AEROSPACE REPORT NO.
ATR-74(7904)-1, Reissue A

EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM

SURVEY AND SYSTEM CONCEPTS FOR A LOW COST BURGLARY ALARM SYSTEM FOR RESIDENCES AND SMALL BUSINESSES

Law Enforcement Development Group

August 1976

DEVELOPMENT

Prepared for

National Institute of Law Enforcement and Criminal Justice
LAW ENFORCEMENT ASSISTANCE ADMINISTRATION
U.S. DEPARTMENT OF JUSTICE

The Aerospace Corporation

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THE AEROSPACE CORPORATION
El Segundo, California

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Approved

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ABSTRACT

Burglary is a growing national problem resulting in staggering financial losses, a substantial portion affecting residences in low income areas and small businesses. Burglary alarm systems would provide an effective deterrent to crime in such areas if they could gain wider acceptance by being made less expensive and more reliable.

A characterization of the crime of burglary, based on data obtained from various government and industry sources, is used to develop a representative analytical burglary model in which typical police responses to a burglary call are examined. Additional analysis compares the effectiveness of several different burglary alarm systems against potential monetary losses and apprehension rates. The results of these analyses are used to identify technical requirements and guide the development of improved burglary alarm systems to provide the following: 1) simple sensors which can discriminate and respond to human intrusion and yet be immune to other signals such as those common to the residential environment; 2) a means for inexpensively communicating the alarm data from the installation to the police or an alarm company (currently, the transmission of intrusion data from an alarm installation depends primarily on leased telephone lines, which are becoming more scarce and more expensive each year) ; and 3) new concepts for logic control of alarm systems to decrease the number of false alarms experienced with current alarm system installations.

Specific technical requirements for simple but effective alarm system components that are analyzed and described were incorporated into subcontracted studies and development efforts. Results of these efforts will be made available by the Law Enforcement Assistance Administration to assist the burglary alarm industry in meeting the national need for reducing the crime of burglary.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

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SUMMARY

This report documents the results of a survey and assessment of existing and proposed residential intrusion alarm systems and provides a detailed analysis of the various aspects of the crime of burglary based on statistical data derived from crime reports. Sections of this document contain detailed discussions of the cost and false alarm problems currently existing with available equipment and other sections provide the technical concepts and requirements definition for further development to help combat these problems. Subcontracted efforts for an electric field detector, a residential control system, and an alarm transmission tradeoff study are specifically proposed for immediate implementation.

Burglary is a recognized national problem resulting in direct losses of over two billion dollars per year. Reported residential burglary is increasing at the alarming rate of 12.5% per year and the problem is virtually unchecked as evidenced by the average conviction rate of only 8.2%. The typical convicted burglary offender is under 25 years old, unsophisticated in his attack, and can be easily dissuaded from attacking a residence or can be apprehended if a simple but effective alarm system is installed.

A. General Survey and Analysis Results

It has previously been estimated and recently confirmed that only one-third of all burglaries are reported. This may be due to many reasons as varied as low individual dollar loss, fear of reprisal, or the belief that the

police are helpless to cope with the problem. Intrusion alarm equipment that is generally available is too expensive for the low income resident who suffers the highest percentage of burglaries and too prone to false alarms for a direct tie-in to metropolitan police switchboards.

The following general conclusions support the development and feasibility demonstration of a low cost security alarm system.

- A need exists for a low cost reliable security alarm system for the low income resident and small businesses.
- A need exists for new and/or modified alarm response tactics.
- The need exists to integrate burglar alarm systems and their components with other crime fighting strategies.
- The need exists for a reliable human discriminating intrusion sensor to reduce the magnitude of sensor-induced false alarms.
- The need exists for the definition and development of new or modified alarm communication methods.
- False alarms are a key problem with existing alarm systems because of the nondiscriminating features of sensors and poor human engineering of control systems.

Many of the sources referenced in the back of this document describe the crime of burglary in terms which enable statistical modeling to be performed. The results of this modeling are given in Chapter IV of this document and support the requirements described in Chapter V, establishing specific requirements for alarm systems in terms of cost, user versatility, false alarm rates, response requirements and expected apprehension rates of the criminal. Additional materials used for establishing the requirements and concepts were specifically obtained from authoritative sources such as The Alarm Industry Committee for Combating Crime, Commerce Business Daily responses, Military Counter-Intrusion Development Program data and policy sources, police crime files, Law Enforcement Assistance Administration (LEAA) funded study programs, FBI reports and various commercial marketing analysis reports.

B. Justification for Alarm Systems

A study of the crime of burglary was undertaken and described in Chapter III to decide whether or not any alarm system, low cost or otherwise, offered sufficient protection against burglary to justify development. The conclusions to be drawn from the resulting evidence is that alarm systems are not only highly effective in reducing the financial loss due to burglary, but that burglar alarms offer the only proven solution if a reduction in the amount of unreported crime and an increase in the offender arrest rate are desired. Also since burglary is now considered to be a career, a multiplying effect on the decrease in the burglary rate should be noticed with the increased arrest probability associated with a proliferation of alarm systems.

Of all the victims of burglary, it is the urban and suburban residents and small businesses who are most in need of some form of protection. Rural crime rates are increasing but not on the same scale. Residential offenses have been climbing fast, reaching 63% of the total with dollar losses multiplying at an alarming 17.7% each year for the past 12 years. Based simply on averaging the national statistics, the large city resident can expect a 10.8% probability of being burglarized within the year. Once again using the national averages, he can expect a loss of $315 from each attack. Unfortunately, only one-third of these crimes will ever be reported to the police and when they are, they are reported so late that only 8.2% of the crimes produce a guilty-as-charged verdict. Rural application of burglar alarm systems are not as effective because of the long response times of response agencies, lower probability of burglary, etc.

The lower income resident and small businessman have not been entirely negelected in the past by commercial alarm companies. However, because alarm systems have cost upwards of $1000 or more to install, because their designs have been so prone to error, and because the alarm users have been so careless in the use of the equipment, police in most instances must answer too many false alarms before catching a criminal. What is needed to satisfy police requirements is a simple system that will produce false alarms only about once a year. Given significant improvements in intrusion sensor design, human interface engineering, automatic error detection and communications technology, an improved burglar alarm system can be produced, and should result in correspondingly impressive improvements in deterrence and apprehension. However, any value for an acceptable cost and false alarm rate must be determined by the particular application.

An inspection of burglary statistics revealed several appealing possibilities as a result of using improved alarm systems; reporting rates should rise from 33% to about 76%, arrests should be at least double their current 17.8% figure, losses should drop from $315 to $35 on the national average and, if the results of the often discussed LEAA program in Cedar Rapids are any indication, court costs should drop considerably because almost all offenders will plead guilty as a result of the on-the-scene arrests.

C. Analysis of System Types

Baseline requirements for a Mean Time Between False Alarms (MTBFA) and alarm system costs are generated in Chapter IV and performance of three alarm system concepts are analyzed using mathematically sophisticated models newly developed at The Aerospace Corporation (though modified to retain uncomplicated structure). Conclusions were drawn from an application of the models to a typical urban scenario (New York Police Department Precinct 103) using widely recognized statistical data for that precinct's response characteristics and for national burglary profiles.

D. Requirements Definition

1. System requirements. Preliminary design requirements have been prescribed in Chapter VI of this document to deal with problems such as those associated with the user and police interface to the alarm control system. Methods for increasing the effectiveness of an alarm system and increasing the total number of installed alarms without overburdening the police or alarm service response companies yield analytical requirement defining Mean Time Between False Alarms (MTBFA). This study shows that a coverage ratio as high as 20% requires an MTBFA of six months for each installed system. This study further enables definition of the acceptable failure rates for specific alarm applications. As the MTBFA approaches a goal of 1.2 years, coverage

approaching 50% can be allowed while not substantially impacting levels of police manpower.

Using the 1972 national loss average of $315 per household about once every ten years, it is seen that an effective burglary deterrent such as an alarm system which lasts about five years should cost the average resident about $162 in order to just break even. Using this figure as a criteria enables a breakdown such as $25 for sensors, a $100 alarm control system and $37 installation components and alarm indicator costs as a practical goal to strive for. Suburban residents with higher probable losses might expect to pay somewhat higher amounts for more sophisticated systems. These same system requirements can be expected to also be valid for small business application.

The component parts of a total burglar alarm system addressed in this document are shown conceptually in Figure A.

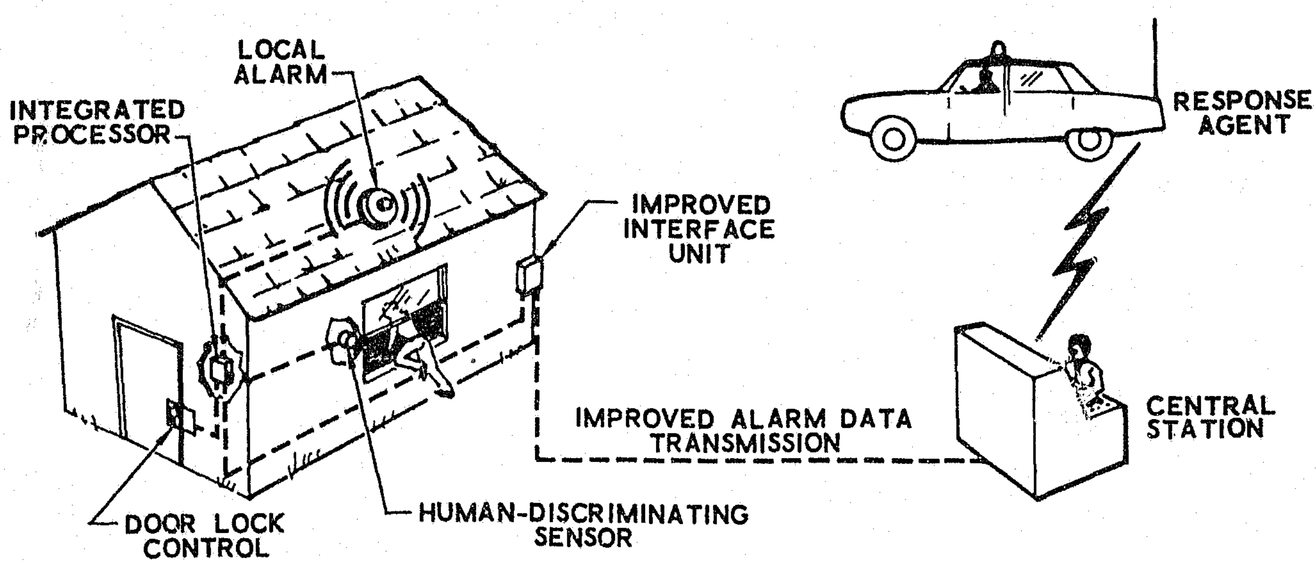


Figure A. Burglary Alarm System Concept

The sensor is a volumetric or restricted area type device which guards the inside of a room. It is coupled to the processor or alarm control system via an internal transmission medium such as power lines or special wiring, as is the case with the entrance controller and the local warning and alarm. The processor monitors the transmission medium and performs the functions of timing, control logic, as well as transmitting and receiving data. It receives information from the entrance controller and turns on a local alarm. At an added cost, the controller can transmit a signal to a central station to summon help. The external interface adapts the processor signals to the particular external transmission medium selected, whether it be phone line, power line, interactive TV or RF system. The central station displays the processor data at some remote location such as an alarm company or police station, and provides limited control of the security alarm system by means of polling, timing and verification of the transmitted data. However, the requirements for a low cost and reliable transmission media for alarm data necessitates a broad review of the total communication technology with possible development or utilization of a new method directed towards the civil sector. A study concluded by GTE-Sylvania [5-3] revealed the type of characterization data necessary to fully utilize internal residential power wiring as an alarm data medium. Transmission requirements beyond the residence support a continued assessment of the power line approach, along with other approaches such as two-way TV, special telephone line systems, and RF systems. Sufficient data must be accumulated to accomplish tradeoff studies involving cost and technical requirements for near and far term alarm transmission solutions.

E. Recommended Developments

System concepts are defined in Chapter VI which include hardware components, functional interfaces, and recommendations for necessary transmission studies. These concepts are based upon the system analysis, the user, alarm company objectives and police objectives in terms of cost, false alarm rates and response. The recommended concepts for development are:

- A human discriminating volumetric sensor
- A residential control system utilizing large scale integration chips providing arming logic, control and identification features at a low manufacturing cost, including provisions for an acceptable human interface with the system
- A transmission media review and tradeoff analysis pointing to the future development of new low cost and reliable methods of communicating alarm data
- Provisions for response control

F. System Concepts

Two primary measures of system performances (i. e., arrest probability and percent dollar savings) were used to evaluate three system reporting concepts (i.e., overt local audible, covert silent reporting, or combination). Only two systems were shown to provide police benefits via greatly improved arrest rates: the covert concept and a version of the combined system with a five-minute delay on the local alarm bell. The covert system should yield the highest police benefits; an 89 percent probability of arrest when considered from the viewpoint of those residents with an alarm system, and 53 percent aggregate probability from the viewpoint of the police serving all burglarized residents. All the systems investigated result in benefits to the residents in terms of percent dollar savings; over 88 percent savings of a resident's expected loss ($315 national average) is probable for any of the three concepts. These results all assume the minimum 0.5 year MTBFA and 20 percent coverage conditions apply and all burglaries that occur in residences covered by one of the alarm systems are reported.

CHAPTER I. INTRODUCTION

This document reports on a survey and concept definition of a cost effective burglar alarm system for low-income residential and small business applications. This system concept was conceived and studied by The Aerospace Corporation under a Law Enforcement Assistance Administration (LEAA) sponsored task administered by the Equipment Systems Improvement Program during fiscal year 1974. The alarm system concept is directed toward reducing the opportunities for successful burglary completion by developing low-cost but highly reliable alarm system components which substantially reduce the occurrence of false alarms and by developing transmission methods that undercut present high system costs.

The conceptual system, which is called the cost effective burglar alarm, is shown in Fig. 1-1. It relies on at least one simple sensor with the capability to discriminate between human motion and other potential alarm sources, a large scale integration (LSI) control system or processor with logic and timing to improve system reliability and operability, and an integrated door lock and alarm control to substantially reduce inadvertent user-caused false alarms. This system is capable of signaling the burglar's presence overtly via an audible local alarm, covertly via silent automatic reporting to a response agent, or by a combination of the two. The type of signaling capability is to be a user option, depending on cost considerations and an evaluation of the available transmission medium.

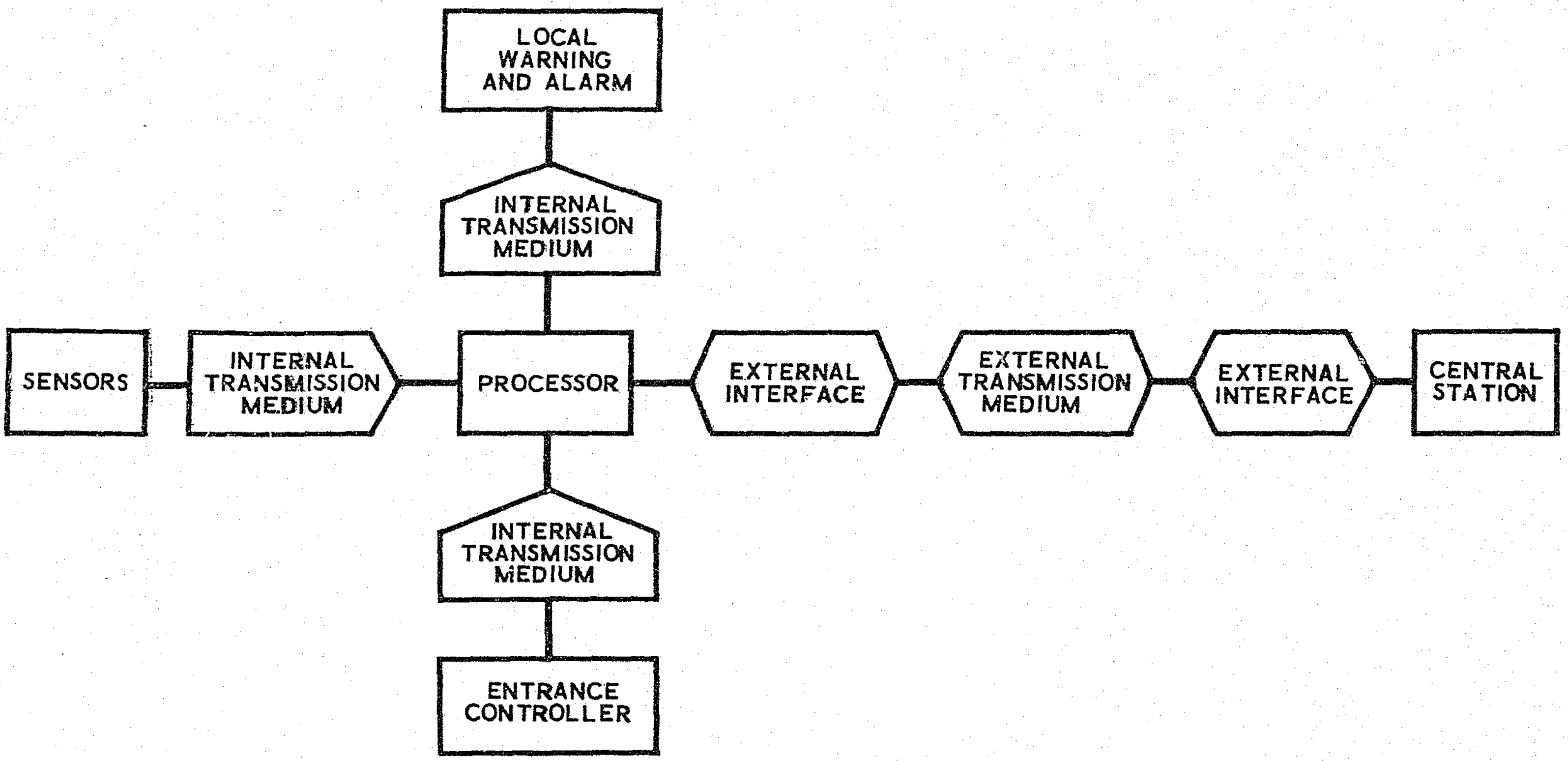


Figure 1-1. Conceptual Burglar Alarm System Configuration

The purpose of this report is to show the results of surveying the requirements for the cost effective burglar alarm system and to identify and discuss the conceptual development of particular system elements. These results are an outgrowth of a survey of present approaches and statistics, coordination with the alarm industry and with ongoing LEAA activities, analytical findings, and the reaction of many public officials to the alarm system concepts. The scope of the system application covers the crime of burglary in (primarily) low-income residential areas, with some application to small businesses.

A. Report Format

The survey of the burglary problem and the identification of specific development concepts are addressed in the technical chapters of this report, which follow the major technical conclusions (Chapter II). These chapters and their purposes are:

Chapter III	To review available data on burglary and determine what potential exists for making an impact on the burglary problem in the near future
Chapter IV	To analyze three types of burglar alarm systems to determine their impact on police workload, arrest probabilities, and savings
Chapter V	To report on state-of-the-art hardware surveys, identify deficiencies, and select promising technological solutions
Chapter VI	To present development concepts in terms of specific hardware and studies

The material in these chapters is supported by appendixes containing detailed information in the areas of internal and external power line characterizations, response/queuing model derivation, and body influence effects for detector development.

B. Concept Definition Background

Great concern has been expressed at the highest government levels about the ever-increasing burglary rate. The basis of such concerns and The Aerospace Corporation's approach to LEAA to alleviate them are discussed below.

1. General considerations. Burglary remains the fastest growing crime nationally, and it is a costly crime, averaging nationally about $315 per burglary in 1972. No panacea presently exists, and the outlook is doubly handicapped by current high alarm system costs coupled with high false alarm rates.

These high costs and high false alarm rates constitute a major problem area. Systems of reasonable quality reportedly cost $400 to $1000 for residential installations and $500 to $3000 for small businesses. Monthly service or rental charges reportedly range from $15 to $50. The percentage of false alarms currently runs between 90 and 97%.

The review of past and ongoing programs has uncovered pertinent findings. For example, burglary is a crime of opportunity that generally strikes unprotected targets, and the majority of burglars are minors, according to arrest data. In the Cedar Rapids, Iowa [3-11] alarm system study, it was found that:

- Displayed business alarm systems served as a deterrent
- Rapid response caused increased clearance rates
- Lower dollar losses occurred

Also, Sylvania [3-17], in its evaluation of small business and residential alarm systems, recommended development of three equipment items:

- A secure deadbolt lock with an integrated shunt switch for reliably arming and disarming the alarm system
- An alarm control that provides maximum system flexibility with minimum user interface requirements
- A low-cost power line transmission system for sending communications from individual sensors to the control system

Coordination with the alarm industry has increased Aerospace understanding of the industry's current emphasis and has resulted in recommendations pertaining to equipment development and studies. The Alarm Industry Committee for Combating Crime (AICCC), in response to a formal Aerospace request, recommended development in several technological areas, including the study of transmission systems and the development of a human-discriminating sensor Primarily the alarm industry supplies equipment, installation and monitoring services for commercial property protection; a small fraction of the effort is on protection of individual residences. However, up until perhaps very recently, the supply of alarm goods and services has not been directed toward protection of ghetto residences, where the highest burglary incidence is taking place. (It should be understood that the market for these goods and services has not been substantiated).

The industrial mobilization role has also borne fruits of technological advance. Sylvania, under subcontract to Aerospace, performed two noteworthy steps. One was to develop a preliminary version of a passively tuned alarm communication link via existing house wiring; the second was to perform an initial characterization of residential wiring in terms of a transmission line. Aerospace also surveyed the industry's current alarm system capability via a Commerce Business Daily announcement seeking R&D sources for alarm system development and feasibility demonstration (Chapter V), as well as by first-hand discussions with many alarm companies and equipment distributers.

2. Anti-burglary weapons tradeoffs. Aerospace emphasis on developing burglar alarm system technology derives from a consideration of available anti-burglary weapons. These weapons can be grouped into four main categories, according to the method of protection provided. These categories, described by actor Henry Fonda as "The Four Ds" in the industrial film "Rip-Off"[1-1] employ the following techniques against the would be burglar: Deter, Defend, Detect and Delay. Any one (or more) of these methods can be used, but maximum protection results when all four are employed.

The first D (Deter) involves presenting the offender with an obviously well protected structure that appears difficult to burglarize. The use of floodlights on potential entrances, bars and screens on doors and windows, and notices warning of an alarm system can all deter the burglar from attempting an attack. It is also recognized that sociological factors must be considered in any overall strategy of deterrence. However, the factors are difficult to define and even more difficult to evaluate in terms of resultant criminal behavior. The development of effective means of controlling or modifying sociological factors for the reduction of burglary is considered a long range solution. The present trends in burglary rates require that the methods be initiated which have a potential for more immediate impact.

The second D (Defend) involves installing solid doors, burglar-proof locks and armored glass, making it more difficult for the burglar to effect entry.

Burglar alarm systems are used in the third D to Detect the criminal and then signal for police protection or frighten him off with a loud alarm bell.

The fourth D (Delay) involves an attempt to slow the burglar once he is inside by using safes to store valuables or by bolting costly items down so they are difficult and time consuming to remove. This also would give the police more time to respond to an alarm call.

The system concept envisioned for residences dictates against relying on Deterrence, Defense, and Delay in reducing burglary. The use of steel doors and barred windows in the home is both expensive and psychologically oppressive and it is difficult to evaluate the true effectiveness of these measures. Hardening the many low-strength wood and glass doors and windows in the average residence would be difficult, although feasible if done during construction or with some of the hardware appearing on the market. The idea of bolting down valuables is generally incompatible with protecting the TV sets, stereos, and miscellaneous items so often taken in residential burglaries. In summary then, the use of moderate deterrent and defense measures along with the use of an inexpensive and reliable alarm system for Detection offers the best hope for residential security. Therefore, the main thrust of the recommended anti-burglary developments is toward Detection.

CHAPTER II. MAJOR TECHNICAL CONCLUSIONS

Three specific areas have been identified and are recommended for further development:

- A low-cost volumetric sensor system to indicate human intrusion into a residence
- An inexpensive means of transmitting alarm data within a residence and to a response agency
- An integrated control system, adaptable to overt or covert application, with a low incidence of false alarms due to user interface, system failure, or inadvertent activation

These developments are primarily intended for low-income residential applications, with some overlap to small business applications. Primary considerations in each development area are low cost and low false alarm rates. All three, if successful, will represent a major technological breakthrough in the war against burglary.

In this chapter, key conclusions that were drawn throughout the report and that support the above recommendations are presented. Some general survey results are first presented; these are followed by highlights of each chapter of the report.

A. General Survey Results

From a review of existing, prototype, and conceptual burglar alarm system designs, it is concluded that the alarm industry has not taken advantage of advancements in the overall technical community and that few systems are being offered for the benefit of the low-income resident in the high-crime area. It is unlikely that many alarm businesses consider this market to offer an adequate opportunity for profit although several are cognizant of a market potential and have recently expended some R&D money toward meeting this need. However, the industry has not solved the human interface and false alarm problem at any level, as evidenced by an over 90% false alarm rate (the majority of these caused by the user). This summary highlights the problem areas that have been found to exist as a result of a limited survey. To overcome these problems, a coordinated hardware development effort is recommended and described herein. This effort should result in state-of-the-art hardware designs that could alleviate most of the difficulties described within a resonable period of time.

The technology does exist within the state-of-the-art for the design of low-cost alarm components and control systems, and this technology can be applied to help resolve the false alarm and high cost problems.

Alarm companies depend almost exclusively on telephone lines for communicating alarm data to their remote stations. This limitation has dictated design restrictions that have not changed basically in 40 years. Almost all communications systems in operation depend on the phone company to provide and maintain the communications medium. Advancements in communications technology since World War II have not generally been applied to the alarm industry. Even the recent knowledge of an impending shortage of phone lines has resulted in only isolated attempts to perform long-range planning. One such attempt is the establishment of an Alarm Facilities Committee by Bell Telephone.

Major growth of multiunit apartment complex communities is now taking place throughout the nation, and interest in protective security systems has been stimulated due to the national burglary problem. However, little planning and development for this growth in terms of equipment and communications techniques has taken place. Fractionated efforts are resulting in a proliferation of alarm systems with little commonality, different principles of operation and as yet untested effectiveness.

Single volumetric sensors afford the greatest potential for inexpensively accomplishing intrusion detection by aleviating the need for individual door, window, vibration, or breakage-indicating sensors. The alarm industry has developed a few new types of sensors which in general meet commercial needs, but these are expensive and most are highly susceptible to false alarms. Few, past developments offer the potential for discriminating between human intrusion and other man-made or natural causes. In general, the alarm industry has not until recently directed substantial resources to this problem since most of the commercial customer's needs have been identified with presently available techniques and components. The application of new, innovative conceptual techniques to volumetric sensor design should aid in simplifying alarm systems and in reducing false alarms.

The LEAA design objective, which is directed toward providing good alarm equipment for the low-income resident, necessitates government funding of the high technical risk and costly development items, which the alarm industry is naturally hesitant to undertake. The application of new technology should provide end-item equipment that can be used by residents and alarm companies for assembling systems that meet the needs described above.

B. Highlights

The analysis and system concepts for a low cost burglar alarm system is addressed in this report in four basic areas:

- Need for a burglar alarm system
- Analysis of system types
- Requirements development
- Development concepts

The major technical conclusions for each area follow.

1. <u>Need for a burglar alarm system: conclusions</u>. The study results of Chapter III show that burglary is indeed a very serious problem and that residential burglary is the particular category most in need of immediate attention. A 12.5% average annual increase in residential offenses and a 17.7% increase in dollar loss as illustrated in Chapter III, Figures 3-4 and 3-6, motivates this recommendation. However, while the data shows a marked trend toward a larger percentage of residential offenses, it can also be shown from the Uniform Crime Reports that the nonresidential burglary rate remains seriously high. Therefore any development work must consider both the residential and the business class of targets.

The use of burglar alarms is the only method known to provide the rapid and thorough burglary reporting required to improve police effectiveness. This was illustrated in the Cedar Rapids, Iowa, study: In cases where intrusions were detected, 88% suffered zero loss, and the average loss for the remainder was \$35, compared to a national average of \$315. Furthermore, every offender captured in Cedar Rapids during the past year pleaded guilty to the charge, resulting in a marked reduction in court costs for the city.

Police currently respond to upwards of 49 false alarm calls for each true call received. False alarms are the most serious obstacle to the widespread use of burglar alarms. The Mean Time Between False Alarms (MTBFA) of many systems is two to three months in many cases, a value which must be raised to about once every 0.5 year to be acceptable to police.

2. <u>Analysis of alarm system types: conclusions</u>. In Chapter IV, three alarm system types (overt, covert, and combined) are analyzed by means of newly derived queuing models to determine their impact on police workload, arrest probability, savings to the resident, and potential alarm system cost. The analysis defines specific response, savings, cost, and utilization models for these parameters and applies them to a typical urban scenario, New York Police Dept. Precinct 103.

The models developed are simple in form but are based on multiserver queuing theory (several responders available) and on national statistics on burglars and burglary rates. Model inputs are MTBFA, residential coverage, and the burglary statistics. Outputs are probability of early police arrival, aggregate probability of arrest, percent dollar savings, probable alarms system costs, and police utilization.

There are several significant numerical results. An MTBFA of more than 0.5 year is needed if the residential coverage does not exceed 20%. This set of values should be used as an initial implementation requirement until the MTBFA of the system is improved to one year, which would allow 50% coverage while maintaining equivalent police effort.

Two primary measures of system performance were used: arrest probability and percent dollar savings. The covert, or silent, reporting system yields the highest probability of arrest benefits (89%) from the viewpoints of a resident covered by an alarm system and aggregate benefits for 50% coverage of 53%. Percent dollar savings to the resident are similar for all three systems investigated (all are over 88%).

Two additional parameters of importance were determined from the analysis. A baseline system cost requirement is established to be $162, including installation, based on the national average dollar losses from burglary. However, this must be considered only as an average, and a measure of adjustment must be developed to account for distributions above the average. An upper limit for police utilization of 0.40 (40%), regardless of coverage, has been assumed in the calculations.

3. <u>Requirements and development concepts: conclusions.</u> Chapters V and VI of this document address specific technical requirements and present concepts for equipment development and studies in

several areas. The first is for the development of a new low-cost volumetric sensor with human discrimination capability. The second is for the design and test of one or more unique alarm control system large scale integration (LSI) chips that can ultimately be purchased by an equipment manufacturer at a low cost yet provide false alarm reduction features found only in expensive systems. A third, yet equally important, effort is for the study of current and evolving communications techniques applicable to transmitting alarm data from the resident to a response agency. This study is needed to highlight new low-cost concepts to meet the needs of the alarm industry now and through the 1980s.

CHAPTER III. SURVEY ON BURGLARY AND THE NEED FOR A BURGLAR ALARM SYSTEM

The purpose of this chapter is to review the available data on burglary and determine what, if any, potential exists for making a significant cost-effective impact on this problem in the near future. The results of the study will show that burglary is indeed a very serious problem and that residential and small business burglaries are the particular categories most in need of immediate attention. It will be demonstrated that the widespread use of improved and cost-effective burglar alarms will better enable current police manpower to deal effectively with the problem.

This chapter contains four major parts. The first deals with offense statistics and the associated financial loss. It is here that the recommendation for stressing the residential problem is developed. The second reviews burglary as it affects the police; it is concluded that alarm systems offer a demonstrated capability of dealing with the problem. The third stresses the main consideration that must be dealt with in designing an alarm system (false alarm frequency). The fourth reviews the characteristics of the offender, which are needed to analyze the effectivity of various alarm system concepts. A brief review of the significant points developed in these four parts is included at the end of the chapter.

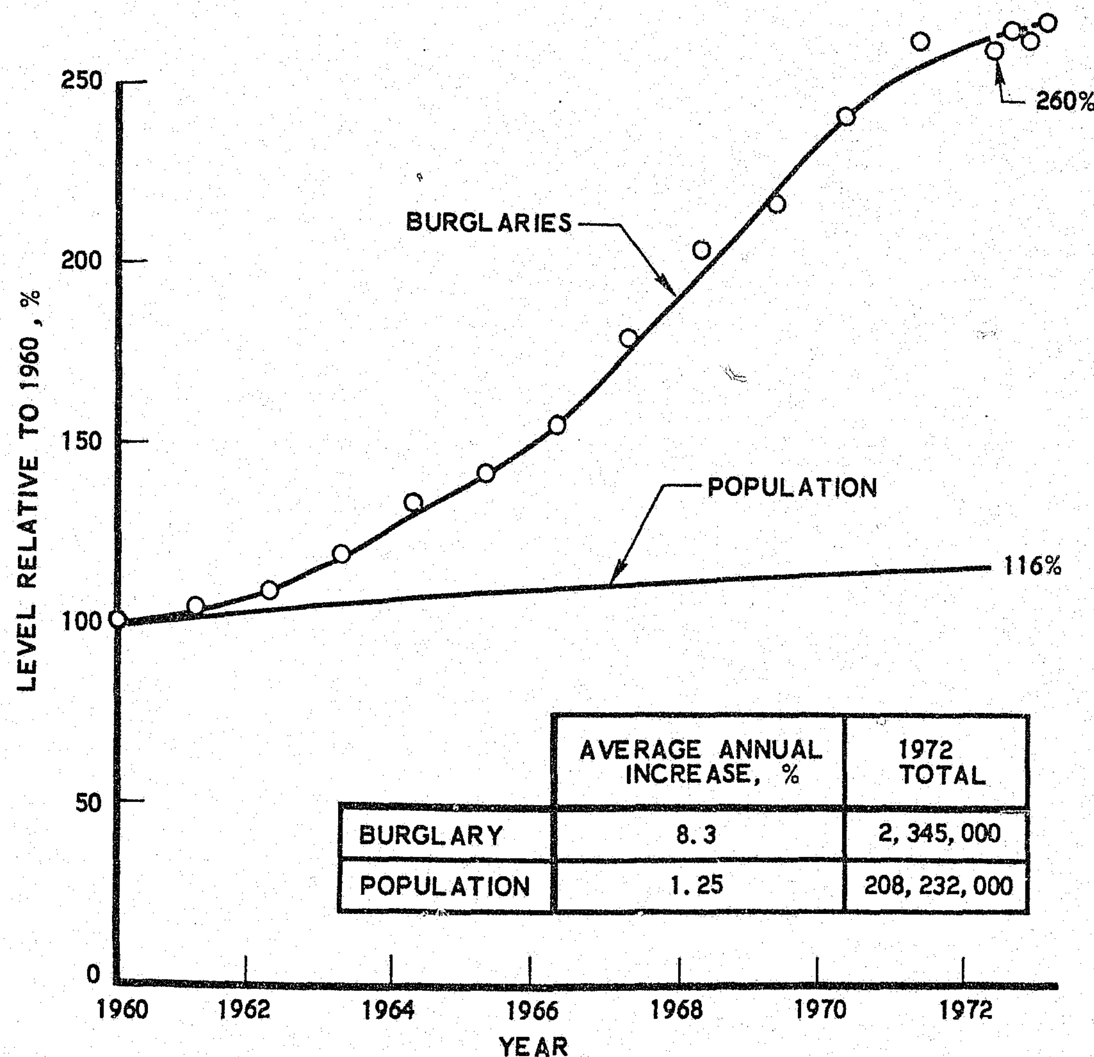
A. The Crime of Burglary

The statistics on the crime of burglary provide the principal inducement for the development of a reliable, low-cost burglar alarm. The following discussion reviews the extent of the burglary problem within the

United States and, in so doing, concludes that the primary emphasis of the alarm development should preferentially be directed toward protecting the urban residence. An estimate of the probability of a burglary attack against this urban residential target is also developed, both for use in the analysis (Chapter IV) and also to substantiate the opinion that residential burglary is a problem of serious and growing magnitude.

1. National burglary trends. The number of burglaries occurring each year in the United States is growing at a rate far in excess of the population. Figure 3-1 illustrates this trend, with the number of reported burglaries relative to the 1960 level. A plot of the increase in the national population has been included for comparison. The data demonstrates that burglary has steadily increased in each of the 12 years considered, until in 1972 the number of reported offenses had risen to over 260% of that experienced in 1960. The preliminary data for the first nine months of 1973 indicates that this trend is still continuing. When averaged over the 12-year period, total burglary has increased 8.3% annually, as compared with the 1.25% annual increase in population. This suggests that the average American is 2-1/4 times more likely to be victimized by burglary in 1972 than he was in 1960.

The concern about burglary cannot be justified solely on the basis of percentage increases. A crime directed against property, as is the case with burglary, seldom results in a threat to the life of the victim. Thus, even large percentage increases in a low-volume property crime may not



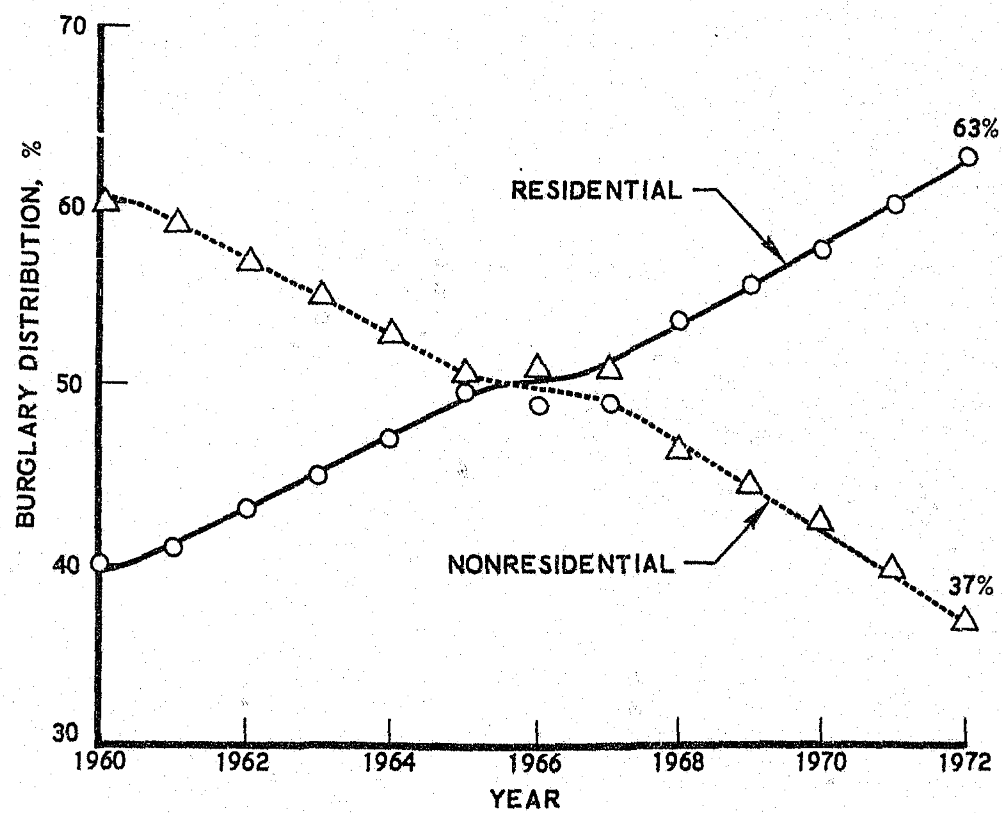
	AVERAGE ANNUAL INCREASE, %	1972 TOTAL
BURGLARY	8.3	2,345,000
POPULATION	1.25	208,232,000

Reference: 1972 Uniform Crime Report (p. 61) and 1973 Preliminaries

Figure 3-1. Burglary Since 1960

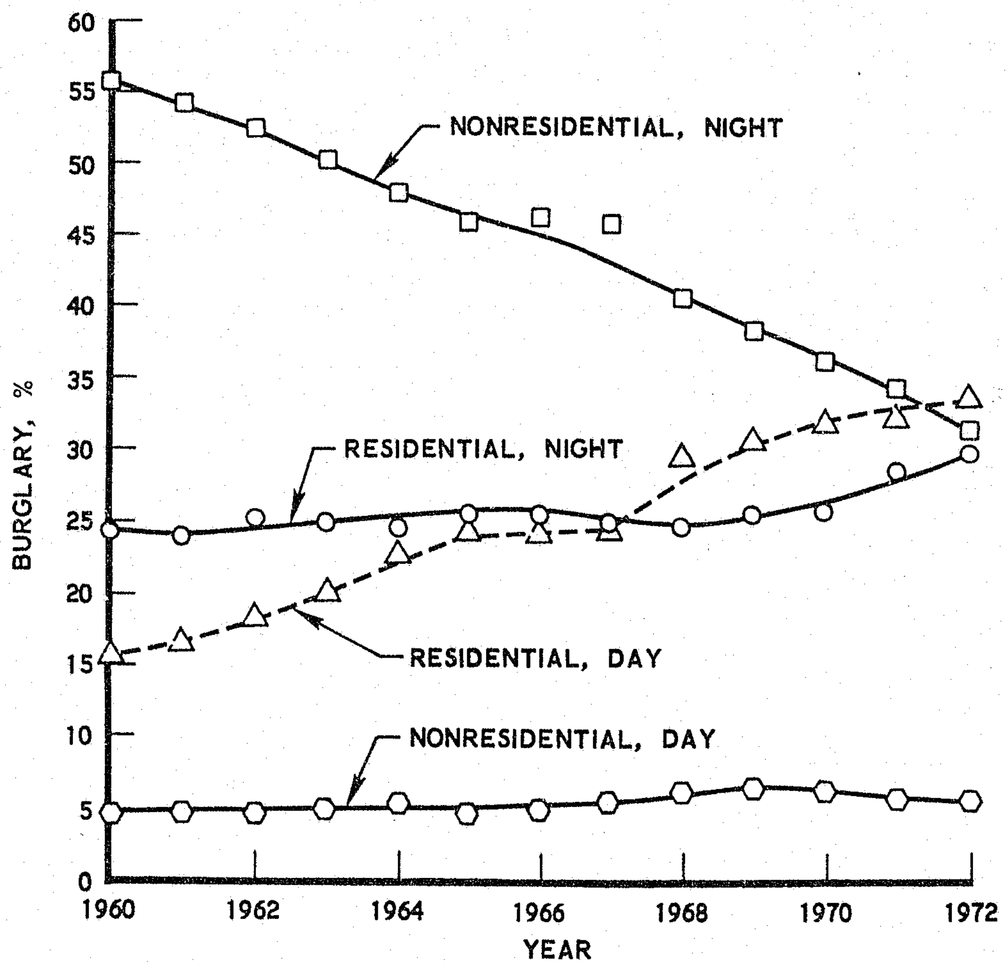
necessarily cause serious concern. Unfortunately, burglary is far from being a low-volume crime. In fact, since 1960, burglary has consistently accounted for from 39 to 45% of all the crime reported in the Uniform Crime Report compiled each year by the Federal Bureau of Investigation. By 1972, a total of 2,345,000 burglaries were being reported annually, or a rate of one report every 13 seconds. Burglary now represents the largest single source of crime in the United States. Thus, concern about burglary is founded upon two factors: the rapidly increasing rate of the crime of burglary and the impact of the sheer number of offenses involved.

2. Residential and nonresidential burglary. The offense of burglary is categorized as either residential or nonresidential in the Uniform Crime Reports, and that distinction will be used here. In reviewing the recent history of these two types of burglary, a tendency toward residential offenses becomes apparent. The percentage of residential and nonresidential burglary over the last 12 years has been plotted in Figure 3-2. The consistent increase in residential attacks has resulted in a gain of from 40% of all burglary in 1960 to 63% in 1972, which is the latest year for which complete data is available. Thus, the character of burglary has been undergoing a fundamental change, a change which is perhaps made more obvious when the relative proportions of daytime and nighttime burglary is considered (Figure 3-3). The marked trend is away from nighttime business burglary with an increasing rate in residential attacks during the day. In summary,



Reference: 1960 - 1972 Annual Uniform Crime Reports (Tables on "Offense Analysis")

Figure 3-2. Residential/Nonresidential Burglary Trend: Relative Distribution

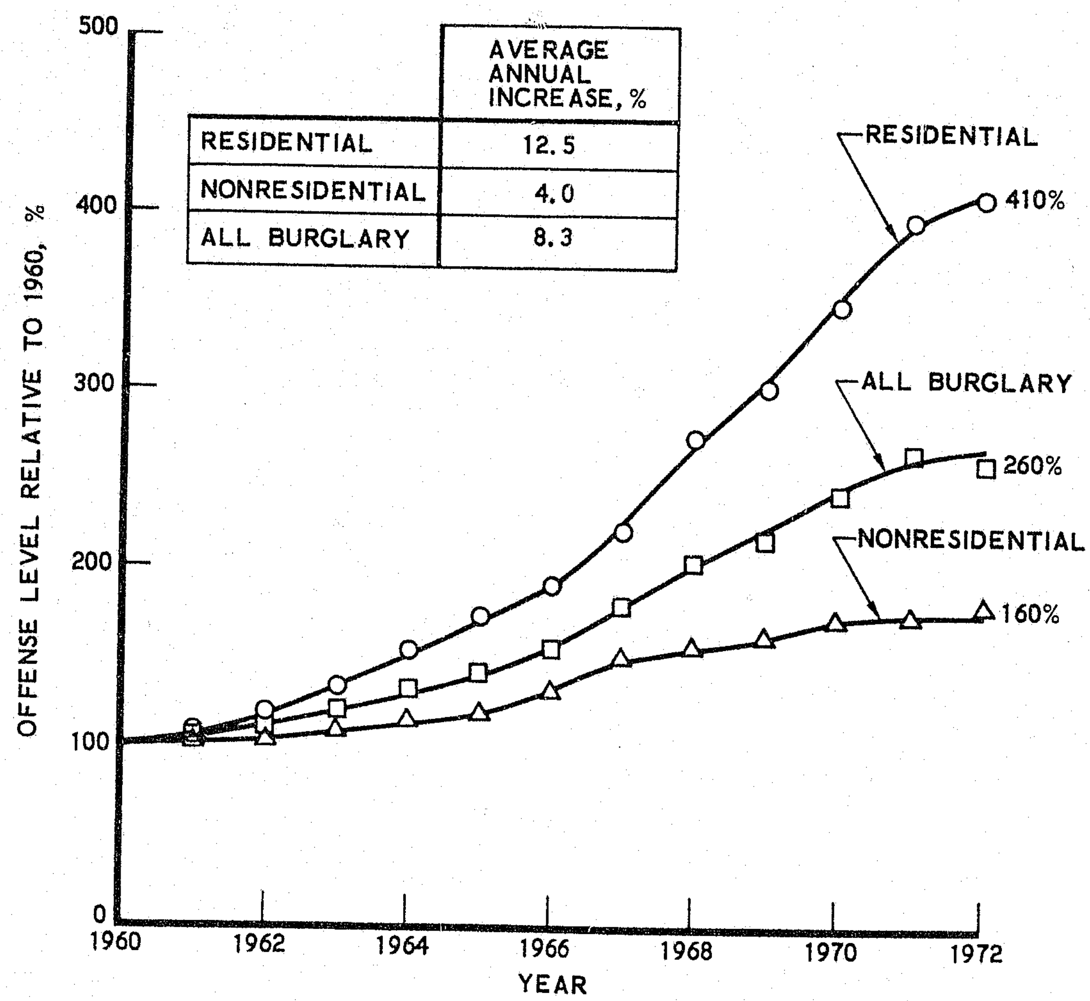


Reference : 1960 - 1972 Annual Uniform Crime Reports (Tables on "Offense Analysis")

Figure 3-3. Trends in Day and Night Residential and Nonresidential Burglary then, the burglar is becoming increasingly aware of the "soft" nature of the residential target, particularly during the day when the residents are away at work. The relatively low coverage by police patrols in residential neighborhoods and the almost complete nonexistence of residential burglar alarms contributes to the impunity with which the average residence is attacked. In fact, impunity may not be a sufficiently forceful description. Harry Scarr, in Patterns of Burglary, 2nd edition, states that many burglars don't just burglarize and get out, they "stop and fix themselves a sandwich."

The effect of the changing complexion of burglary can be demonstrated rather vividly if the comparison is made for residential and nonresidential offenses separately. Figure 3-4 illustrates the trends for these two categories of offenses (the overall burglary trend from Figure 3-1 has been added for comparison). Figure 3-4 represents the combined effect of the data from Figures 3-1 and 3-2. Thus, nonresidential offenses have risen far less than the average, to 160% of the 1960 level for an average annual increase of 4% as compared with 260% or 8.3% annually for the aggregate burglary figures. Total residential attacks are up markedly from the average, however, rising 12.5% annually to 410% of the 1960 level. Based solely on the quantitative increases, there is considerable strength to the argument that residential burglary is the area of most immediate concern.

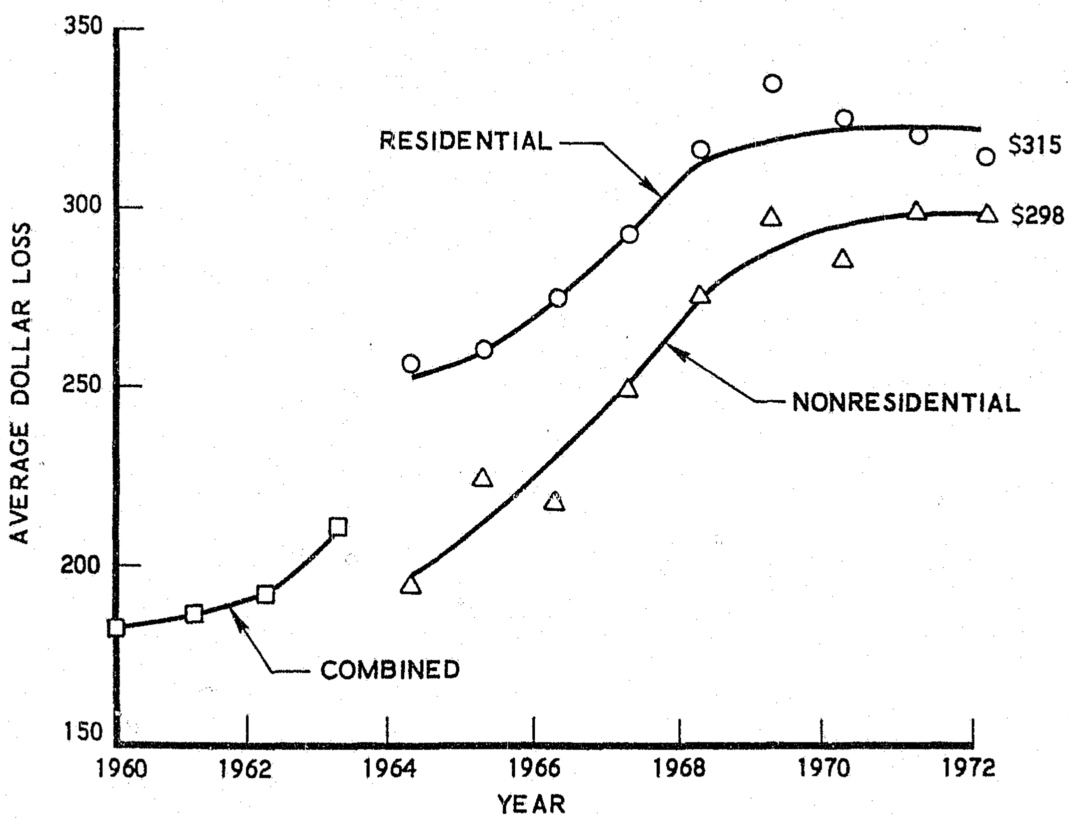
3. Financial loss due to burglary. The criterion used above for evaluating that segment which would benefit most from new alarm system development was based strictly on the relative volume of offenses, but perhaps an even more appropriate consideration would be the dollar loss associated



References: Figs. 3 - 1 and 3 - 2

Figure 3-4. Residential/Nonresidential Burglary Trends with residential and nonresidential attacks, since the cost of any alarm system must ultimately be weighed against the anticipated dollar savings resulting from use of that alarm. As Figure 3-5 illustrates, burglary losses for both residential and nonresidential categories have consistently risen over the 12-year period (dollar loss was not given for each category separately until 1964). However, residential burglaries have historically resulted in a greater dollar loss per offense than has burglary directed against businesses. The latest data for 1972 indicates an average loss of $315 and $298, respectively, for residential and nonresidential attacks. This represents an average annual increase of over 4.6% for residential loss, as comparied with only a 2.9% rise in the consumer price index over the same period. [3-1] Thus, not only will the average citizen in 1972 be 2-1/4 times more likely to be burglarized than in 1960, his average loss will be 72% higher.

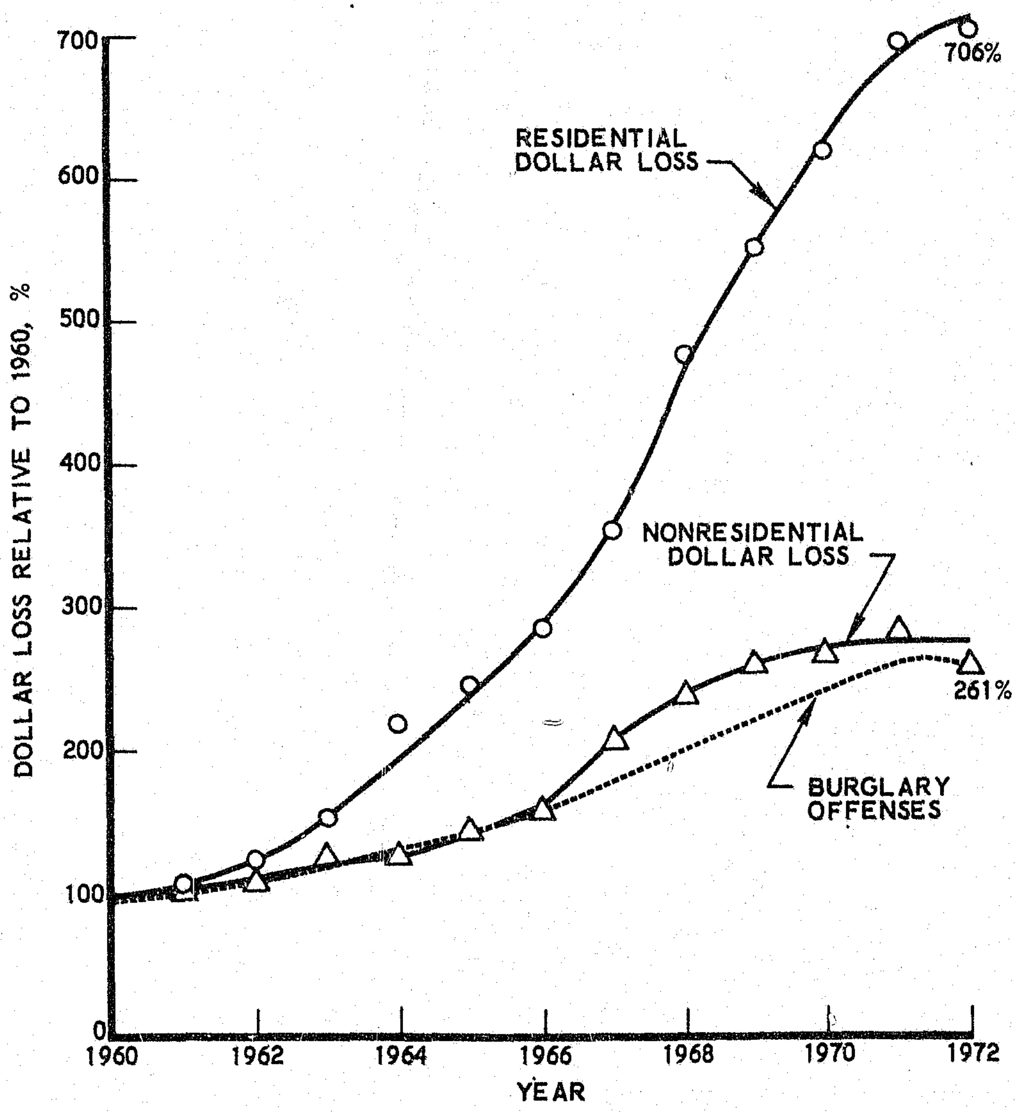
The total effect of the rising burglary rates (Figure 3-1), together with the increase in residential attacks (Figure 3-2), and the higher residential losses (Figure 3-5), have been combined in Figure 3-6 to show the relative financial impact of residential and nonresidential burglaries. Again, the increase in the aggregate number of burglary offenses has been carried over from Figure 3-1 for comparison. The nonresidential dollar loss has increased in a manner remarkably similar to the trend for total offenses (Figure 3-4). However, the rate at which the residential dollar losses have climbed over the past 12 years has to be considered awesome. The 1972 dollar loss of $465,000,000 was 706% of that in 1960, or an average annual



References: 1960 - 1972 Annual Uniform Crime Reports

Figure 3-5. Average Dollar Loss per Burglary Trends

	AVERAGE ANNUAL INCREASE, %	1972 LOSS
RESIDENTIAL LOSS	17.7	$465,000,000
NONRESIDENTIAL LOSS	8.3	$258,000,000
BURGLARY OFFENSES	8.3	-

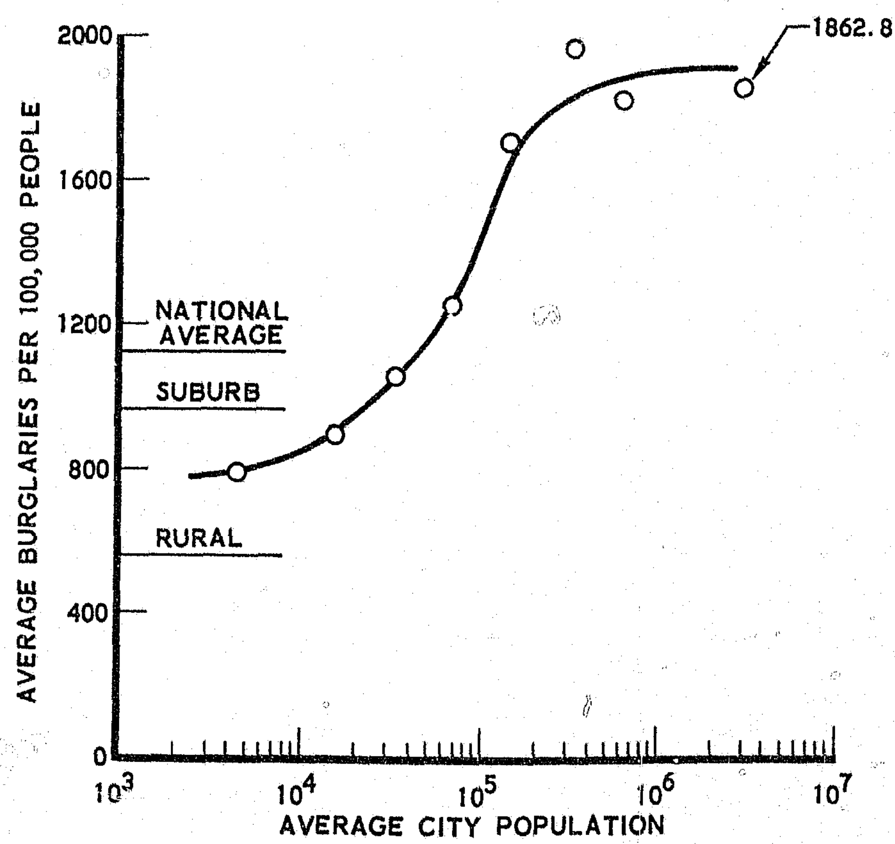


References: Figs. 3-4 and 3-5

Figure 3-6. Residential/Nonresidential Dollar Loss Trends increase amounting to a staggering 17.7%. Thus, this dollar loss criteria provides the most powerful motivation for recommending that immediate attention be directed toward alleviating the residential burglary problem. The direct results of this attention should also benefit the small businessman who suffers the brunt of the nonresidential offenses.

4. Burglary versus city size. Particularly hard-hit by burglary are those residents living in the larger cities of the United States, according to the Uniform Crime Report figures (Figure 3-7). There are areas within each city where the rate is much higher than average. The conclusion drawn here is that the initial alarm development effort should be directed toward application in a large city environment. This decision should also benefit from two other considerations: The population density is higher in the large cities, which shortens average police travel distances and thus the time needed to respond to the alarm and apprehend the burglar, and the number of police per capita is also higher in the larger cities (3.3/1000 population for cities over 250,000 versus 1.8-2.2/1000 for smaller cities, [3-2] which again illustrates the police resources that can be brought to bear on the burglary problem.

5. Estimated probability of urban residential burglary. The discussion above has dealt primarily with residential burglary on an aggregate basis, but another interesting approach (perhaps more easily related to) is to compute what the probability was that the average residence in a large American city was burglarized in 1972. However, before that estimate can be made, two important prerequisite assumptions must first be discussed:



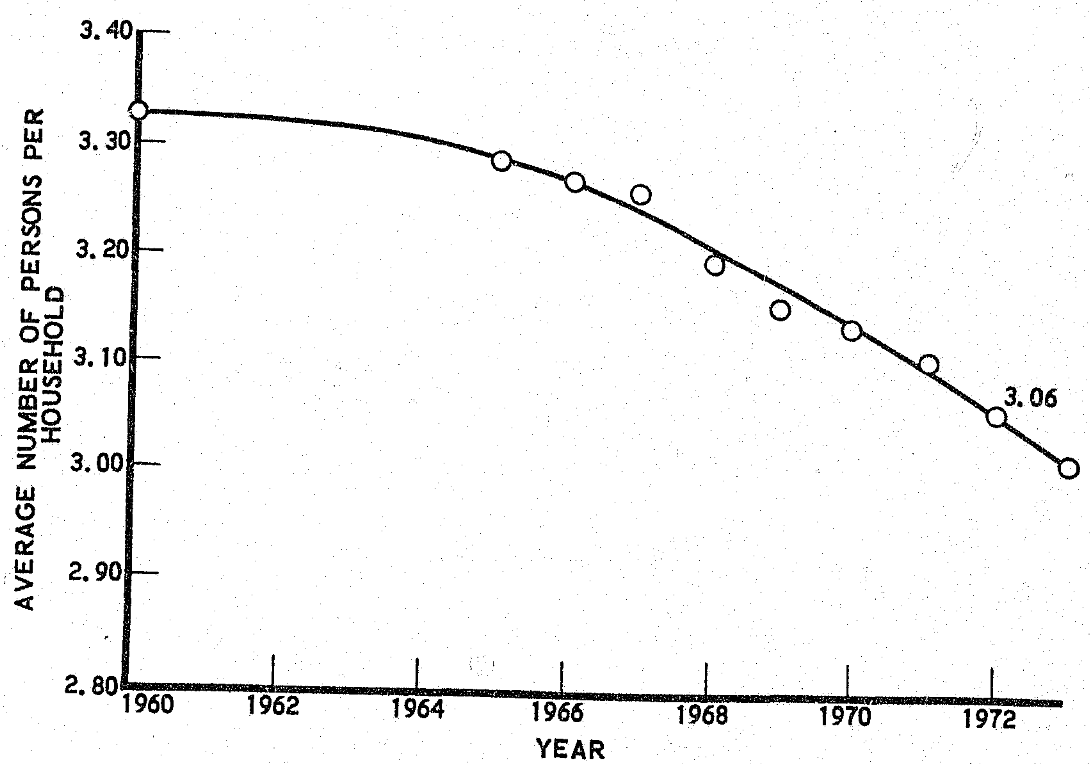
Reference: 1972 Uniform Crime Report (pp. 61 and 102)

Figure 3-7. Per Capita Burglary Versus City Size household population, and the rate of unreported burglaries. First, burglary is an assault on a residence, and not on the individual citizen. Therefore, it is not appropriate to continue discussing this crime on a per capita basis since it is the per household rate that is important in an alarm application (because the alarm protects the household). Statistics from the Bureau of the Census (Figure 3-8) show a declining average population per household, which is defined as all persons, related or unrelated, residing in common living quarters (house, apartment, or single room). For the year 1972, the figure was 3.06, and that value will be used here. Note that the United States is undergoing something of a "residence explosion." This phenomenon offers more potential targets to the criminal with each target having fewer occupants to watch over the residence. However, using the 1862.8/100,000 value from Figure 3-7 as typical of the large city and realizing that 63% of all burglaries are residential (from Figure 3-2), the probability of the urban residence reporting a burglary is:

$$\text{Average burglary reporting probability} = \frac{1862.8 \times 63\% \times 3.06}{100{,}000}$$

$$= 3.59\% \text{ per household}$$

The preceding calculation shows that 3.59% represents the average rate of reported burglary per residence. This differs considerably from the actual rate experienced since a large percentage of these crimes are never reported to the police. Estimates of the actual extent of unreported burglary vary widely. Specific examples show that actual burglaries occur at 1.7 times,[3-3] 3.2 times,[3-4] 3.8 times[3-6] the number of reports, and in one Boston area indicating a 54.2% burglary rate, 46 times[3-6] the number of reports. Unfortunately, the Uniform Crime Reports data could not be used

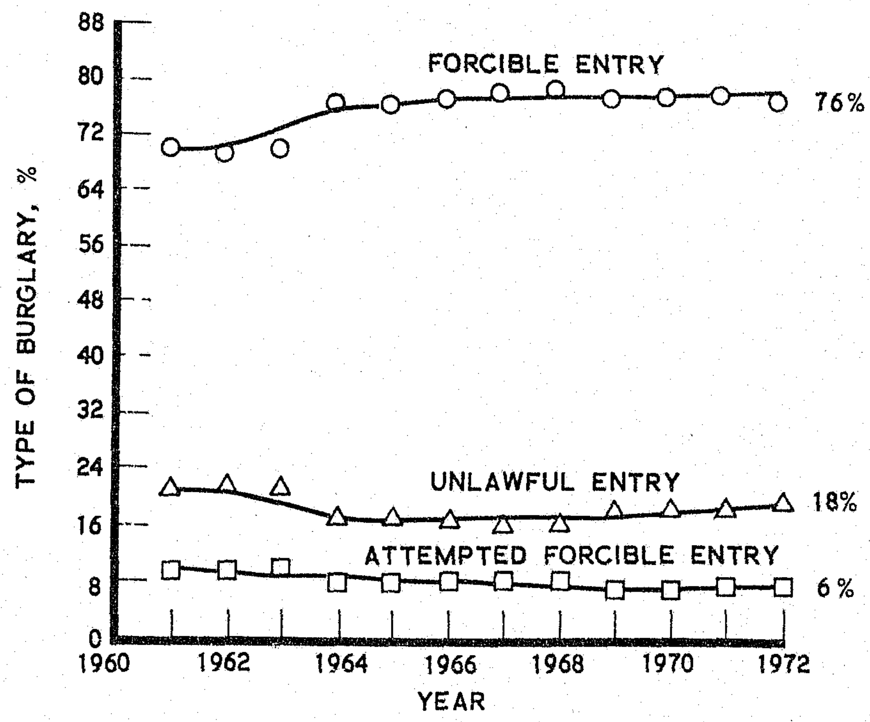


Reference: Population Characteristics, Series P-20, No. 251 (June 1973), U.S. Dept. of Commerce

Figure 3-8. Average Population per Household Trends since estimates of unreported crimes are not included. Given this high variability, it is difficult to accurately select the large city average desired, but a rate of 3 times the actual number of reports seems to be a conservative figure and will be used here. The estimated rate of actual burglary experienced by the urban household is then:

$$\text{Average urban burglary probability} = 3.59\% \times 3 = 10.8\% \text{ (experienced)}$$

6. Estimated frequency of urban residential alarms. The 10.8% figure represents the probability that a typical urban home will be subjected to burglary during any one year. However, this value is not equal to the probability that an alarm-equipped residence will sound the alarm. This is because the crime of burglary, as defined in the Uniform Crime Report and elsewhere, consists of three more specific offenses: Forcible Entry, in which deliberate force is used to gain access to the structure; Unlawful Entry, where the burglar simply enters (e.g., through an unlocked door); and Attempted Forcible Entry, in which (as the name implies) an unsuccessful effort is made to burglarize the structure. Since any alarm system must be deliberately armed before functioning, it will not be actuated where the residence is purposely or accidently left open. Also, since most alarm systems require actual intrusion into the structure before they are triggered they are not capable of detecting unsuccessful attempts. Figure 3-9 displays the relative percentage breakdown of these offenses over the past 12 years. The specific crime against which an alarm can defend is Forcible Entry and using the figure of 76%, the probability of a residence equipped with a perfect alarm system sounding that alarm sometime during the year is:



References: 1961 - 72 Annual Uniform Crime Reports (Tables and/or Text on "Crime Trends, Offenses Known Breakdown")

Figure 3-9. Trends in Forcible, Unlawful, and Attempted Forcible Entry

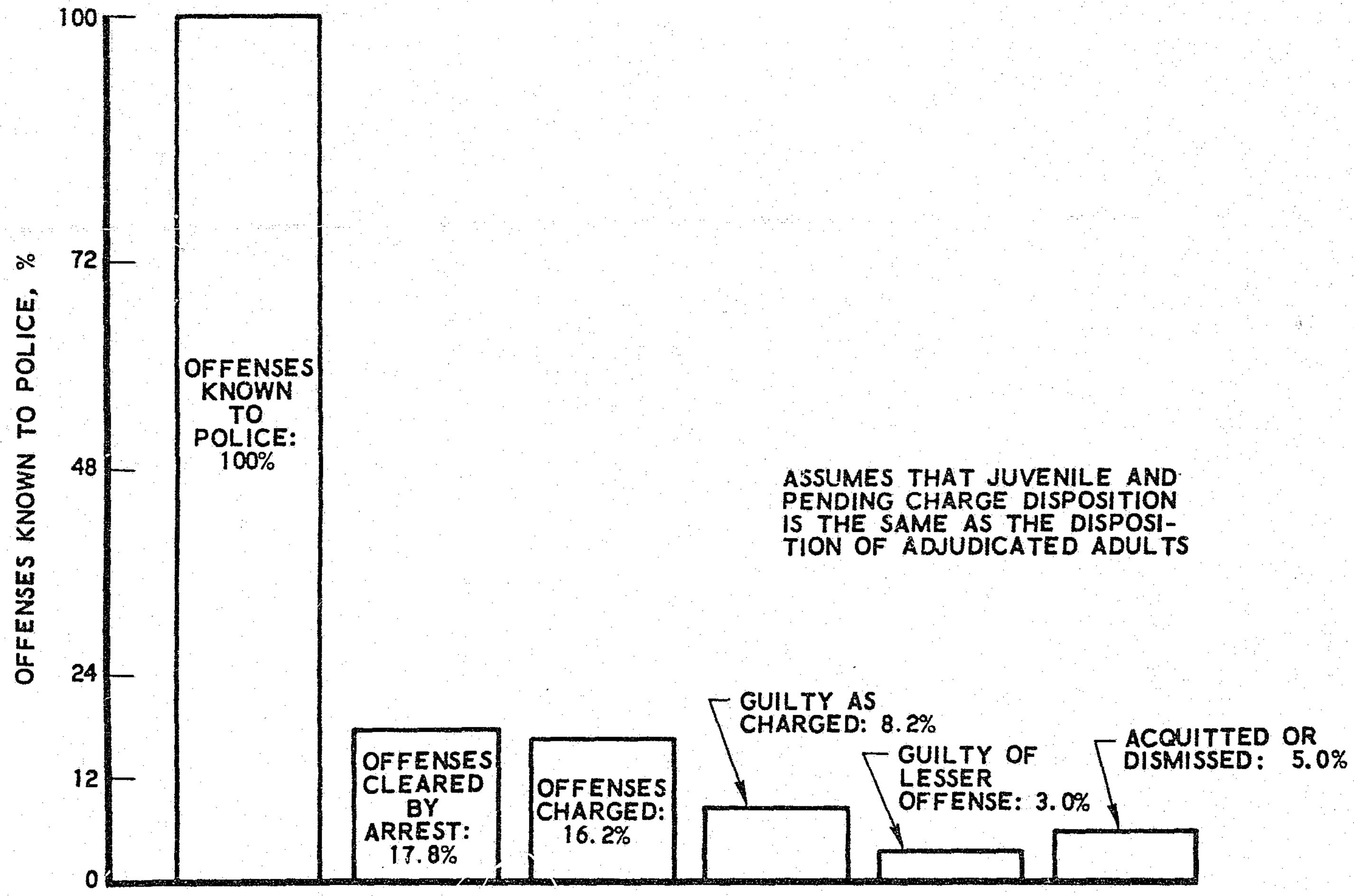
Probability of urban alarm sounding = 10.8% x 76% = 8.2%

7. Summary. In summary, burglary is the highest-volume crime in the United States, with 2,345,000 reported offenses in 1972. The volume of this crime is rising at a rate far in excess of the population increase, with a large percentage of that increase going toward residential attacks. More specifically, the dollar loss associated with nonresidential targets has increased at a rate of 8.3% annually over the past 12 years to $258,000,000, but residential burglaries have grown at a startling 17.7% per year over the same period, for a total loss of $465,000,000 in 1972. The conclusion to be drawn, based on national FBI statistics, is that the residential area is the segment toward which any burglar alarm development effort should be directed. The urban residential problem should be stressed in particular, since medium and large cities have roughly twice the small-city burglary rate. Considering that 63% of all burglary is now directed against residences with an average of 3.06 persons/household, and assuming there are roughly three offenses committed for each one reported, the probability of the large-city residence being burglarized in one year is 10.8%. Since only 76% of all burglary is classified as Forcible Entry (which is the category against which an alarm system will operate), the probability of receiving an alarm signal from this urban residence is now 8.2%. Considering that there are specific areas within each city where burglary rates are much higher than the averages used here, there would definitely appear to be a large and enthusiastic market for a cost-effective residential alarm.

B. Burglary and the Police

The crime of burglary presents the police with a very real problem, both because of the large number of offenses involved and also because its secretive nature makes it very difficult to combat. The purpose of this discussion is to review burglary as it relates to the police and to substantiate, insofar as is possible, the following contention: That the volume of burglary offenses, even though larger than any other crime, is of manageable proportions. However, significant improvement in police effectiveness against burglary can be made only if the "visibility" of the crime is increased. Widespread proliferation of alarm systems, provided that they are highly reliable systems, will dramatically improve this visibility.

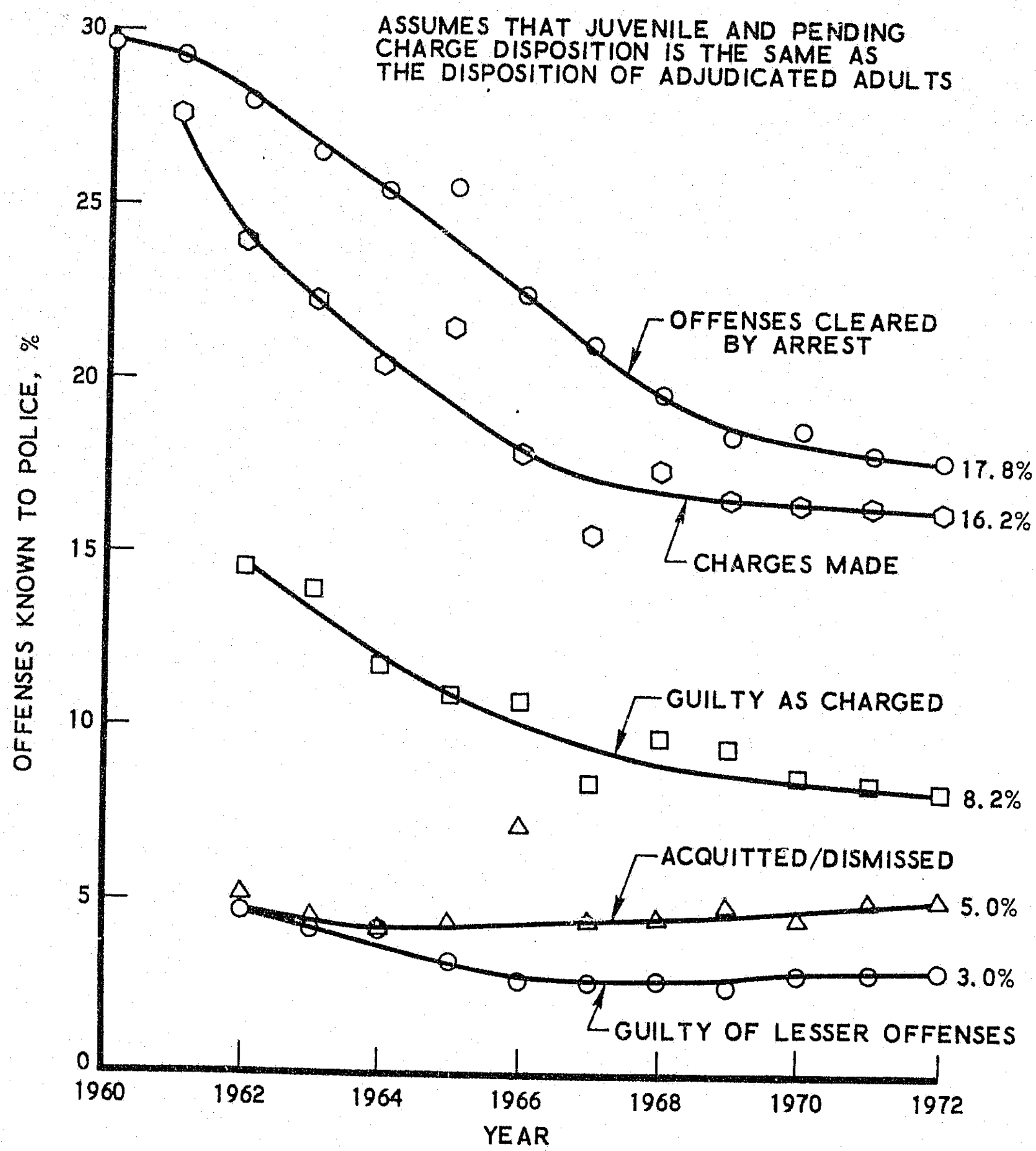
1. Probability of arrest and conviction. The primary objective of the burglar is assumed to be to commit a crime of zero visibility, and with such being the case, the police are left with very little opportunity to make an arrest at the scene and even less likelihood of apprehension based on residual evidence or witness identification. The degree to which police efforts are defeated can be seen by considering the data on burglary disposition given (Figure 3-10). From the referenced reports used, it is seen that for every 100 burglaries committed in the United States in 1972, only 17.8 were cleared by arrest. In a number of these cases, victims refuse to prosecute, or the police may drop charges. Thus, only 16.2% of the offenses result in formal charges. Adjudication produces acquittal or dismissal in over 20% of the cases (5.0 out of every 100 burglaries reported), with only 8.2 out of every 100 burglars found guilty as charged. An additional three



Reference: 1972 Uniform Crime Report (p. 115)

Figure 3-10. Burglary Clearances, Charges, and Disposition (1972) in every 100 produce guilty verdicts for more minor charges. The statistics are, then, very much in favor of the burglar. He has less than one chance in six of ever being charged with burglary and less than one chance in 12 of being convicted of that charge. There seems every reason to believe that this situation will continue unless some radical change is made in the environment in which the burglar operates.

The statistics on disposition (Figure 3-10) define the situation as it existed in 1972. However, data from the preceding 12 years is even more disturbing. A plot of arrest and disposition data since 1960 (Figure 3-11) indicates that the 1972 data reflects only the latest phase of a steadily deteriorating situation; i.e., both law enforcement agencies and the judicial system are increasingly ineffective in dealing with the crime of burglary. Clearances have steadily dropped from 29.5% in 1960 to the low of 17.8%. The rate of guilty-as-charged verdicts, starting with the data in 1962, has fallen from 14.6% to the current 8.2% figure. The lesser-offense conviction rate has also fallen off, while the percent acquitted or dismissed has remained relatively constant. It may be possible to take some comfort in the fact that the deterioration appears to be slowing in recent years, but even that assumption, if true, should provide little consolation for two reasons. First, this data shows percentage, not absolute performance. (Even a constant percentage, coupled with the rapidly rising offense rate, produces a correspondingly rapid increase in the total number of successful burglaries.) Second, these percentages relate only to the one out of three crimes reported to the police. By including the estimated unreported offenses, the figures



References: 1960 - 1972 Annual Uniform Crime Reports (Tables on "Offenses Known, Cleared, Charged, and Disposed")

Figure 3-11. Burglary Clearance, Charge, and Disposition Trends for arrest and disposition would be further reduced by 67%. Thus, the burglary problem cannot be attacked effectively until the arrest and conviction probabilities are increased significantly.

2. Police related problems. There then appear to be not one, but at least three, problems related to burglary with which the police must contend: 1) How can burglary offense rates be reduced? 2) How can the reporting rate of those burglaries committed be increased? 3) How can the police deal more effectively with reported offenses? Each of these points will be discussed in turn.

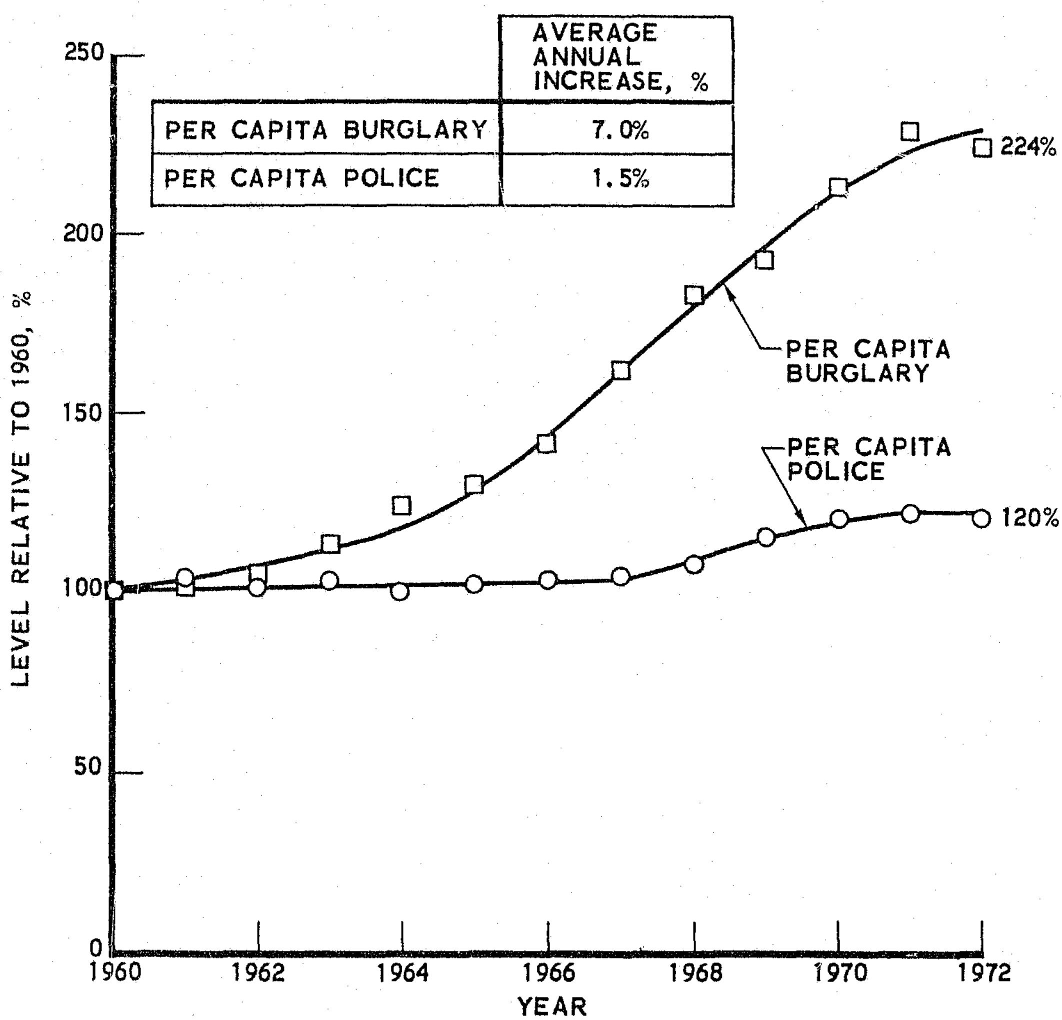
- Reducing burglary rates. The burglary rate will be reduced when the criminal becomes convinced that burglary is not profitable. From the sociological standpoint, one might argue that the root causes that motivate the burglar should be removed. This report tacitly assumes that the sociological aspects which encourage burglary will not change in the near future and that burglars will continue to practice. Some experts contend that residences should be sufficiently hardened so as to prevent the successful execution of burglaries. This approach is assumed to be basically unrealistic because residences would have to be turned into fortresses, which is not only expensive but also unpalatable to most residents. Therefore, this report assumes that burglars will continue to operate in large numbers against relatively "soft" targets and that the burglary rate will only be reduced when the problems of reporting and arresting burglars are solved.

- Improving reporting. Burglary offenses are generally reported to the police by the victim personally, but there are inherent weaknesses in continuing to rely on this method. If the burglar performs his job well, neither the victim nor his neighbors ever see the offender, and the crime is not discovered until hours or even days after it occurs. The most significant improvement in the reporting system must come by substantially reducing the amount of unreported crime, and this would require the addition of automatic reporting systems. Improvements in the reporting of offenses should accomplish not just one but two things: increase the reporting of burglaries in progress (not after the fact), and report a larger percentage of the total crimes committed. As indicated in Chapter IIIA, Forcible Entry occurs in 76% of the cases now reported. This suggests that, for alarm-equipped residences, the reporting rate could rise from the current 33% to some level close to 76%, depending on how well the alarm systems work. However, the most important benefit of the alarm concept to the police is to increase the visibility of the burglar during the offense. It will be shown below that police effectiveness increases markedly when alarm systems are employed. Thus, widespread use of effective and reliable alarms is felt to satisfy both of the requirements for improved reporting, that of reducing unreported crime and that of reporting the crime quickly enough to permit the police to respond.

- Improving police effectivity. The inability of law enforcement and judicial agencies to deal effectively with burglary contributes, in large measure, to the growing seriousness of the problem. However, given the clandestine nature of the crime and the delayed method by which most incidences are reported, it seems surprising that the police are able to do as well as the 17.8% the clearance figure indicates. The contention in the following discussion is that police effectiveness will improve when the surreptitious nature of burglary is overcome.

3. Police coverage. The visibility of burglary can be improved in either one of two ways. Either enough police can be on hand to discover the burglar in the act, or an alarm or observer can summon the officer when needed. Taking the first approach, and assuming no alarms at all, the effectiveness of the police initiative against burglary will be a function of the coverage of the neighborhood by patrolling officers. Since the trend of burglary has been from the business to the residential areas, the total number of police must increase to provide the residential districts with daytime coverages comparable to those provided for the more sharply defined and concentrated business community. However, per capita police coverage underwent almost no change between 1960 and 1967 (Figure 3-12). A significant increase did take place between 1967 and 1970, but the recent trend suggests that per capita manpower levels are again remaining almost constant. Thus, the over 100% per person increase in burglary over the last 12 years (Figure 3-12) has been countered with only a 20% increase in uniformed officer protection. It follows that law enforcement efforts should be less effective against burglary than they once were.

One possibility for improvement in combating burglary, then, is to increase the police manpower proportionately with the burglary rate. However, consider the magnitude of such an undertaking. In 1960, there was an average of 1.70 uniformed officers for every 1,000 inhabitants in the United

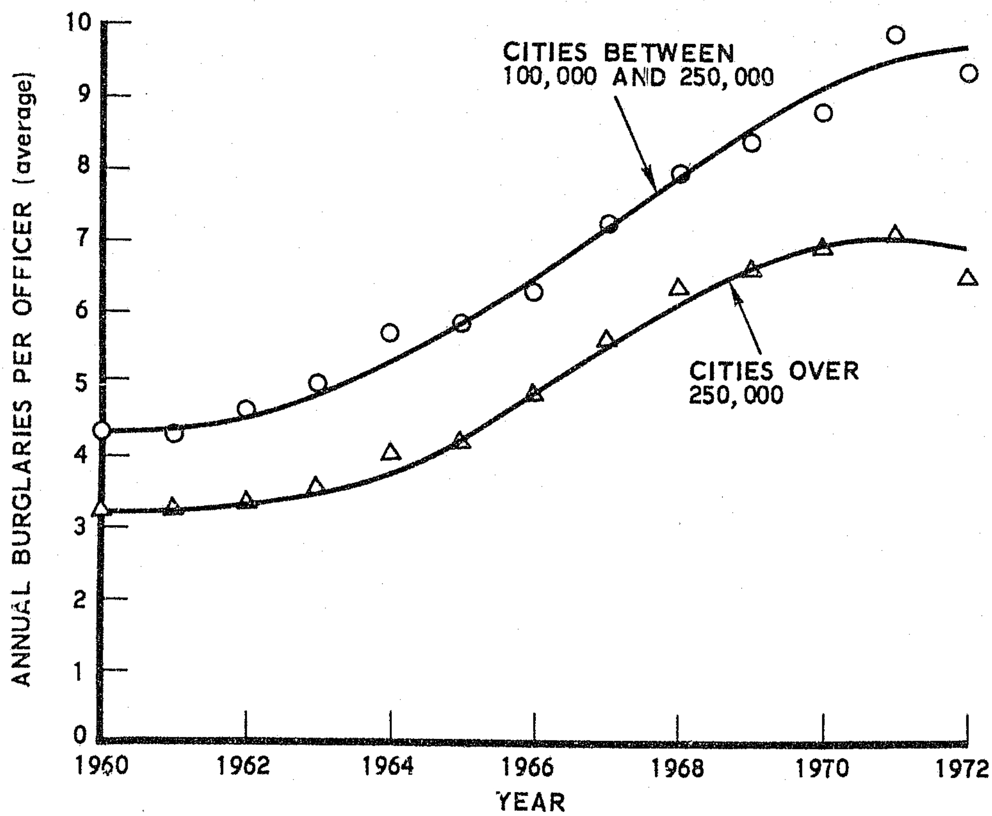


References: 1960 - 1972 Annual Uniform Crime Reports (Tables on "Full Time Law Enforcement Officers" and "Crime Rates by Population Groups")

Figure 3-12. Per Capita Burglary and Police Manpower Relative to 1960

States (an estimated total of 305,000 men). In 1972, the number had risen to 2.04 per 1,000 nationally (or 425,000 officers). However, had the per capita police coverage risen with the burglary rate over this period, 3.81 police per thousand (or a total of 790,000) would be needed. If one assumes that each officer costs $15,000/man-year to support, to make up this deficit would cost $5,475,000,000. Since reported burglary, on which these calculations were made, resulted in a reported loss of $722,000,000 in 1972, it does not seem very cost effective to match the rising burglary rate with a corresponding increase in police coverage.

- <u>Offenses versus police manpower.</u> Two basic conclusions have been developed about the burglary problem thus far: 1) Some automated method, such as the use of alarm systems, should help provide rapid and timely visibility of a greater percentage of offenses to the police; and 2) Police manpower levels cannot reasonably be expected to be raised to match the burglary rate. The possibility exists that a relatively constant police force, when subjected to a significantly enlarged volume of burglary reports, simply may not be able to handle the situation. This aspect of the burglary problem is dealt with in detail in Chapter IV, but a qualitative assessment of the situation is given here. Data on the number of burglary offenses per uniformed officer per year for the two large-city categories of interest are presented in Figure 3-13. While the number of offenses per officer has more than doubled in the past 12 years, there are still less than ten reported burglaries per officer each year. Even when this number is tripled to account for all unreported offenses and assuming that only one-fourth of the



References: 1960 - 1972 Annual Uniform Crime Reports (Tables on "Full Time Law Enforcement Officers" and "Crime Rates by Population Groups")

Figure 3-13. Large-City Trends in Annual Burglaries per Law Officer officers are available to answer burglary calls, this still amounts to less than one burglary call every three days for each officer. Thus, given a perfect reporting system, it would appear that police resources exist to respond quite comfortably to every actual burglary offense.

4. Police effectiveness and alarm systems

- Police effectiveness without alarm systems. The viability of alarm systems in combating burglary has been discussed several places in the preceding discussion. It now remains to substantiate that supposition. Consider first the current burglary situation in some typical urban areas. Recent studies relating to burglary reviewed 1,860 offenses in the Boston area[3-6] and another 67,028 burglaries in New York City.[3-7] In both instances, the probability of apprehension was about 4%, and in those cases in which the offender was not apprehended at or near the scene the subsequent detective effort met with success in only 1% to 2% of the cases. In these studies, it was concluded that clearance by investigation was simply a chance event and that none of the characteristics of the crime uncovered during the investigation had much effect on apprehension.

Studies in Manhattan,[3-8] Washington, Chicago, and Boston[3-9] have concluded that increased patrol efforts have little, if any, impact on burglary. As far as the origin of burglary reports[3-6] is concerned, 6% of the offenses were detected by residents or neighbors during their execution; less than 1% were discovered by patrolling police; and the remaining 93% of the cases were not discovered until some time after completion of the crime. These statistics suggest that the effectiveness of the police in areas without appreciable alarm coverage is much lower than the national averages would indicate. Unfortunately, the FBI data used to construct Figure 3-10 did not differentiate between alarmed and nonalarmed clearances, but, based on the Boston and New York data above, it seems that the differential between the 6% detected and the 17.8% arrested must come from the fact that some areas of the community are better equipped to combat burglary for some unspecified reasons.

- <u>Police effectiveness with alarm systems.</u> Underwriters' Laboratories, Inc. has actively participated in setting standards for alarm systems and each year has compiled data on burglary attempts, alarm failures, and the capture of offenders. In 1971, for example, the results of their survey on both central-station and local-mercantile systems was reported. [3-10] The central-station connected systems, either with or without a local alarm had 3900 burglary attempts into alarmed areas in the 47,559 locations reporting. These attempts resulted in a total of 1,087 captures (27.9%), with only 26 system failures (0.7%). Of the 18,779 local-mercantile stations which have a local alarm and in some instances automatic reporting service, 273 burglary attempts resulted in 50 captures (18.3%) with 18 system failures (6.5%). There were, in addition, 336 successful burglaries through unprotected accesses within protected areas which amounts to 13.4% of all attempts. Another survey of the Underwriters' Laboratory central stations conducted at about the same time by the Alarm Industry Committee for Combating Crime produced similar results. Based on these figures, it can be stated that alarm systems do produce an appreciable increase in visibility and subsequent improvement in the arrest rates.

The above data on Underwriters' Laboratory central stations reflects the experience of using equipment and installations of proven quality. However, these stations are, on the average, more expensive than those suggested in later sections of this report for residences and small businesses. A LEAA-sponsored program was carried out in Cedar Rapids, Iowa, for the specific purpose of investigating the potential for a low-cost (less than $200) system.[3-11] The results of the 350 installations showed much the same rate of success as was found in the Underwriters' Laboratory central stations. In 1970 as a part of this experiment, the experience of 142 alarmed and nonalarmed businesses was compared. The alarm equipment resulted in 12 arrests at the scene out of 46 burglaries (26%), while the unequipped businesses experienced 36 burglaries with only one arrest (3%). In 1971, with 115 businesses, alarms produced eight arrests in 22 attacks (36%), while there were only three arrests in 33 burglaries (9%) at the unequipped establishments. Thus, alarm installations unquestionably lead to a significant improvement in the probability of arrest of the offender. In fact, The Aerospace Corporation study conducted in preparation of this report failed to uncover a single reference to any method, other than the use of alarm systems, which leads to such a demonstrable increase in the burglary arrest rate.

5. <u>Criteria for combating burglary.</u> A strong point relative to alarm systems should be made; this point pertains to the criteria by which success should be judged. The discussion thus far has concentrated on increased arrest probability as the objective in combating burglary. There

is much to commend this approach, since if arrest rates are held high enough for long enough, it would seem possible to exhaust the available supply of burglars and thus drive the overall offense rate down. However, some prefer to stress the reduction in dollar loss as being more appropriate. (Obviously, from the police viewpoint, this is less important than the arrest and subsequent correction of the offender.) In the Cedar Rapids study, the alarm systems produced more startling improvements in the dollar loss rates than in arrest rates. In those cases where alarms were received, between 88% and 90% of the attempted burglaries resulted in zero loss, and, in the remaining cases, losses averaged only $35. In addition, the head of the Crime Prevention Bureau responsible for the Cedar Rapids burglar alarm system, stated in a recent telephone conversation that every offender captured through use of the alarm system has pleaded guilty, which has resulted in a significant reduction in court costs for the city. So, judging by either the increased dollar savings or arrest probability criteria, the use of alarm systems appears to offer great promise.

6. Summary. In summary, then, arrest and conviction rates have consistently declined over the past 12 years because of the changing character of the burglar and the shift to residential targets and, to a lesser extent, because police manpower and the judicial system has failed to keep pace with the rising crime rate. Improvements in the underlying social causes of burglary, in the hardening of targets, or in the classical method of people becoming more involved are all felt to offer little potential for constraining the rapidly rising increase in burglary. The use of alarms

should permit current police manpower to significantly increase the arrest rate from the 1972 national average of 17.8% to at least 30% or more (see Chapter IV for a detailed analysis), to boost the reporting rate from the present 33% to over 70%, and to substantially cut the dollar loss due to burglary (again, see Chapter IV for a detailed evaluation).

C. Burglar Alarm Systems Concepts

The purpose of this discussion is to review some of the considerations related to burglar alarm system design. In particular, the discussion will stress the ideas that are important at the system concept level rather than any detailed assessment of specific hardware concerns. This discussion will deal almost exclusively with the problem of reducing both false alarms and system cost and how these two considerations should influence the system design.

1. Alarm systems types. Before beginning the discussion of alarms, it is desirable to define the two types of systems in use today. The first is known as a local alarm or overt system, in which a local bell is used. The primary purpose of the bell is to frighten the burglar away and thus minimize the resulting dollar loss. Another intent is to attract the attention of the resident, the neighbors, or police. The second type of alarm system is known as the silent or covert alarm. Here, the objective is to secretly announce the presence of the offender to a private alarm company or to the police. When the signal goes to a private "central station," the company itself may respond with a patrol guard or they may, in turn, notify the

police. Sometimes both respondents are sent. When the system is a "direct connect," the alarm goes directly to a panel in the police station. The primary purpose of the silent alarm is, obviously, to facilitate apprehension of the burglar at the scene of the crime.

There are numerous reasons for choosing either the local or the silent alarm. The local alarm is selected in most instances because the alarm user is far less concerned with catching the criminal than he is with scaring him off and reducing his personal contact and the financial impact of burglary. Another reason is that they are generally cheaper and, in some communities, preferred by the police department. The local system is also less expensive on a monthly basis because no rental of telephone lines into the alarm agency is involved and there is no charge for the response agency since any calls made go directly to the police.

The chief advantage of the silent alarm, on the other hand, is that the burglar is (hopefully) unaware of the signal that has been sent. This allows the police to respond and arrest and, in the long term, correct the offender and remove him from the burglar population. This system is generally preferred by alarm response companies and those police departments where sufficient manpower and concern exist to deal forcefully with the burglary problem. Use of the silent alarm may also be desired in some areas due to the local disturbance caused by the loud alarm bell.

A detailed analysis of the reduction in dollar loss and the increase in arrest probability was carried out in Chapter IV, comparing both the local and silent systems and a combination system that adds the local bell to the automatic reporting of the system. However, the results of any analysis must be combined with some other very real considerations when selecting the type of system to design. Both police preference and local ordinances may dictate against the chosen system. Other factors completely beyond the control of the designer may also be at work here. In Los Angeles, for example, alarm bells are being added to the silent systems because the courts are releasing so many burglars that arrests become an exercise in futility. Thus, provisions should probably be made for the systems to operate in either the silent or the local alarm mode, or both, and the choice of usage should be made to fit the particular application.

2. <u>False alarms.</u> Many obstacles confront the designer of any burglar alarm, but concern about the occurrence of false alarms is the largest of all. False alarms are not just "a" problem in the design of an alarm system, they are "THE" problem. Any sensing device will understandably give erroneous signals from time to time, and burglar alarms are no exception. However, when erroneous signals occur much more frequently than true signals, the response agency is naturally going to question whether the use of the system is worth the aggravation. Even the best burglar alarm systems, both now and for the foreseeable future, will continue to transmit significantly more false alarms than true alarms. Police departments will usually accept a high number of false alarms since it is in the nature of law enforcement work to require pursuing many false "leads" for each successful apprehension. However, some agencies have had some very bad experiences

with this problem; the worst situations have naturally received the most publicity. Thus, the notoriety of false alarms is all-pervasive within the law enforcement community and has engendered a very negative outlook on the part of many police departments toward any alarm system, good or bad. The discussion below deals with some details associated with false alarms, such as the various definitions used, typical frequency of false alarms, etc., but it must be stressed at the outset that the single most important criterion in developing any new alarm system must be to very sharply reduce the false alarms from the levels currently being experienced, particularly in light of the intention of increasing the total number of alarm systems in use.

Just what constitutes a "false alarm" is a subject of great debate right now, particularly among members of the alarm industry, represented by the Alarm Industry Committee for Combating Crime (AICCC), and heads of the law enforcement community, who comprise the International Association of Chiefs of Police, Inc. (IACP). In fact, the AICCC was formed in 1969 chiefly in response to rising criticism about false alarms.

The false alarm debate has lead the AICCC to break both true and false alarms into several generic categories. For example, "Actual Alarms" are those that result from the actual or attempted entry of anyone not authorized by the alarm user, as well as alarms detected as a result of property damage. This definition includes alarms due to doors or windows being left open, blown open accidentally, or as a result of storm damage. The argument here is that the systems are designed to detect not only burglars but any reduction in the integrity of the protected premise, regardless of the cause. The AICCC maintains that a response that results in closing an open door has accomplished one of the purposes of the system.

The AICCC groups some of the false alarms into "External Alarms," which are those initiated in any place other than the protected premises. Most of these are due to difficulties with the phone lines used to communicate the alarms to the response agency. The AICCC feels that false alarms of this sort bring unjustified criticism of the industry and its equipment, whereas in fact they have no control over the telephone company or its equipment.

There are two other categories used by the AICCC: "Equipment Alarms" and "Internal Alarms." Equipment alarms are those false alarms resulting from actual equipment malfunctions and are the admitted responsibility of the alarm company or the alarm user who fails to properly maintain his equipment. Internal alarms are false alarms initiated on the protected premises by any cause other than equipment failure, the chief contributor being user error. Either the windows were not shut properly, the user misused the equipment or he failed to notify the response agency of some change in operating hours, or authorized personnel entered the secured area inadvertently. Internal alarms will be shown to constitute the largest percentage of calls of all four categories, and these are felt to be the mutual responsibility of both the user and the alarm operator. Specifically, the alarm company should more thoroughly train the user, and the user, in turn, must exercise greater care in the use of the system.

3. Measures of false alarms. The classical method used to discuss the effect of false alarms on police workloads has been in terms of the "false alarm ratio," which is computed by dividing the number of false calls received by the total number of calls. Thus, a false alarm ratio of 50% implies one false call for every true call and 90% implies nine out of ten are false calls. This measure of effectiveness has been used for years, and much of the data on alarm system performance is available only in this form. Unfortunately, the use of the false alarm ratio can be very misleading since it depends for its value not only on alarm system reliability but also on the local burglary rate. For example, consider two communities, one with a 20% burglary rate and another with a 5% rate. If every alarm system in both cities transmits four false calls each year, the false alarm ratio in the first city would be 4/4.20 = 95%. The ratio in the second city would be 4/4.05 = 99% because it suffered fewer burglaries. Also misleading is the fact that the second city has the higher figure with the same alarm system reliability. Therefore, while the false alarm ratio is probably a good indicator of the police frustration level, it can be a very erroneous measure of the quality of the system design from a false alarm standpoint.

In recent years, many researchers have alluded to the deceptive nature of the false alarm ratio in discussing alarm reliability. This has led to the generation of two other terms: False Alarm Rate and Mean Time Between False Alarms (MTBFA). The false alarm rate is the average rate at which false alarms are received from each installation. Thus, a system that errs twice a year has a false alarm rate of two alarms per year. The MTBFA parameter is the reciprocal of the false alarm rate and designates the average time between receipt of false alarms from each installation. For the system with two false calls per year, the MTBFA is one-half year. Both of these measures are better suited for use in describing false alarm reliability than the false alarm ratio. The MTBFA parameter is used throughout this report.

Numerous studies over the years have dealt with the frequency of false alarms. As mentioned earlier, much of this data has been in the form of the false alarm ratio, where some typical values have been over 0.90,[3-12] 0.93,[3-13] 0.95,[3-14] and 0.98.[3-15] Again, without the burglary rate for these communities, this ratio is misleading. As can be seen, however, the unhappiness of some law enforcement agencies is understandable since these numbers imply that police responded to anywhere from 9 to 49 false calls for every true call. Care must also be taken to ensure that these numbers reflect the false alarm ratio using the strict definition of false alarms desired in this report. The 0.93 number, for instance, includes in "true calls" the open door and window alarms discussed previously. Redefining these as "false" would raise the 0.93 figure still higher. In any event, the experience of most communities has been that the false alarm ratio equals or exceeds 0.9, and thus, only 10% or fewer of the alarms received are due to an actual burglary.

Considerably less research has been done in developing representative values for the MTBFA. One report[3-16] completed recently generated estimates of this parameter for six cities ranging in size from 111,000 (Cedar Rapids, Iowa) to 2,816,000 (Los Angeles, California). The values varied from a low of 0.29 years for Los Angeles to 0.48 years for Washington, D.C., with Cedar Rapids showing exceptionally good performance with 1.15 years. (This last figure is not thought to be correct based on brief telephone contacts with the Cedar Rapids police department.) Thus, average MTBFA values range between 1/4 and 1/2 year, with the higher figure representing very good performance for the average system in use today. This implies that between two and four false calls are sent each year from each installation, a figure which is solely a function of the reliability of the system in terms of false alarms and is independent of the local burglary rate.

4. Acceptable false alarm rate. No recommendation has thus far been made for what an acceptable level of false alarms might be for any given community. This problem is fairly complex, since the permissible level depends on the per capita number of police available, the amount of time spent on each call, and the number of alarm systems in use in the community. All these factors are considered in detail in Chapter IV, but a qualitative argument is appropriate here. Consider the 10.8% probability of being burglarized developed in Chapter III.A. This implies that one true burglary will be experienced every 9.26 years. Since the current alarm systems detect burglars in only 76% of the attacks, an average of 12.18 years will

elapse before a perfect burglar detector transmits an alarm. If an MTBFA of 0.25 years is appropriate, during that 12.18 years, 49 false calls will be sent for the one true call for which the system was installed. Although this is a highly simplified analysis of the problem, it does appear that 49:1 might prove somewhat unpalatable to the police, whereas they may be inclined to tolerate something on the order of 10:1 or less. This requires an MTBFA of 1.2 years or more, which is significantly higher than the levels currently being achieved. An analysis of the residential alarm requirements [3-16] performed by The MITRE Corporation in 1973 concluded that a two-year MTBFA was required in the near future, with that figure increasing as more systems are installed and technology develops. Again, the apparent severity of this requirement results from the sheer volume of alarm installations contemplated and from the danger that false alarms emanating from such a large percentage of residences may either overwhelm the police resources or inure the law enforcement community to the constant stream of alarms, which, in turn, would lead to the ignoring of those alarms.

It is relatively easy to suggest estimates for alarm requirements, e.g., the 1.2-year MTBFA figure just discussed. However, it might well be that this figure, however desirable, is simply unattainable. Complicating this problem is the fact that no real in-depth study of the causes of false alarms is available. Underwriters' Laboratories is presently conducting an extensive study of this problem, to be completed at the end of 1974. However, until this data is available, another less detailed study can be used.

The AICCC conducted a survey of 1972 data[3-13] in which alarms were classified according to the four categories discussed previously (Table 3-1). The first column, entitled Alarms Received, tabulates the survey results. Rows have been added at the bottom of the table for MTBFA and False Alarm Ratio. One of the categories was "Unknown" so, to compensate for this, these alarms were distributed to the other causes in proportion to their share of the total and entered in the column "Alarms Distributed." Thus, the current systems have an MTBFA of about 0.36 years, with a false alarm ratio of 0.908.

In reducing the number of false alarms, several assumptions must be made since no detailed hardware is available at this conceptual level. The first will be that the number of "actual" alarms remains unchanged. The second is that "external" alarms can be reduced 50% by using a more reliable path than the phone lines, by digital coding, or by some other method yet to be developed. The third assumption is that "internal" false alarms can be reduced 75% by both altering the current system to prevent user personnel from entering the alarmed area inadvertently, and by eliminating the requirement for door and window sensors. One method of accomplishing this might be to include the alarm switch within the normal door lock, so that any authorized person entering the area must disarm the system in the natural process of unlocking the door. Door and window sensors may also have to be removed. The last assumption is that equipment-caused alarms can also be reduced 75% by using new human-discriminating sensors and automatic sensor subsystem monitoring to distinguish false equipment alarms from true alarms.

Table 3-1. Effect of System Improvements on the Mean Time Between False Alarms (MTBFA)

	Alarms Received*	Unknown Alarms Distributed	Alarms Reduced By	"Improved Silent Alarm Rate"	"Improved Local Alarm Rate"
Total	38,789**	38,789		14,103	11,285
"Actual"	2,906	3,570	0%	3,570	3,570
"False"	35,883	35,220	-	10,533	7,715
External	3,552	4,363	50%	2,182	0
Internal	15,944	19,586	75%	4,897	4,897
Equipment	9,175	11,271	75%	2,818	2,818
Unknown	7,212	0	-	0	0
MTBFA, yr	-	0.36	-	1.21	1.65
False Alarm Ratio	-	0.908	-	0.747	0.684

*Based on one month's experience with 152,425 systems

**This number was changed from 38,898 because the total did not equal the sum of the parts

Reference: <u>AICCC False Alarm Study,</u> Alarm Industry Committee for Combating Crime (circa 1971)

Given the preceding assumptions, the effect on false alarm frequency can be computed. The "Improved Silent Alarm" column shows an increase in MTBFA from the initial 0.36 figure to 1.21, which, coincidentally, is almost exactly the suggested 1.2-year figure. By removing the external alarm category completely, the local system MTBFA of 1.65 years was derived. Thus, it at least appears possible, given sufficient improvements in equipment design and human engineering, to achieve an MTBFA value of 1.2 years. However, to reach the two to six year figure, as foreseen in the MITRE[3-16] analysis, false alarms would have to be almost completely eliminated in at least one or two categories. This would seem to be an extremely difficult task, at least with the current and projected levels of alarm technology.

5. Summary. In summary, then false alarms are the major concern which must be dealt with in developing an alarm system. The false alarm problem is paramount to almost any other consideration since police are currently responding to anywhere from nine to 49 false calls for every actual burglary detected. If one assumes that ten false calls for each true call is a ratio acceptable to the police, the MTBFA will have to be increased to about 1.2 years, up from the current 0.25-year level. This rate appears achievable, provided that significant improvements are made in the performance of sensor characteristics, techniques for arming and disarming the system, and reliable transmission of alarm data.

The following is a summary of current burglar alarm system problems:

- Police currently respond to between 9 and 49 false alarm calls for each true call received.
- Excessive false alarms are the most serious obstacle to the widespread use of burglar alarms.
- The MTBFA of current systems is now between 0.29 and 0.48 years, a value which must be raised to somewhere around 1.0 year for the proliferation of a large number of systems to be acceptable to police.
- It is possible to achieve the 1.2-year MTBFA value, given sufficient improvement in data link error rate, human engineering to reduce user error, human-discriminating sensors, and automatic detection of equipment malfunction.
- No satisfactory criteria for defining a specific system cost requirement are currently available.
- Past studies have suggested costs of $381 to $1,987 for alarm systems, but when one study required a $12 monthly fee, 17.7% of the participants dropped out.
- The typical cost of a leased residential alarm system with only a local bell is about $250 installed, with a $12 monthly rental fee; any new system should be considerably below this cost level.
- The final system should be as simple as possible, using only one strategically placed human-discriminating volumetric sensor.

- Some method of drastically reducing the cost of interconnecting system elements is needed.
- Provisions should be included for automatic component self-testing and status interrogation capability from a central station.
- The cost of communicating to the central station must be sharply reduced.

D. Burglary and the Offender

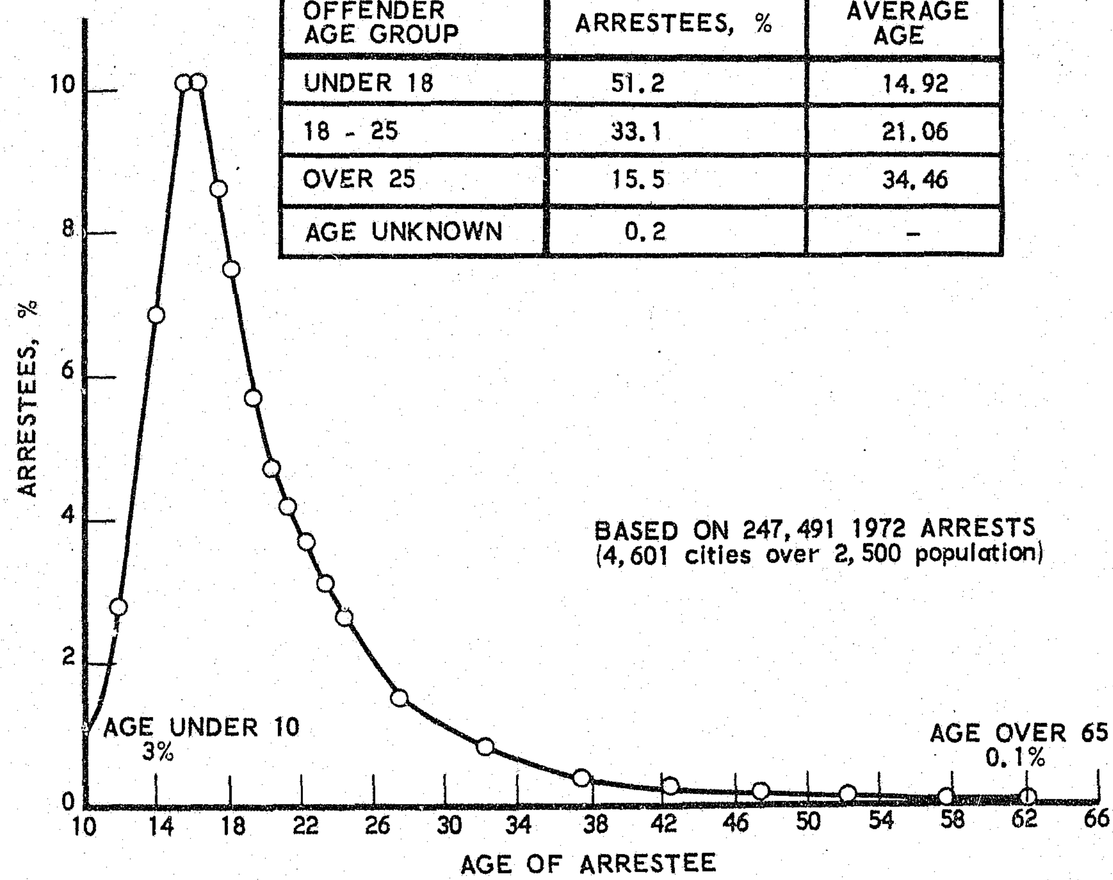
The design and evaluation of any burglar alarm system must consider the characteristics of the criminal against which the system will operate. The purpose of this discussion is to present these characteristics. The attributes discussed below include such factors as the number of burglaries committed each week, the time required to complete burglaries, and the age distribution of offenders.

The characteristics of burglars that are of interest in alarm design are almost universally a function of the age of the offender. For example, younger offenders spend less time inside the target, stage fewer burglaries per week, and achieve a lower financial return from each successful attack. Thus, it would be desirable to accurately determine the relative number of burglars in each age bracket. Unfortunately, data is available only on the arrestee population and not on the burglar population per se, since there is no way to identify a burglar until after he has been apprehended. The first impulse might be to assume that the arrestee population contains a higher percentage of the younger, less experienced talent than exists in the burglar population as a whole. Offsetting this, however, may be the fact that older offenders, even though perhaps more skillful, commit more offenses in the long run and therefore expose themselves to the possibility of more arrests. In any event, some estimate of the burglar age distribution is needed, and thus the assumption will be made here that the arrestee age distribution approximates the offender age distribution closely enough for the purposes of this analysis.

1. Burglar age distribution. The burglar population, as is the case with most property crimes, includes a disproportionate share of young offenders. The age distribution of 1972 arrestees is displayed in Figure 3-14. The mode, or peak, of the distribution is sharply defined at 10.1% for the 15- and 16-year-olds. This curve is specifically for city arrestees because of the emphasis here on a large-city alarm application, but it actually differs very little from the national averages. Over 51% of the offenders are under 18, with 3% age 10 or younger. The eight-year bracket from age 18 through 25 accounts for another 33.1%, while only 15.5% are found from age 26 up. Thus, numerically, burglary is obviously a young man's crime (94.8% of all arrestees were male), but, as will be shown, both the quality and quantity of their work improves with age and experience.

2. Burglar offense rate. The number of burglaries perpetrated each week varies considerably with age of the offender. One study just completed on residential crime [3-6] includes interviews with 97 known burglars and data from these interviews will be used for the remainder of the information in this discussion. (It must be recognized that for various reasons, these interviews may not be fully representative of the views and characteristics

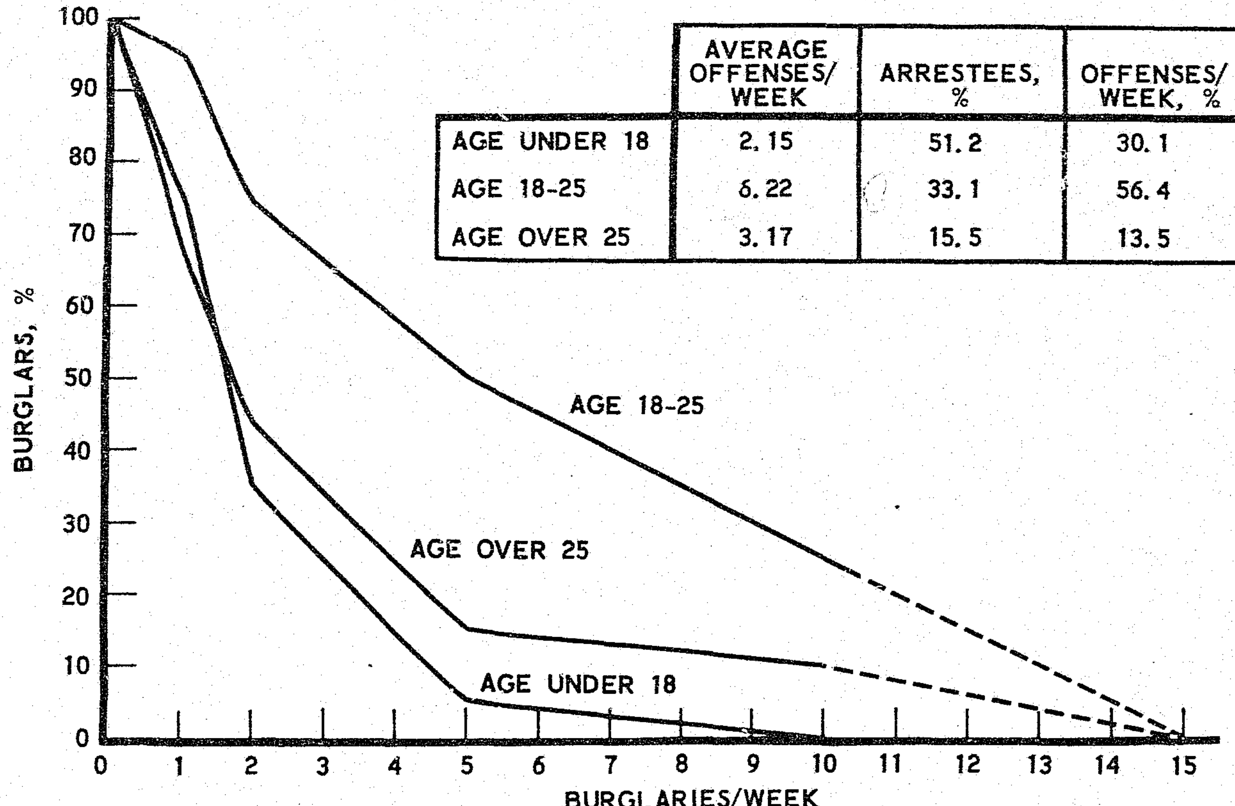
OFFENDER AGE GROUP	ARRESTEES, %	AVERAGE AGE
UNDER 18	51.2	14.92
18 - 25	33.1	21.06
OVER 25	15.5	34.46
AGE UNKNOWN	0.2	–



Reference: 1972 Uniform Crime Report (Table 38)

Figure 3-14. Distribution of City Burglary Arrestees by Age (1972) of the average burglar, and the actual number of crimes perpretrated may be exaggerated. However, they are considered sufficient for the offender analysis developed in this report.) Figure 3-15 displays the number of burglaries committed each week by the three age groupings used in the survey: less than 18, 18 through 25, and over 25. For example, 75% of the offenders between the ages of 18 and 25 committed two crimes a week, while 50% of them executed at least five burglaries every week. The burglars both older and younger than this group committed significantly fewer offenses. Note that the effect has been to increase the share of offenses committed by the 18 to 25 year olds to 56.4% of the total, whereas they constitute only 33.1% of the offenders (Figure 3-15). Thus, based on the actual number of burglaries committed, it is the young adult, and not the teenager, who presents the biggest threat.

3. Burglary dollar return. The interviewees in the Urban Systems report also estimated the dollar loss to the victim resulting from their successful burglaries, and this information is presented in Figure 3-16 (the plotting technique uses linear fits between data points, a practice which is common to all interview data in this section). There is obviously a remarkable change in the financial impact of burglary as the offender's age increases. Only 5% of the attacks by the under-18 group produced more than $300, while 52% of the over-25 burglars did this well. The average dollar loss per offense (Figure 3-16), multiplied by the offense percentages from Figure 3-15, results in a combined average loss of $280.50/burglary. This number is somewhat below the national average of $315, probably because the burglar estimates lower costs than the victim since he will receive less when fencing the stolen



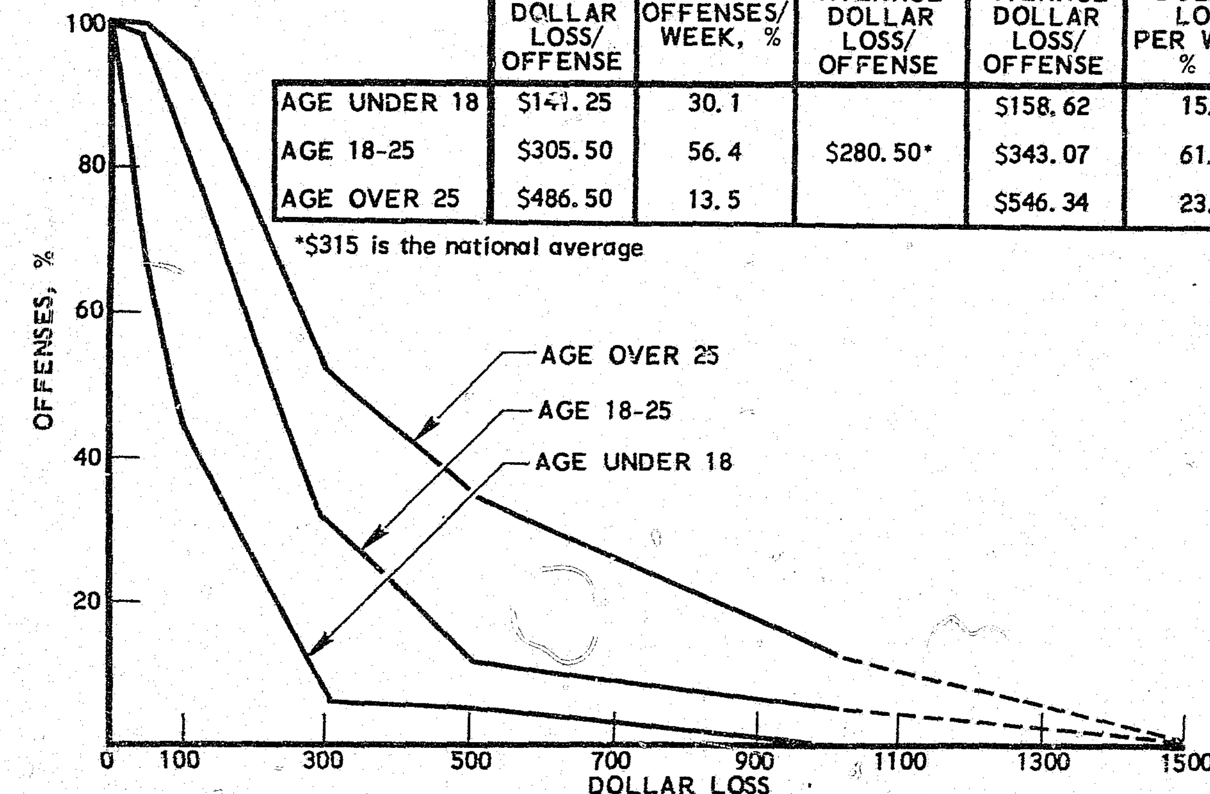
	AVERAGE OFFENSES/ WEEK	ARRESTEES, %	OFFENSES/ WEEK, %
AGE UNDER 18	2.15	51.2	30.1
AGE 18-25	6.22	33.1	56.4
AGE OVER 25	3.17	15.5	13.5

Reference: Crime and Housing in a Metropolitan Area (Table B-47)
Urban Systems Research and Engineering, Inc. (1973 draft)

Figure 3-15. Percent of Burglars Versus Weekly Offenses Committed

	AVERAGE DOLLAR LOSS/ OFFENSE	OFFENSES/ WEEK, %	COMBINED AVERAGE DOLLAR LOSS/ OFFENSE	ADJUSTED AVERAGE DOLLAR LOSS/ OFFENSE	DOLLAR LOSS PER WEEK, %
AGE UNDER 18	$141.25	30.1		$158.62	15.1
AGE 18-25	$305.50	56.4	$280.50*	$343.07	61.4
AGE OVER 25	$486.50	13.5		$546.34	23.4

*$315 is the national average

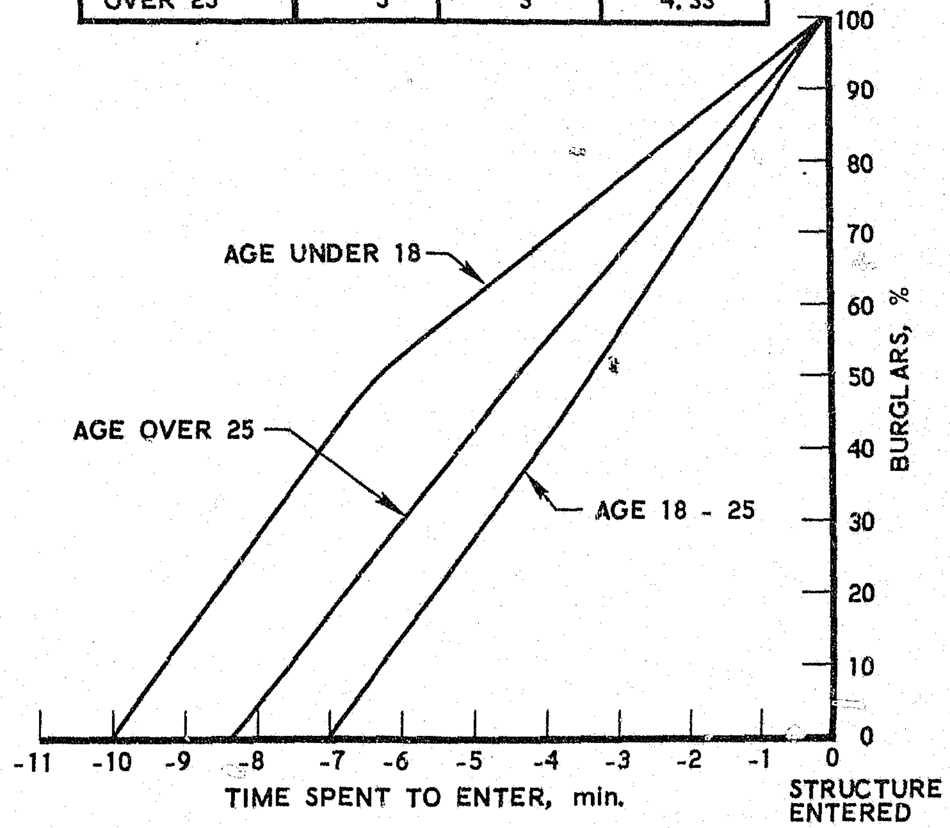


Reference: Crime and Housing in a Metropolitan Area (Table B-37)
Urban Systems Research and Engineering, Inc. (1973 draft)

Figure 3-16. Percent of Burglaries Versus Dollar Loss property. In order to achieve values that correspond to the $315 national figure, the average dollar loss numbers were scaled up by $315/$280.50 and listed as "adjusted" average dollar loss. The final column of the table lists the percentage share of the weekly dollar losses resulting from the different age groups. Here again, there is a surprising decline in the influence of the teenage offenders. The under-18 group constitutes 51.2% of the offenders, commits just 30.1% of the offenses, and realizes only 15.1% of the total weekly dollar loss. On the other hand, the more skillful and more aggressive 18 to 25 group, starting with 33.1% of the work force, commits 56.4% of the crimes, and receives 61.4% of the dollar value obtained. This seems to provide a strong argument for correcting the offender while he is still a teenager, since it is obviously going to be more difficult after his proficiency increases with age.

4. Time spent entering. The ability of the police to respond to an alarm and then to make a successful arrest depends in large part on the amount of time the burglar spends at the scene. Figure 3-17 presents estimates of the time spent in actually breaking into the residence. For alarm systems equipped with door or window sensors, the alarm signal will be initiated sometime during the break-in period, which gives the police just that much more time to respond. The time scale has been made negative to imply that this is the "countdown" phase of the burglary, with the time of burglary actually starting at the time the offender enters the structure. The youngest offenders spend more time entering through either doors or windows, while the young adult works less time than the rest. Thus, inclusion of

OFFENDER AGE GROUP	AVERAGE TIME, min.		
	DOOR	WINDOW	OVERALL
UNDER 18	8	3	6.33
18 - 25	4	2	3.33
OVER 25	5	3	4.33



Reference: Crime and Housing in a Metropolitan Area, 1973 draft (Tables B-31 and B-35) Urban Systems Research and Engineering, Inc.

Figure 3-17. Time Required to Enter a Structure perimeter sensors in the alarm system would prove to be the most effective against the least effective burglars and, conversely, least effective against the most effective 18-25 year-olds.

5. Time spent burglarizing - silent alarm. The offender spends much more time within the residence than he does entering. Figure 3-18 presents the time distributions for burglarizing the structure, and here the youngest offenders actually spend the least amount of time. This is in direct contrast to the entering phase of the burglary, where the juveniles took the longest time. Two phenomena are probably at work here. The teenager is less facile at breaking and entering, but once inside he is much more afraid of capture and leaves early. The young adult enters the fastest but, once there, spends more time in completing the burglary. However, the oldest offenders seem almost casual by comparison. Note that over 20% of this group think nothing of staying 30 minutes or more. From the tabular summary, then, all offender categories spend an average of over 15 minutes completing their work. This amount of time is usually more than sufficient to permit police to respond, even under adverse conditions.

6. Effect of a local bell. The time spent by a burglar inside the residence is strongly influenced by the introduction of a local bell that loudly announces his presence. The question that was asked of the burglars was: "What would you do if a burglar alarm sounds? Leave Immediately, Quickly Finish, or Ignore the Alarm?" As can be seen from Figure 3-19, the impact of the bell was very strong within each age group but became less so with increasing age. Over three-fourths said they would leave immediately, while only 4% in the over-25 category stated that they would ignore the alarm. Some

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1 OF 2

Each of the preceding communication systems and other systems need to be investigated in detail and a tradeoff study performed to assess the feasibility of new residential security alarm systems that tie in to the police and/or alarm response companies.

2. Study requirements. This section defines the minimum information to be derived from this investigation. Other information that is considered significant should also be included in the study. This information and additional material developed during the study shall be expanded and included with the Study Final Report.

a. Transmission system parameter definition. The study should identify and include a comprehensive list of those parameters, both qualitative and quantitative, that provide adequate information to formulate a valid comparison of the various transmission media. The set of parameters should include, but shall not be limited to, the following.

(1) Cost. As a minimum, the study should consider the following costs associated with the alarm transmission media:

- Initial development
- Implementation (area and user)
- Recurring
- Maintenance
- Updating and expansion
- Impact on total alarm system

(2) Reliability. The study should consider, as a minimum, the following reliability factors:

- Media failure (e.g., cut transmission line)
- Reduced effectivity in alarm transmission, as evidenced by false alarms or undetected true alarms, due to inherent media limitations

(3) Technical characteristics. The study should consider the following technical alarm transmission media characteristics:

- Traffic requirements and sources
- Bandwidth, or the information transfer rate
- Range, including range versus power requirements
- Interference considerations, including those indigeneous to the media and those induced from external sources
- Media capability as an interactive system, and its ability to handle multiple alarm transmissions
- Equipment interfacing at transmitting and receiving ends
- Possible transmission methods, including carrier and modulation techniques
- Technical development time and effort necessary to obtain an acceptable transmission system

(4) Tampering susceptibility. The study should consider the media's susceptibility to inadvertent or deliberate tampering.

(5) Updating and expansion potential. The study should consider the media's potential for: expanding to serve new users and updating as new generations of alarm systems are developed.

(6) Other considerations. The study should consider the influence and/or constraints imposed upon the operating system due to, at a minimum, the following:

- Federal, state, and major urban governments (e.g., Chicago, Los Angeles, New York)
- Alarm system manufacturers and installers
- Existing communications link owners (e.g., telephone or utility companies)
- Ultimate residential and commercial alarm system users
- Potential sharing or constraints from other alarm system needs (e.g., citizen alarms, emergency medical services, "911")
- Alarm response elements to include public and private policing, individual citizens (Buddy response systems), and citizen groups (tenant patrol)

b. Transmission media. The study should identify all transmission media that can be considered feasible for utilization as an alarm data communications link. As a minimum, the following should be included: interactive CATV, all types of telephone and power lines, RF (transmitter-receiver pairs), and combinations of media. Feasibility of utilization should be determined based upon a definition formulated by the study.

c. State-of-the-art determination. To prevent duplication and to ensure the use of existing information, this study should determine current capabilities and levels of effort in the private and government sector.

(1) Media in use. The study should identify and investigate alarm transmission media presently being used in private and government alarm communication systems.

(2) Relevant technology. The study should identify and investigate applicable concepts and hardware in the research and development stage in both the commercial and military sectors that are available.

(3) Regulations and constraints. The study should identify existing laws, regulations, codes, and other restrictions that govern the use of the alarm transmission media identified. These may originate from government agencies (e.g., FCC), independent companies (e.g., Bell System companies), or standard groups (e.g., Underwriters' Laboratories). Recommendations should be made for developing necessary model codes, regulations, or laws commensurate with media recommendations.

(4) Future developments. The study should identify the technologies, equipments, or systems requiring further development for each identified media.

d. Comparative evaluation. The results of this investigation should be a quantitative summary from which the relative advantages and disadvantages of each media with respect to each parameter may be determined, based on the best available information. Keeping in mind that this summary will be used in making decisions as to which media is best suited for various types of alarm and response systems, the relative significance of the parameters should be indicated. Areas should be identified for which information is unavailable, and an assessment shall be made of the impact of this lack of information upon the comprehensiveness of the summary.

e. Conclusions and recommendations. At completion, the study should have considered and answered, as a minimum, the following questions:

- At present, which is the best choice for alarm transmission media through 1980?
- Which of the alarm transmission media require new or expanded development efforts?
- If only system modifications are introduced, what will be the most beneficial alarm transmission media through the 1980's?
- What factors, not thus far considered, are of significance in the investigation and selection of alarm transmission media?

APPENDIX A. AN INTERNAL RESIDENTIAL POWER NETWORK AS A COMMUNICATIONS MEDIUM

Introduction

The purpose of the tasks outlined below is to devise a set of design tools that will provide the communications system designer with a basis for implementing an alarm system interconnected by the internal wiring existing in the typical residential or small business location. An integral part of this effort will be the laboratory verification of adequate numbers of analytical predictions to ensure the accuracy of all results. It should be noted that this discussion is intended to be introductory and that no attempt has been made to estimate the magnitude of the tasks defined.

1. N-Port Characterization

Given information governing the topology and electrical properties of a power interconnection network (A.4), it is possible to calculate a set of parameters that, when exercised in a communications sense, allows the prediction of system behavior. This task involves the implementation of a (or use of an existing*) distributed element, ac circuit analysis computer program to characterize numerous interconnection topologies as N-Port equivalent circuits. The program will accept as inputs the network topology and the values for the required electrical properties (e.g., wire type, length, and characteristic impedance; transformer type and location;

*Existing programs include OPTINET, National CSS, Inc., and COMPACT or MICAP, TYMSHARE Corp.

and loads and locations). Using these data, the program will calculate and tabulate the set of N-Port parameters representing the network. In this fashion, networks of varying complexity will be analyzed and their parameters compared. Such comparisons will provide a basis from which to devise a classification scheme for establishing categories of equivalent circuits based on a qualitative measure of complexity. This system should prove of significant value to the communications system designer in that it brackets the characteristics of any particular alarm installation.

2. Performance Prediction

Given the set of N-Port parameters that represent the electrical transport properties of an interconnection network, it is possible to determine the signal levels appearing at any port (e.g., wall outlet) based on knowledge of the excitation sources and loads connected to the other ports. For example, if the transmitting end impedance and receiver sensitivity were to be specified for a parametrically characterized N-Port, it would be possible to predict the required transmitter output power versus receiver input impedance. This activity will consist of the implementation of a second (or, once again, the use of an existing) computer program to determine the communications system transmission properties for each wiring category network. The quantities calculated will be organized in a manner similar to the classification scheme outlined above and will include transmission attenuation, driving point impedance, required transmitter power, receiver sensitivity, etc. These data will form the basis for a communications system design aid, making it possible to easily determine the bounded requirements imposed on a transmitter/receiver pair based on an estimate of the interconnection network's complexity.

3. Transmission Medium Perturbations

The electrical properties of the appliances found in the typical residence or small business can be divided into two categories, power consuming and spurious generating. Until recently, only those spurious phenomena that interfered with proper appliance operation had been investigated (e.g., diathermy machine/television receiver interference). To fully exploit the internal power distribution network as a communications medium, it is important to have a detailed understanding of the characteristic modes of spurious signal generation exhibited by commonly encountered appliances.

To satisfy this requirement, the data presented will be used as a basis for the analytical characterization of such appliances. These data, supplemented by additional measurements when needed, will be mathematically modeled as Thevenin equivalent noise sources. The models will then be used to exercise the previously derived N-Ports to establish their loading effects and background noise influence on the transmission medium. Attention will also be given to the identification of the most probable sources of communications disruption due to noise susceptibility. The information made available by this examination will aid in the election of the optimum frequency/frequency range for the FSK (frequency shift keying) communications system.

4. Technical Considerations

Consider an arbitrary network made up entirely of the interconnection wiring and loads (refrigerators, TV sets, etc.) found in the typical residence or small business. To indicate the general nature of the network, let it be represented by a box symbol. If a conductor is fastened to any node (interconnection point) in the network and brought out of the box for access, the end of this conductor is designated as a terminal. Two associated terminals are called a Port, suggesting a port of entry into the network (e.g., wall outlet).

The symbolic representation of a one-Port network is shown in Fig. A-1a. The pair of terminals is usually connected to the energy source that drives the network. Figure A-1b shows a two-Port network; Port 1-1′ is assumed to be connected to the driving force (or the input), and Port 2-2′ is connected to a load (an output). The general representation for a network containing an arbitrary number of electrical sources and loads is shown in Fig. A-1c and is referred to as an N-Port (where N = the total number of ports).

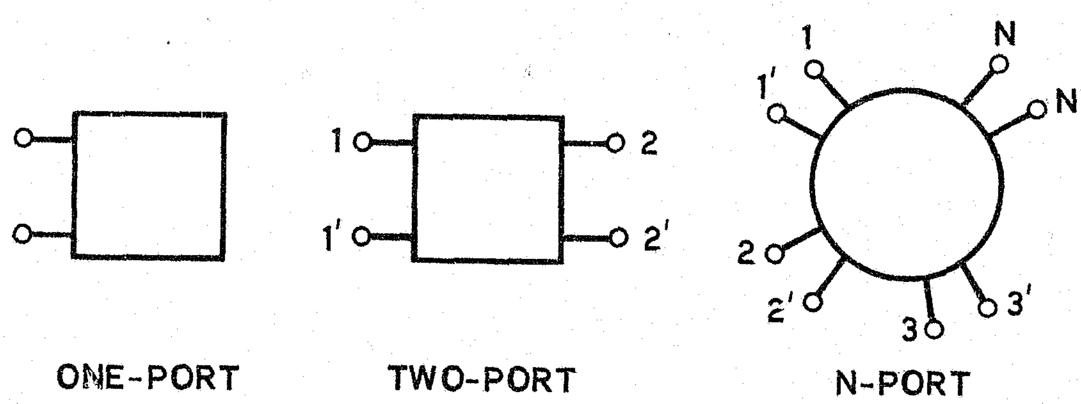

Figure A-1. Black Box Symbology

APPENDIX B. EXTERNAL POWER LINES FOR ALARM CARRIER TRANSMISSION

Introduction

During the past few years, several companies have been developing concepts and equipment aimed at the automation of utility meter reading. The conclusion reached by two of the companies, General Electric Corp. and Automatic Technology Corp., is that the most promising solution to the problem of transmission medium selection rests with utilization of the existing power interconnection network. Toward this end, each company has developed test equipment that allows rapid and accurate measurement of various electrical phenomena associated with operating existing power lines as a communications network. The quantities measured include transmission attenuation and noise power density, which, when combined as a ratio, yield a figure-of-merit characteristic of the particular network being examined. By performing similar measurements on numerous power installations, it is possible to produce figure-of-merit profiles that indicate the general operating communications environment for the interconnection network.

Such tests are not an end in themselves since they are valid for only one combination of power line conditions. In effect, these same tests must be performed under all possible utility distribution system conditions expected.

1. Analytical Versus Experimental Approach

The main thrust of the development activities thus far attempted has been centered around the application of experimental techniques for the characterization of utility lines as a communications medium. On the surface, this would appear to be the only approach possible because of the multiplicity and complexity of power distribution networks. However, no matter how complex such a system may appear, it can be considered to be comprised of a multitude of interconnected, relatively simple electrical subnetworks (e.g., distribution transformer or length of transmission line). Individually, it is a relatively simple matter to mathematically model, by applying computer-aided electronic design techniques, these subnetworks as N-Ports,[B-1] using data measured on the device in question (isolated from the distribution system). Once modeled in this fashion, the subnetworks can be interconnected mathematically and exercised as a simulation of the actual power distribution system.

The advantage of this method of characterization is the economy with which performance data can be realized. It is not intended to minimize the value and importance of performing extensive measurements on operating utility networks; without the benefit of such data, little confidence could be held in the predicted performance.

2. Measurement Activities

Using equipment similar to that employed by General Electric for its Automatic Meter Reading Communications Project, a two faceted measurement program will be conducted. The first phase will be concerned with the experimental characterization of the unique subnetworks associated with a power distribution network. Once completed, the measurement activities will be addressed toward the second phase: the performance of the entire system when viewed as a communications medium.

The data gathered during the subnetwork phase of this investigation will form the basis for the mathematical simulation of the individual building blocks, while the overall measured data will be used to verify the validity of the predicted system performance. Several such vehicle power distribution networks will be considered, to the extent that time and funding permit.

3. Analytical Activities

Using techniques identical to those described in Appendix A, the vehicle power distribution network will be simulated and exercised to yield a prediction of the system performance. By comparing predicted and measured performance, it will be possible to refine the computer model until close agreement is achieved. The facsimile power network will then be examined in detail to produce comprehensive performance predictions between every possible location that might be considered as a communications interface. Similar calculations will be conducted on each interconnection network experimentally examined.

APPENDIX C. RESPONSE MODELING DERIVATION

1. Introduction

It is desired to find the distribution describing the time it takes the police to arrive at the scene of a burglary once they have been notified. The known parameters are:

ρ = police utilization = average fraction of the time a patrol car is busy answering a radio dispatched call

A = precinct area (assumed to be square, $d^2 = A$)

N = total number of patrol cars

$\bar{t}_s$ = mean time spent servicing a call

$= \bar{t}_T + \bar{t}_I$ = mean travel time + mean investigation time

V = average speed of patrol car while traveling to a call

A set of probabilities (p_k, k = 0, 1, 2, $\cdots$) are used to describe the number of calls currently being serviced or waiting for service. This set of probabilities depends on the distribution for the service time. The multiserver queuing problem has been solved for only two service time distributions. One is the exponential distribution

$$\Pr(\text{service time} > t) = \exp(-t/\bar{t}_s)$$

The other distribution is the constant service time

$$\Pr(\text{service time} \le t) = U(t - \bar{t}_s)$$

where U($\cdot$) is the unit step function.

The exponential and constant service time distributions provide best- and worst-case bounds on system performance. Any realistic service time distribution will result in a system performance bounded by the system performances for these two cases. Furthermore, for low utilization the system performance is about the same for both cases; i.e., the real system should perform within these relatively narrow bounds. As N becomes larger, the bounds remain tight for higher utilizations. Specifically, the (p_k, $k = 0, 1, \cdots, N - 1$) are about the same.

2. Exponentially Distributed Service Time

Using the method of statistical equilibrium, it can be shown that for the case of Poisson arrivals

$$0 = p_{k-1}\lambda + p_{k+1}(1 + k)\mu - p_k(\lambda + k\mu) \qquad (k < N)$$

$$0 = p_{k-1}\lambda + p_{k+1}N\mu - p_k(\lambda + N\mu) \qquad (k \geq N)$$

where $\bar{t}_s = 1/\mu$ and $\lambda = N\rho/\bar{t}_s$.

The solution for this set of equations is

$$p_k = \begin{cases} \dfrac{(N\rho)^k}{k!}\, p_0 & (1 \leq k \leq N) \\[2ex] \dfrac{(N\rho)^k}{N!\, N^{k-N}}\, p_0 & (k > N) \end{cases}$$

$$p_0 = \left[\sum_{k=0}^{N-1} \frac{(N\rho)^k}{k!} + \frac{1}{1 - \rho}\,\frac{(N\rho)^N}{N!}\right]^{-1}$$

The probability that there are no patrol cars free is

$$P_N(\rho) = 1 - \sum_{k=0}^{N-1} p_k$$

3. Constant Service Time Distribution

Erlang[C-1] introduces the equation

$$\rho e^{-\rho} e^{i\frac{2\pi k}{N}} = a_k e^{-a_k} \qquad (k = 0,\ 1,\ \cdots,\ N-1,\ i = \sqrt{-1})$$

and shows that

$$P(\mu,\ N) = \Pr\ (\text{at least } \mu \text{ servers are free})$$

$$= \frac{N(1-\rho)\ g\ (N-\mu+1)}{G(1)}$$

where

$$G(y) = y \prod_{\nu=1}^{N-1} (\beta_\nu - y) = \sum_{\nu=1}^{N} y^\nu\ g(\nu) \text{ and } \beta_\nu = \frac{a_\nu}{\rho}$$

Now

$$P(\mu,\ N) = \sum_{k=0}^{N-\mu} p_k$$

thus

$$p_o = P(N, N)$$

$$p_1 = P(N-1, N) - P(N, N)$$

$$\vdots$$

$$p_k = P(N-k, N) - P(N-k+1, N)$$

$$k = 1, 2, \cdots, N-1$$

To solve for the complete set of probabilities (p_k), it is observed (by the method of statistical equilibrium) that

$$p_s = \sum_{\mu=0}^{N} p_\mu \, e^{-N\rho} \frac{(N\rho)^s}{s!} + \sum_{\mu=0}^{s-1} e^{-N\rho} \frac{(N\rho)^\mu}{\mu!} \, p_{N+s-\mu}$$

and

$$p_o = \sum_{\mu=0}^{N} p_\mu \, e^{-N\rho}$$

This set of equations may be solved to yield

$$p_N = e^{N\rho} p_o - \sum_{\mu=0}^{N-1} p_\mu$$

$$p_{N+1} = e^{N\rho} p_1 - (N\rho) \sum_{\mu=0}^{N} p_\mu$$

and

$$P_{N+k} = e^{N\rho} p_k - \frac{(N\rho)^k}{k!} \sum_{\mu=0}^{N} p_\mu - \sum_{\mu=1}^{k-1} \frac{(N\rho)^\mu}{\mu!} P_{N+k-\mu}$$

for $k = 2, 3 \cdot \cdot \cdot$, which can be used in the previously presented equation for the probability that there are no patrol cars free, i.e.

$$P_N(\rho) = 1 - \sum_{k=0}^{N-1} p_k$$

This probability of patrol car unavailability $P_N(\rho)$ (for $N = 12$) has been plotted as a function of ρ in Fig. C-1. Note that for $\rho < 0.4$, $P_N(\rho) \cong 0$. This is one of the reasons that police utilization should be kept less than 40%. Above this value it is increasingly probable that all cars will be busy when a new call is received. Note that the utilization ceiling of 0.4 has a mathematical justification as well as the practical justification of being a maximum increase in police workload.

4. Travel Time

The travel time model is based on the assumptions that the precinct is a square region, d miles on a side, of area $A = d^2$ and that burglaries are equally likely to occur at any location throughout the precinct, i.e., that burglaries are uniformly distributed. In the case of only one patrol car, the question arises: What would the distribution for travel time to the scene be, assuming that the car position at the time of the crime is also uniformly distributed over the entire precinct? This question is answered by letting

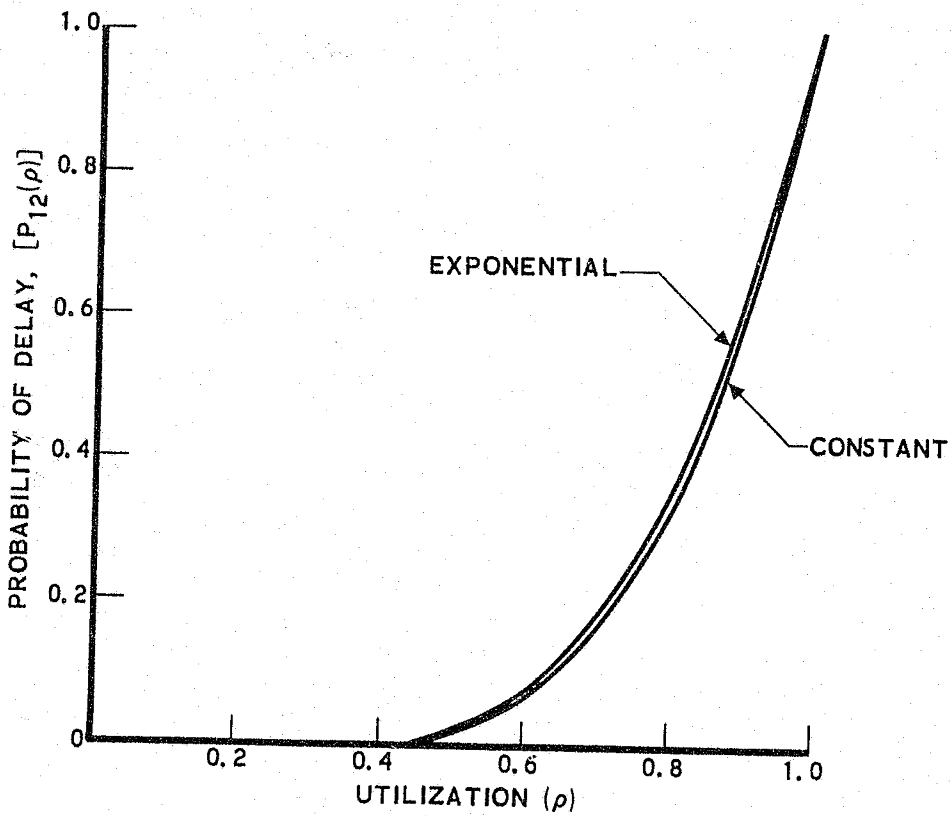

Figure C-1. Probability of Queuing Delay (Number of Servers N = 12)

(x_1, y_1) be the location of the crime and (x_2, y_2) the position of the car, so that the travel time can be expressed as

$$t_T = \frac{1}{V} \left\{ |x_2 - x_1| + |y_2 - y_1| \right\}$$

The travel time is found to have probability density function

$$f_1(s) = \begin{cases} \frac{V}{d} \left[4\left(\frac{tV}{d}\right) - 4\left(\frac{tV}{d}\right)^2 + \frac{2}{3}\left(\frac{tV}{d}\right)^3 \right] & \left(0 \le \frac{tV}{d} \le 1\right) \\ \frac{V}{d} \left[\frac{16}{3} - 8\left(\frac{tV}{d}\right) + 4\left(\frac{tV}{d}\right)^2 - \frac{2}{3}\left(\frac{tV}{d}\right)^3 \right] & \left(1 < \frac{tV}{d} \le 2\right) \end{cases}$$

The probability distribution function is defined as

$$F_1(t) = \Pr(\text{travel time} \le t) = \int_0^t f_1(s)\, ds$$

The single patrol car question can be extended to the case where there are k cars available. In this case

$$[1 - F_1(t)]^k = \Pr(\text{all the cars would take longer than } t)$$

Thus

$$F_k(t) = 1 - [1 - F_1(t)]^k$$

and

$$f_k(t) = k\, f_1(t)\, [1 - F_1(t)]^{k-1}$$

are the distribution and density functions, respectively, for travel time when the nearest of k available cars is chosen. Thus

$$f_T(t) = \sum_{k=1}^{N} p_{N-k}\, k\, f_1(t)\, [1 - F_1(t)]^{k-1} + \sum_{k=N}^{\infty} p_k\, f_1(t)$$

is the density function for travel time and

$$F_T(t) = \sum_{k=1}^{N} p_{N-k}\, (1 - [1 - F_1(t)]^k) + \sum_{k=N}^{\infty} F_1(t)\, p_k$$

is the distribution function.

5. Overall Response Time

The response time (t_R) comprises three elements: processing delay (t_d), dispatch waiting (t_W), and travel time (t_T)

$$t_R = t_d + t_W + t_T$$

An overall distribution function for the response time may be obtained by mathematically convolving the individual distributions as follows

$$F_R(t_R) = F_d * F_W * F_T(t_R) \quad \text{(* indicates convolution)}$$

$$= \Pr\left\{t_d + t_W + t_T \le t_R\right\}$$

The equation for F_R can be greatly simplified by considering that for low utilizations (< 40%, as shown previously) $t_W = 0$ more than 99% of the time. For this analysis, the conservative approximation is made that the probability of capture is zero if $t_W \neq 0$. The delay time t_d is assumed to be equal to 30 seconds (0.5 min.), so, F_R may be formulated as

$$F_R(t_R) = \sum_{k=1}^{N} p_{N-k} F_o (t_R - 0.5)$$

This formula was then evaluated to determine apprehension and residential benefits.

Figure C-2 shows the distribution function for both the exponential and constant service time cases. The difference in the two functions is found always to be less than 0.0002 for all values of t (a very tight bound), so only one curve need be plotted. It is emphasized that the closeness of the two functions results from low utilization; at higher utilizations a looser bound results.

Figure C-3 shows this curve overlaid on the burglary duration distributions for three age groups in the case of the burglars who finish quickly because a combination alarm (local audible and remote/automatic reporting) is tripped.

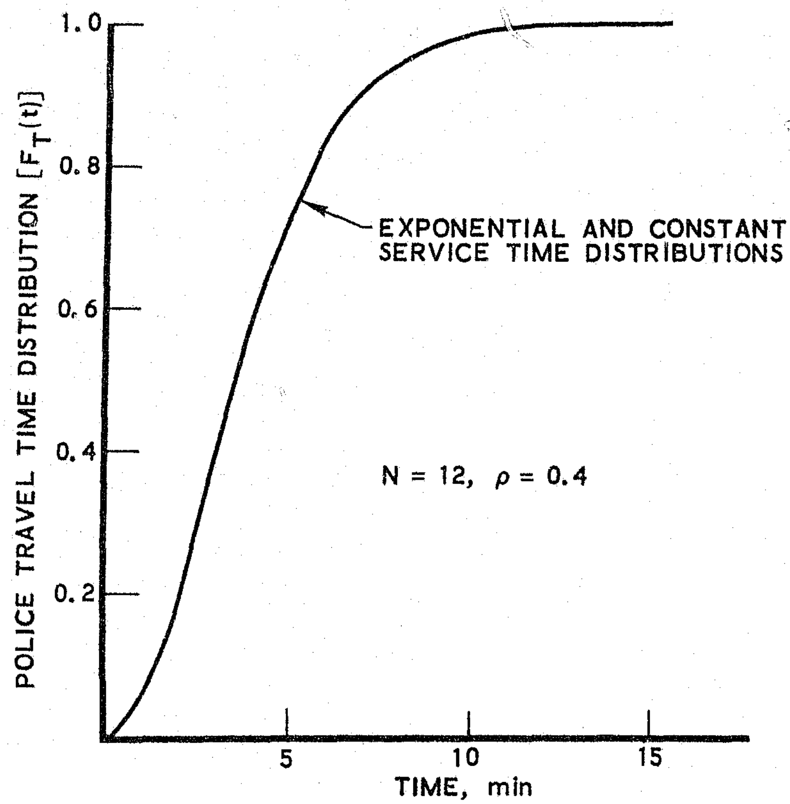

Figure C-2. Police Travel Time Distribution [$F_T(t)$]

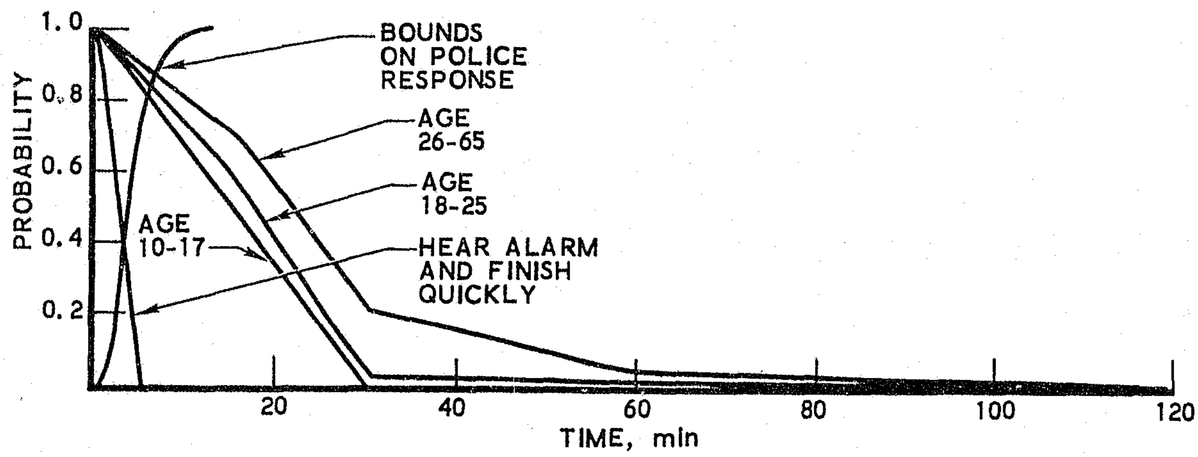

Figure C-3. Burglary Duration Distributions Versus Police Response Time (with Automatic Reporting)

APPENDIX D. BODY INFLUENCE DETECTORS

The concept of operation, which will be discussed as an explanation of the performance of one type of human proximity detector, is based on the perturbation produced in the surface ambient electrostatic field of the earth E_{ex} by the presence of a body possessing a high electrostatic dielectric constant. Below 30,000 feet, the earth exhibits a vertically directed electrostatic field, which is produced by a downward flow of current into the negatively charged earth and which arises from within the clouds and strata of the troposphere.

The vertical ambient field varies between 67 and 317 volts per meter[D-1] for overland sites, yielding a representative value of 150 volts per meter[D-2] at the surface.

Any body possessing a dielectric constant ϵ different from that of the standard atmosphere (1.00 in cgs electrostatic units) will distort the ambient electric field. The greater the dielectric constant of the perturbing body, the greater the ambient field distortion in the vicinity of that body. The degree of field distortion decreases rapidly and nonlinearly with distance from the body, becoming negligible within a range of several meters.

The dielectric constant of muscle and organ tissue displays a commonly encountered relaxation dependence upon frequency. The dielectric relaxation for a postmortem sample of muscle tissue is shown in Fig. D-1 for frequencies below 1 MHz.[D-3] Schwan extended his lower frequency

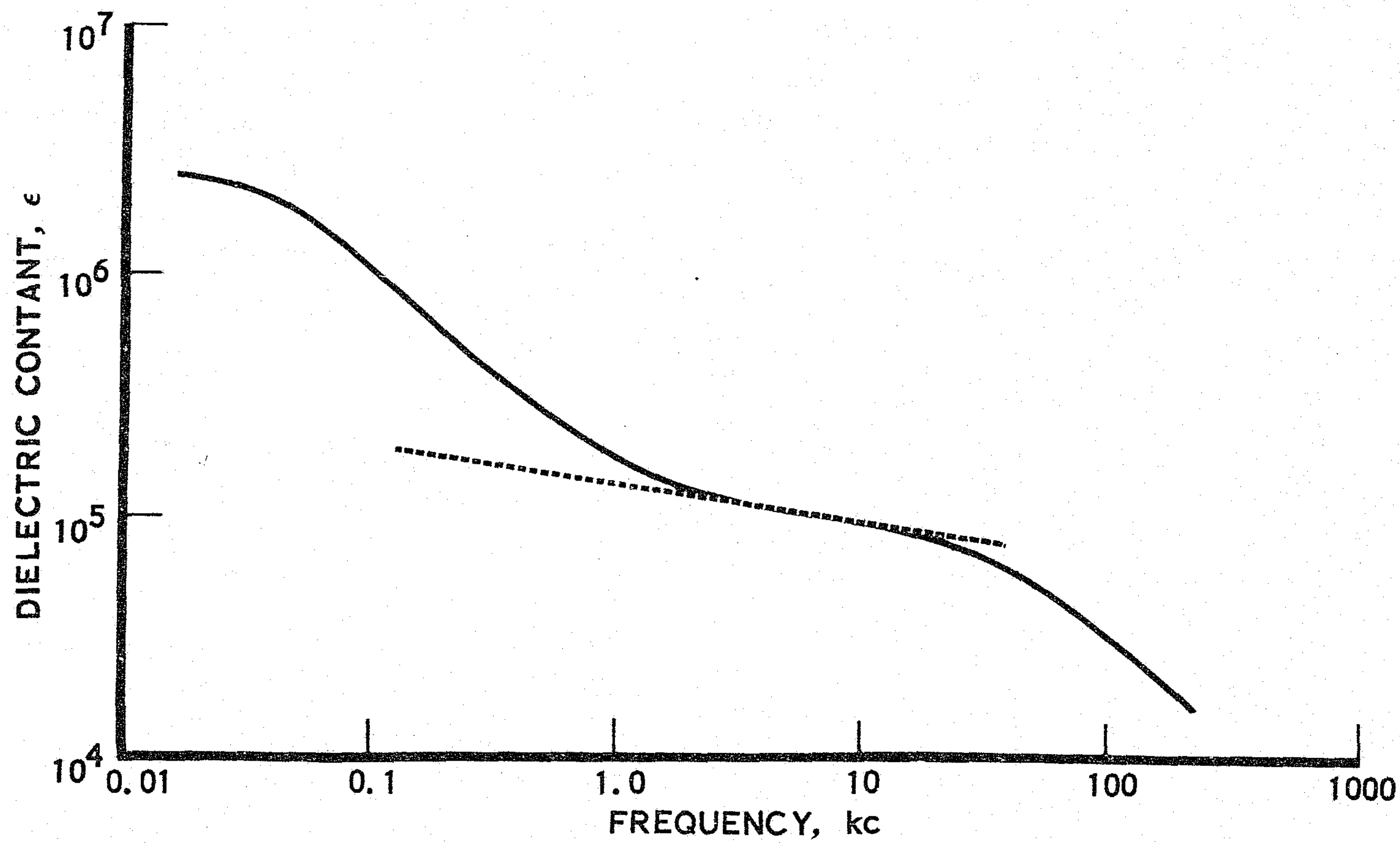

Figure D-1. Dielectric Constant of Muscle Tissue in the 20-cps to 200-kc Frequency Range. (The Dielectric Constant Reaches Enormous Values—Exceeding One Million—at Low Frequencies.)

limit to 10 Hz in separate tests[D-3] on live animals and observed a decrease in ϵ to 10^6, which may have resulted from a variation in either the method of measurement or the specimen condition. As the observation frequency approaches zero, ϵ would be expected to remain very large ($\sim 10^6$).

A reasonable geometric representation that may be used to analytically describe the shape of a human or household pet is an ellipsoid of revolution. In the case of a man walking, the major axis of the ellipsoid is vertical; for a pet, the long axis is horizontal. This distinction in major axis orientation is significant in computing the electrostatic distortion produced by the presence of an animal because an electrostatic influence detector will usually be located either at or above an individual's head level or near the floor. In both cases, ellipsoidal end effects field distortion dominates the field perturbation pattern. In Fig. D-2, the vertically oriented dielectric ellipsoid representing a man of height 2a and chest width 2b is shown standing in the y-z plane. The electrostatic field of the earth E_{ox} is vertical. The electrostatic dielectric constant of the body is labeled ϵ_1 and that of the air ϵ_2.

1. Analysis

Two means are available for electrically detecting the presence of a dielectric body that has caused a displacement in the earth's electrostatic field. One means, a capacitive detector, directly measures the current produced in a load resistor by the change in electric charge on the terminals of the capacitive pickup. The second method is magnetic induction; it

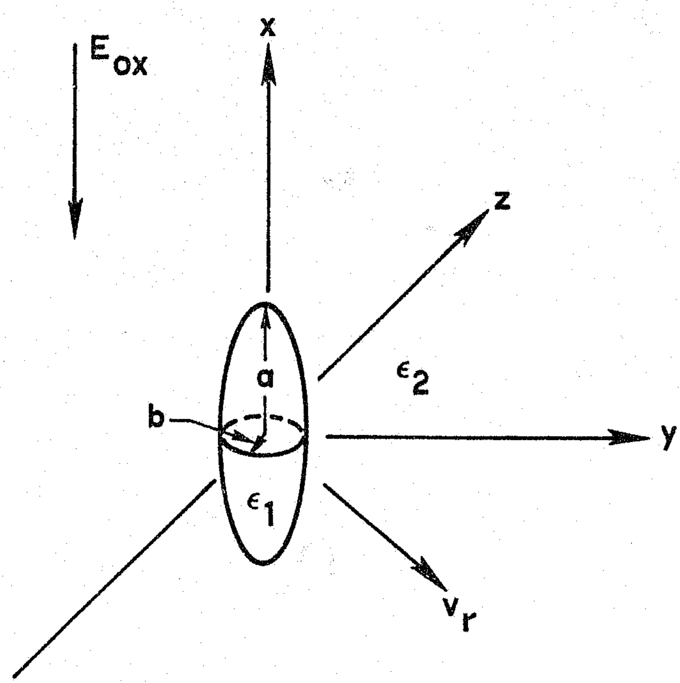

Figure D-2. Dielectric Body in the Earth's Electrostatic Field employs an inductive loop detector to sense a change in the magnetic field generated by a perturbation of the earth's ambient electrostatic field in the vicinity of a moving dielectric body. A third possible detector category might combine the above methods, e.g., the use of a capacitive input coupled to a twisted pair antenna. Only the first two detector options have been examined at the present time.

2. Capacitive Detector

The diagram in Fig. D-3 shows the essential elements of a capacitive detector. It consists of an input capacitor of capacitance C and average terminal separation d across which a changing electric field $\dot{E}_{ex}$ is applied.

The current I flowing in load resistor R_o as a function of the charge on C, E_{ox}, and the circuit parameters is

$$I = \frac{dQ}{dt} = \dot{Q} = C\dot{V} = C \frac{dE_{ex}}{dt} d = C\dot{E}_{ex} d$$

The time variable vertical component of the electric field $\dot{E}_{ex}$ is related to body motion in the r direction as

$$\dot{E}_{ex} = \frac{dE_{ex}}{dt} = \frac{\partial E_{ex}}{\partial r} \cdot \frac{\partial r}{\partial t} = v_r \frac{\partial E_{ex}}{\partial r} \qquad \text{(D-1)}$$

Finally, the detected output voltage V_o is

$$V_o = R_o C d v_r \frac{\partial E_{ex}}{\partial r} \qquad \text{(D-2)}$$

The direction of body motion that can produce a finite value of V_o is unrestricted for a generally shaped dielectric body. In the geometry of

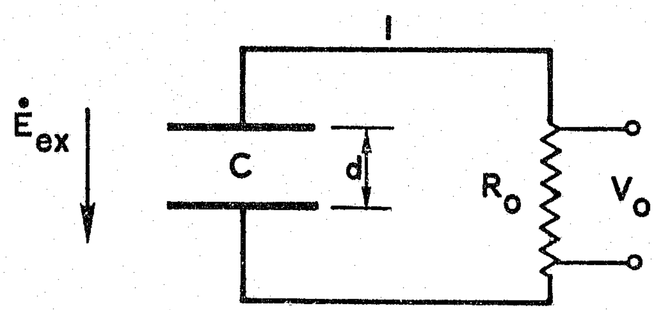

Figure D-3. Capacitive Detector

Fig. D-2, body motion is most conveniently represented as lying in the horizontal plane v_r. The most significant quantity appearing in Eq. (D-2) is the horizontal derivative of the vertical component of the earth's electric field $\partial E_{ex}/\partial r$. The determination of this horizontal gradient of E_{ex} represents the principal effort in the analysis.

For the ellipsoid of Fig. D-2, the vertical electric field exterior to the body is given by[D-4]

$$E_{ex} = E_{ox} \frac{1 + \frac{ab^2}{2} \cdot \frac{\epsilon_1 - \epsilon_2}{\epsilon_2} \int_o^{\xi} \frac{ds}{R_s (S + a^2)}}{1 + \frac{ab^2}{2} \cdot \frac{\epsilon_1 - \epsilon_2}{\epsilon_2} \int_o^{\infty} \frac{ds}{R_s (S + a^2)}} \qquad \text{(D-3)}$$

where

$$R_s = (S + b^2) \sqrt{S + a^2} \qquad \text{(D-4)}$$

and ξ is the ellipsoidal coordinate variable defined by the parametric equation

$$\frac{x^2}{a^2 + \xi} + \frac{r^2}{b^2 + \xi} = 1 \qquad \text{(D-5)}$$

where r^2 has been set equal to $y^2 + z^2$. The coordinates x and r represent the vertical location of the detector and its lateral displacement, respectively, each measured from the body center. Solving Eq. (D-5) for ξ yields

$$\xi = \frac{-\hat{F} \pm \sqrt{\hat{F}^2 - \hat{G}}}{2} \qquad \text{(D-6)}$$

where

$$\hat{F} = a^2 + b^2 - x^2 - r^2$$

$$\hat{G} = a^2b^2 + a^2r^2 - a^2b^2$$

From Eq. (D-6)

$$\frac{\partial \xi}{\partial r} = \frac{2\,ra^2 + r\left[-\hat{F} \pm \sqrt{\hat{F}^2 - \hat{G}}\right]}{\pm\sqrt{\hat{F}^2 + 4\hat{G}}} \qquad \text{(D-7)}$$

which is required to obtain $\partial E_{ex}/\partial r$ from

$$\frac{\partial E_{ex}}{\partial r} = \frac{\partial E_{ex}}{\partial \xi} \cdot \frac{\partial \xi}{\partial r} \qquad \text{(D-8)}$$

$\partial E_{ex}/\partial \xi$ is obtained from Eq. (D-3) as

$$\frac{\partial E_{ex}}{\partial \xi} = \frac{E_{ox}\,\frac{ab^2}{2}\,\Delta\epsilon}{(\xi + a^2)^{3/2}\,(\xi + b^2)\left[1 + \frac{ab^2}{2}\,I \cdot \Delta\epsilon\right]} \qquad \text{(D-9)}$$

in which the representations

$$\Delta\epsilon = \frac{\epsilon_1 - \epsilon_2}{\epsilon_2}$$

and

$$I = \int_0^\infty \frac{ds}{R_s\,(s + a^2)} \qquad \text{(D-10)}$$

have been used.

The quantity $\partial E_{ex}/\partial r$ is obtained by substituting Eqs. (D-7) and (D-9) into Eq. (D-8) and taking the principal roots of the radicals as

$$\frac{dE_{ex}}{\partial r} = \frac{E_{ox}\, ab^2 \Delta\epsilon \left\{2ra^2 + r\left[-\hat{F} + \sqrt{\hat{F}^2 - \hat{G}}\right]\right\}}{2\left(1 + \frac{ab^2}{2} I\Delta\epsilon\right)\sqrt{\hat{F}^2 - \hat{G}}\left[a^2 - \frac{1}{2}\left\{-\hat{F} + \sqrt{\hat{F}^2\hat{G}}\right\}\right]^{3/2}\left[b^2 + \frac{1}{2}\left\{-\hat{F} + \sqrt{\hat{F}^2 - \hat{G}}\right\}\right]} \tag{D-11}$$

Both the definite integral I of Eq. (D-10) and the horizontal gradient of E_{ex}, Eq. (D-11), must be evaluated numerically. Real solutions for Eq. (D-11) are found to exist from an examination of the discriminant, subject to the constraints

$$r > b > \sqrt{2}\, x$$

$$r > a \tag{D-12}$$

The definite integral I of Eq. (D-10) was evaluated using sixth-order Gaussian quadratures with nonuniform integration intervals adjusted to produce approximation accuracy of 1 part in 10^6.

The field gradient Eq. (D-11) is a nonlinear function of detector separation, which decreases rapidly with r. The evaluation of Eq. (D-11) as a function of r was allowed to proceed in steps equal to b until the value of $\partial E_{ex}/\partial r$ changed less than 0.01%. For all computed results presented, the following parameters were used:

E_{ox} = 150 V/m

ϵ_1 = 10^6

2a = 6 ft (body height)

2b = 20 in. (body chest width)

The results for the detected voltage V_o applicable to the capacitive detector are presented in the table following the summary discussion.

3. Calculated Results for Typical Detector Characteristics

Table D-1 presents the parameter values assumed in the associated calculations for the capacitive detector.

Table D-2 summarizes the values of computed V_o as a function of detector separation distances r.

A rapid decrease in detected voltage is observed to occur (Table D-2) with increasing detector separation distance. As the separation distance changes from 10 in. to 13 ft, the detected signal drops by 65 dB.

4. Summary

The electric influence detector has been analyzed to determine the respective range-dependent sensitivities to the movement of a human or animal body in their vicinities. A capacitive detector is shown to be capable of producing a substantial detected voltage at separation distances at least as great as 13 ft from a slowly moving human. The physical effect by which these signals are produced is the perturbation of the earth's surface electric field caused by the presence of a sizable body with a very large low-frequency dielectric constant.

The calculation reveals that the detectable signals decrease very rapidly with the detector separation distance. For a detector located 4 in. from the floor, the detectable signal level decreases 65 dB as the separation distance enlarges from 10 in. to 13 ft.

Table D-1. Detector Height 10 Centimeters Above the Floor

Capacitive Detector:
$C = 10$ pf
$R = 10$ MΩ
$d = 1$ mm
$v_r = 1$ mi/hr $= 1.5$ ft/sec

Table D-2. Detected Signal from a Moving Man[a]

Separation Distance r,m	Capacitive Detector V_o, mV
0.25	270
0.5	61
1.0	13
1.5	4.2
2.0	1.7
2.5	0.85
3.0	0.45
3.5	0.26
4.0	0.16

[a]Detector height = 10 cm above the floor.

NOTES

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