call which might originate only one or two blocks away from the proper answering point would still have to be routed (perhaps many miles) to the central distribution point where the reverse telephone directory is located and then back to the proper answering point.

Selective routing could exist in several different forms. In one form, the telephone company does the actual routing of the caller's voice but may include the caller's number [automatic number identification (ANI)] when they forward the call back to the proper answering point. At the answering point, the Public Safety Agency may have a computer that can then look up the caller's address [automatic location identification (ALI)] and any other information which they deem necessary [e.g., the fire zone or certain law enforcement information defined as supplementary dispatch support data (SDSD) by the Alameda County 911 project].

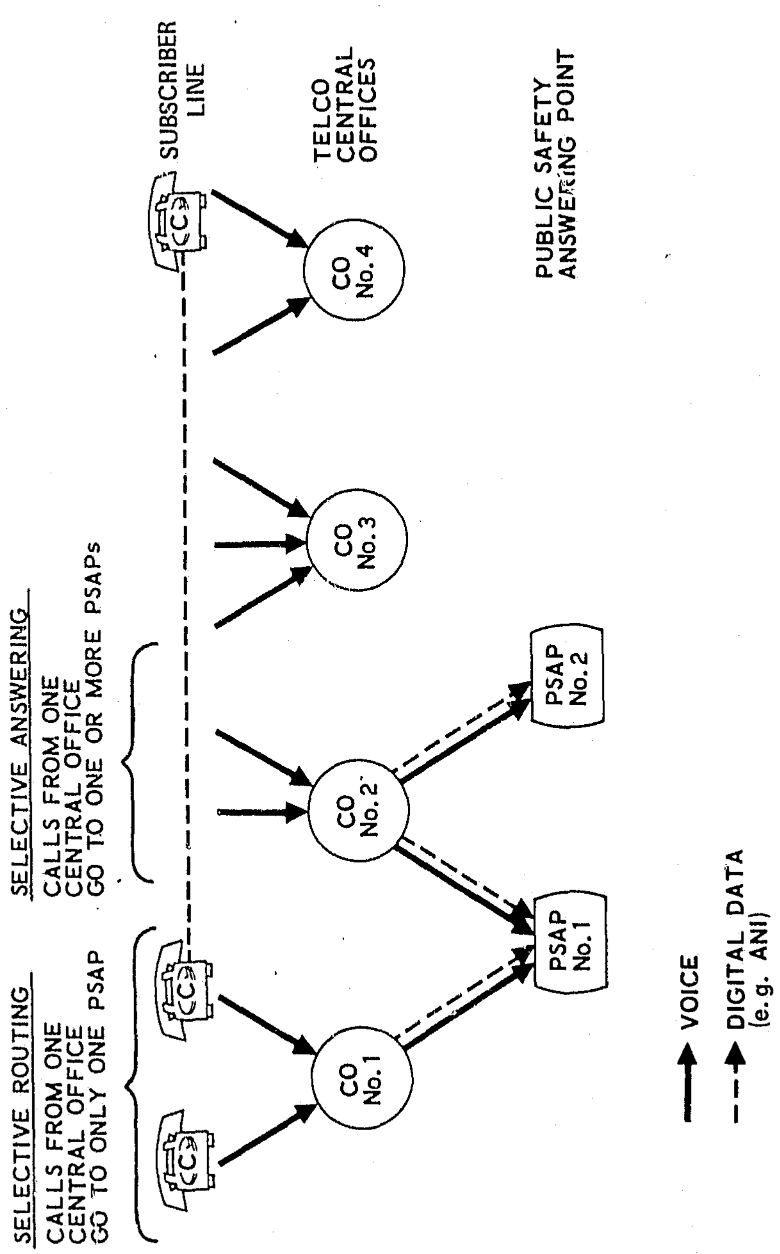

Figure 14. Selective Routing and Selective Answering Concepts

Another version of selective routing would have the telephone company forward both the ANI and the ALI information, but the Public Safety Agency would provide their own supplementary dispatch support data (SDSD). It is not likely that the telephone companies would be interested in, or indeed even legally permitted to provide SDSD, because of the FCC prohibition against telephone companies providing "data processing" services. For that matter, the legal questions relating to, or arising from, the telephone company providing automatic location identification (ALI) without the caller's prior consent is an issue which has not yet been resolved. In any event, it is obvious that there are many questions with respect to: who provides ANI, ALI, SDSD, where the equipment may be located, and who owns it?

Under the selective answering concept all telephone calls dialed 911 are routed simultaneously to one or more (usually not more than three) municipal public safety answering points which serve the citizens living within a particular telephone central office service area. The call is preceded by a brief coded multifrequency (MF) tone sequence lasting about a second, which conveys the callers number (ANI). The answering agency automatically determines whether the call is for him, and if it is, answers the call. This determination may be done by a minicomputer in less than one second. In cases where a mutual support agreement exists between neighboring communities, particularly for citizens living in the overlap region, these calls could be answered by either municipal[redacted] be the case, for example, when a major emergency has occupied most of the resources of the neighboring community.

Chapter IV of this report goes into more detail concerning the design of central office equipment and describes its capabilities, particularly with regard to ANI. The manner in which the telephone company can provide ANI and ALI will also be evident to readers of Chapter IV and therefore in this section we shall only describe systems which could be assembled by Public Safety Answering Agencies for their own use.

B. Minicomputers for Automatic Location Identification (ALI)

We shall briefly consider now the design of an ALI system, assuming the telephone company has taken the responsibility of call routing (i.e., voice routing) and the Public Safety Agency has taken the responsibility for ALI (and perhaps SDSD also). We have already shown that the call volume is not significantly large and it is fairly easy to show that most minicomputers have the necessary capability. Therefore this section describes a variety of minicomputer systems which can accomplish the function of automatic determination of caller location (ALI) based on the callers number. The object will be to illustrate typical costs as a function of the size of the ALI minicomputer system.

Figure 15 is a block diagram of the ALI minicomputer system under consideration. The four principal components of this system are the minicomputer, a disc storage unit, a tape reader, and cathode ray tube (CRT) input/output consoles. For purposes of cost analyses, the number of CRT consoles under consideration here range from 1 through 60. The tape reader is used primarily to update the telephone directory stored in the disc file on a daily basis, or less frequently if desired. One item, required in the use of multiple CRT consoles, but not shown in Figure 15 is an input/output multiplexer. The multiplexer routes signals to and from each CRT console without any apparent interrpution or mutual interference. A modem (not

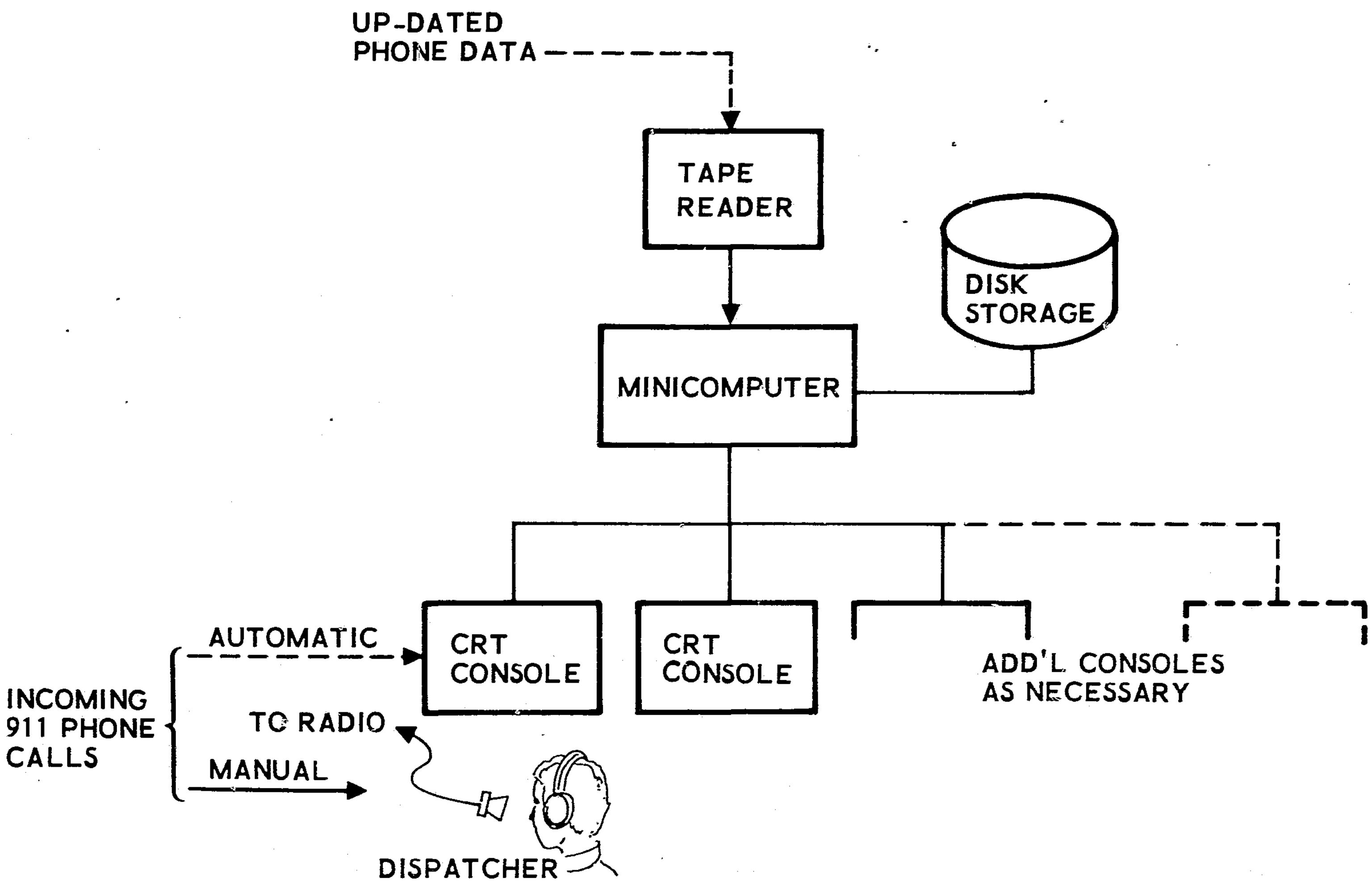

Figure 15. 911 Minicomputer System

shown) for each remotely located CRT console is also required when remote operation is desired. There are a variety of minicomputer manufacturers and peripheral suppliers which provide equipment that can accomplish the desired functions. In these analyses we have chosen a supplier (Data General Corporation) which we believe to be representative of these systems in terms of cost and performance.

For purposes of these calculations we have assumed that each file entry consists of 50 alphanumeric characters which might include the caller's name and address and any other desired identification (e.g., location coordinate or dispatching instructions). In Alameda Country there are 469,000 telephones and, at 50 characters per entry, this would result in 23.45 million characters. Since each character can be characterized by a single 8-bit byte, we require a storage capacity of at least 24 million bytes if we wish to store the entire Alameda County directory in one location. The Data General Type 2314 Disc Pack has a 25 million byte capacity and would be adequate. At the other extreme, a few hundred subscriber files could be stored directly in the core memory. For example, a system with 200 subscribers would require a capacity of about 10,000 bytes. Since most minicomputers today use 16 bit words, one only needs about 5,000 words of core memory to store these 200 subscriber telephone files. This is a relatively small system, even for minicomputers.

The operation of the systems shown in Figure 15 could be either automatic or manual. In a fully automatic system the number of the calling party (ANI) is received via the telephone company phone lines. The minicomputer

receives this ANI information and automatically retrieves the caller's name and address from disc storage and presents the results on the CRT display. Alternatively, the ANI information could be received manually (i.e., by voice or on an independent digital display) and the dispatcher could manually type this ANI information on the CRT console keyboard. The minicomputer would subsequently retrieve the caller's name and address from disc storage and display it on the CRT. The systems discussed in this section are manual.

Another option which could be provided is to have the information retrieved from storage and displayed on the CRT while simultaneously held in buffer storage at the CRT console. This information can subsequently be automatically forwarded to other locations at the press of a button. This capability is not costed in the systems described in this section but can be included.

Table 19 is a compilation of computer hardware options for systems ranging in size from 200 subscribers (i.e., phones) to 500,000 subscribers. The vertical column at left shows the principal components required in each of the six systems considered. Note there are two systems having a capacity of 500,000 subscribers. One of these systems has 12 CRT consoles and the second has 60. In the latter system, the CRT consoles could be placed at remote locations throughout the county. The maximum traffic rate of about 2,000 to 3,000 calls per day as discussed in Chapter II would result in an average of about ten calls per hour per CRT console when 12 consoles are employed; only two calls per hour per CRT would be received on the average if 60 consoles are employed.

Table 19. ALI Computer Hardware Options and Relative Costs (Early 1973)

Component	Subscribers 500,000A	500,000B	100,000	50,000	10,000	200
Minicomputer	$13,300	$ 13,300	$ 9,800	$ 7,600	$ 5,600	$5,600
Disk Storage	22,000	22,000	13,700	10,700	5,500	--
Tape Reader	2,000	2,000	2,000	2,000	1,500	--
CRT Consoles & Multiplexers	28,500(12)	122,000(60)	6,100(2)	2,300(1)	2,300	2,300
Interface Equipment 10%	6,600	16,000	3,100	2,200	1,500	
Total Cost[a]	$72,400	$175,300	$34,700	$24,800	$16,400	$7,900
Typical Monthly Lease with Maintenance	2,353	5,697	1,127	806	533	256
Typical Cost Per Call[b]	2.6¢ - 3.9¢	6.2¢ - 9.3¢	6.2¢ - 9.3¢	8.8¢ - 13.2¢	29¢ - 44¢	--

[a]Costs not included: installation, operating expenses, and telephone

[b]Based on 2.5 calls per 1000 population per day and 500 subscribers per 1000 population

Figure 16 is a graph of the results shown in Table 19 and indicates the typical minicomputer system cost per call as a function of the number of telephone subscribers in the minicomputer system. Obviously the economic tradeoff favors a single centralized system. One should bear in mind, however (as discussed in Section II. C), that the telephone costs decrease if one uses several distributed answering points and, hence, a curve opposite to that shown in Figure 16 would represent the typical telephone cost as a function of the size of the system.

C. Minicomputer Subsystem Costs

To illustrate typical costs for components of minicomputer system discussed in the previous section, a series of tables, of equipment offerings, their performance, and their price (1973) were prepared and are presented in this section. The first table (Table 20) represents candidates selected from the low end of the minicomputer lines of established and reputable minicomputer manufacturers. The specific configuration of each machine was selected in an attempt to equalize their general performance and provide a consistent relative cost figure for a computer having a 16,000-word memory capacity and 16-bit word length. In some instances, a core memory capacity of 16,000 words might be considered large; however, such a capacity, or even larger, is preferable on the basis of programming efficiency and simplicity. In any case, hardware costs are rapidly decreasing and the cost of additional memory will not inordinately alter the conclusion. (For example, a cost of $1,800 for an 8,000-word memory has been offered by at least three manufacturers. The average cost (1973) for a 16,000 word "basic system" turns out to be about $7,270.)

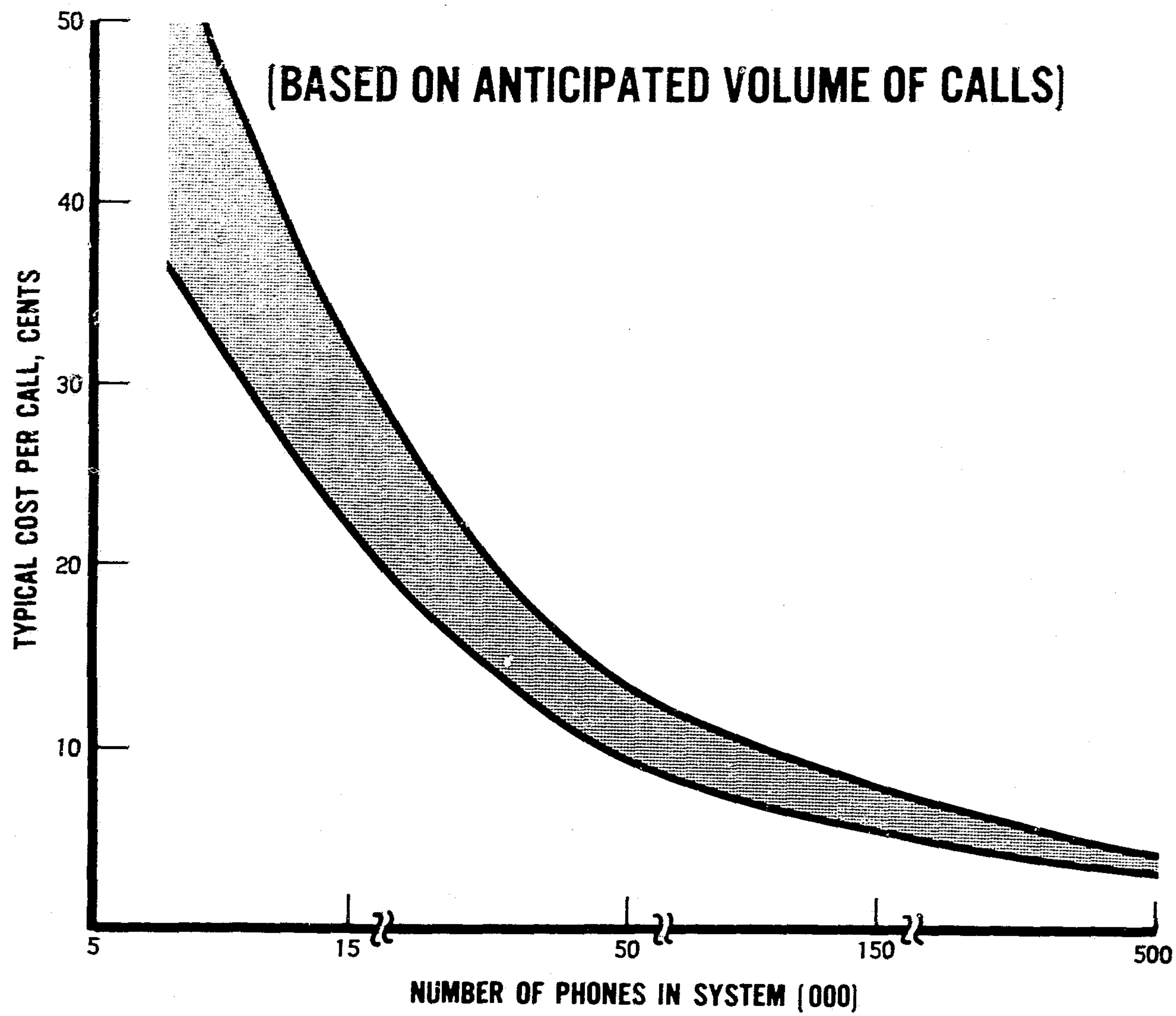

Figure 16. 911 ALI Hardware Cost Per Call as a Function of Size of Installation

CONTINUED

1 OF 3

Table 20. Representative Candidate Minicomputer "Basic Systems"

Equipment Characteristics	Manufacturer and Model		
	Comp. Auto. Alpha 8	Data General Alpha LSI	Data General Nova 2/4
Word length, instruction length (bits)	8,8/16/24/2	16, 16	16, 16
Cycle time, microseconds/word	1.6	1.6/1.6	0.8
Word cap, min/max	4,096/32,768	4,096/262,144	4,096/32,768
No. of directly addressable words	512	1,024	1,024
Hardware multiply/divide	No	Standard	Standard
Hardware floating point	No	No	Standard
Hardware byte manipulation	Standard	Standard	No
I/O word size, bits	8	8/16	Standard
Direct memory access channel	Optional	Standard	1 and 2-pass
Assembler	1-and 2-pass	2-pass	No
Macro assembler	No	Yes	Yes
FORTRAN compiler	No	Yes	ALGOL, Basic
Other compilers	No	Basic	
Price of basic system	\$2,800/4K	\$1,990/4K	\$3,850/4K
Word length 16-bit memory size for price figure	2K	4K	4K
Additional 16-bit memory required to provide 16K word configuration	14K	12K	12K
Cost of additional memory (\$)	\$3,150	\$2,700	\$2,700
Total price of "Basic System"	\$5,950	\$4,690	\$6,550

Table 20. Representative Candidate Minicomputer "Basic Systems" (Continued)

	Manufacturer and Model			
Equipment Characteristics	Data General Nova 800	DEC PDP-11/05	H-P 2100A	Interdata 7/16
Word length, instruction length (bits)	16, 16	16, 16/32/48	16, 16	8/16/32, 16/32
Cycle time, microseconds/ word	0.8	0.9	0.98	1.0
Word cap, min/max	2,048/32,763	4,096/28,672	4,096/32,769	8,000/32,000
No. of directly addressable words	1,024	28,672	2,048	4,000
Hardware multiply/divide	Optional	Optional	Standard	Standard
Hardware floating point	Optional	No	No	Standard
Hardware byte manipulation	Standard	Standard	No	Standard
I/O word size, bits	16	16	16	Standard
Direct memory access channel	Standard	Standard	Optional (2)	1-pass
Assembler	2-pass	2-pass	2-pass	Yes
Macro assembler	No	Runs on 11/20	No	Yes
FORTRAN compiler	Yes	Yes	Yes	Yes
Other compilers	ALGOL, Basic	Basic	ALGOL, Basic	Basic
Price of basic system	$6,600/4K	$4,795/4K	$6,900/4K	$3,200/8K
Word length 16-bit memory size for price figure	4K	4K	4K	2K
Additional 16-bit memory required to provide 16K word configuration	12K	12K	12K	14K
Cost of Additional memory ($)	$2,700	$2,700	$2,700	$3,150
Total price of "Basic System"	$9,300	$7,495	$9,600	$6,350

Table 20. Representative Candidate Minicomputer "Basic Systems" (Continued)

Equipment Characteristics	Manufacturers and Models			
	Microdata 400/10	Microdata 1600/30	Prime 100	Varian 620/L
Word length, instruction length (bits)	8, 8/16	8,8/16/24/32	16, 16	16, 16/32
Cycle time, microseconds/ word	1.6	1.0	1.0	1.8
Word cap, min/max	1,024/65,536	4,096/65,536	4,096/32,768	4,096/32,768
No. of directly addressable words	4,096	32,768	32,768	2,048
Hardware multiply/divide	No	Standard	Optional	Standard
Hardware floating point	No	Optional	No	No
Hardware byte manipulation	Standard	Standard	Standard	No
I/O word size, bits	8	8	16	16
Direct memory access channel	Standard	Optional	Standard	Standard
Assembler	2-pass	2-pass	2-pass	2-pass
Macro assembler	No	No	Yes	No
FORTRAN compiler	No	Yes	Yes	Yes
Other compilers	No	PL-1	Basic	Basic, RPG
Price of basic system	$2,250/4K	$6,075/4K	$4,600/4K	$5,400/4K
Word length 16 bit memory size for price figure	2K	2K	4K	4K
Additional 16 bit memory required to provide 16K word configuration	14K	14K	12K	12K
Cost of additional memory ($)	$3,150	$3,150	$2,700	$2,700
Total price of "Basic System"	$5,400	$9,225	$7,300	$8,100

1. Disc storage. Table 21 illustrates the general price level for disc storage devices. The prices of Digital Equipment Corporation (DEC) are listed to show typical costs for disc storage devices when purchased from a minicomputer manufacturer. Also included are prices from DIVA, who is an interface and controller manufacturing firm which has probably sold more large disc controllers for minicomputers than any other manufacturer. DIVA uses disc drives assembled by Century Data, Control Data Corporation (CDC), and other manufacturers. The prices per bit quoted by DIVA are generally the lowest to be found, with the possible exception of the CDC Model 9780. Control Data Corporation is one of the largest disc manufacturers in this country and supplies discs for its own computer line and to many other computer and minicomputer manufacturers as well.

2. CRT terminals. Table 22 illustrates the cost of typical cathode ray tube (CRT) display terminals which may be considered to lie in the low cost region, i.e., less than $1,500. It should be noted that the cost of these terminals has dropped significantly in the past two years.

All of the "big four" cathode ray tube (CRT) manufacturers (i.e., Beehive, Conrac, Hazeltine, and LSI) have announced new low-cost CRT displays. Table 22 shows a cross section of low-cost CRTs that are presently available and will interface to a minicomputer via a typical ASR-33 interface card. The price of an interface card will vary from no cost to $1,400, depending upon data flow rate, type, and speed.

Table 21. Representative Candidate Minicomputer Disc Memory Systems (Prices are based on mid-1973 data sheets)

Equipment	Disc Supplier and Model											
Characteristics	DEC RK05	DIVA DD-11[a]	DIVA DD-11/2[a]	DIVA DD-14[a]	DIVA DD14-2[a]	DIVA DD-18[a]	DIVA DD-23[a]	DEC RP03	DIVA DD-25[a]	DIVA DD-30[a]	CDC 9780	DIVA DD-32[a]
Capacity (M-words for 16 bit words)	2.4	3.75	7.5	14.5	14.5	29	29	40	58	58	100	116
Average Access Time (milliseconds)	70	32	32	35	35	35	35	29	32	32	30	32
Transfer Rate (kilobytes/sec)	90	156	156	312	312	312	312	133	312	624	806	62[illegible]
Cost (kilo $)	16.1	10.5	12.5	12.8	19.9	23.1	16.3	51.0	51.0	20.6	23.1[b]	37.2
Cost/Megaword ($)	6720	2800	1666	882	687	796	562	1272	458	335	231+	320
Cost/Megabyte ($)	3360	1400	833	441	343.5	398	281	636	229	117.5	115.5+	160
Average Cost/Megabyte ($) (for memory size)	3360	1400	833	441	341	341	341	636	203	636	115.5+	160

[a]DIVA prices include software drivers.
[b]W/O Controller (other prices include controller and interface to minicomputer)

Table 22. Low-Cost Cathode Ray Tube (CRT) Displays

Equipment Characteristics	Manufacturer				
	Car-Mel Electronics Inc.	Conrac Corporation	Datamedia Corporation	Digi-Log Systems	Research Inc.
Model	1-211 Informer	480 TTY Plus	Elite 1500/2000	33/109/209	Teleray 3300/11
1st installed	1972	1968	1970	1971	1972
No. installed	108	"sev. thousand"	400	750	over 300
Display specification					
Screen size	4-1/2 × 3 inches	3-1/2 × 7 inches	6 × 9 inches	11-inch diagonal	6-1/2 × 8-1/2 inches
Max chars displayed	32 × 16 chars	80 × 12 chars	80 × 24 chars	80 × 16 chars	80 × 24 chars
Displayable char set	64 (5 × 7 matrix)	64 (5 × 7 matrix)	64 (5 × 7 matrix)	64 (5 × 7 matrix)	96[a] (5 × 7 matrix)
Communications modes	Full/half-duplex	Full/half-duplex	Full/half-duplex	Full/half-duplex	Full/half-duplex
Max asynch rate	9600 bps	9600 bps	4800 bps	9600 bps	9600 bps
Max synch rate	9600 bps	9600 bps			
Line selection	Switch-select	Switch-select	Switch-select	Switch-select	Switch-select
Max parallel rate	--	500,000 cps	--	--	--
Block transfers	512 characters	960 characters	--	1280 characters	--
Error checks	parity[b]	parity and LRC	none	none	parity
Comments	Has scrolling; rack mount available	9-inch high profile	Drives 16 monitors; available as RO or cont.		Selectable double-size characters
Standalone sales					
Primary customers	OEMs	OEMs	OEMs	End-users	End-users
Purchase Price	Approx. $1000	$900 to $1200	$1100 to $1516	$1195 to $1395	$1200 to $1400
1-year lease	Not offered	Not offered	$65-$75/month	Not offered	$75/month
Min maintenance	$50/repair	Not offered	$20/month	$15/month	$20/month
Low price includes	Standard features	Standard features	80 × 6 or 64 × 8 char display	Keyboard and interface	

[a]Up to 96 characters
[b]Optional

The cost of the basic minicomputer system frequently includes enough electronics to interface with the first terminal without additional cards. Since most 911 applications do not require high speed by standards usually used in the computer industry, a figure of approximately $400 per interface card may be used for cost estimates. Even such "slow speed" devices are still capable of printing out a complete name, address, and auxiliary information in a time of well under two seconds.

3. Printing terminals. Table 23 provides information equivalent to that of Table 22 for printing type terminals rather than cathode ray tube (CRT) terminals. In general, the printing type terminals have the advantage of producing a hard copy for historical records but usually impose speed and reliability limitations compared to CRT terminals. Inexpensive printing terminals usually print at a rate of about 10 to 15 characters per second. The ten character per second speed of such machines may be acceptable in certain applications; for example, the name and address of most 911 callers can probably be presented using about 25 to 30 printed characters, taking about 2-1/2 to 3 seconds to print.

On the other hand, the devices set forth in Table 23 are the only machines capable of printing 20 characters per second or more. The average price of these terminals is about $3,500. This is substantially greater than the $1,500 price of low-cost CRT terminals.

Table 23. Candidate Printer Type Terminals

Manufacturer	Model No.	Price (Dollars)	Type	Printing Rate (Characters/Second)	Characters Per Line	Characters Set Size
Anderson Jacobson	AJ630 KSR	3900	Thermal	10, 15, and 30	140	88
Computer Transceiver	310 and 320	3800	Thermal	10, 15, and 30	80	120
G.E. Terminet	300	3625	Character print	30	75	94
	1200	4595	Character print	120	80	94
Singer	30KSR	2225	Serial dot matrix	10, 15, and 30	80/132	64
Texas Instrument	TI 700	2825	Thermal	30	86	128

4. Record keeping. In some applications, there is a requirement for keeping a log of emergencies handled, though the need to refer to this log may be infrequent; therefore, the most practical logging scheme might be one in which a computer can look up and sort files to extract a given file only upon request. At least four logging system possibilities (i.e., magnetic tape, tape cassette, paper tape, and "floppy disc") can be explored in future design studies.

The test logging system would most probably be a standard magnetic tape system. A good quality system of this type may cost some tens of thousands of dollars. An alternative could be the minitape or tape cassette devices. These latter recorders, although low in cost, still have several inherent disadvantages. These include:

- Lack of standardization within the industry
- Reliability problems
- Possible misuse of the devices for logging functions. Most of these devices are designed to be poor men's semi-random access systems (.e.g., "DECTAPE")

An approach to overcome these disadvantages would be to go back to high-speed paper tape readers and punch devices. Reliable models of these can be purchased for under $4,000. This cost figure includes an interface to the minicomputer.

Another approach would be to use one of the new "floppy disk" systems. These devices are so new that, with the exception of expensive IBM models used within IBM hardware, reliability history is not available. Also, the industry still faces the same standardization problems that have hindered the low-cost magnetic tape systems.

In view of the forgoing, the most pessimistic approach will be taken in providing a price for the history logging device. It will be assumed that a reliable "cheapie" tape or disc system cannot be found at the time of initial installation and that this function will be performed by a high speed paper (or mylar) tape reader/punch at a cost not to exceed $4,000.

An additional line item not yet considered is a device required to update the computer core and/or disc memory with new or corrected file content information (e.g., addresses, etc.). It is anticipated that this and the preceding data logging line item can be done with the same hardware line item. For this reason, no hardware cost is presently assigned to this system component.

5. Telephone Company Interface. The last hardware cost to be considered is that for an interface between telephone company equipment which, it is to be assumed, will provide the calling telephone number in a register. An interface to this register would consist of:

- An interrupt signal from the telephone company conveying the message that an incoming "911" call has been initiated
- The reaching of the register within telephone company equipment conveying the incoming telephone number in response to the interrupt.

Details of hardware for an interface of this nature is discussed in Chapter IV.

D. Centralized Voice/Data (CVD) Concept

On the basis of the overall technical/cost requirements and certain important subjective factors (e.g., user privacy), Aerospace synthesized a 911 system, capable of serving 1,000,000 people, referred to as Centralized Voice/Data (CVD) System. Many of the proposed sophisticated features of an advanced 911 system represent concepts of design and operation never tried before and consequently some questions remain. Therefore, one goal of the CVD system is an installation which will minimize the cost and impact upon the existing telephone plant and government operations because of its installation, or in the event it proved unsatisfactory, its removal. Another important object was to provide a system having maximum physical and administrative security to insure confidentiality of files and user privacy. These important features, as well as ease of cost accounting, could be met by a centralized equipment system which minimizes co-mingling of either records or equipment with other municipal or telephone company operations. The CVD system appeared to meet most of these objectives.

The Centralized Voice/Data System is described in the simplified diagram shown in Figure 17. Note that the citizen's emergency telephone call is routed, via the central office, to the Centralized Voice/Data (CVD) System located at the central public safety answering point (PSAP). The only interface with the existing telephone equipment is by virtue of the leased telephone lines from the central offices to the Centralized Voice/Data (CVD) System.

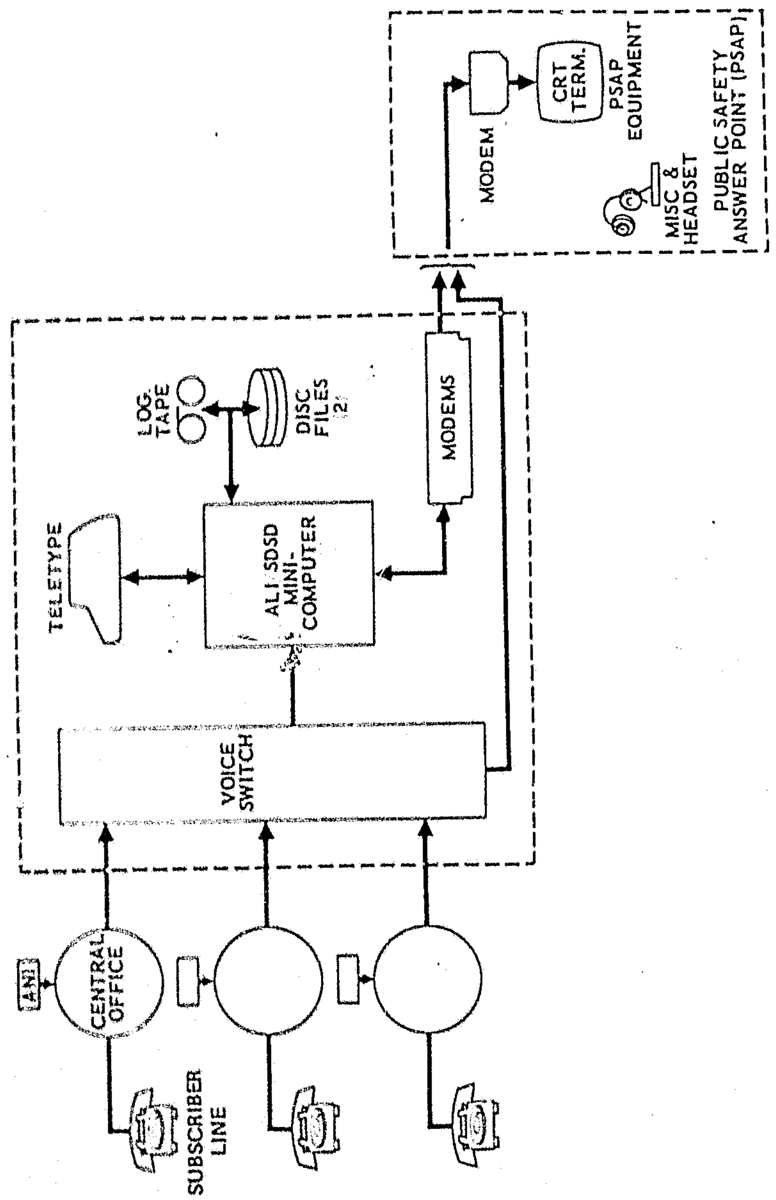

Figure 17. Centralized Voice/Data Distribution System

Such leased lines are customarily provided by telephone companies; however, they do not include ANI as noted earlier. ANI is normally generated and transmitted by telephone equipment in the form of what is referred to as a multifrequency (MF) tone sequence lasting about one second for a seven-digit number. Thus, in operation, the caller's voice arrives on a leased line from the central office to the Centralized Voice/Data (CVD) System and this is preceded by a one-second tone burst identifying his number. This is all that is necessary to permit the voice switcher and ALI computer to properly route the call to the local public safety answering point (PSAP), along with the caller's address (ALI) and other details (SDSD).

The heart of the 911 CVD system is consequently localized at one point which can be technically, operationally, and financially accounted for with minimal difficulty and which provides maximum security and privacy.

All of the CVD equipment required for installation at either the central public safety answering point or the local public safety answering points is available at this time and does not require development expense or time. For example, the minicomputer and its associated disc, modems, and other accessories are readily available from at least ten different manufacturers. The cost of these components has dropped in the past few years and basic minicomputer systems can be purchased for as low as $5,000 or less. The voice switcher, which represents an important part of the CVD system, is also available at a price on the order of approximately $130,000, for a system having the necessary capability. This latter equipment contains a minicomputer which must be programmed, and this software cost effort represents additional costs on the order of $60,000 to $75,000. A system such as the one described in Figure 17 has been considered by 911 system planners in Minneapolis, Minnesota.

1. Reliability. A point of vital interest is the question of reliability of 911 service. The equipment shown in Figure 17 can be designed to essentially eliminate the possibility of catastrophic failures wherein the entire system becomes inoperative. Preventing all possible partial failures becomes progressively more difficult. For instance, the voice switcher includes redundant switching paths which, in effect, provide a self-healing effect so that if one particular switching route becomes disabled, a second route will immediately take over. Similarly, redundant circuits are provided in the minicomputer and associated equipment. The basic voice switcher has an estimated mean time before failure (MTBF) of 14 years. It appears that at the subsystem level a failure is most likely to occur in the ALI disc file system; however, failure-detecting mechanisms and repair procedures could quickly reactivate the system in a matter of minutes. Even if the ALI subsystem is disabled, the system in Figure 17 could still properly route the caller's voice to the proper local public safety answering point (PSAP) with ANI, but not with ALI. Such an ALI computer failure would not be expected to occur more often than once or twice a year. The entire question of reliability cannot be properly analyzed until specific equipment components are selected; however, at this time it appears that the reliability of the various component options is adequate for the intended application.

Additional information regarding minicomputer systems reliability is included in Appendix A.

2. CVD System Costs. Summary Centralized Voice/Data (CVD) System cost estimates were prepared by Aerospace for two options.* Option A uses a full-size cathode ray tube (CRT) terminal at each of the 56 locations (average price $1,900 each) while Option B uses a miniature CRT terminal costing only about $500. The ALI/SDSD (supplementary dispatch support data) computer system comprises a minicomputer, two parallel high capacity disc files (one for backup), a magnetic tape recorder for logging information, a teletype terminal for monitoring, and all the cabling and interface equipment required. The data communications system comprises the modems and multiplexers necessary to feed data to and from the 56 remote terminals over ordinary telephone lines. Under Option A, modems are required at both the sending and receiving terminals, while under Option B modems are required only at the sending end, since the proposed miniature cathode ray tube (CRT) terminal has a built-in receiving modem. Total hardware cost under Option A is estimated at $368,000 and under Option B at $270,100.

Engineering services are required to integrate and make operational the system described above. Total cost for these services is estimated at approximately $277,500. Thus the total cost for hardware, and for hardware and software engineering, is estimated at between $528,000 and $626,000 depending upon whether Option A, Option B, or a combination is chosen.

*Based on estimated user requirements in the proposed Alameda County 911 system.

Actual telephone company quoted cost to engineer and modify telephone company central offices to permit them to forward ANI information is not available at this time. Rough estimates obtained by the Minneapolis 911 Project Office indicate that ANI-equipped lines can be provided at a cost of approximately $800 to $1,000 per line (i.e., 250 lines for $250,000 maximum in Minneapolis). Based on analysis of emergency telephone traffic in Alameda County, Aerospace estimates a need for approximately 66 voice telephone lines with ANI from the central offices to the voice switcher. However, even assuming 50 percent more (total of 96) lines with ANI at about $1,000 per line would indicate a price of $96,000 for ANI equipped lines; this number generally correlates with estimates made in the ANI study discussed in Chapter IV.

The recurring annual telephone line lease costs, based on Aerospace's traffic analyses and line mileage estimates, indicate an annual cost of about $140,000. Equipment maintenance is estimated at about 12 percent of installed equipment cost per year maximum.

In summary, the estimated total cost for the Centralized Voice/Data (CVD) System for a service area of about 1,000,000 population might be about $700,000 plus $250,000 annually, the principal uncertainty being phone company cost to provide automatic number identification (ANI). These costs, which are itemized in Table 24, are exclusive of day-to-day operating costs for personnel and facilities and also do not take into account the fact that existing telephone line costs that would be replaced should be subtracted from the recurring costs associated with the 911 system that replaced them.

Table 24. Centralized Voice/Data (CVD) Distribution System Cost Estimates

Hardware	Option A	Option B
Automatic Location Identification/Supplementary Dispatch Support Data (ALI/SDSD) Computer System	$ 43,000	$ 43,000
Data Communications System	39,000	19,500
56 Remote Terminals [cathode ray tube (CRT)]	106,400	28,000
56 Telephone Stations	19,600	19,600
Voice Switcher, 96 Line	130,000	130,000
Integration Components	30,000	30,000
Total Hardware	$368,000	$270,100
Engineering (Both Options)		
Automatic Location Identification (ALI) Software Design and Programming	$ 60,000	
Supplementary Dispatch Support Data (SDSD) and Geographic Base File Storage [a]	97,500	
Voice Switcher Software Programming	60,000	
Hardware Engineering and Integration	60,000	
Total Engineering	$277,500	
Telephone Company Equipment and Engineering	$ 96,000	
Total Installation	$741,500	$643,600
Recurring Costs	Option A	Option B
Leased Telephone Lines	$140,000	$140,000
Equipment Maintenance	43,000	32,000
Automatic Location Identification (ALI) and Supplementary Dispatch Support Data (SDSD) File Maintenance[a]	72,000	72,000
Total Annual	$255,000	$244,000

[a] Oakland 911 Project Office Estimates.

CHAPTER IV. AUTOMATIC NUMBER IDENTIFICATION (ANI)

This chapter will present a brief history of ANI development and will describe the operation of various types of telephone company central office equipment used in the United States with emphasis on automatic number identification (ANI) features.

The material presented in this chapter is based on the technical literature of the Bell Telephone Laboratories listed in the bibliography, augmented by information and cost estimates provided by independent manufacturing companies who market ANI and automatic message accounting (AMA) systems and related components. Some of the companies contacted were:

GTE Automatic Electric; ITT Telecommunications Division; GD/Stromberg-Carlson; Continental TEL/VITEL, Northern Telcom

A. History of ANI

Telephone company central offices have included equipment capable of automatically identifying a caller's number for many years. Historically, this capability has been developed as a part of automatic message accounting (AMA) systems which reduce the manual processing necessary in preparing customer billing and to eliminate the need for manual operator number identification (ONI) on direct distance dialing (DDD) calls.

The earliest automatic ticketing (AT) systems printed billing information, including the calling party's number, on tickets. This equipment was designed to service large central offices. AMA systems introduced after

World War II were designed to provide similar billing data, but on punched paper tape in a form suitable for machine processing. Both automatic ticketing (AT) and automatic message accounting (AMA) systems were complex and expensive and were only economical in large central offices where common equipment costs were distributed over many lines.

The rapid growth of direct distance dialing (DDD) following the introduction of crossbar switching systems increased the cost of accounting and led to the introduction of centralized automatic message accounting (CAMA) systems capable of servicing many small local offices. One of the earliest centralized automatic message accounting installations at Detroit served 800,000 telephones in 99 panel and No. 1 Crossbar local offices when put into service in 1953.

Centralized automatic message accounting systems were designed such that the calling party's number could be obtained by the centralized automatic message accounting operator and manually entered at the centralized automatic message accounting (CAMA) location or by Automatic Number Identification (ANI) equipment located at the local or tributary office which transmitted the calling number to the centralized automatic message accounting office over an interoffice trunk circuit.

The first automatic number identification equipments designed for use in tributary offices went into operation in 1960. These systems were intended for the larger (greater than 10,000 lines) central offices for reasons of economy. The continuing growth of direct distance dialing coupled with the advent of the transistor, and more recently integrated circuits, led to the development of ANI equipment designed for installation in smaller, older local offices.

Today, the cost of including automatic number identification in small (2000 lines or less) offices varies from \$10 to \$30 per line. The equipment required for a 2000 line office fits into a single rack or equipment bay.

In 1965 the first Electronic Switching System, ESS No. 1, went into service, followed in 1969 by ESS No. 2. ESS No. 1 is designed for large offices with heavy traffic, while ESS No. 2 is intended for medium-sized (1000 - 10,000 lines) non-metropolitan offices. Both systems provide self-contained ANI and AMA as well as signalling circuits for transmission of stored data to external offices. Although an ESS does not normally forward calling party identification past the local office, this system contains all of the necessary common control and peripheral equipment necessary to do so.

Table 25 summarizes the chronology of these developments.

B. Existing ANI Capability

1. Types of central offices. Telephone central offices are generally classified in terms of the type of switch gear used. Figure 18 indicates the percentage by switching gear for all offices and all individual lines in the U.S. at the end of 1973. Approximately 90 percent of all central offices and lines are associated with either crossbar or step-by-step equipment. Electronic switching system (ESS) installations represent a small but rapidly growing segment of the population.

The distribution of office sizes is of interest because ANI techniques were first introduced into large metropolitan offices and have not until recently been practical for small offices.

Figure 19 illustrates the distribution of the number of offices by size and distribution of lines and by the size of the terminating office. These

Table 25. History of Automatic Number Identification

Date	Development
1900	Message register - accounted for local calls.
1920	Message register incorporated into panel central offices.
1930	Message register in panel system expanded to handle extended-area dialing.
1944	Step-by-step central offices arranged for automatic ticketing - calling number printed on ticket for hand processing.
1949	Step-by-step AMA first available - calling number and other data produced on tape for machine processing (ANI-A).
1950	Automatic message accounting for No. 1 and No. 5 Crossbar. Local offices introduced (LAMA).
1950	Crossbar tandem arranged with centralized AMA to service local offices without AMA. Operator number identification (ONI) used to enter calling number at CAMA office.
1957	Conversion from automatic ticketing to AMA in step-by-step offices developed.
1960	ANI-B developed for use in existing panel, step-by-step, and No. 1 crossbar offices arranged to work into CAMA tandem offices. Calling number is automatically identified at the local office and forwarded to the CAMA office. ANI-B designed for large local offices - 60,000 numbers.
1965	ANI-C developed for small (less than 3000 lines) step-by-step offices where ANI-B equipment is uneconomical.
1965	ESS No. 1 introduced with self-contained AMA operating under program control. Designed for large metropolitan areas.
1969	ESS No. 2 introduced; smaller, more efficient than ESS No. 1; designed for 1000 - 10,000 line offices.
1973	ANI-D developed for small step-by-step offices; functionally similar to ANI-C but smaller (by 1/3) and less expensive; compatible with TSPS and new AMA system now in development.

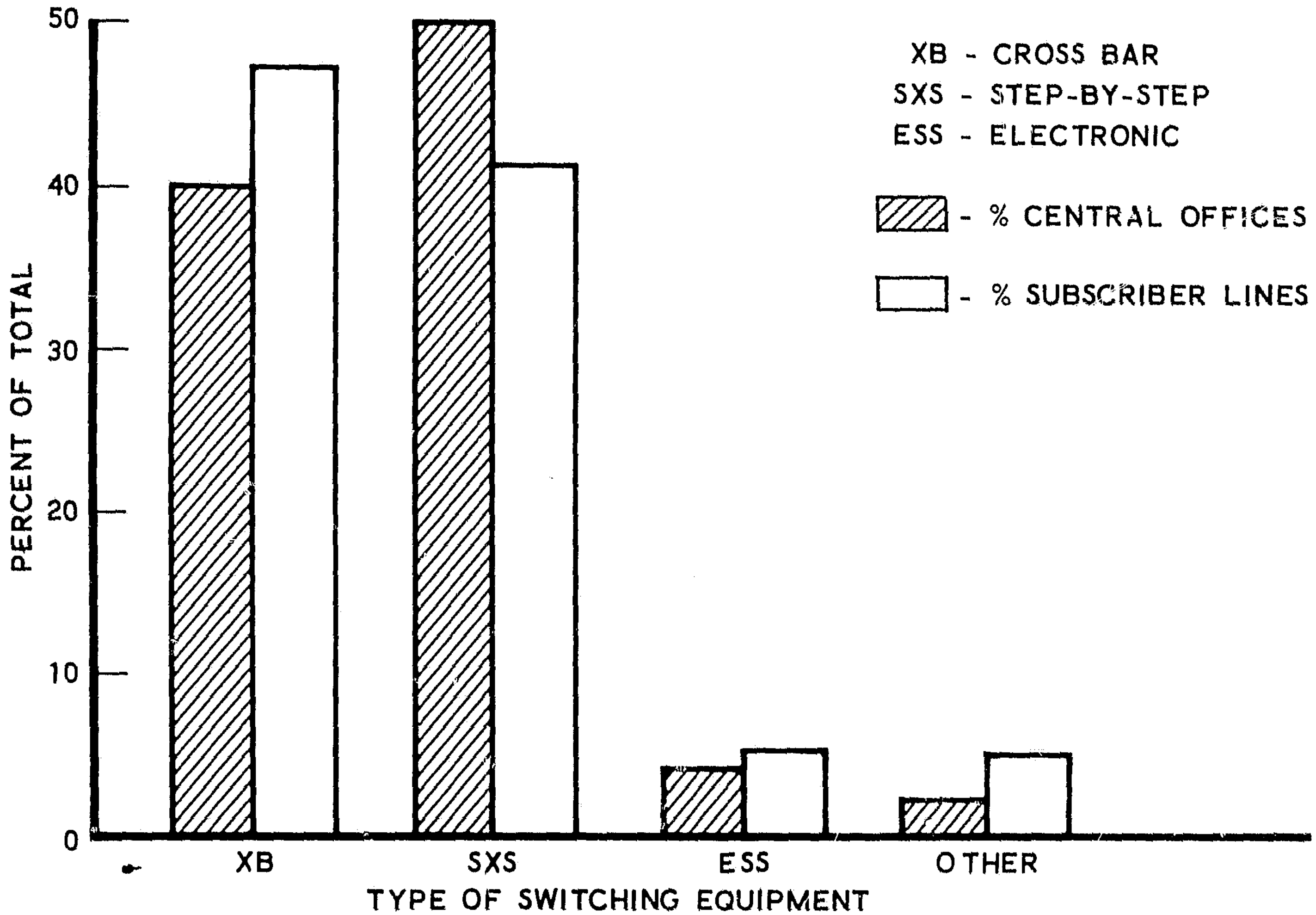

Figure 18. Distribution of Central Offices and Lines by Type of Switching Equipment - 1973

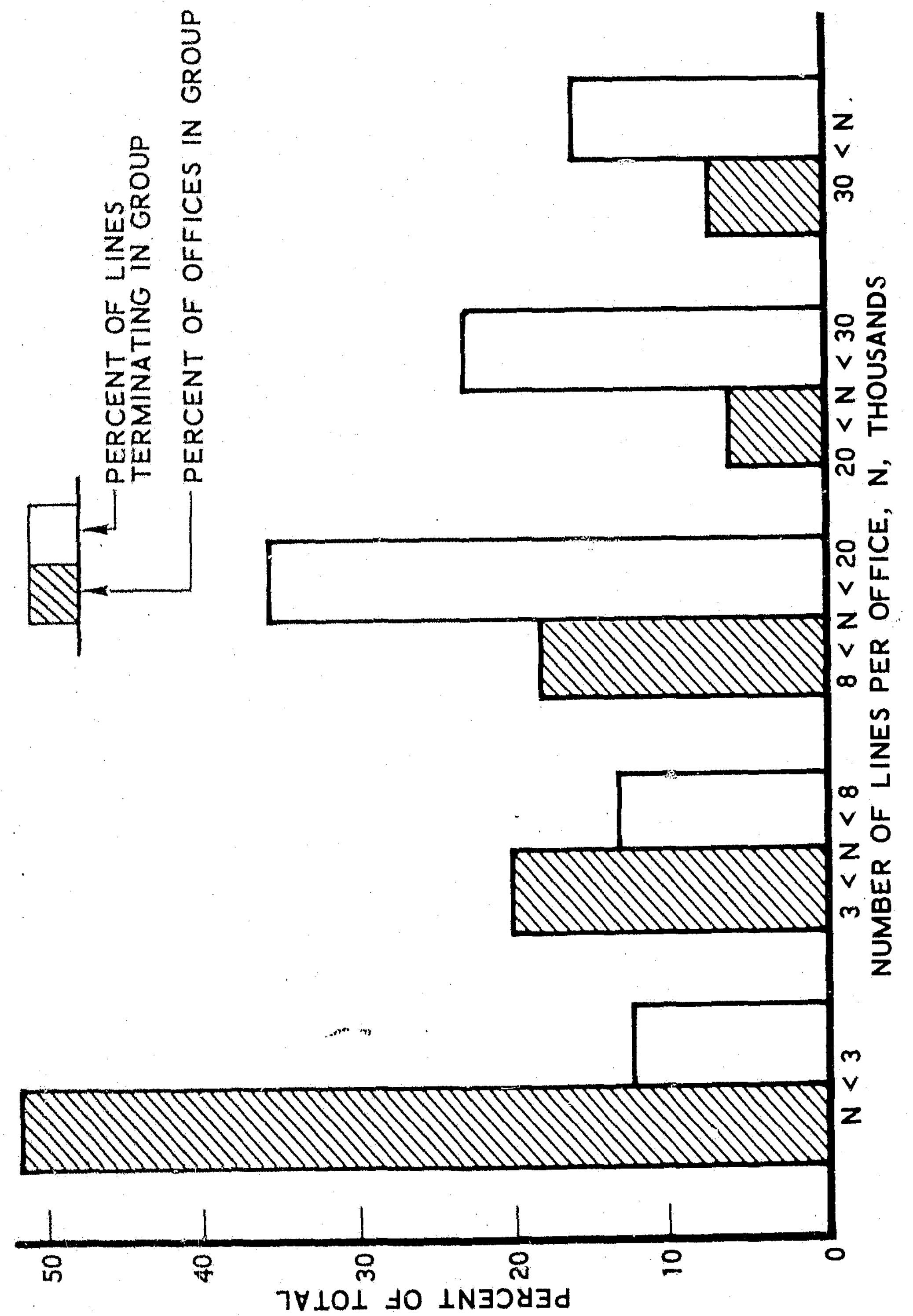

Figure 19. Distribution of Central Offices and Lines by Size of Central Office

data are based on a local region with more than 60 central offices, serving approximately 450,000 subscriber lines. The region includes both Bell System and independent operating companies, and is presumed to be representative of the nationwide distribution. This figure illustrates that almost 75 percent of the lines terminate in offices with more than 8000 lines, while approximately 75 percent of all offices terminate less than 8000 lines.

Because we are primarily interested in the process of calling number identification within each office, a further classification is appropriate:

- Offices with local automatic message accounting (LAMA) - Includes all electromechanical offices with local automatic message accounting which generate ANI for local use and accept ANI from remote offices. This class excludes offices with ESS
- Offices with ANI - Includes all offices with ANI arranged to automatically forward calling number information to a CAMA equipped office.
- Electronic switching system (ESS) - Offices which perform calling number identification in electronic memory under stored program control
- Offices without ANI - Offices with no provisions for either ANI, LAMA, or CAMA

Figure 20 summarizes the distribution of central offices and subscriber lines in terms of these four categories. LAMA equipment is generally found in the large metropolitan offices which account for most of the subscriber

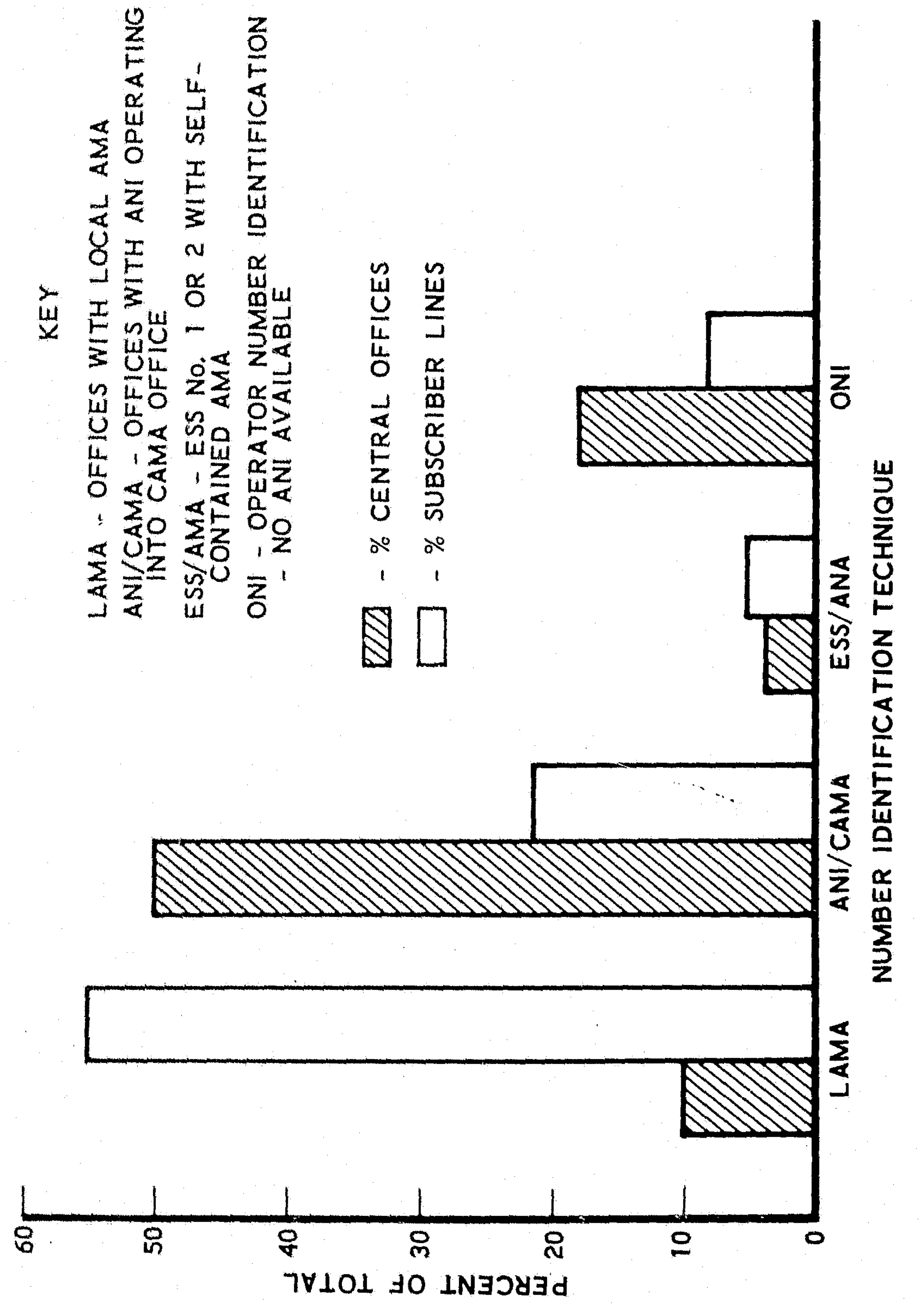

Figure 20. Distribution of Central Offices and Subscriber Lines by Number Identification Technique - 1972

lines. On the other hand, a relatively large number of small and medium-sized central offices are equipped with ANI operating into a centralized automatic message accounting (CAMA) office.

The column labeled ONI in Figure 20 indicated that a significant percentage of central offices in the United States have neither AMA or ANI. Because these offices tend to be smaller than the average, the percentage of lines without AMA or ANI is estimated to be less than 10 percent of the total. Of these, the majority of lines are to be found in rural areas where the need for centralized and/or automated 911 service is not as critical as it is in the large metropolitan areas.

Figure 20 does not reflect party line and other special subscriber classes on which existing offices do not provide ANI.

2. Central offices with local AMA. Figure 20 indicates that central offices with local AMA systems account for more than 50 percent of all subscriber lines. For historical reasons, these offices are usually large ones with either step-by-step or No. 1 crossbar switching equipment. This section describes the ANI techniques used in these types of offices.

a. Automatic ticketing (AT). Automatic ticketing for step-by-step offices was first introduced in 1944 in Los Angeles. This development was the first in which the calling number and other information were automatically printed for extra-charge calls for billing purposes.

Figure 21 illustrates the major elements of the automatic ticketing (AT) system. An identifier determines the calling number and other information required for billing and passes this information to the sender,

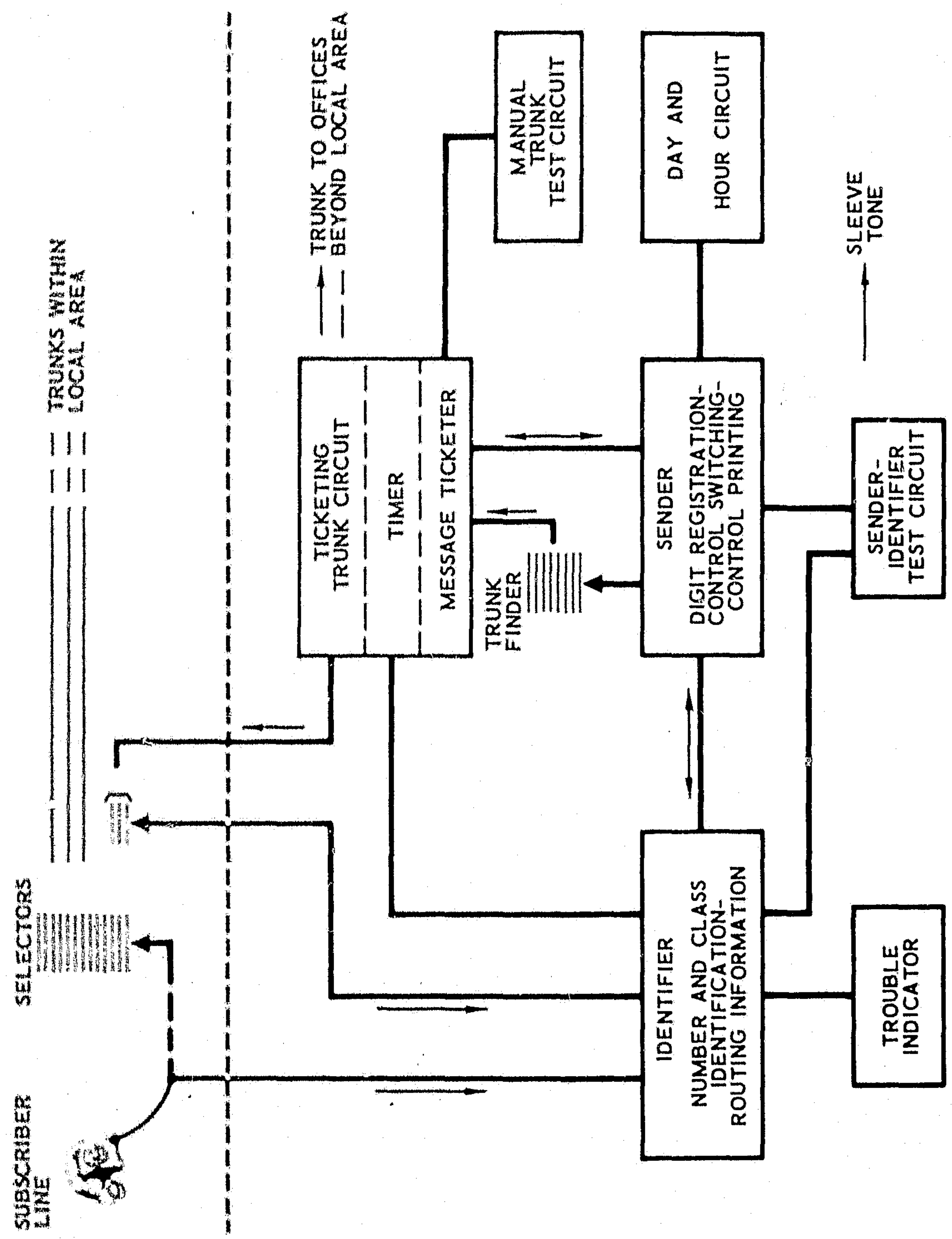

Figure 21. Automatic Ticketing in Step-by-Step Offices

which controls the printing of data for each call. It is important to note that the calling number is only obtained for extra-charge calls routed by the control equipment to the ticketing trunk.

b. Automatic message accounting (AMA). A greatly improved form of recording, the automatic message accounting (AMA) system, was introduced in 1949 with the No. 1 crossbar and later the No. 5 crossbar system. The success of these systems led to the development in 1957 of equipment for converting older step-by-step offices for AMA.

Figure 22 illustrates a step-by-step office converted for AMA. As in automatic ticketing, an identifier determines the calling party's directory number and other information which is transmitted to the sender. When the sender has collected all pertinent information, it transfers this information to a transverter which translates the information into a format suitable for recording on paper tape. For step-by-step offices converted to AMA, the calling-line data obtained by the identifier is in directory number form and no number translation is required.

c. Calling number identifier in step-by-step offices. Figure 23 shows an identifier used in early step-by-step offices. Although out of date, the principles of operation used in these early devices is reflected in the latest solid-state ANI equipment.

The identifier applies a tone to the sleeve of the outgoing trunk to which the calling line has been extended. This tone finds its way through an equipment-to-directory number translating jumper to one terminal common for each 1000 numbers, one common for each 100 numbers, and one

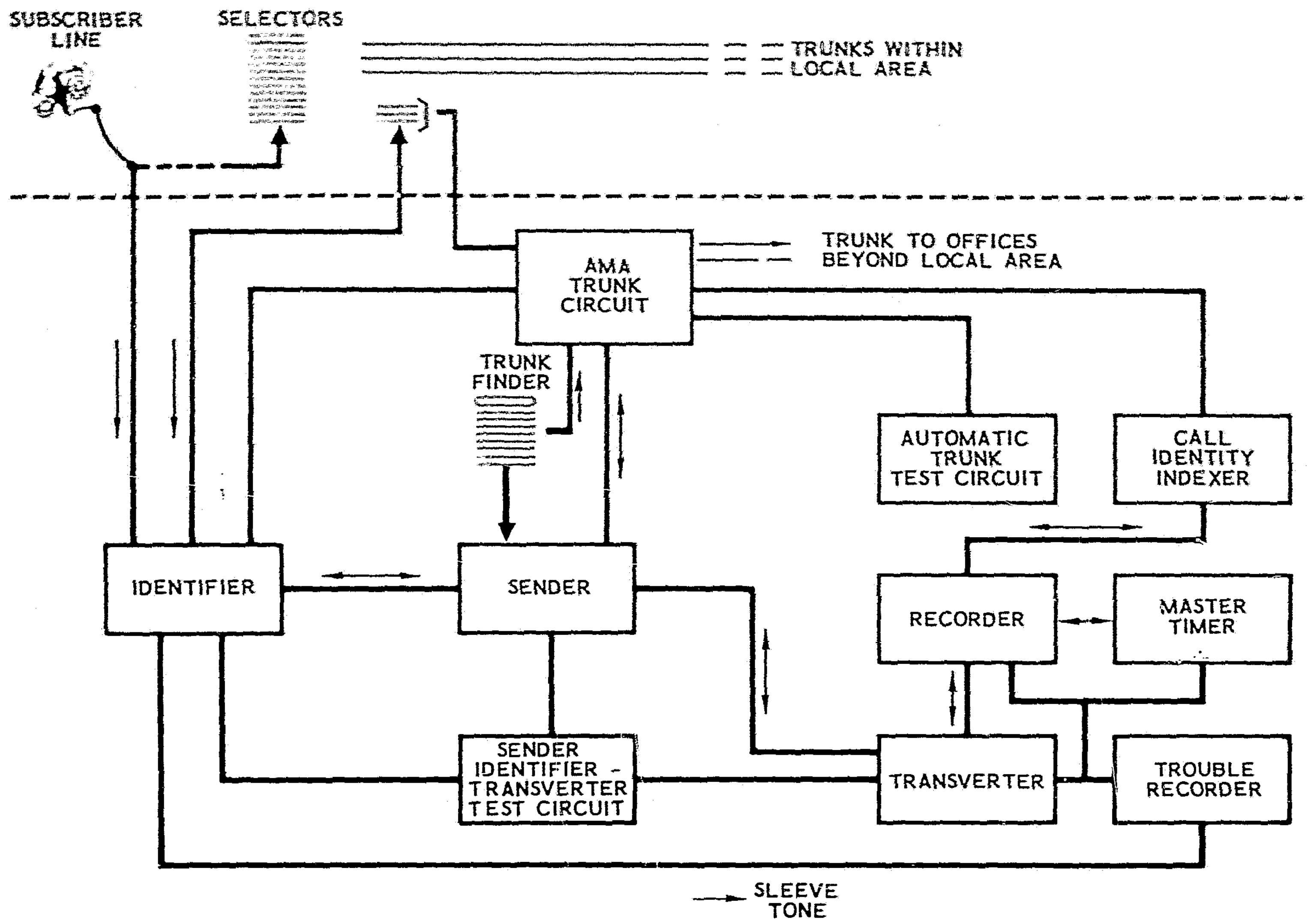

Figure 22. Automatic Message Accounting in Step-by-Step Offices

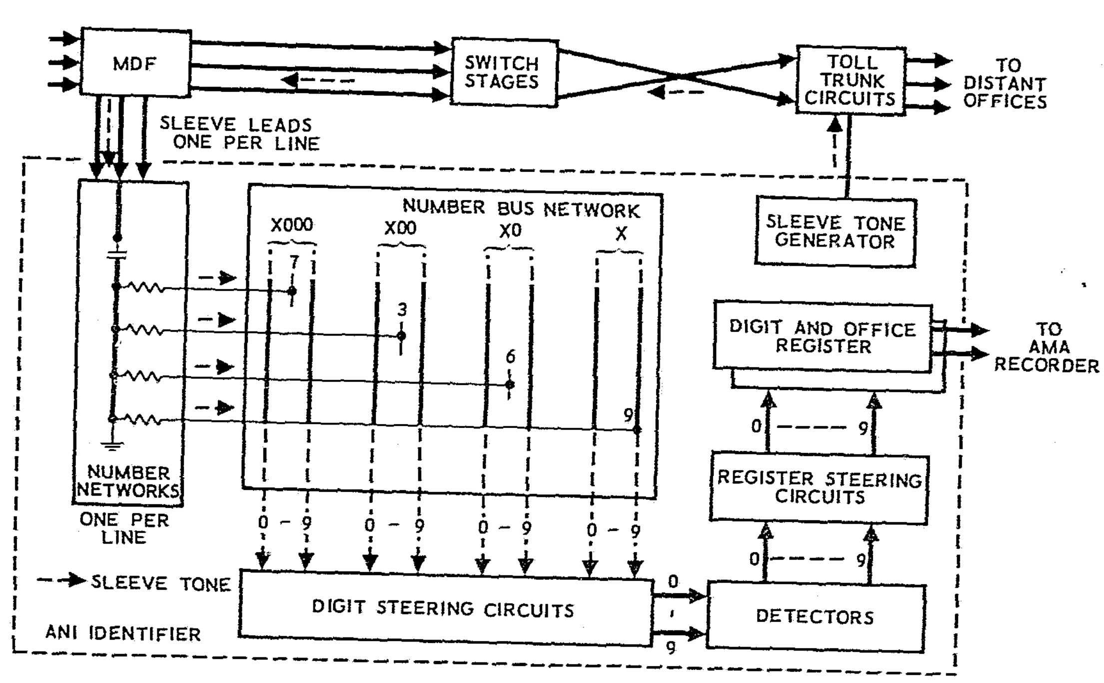

Figure 23. AMA Identifier. Typical Calling Number Identifier Circuit Used in Step-by-Step and No. 1 Crossbar Offices with AMA

per number in each 10 block. The numbers of the terminals with tones correspond to the various decimal digits of the calling numbers. The amplifiers/detectors scan the terminals sequentially, and each time a tone is detected, the corresponding digit is registered on relays in the identifier. Calling number information is provided on 40 output leads, ten leads for each digit in a four-digit number.

d. Calling number identification in No. 5 crossbar offices with automatic message accounting (AMA). In the No. 5 crossbar system, subscriber lines terminate on verticals of crossbar switches on the line link frame. They are identified for switching purposes by the number of the frame on which they appear and their position on that frame. This position on the frame is defined by the horizontal group, vertical group, and vertical locations file. The series of numbers specifying the link frame, vertical group, horizontal group, and vertical file is known as the equipment number.

Figure 24 illustrates the major elements of a No. 5 crossbar office. When a subscriber connected to a No. 5 crossbar office picks up his handset to place a call, the marker seizes the calling line link frame, finds the calling line, connects it to the originating register, and tells the register the equipment number. When all other billing information has been collected, the originating register transfers this data via a marker to the outgoing sender. The sender controls the selection of the called number and at the same time transfers billing information to the local (automatic message accounting (AMA)) equipment as shown in Figure 25. Since there is no fixed relationship between the equipment number and the directory number, a

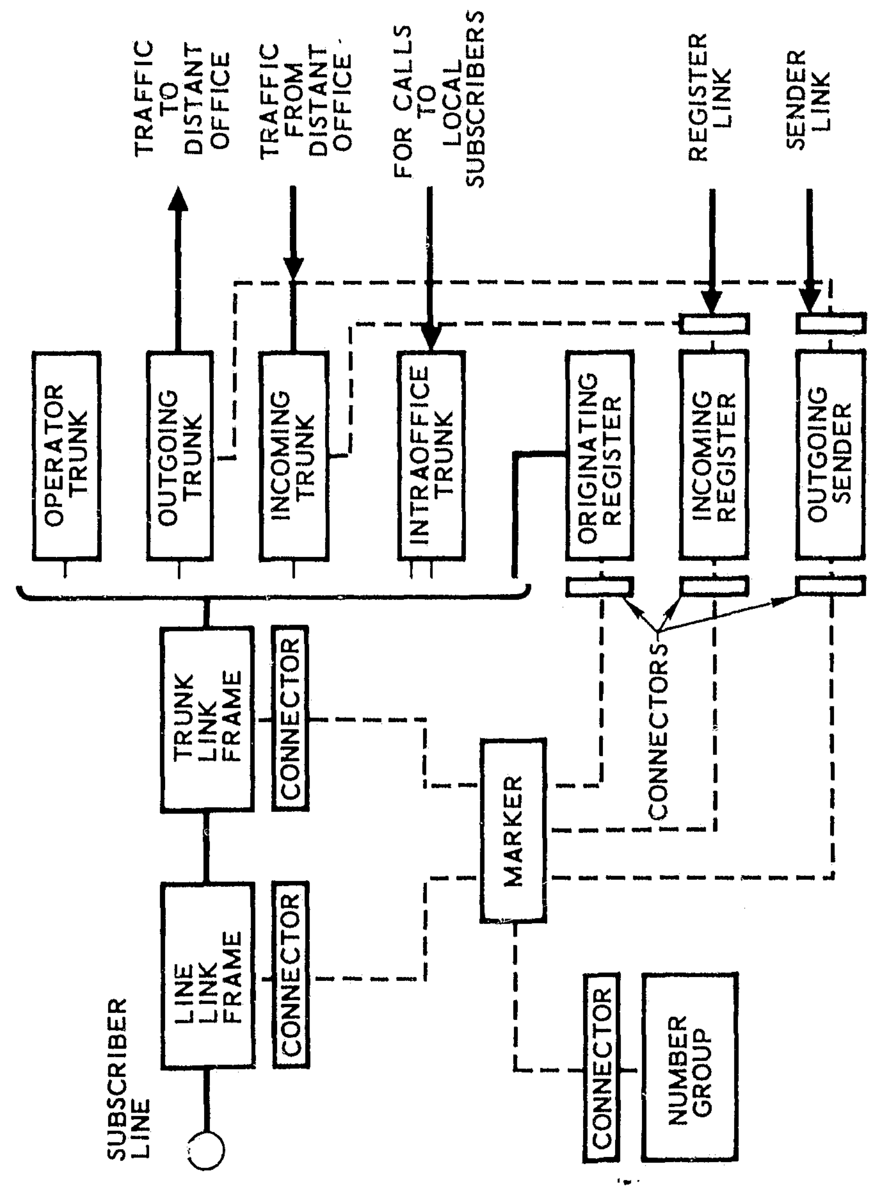

Figure 24. No. 5 Crossbar Switching System

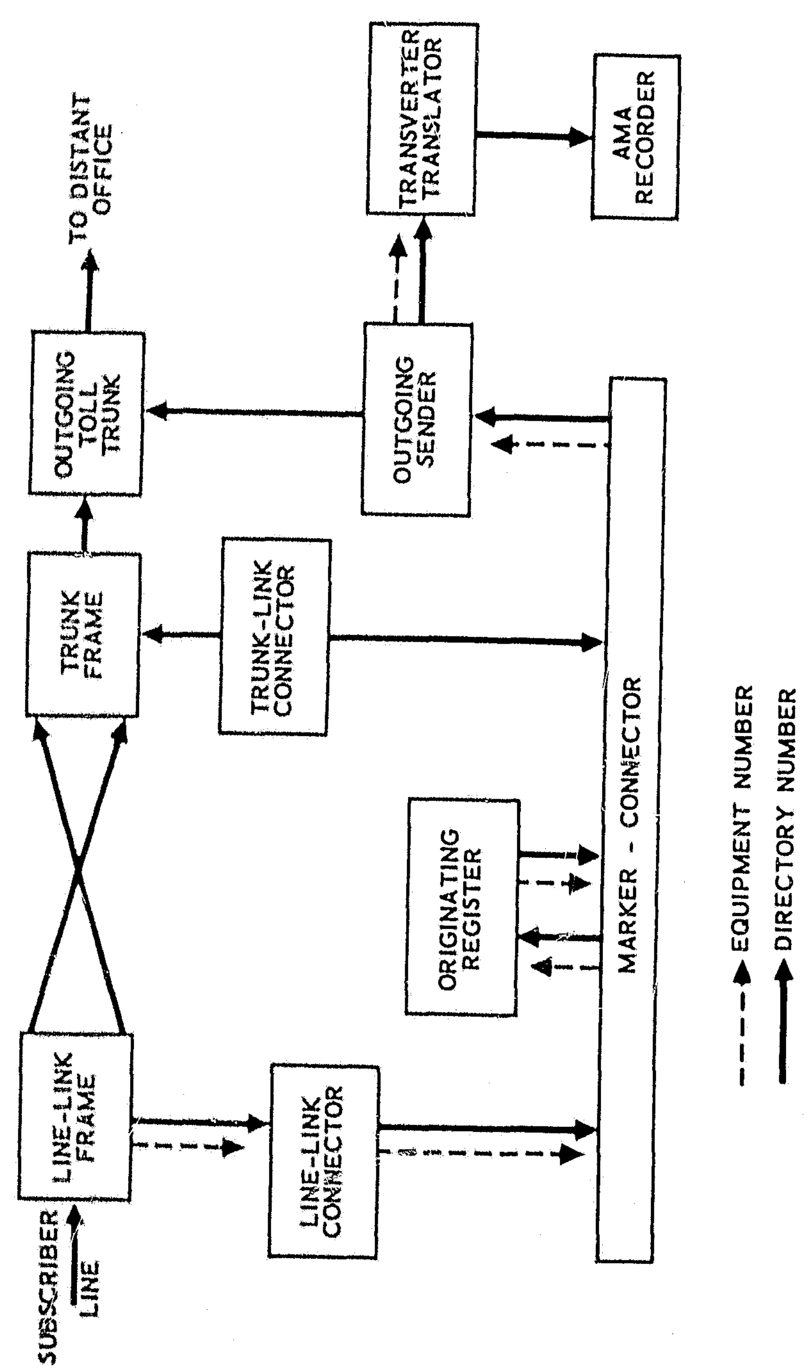

Figure 25. ANI in No. 5 Crossbar Offices with AMA

translator is required to convert the equipment number to a directory number for AMA recording. The transverter uses this information to obtain a translator which translates the equipment number to a directory number which is returned to the transverter for recording on the AMA tape.

The original No. 5 crossbar translator with a capacity for 1000 directory numbers occupied a single frame 11 feet 6 inches high and about 44 inches wide. In 1958, a more compact unit was developed with a capacity for 2000 lines in 34-inch wide frames. Electronic translator systems (ETS) are now available for use in tandem crossbar offices.

3. ANI for No. 1 crossbar, step-by-step and panel offices. In the late 1950s, ANI equipment was developed for local offices served by centralized automatic message accounting (CAMA) offices. This equipment obtains the calling number and automatically forwards it via multifrequency (MF) signaling over an ANI trunk to the centralized automatic message accounting (CAMA) office.

Figure 26 is a block diagram of the major equipment items required for automatic number identification, exclusive of maintenance facilities. These are:

- ANI outgoing trunk circuit
- Link circuit to connect the trunk to an outpulser
- Outpulser and identifier-connector circuit to seize and prime an identifier
- Identifier circuit to determine the calling customer's number and forward it to the outpulser, which in turn transmits

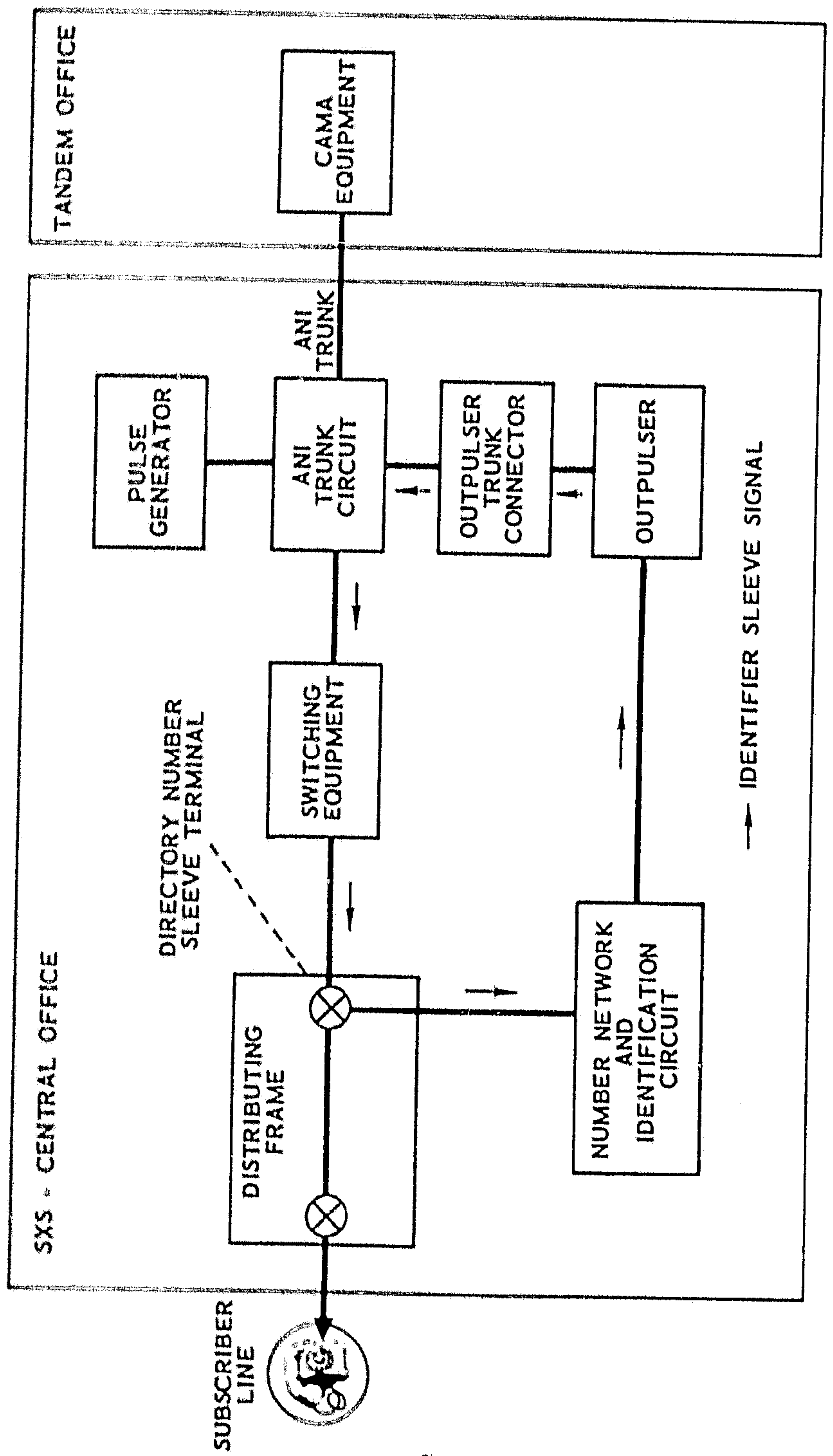

Figure 26. The ANI-C System Works with Existing Switching Equipment in Central Offices. Number Network Identification Circuitry Includes Glow Lamps, Dividing Resistors and Identifier. Identity of Number is Sent to CAMA Office over an ANI Trunk

the number to the centralized automatic message accounting (CAMA) office

- Number network and bus system to connect each customer's directory-number sleeve wire to a grid of bus panels and to connect the output of these panels via an identifier connector to an identifier

Fundamentally, the operation is quite simple. A call proceeds in the normal fashion until the called number has been transmitted to the centralized automatic message accounting (CAMA) sender, whereupon the identification equipment comes into play. This action is initiated by the outgoing trunk, which establishes a connection through the link to an outpulser. This circuit, by means of connecting facilities within itself, seizes an identifier. The identifier connects itself to the number network and bus system and signals the trunk to apply an identification signal to the sleeve wire toward the local switch train. This identification signal finds its way over the sleeve of the switch train and back to the customer's line equipment. Here the path continues through the distributing frame cross connections that attach directory number significance to the line circuit, and the identification signal reaches the directory number sleeve terminal. All of these sleeve terminals are cabled individually to networks connected to a bus system. These buses are arranged in a grid pattern in such a manner that the identifier can quickly scan the groups of output leads and identify the central office and the four digits of the calling number. This information is transferred to the outpulser, which forwards it to the centralized automatic message accounting (CAMA) point by multifrequency pulsing. Then the outpulser releases its connection through the link and the trunk connects the transmission circuit through for talking.

a. Number network and bus system. The ANI-B system first developed for No. 1 crossbar, step-by-step, and panel offices uses an identification arrangement shown in Figure 27. The customer's directory number sleeve wires are cabled from the distributing frame to terminals on the number networks at panels in the primary bus system. The sleeve terminations are arranged in a square pattern of 100 rows and 100 columns. Each sleeve wire is connected through a 0.05-microfarad capacitor and 510-ohm resistor to ground; the junction of these components is connected through 20,000-ohm resistors to one vertical and one horizontal bus in the grid. Thus, each sleeve is associated with one of the 10,000 coordinate points in the grid and may be identified in terms of the vertical and horizontal buses to which it is attached.

The primary 100 x 100 bus matrix is further subdivided into two secondary 10 x 10 bus matrices. With this arrangement, an identifier equipped with ten detectors may be switched from one group of ten secondary buses to another. With an input signal at one of the number networks, an output signal will appear on one bus in each of the four secondary groups of ten, and the buses so marked correspond to the numerical digits of the customer's number. Thus, the identifier makes four successive tests to identify completely a number in a 10,000-line unit.

In multioffice buildings, a single group of ANI equipment may serve as many as six central offices, each having a maximum of

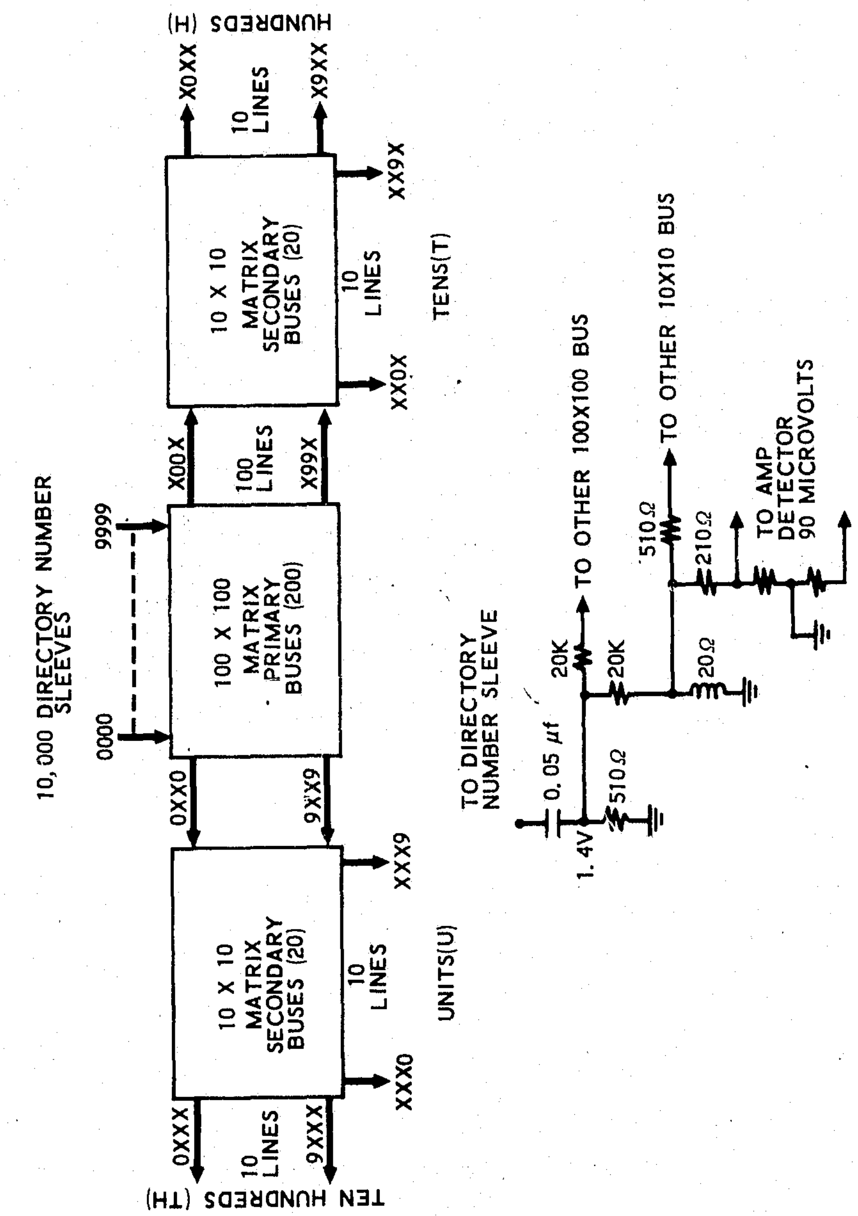

Figure 27. Number Network and Bus System used in ANI-B for Large Panel, Step-by-Step, and No. 1 Crossbar Offices

10,000 numbers. In buildings containing more than six central offices, a second group of identification equipment is required and simultaneous identifications may be made in the two groups. Successive groups of thousands buses are tested until a signal is found, then the hundreds, tens and units are examined to complete the identification. Office identification is accomplished by recognizing the particular thousands group in which the signal is found.

In offices with two parties (one identified as tip and the other as ring), the tip parties are connected to a second set of primary buses. Before the identifier connects to the secondary buses, it is provided with information as to whether the calling customer is a tip party and, if so, it transfers the two secondary grids from the primary that contains the ring party numbers to the one that contains the tip parties. In this way, it differentiates between the two parties on a line in spite of the fact that the signal is present in the number networks for both parties.

b. Identifier and outpulser. During its search for the calling number, the identifier scans the groups of secondary buses by connecting its detectors to the thousands buses of each office secondary grid, one after another. Meanwhile, the identifier keeps track of its progress and, when it finds the signal, grounds a corresponding lead to the outpulser, thus enabling that circuit to register the office of the calling customer. During this action, the particular thousands digit registered in the identifier is being transferred to the outpulser. Thereafter the identifier scans the hundreds, tens, and units buses and registers these digits in the outpulser. Although identification is made on a one-out-of-ten basis, a translation is introduced so that registration in the outpulser is on a two-out-of-five basis.

With the registers in the outpulser full and checked against missing or extra information, and the digit representing the office translated to the corresponding three-digit office code, the outpulser releases the identifier and starts outpulsing the calling number to the centralized automatic message accounting (CAMA) office. The information is sent in the following order: KP signal, information digit, three-digit office code, four numerical digits, and ST signal. The KP and ST signals use the conventional frequencies that serve to actuate a receiver at the beginning and end of a sequence of information. The information digit serves to indicate one of four conditions:

- Calling customer identified automatically
- Calling customer on a four-party of multiparty line, therefore requiring identification by the centralized automatic message accounting (CAMA) operator. No office of numerical digits are sent for these calls
- Calling customer is under service observation, and therefore the automatic message accounting (AMA) record for his call requires a service-observing mark in addition to the usual information
- Calling customer could not be identified because of trouble in the automatic equipment. This condition requires identification by the CAMA operator. No office or numerical digits sent for these calls

When all digits have been outpulsed, the outpulser is released and the trunk is closed through for the talking condition.

c. <u>Trunk circuits</u>. The trunk circuit requirements for ANI in No. 1 crossbar, step-by-step, and panel offices are similar. These trunks must be able to recognize the correct time to perform the ANI function and then seize an outpulser through the outpulser link. They must participate in several ways in the party-test function before number identification and must provide a path between outpulser link and outgoing cable over which the outpulser can forward the calling number after it has been identified. Then, after release of the outpulser, they must provide a transmission path with talking battery and supervision toward the calling customer and trunk supervision toward the tandem end. Also they must provide the necessary sleeve ground to hold the originating switch train.

Due to inherent differences in the three switching systems, it has been found best to design separate trunks for each. Furthermore, variations within each of the systems in methods of pulsing and signaling have resulted in two types of trunks for each system. In No. 1 crossbar and panel, one type is provided when the called number is to be transmitted by multifrequency (MF) pulsing and the other type when printed circuit integrator (PCI) pulsing is used. In step-by-step, one type of trunk is provided for loop signaling and the other for the so called "E and M lead" signaling which is required for the longer distances and when voice repeaters or carrier circuits are used.

Crossbar and panel trunks must receive a signal from centralized automatic message accounting (CAMA) indicating readiness to receive the called number. For multifrequency (MF) circuits, this signal is a momentary reversal of battery and ground and is relayed through the ANI trunk and

back to the direct distance dialing (DDD) sender as a go-ahead signal. For printed circuit integrator (PCI) circuits, the corresponding signal is the removal of battery and ground at the centralized automatic message accounting (CAMA) end of the trunk. At the time this occurs, the ANI trunk is cut through and the signal is transmitted directly to the subscriber sender (in this case, there is no DDD sender connected).

All the ANI trunks need a "start identification" signal from centralized automatic message accounting (CAMA) to indicate when the equipment is ready to receive the calling number. Crossbar and panel trunks must also recognize when the district junctor or selector has reached the cut-through position. Only then is the sleeve continuous, as required for transmission of the start identification signal, together with detection of district junctor or selector "cut-through," when required, causes the ANI trunk to initiate the identification function.

d. <u>Electronic ANI systems</u>. In the last few years, a number of electronic ANI systems have been involved for use in centralized automatic message accounting (CAMA) tributary offices. These systems are functionally similar to the older electromechanical ANI systems and are compatible with all classes of switching systems which provide a continuous sleeve lead through the switch train. These electronic ANI systems use a combination of electromechanical and solid-state components and provide significant cost, space, and power savings over older systems.

4. ANI in electronic switching systems. Introduction in 1965 of the first (No. 1) electronic switching system (ESS) by Bell Laboratories marked a major advance in switching system technology in terms of speed, flexibility, and ease of maintenance. Since that time the major independent telephone equipment manufacturers have introduced their own electronic systems. These systems are being used for practically all new central office installations and are rapidly replacing older electromechanical offices. It is estimated that by the year 2000 all central offices will be electronically controlled.

The electronic switching system (ESS) is particularly interesting with respect to the problem of providing ANI for 911 for several reasons:

- Calling line identification is accomplished on all incoming calls
- Line equipment number to directory number translation is available as a standard software routine
- Three-digit called number translation is available as a standard software routine for selective call routing
- Digit signaling over inter-office trunks is controlled by standard software routines using either multifrequency (MF) or dial pulse signaling techniques
- All trunk circuits are available to, and controlled by, the central control unit and are not peculiar to the service to which they are assigned.
- The control unit includes interface provisions for transmission of digital data to remote terminals or processor [common channel interoffice signaling (CCIS)]

- Peripheral circuits have been designed to give coin lines dial tone before coin deposit to support 911 services

Thus ESSs provide all of the basic functions needed for obtaining and transmitting 911 ANI information to a remote public safety answering point (PSAP) central office.

a. Major components. Electronic switching systems (ESSs) contain three basic elements as shown in Figure 28:

- Switching networks using high-speed ferreed switches
- Control unit which directs switching operations and maintenance
- Two memories - a temporary memory (call store) for storing information such as availability of circuits, called number, calling number, type of call; and a semipermanent memory (program store) containing all the information which the control unit needs to process an incoming call

Figure 29 illustrates the functions required to process a call.

b. Equipment number identification. Each subscriber line connects to a saturable-core transformer called a ferrod sensor. This device indicates whether the line is on- or off-hook. Each ferrod sensor is scanned about five times every second by electronic circuits which report the state of the line to the central control unit. Whenever a change of state of any subscriber line is found, the line scanning program temporarily stops the scanning

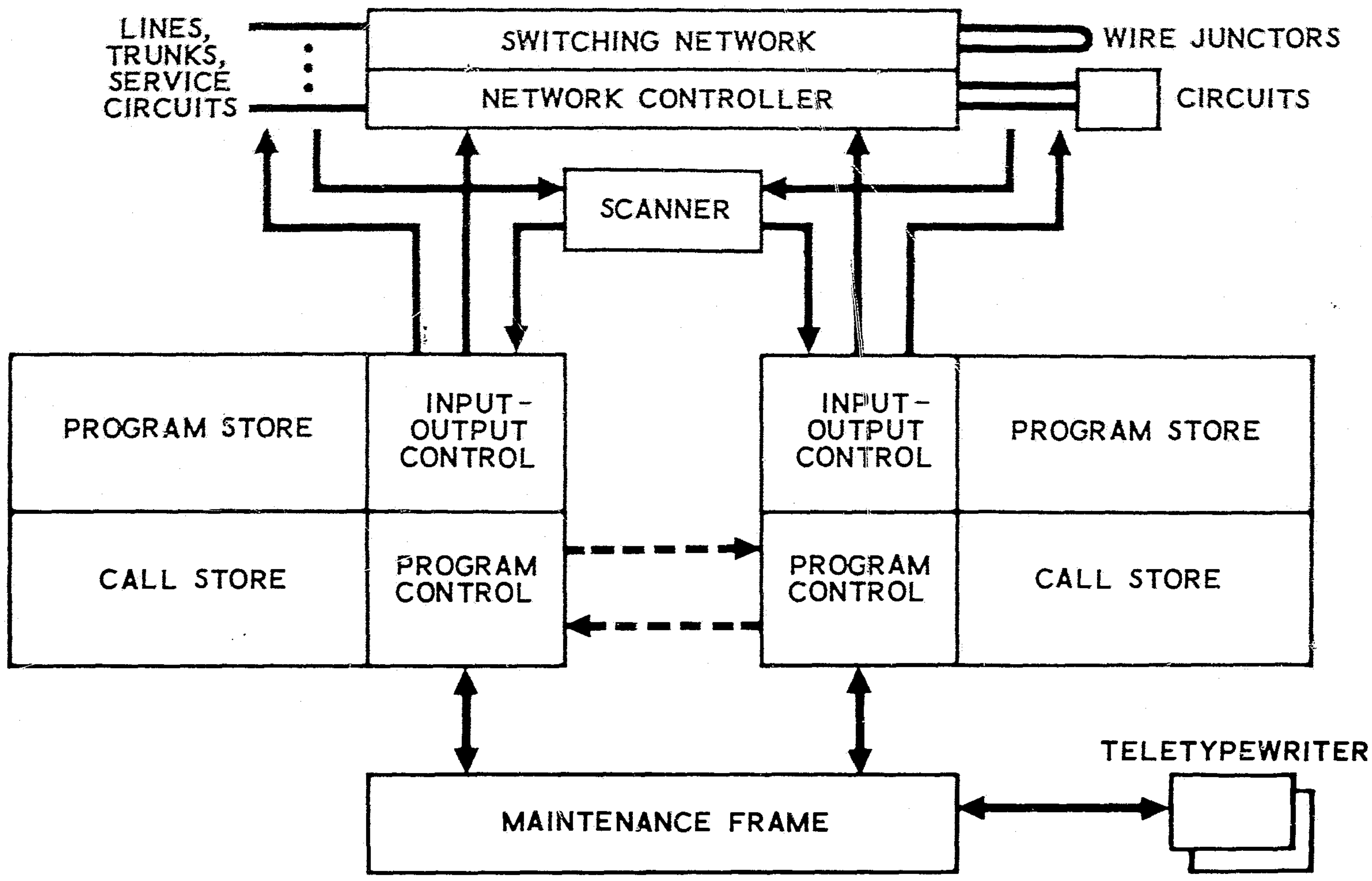

Figure 28. Electronic Switching System

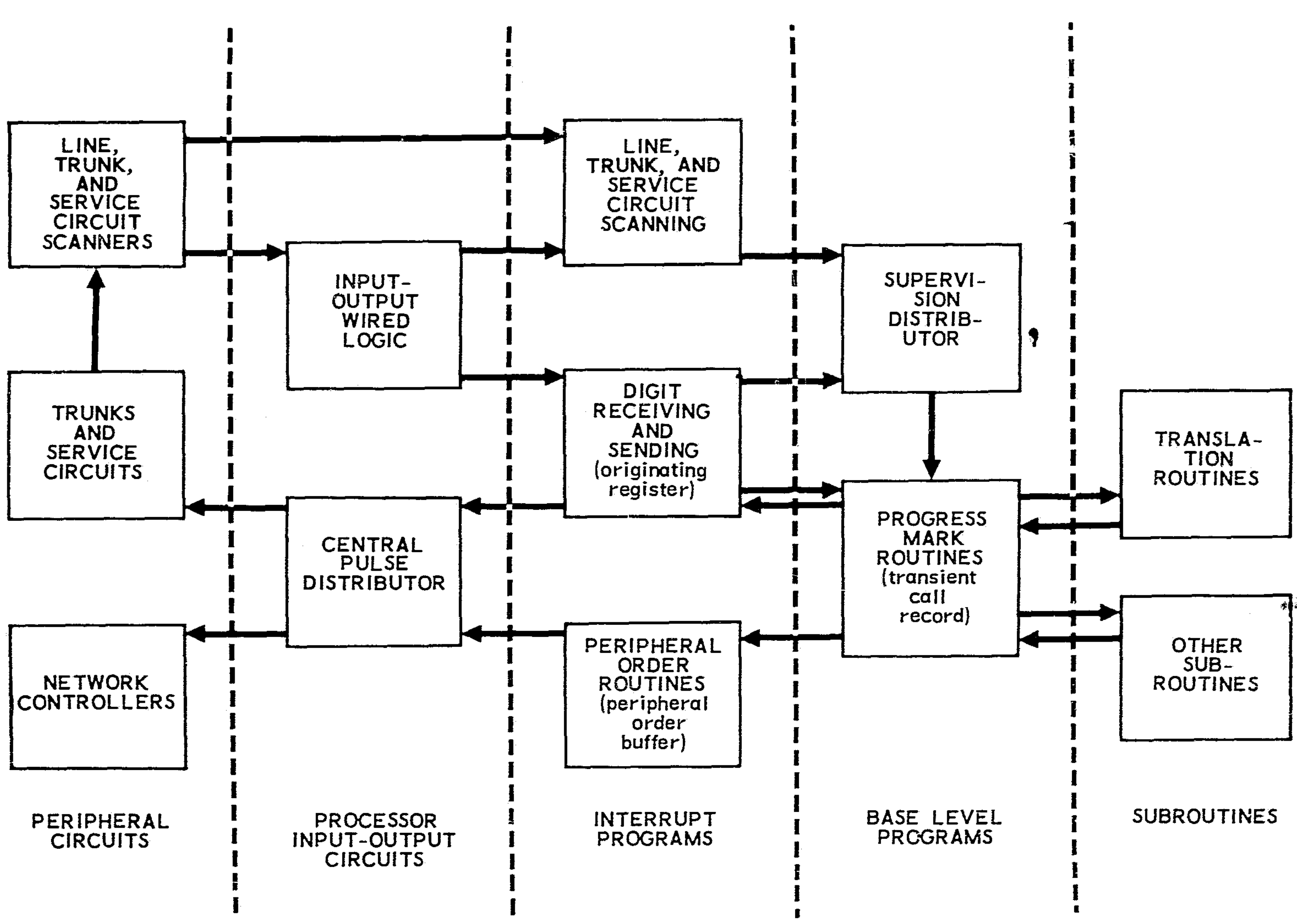

Figure 29. ESS Call Processing Information Flow

action and records the equipment number in the transient call register in call store memory. Figure 30 illustrates arrangement of data in the transient call register.

c. Originating number translation. Line originating translation provides a conversion from the line equipment number to the line class and directory number. Each line in an electronic switching system (ESS) office has a terminal equipment number which is used to refer to that line during the processing of calls. Class data derived from the originating line translation includes type of service, i.e., individual two-party, PBX; routing and billing instructions; and type of dialing. Translation is required whenever a digit receiver is selected, a billing entry is prepared for automatic message accounting, or a special service (such as 911 ANI) is required.

Translation is accomplished by stored program table look-up. The first six bits of the equipment number are used to address a translation table in memory which contains a one word entry for each terminal equipment number on the input network on which the line appears. This word may contain the directory number, or it may be a pointer to another table which contains the directory number and other data required to process the call.

The translator is designed so that additional data can be added to the data base as new services are defined. For example, the street address corresponding to location of the instrument associated with the line equipment number [or a code identifying the responsible fire, police, and hospital public safety answering point (PSAP)] could be included in translation store. The translation process could then provide information necessary for automatic

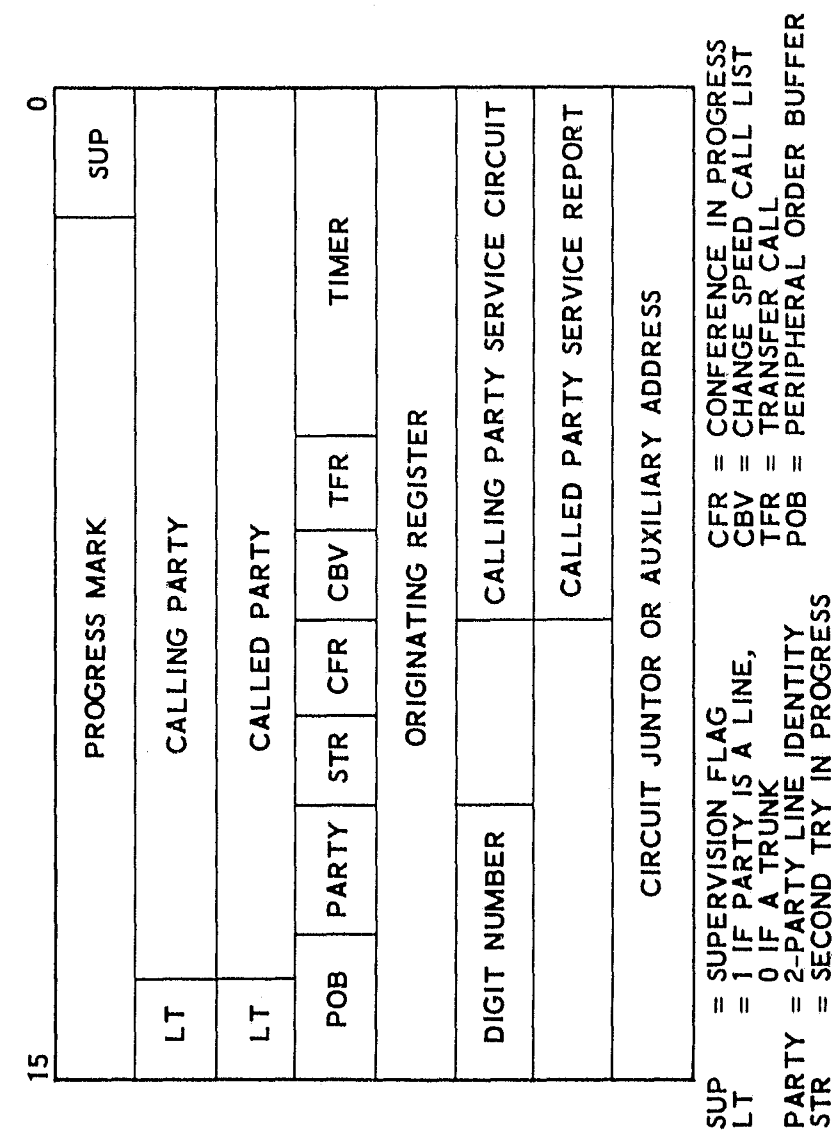

Figure 30. Transient Call Register

selective routing of emergency calls to the proper PSAP as well as automatic location identification (ALI) to the answering service.

d. Digit translation. As the customer begins dialing and each digit is received, a report is made to a digit analysis program which controls the originating register. After three digits have been received, the digit analysis program requests a translation of these digits to determine the routing of the call. The first three digits represent an office code, an area code, or a service code. If the call is not an intra-office call, translation is requested to determine routing and an indication of whether or not the call is to be billed. If the call is billable, the digit program requests that an automatic message accounting (AMA) register be connected to the originating register. This register is actually a block of temporary memory that accumulates pertinent data on the call as it progresses. The number of registers available in a given system depends on the type and volume of traffic and is determined to ensure a low probability of blockage due to the unavailability of a register.

If the first three digits are a service code (such as 911) the appropriate service routine is called to control the necessary service functions.

e. Electronic switching system/automatic message accounting (ESS/AMA) operation. All ESS/AMA functions are accomplished under stored program control in such a way that the only special central office equipment required for the AMA function is a magnetic tape unit. Two programs are used: a data accumulation program and a data transfer program. The first records the charge details on all calls classified as billable, then encodes the data and transfers it to a memory register. When the register is full, the

second program takes over and transfers the data to magnetic tape. Figure 31 illustrates a typical layout of an AMA call store register.

The process of forwarding 911 ANI or ALI data to the proper public safety answering point (PSAP) would be handled in exactly the same way except that the 911 data transfer program would control transmission of data over an interoffice trunk via multifrequency (MF) digit sending circuits.

C. Required Modifications for 911/ANI

This section describes the requirements for and proposed modifications to telephone central offices to provide ANI information to remote public safety answering points (PSAPs) for incoming 911 calls.

1. ANI functional requirements for 911. Four basic functions are required at local central offices for providing ANI on incoming 911 calls:

- 911 service code must be intercepted and used to initiate emergency call processing
- Outgoing trunk must be obtained for routing the call to the proper public safety answering point (PSAP)
- Signals necessary for proper supervision of the call must be sent to the calling and called party instruments. Special features such as called-party hold, called-party disconnect, dial-tone first on pay phones, ring-back while calling party is holding, may be required
- Calling number must be obtained and stored for transmission to the PSAP at the proper time.

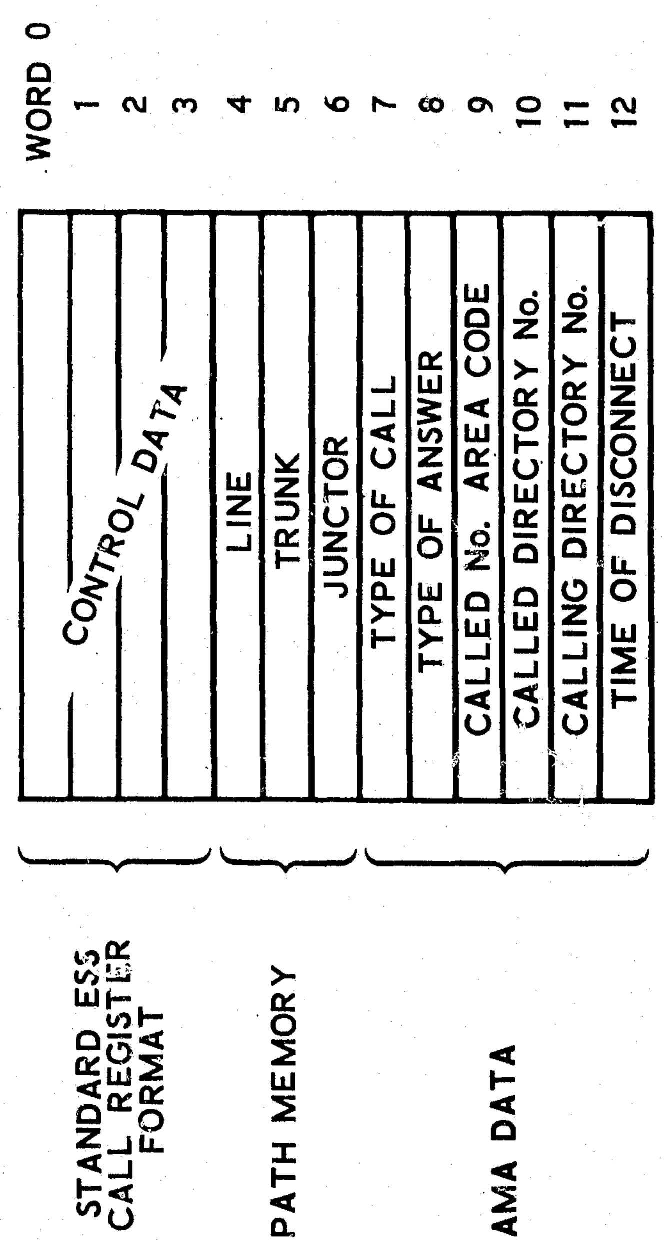

Figure 31. AMA Register in No. 1 ESS

The first three functions have been implemented as part of many local 911 systems in operation today. Therefore, our principle concern is with modifications required to implement the last item.

2. Description of modifications. The proposed modifications are designed to make maximum use of existing number identifiers, translators, register/senders, and interoffice trunk circuits. Exact configurations will vary with the size of each office, type of equipment installed, and emergency traffic expected.

a. Modifications to local automatic message accounting (LAMA) offices. In order to provide ANI information to a 911 outgoing trunk, central offices equipped with LAMA must perform the following functions:

- Examine the first three digits (911) of the called number, seize an idle outgoing trunk to the 911 office
- Identify the calling line and translate it, if necessary, to the calling party's directory number
- Seize an idle outgoing sender circuit and transmit the calling party number to it
- Seize the line link frame associated with the calling line and connect the calling line to the selected outgoing trunk
- Transmit the calling number to the 911 office via the selected outgoing trunk by means of multifrequency (MF) signaling

The equipment required to perform these functions is shown in Figure 32; for a comparison with a No. 5 crossbar arrangement. Specific

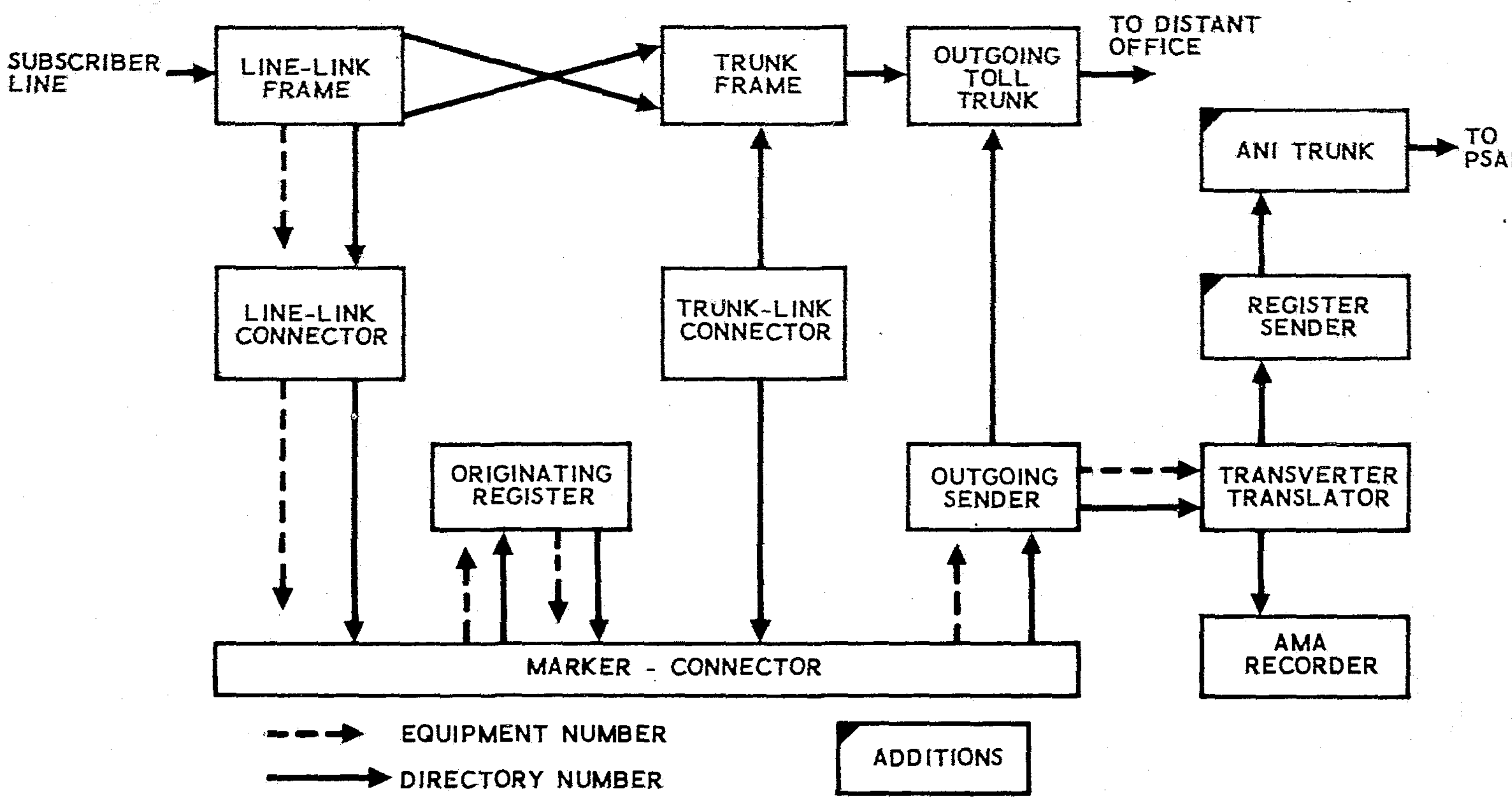

Figure 32. Modifications to No. 5 Crossbar Offices with AMA

configurations will vary between step-by-step offices which use identifier circuits to generate the calling party directory number, and crossbar offices which translate the equipment number to a directory number.

The additional equipment required for 911 ANI includes 911 trunk circuits, register sender circuits to obtain the calling number from the transverter, connector circuits to control and sequence transfer, and for some offices, multifrequency (MF) sending equipment similar to that used in typical ANI installations. Since older No. 1 crossbar and step-by-step offices do not use multifrequency (MF) senders for interoffice signaling, MF signaling equipment must be added. New trunk circuits will also be required for the older offices with trunks arranged for MF signaling.

Since 911 calls will not require service from common AMA equipment, it will be possible in most cases to arrange existing translators, transverters, and senders to service both 911 and toll calls on a non-interfering basis.

The quantity of equipment required will vary from office to office and will depend principally on the number of 911 trunk circuits required. For the purpose of cost estimating we have assumed a 15,000 line step-by-step office with AMA which includes four office codes and requires four 911 trunks. Modifications to this office would include:

- Two register-senders
- One MF signaling circuit

- Four trunk circuits
- Miscellaneous common control

This equipment would require approximately 36 inches of rack space.

b. Modifications to ANI-equipped offices. The ANI functions described above are precisely those required to provide ANI information for a 911 system. Normally, these functions are only performed for incoming calls determined to be toll or extra-charge calls. Therefore, existing elements can service 911 calls without interference to toll calls. Common control equipment must be modified to intercept the 911 call, route it to the proper ANI trunk, initiate the identifier and outpulser functions, and connect and disconnect the multifrequency (MF) transmitter and the ANI trunk.

These modifications will require the addition of ANI trunk circuits as required to connect existing identifier, outpulser, and multi-frequency (MF) signaling circuits to the ANI trunks, and to enable these circuits upon receipt of the 911 digits. Figure 33 illustrates these additions which are similar to those required when traffic service position system (TSPS) trunks are added to a local office.

c. Modifications to electronic switching system (ESS) offices. Existing ESS designs include hardware and peripheral equipment for providing ANI on 911 trunks. Software service routines will have to be developed for these special 911 services and these new routines must be integrated into

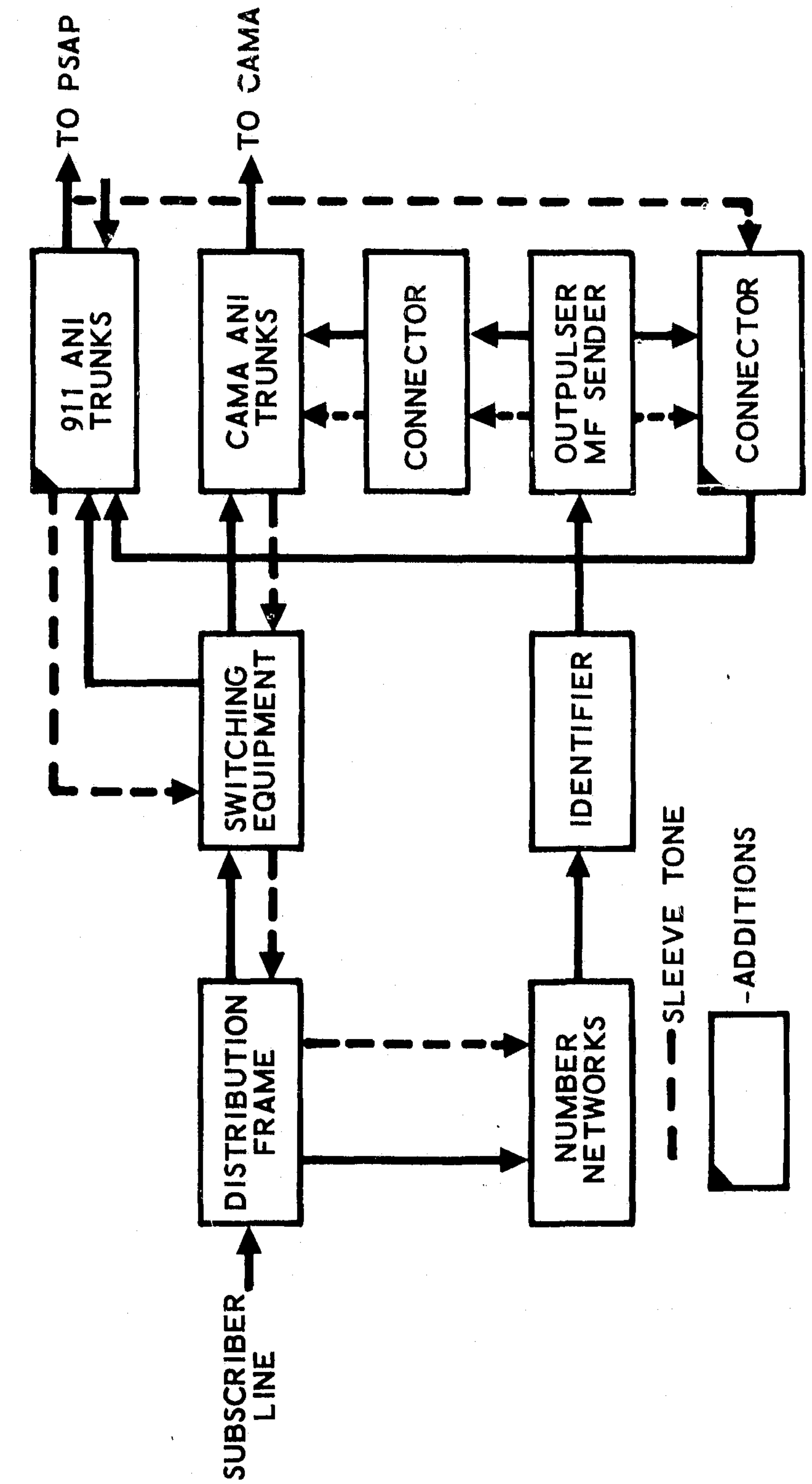

Figure 33. Modification to ANI-Equipped Offices

existing operating systems in each individual office. These special features can be installed at the factory for future installations.

Some additional memory, both call store and program store, must be allocated to the 911 routines. However, because of the relatively large amount of storage allocated to existing translation routines, the cost of storage can be expected to be negligible.

If the cost of developing and documenting the 911 routines can be amortized over all existing electronic switching system (ESS) offices, then the principal cost factor for 911/ANI modifications to ESSs will be the labor required for local engineering, integration, and documentation.

d. Modifications to offices without AMA or ANI. As indicated in Section C a small percentage of existing lines terminate in central offices which are not equipped with either AMA or ANI. Recent developments of compact and inexpensive ANI equipment for small offices has made it practical to add ANI to existing small offices. It is expected that the telephone operating companies will continue to upgrade their smaller offices as part of the continuing growth of the DDD network.

The major elements of an ANI tributary system were described in Section C. This equipment is available from several vendors in packages which can accommodate offices with from 500 to 100,000 lines. Additional technical information is readily available on a specific product which is typical of those available from telephone equipment manufacturers.

3. Cost of modifications. Table 26 summarizes modification costs for the various types of offices considered. Cost elements include both

Table 26. Comparison of Modification Costs

Item \ Office Type	Local Automatic Message Accounting		Automatic Number Identification/ Centralized Automatic Message Accounting		Electronic Switching System
	Step-By-Step	Crossbar	Step-By-Step	Crossbar	
Engineering	$1500	$1500	$ 900	$ 900	$1000
Trunks (4)	1200	1200	1200	1200	--
MF Sender (1)	800	--	--	--	--
Register-Sender (2)	1200	1200	--	--	--
Common Control	1200	1000	600	600	--
TOTAL	$5900	$4900	$2700	$2700	$1000

engineering labor and material as summarized below. All estimates assume a nominal 15,000 line office. Modification costs for a particular office will vary widely depending on size, equipment and traffic considerations.

- Engineering and documentation. This cost element includes design engineering which is distributed over many similar offices as well as the local installation engineering necessary to work out the detailed modifications for each office. Costs have been converted from engineering hours on the basis of $15 per hour.
- Trunk circuits. Dedicated trunk circuits from each local office to the appropriate public safety answering point (PSAP) are required. A minimum of two circuits are

required for redundancy. Four trunks have been costed to allow for traffic loading. Larger offices may require substantially more trunks.

- MF signaling circuits. Additional multifrequency (MF) signaling circuits may be required depending on the number of trunks, traffic activity, and type of office. A single MF sender circuit can service up to 60 trunks in conventional ANI installations (see Appendix A). Existing senders in ANI equipped offices can be used as common equipment in many cases.
- Shift register senders. In large offices with many trunks electronic shift registers may be required by traffic loading to hold line numbers until common signaling equipment is available. Two shift register senders have been costed for a local automatic message accounting (LAMA) step-by-step office.
- Common control circuits. These circuits are required for interconnection and control of other elements and include connections, markers, sequencers, check circuits, test panels, relay rack, and power supplies.

D. Interfacing ANI to 911 Systems

A complete definition of the interface between telephone company provided equipments and 911 provided terminal or switching equipment must address:

- Applicable voice connecting arrangements (VCA) as prescribed by the FCC and Bell System Technical References
- 911 system configuration and data flow
- Subscriber line and trunk signaling and supervision requirements
- Definition of the peculiar characteristics of all connecting central office trunks
- Number of central office trunks, PSAP connections, expected traffic loading

This section discusses these items in general terms with emphasis on the public safety answering point (PSAP) functions peculiar to processing incoming ANI information.

1. Telephone Company (Telco) voice connecting arrangements (VCA). Federal Communications Commission (FCC) tariffs and corresponding intrastate tariffs filed by the Bell System provide for the electrical connection of customer-provided voice transmitting and receiving terminal equipment and communications systems to the Bell System telecommunications network by means of a voice connecting arrangement (VCA). The connecting arrangement includes circuit elements to provide network control signaling unit functions as well as certain other network protection functions and is furnished, installed, and maintained by the telephone company. In addition, the tariffs require compliance by the customer-provided equipment

with certain network protection criteria specified in applicable Bell System technical references.

Figure 34 illustrates the interface between Telco and non-Telco provided equipment. The voice connecting arrangements (VCA) would be provided and installed by the Telephone Company at the public safety answering point (PSAP) location. The specific VCA which applies will depend on the type of trunks (two wire or four wire), the type of supervision (E&M or Loop), and on the peculiar features of the equipment used for PSAP call switching and distribution. Table 27 lists several VCA interfaces, and their applicability. The reader should refer to these documents for detailed electrical and mechanical interface specifications. Figure 35 illustrates a two-wire trunk interface with E&M signaling as specified in VCA CDQ2X. The reader is referred to Bell Systems Technical Reference Pub. 42502 for further detail.

2. <u>911 operations</u>. The public safety answering point (PSAP) interfaces described in this section are based on a number of assumptions regarding the configuration and operation of the 911 system. Figure 36 illustrates a configuration in which dedicated trunks are used between central offices and PSAPs. For this configuration:

- All central offices are connected to a central PSAP via dedicated 911 trunks
- All incoming 911 calls are routed by local offices to the central PSAP where they are answered by 911 dispatchers

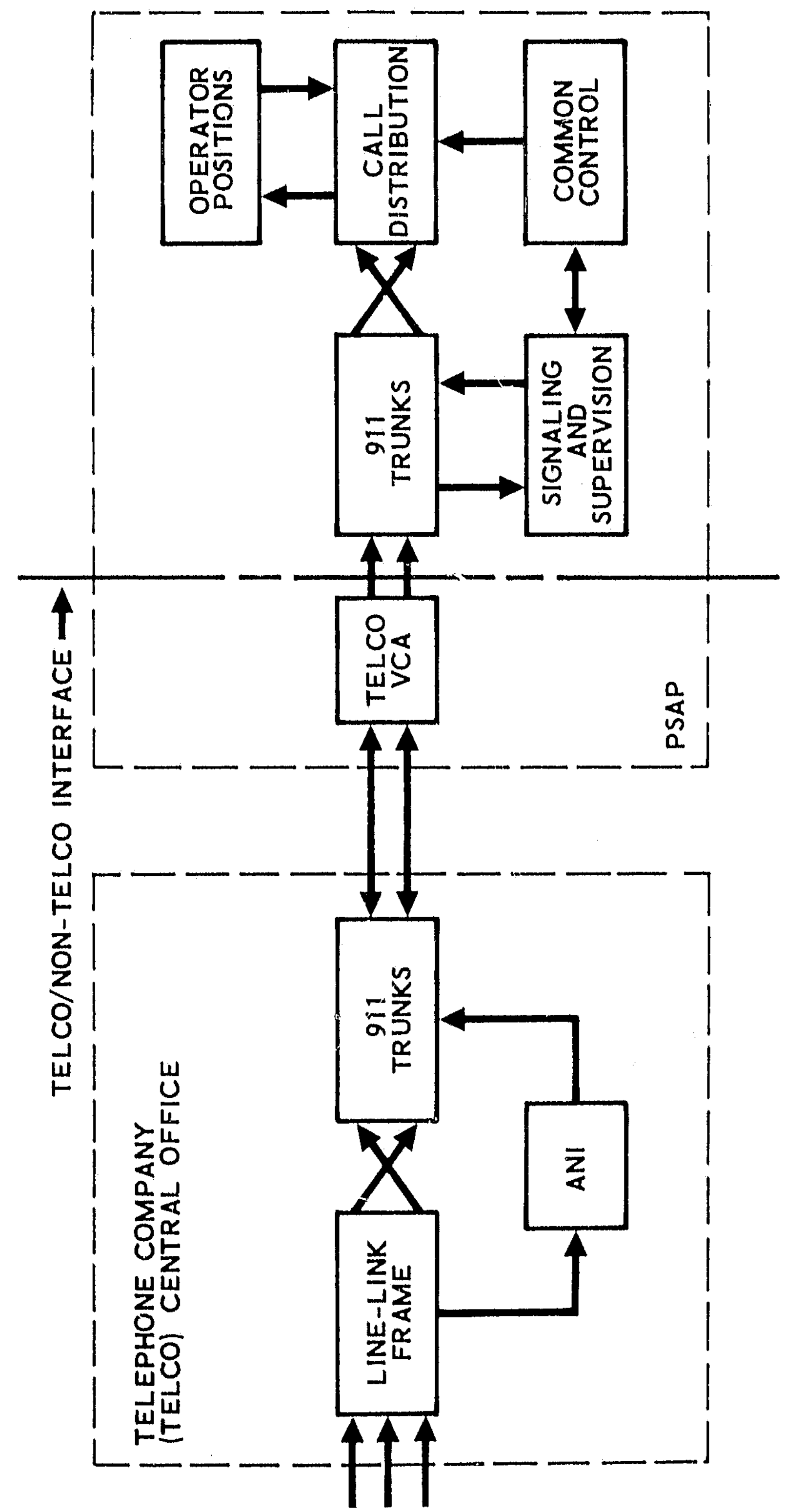

Figure 34. Telco/PSAP Interface

Table 27. Voice Connecting Arrangements for Private Lines

Bell System Tech. Reference	VCA	Application
PUB42501 (August 1969)	CDQ4W	Automatic voice connecting arrangement arranged for two-way service, which provides a four-wire voice transmission interface to customer-provided dial switching equipment — used with a Telephone Company-provided four-wire private line channel equipped with Telephone Company-provided channel signaling with a contact-type signaling interface.
PUB42502 (June 1971)	CDQ2W/CDQ2X	Voice Connecting Arrangement CDQ2W is arranged for two-way service and provides a two-wire interface to customer-provided dial switching equipment. Used with Telephone Company-provided private line channel and Telephone Company provided channel signaling with a contact-type signaling interface. Voice Connecting Arrangement CDQ2X is arranged for two-way service and provides a two-wire interface to customer-provided dial switching equipment. Used with Telephone Company-provided private line channel and Telephone Company-provided channel signaling with an E- and M-type signaling interface.
PUB42503 (February 1971)	C234W	Voice connecting arrangement, arranged for two-way service, which provides a four-wire voice transmission interface to customer-provided dial switching equipment. Used with a Telephone Company-provided four-wire private line channel and customer-provided channel signaling.

Table 27. Voice Connecting Arrangements for Private Lines (Continued)

Bell System Tech. Reference	VCA	Application
PUB42504 (September 1971)	C232W	Voice connecting arrangement arranged for two-way service, which provides a two-wire interface to customer-provided dial switching or station terminal equipment. Used with a Telephone Company-provided private line channel and customer-provided channel signaling (inband signaling only).
PUB42505 (October 1971)	CDQ4X	Automatic voice connecting arrangement, arranged for two-way service, which provides a four-wire interface to customer provided dial switching equipment. Used with a Telephone Company-provided four-wire private line channel equipped with Telephone Company-provided channel signaling with an E and M signaling interface.

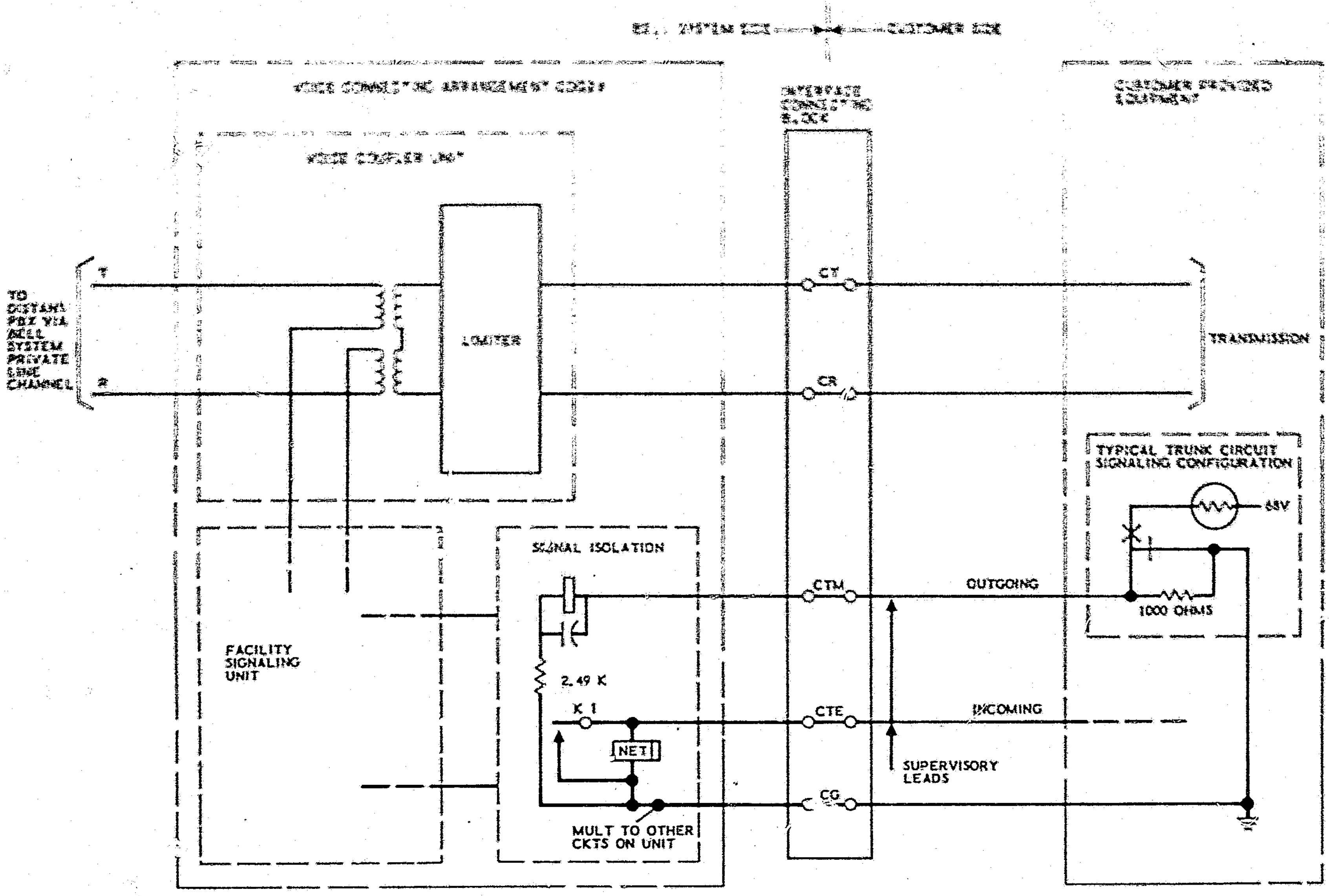

Figure 35. Voice Connecting Arrangement CDQ2X

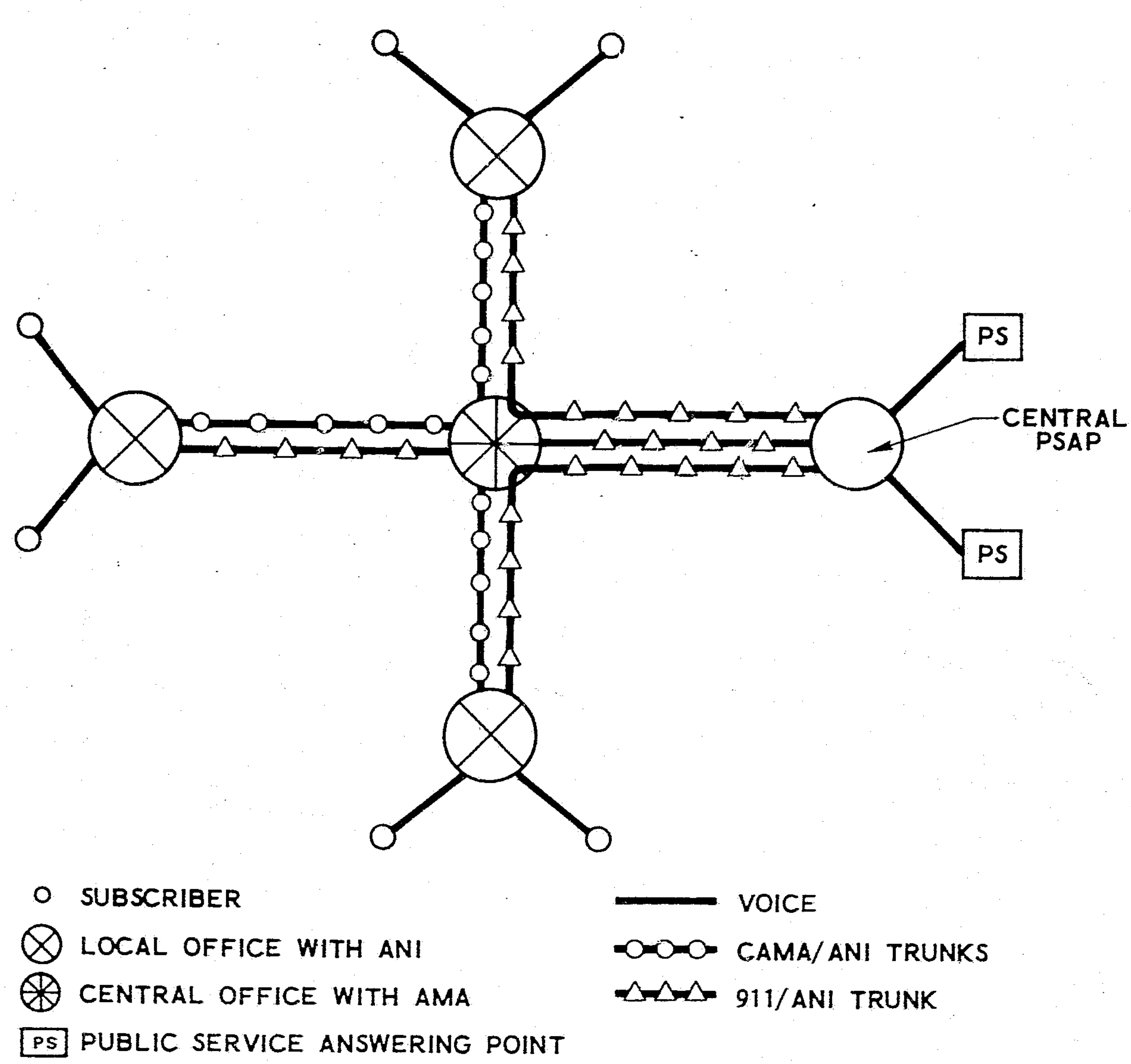

Figure 36. ANI Path Through Dedicated 911 Trunks

- The Telco/Central PSAP interface will be implemented by means of a Telco-provided voice connection arrangement (VCA) located at the central PSAP
- Central offices forward ANI information over the 911 trunk automatically upon request of the PSAP which processes this information for display to the 911 dispatcher
- The ANI information from the central offices may be used by the central public safety answering point (PSAP) data processing facilities for automatic location identification (ALI) or other 911 services, but it is not forwarded beyond the central PSAP
- 911 dispatcher at the central PSAP may connect the calling party to the appropriate local PSAP or he may relay the request for service himself
- The central PSAP may or may not be required to transmit digital data to the local PSAPs

In areas where one or more centralized automatic message accounting (CAMA) office(s) collect ANI information from a relatively large number of local offices equipped with ANI equipment, the cost of central office modifications can be significantly reduced by forwarding all 911 calls through the CAMA office(s) along with the appropriate ANI information. This approach would require a relatively small number of dedicated 911 trunks since existing local office CAMA trunks would be used for both CAMA and 911 ANI. Only CAMA offices would be connected to the central PSAP. This configuration

suggests the use of common channel interoffice signaling (CCIS) between centralized automatic message accounting (CAMA) and public safety answering point (PSAP) offices in lieu of conventional multifrequency (MF) signaling.

3. Central PSAP ANI interfaces. Consider a central PSAP which includes a small crossbar tandem switching system with electronic control and automatic call distribution to operator positions as shown in Figure 34. In order for this system to receive and process ANI data from remote central offices it must perform a number of functions.

a. Reception of ANI digits. The outgoing trunk circuits in the calling office terminate on incoming trunk circuits in the central PSAP. These incoming trunks appear on both the trunk-link and incoming register link frames. The incoming register link frame provides access to incoming registers which record the frame number of incoming trunk for subsequent use in connecting the call to the next available operator.

After the incoming register records the necessary connection information, it causes the incoming trunk circuit to signal the outgoing sender in the calling office to pulse out the calling number. The multifrequency (MF) pulses are received and stored by the incoming register. As each digit is received and checked, the incoming register transfers it to common control storage. After receipt of the last digit the register is disconnected from the incoming trunk and is ready to service the next call.

b. ANI digit analysis. When all ANI digits have been received, an ANI digit analysis program is called. The first digit must be a KP pulse to ensure that none of the first digits have been missed. The next digit received is an ANI information digit (see Section IV.B.3.b). This digit may indicate that the local office is unable to identify the calling party due to equipment failure or that the originating party has a multi-party line. In either of these cases, the operator to whom the call is connected must be advised that she must obtain the calling number verbally.

The ST pulse is the last multifrequency (MF) pulse received and is normally used as a traveling class mark for dial pulse trunks which do not forward an initial one (station-to-station) or zero (operator-assisted) digit with the called number. This digit is also used to distinguish between coin and non-coin lines. After receipt of the ST digit, the ANI analysis program deactivates digit scanning and returns control to a connection program for connection of the call to an operator.

c. MF receivers. The functions described above are typical of those performed in existing tandem crossbar or electronic switching systems which use multifrequency (MF) signaling on interoffice trunks.

Multifrequency (MF) receivers and senders which have the characteristics summarized in Tables 28, 29, and 30 can be obtained as part of a complete switching system or as separate items. The number of units required at the public safety answering point (PSAP) will depend on the number of trunks to be serviced. Since the receiver is only connected to the trunk for a few seconds during each call, a few receivers can service a relatively large number of trunks.

Table 28. Multifrequency Receiver Specifications

Input Impedance	10 kΩ dc blocked, isolated from ground
Input Amplitude	0 to -22 dBm (600Ω)/tone
Frequency Tolerance (sender)	± 1.5 percent
Carrier Shift Tolerance (transmission channel)	± 10 Hz
Level Difference Between Lines	6.5 dB maximum
Minimum Pulse Length	
before KP	55 ms
after KP	27 ms
Minimum Interdigital Interval	20 ms
Maximum Pulsing Rate	10 digits/s
Maximum Input Noise	57 dBrn 3 kHz flat weighting
Outputs	50 ± 5 ms ground true, battery false

Table 29. Multifrequency Sender Specifications

Output Amplitude	-10 dbm ±0.5 db
Digit Pulse Duration	68 ± 7 ms
Interdigital Interval	68 ± 7 ms
KP Pulse Duration	100 ± 15 ms

Table 30. Frequencies for Multifrequency Pulsing

Digit	Frequencies	
1	700 + 900	
2	700 + 1100	
3	900 + 1100	
4	700 + 1300	
5	900 + 1300	
6	1100 + 1300	
7	700 + 1500	
8	900 + 1500	
9	1100 + 1500	
0	1300 + 1500	
Use	**Frequencies**	**Explanation**
KP	1100 + 1700	Preparatory for digits
ST	1500 + 1700	End of pulsing sequence
STP	900 + 1700	Traffic Service Position System
ST2P	1300 + 1700	Traffic Service Position System
ST3P	700 + 1700	Traffic Service Position System
Coin Collect	700 + 1100	Coin Control
Coin Return	1100 + 1700	Coin Control
Ringback	700 + 1700	Coin Control
Code 11	700 + 1700	Inward Operator
Code 12	700 + 1700	Delay Operator
KP1	1100 + 1700	Terminal Call
KP2	900 + 1700	Transit Call

E. Summary and Conclusions of ANI Study

Based on the above discussion, we may conclude that the inclusion of ANI in 911 systems, employing either the selective routing or selective answering concept, is technically feasible and economically practical. Principal results are summarized below.

- Prevalence of ANI. Approximately 80 percent of the subscriber lines which terminate in central offices are equipped with ANI for automatic message accounting (AMA)
- Services Without ANI. ANI is not available to certain classes of service even though the subscriber line terminates on a central office equipped with ANI. This exclusion applies to party lines with more than two parties, certain PABX installations, and coin telephones.
- Types of Central Offices with ANI. ANI equipment is available for all major types of central office equipment in use today, i.e., step-by-step, crossbar, panel, and electronic switching systems (ESS). Stand-alone systems are available for adding ANI to older panel, step-by-step, and No. 1 crossbar systems. ANI is built into all modern No. 5 crossbar and electronic switching systems.
- ANI for 911. ANI can be provided with 911 calls using techniques and equipment identical to that which is used to provide ANI for AMA. In offices already equipped with ANI for AMA, existing elements can be used to provide both services.
- AMA Versus 911 ANI Traffic Loading. The volume of ANI traffic for 911 would be less than 0.1 percent of the current ANI traffic

for AMA. Therefore, the addition of this function to existing office equipment would have a negligible effect with respect to traffic loading.

- Cost of Modifications for 911 ANI. The cost of modifications to central offices to provide ANI with outgoing 911 calls will range from $2700 to $5900 per office depending on the size and type of office.
- Cost Versus Office Size. The cost of central office modifications will depend principally on the number of trunks required between the office and the central PSAP. Modern ANI systems are designed to handle multiple (up to 10) prefixes per office, i.e., offices with up to 100,000 equipped lines. Separate trunks are not required for each prefix.
- Telco/PSAP Interfaces. A Telco provided voice connection arrangement (VCA) is required at the PSAP. The PSAP voice switching and distribution system must be equipped with MF signaling and trunk supervision circuits capable of interfacing with all local central offices connected to it. These interfaces are similar to those required in a Telco tandem office with central AMA, and can be implemented with equipment available from several manufacturers.
- Trends. Electronic Switching Systems (ESS) are rapidly replacing older central office equipment. By the year 2000 virtually all central offices will be converted to ESSs. These systems can be arranged to provide 911 ANI with minor program modifications. ALI could also be provided by these systems but with some increase in memory.

Table 31 summarizes the types of central office equipment, the ANI techniques used, the modifications required, and the estimated costs per office for each type.

1. Classification of central offices. For purposes of discussing ANI, central offices have been grouped into four major categories:

- Those offices which accomplish the ANI function as an integral part of the common control equipment which performs local automatic message accounting (LAMA offices)
- Those offices which are equipped to identify the calling number and to transmit it over an outgoing trunk to a remote office with centralized automatic message accounting (CAMA). These offices, sometimes called CAMA tributaries, will be referred to as ANI/CAMA offices.
- ESS offices which determine the calling number under stored program control
- Those offices which have no provisions for ANI and which must rely on operator number identification (ONI) for billing of toll calls

2. Techniques for ANI. Western Electric and all of the major independent telephone equipment manufacturers make a variety of ANI and centralized automatic message accounting (CAMA) equipment. The specific details of

Table 31. Summary of Results

[illegible]	[illegible]		[illegible]	[illegible] PSAP[a]	Cost: Per [illegible]	Per Line
[illegible]			[illegible]	[illegible] interface between AMA [illegible] to sieze ANI trunks	$4[illegible]	$0.[illegible] to $1.[illegible]
Large Crossbar [illegible] AMA	4	2[illegible]	Equipment number determined by scanner, translated [illegible]	Same as above	$4[illegible]	$0.[illegible] to $1.00
Panel, step-by-step, No. 1 Crossbar with ANI	4[illegible]	[illegible]	Directory number [illegible] remote CAMA office [illegible] MF[b] signaling	Add ANI trunk circuits [illegible] ANI trunk	$27[illegible]	$0.2[illegible] to $0.5[illegible]
[illegible] Crossbar with ANI	[illegible]	[illegible]	Same as for crossbar with AMA except that translated number is outpulsed via sender to remote CAMA office	Same as above	$27[illegible]	$0.2[illegible] to $0.5[illegible]
Electronic switching with AMA	4	6	Line scanner detects off-hook line, sends line number to originating register, where it is translated, placed in AMA register, recorded on tape	Add outgoing ANI routine called by 3-digit translation analysis program	$1[illegible]	$0.10 to $0.20
Panel and manual offices without AMA or ANI	1[illegible]	9	Calling number obtained by operator for extra charge on DDD calls (ONI)[c]	Add complete ANI system or retain ONI	$4k-$5k	$10 to $50

[a] PSAP - public safety answering point
[b] MF - multifrequency
[c] ONI - operator number identification

these equipments vary among manufacturers with installation, size, and with equipment age; however, one of two basic techniques are used in these equipments:

- Continuous Sleeve Identification. In older central office equipment not originally designed for ANI, the location of the line-finder cannot be determined directly. The continuous sleeve technique takes advantage of the existence of a continuous electrical path from the sleeve of the selected outgoing trunk, back through the switching equipment to the sleeve of the incoming line on the master distribution frame (MDF). A tone or other identifying signal is placed on the trunk sleeve after the trunk is seized and fed back to the MDF. Each MDF sleeve termination is connected to an identifier or decoding matrix which detects the identifying signal to produce a number which is unique for each terminating line. The identified number is held in a register, translated as required, and transferred to the local AMA or sent over an ANI trunk to a remote CAMA. This ANI technique is found principally in panel, step-by-step and No. 1 crossbar equipments.
- Equipment Number Identification. No. 5 crossbar and electronic switching systems (ESSs) are designed in such a way that the line scanning circuits automatically associate a unique equipment number with each incoming line in the

"off-hook" condition. This number is stored, translated and processed as required for either ANI or AMA operations.

3. Functions required for 911 ANI. To provide ANI to a central 911 answering point, each telephone central office must perform the same functions now completed by existing ANI/CAMA equipment on incoming toll calls. These functions are:

- Intercept the 911 call number
- Identify the incoming line
- Connect the incoming line to a 911 trunk
- Transmit the directory number to the 911 PSAP

4. Modifications required for 911 ANI. Modifications of offices with existing ANI equipment for operation with 911 PSAPs would require the addition of common control register-senders, signaling circuits, and trunk circuits wherever capacity for these common equipment functions is not already available. Detailed modifications will vary widely from one office to another. The one-time cost for plant engineering peculiar to each office is expected to be a major factor in the overall cost. Electronic switching system (ESS) offices can provide all necessary ANI functions under program control and require only assignment of 911 trunk circuits, a 911 control routine, and appropriate data base changes.

5. Cost of modifications. Estimates for the cost of modifications are shown in Table 31 on a per office and per line basis. The per office costs are based on a nominal 15,000 line office with four 911 ANI trunks. The office modification cost is determined more by the number of trunks and

registers required than by the number of lines served. However, the cost per line is a strong function of office size. The cost per line is probably a more meaningful parameter for comparing the cost of 911 ANI service with that of other special telephone services. The principal cause of the large range in line costs shown is the range of office sizes. Per line costs will be higher for smaller offices since the average office size is between five and six thousand lines; however, ANI is not a pressing need in these cases.

6. Central office - PSAP interfaces. A Telco-provided voice connecting arrangement (VCA) is required for each trunk line terminating on non-Telco equipment at the public safety answering point (PSAP). The type of VCA required for each trunk will depend on the type of trunk (two- or four-wire), the supervisory signaling used by the central office (E&M or D. C. Loop), and the signaling technique used for routing the call (dial pulse or multifrequency (MF) signaling). In all cases, the PSAP terminal must be equipped with MF receivers and registers which are compatible with the remote central office signaling equipment. Sufficient receivers and registers must be provided to handle the expected 911 traffic.

The use of common channel interoffice signaling (CCIS) is an attractive alternate to MF signaling between large electronic switching systems and a central PSAP. CCIS is used for transmission of multichannel digital signaling data between certain types of electronic central offices. Its use would eliminate the need for special signaling and trunk circuits on each ANI trunk. The rapid growth of ESS installations would favor this approach.

F. Recommendations

This Automatic Number Identification (ANI) study has suggested a number of areas for further consideration.

- Several cities and counties are now studying implementation of local 911 systems with ANI. The costs proposed by the implementer should be carefully evaluated in light of the cost data developed in this document.
- Consideration should be given by the Federal Communications Commission and Public Utilities Commission to establishing a specific tariff for voice with ANI connecting arrangement service offering for public safety agencies. The first step in this direction would be the preparation of a definitive Telco-Public Safety Answering Point (PSAP) interface specification and interconnect arrangement, and agreements relating to Telco supplying of updated telephone directory data.
- The possible adaptation of common channel interoffice signaling (CCIS) in lieu of multifrequency (MF) signaling for 911 ANI deserves further investigation. This signaling technique could significantly reduce the cost of Telco terminals and voice connecting arrangements (VCA) at the PSAP but would require other modifications at the central offices.
- The possible use of common centralized automatic message accounting (CAMA)/911 ANI trunks should be investigated for use in areas where a small number of CAMA offices service a relatively large number of ANI tributary offices. This approach could significantly reduce the number and cost of trunks terminating at the central PSAP.

NOTES

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2. C. E. Hill and R. W. Johnson, "911 Proves Itself in Seattle," Bulletin (November 1973).
3. Reference Data for Radio Engineers, ITT, 5th Edition.
4. Cohn, "Law Enforcement Technology," 1 (1967).

APPENDIX A. MINICOMPUTER SYSTEM RELIABILITY ESTIMATES

Table A-1 provides some raw data regarding expected and actual performance of four leading minicomputers. A 12K word version is provided as a standard baseline for the size of the minicomputer.

Table A-2 weighs this data in the favor of actual hard data obtained from computer users versus manufacturer's reliability claims. A failure rate of 1.62 failures/year is determined by this very simplistic calculation.

Table A-3 provides the equivalent of Table A-1 for, in this case, disc memory failures.

Table A-4 attempts to obtain a failure/year figure for disc controller electronics, whereas Table A-5 computes an equivalent figure for disc spindle units. The IBM data is provided a lighter weighing factor because the 2314/2319 disc series is not a current IBM line. These discs had hydraulic features that are not used in the more modern DIVA and DIABLO discs. The latest line of IBM discs (the 3300 series) is said to have a reliability of from "2 to 3 times better than the 2314/2319 series," however, to the best of our knowledge has not yet been interfaced with a minicomputer.

Table A-6 takes the numbers for failures/year previously derived in Tables A-2, A-4, and A-5 and first totals them, and then provides a figure that could be said to represent a MTBF. If it is assumed that 358 days out of 365 the computer system should provide 24 hours of uninterrupted operation--the probability of this 24-hour provision being achieved is about 98 percent.

Table A-1. Minicomputer Failure History[a]

Computer Type Or Brand	Source	Mean Time Between Failures (MTBF) (Hours)	Failures Per Year
HP 2100	The Magnavox Company, Torrance, Calif. (W. C. Euler) Conversation of 1/13/74	8000 Hrs. @ 60% Duty Cycle = 4800 Hrs.	1.8
HP 2114 and HP 2116	Naval Weapons Systems Laboratory, Seal Beach, Calif. (P.D. Sutton) for 1.5-year history	~4320 @ 100% Duty Cycle	2
Computer Automation	Letter to USAF contractor written during summer of 1973 based upon "3000 Installations"	8760 Unknown Duty Cycles	1
Data General	Visit to Data General representatives on 12/20/73	8760 (CPU only at unknown duty cycles)	1
DEC PDP-11	DEC estimate for 4K PDP 11/20 given to Aerospace on 11/14/72	5700	1.5

[a] Includes CPU, ~12K Core, + I/O Electronics

Table A-2. Computer Failure/Year Determination

Computer	Failures/Year	Weight Factor	Failures/Year x Weight Factor
HP 2100	1.8	3	5.2
HP 2114/2116	2	3	6.0
Computer Automation	1	1	1.0
Data General	1	1	1.0
DEC PCP-11/20	1.5	2	3.0
		10	16.2

$$\frac{\text{Total Failures/Year}}{\text{Total Weight Factor}} = \frac{16.2}{10} = 1.62 \text{ Failures/Year}$$

Table A-3. Disc Failures

Disc Type	Source	← Failures/Year For →	
		Controller Electronics	Spindle Units
IBM 2314/2319 30 M-byte disc pacs	IBM L.A. Maintenance Dept. (C. King) Telecon of 1/17/74	2 (Controller services 8+ spindles)	6
DIVA mini-computer type	DIVA (V. Malley) 1/17/74	0.23 Calculated (Controller services 4 spindles)	2.3
Diablo Series 30	DIABLO (B. Wicks) Telecon of 1/18/74	1 (Controller services 4 spindles)	2 (Specification) 1.25 (Actual History)
Diablo Series 40	Diablo (B. Wicks) Telecon of 1/18/74	1 (Controller services 4 spindles)	2 (Specification)

Table A-4. Disc Controller Failure/Year Determination

Disc Type	Failures/Year[a]	Weight Factor	Failures/Year x Weight Factor
IBM	1	1	1
Diva	0.23	1	0.23
Diablo Series 30	1	1	1
Diablo Series 40	1	1	1
	Total	4	3.23

$$\frac{\text{Failures/Year Total}}{\text{Weight Factor Total}} = \frac{3.23}{4} = 0.81 \text{ Failures/Year}$$

[a]Based upon controller servicing up to four spindles

Table A-5. Disc Spindle Units Failure/Year Determination

Disc Type	Failures/Year	Weight Factor	Failures/Year x Weight Factor
IBM	6	1	6
Diva	2.3	3	6.9
Diablo Series 30 Spec.	2	2	4
Diablo Series 30 History	1.25	3	3.75
Diablo Series 40 Spec.	2	2	4
	Total	11	24.65

$$\frac{\text{Failures/Year Total}}{\text{Weight Factor Total}} = \frac{24.65}{11} = 2.24$$

CONTINUED

2 OF 3

Table A-6. System Reliability

Quantity	Item	Failures/Year	Source
1	Computer + ~12K Memory + I/O	1.62	Table A-2
1	Disc Controller Electronics	0.81	Table A-4
2	Disc Spindles	4.48	Table A-5
	Total	6.91	

$$\text{MTBF} = \frac{8760 \text{ Hours/Year}}{6.91 \text{ Failures/Year}} = 1270 \text{ Hours}$$

Probability of walking into computer room and having system work without a failure for the next 24 hours:

$$\cong \frac{358}{365} \times 100 = 98.1\%$$

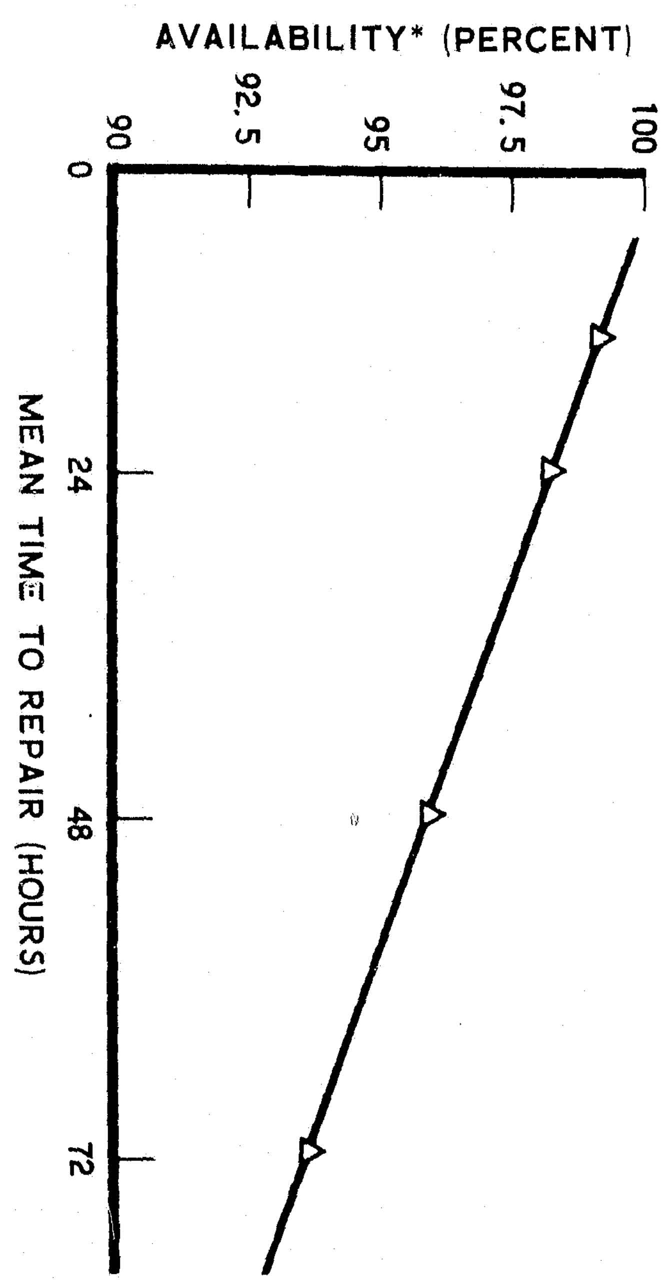
Table A-7. Computer Downtime Caused by "Unscheduled" Corrective Maintenance (Based Upon 6.91 Failures/Year)

Mean Time to Repair (MTTR) (Hrs)	Downtime (Hrs) Caused By "Unscheduled" Corrective Maintenance	Downtime Percent/Year	Availability[a] (Percent)
1	6.91	0.08	99.92
4	27.64	0.32	99.68
8	55.28	0.64	99.36
12	82.92	0.96	99.04
16	110.56	1.28	98.72
20	138.20	1.60	98.40
24	165.84	1.92	98.08
48	331.68	3.84	96.16
72	4[illegible].52	5.76	94.24

[a]Corrective maintenance only considered. This figure does not take into account factors which include preventative maintenance, hardware and software system change implementation, power outages, system software failures, computer terminal failures (e.g. ASR-33) and hardware failures other than the CPU, the I/O interfaces, 12K words of core memory electronics, and a dual spindle disc.

Table A-7 brings mean-time-to-repair considerations into performance computations. The availability figure provided is very carefully defined in the footnote of this table.

Figure A-1 illustrates the relation between system availability and mean-time-to-repair (MTTR) based on the figures presented in the tables.



* SEE TABLE 7 FOR "AVAILABILITY" DEFINITION

Figure A-1. Availability* Versus MTTR (Based upon 6.91 Failures/Year)

APPENDIX B. OMAHA TRAFFIC DATA

The data plotted in Figures 9 through 12 is presented here in table form to provide additional detail. The information was provided to us by Omaha Public Safety Department personnel during a briefing they presented in Oakland on November 5, 1973 and is herein gratefully acknowledged.

Table B-1. Public Safety Department 911 Telephone Calls by Day from Saturday 28 July 1973 through 3 August 1973

Hours	Sat. July 28	Sun. July 29	Mon. July 30	Tues. July 31	Wed. August 1	Thurs. August 2	Fri. August 3	Average
0000-0100	49	55	38	29	40	41	66	45
0100-0200	60	54	22	25	49	33	48	41
0200-0300	38	56	19	27	29	22	26	31
0300-0400	38	22	9	18	19	15	21	20
0400-0500	23	28	10	10	9	8	12	14
0500-0600	13	13	5	8	8	16	9	10
0600-0700	12	17	12	24	18	9	11	14
0700-0800	15	10	15	24	30	33	20	21
0800-0900	27	21	33	20	44	40	32	31
0900-1000	35	20	23	20	29	32	37	28
1000-1100	34	21	21	23	32	28	43	29
1100-1200	29	23	27	29	40	29	34	30
1200-1300	24	39	22	23	38	38	36	31
1300-1400	32	34	33	36	34	43	44	36
1400-1500	42	31	33	27	28	38	62	37
1500-1600	30	34	31	28	37	50	33	34
1600-1700	39	27	55	41	53	43	62	46

Table B-1. Public Safety Department 911 Telephone Calls by Day from Saturday 28 July 1973 through 3 August 1973 (Continued)

Hours	Sat. July 28	Sun. July 29	Mon. July 30	Tues. July 31	Wed. August 1	Thurs. August 2	Fri. August 3	Average
1700-1800	49	43	29	50	48	69	48	49
1800-1900	59	38	39	42	59	57	43	48
1900-2000	43	41	60	65	79	48	45	54
2000-2100	76	34	40	63	59	24	48	49
2100-2200	49	45	52	48	56	38	83	53
2200-2300	65	62	48	54	50	53	80	59
2300-2400	59	43	59	18	40	89	94	69
Total	940	810	735	755	918	896	1037	

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