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STUDY OF TACTICAL MOVEMENT CONCEPTS AND PROCEDURES FOR CIVIL DEFENSE PLANNING

by

W. A. Hamberg, A. M. Salee,
and R. H. Watkins

31 August 1963

Prepared under Contract OCD-OS-62-187
for Director of Research, Office of Civil Defense
Department of Defense
Washington 25, D.C.

OPERATIONS RESEARCH, *Incorporated*
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ABSTRACT

A study was made of the factors and determinants that affect the emergency movement to shelters of urban populations under conditions of little or no warning. An analytical model was developed to determine the number of people arriving at shelter as a function of time. The efficacy of this model was demonstrated by the proof-testing of it on three selected cities. The method is general in nature and permits practical application in analyzing sheltering capabilities under varying conditions of weather, seasons, and days of the week. Techniques are developed for determining postures (i.e., activity and place) of the major elements of the population, and by integrating these postures the distribution of the population at any selected moment is determined. An example of a "hand" solution of the model is presented in detail for one city; results are shown for three cities. General conclusions and recommendations are delineated; suggestions are made for future application and exploitation of the method and techniques for the evaluation of sheltering policies and operating plans.

ACKNOWLEDGMENTS

The authors wish to acknowledge and express their appreciation for the invaluable advice and assistance rendered by their associates. Dr. T. L. Newberry, Mr. J. C. Edenfield, and Mr. D. T. Kelley conducted the experiment reported in Appendix E, and Mr. Robert R. Hare, Jr., and Mr. Patrick M. Gordon developed the general mathematical model described in Appendix F. The major portion of the great volume of detailed calculations was accomplished by Mrs. Dorothy Watters Scheid. Mr. Stanley R. Parent and Mr. Ronald D. Lipps were very helpful in the correlation of data and the preparation of the final report. The bulk of the editorial work was accomplished by Mrs. Marilyn L. Taylor. Throughout the progress of the work the group leaned heavily on the technical direction of Mr. J. B. Talbird, Program Director, and Dr. Harold O. Davidson, Vice President. Finally, the work could not have been completed at all, without the patience, advice, and helpful assistance of Mr. Herbert E. Kunde and his associates in the Office of Civil Defense. To all those mentioned above as well as others who helped with the project, the authors are grateful.

SUMMARY

1. This study is concerned with civil defense aspects of the movement of large numbers of people from where they are to a place of shelter or refuge. This movement was considered to be of an emergency nature with relatively short warning times and with the likelihood of fallout arriving in a few hours or less. Thus the problem is one of analyzing the movement of a fast reacting public to shelters within their own urban community. This short, fast movement was referred to as tactical evacuation. Although the study covered many facets of the tactical evacuation problem, two interrelated objectives stand out as dominant:

a. The formulation of a method to estimate the population configurations of urban areas.

b. The mathematical treatment of the movement of urban populations — whether their destinations are shelters in the immediate vicinity or centers for redistribution to more remote areas. In addition, the report deals with a number of tasks related to the problem of the tactical movement process.

2. Two major constraints were placed on the nature of the mathematical techniques employed in this study:

a. The input data descriptive of the particular area being analyzed should be reasonably available.

b. The mathematical method should be such that manual computation is feasible.

3. The technique developed combines readily available statistics on population and shelter characteristics with various general inputs concerning population distribution and response characteristics. Since many of the general input data are not available now, assumed values, based on judgment and experience, have been used where necessary. A minimum of statistical assumptions is made concerning the character of the data, and the method easily allows the substitution of empirical data, if available. Furthermore, the method is capable of reflecting a wide range of population and urban characteristics that would influence the movement process.

4. Three cities are analyzed according to the method developed in this study. This analysis of selected cities was primarily undertaken to test the developed method's adaptability to urban areas of differing character. Although the results of this preliminary analysis can scarcely be considered definitive, they do show that the method developed is sensitive to various urban characteristics and is applicable to any selected local area.

5. With regard to the model, the report concludes that its validity is sufficient to warrant further application, and that it is suitable for extension toward measures of effectiveness more sensitive than the current time-oriented sheltering rates. The most suitable measures would be based on the concepts of overall probabilities of survival. Information of this nature would provide the most significant cost-effectiveness criteria for determining the feasibility of future shelter policy and improvement of operations in selected local areas.

6. Owing to the prototype nature of this study, only tentative conclusions can be shown regarding the specific areas analyzed. However, the analysis of the three cities does serve to support the following general conclusion about the movement process.

a. Under conditions of short warning times a well-disciplined and well-trained population can move to shelters in a reasonably short period of time, provided there are sufficient shelters available and panic conditions can be avoided or alleviated.

b. Shelters on the periphery of urban areas would offer little improvement over the present conditions (Phase II) where the shelters are concentrated mainly in the central business districts. The greatest number of people per time interval can be sheltered when shelter locations more closely correspond with the resident population distribution.

c. The physical movement of large groups of people over short distances will very likely be at a walking speed, since traffic densities and management of other means of transport will very quickly degenerate into a pedestrian situation.

d. Changes in the nature of the threat trend toward shorter warning times. The current threat is for most practical purposes just at the threshold point; i.e., movement times for the mass of the population from time of warning to time of sheltering is already measured in minutes.

e. Weather, traffic, and other environmental conditions will affect the warning, reaction, and movement times. Analytically this effect can be determined by varying the input parameters of the movement model described in this study. Weather will affect warning time and movement velocity. Traffic will be mainly pedestrian. Night and day, day of the year, and season will change the "posture" and relative location of the urban population. Also they will have some influence on the sheltering rate of urban areas, although the net overall effect does not appear to be significant for the normal range of environmental conditions.

f. Tactical movement concepts and procedures that may improve lifesaving potentials of sheltering complexes include shelter assignment plans, public orientation and training, practice alerts and movements, improved location of shelters, and traffic direction and control.

7. The foregoing conclusions are based on the analysis of the three cities, but are believed to be generally valid for most areas and conditions. Resort areas that have abnormal changes in seasonal populations, as well as areas under the impact of other emergency conditions such as floods and storms, will probably be exceptions

to these conclusions. When considering the national population, these exceptions are not likely to be significant percentagewise. Therefore the following recommendations are offered:

a. Continue the shelter marking and stocking program but give increased attention to matching shelter location to normal population distribution.

b. Continue to investigate and evaluate shelter assignment plans, but also include increased training and better traffic direction and control methods.

c. Consider the overall measure of effectiveness as <u>the number of people sheltered as a function of time.</u>

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I. INTRODUCTION

1.1 The civil defense problem today, and for the foreseeable future, is a product of the nuclear weapon threat of a general war. Of course, other agents of disaster and public catastrophe might bring the civil defense organization into action, but the mere possibility of the nuclear megaton attack dominates and sets the dimensions of the overall problem. No government can avoid the responsibility of taking all reasonable measures to improve the probability of survival of its people from whatever threat—nuclear or other attacks, disease or pestilence, or natural disaster. In our society the civil defense organization is established and maintained primarily to alleviate the impact of the first threat, and having attained a capability in this respect, it is well prepared to meet its responsibilities when natural disasters strike.

1.2 The existence of a viable, useful, and healthy society after a major disaster presupposes some means of preserving and safeguarding the population. This means that before or in the very early phases of an attack, the population must have and must understand the means of avoiding the attack or of protecting themselves from its effects. The process of avoiding the effects could involve either the movement of large numbers of persons completely away from the threatened area or the provision of local protection. An optimum protection strategy must allow for the possibility of various combinations of these alternatives to meet varying emergencies. It must also be dynamic and responsive to changes in the character and degree of the threat as well as in the condition, attitude, and posture of the people. Owing to increased capability of weapon delivery and the consequent possibility of greatly reduced warning time, it seems likely that considerable reliance will have to be placed on the provision of local protection that a population can achieve in a relatively short time. This report deals chiefly with this problem.

1.3 The protection of the people from the effects of nuclear radiation that results from fallout is only one aspect of the civil defense problem. Because large numbers of people are involved, the need for reaching protection with a minimum amount of radiation exposure and the necessity of remaining in the protective environs (shelters) for a substantial period of time are major aspects of the problem from a cost, control, and logistics viewpoint. Nothing is foreseen that will simplify this problem. On the contrary, weapon technology and military tactics are more likely to complicate it.

1.4 The sheltering process can be considered as a number of subprocesses, some sequential in nature and others with complicating interactions. At the risk of oversimplification, one can look at the sheltering problem in five parts:

a. The need to make the public aware of the danger and the importance of taking action.

b. The response of the individuals to this information.

c. The movement to a place of shelter.

d. The reception and housing in the shelter system.

e. The recovery and rehabilitation after the danger has subsided.

1.5 The Office of Civil Defense (OCD) research studies are concerned with all these areas. However, this study is concerned only with the second and third parts and with the response aspect as it serves as an input to the movement problem.

1.6 Thus the problem that Operations Research Incorporated has attempted to solve is concerned principally with the actions and movement of people from where they are at the instant of "becoming aware" to the time they arrive at a shelter entrance. In the approach to this problem other corollary and supporting tasks were performed and are described within the text of the report. These are as follows:

a. Review and summarization of previous evacuation studies and plans.

b. Updating of evacuation capabilities as a function of warning time.

c. Consideration of the actual and/or potential availability of community fallout shelters on the periphery of urban areas.

d. Evaluation of the traffic, transportation, management, and other problems involved in movement of large groups of people over short distances to community shelters.

e. Projection of current and potential evacuation capabilities as a function of change in threat and of progress in shelter programs.

f. Evaluation of the lifesaving potential of tactical evacuation[1/] procedures under varying weather, traffic, and other environmental conditions.

g. Recommendation of tactical evacuation concepts and procedures that may be adopted to augment the lifesaving potential of shelters.

h. Analysis of a number of typical densely populated areas in which actual or potential community fallout shelters are available.

i. Investigation of the feasibility of emergency movement of large numbers of people for very short distances to shelter to achieve more balanced population densities.

j. Consideration of daytime or nighttime population differentials and other factors that markedly increase or decrease the population densities.

k. Experimental measurement of the distribution of prepare-to-move times for a sleeping at-home population.

1.7 Appendix A, "Review of Related Studies," deals with task a. and Appendix G, "Balancing Population Densities," with task i. The experimental investigation mentioned in task k. is included in Appendix E,

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1/ The terms "tactical evacuation" and "tactical movement" are used synonymously throughout this report.

"Experimental Measurement of Time Required for an At-Home Sleeping Population to Prepare for Movement to a Civil Defense Fallout Shelter."

1.8 The other tasks enumerated have been treated in relation to the central problem of the tactical movement of populations. They have been considered especially with regard to how they affect the movement process or are affected by it. The concept of lifesaving potential in tasks f. and g. has been replaced by the concept of sheltering rate, which is at least roughly correlated with it. This was necessitated by the exclusion of the last two parts of the sheltering process (see paragraph 1.4) from the scope of this study. Further, to investigate directly the concept of lifesaving potential, detailed information on the character of the shelters would be necessary together with hypothetical attack patterns and assumed interrelations between attack pattern and shelter characteristics.

1.9 The principal output of the movement analysis is the number of persons sheltered as a function of warning time and is directly related to tasks b. and e. Task j. is considered in Section II, "Population Analysis," and task d. in Section III, "Tactical Movement." Task h. is performed in Section IV, "Analysis of Three Cities;" task c. was treated in the analysis of Tampa by examining the effect of peripheral shelters on the movement process.

1.10 The solution to the movement problem was accomplished by the development and proof test of a mathematical model that describes the significant processes that take place. This model was first developed in prototype form and pilot-tested on the city of Milwaukee. After several modifications, it was considered ready for full-scale application on three cities selected in conjunction with officials of OCD. The cities were Milwaukee, Salt Lake City, and Tampa. The results of these exercises are described in Section IV. A draft report of the general model itself was published in November 1962 and, because it was needed by other contractors, was distributed for their use as requested. The report is now included as Appendix F and further separate publication is not contemplated.

1.11 The specific technique used in this analysis is contained in Appendix B. Although the model has since been programmed and is running on the IBM 1620, it is basically designed for hand computation using standard mathematical tables and mechanical desk computing machines. The results and techniques used in this study and described in this report were accomplished by this method. This technique and method do not depend on highly sophisticated people or machines, but can be used as a planning and operating tool by an ordinary engineering or technical staff.

1.12 The quantitative results contained herein are shown for illustrative purposes only. They emanate from assumed input data, which may or may not be valid for purposes other than the proof-testing of the model. Furthermore, until a sensitivity analysis has been made for the entire process, it would be difficult to judge the effect of individual errors in input data or of disagreements that the reader might have with any assumed value.

1.13 The essential elements of the problem were solved, proved, and disseminated by March 1963. This made it possible to exploit and apply the method to a large-scale planning project covering Montgomery County, Maryland. This application will be covered in other reports, but it is pertinent to note here that, although the model was intended to cover urbanized areas, it was readily usable for a county that consists of the complete range of rural, suburban, and urban areas.

1.14 The following sections are organized to present a logical description of the analysis and research. Insofar as practicable, the voluminous details and tabulated data have been omitted[2/] and only significant results presented. Section II describes the philosophy and mechanics of analyzing the population's response actions. It also describes the development of the input data required for the movement analysis. The third section covers the tactical movement model and its application. At the risk of some oversimplification, this section has avoided mathematical sophistication and treats the problem from a practical viewpoint. The technical backup is contained in a supporting appendix. The fourth section deals with the analyses of the three cities and covers in detail the analysis of Salt Lake City. This is included to provide an example of the methods of computation recommended. A fifth section discusses other applications of the methods and suggests areas for further research. The last section contains the conclusions derived from the research and analysis.

2/ Operations Research Incorporated will maintain all worksheets and data for a period of 1 year. Then they will be destroyed, or disposed of, in accordance with instructions from OCD.

II. POPULATION ANALYSIS

INTRODUCTION

2.1 The mathematical treatment developed in this study consists of two major elements: a population analysis and a movement model. The function of the population analysis is to develop detailed population configuration inputs to the movement model. This section discusses the general outlines of the population analysis and Section III deals with the movement model. A more mathematical treatment of both can be found in Appendix B. For a detailed calculation for Salt Lake City consult Appendix C.

2.2 Each of the two phases of the analysis is conceptually independent of the other. The output of the population analysis consists of information that may be of interest apart from its subsequent use in the movement model. Actual demographic surveys, if available, could replace the population analysis as inputs to the movement model.

2.3 Since the subsequent analysis consists of a mathematical treatment of the transfer of an alerted and presumably endangered population from its normal configuration to one or more destinations of greater safety, the technique of population analysis as developed here is an attempt to describe these spatial distributions in such a manner that, regardless of the time of alert, reliable input information can be supplied to the movement model. Further, it attempts to supply certain detailed information on the distribution of situations or conditions that will influence the response of a population to an alert.

ANALYSIS

2.4 The population configuration of any area is obviously not static. It is both directly and indirectly time-dependent in a highly complicated manner. Currently available data are not immediately applicable to this problem. Whereas Bureau of the Census data are relevant to population activities and characteristics, they are restricted to residents and do not reflect time dependencies. Peak population estimates do attempt to establish an upper bound, but they are inadequate as a continuous description.

2.5 The general time-dependent nature of urban population configurations is perhaps best described in terms of working and nonworking groups. Those at work will be found in greatest concentration in the major business section of the city and in minor concentrations in industrial areas. Even during normal nonworking hours, these areas will still have greater numbers of workers than other areas of the city. Nonworking groups may be sorted into groups that are at home, shopping, in transit, or in some other nonworking, not at-home posture. The number of people in each category fluctuates during the day. At midday, many people will be shopping, whereas the in-transit group swells during morning and evening rush hours. As the evening rush hour progresses, the in-transit group spreads out more uniformly over the city.

2.6 The most important difference between daytime and nighttime configurations lies in the number of people found in industrial and business areas, the population of which is mainly drawn from the residential portions of the city. From daytime to nighttime, therefore, population densities will change sharply in the relatively small business and industrial areas, but will experience more moderate changes in primarily residential areas. See Figures 1a and 1b for an illustration of this effect in Salt Lake City, Utah.

2.7 In addition to the daily fluctuations in population distribution there are slower frequency variations. First are the differing configurations of week-end and weekday populations. Second are the seasonal variations, especially of school populations. Finally, there are holiday populations, which will probably differ significantly from week-end populations only on certain holidays.

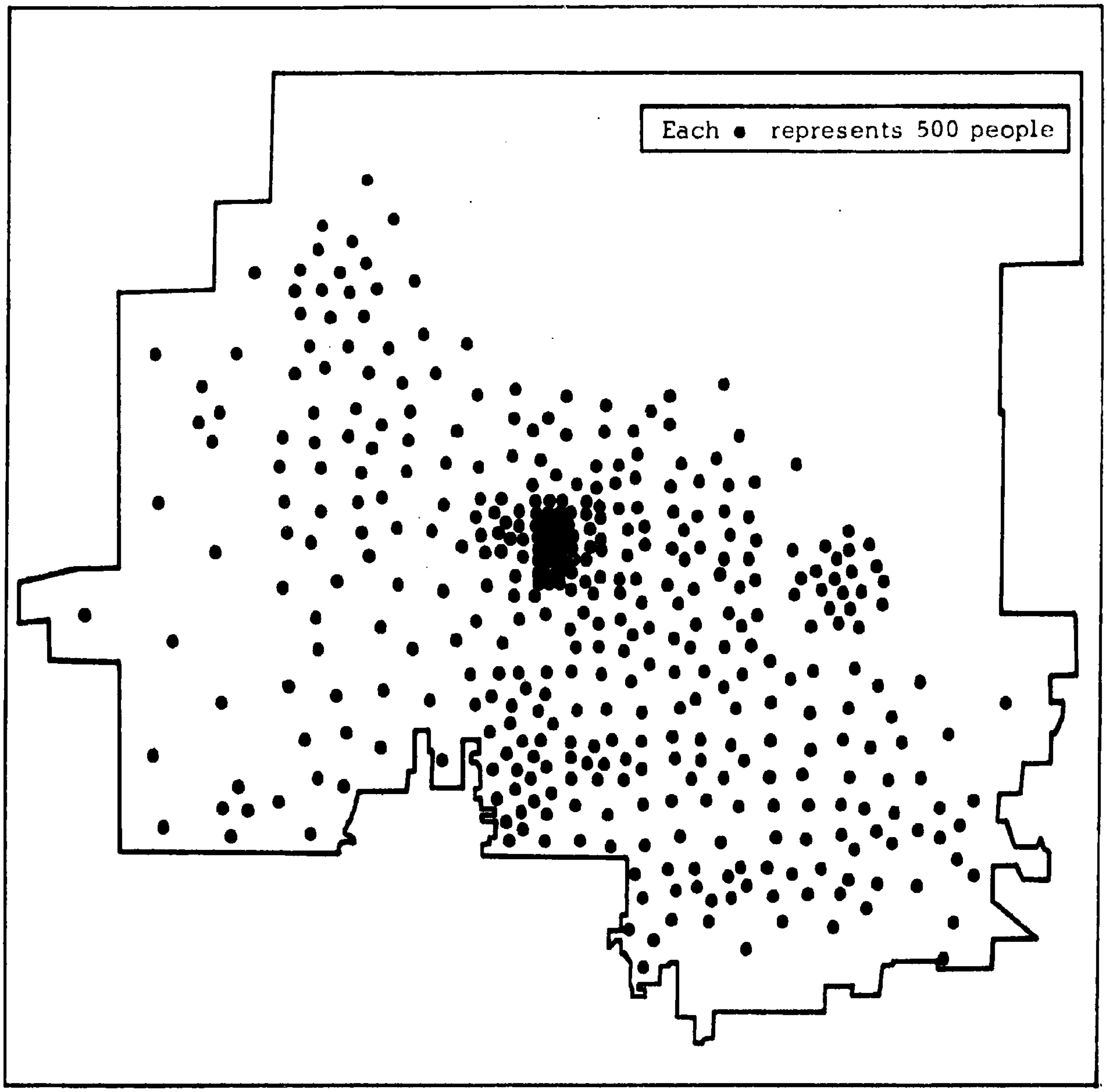

FIGURE 1a. DAYTIME POPULATION DISTRIBUTION, SALT LAKE CITY

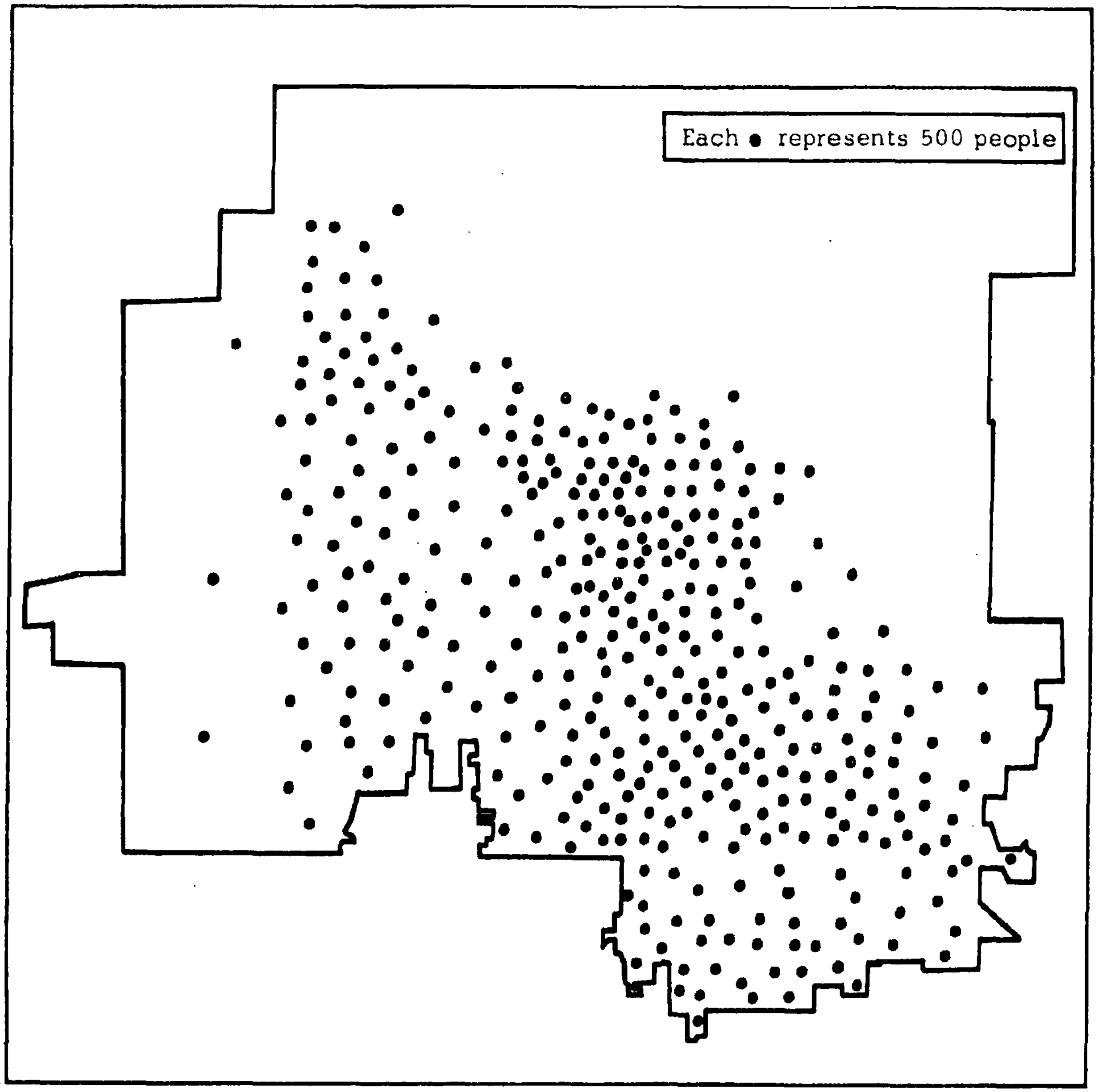

FIGURE 1b. NIGHTTIME POPULATION DISTRIBUTION, SALT LAKE CITY

2.8 Since the purpose of the population analysis is to determine the prealert characteristics of the population in detail, it is necessary that the region under consideration be divided into smaller areas. The smaller areas, which must conform to areas for which population statistics are available, will be referred to as subareas. The analysis should be performed on as small segments as possible. If a computer is used, each subarea should contain one census tract. However, if the calculation is done by hand, the labor of computing for so many subareas would be prohibitive, and it would be necessary to group census tracts of similar characteristics.

Postures

2.9 Although the most basic requirement is information on the number of persons in each subarea at the time of the alert, it is also necessary to have information on the population by significant subgroups or "postures." For the purpose of the study a posture is defined as any recognizable segment of the population whose response to a warning to move differs significantly from the responses of other segments (e.g., different responses can be expected from persons at home depending on whether they are awake or asleep).

2.10 Identification of Postures. The technique used in this study was to identify a large number of postures for a tentative determination of the response of persons in each of them. Initially 19 postures were identified and chosen, as follows:

1 to 4 — Business workers, cross-classified by location, i.e., whether in central business district or outside of it, and whether indoors or outdoors;

5 to 8 — Industrial workers, in central business district or outside, indoors or outdoors;

9 to 12 — Persons in public place, employed or transient, indoors or outdoors;

13 to 14 — Persons at home, awake or asleep;

15 to 16 — Persons at recreation, local or remote;

17 — Persons in transit;

18 — Pedestrians on streets;

19 — Persons at school.

The existence of special groups, such as persons in hospitals, was recognized, but this small fraction of the population was not considered. Other probably significant means of classification, such as age, family size, or possession of private vehicles, have also been neglected in this application.

2.11 After a preliminary analysis (for a discussion of the techniques see paragraph 3.13) in which the movement characteristics of the postures were estimated, the following seven postures were chosen for final analysis:

a. At home, awake;

b. At home, asleep;

c. Business workers, indoors;

d. Industrial workers, indoors;

e. Public place, indoors;

f. Public place, outdoors;

g. At school.

Many more postures than these could have been carried into the final analysis. However, because of the lack of empirical studies in this area, it is doubtful, for the present at least, that a finer analysis would be beneficial.

Population Allocations

2.12 Since basic census data are enumerations of residents of given areas, these figures are not directly usable in describing the actual number of people within a subarea as a function of time, nor do they give immediate information about the postures of the population. The approach in this analysis has been to combine census data on the employment and general characteristics of the population with data on land-use types in order to estimate the actual time-dependent distribution of people over the subareas. Peak population estimates have been used, where available, as a check on the accuracy of the results.

2.13 The subarea data used are as follows:

a. Resident population;

b. School-attending population;

c. Employed population;

d. Total land area;

e. Land area, classified by usage type, i.e.,

(1) Industrial,

(2) Commercial,

(3) Local business and shopping.

2.14 In addition, the following data on the area as a whole are required:

a. The total number of jobs held within the area.

b. The number of residents holding jobs, classified by occupational categories of mining; construction; manufacturing; railroad and Railway Express; other transportation; communication, utility, and sanitary; wholesale trade; eating and drinking places; other retail trade; business and repair services; private household; other personal services; hospitals; educational services; other professional and related services; public administration; other industries.

2.15 The analysis as described here was performed for a typical weekday with school in session. It was made for three times of day, 2:30 a.m., 11:00 a.m., and 5:30 p.m. These times should not be regarded as unique instants but rather as representative of important recurrent phases of the population distribution.

2.16 The approach taken to the problem of population analysis has been straightforward in essence, although somewhat complicated in detail. The population was divided into two groups: one group considered to remain within its resident subarea and a second group, consisting both of residents and nonresidents, distributed over all subareas. For the distributed group a density was determined by dividing the total number of people in any one activity group by the total urban land area of usage type relevant to that activity. This density was then multiplied by the appropriate land area within each subarea to produce an estimate of the number of people of a given activity group within a given subarea.

2.17 The population was first divided into three major segments:

a. Persons at school;

b. Persons at work;

c. "Free" population, those neither at work nor at school.

The school population was assumed to be entirely within its resident subarea when at school and was estimated by means of an assumed function giving the fraction of school-age persons at school at any time. Similarly, a function was assumed giving the fraction of employed persons at work at a given time. Those at work were assumed to be distributed over those subareas containing business, commercial, or industrial area. The free population of a subarea was taken to be the total resident population of that subarea less those residents actually at work or at school. This group was partly distributed over the entire area and partly allocated to its resident subarea.

2.18 Treatment of Employed Population. Nonresident employees were assumed to be distributed into employment categories in the same ratio that resident employees were. This assumption, together with the data on the number of resident employees by occupational categories and the distribution of employed persons at work at a given time, made it possible to calculate the number of people actually at work within the area in a given category at a given time. The numbers of people at work in each of the sixteen occupational categories were allocated to major employment locations. For this analysis the five employment locations chosen were as follows:

a. Industrial workers, indoors;

b. Industrial workers, outdoors;

c. Business workers, indoors;

d. Business workers, outdoors;

e. Public place workers, indoors.

2.19 Treatment of Free Populations. The free population within each subarea was allocated to the following activity groups:

a. At home, awake;

b. At home, asleep;

c. At recreation;

d. In stores;

e. In transit;

f. On streets.

2.20 Determination of Densities. The various population segments that have been enumerated so far were either attributed to their resident subareas or distributed over the following categories:

a. Business workers, indoors;

b. Industrial workers, indoors;

c. Public place, indoors;

d. Business workers, outdoors;

e. Industrial workers, outdoors;

f. Public place, outdoors.

The various distributed elements were summed over all subareas. A density in people per square mile for a category was determined by dividing the total population in that category by the total land area of relevant usage type.

2.21 Final Distribution. For each subarea the number of people distributed into it by postures was calculated by multiplying the population density of a distributed posture by the amount of land within the subarea of the relevant land-use type. This, together with the previously calculated number of people remaining in the subarea, gives the final result of the population analysis which is for any subarea, the number of persons who are

a. At home, awake;

b. At home, asleep;

c. At school;

d. Business workers, indoors;

e. Industrial workers, outdoors;

f. In public places, indoors;

g. In public places, outdoors.

III. TACTICAL MOVEMENT

INTRODUCTION

3.1 As used in this report a tactical movement may be considered to be the movement of a previously unsheltered urban population under conditions of little or no warning. It is assumed that at the beginning of the alert the population is in its normal configuration for that hour and that day. The destination of this movement may either be a permanent or temporary shelter or an assembly point from which people will be redistributed.

3.2 This section consists of an outline of an analytical treatment of the movement to shelter. This analysis will primarily result in a mathematical function relating the number of people sheltered to a measure of time after some initial event (t_o); a secondary output will be the number of people in transit to shelter as a function of time. Appendix B contains the mathematical presentation of the method.

3.3 The use of the technique in this report does not fully exploit its ability to represent real situations. The explicit examples considered are exercises of the technique to determine the general character of the results rather than full-scale applications. The simplifications in this treatment are of several types: (a) in most instances experimentally measurable data have been replaced by assumed inputs; (b) some quantities that the model allows to be treated as variables have been replaced by constants; (c) fine details of topography, shelter distribution, and population configurations that the technique can utilize have been avoided.

MOVEMENT

3.4 The movement model as used in this report includes more than an analysis of the physical movement of the population. The range of time over which it extends is from t_o, which is the first sounding of public warning on local level, to a cutoff time that is reached when all the population has arrived at the destination of its movement. The initial instant could have been chosen to be a time other than the one used in this study; however, t_o should satisfy two criteria:

a. It should be a unique, recognizable instant with respect to the analyzed area.

b. It should occur before any movement has started.

The t_o used in this study is the latest instant that meets both of these conditions.

3.5 The time consumed by an individual between t_o and his arrival at final destination has been divided into three components:

a. Warning time t_w, the time between t_o and the correct interpretation of the warning signal;

b. Preparation time t_p, the time between correct interpretation and the initiation of movement;

c. Movement time t_m, the time between initiation and termination of movement.

Warning

3.6 Since this report considers the initial time of the analysis to be the first sounding of the public alarm, it is not necessary to consider the length or variability of time between whatever observation initiates the alert for the country as a whole and the initial time chosen for this analysis. However, this time span could be brought within the scope of the analysis by a redefinition of the initial event. Then warning time t_w for any member of the population will be the sum of the time between the general initiation of public warning and the sounding of it in his vicinity and the time between that instant and his correct interpretation of the warning.

3.7 Dissemination. Virtually all currently operational warning systems are of the sirens or indoor gongs or lights and are controlled by local authority. The alarm system within an area may be centrally controlled or the system may have several control centers. In the latter, the sounding of an alarm may not be simultaneous over the whole area. In this study, however, simultaneity was assumed in all applications.

3.8 There is relatively little definite information about the performance of the present alerting system. The extent to which the present signal system provides adequate coverage is not fully known. Wang 1/ conducted a survey by mail in May 1959 covering 72 critical target areas listed by OCD and concluded that "in no case was an evaluation based on what appeared to be scientifically sound analysis." There are apparently no current national data available within OCD on the performance of outdoor alerting systems. Some data of use in estimating the performance of the present system arise from false alerts. The three major false alerts that have been documented occurred in Oakland (1955); 2/ Washington, D. C. (1959); 3/ and Chicago (1960). 4/ Although these studies emphasized sociological aspects, the data are pertinent to the present problem in that they aid in the development of estimates of the nature of individual responses during the alert period.

3.9 Reception. Information is not available for determining the length of time between the sounding of an alarm and its perception. The three false-alert studies indicate that ambient noise levels and the activities in which people are engaged influence the perception of signal. These studies also show that other factors such as world political climate and the use of fire and police sirens affect the population's sensitivity to a warning signal.

1/ Theodore Wang et al., Air Raid Warning in the Missile Era, ORO TP-1 1960, pp 53 to 55.

2/ William A. Scott, Public Reaction to a Surprise Civil Defense Alert, Oakland, California, Survey Research Center, University of Michigan, Ann Arbor, 1955.

3/ Harry B. Williams and George W. Baker, Operation 4:30 - Survey of the Responses to Washington, D. C. False Air Raid Warning, The Disaster Research Group, National Academy of Sciences - National Research Council, 1959.

4/ Elihu Katz et al., Joy in Mudville, National Opinion Research Center, University of Chicago, 1960.

3.10 The effectiveness of an outdoor alarm in waking a sleeping person is open to question. In the Chicago study, 12 of the persons interviewed were asleep at the time of alert; of these, two were awakened. In the case of indoor (home) alarms, an experiment conducted as part of this study (see Appendix E) is relevant. Telephone calls were made between midnight and five in the morning, and the time between the first ringing of the bell and answering was recorded. In a sample of 103, 100 responded; of these 100, the mean time consumed was 0.33 min and the range was from .06 to 6.84 min, with 90 percent of the cases included in the range of .10 to .90 min. In a similar study, Wang[5/] reports that approximately 90 percent heard the signal within a half minute, an additional 5 percent during the second half minute, and an additional 1 percent each succeeding minute.

3.11 Other means of warning exist and will be used. Word of mouth, the telephone, and radio broadcast are important means of communication during emergencies. However, the effectiveness of these methods is reduced by their incomplete distribution. A radio or television message would gain wide attention during peak listening hours, but would be relatively ineffective in early morning.

3.12 Interpretation. An alerting signal does not become a warning signal until it has been correctly interpreted. Since signals of one meaning or another are part of everyday life, the need to distinguish the civil defense warning from all others is crucial in the alerting operation. The three false alerts sharply point out this difficulty. Also pertinent is the following observation on an emergency evacuation of Creve Coeur, Illinois, necessitated by an accidental discharge on a large quantity of liquid anhydrous ammonia: "Sirens, both fixed and mounted on vehicles, were used almost continuously throughout the emergency period....they effectively cleared a path for emergency vehicles, and they summoned the members of the various volunteer fire departments to the fire stations, but as a warning to the general public, they were generally less than adequate. Some people reported sleeping undisturbed while sirens wailed continuously nearby. Many who heard the sirens had no reason to believe that any was being directed to them and reported various interpretations of the sirens to mean fires, ambulances, police, etc. There seems to be little doubt that the general public has been thoroughly conditioned

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5/ Wang, op. cit.

over the years to associate sirens with specific hazards and that general emergency or threat to the community is not one of these hazards."[6]

3.13 Values of t_w. High and low time bounds were estimated for t_p for each of the 19 postures mentioned in paragraph 2.10. These bounds were related to the mean and standard deviation of both of the components. A first determination was made of the mean and standard deviation of the total departure time (t_d, the sum of t_w and t_p for these 19 postures. The results of this analysis established seven postures as sufficiently distinct to be used in the final analysis (see paragraph 2.11).

3.14 Table 1 presents the results of the analysis of t_w. The distribution of warning times about the mean was assumed to be approximately normal. This assumption is not necessitated by the movement model, but was made because of the lack of empirical data on the actual character of these distributions.

TABLE 1

MEAN AND STANDARD DEVIATION OF t_w

Posture	Mean, min	Standard Deviation, min
At home, awake	4.50	.83
At home, asleep	7.25	.91
Business worker, indoors	7.50	1.50
Industrial worker, indoors	7.00	1.33
Public place, indoors	7.00	1.33
Public place, outdoors	3.75	.75
At school	4.25	.91

[6] Institute for Cooperative Research, Task Silence, University of Pennsylvania, Philadelphia, Pennsylvania, September 1962, p6.

Preparation for Movement

3.15 Once an individual is alerted to impending attack and decides that action must be taken, he begins preparing to move to shelter. The span of time devoted to this operation, t_p, begins with the decision to take shelter and ends as the individual leaves a building and starts walking to shelter or to some means of transportation. For those alerted while outdoors, this time period ends when they have determined the location of a shelter and begin moving toward it.

3.16 The actual time devoted to preparation may vary greatly. For most of the population, this time represents a period of dressing, monitoring the radio, and a number of other actions, both necessary and unnecessary. The length of time consumed in preparation for movement will, in general, depend on the number and character of the actions that must be performed in this period. Various portions of the population will find activities of the following types necessary:

a. Gather family.
b. Get dressed.
c. Gather personal belongings, supplies, and special medicines.
d. Monitor alert.
e. Determine shelter location.
f. Receive instructions.
g. Turn off appliances, shut down machinery, lock up, etc.
h. Queuing for departure.

Not all these operations are ascribable to all members of the population. It is assumed that if postures have been properly chosen, reasonably reliable estimates can be made of the time bounds for the operations relevant to persons in a given posture.

3.17 There are few available empirical data for the determination of these times. In an experiment performed as a part of this study (see Appendix E), the preparation time for a sleeping population was measured. The mean preparation time determined in this study was 4.88 min, and the distribution about the mean was approximately normal. This study was performed with a volunteer population and, although some element of surprise was included in the choice of time for the preparation to begin, it was considered to be a lower limit of preparation time rather than a realistic estimate for a large population in the event of an actual disaster. The estimated value of t_p for schools was based on information supplied by the Montgomery County (Maryland) Board of Education. Other time values were assumed on the basis of logic and experience. For these values, time bounds were estimated for each operation relevant to a member of a given posture, and these time bounds were used to determine means and standard deviations. Table 2 presents these values.

TABLE 2

MEAN AND STANDARD DEVIATION OF t_p

Posture	Mean, min	Standard Deviation, min
At home, awake	2.95	.30
At home, asleep	6.15	.28
Business workers, indoors	5.35	.86
Industrial workers, indoors	4.85	.66
Public place, indoors	4.75	.64
Public place, outdoors	1.75	.20
At school	2.55	.30

Departure Time

3.18 The total mean preparation time for each posture, t_d, and its standard deviation were obtained by adding the means and standard deviations for t_w and t_p. Table 3 presents the mean departure times and standard deviations.

TABLE 3

MEAN AND STANDARD DEVIATION OF t_d

Posture	Mean, min	Standard Deviation, min
At home, awake	7.45	.88
At home, asleep	13.40	.95
Business workers, indoors	12.85	1.73
Industrial workers, outdoors	11.85	1.49
Public place, indoors	11.75	1.48
Public place, outdoors	5.50	.77
At school	6.80	.96

The mean and variance of the departure time allow the computation of one of the basic inputs to the movement model: the fraction of persons in each posture departing for shelter in successive 1-min intervals after t_o. These are listed in Table 4.

TABLE 4

DEPARTURE TIME BY POSTURES

Posture	Fraction Departing in Successive 1-min Intervals														
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
At home, awake	.00	.00	.09	.22	.43	.22	.04	.00	.00	.00	.00	.00	.00	.00	.00
At home, asleep	.00	.00	.00	.00	.00	.00	.00	.01	.06	.32	.34	.22	.05	.00	.00
Bus. worker, indoors	.00	.00	.00	.00	.00	.01	.04	.09	.17	.22	.22	.14	.08	.02	.01
Indus. worker, indoors	.00	.00	.00	.00	.00	.03	.08	.17	.26	.24	.14	.06	.02	.00	.00
Public place, indoors	.00	.00	.00	.00	.01	.02	.09	.18	.27	.23	.13	.06	.01	.00	.00
At school	.00	.03	.17	.38	.31	.10	.01	.00	.00	.00	.00	.00	.00	.00	.00

Movement to Shelter

3.19 The character of the initial movement will be largely determined by the relative distributions of people and their destinations. The urban configuration and population density will be secondary influences on the movement process. These three factors will largely determine the utility of the various available means of transportation.

3.20 Origins. The population analysis supplies the necessary information on the distribution of origins of the movement.

3.21 Destinations. The pattern and character of the destinations of the movement will be a chief determinant of the movement process. Whether the destinations are only temporary (i.e., redistribution points) or whether they are longer term shelters, it will be necessary to consider their capacity, which, in the case of a redistribution point, would be measured in persons per unit time. In the case of shelter, the capacity used in this study has been the rated capacity. In further treatment it would be desirable to consider the possible effects of the use of some or all of the shelters beyond their stated capacity.

3.22 Shelter Adequacy. As a determinant of the rate of flow of a population into shelter it is necessary to consider both the total shelter capacity of an area and the spatial distribution of shelters. Even a large excess of shelter capacity over population does not necessarily ensure that there are shelters that can be reached by the entire population under the time constraints of an actual disaster. Since the physical requirements of shelters make them tend to cluster in business and industrial sections of a city, theoretically adequate capacity may be inadequate in practice. The problem is further intensified by the fact that adequacy of shelters in a region will vary in time owing to the varying numbers of people to be served by them. If the attempt were made to provide shelter space at all times within a short distance of the entire population of a city, it would undoubtedly be necessary to designate and stock a considerable excess of shelter spaces.

3.23 The primary effect of the distribution of shelter adequacy will be to dictate the pattern of origins and destinations within the area under consideration. The ease and orderliness of the movement will be directly related to the simplicity of this pattern. If the movement to shelter is a direct flow from origin to the nearest shelter and that shelter has capacity to receive all arrivals, there will be no conflicting flow patterns and the movement should proceed at a relatively fast rate. However, many areas will have a deficiency of shelter spaces at one or more times. Some large areas will be completely devoid of shelter spaces. These regions will naturally be the source of an outflow of population. If these regions are separated from areas of excess shelter space by other regions with inadequate or barely adequate space, complicated patterns of cross movement may result from the attempt to direct people from regions of shelter deficit to those of shelter surplus.

3.24 A recent study of Boston[7/] may serve as an example. The survey finds that there are 2,885,545 shelter spaces in Boston having a protection factor of 40 or greater. The peak daytime population of Boston is given as 1,214,695 and the peak nighttime population as 938,376. Despite this large excess capacity, in the daytime only 32 percent of the shelter spaces will be filled by persons who have to travel less than a mile to reach them. At night only 22 percent of the shelter spaces will be so filled. Although at night there are slightly more than three shelter spaces for each person to be sheltered, approximately 300,000 people (32 percent of the population of the city) will be farther than 1 mile from an unoccupied shelter space.

3.25 Priorities. In order to direct as large a number as possible to the most desirable destinations, it would be necessary to establish a system of priorities of destinations. Shelters, for instance, could be considered to have a higher priority than redistribution points and stocked shelters a higher priority than unstocked ones. In this case, it would be necessary to consider independently the distribution of several categories of shelter spaces.

Urban Configuration

3.26 In analyzing the movement process, one must take account of the physical characteristics of areas through which the movement is to be made. Physical features relevant to this problem may be either natural or man-made. The chief effect of urban configuration on the movement process will be through the pattern of trafficways[8/] and the physical topography of the region.

3.27 The pattern of trafficways will determine the actually traversed — as opposed to the straight-line — distance from origin to shelters. The rate of flow will obviously be limited by the capacity of the trafficways; in addition the existence and effect of constrictions must be determined.

3.28 Urban configurations frequently inhibit movement in one or more directions. Cities are often the result of expansion of centers of commerce founded on rivers, harbors, mountain passes, and other geographic barriers. This introduces physical barriers that must be considered in analyzing any

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7/ Leland H. Towle and John G. Gregory, Development of a Shelter Allocation and Use Plan, Stanford Research Institute, January 1963.

8/ A trafficway may be defined as a region through which traffic of any type may flow. It includes roads, railways, sidewalks, paths, and unobstructed areas that will allow the passage of vehicles or pedestrians.

large-scale movement of people. Man-made barriers such as railroad rights-of-way, industrial areas, and large public institutions are, in many instances, equally effective obstacles. The presence of sharp inclines must be considered in attempting to estimate the speed of pedestrian movements.

3.29 Population Density. The demand for a limited supply of transportation and the number of persons or vehicles using the trafficways to shelter will be related to population density. In areas of low population density, there is likely to be little immediate congestion of streets and walkways. In areas of higher density, public transportation would be exhausted quickly, and all vehicular traffic would tend to be limited by the speed of pedestrian movement. At very high densities the flow of pedestrian traffic may well begin to be impeded by congestion.

3.30 Transportation. The utility of a means of transportation in an emergency depends on a number of factors, among which are (a) ease of acquisition, (b) continuity and dependability of operation, (c) speed, and (d) capacity. The first three of these are situation-dependent and are highly influenced by the general determinants mentioned in paragraph 3.19. The relevence of these utility factors will also depend on the time available to make the movement.

3.31 In the case of walking, ease of acquisition is almost unlimited but continuity and dependability of operation depend on the physical condition of the individual and congestion on streets and sidewalks. Speed would be low, thereby limiting distance, but carrying capacity is of no concern except where the injured, infirm, or small children must be carried.

3.32 Automobiles, when in parking lots or public garages, would not be readily accessible and would have very low utility. Cars already on the street would be valuable for their high speed and carrying capacity, but only so long as streets are passable. This lends cars great utility in low population-density areas and early in the alert in high population-density areas as long as streets are still relatively clear.

3.33 The utility of buses, which generally have considerable capacity and speed, would largely depend on the existence of a well-formulated plan for their use. Even given a plan, their utility would be limited by the fact that they are mainly restricted to business and dense residential areas of a city. The utility of the other means of transportation would suffer most from the difficulty of acquisition arising from the highly centralized location of depots or points of entry. The time required to reach railroad trains would, in most cases, exceed that which is available. In the case of a well-planned strategic evacuation, rail, truck, barge, or ship traffic could be reached, boarded, and gotten underway in an orderly fashion, given ample time. In a short-range tactical movement, however, the utility of these vehicles would be so low as to make them almost useless to all but a very small number of persons.

3.34 For all vehicular modes of transportation, it is necessary that there be some means of removing the vehicle from the areas of traffic flow once it has arrived at its destination. Since there are, at present, no adequate provisions for this in the emergency movement to shelter and no immediately feasible means of providing for it, it seems likely that all private and many public vehicles will be abandoned when they have reached as near to shelter as possible. This would shortly produce complete impediments to traffic flow near many shelter points.

3.35 Also the utility of most readily available vehicular modes of transportation is limited by the congestion caused by the attempt to employ them in a short time. Furthermore, it is unlikely that, when the time available is limited, the initial movement could be subjected to any more definite control than had been functioning at the beginning of the alert. It is quite possible that ordinary means of traffic control would be unable to impose order on the flow of vehicular traffic.

3.36 Velocity of Movement. In general, it may be concluded that, outside of the early stage of an alert and areas of low population density, the rate of flow of population in a short-range tactical movement to shelter will be limited by the velocity of pedestrian traffic. This velocity in turn will vary with the extent to which the paths of movement are congested with other persons moving to shelter or with abandoned vehicles.

3.37 Other Determinants of Movement. The speed and facility with which the movement will take place will also depend on a number of other conditions, such as weather, time of day and year, and condition of trafficways.

Termination of Movement

3.38 The movement analysis terminates when all shelters are filled or when all persons are either sheltered or evacuated. It is assumed in this study that destination shelters are accessible, open, and habitable. The actual process of entering shelter may be simple and direct or complicated and time-consuming. This study does not consider queuing problems that might arise at final destination.

Analytical Treatment

3.39 The analytical treatment of the movement to shelter is discussed in Appendix B. The method, in general, avoids statistical assumptions about the nature of the input parameters. This approach was adopted since the behaviour of the population under study will not necessarily be describable by any well-known distribution functions. Whereas most of the information on responses and distribution was estimated in this application, the structure of the movement model is such that it facilitates the insertion of empirical data as they become available.

3.40 In order to avoid the approximation of experimental data by continuous functions, all the input time distributions have been assumed to be discrete; this is equivalent to replacing a continuous curve by a histogram. For instance, the distribution of departure for shelter is not taken to be a continuous function that, when integrated, will indicate the fraction of the population departing in some arbitrarily small time interval. Instead, it is a series of discrete numbers giving the fraction that departs during some small time interval (Δt) chosen in advance. The output information will consist of the number of persons in various states, e.g., in transit and in shelter, at the end of each successive Δt; which should be small enough to give sufficiently fine results without unduly complicating the gathering of data or the calculations.

3.41 Major Inputs. The major inputs to the movement analysis and their sources are summarized as follows:

a. Population of subarea taken from population analysis (totals).

b. Distribution of starting times taken from population analysis (posture distribution) and distribution of preparation times by postures.

c. Distances and areas measured from city maps.

d. Destinations taken from National Fallout Shelter Survey, Phase II.

e. Velocity estimated from transportation use, character of trafficways, and climatic conditions.

3.42 Shelter Distribution. For the areas analyzed in this report there are data on the number and capacity of shelters by census tract. The analysis itself is carried out on a shelter-by-shelter basis in terms of the associated area of the shelter. The associated area may be defined as that region from which the shelter draws its occupants. In general, it is not necessary in the analysis that one actual area of city be uniquely assigned to any definite shelter. In the case of overlap the associated area would then be thought of as the spatial distribution of those to be sheltered. Any number of assignment rules might be used to determine the associated areas. In this report, it was taken as that area nearer to a given shelter than to any other shelter. This assignment was made independently of the capacity of the shelter. This shelter would be a final destination for all those arriving before it reaches capacity, after which time it would serve as an information point and center for redirection to more distant areas with excess capacity.

3.43 The main features of the movement model will be illustrated first by a considerably simplified application of it to a hypothetical subarea. Subsequently, the extension of the method to more general cases will be discussed.

Treatment of a Hypothetical Subarea

3.44 Description of Subarea. As a result of a population analysis, the number of persons in the subarea is known, both by total and by postures, since the fraction of persons departing in each Δt after t_o is assumed to be known. It is also assumed that the population and the subarea have the following properties:

a. The subarea has circular boundaries.

b. At the center of the subarea is one shelter with capacity to receive the entire population of the subarea.

c. The distribution of persons by posture is uniform over the entire subarea.

d. All persons within the subarea move at the same uniform velocity v towards the shelter once they have departed for it.

e. Each person travels in a straight line from point of departure to shelter.

3.45 Arrivals at Shelter. Consider the subarea to be divided by a series of concentric circles into rings of width $v\Delta t$; this means that each ring is of such a width that it can be traversed in the time interval Δt. The area of the i^{th} ring will be $\pi v^2 \Delta t^2 (2i-1)$, and this information together with the assumed uniform distribution of postures allows the calculation of the number of residents in the i^{th} ring departing in each time interval after t_o. Further assume that the population of the i^{th} ring is concentrated on the outer rim of the ring. (This assumption will produce no appreciable error if the interval Δt is chosen to be sufficiently small.) The following relation holds:

> Number of persons arriving at shelter in K^{th} time interval = number of first-ring residents departing in $(K-1)^{th}$ interval + number of second-ring residents departing in $(K-2)^{th}$ interval + number of third-ring residents departing in $(K-3)^{th}$ interval + etc.

The number of persons sheltered by the end of any time interval is the sum of the arrivals in that time interval and the arrivals in all previous time intervals.

3.46 Example. Consider a subarea with an area .239 sq mi and a total population of 1100 persons, characterized by a departure time distribution as follows, where f_i is the fraction of the population departing for shelter in the i^{th} time interval after t_o (Δt = 1 min):

i	1	2	3	4	5	6	7	8	9	10	11
f_i	.00	.02	.03	.05	.20	.30	.25	.10	.03	.02	.00

If persons move to shelter at a uniform speed of 5 mph, the width of a ring that can be traversed in a minute will be 440 ft and the subarea will be divided into four rings. The number of persons in each ring will be as follows, where p_j is the population of the j^{th} ring.

j	1	2	3	4
p_j	100	300	500	200

If N_k is the number of persons arriving at shelter in the K^{th} time interval

$$\begin{aligned} N_3 &= f_1 p_2 + f_2 p_1 \\ &= .00(300) + .02(100) \\ &= 2 \end{aligned}$$

$$N_4 = f_1 p_3 + f_2 p_2 + f_1 p_1$$
$$= .00(500) + .02(300) + .03(100)$$
$$= 9$$

$$N_5 = f_1 p_4 + f_2 p_3 + f_4 p_1$$
$$= .00(200) + .02(500) + .03(300) + .05(100)$$
$$= 24$$

$$N_k = \sum_{j=1}^{k-1} f_j p_{k-j} \, .$$

If A_m is the number who have arrived by the end of the m^{th} time interval, then

$$A_3 = N_1 + N_2 + N_3$$
$$= 2$$

$$A_4 = N_1 + N_2 + N_3 + N_4$$
$$= 11$$

$$A_5 = N_1 + N_2 + N_3 + N_4 + N_5$$
$$= 35$$

$$A_m = \sum_{k=1}^{m} N_k$$
$$= \sum_{k=1}^{m} \sum_{j=1}^{k-1} f_j p_{k-j} \, .$$

Figure 2 illustrates the calculation of arrivals at shelter for all time intervals. Figure 3 presents, as a function of time, the number sheltered,

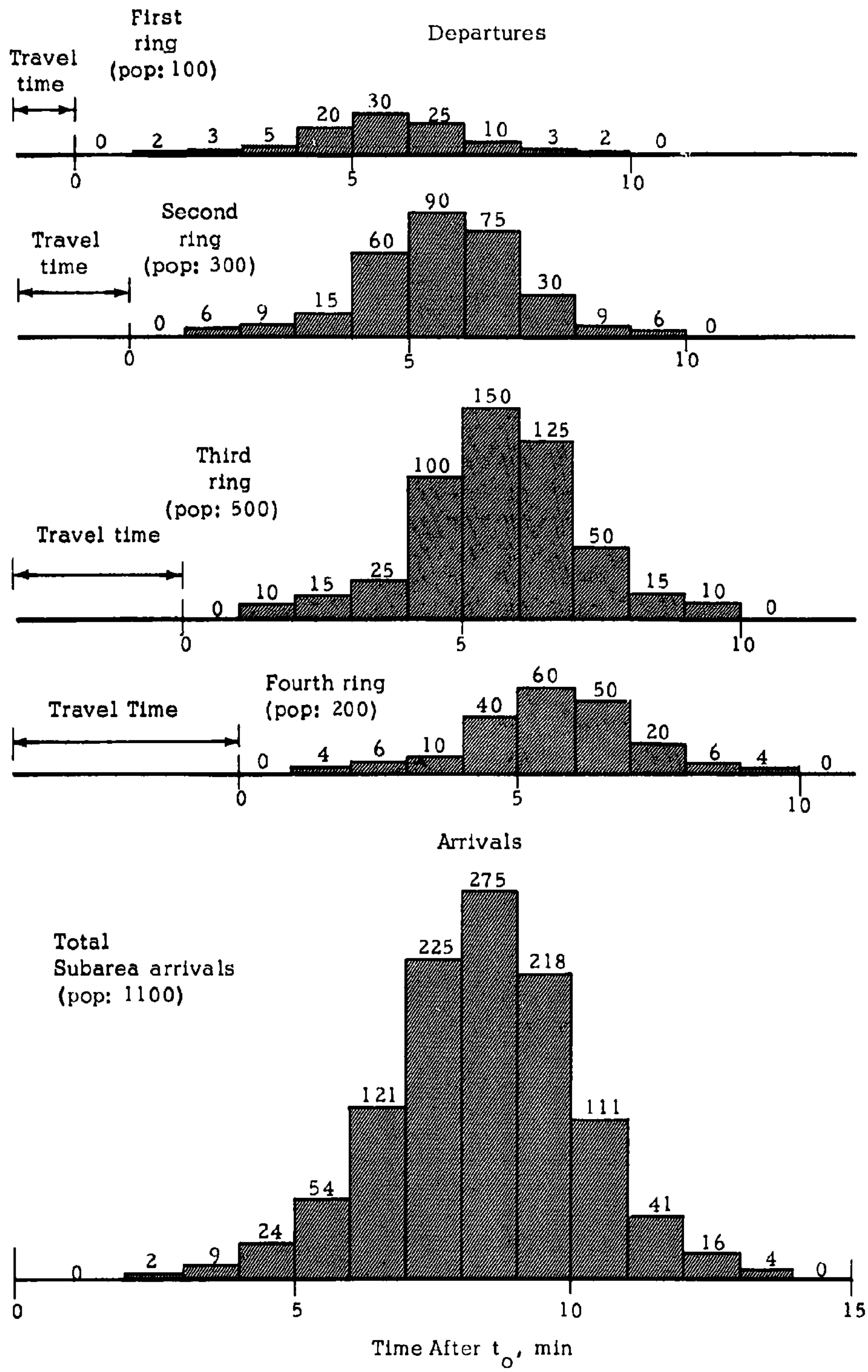


FIGURE 2. ARRIVALS AT SHELTER

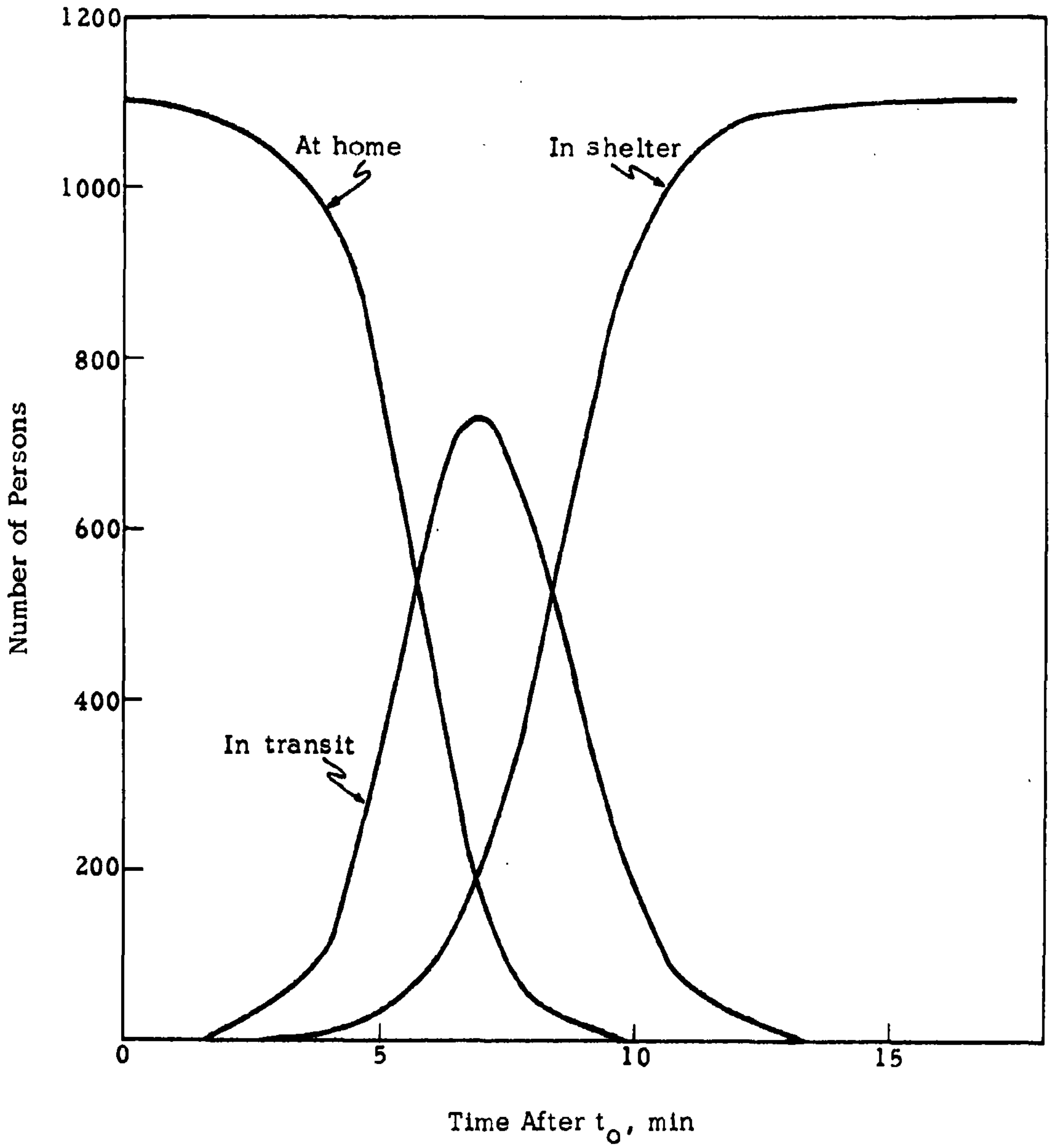


FIGURE 3. POSTURES OF POPULATION FOR HYPOTHETICAL SUBAREA

the number not yet departed for shelter, and the number in transit to shelter.

Extension of Method

3.47 The method as used in this study is not limited to the simple assumptions mentioned in paragraph 3.44. It can easily be extended to deal with the following situations:

a. The existence of no shelters within a subarea.

b. The existence of more than one shelter within a subarea; in this case the subarea is replaced by the area associated with each shelter.

c. The existence of a velocity distribution.

d. The existence of a deficit or surplus of shelter spaces within a subarea.

3.48 Redistribution. Note that the result at this stage is not necessarily the number of persons arriving at shelter as a function of time. The result will only give this information if the receiving subarea has sufficient shelter capacity to accept all the arrivals. For all other persons the destination shelter of the first movement is assumed to act as an information, control, and redistribution point. The treatment of persons who are not sheltered at the first arrival point will depend on the redistribution rules that are used. In this study, unsheltered persons were redirected to subareas that would be likely to have capacity to receive them. Given the output of the first movement calculation, their destinations, and information on travel times within or between the subareas, the time of arrival at subsequent destinations can be calculated.

IV. ANALYSIS OF THREE CITIES

INTRODUCTION

4.1 Three cities were chosen for a preliminary exercise of this model: Salt Lake City, Utah; Milwaukee, Wisconsin; and Tampa, Florida. The detailed calculations for Salt Lake City, along with the results for the other two areas, are presented in Appendix C.

4.2 Note that these calculations were a prototype trial of the analytical method outlined in this report. The results should not be taken to have a definitive quantitative value or to represent adequately the individual characteristics of the three cities. Only certain gross features of the output can be taken, at this time, as truly representative of a real-life situation.

4.3 Choice of Cities. The three cities were chosen on the basis of an attempt to reflect as wide a variety of city types as possible. The three cities are from different civil defense regions and range in size from Salt Lake City (65th largest city in the United States) to Milwaukee (11th largest). They are characterized by varying population densities, mixtures of industries, compactness, and urban configurations.

GENERAL CHARACTERISTICS OF THE CITIES

Salt Lake City, Utah

4.4	Resident population (1960)	189,454
	Total land area (sq mi)	56.1
	Population density (persons/sq mi)	3,377
	Shelter capacity (protection factor of 40 and above)	140,145

4.5 The population of Salt Lake City tends to be fairly well concentrated in the SMSA,[1] with its extension limited in various directions by mountains, deserts, and the Great Salt Lake. The chief characteristics of interest in this analysis are (a) the rather sharp division between urbanized and nonurbanized areas, (b) the relative central location of the main business district, (c) the mainly rectangular-grid pattern and high capacity of streets, and (d) the absence of significant barriers to movement within the city. For an outline of the analyzed area and the subareas into which it was divided, consult Figure 4.

4.6 Shelter Distribution. As can be seen from Figure 4 and Table 5, there are only two subareas (C and D) within Salt Lake City that have an excess of shelter spaces over resident population. These two subareas are adjacent and are remote from subareas with the greatest deficiencies. Subarea D with 18 percent of the resident population and 6 percent of the total land area has 74 percent of the shelter spaces. Subarea C with 8 percent of the total land area and 2 percent of the resident population has 11 percent of the total shelter spaces. Subareas F, G, J, K, and L combined contain 28 percent of the resident population, 40 percent of the land area, and 2 percent of the shelter spaces.

Milwaukee, Wisconsin

4.7	Resident population (1960)	943,642
	Total land area (sq mi)	145.64
	Population density (persons/sq mi)	6,479
	Shelter capacity (protection factor 40 and above)	849,118

4.8 As contrasted with Salt Lake City, Milwaukee (see Figure 5) is part of a more diffuse population center and is not so sharply differentiated from neighboring urbanized areas. Other points of special interest to the analysis are (a) Milwaukee has a typical "coastal" configuration;

1/ Executive Office of the President, Bureau of the Budget, The general concept of a metropolitan area is one of an integrated economic and social unit with a recognized large population nucleus," Standard Metropolitan Statistical Areas, p. 1, 1961. The term SMSA was defined to replace such earlier concepts as standard metropolitan area, metropolitan district, etc.

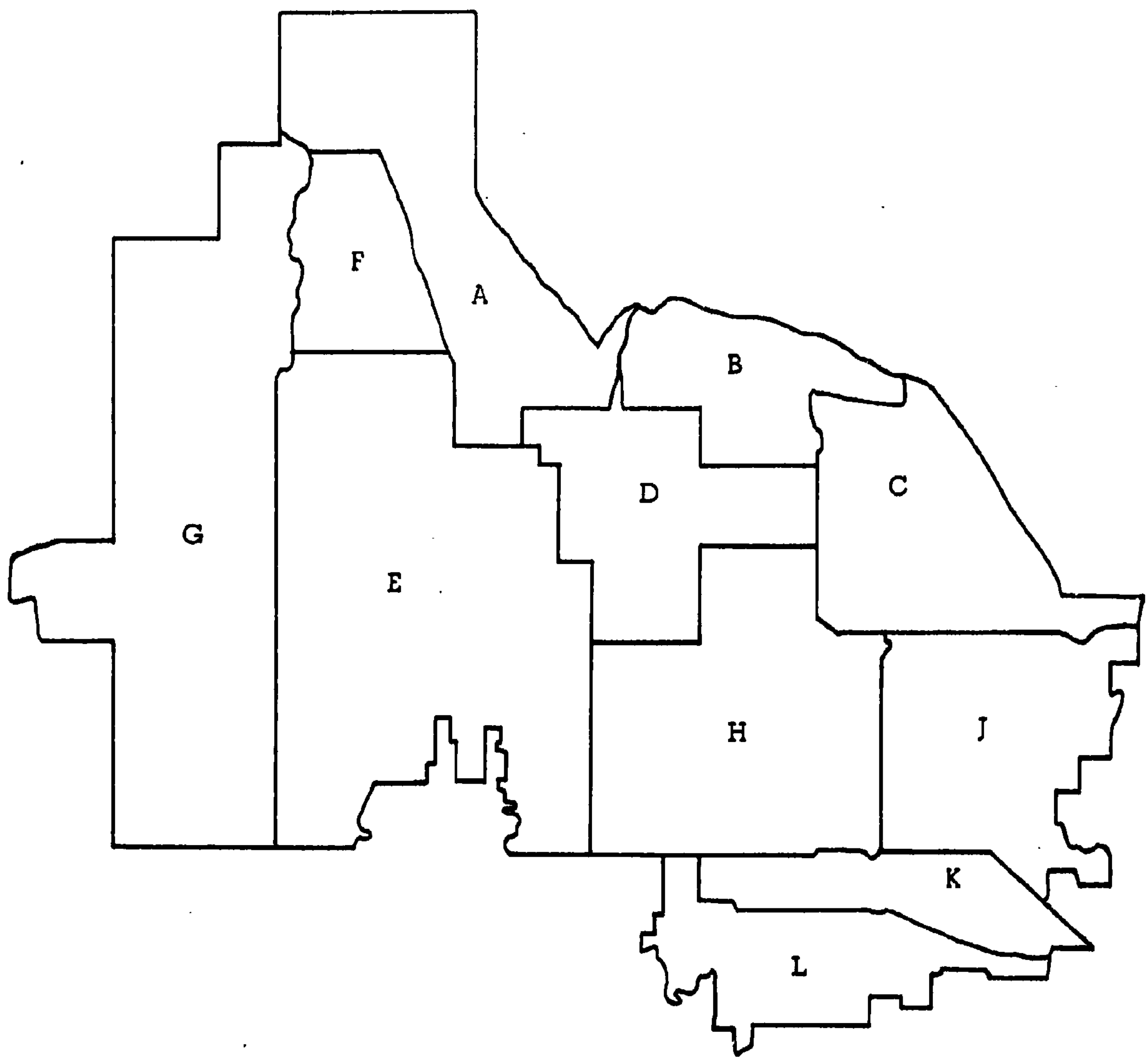


FIGURE 4. SALT LAKE CITY SUBAREAS

TABLE 5

SHELTER DISTRIBUTION,
SALT LAKE CITY

Subarea	Resident Population[1]	Shelter Spaces[2]	Excess Shelter Spaces
A	7,477	2,680	- 4,797
B	10,947	1,609	- 9,338
C	3,597	15,667	12,070
D	34,104	103,586	69,482
E	33,649	6,473	-27,176
F	10,893	-	-10,893
G	1,650	283	- 1,367
H	46,993	7,632	-39,361
J	18,827	944	-17,883
K	5,859	843	- 5,016
L	15,458	117	-15,341

1/ 1960 Census.

2/ Protection factor of 40 or greater.

1

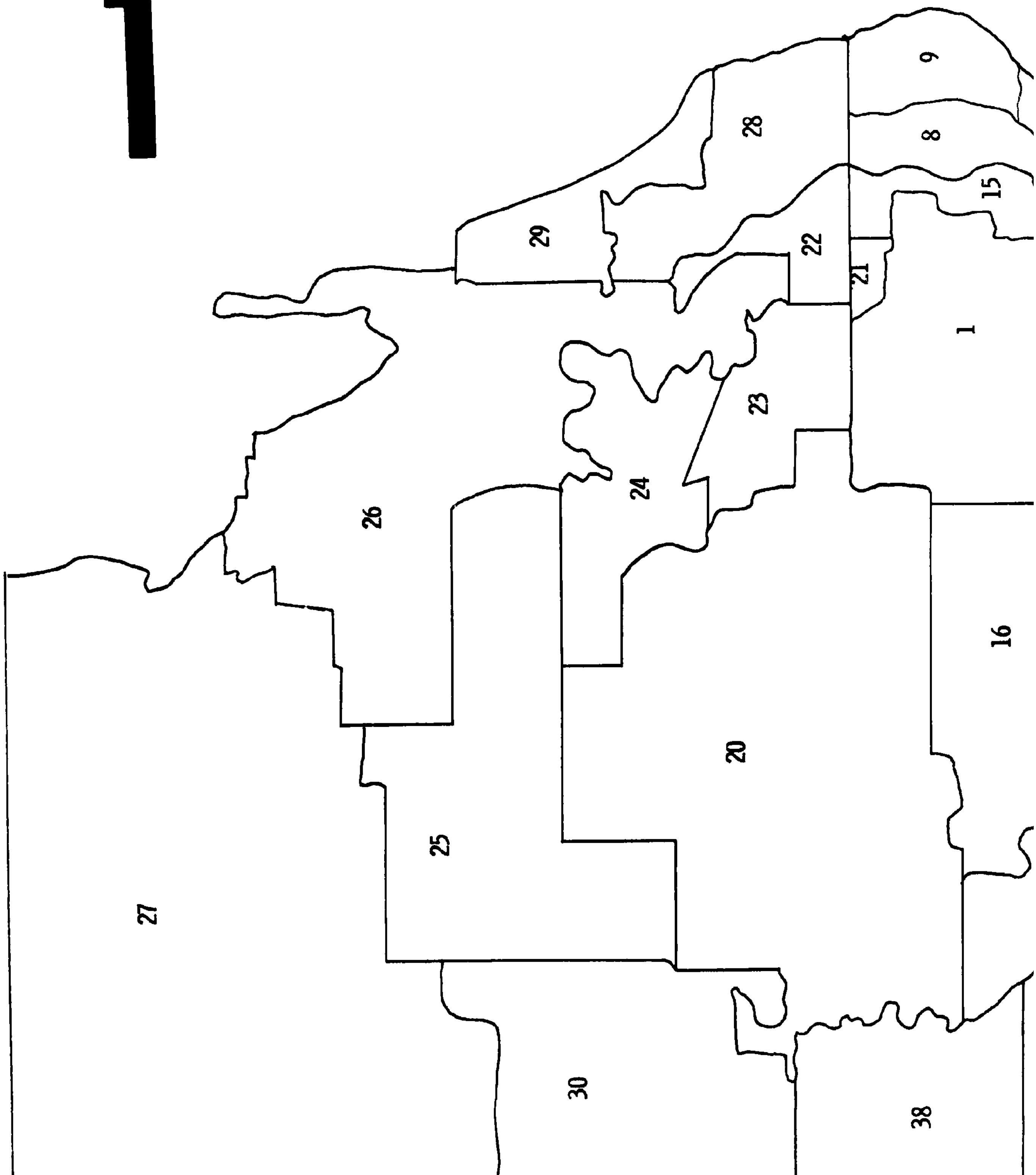
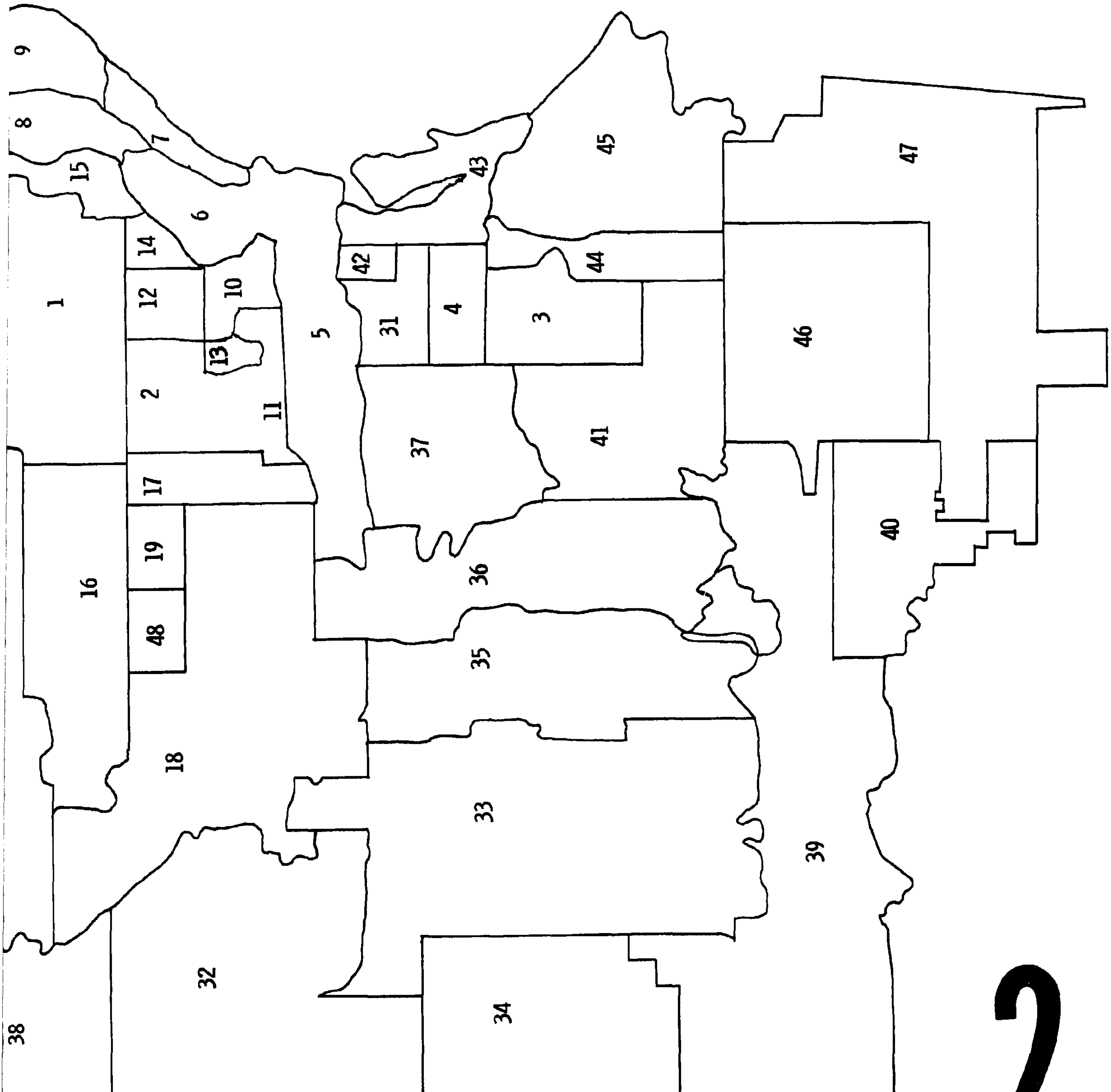


FIGURE 5. MILV



URE 5. MILWAUKEE SUBAREAS

2

(b) the street pattern is not so regular as in Salt Lake City; (c) the presence of the Milwaukee, Menomonee, and Kinnickinnic rivers serve as effective barriers to large-scale population movements.

4.9 Shelter Distribution. The distribution of shelter spaces in Milwaukee is more nearly adjusted to population distribution than is the Salt Lake City shelter distribution. As can be seen from Table 6, 16 of the 48 subareas have excess shelter spaces, and these 17 subareas are better distributed with relation to shelter deficit subareas than are the subareas in Salt Lake City.

Tampa, Florida

4.10	Resident population (1960)	274,970
	Total land area (sq mi)	85.0
	Population density (persons/sq mi)	3,235

4.11 Tampa is characterized by a somewhat more dispersed population than the other two cities. There is a considerable amount of unused or unusable land area within the corporate limits. A number of these are lakes or marshy regions and would constitute a barrier to the movement of persons to shelter.

4.12 Shelter Distribution. After a preliminary analysis of outputs for the first two cities, it was decided to test the effect of bringing the shelter distribution into greater conformity with the population distribution. Tampa (see Figure 6) was selected for this in that, on the basis of preliminary data available, it had the least adequate shelter distribution of the three cities. To obtain this end each subarea was assumed to have sufficient capacity to shelter its peak population. Furthermore, the number of shelters was increased in all subareas with inadequate shelter capacity.

ANALYSIS OF THE CITIES

4.13 The boundaries of the analyzed areas in this report do not necessarily correspond either to the corporate boundaries of the three cities or to the boundaries of the SMSA as defined by the Census Bureau. The chief goal was an analysis of the central city, and in all cases the entire central city is included in the analyzed area. However, the movement model assumes that fringe effects are negligible, at least to a first approximation. In order to bring the analyzed areas into reasonable conformity with this assumption,

TABLE 6

SHELTER DISTRIBUTION, MILWAUKEE, WISCONSIN

Sub-area	Resident Population1/	Shelter Spaces2/	Excess Shelter Spaces	Sub-area	Resident Population1/	Shelter Spaces2/	Excess Shelter Spaces
1	96,080	24,782	-71,298	25	29,478	3,766	-25,712
2	34,596	30,086	-4,510	26	13,285	3,873	-9,412
3	24,222	990	-23,232	27	13,209	0	-13,209
4	11,901	22,988	11,087	28	22,455	1,508	-20,947
5	1,396	137,480	136,084	29	11,925	2,525	-9,400
6	19,634	154,226	134,592	30	8,416	0	-8,416
7	4,233	21,066	16,833	31	17,359	1,585	-15,774
8	14,778	21,303	6,525	32	19,387	520	-18,867
9	8,795	10,732	1,937	33	54,093	9,495	-44,598
10	2,978	89,222	86,244	34	5,650	0	-5,650
11	8,235	37,018	28,783	35	34,582	4,035	-30,547
12	8,994	10,973	1,979	36	18,466	61,900	43,434
13	6,268	10,034	3,766	37	45,379	15,206	-30,173
14	1,615	38,213	36,598	38	4,099	0	-4,099
15	10,040	2,459	-7,581	39	16,007	0	-16,007
16	45,507	10,403	-35,104	40	3,244	468	-2,776
17	19,036	8,164	-10,872	41	20,185	26,952	6,767
18	45,159	9,811	-35,348	42	2,497	7,994	5,497
19	4,108	302	-3,806	43	693	7,627	6,934
20	123,030	33,713	-89,317	44	3,882	671	-3,221
21	4,114	0	-4,114	45	34,933	4,709	-30,224
22	3,644	9,453	5,809	46	16,218	442	-15,776
23	18,371	1,701	-16,670	47	7,163	2,108	-5,005
24	17,464	7,829	-9,535	48	6,839	786	-6,053

1/ 1960 Census.

2/ Protection factor of 40 or above.

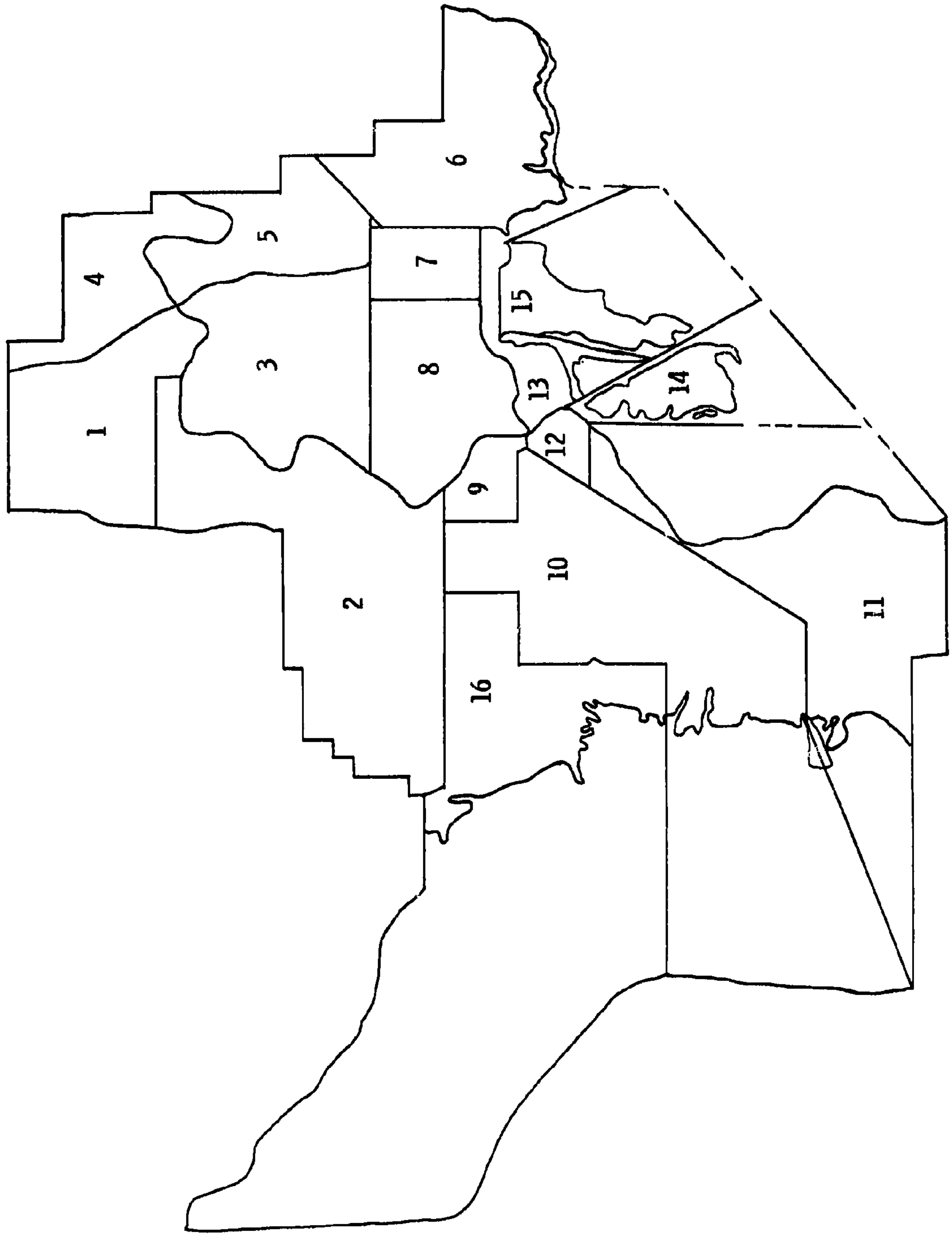


FIGURE 6. TAMPA SUBAREAS

contiguous urban areas of high population density were adjoined to the central city; this was especially necessary in the case of Milwaukee. Note that in all three cases the accuracy would have been increased somewhat by an expansion of the areas considered.

Inputs to Population Analysis

4.14 Population Data. The population and employment statistics used in the analysis of all three cities were taken from the U. S. Census of Population and Housing: 1960, Census Tract Reports, Series PHC(1)-92. No attempt was made to update these figures. Projection techniques are available and can be incorporated in the analysis for further application, or locally updated figures can be used.

4.15 Subareas. In this study the subareas in the analysis were made up of groups of census tracts. The 49 census tracts of Salt Lake City were grouped into 11 subareas, the 61 census tracts of Tampa into 17 subareas, and the 232 census tracts of Milwaukee into 48 subareas. This aggregation of tracts into subareas was necessitated by the requirement for manual calculation in this analysis. Although in all cases an attempt was made to preserve reasonable homogeneity of character within the subarea, this grouping of census tracts has produced some loss of sensitivity in the population analysis and movement model.

4.16 Time of Warning (t_o). For each of the cities the analysis was performed for three different values of t_o, time of initiation of warning: 2:30 a.m., 11:00 a.m., and 5:30 p.m. These times were not chosen as unique instants but rather as representative of important and recurrent population configurations. The first represents the nighttime, mainly residential configuration; the second, a typical weekday daytime configuration; the third, a time with a large segment of the population in transit.

4.17 Other Inputs. Owing to the scarcity of data on the allocation and distribution functions used in the population analysis, these values were assumed in this application. See Section III for a discussion of these functions.

Output of Population Analysis

4.18 The output of the population analysis is the number of persons in each subarea by postures. See Tables C.17 to C.27 for the Salt Lake City results for the three times of day.

4.19 Shelter Adequacy. The relation between the time-dependent populations of a subarea and the shelter capacity of that subarea determines the pattern of shelter adequacy and inadequacy. A rough measure of shelter inadequacy at a given time is the percentage of population for whom there are no shelter spaces within whatever subarea they are at that time. In Salt Lake City, using this criterion, at least 70 percent of the population is inadequately provided with shelters at all times. The shelter capacity of Tampa was assumed to be such as to provide adequate coverage at all times. Milwaukee best illustrates the time dependency of shelter adequacy. The population analysis indicates that at 11:00 a.m., 48.9 percent of the population is inadequately provided with shelters; at 5:30 p.m., 52.8 percent; and at 4:30 a.m., 65.7 percent. These variations are primarily caused by the nighttime movement of persons from commercial to residential areas, which is usually equivalent to a movement from regions of high shelter density to those of low shelter density.

Inputs to Movement Model

4.20 In addition to the output of the population analysis there are the following major inputs to the movement model: departure time data, shelter data, and velocity of movement. The departure time data (see Table 5) were assumed in this application.

4.21 Shelter Data. In the case of Salt Lake City and Milwaukee the shelter data were taken directly from the National Fallout Shelter Survey, Phase 2. Only those shelters with a protection factor of 40 or greater were included in the data used in this study. For Tampa, however, the shelter data were not taken from the previously mentioned survey; well-distributed shelters of adequate capacity were assumed, as discussed in paragraph 4.12.

4.22 Associated Area. The area associated with each shelter within a subarea was determined by assuming the shelters were uniformly distributed over the subarea (i. e., the associated area of a shelter within a subarea was set equal to the average area per shelter within that subarea). In addition, each shelter within a subarea was assumed to have the average shelter capacity of that subarea. These two assumptions were made in order to facilitate the hand calculation of the movement model, for the assumptions allowed the simultaneous calculation of the number of arrivals at all shelters within a subarea.

4.23 The effect of the two assumptions is to smooth out the irregularities of the distribution of shelters and shelter spaces, which represents an improvement, in nearly all cases, in the distribution of shelters and renders the movement calculation insensitive to fine changes in the shelter distribution. Both of these effects may be considerably reduced by decreasing the size of the subareas so that each contains only one census tract. The effects could be entirely eliminated by performing the analysis on a shelter-by-shelter basis. There would be no theoretical difficulty in this approach; however, it would require the use of a computer with large storage capacity.

4.24 Velocity. As discussed in Section III, it was assumed that in the fairly high-density urban regions covered in this study, the velocity of movement towards shelter would approach that of a population moving on foot. In all three cities analyzed in this study a mean velocity of 4 mph was assumed. If the velocity were lowered or raised, the only effect on the output curves would be to stretch or compress them along the time axis. However, the effect of replacing a distributed velocity by an undistributed one is somewhat more serious, since the real distribution of velocities would reflect a number of urban characteristics, such as the capacity of road networks, topography, and population density. Note that the movement model provides for the input of a velocity distribution. Constant velocities were assumed in this prototype analysis because of the lack of empirical data and the requirement of noncomputerized calculation.

4.25 Redistribution. The assumption in this analysis was that persons would move to the nearest shelter regardless of its capacity or the probability of their finding shelter there, and that if the first shelter were full, the excess arrivals would be redirected to areas with a surplus of shelter spaces. This redistribution was assumed to continue as long as there were shelter spaces to be filled. Naturally, owing to the assumed adequacy of shelter spaces in Tampa, no persons had to be redistributed beyond the shelter at which they first arrived. In Salt Lake City and Milwaukee, where actual shelter space data were used, a large number of persons were not sheltered in the initial movement to shelter and were redistributed to destinations more remote from their origins.

Results

4.26 The primary output of the movement model is a functional relation between time after sounding of warning and number of persons who have reached shelter. Figures 7 to 9 present these outputs for the three cities and the three different times of t_o, time of initial sounding of warning.

4.27 Tampa. Owing to the assumed distribution of shelter spaces, the Tampa results are the most simple and represent an output of the movement model relatively "unperturbed" by actual conditions. In the middle region of time values the curves are practically linear, indicating a constant rate of arrival. This linear region reflects a "saturation" period during which large numbers of persons are in transit towards shelter, and consequently the chief determinant of rate of arrival is the movement velocity, which was

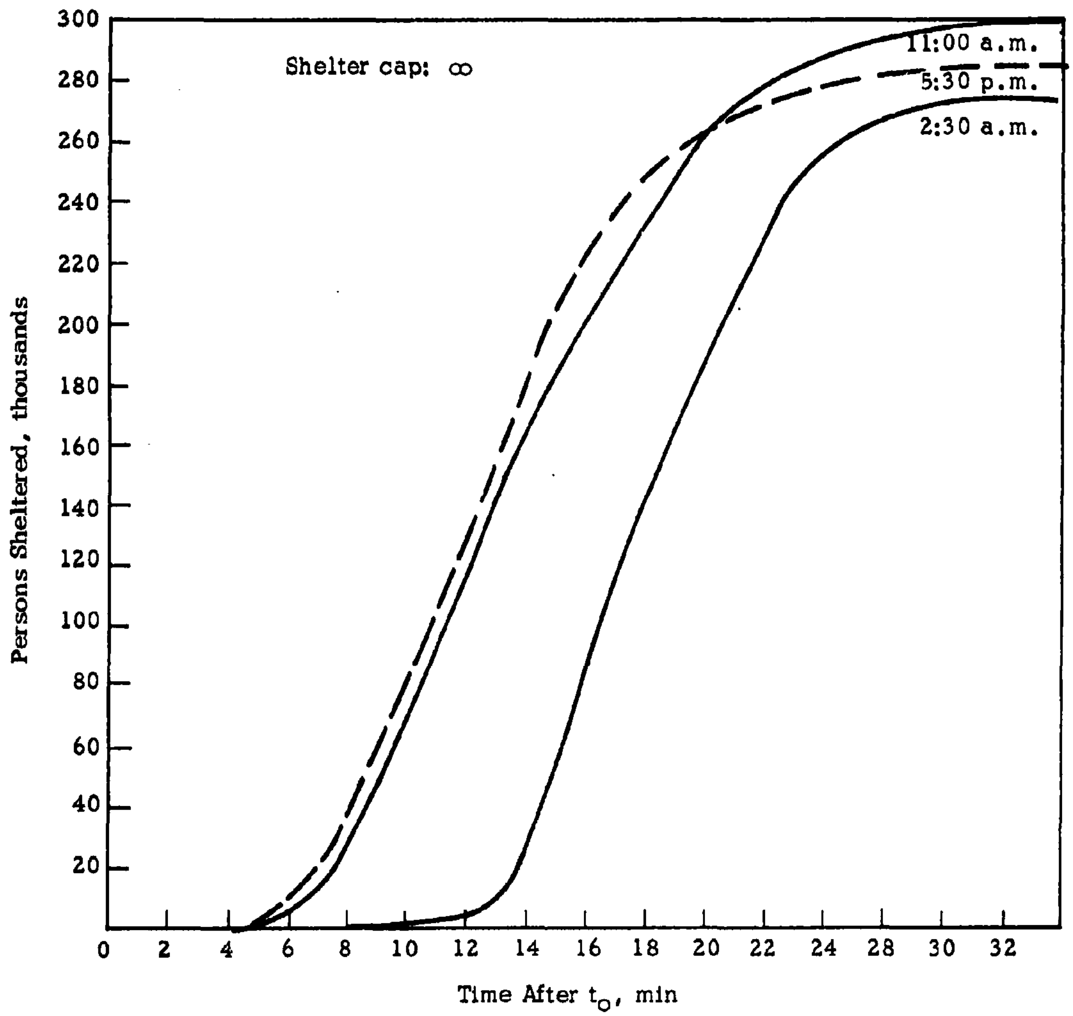


FIGURE 7. NUMBER OF PERSONS SHELTERED IN ALL TAMPA SUBAREAS

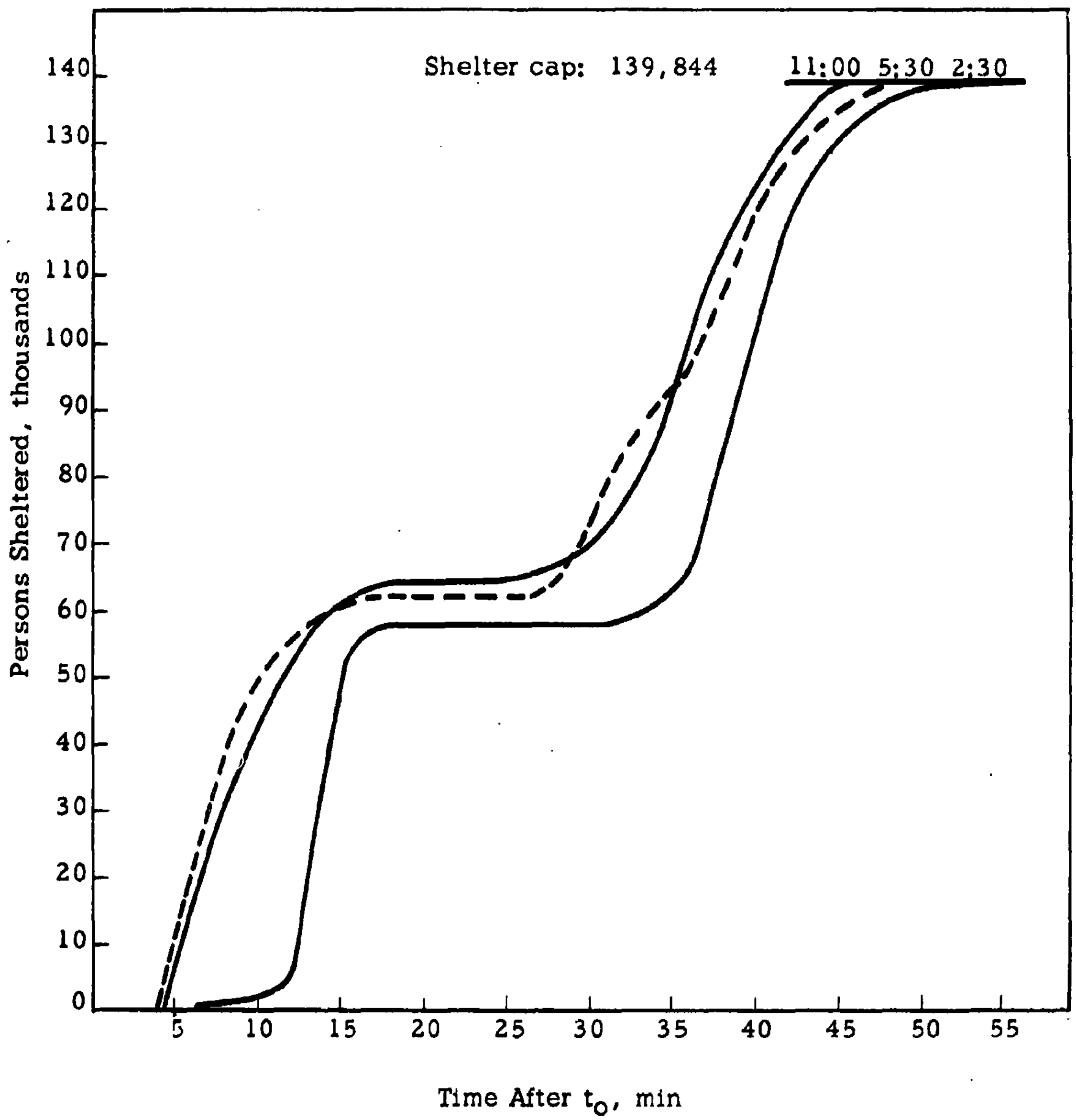


FIGURE 8. NUMBER OF PERSONS SHELTERED IN ALL SALT LAKE CITY SUBAREAS

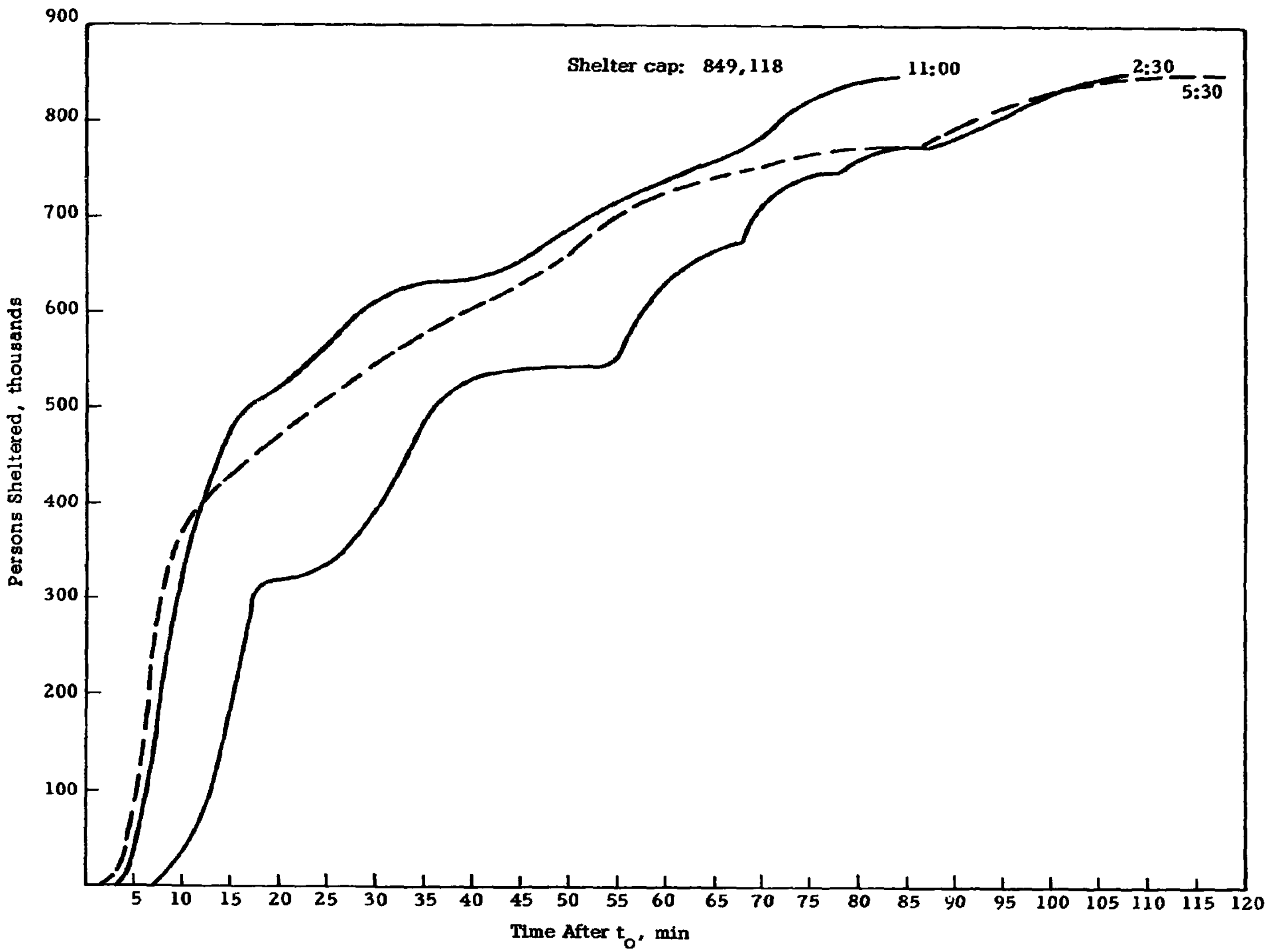


FIGURE 9. NUMBER OF PERSONS SHELTERED IN ALL MILWAUKEE SUBAREAS

assumed to be constant. The effect of fast starters and slow starters is reflected mainly at the two extreme ends of the curve.

4.28 Salt Lake City. The plot of arrivals versus time for Salt Lake City is considerably less regular than that for Tampa; this is basically the result of the use of real rather than assumed shelter data. The most noticeable differences between the output for Salt Lake City and Tampa are (a) the presence of a plateau of several minutes duration when no one is sheltered and (b) less-pronounced tapering off at the end of the curves.

4.29 The plateau, although somewhat exaggerated by the relatively small number of subareas into which the city was divided, represents a characteristic of the distribution of shelter adequacy, as discussed in paragraph 4.19. During the first time span (from t=0 to t=15) the increase is caused by (a) the filling of shelters scattered throughout the city and (b) the sheltering of the entire population of the two subareas with excess capacity. The plateau represents time during which persons are being relocated from relatively remote subareas with no more shelter capacity to the central portion of the city. The somewhat more irregular character of the curves after this plateau are due to the varying rates of arrival of persons from these remote subareas.

4.30 The less-pronounced tapering off of the arrivals in the Salt Lake City curves, as compared with the curve for Tampa, is caused by the fact that in Salt Lake City all shelters are filled before the whole population has been sheltered. Therefore the Salt Lake City curves do not fully reflect the tapering off due to slow starters.

4.31 Milwaukee. The Milwaukee curves are rather similar to the curves for Salt Lake City. The less-pronounced "plateau effect" in the case of Milwaukee is partly due to the large number of subareas into which Milwaukee was divided, but is mainly due to the better distribution of shelter spaces in Milwaukee. The steadily decreasing rate of arrivals, i. e., decreasing slope of curves, is mainly due to the gradual filling of shelters, thus producing a constantly decreasing number of destinations at which persons can find shelter.

COMPARISON OF THE THREE CITIES

4.32 Time of Alert. For all three cities and for most values of t the number of persons sheltered at 2:30 p. m. is less than at the other two times. This is partly due to the higher mean starting time of persons at home asleep, and partly due to the fact that there is a less adequate distribution of shelter spaces at night. This more inadequate distribution also causes the plateau effect to be more pronounced in the case of the 2:30 a.m. figures. The difference between the 11:00 a.m. and the 5:30 p.m. figures is not so great; however, in all three cases the results indicate the initial rate of the 5:30 p.m. filling of shelters is more rapid than the 11:00 a.m., until a point is reached when the 11:00 a.m. curve crosses the 5:30 p.m. curve. Two factors contribute to this effect: (2) at 5:30 p.m. there is a large component of population in transit, and a quicker response time is attributed to this than to most other population segments, thus accounting for its initial advantage and (b) on the other hand, since the 5:30 p.m. population is less concentrated in the central business district, there is a less adequate distribution of shelter spaces, which accounts for the ultimately slower rate of filling shelters at this time. As might be expected, this effect is less noticeable for Tampa, where shelters were assumed to be well distributed over the whole area.

4.33 Numbers Sheltered. Figure 10 illustrates the number of persons sheltered as a function of time after the alert (t_o, 5:30 p.m. in all three cases). For an indication of time spans involved in the movement, consult Table 7. This table deals with the range of time between t(5%), the time at which 5 percent of those ultimately sheltered have reached shelter, and t(95%). Also given is an indication of the average sheltering rate during this period.

TABLE 7

TIME SPAN AND SHELTERING RATE

City	t(5%), min	t(95%), min	Time Span, min	Sheltering Rate, persons/minutes
Tampa	7	21	14	17,000
Milwaukee	5	93	88	8,600
Salt Lake City	5	44	39	3,300

4.34 Figure 10 illustrates the percentage of the total population within the analyzed area sheltered as a function of time after alert (t_o, 5:30 p.m. in all three cases). In this figure the relative adequacies of shelter dist butions in the three cities are clearly illustrated. Figure 11 illustrates the percentage of shelter spaces occupied as a function of time.

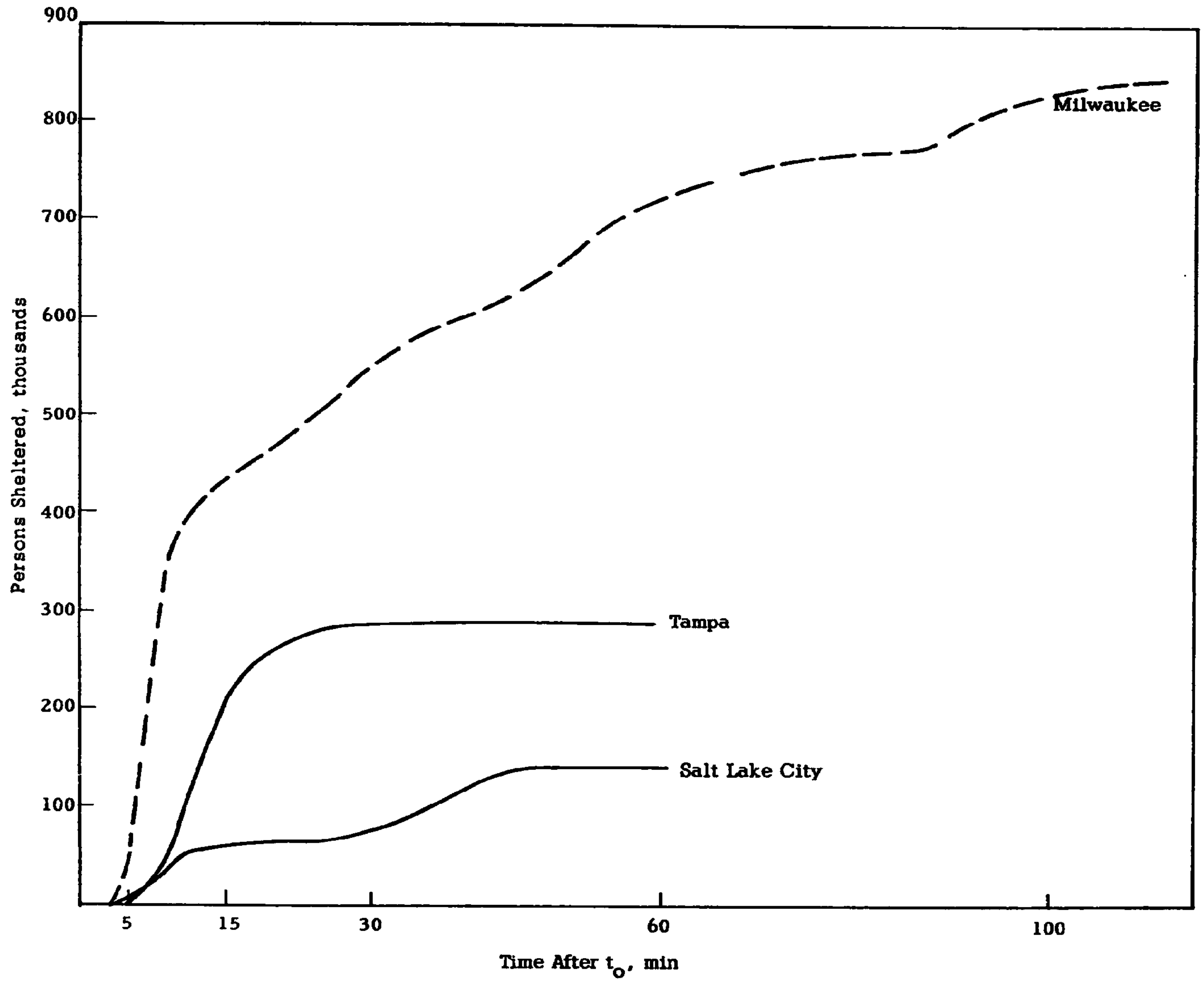


FIGURE 10. NUMBER OF PERSONS SHELTERED IN EACH OF THE THREE CITIES AT 5:30 P.M.

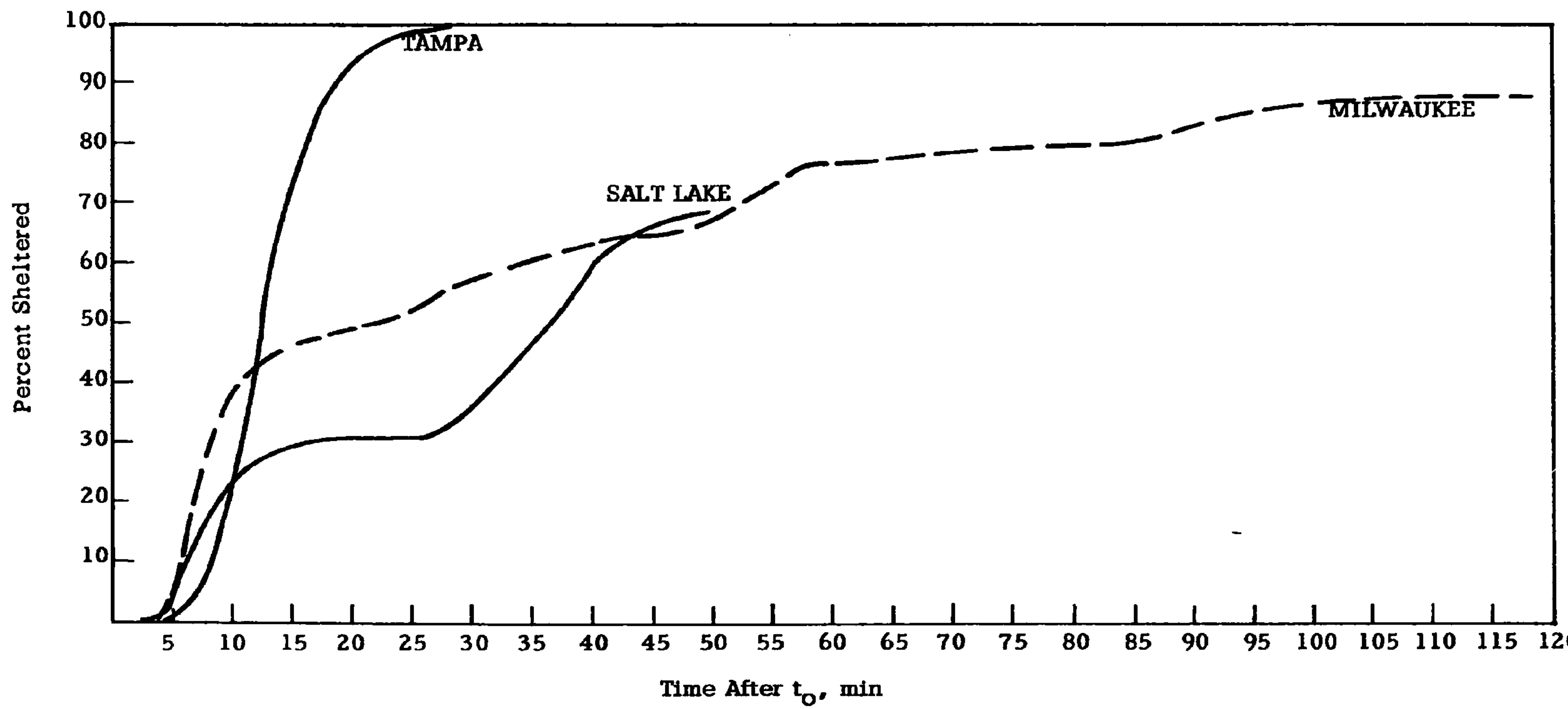


FIGURE 11. PERCENTAGE OF TOTAL POPULATION SHELTERED IN EACH OF THE THREE CITIES AT 5:30 P.M.

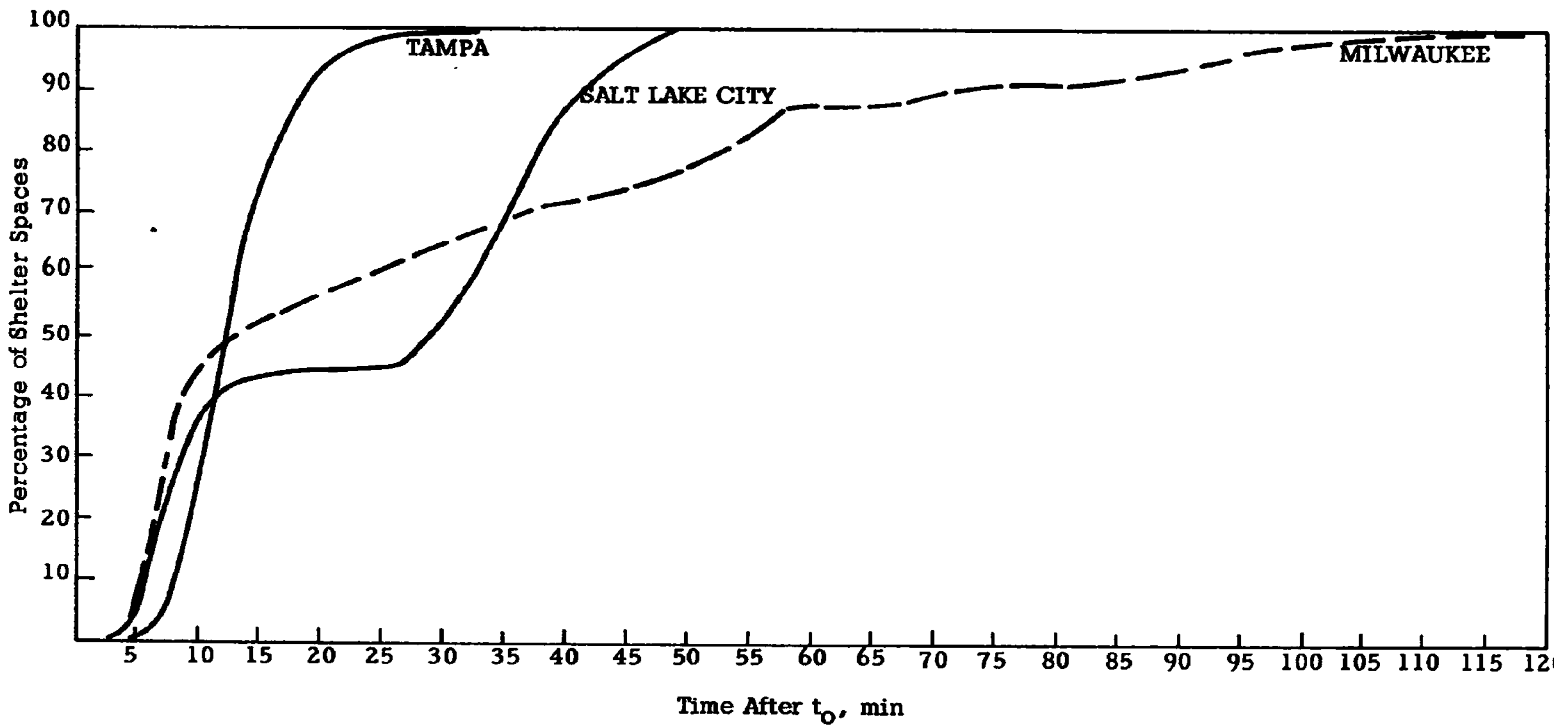


FIGURE 12. PERCENTAGE OF SHELTER SPACES OCCUPIED IN EACH OF THE THREE CITIES AT 5:30 P.M.

V. FURTHER APPLICATIONS AND EXTENSIONS

PROGRAMMING

5.1 The population analysis and movement model have been programmed in FORTRAN for use on an IBM 1620 computer. This program has been successfully applied in an analysis of Montgomery County, Maryland. The whole analysis is within the capacity of an IBM 1620 computer with 40,000 core storage positions. The program as now written does not include a distributed velocity, but there appear to be no theoretical or practical difficulties in programming or computer capacity that would prevent the inclusion of a velocity distribution.

SENSITIVITY ANALYSIS

5.2 It would be desirable to perform a sensitivity analysis to establish guidelines for any further refinements of the population analysis and the movement model. This sensitivity analysis would be approached through an analysis of the variances and an iterative exercise of the model to determine the significance of the various input parameters on the movement time. This might well result in both refinements and simplifications of the model and indicate areas in which empirical studies could most profitably be made.

REFINEMENTS

5.3 In the course of actually performing the analysis, a number of alternative approaches have been developed that show promise of being able to increase considerably the sensitivity and accuracy of the population analysis. Time constraints did not allow the full investigation of these alternatives; consequently, some of these have not been incorporated in this trial of the method.

Population Analysis

5.4 School Population. In this study all school children were assumed to attend school in their resident subareas. The method was modified before its application to Montgomery County, Maryland, to incorporate actual school attendance figures by census tracts.

5.5 Employed Populations. The density method as used in this study to allocate employed persons seems to be most effective over relatively small areas where natural pressures have operated to equalize land-use factors. The use of a uniform employment density over an urban area, as was done in this study, results in an under-allocation of employed persons to central business districts and an over-allocation to fringe areas. The regions of best agreement are, as is to be expected, those intermediate between these two extremes. Rough adjustment factors were used in this application to meet these disparities. Several methods for dealing with them more effectively are outlined in the following paragraphs.

5.6 Land-Use Factors. One approach to the problem would be to develop a formalized method of adjusting business and commerical areas to reflect the actual employment density within them. Judgment rules would be developed to relate the types of businesses and industries within a region to the expected densities. There are two difficulties involved in this approach: (a) the somewhat arbitrary character of the judgments involved, and (b) the fact that the attempt to obtain greater accuracy by this method would involve quite detailed statistical analysis of local characteristics.

5.7 A more satisfactory approach would be to explore the possibility of using special printouts of unpublished Bureau of the Census data, available on magnetic tapes, which contain a finer analysis of the distribution of employed persons than the published census tract reports. These data would allow the calculation of employment densities by broad location categories. The final allocation of employees within the regions could be made by the density methods as used in this study. However, the possibility of increased refinement through a combination of the density method and the gravity method should be explored. The gravity method is a technique that has been used mainly, and with success, to predict the origin-destination pattern of urban trips. The combination of a finely analyzed density approach and a gravity model might offer considerable accuracy in the calculation of population distributions.

5.8 Updating. In further applications of this technique, population statistics that have been updated from the 1960 census should be employed; these may be available from local sources. If these are unavailable, census data may be adjusted for population growth, letting the degree of accuracy required determine the method used. In the analysis of Montgomery County, census tract statistics were used, which had been updated to 1962 on the basis of a house count by the Maryland-National Capital Park and Planning Commission.

Movement Model

5.9 Empirical Studies. The chief region of refinement in the movement model would be the substitution of empirical data for the assumed response-time distributions. This should be done after a sensitivity analysis has been performed to determine which data affect outputs more significantly. This information, in conjunction with a feasibility analysis of gathering the significant data, would indicate those areas in which empirical studies of response times should be undertaken.

5.10 Velocity Distribution. The use of a distributed velocity in the movement model would produce results of greater realism and would allow a more adequate treatment of factors that affect velocity, such as population density, availability of transport, character and capacity of trafficways, weather conditions, and time of day.

5.11 Shelter-By-Shelter Analysis. Although a reduction of the movement analysis to a shelter-by-shelter basis is within the capability of the model, the increase in accuracy to be gained by this approach would probably not warrant it in a general analysis of a large area. However, it would be desirable as a technique of microanalysis of critical areas or as a test of the effect of small changes in shelter distribution.

EXTENSIONS

5.12 Shelter Adequacy. The movement model could easily be extended to include, as secondary outputs, measures of the adequacy of shelter distribution. Possible measures are (a) the mean distance of persons from available shelter spaces, (b) a relation (possibly correlation coefficient) between population and shelter distributions, and (c) a distribution of distance or time to shelter.

5.13 Sheltering. Certain aspects of the actual sheltering process could be profitably brought within the scope of this analysis, in particular such aspects as (a) queuing problems, (b) over-capacity filling of shelters, (c) protection factors, and (d) command and control problems.

Survival Probabilities

5.14 It would not be difficult to extend the movement model to include information on the protection factors of the population in various postures, in transit to shelter, and in shelter. This would allow the computation of average protection factors and, given assumed rates and patterns of ambient radiation, cumulative dose rates. This information would be valuable in examining the effect of various policies of directing the movement to shelter on the probability of survival of the sheltered population. An approach of this type might be especially relevant to the evaluation of differences between shelter allocation plans, since it does not necessarily follow that the method that shelters the largest number of persons the fastest would necessarily produce the highest survival probabilities.

5.15 Protection Factors. To illustrate the method of calculating mean protection factors, consider the hypothetical subarea discussed in paragraphs 3.44 to 3.46. The subarea was assumed to have 1100 persons at home at the time of the alert and to be characterized by a certain distribution of departure times. Figure 13 indicates the number of persons at home, in transit to shelter, and in shelter. If protection factors are assumed for each of these situations (e.g., at home, 5; in transit, 1; in shelter, 50) the mean protection factor P(t) of the population can be calculated, where P(t) is defined so that it is equal to the maximum possible dosage that the population could receive at time t divided by the actual dosage they do receive. Therefore,

$$P(t) = \frac{n\,r(t)}{\sum_{i=1}^{n} d_i(t)}$$

$$\frac{1}{P(t)} = \frac{1}{n\,r(t)} \sum_{i=1}^{n} d_i(t)$$

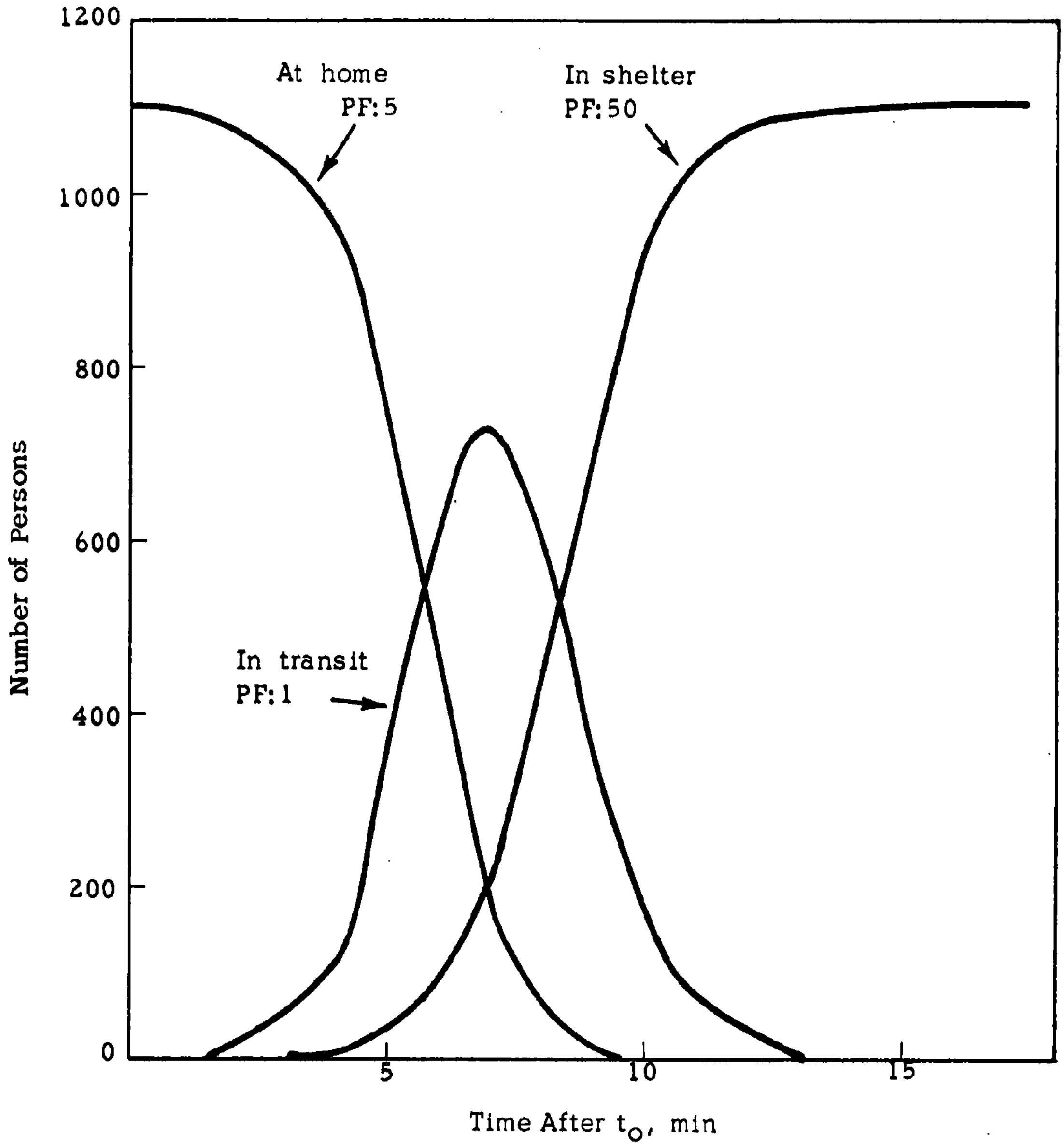


FIGURE 13. PROTECTION FACTORS IN HYPOTHETICAL SUBAREA

where n is the number of persons, $r(t)$ is the ambient radiation level, and $d_i(t)$ is the dosage received by the i^{th} member of the population. However,

$$d_i(t) = \frac{r(t)}{p_i(t)}$$

where p_i is the protection factor of the i^{th} member of the population. Therefore,

$$\frac{1}{P(t)} = \frac{1}{n\,r(t)} \sum_{i=1}^{n} \frac{r(t)}{p_i(t)}$$

$$= \frac{1}{n} \sum_{i=1}^{n} \frac{1}{p_i(t)} \quad ,$$

which indicates that the appropriate average protection factor is the harmonic and not the arithmetic mean. Figure 14 illustrates the mean protection factor in the hypothetical subarea.

5.16 Cumulative Dosage. If $D(t)$ is taken to be the mean cumulative dosage of the population at time t, then,

$$D(t) = \frac{1}{n} \int_{o}^{t} \sum_{i=1}^{n} d_i(t)\,dt$$

$$= \frac{1}{n} \int_{o}^{t} \frac{n\,r(t)}{P(t)}\,dt$$

$$= \int_{o}^{t} \frac{r(t)}{P(t)}\,dt \quad .$$

Figure 15 illustrates the $D(t)$ for the population of the hypothetical subarea, assuming a constant ambient radiation level $[r(t) = c]$.

5.17 Given values of $D(t)$ the extension to survival probabilities would be straightforward. However, the variance of the individual dosages about this mean would have to be determined to yield completely satisfactory information on survival probabilities. Various techniques are available for estimating this quantity. However, it would be preferable—and in conformity with the nonparametric approach of the movement model—to incorporate a calculation of this type in the computer program thereby providing the distribution of dosages.

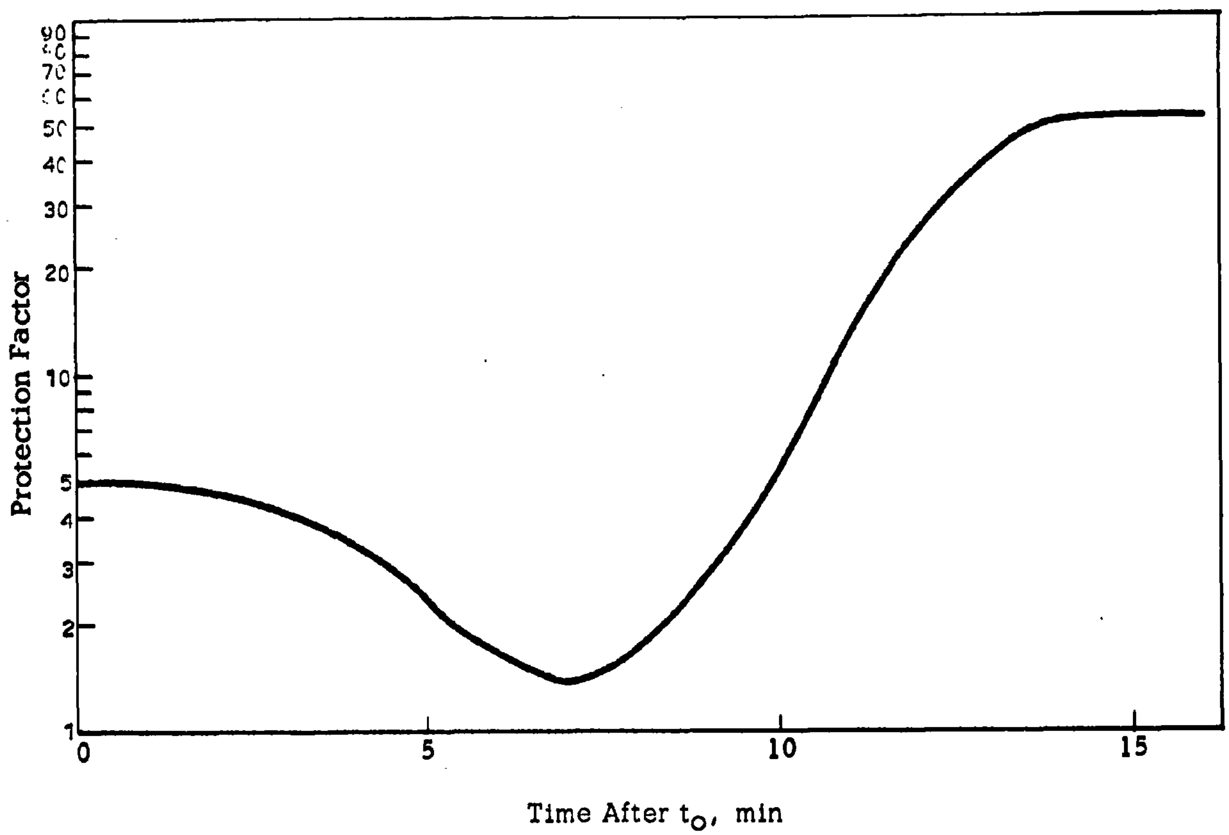


FIGURE 14. MEAN PROTECTION FACTOR IN HYPOTHETICAL SUBAREA

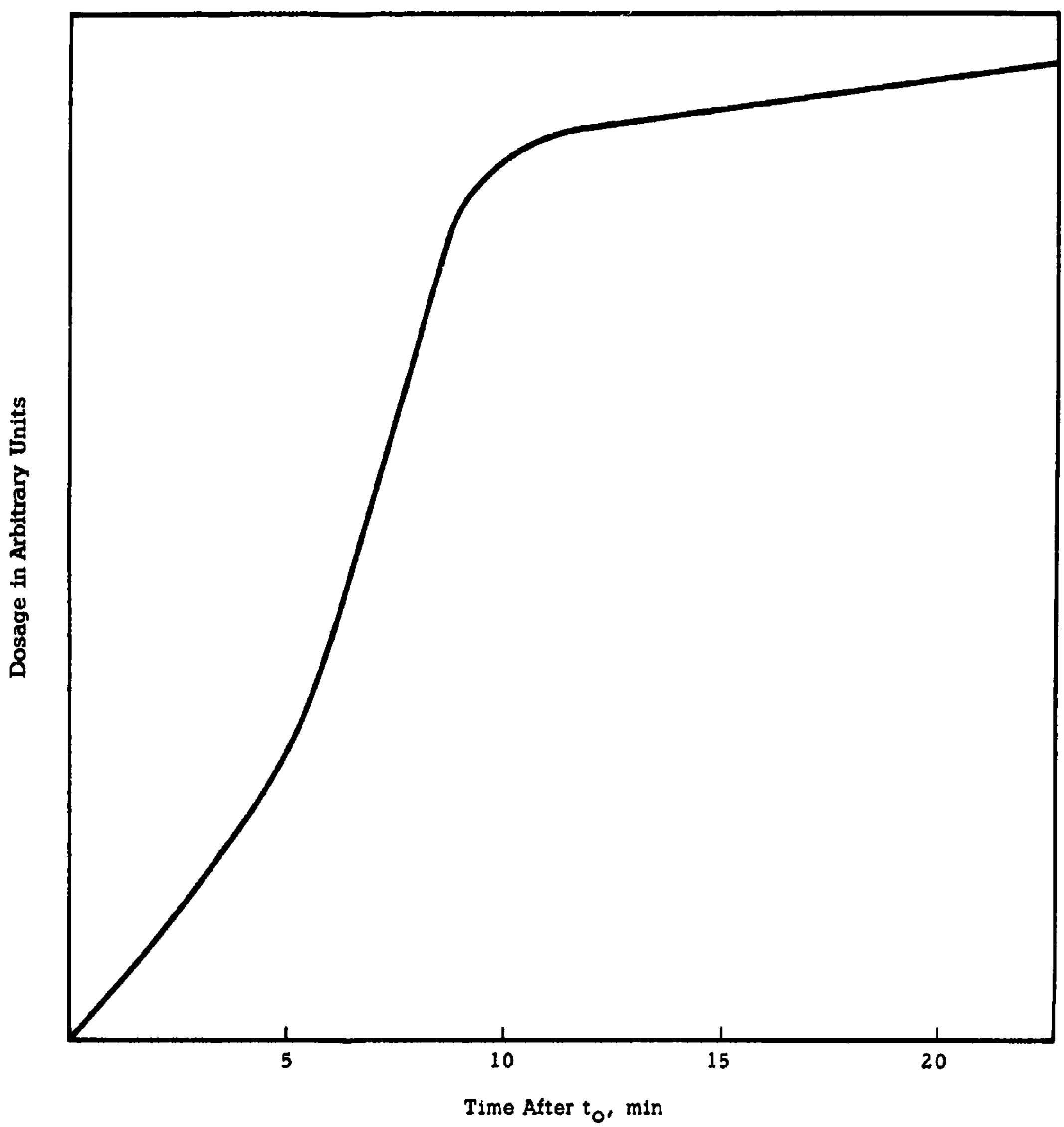


FIGURE 15. CUMULATIVE DOSAGE VS TIME
FOR HYPOTHETICAL SUBAREA

Cost and Effectiveness Analysis

5.18 The model presents, especially if extended as discussed previously, a number of possible effectiveness measures. These might be combined with cost information to evaluate varying levels of shelter adequacy, capacity, distribution rules, etc. A particular area of interest might be a comparative analysis of the effectiveness of equal expenditures on:

a. Improving existing shelters,

b. Providing new shelters in essentially the same locations as at present, or

c. Improving the distribution of shelters, by construction of shelters in deficit areas.

FURTHER PRACTICAL APPLICATIONS

5.19 Further applications of the technique used in this report will provide useful information to local civil defense officials and to federal planning offices. Items of particular interest to local officials include (a) peak population estimates, (b) crowd movement data, and (c) time requirements for effective information dispersal. Information of interest to federal planning offices includes (a) evaluation of alternative shelter improvement concepts, (b) evaluation of effectiveness of shelter assignment plans, (c) estimates of average protection factors of moving and sheltered populations, and (d) estimates of minimum time requirements for sheltering normal city populations under different aspects of control and environmental conditions.

VI. CONCLUSIONS

6.1 Two general categories of conclusions may be drawn as a result of this prototype exercise of the movement model. One category of conclusions concerns the model itself; the second concerns the actual movement process and corollary aspects.

MOVEMENT MODEL

6.2 Since there are no independent analyses of the movement process in the terms in which it is studied in this report, the main determinants of the reliability and validity of the model are the nature of its inputs and the techniques used to derive the conclusions. It can best be judged in terms of the reasonableness of its results.

6.3 Inputs. The movement model has the capability of reflecting all the major determinants of the process of movement under alert conditions: (a) prealert population configurations, (b) frequency distribution of departure time characteristics of various population segments, (c) location and capacity of destinations, and (d) velocity of travel towards destination, reflecting environmental characteristics.

6.4 Values of Inputs. The assumed values of the input parameters in this application were the result of an attempt to reflect the idealized situation of an informed, disciplined, and well-trained population moving to shelter under an alert condition.

6.5 Techniques. The statistical techniques used to arrive at the results of the analyses are quite straightforward and are advantageous in that they have a minimum amount of built-in statistical assumptions regarding the character of the alerted population's response. One of the chief advantages of the method is its receptivity to the inclusion of experimentally measured distributions of response times and movement characteristics.

6.6 Nature of Results. The overall results for the three cities reflect in a reasonable manner general characteristics of the city and its real or assumed relative distribution of shelter spaces and people.

6.7 Independent Checks. As a part of work performed under another contract with OCD, an independent study was made of the filling of shelters in a critical area of Montgomery County, Maryland. This study was made using a detailed on-site analysis of the characteristics of the surrounding area, especially the residential configuration and the capacity of the roadways. The resulting estimate of the filling time of the shelters in the region was within 3 percent of that calculated by use of the movement model.

6.8 In summary it may be concluded that the movement analysis has the capability to produce a useful approximation of the movement characteristics of a population under conditions of a tactical movement to shelter.

MOVEMENT PROCESS

6.9 The conclusions drawn regarding the movement process must be recognized as tentative because they depend on specific values of the outputs of the three analyses performed in this study. However, two conclusions emerge that are not highly sensitive to small changes in the input data and would be affected only by major changes, even though they depend on results of the analyses. One conclusion concerns the effect on the movement of the "initial conditions" of the movement. By initial conditions are meant such determinants of the movement process as weather, time of day and year, and general environmental conditions. The other conclusion concerns the relative importance of shelter capacity and shelter distribution.

Determinants of the Movement Process

6.10 Velocity. It was concluded in the discussion of the general problem of transportation that, except for the early stage of an alert and areas of low population density, the rate of flow in a short-range tactical movement to shelter will be limited by the velocity of pedestrian traffic.

6.11 Time of Day. In general the outputs of the analysis of the 11:00 a.m. and 5:30 p.m. alerts have not differed greatly. Although the 2:30 a.m. results differ somewhat, it is probable that the regions of uncertainty of the three results overlap. Although these results depend on the response time distributions assumed in this study, they would be affected only by major changes in them. This may indicate that the time of day of an alert is not a crucial factor in the sheltering process when considering an entire metropolitan area.

6.12 Environmental Conditions. The chief effect of environmental conditions of the movement process would be on (a) the population distribution and (b) the velocity of movement. In relation to the population distribution, the three tested — nighttime, daytime, and in transit — undoubtedly represent the two extreme cases of population distribution and one intermediate condition. It is highly doubtful whether any analytical technique is sufficiently sensitive to warrant a more detailed analysis of distribution types than these. Since the movement velocity used in this study was considered limited to the velocity of pedestrian travel, the effect of environmental conditions, at least for urban areas of the type analyzed in this report, does not appear to be highly significant. For, of all types of transport, a pedestrian movement over short distances is probably the least sensitive to environment. The effect of severe conditions could be allowed for in a reduction of the mean velocity, with a consequent stretching of the output along the time axis, but with no essential change in the character of the results.

6.13 It may be concluded that the movement process is not highly sensitive to the ordinary range of initial conditions, in the sense of paragraph 6.9.

6.14 Distribution. As can be seen from the analysis of Milwaukee and Salt Lake City, a considerable portion of the time lag in arriving at shelter is caused by the relative disparities between population and shelter distribution. This can be seen clearly when the curves for these two cities are compared with the results for Tampa. The effect can also be seen in the more gradual filling in the 2:30 a.m. curves, and a similar result occurred in the analysis of Montgomery County. This effect is independent of the assumed starting time distribution and can be removed only by assuming unrealistically high redistribution speeds. At the level of overall shelter adequacy found in the areas analyzed, the problem of inadequate relative distribution of shelters and persons to be sheltered begins to assume the magnitude of the problem of inadequacy of shelter spaces. This result indicates the need for further investigation of the location of new shelters to offset the effects of their present concentrations in areas remote from regions of a primarily residential character.

6.15 At present there are relatively inadequate numbers of shelters in most peripheral regions of the three cities studied in this report. A more cursory treatment of other areas indicates that this is the most common condition of shelter distribution. An immediate step that is indicated to offset this condition may be a more thorough use of those governmental and public institutions that tend to have distributions in conformity with the population. Among these are police and fire stations and, more significantly, schools. In many cases upgrading of the protection offered by these might be feasible. Changed standards of construction and other inducements might provide more adequate distributions for future protection.

Nature of Threat

6.16 These conclusions would undoubtedly be affected by a change in the nature of threat. However, it is well to distinguish between two aspects of the change of threat: (a) change in warning time and (b) qualitative changes.

6.17 Change in Warning Time. The output of the analysis performed is sheltering capability as a function of warning time. It covers the complete range of warning time from zero up to infinitely large values.

6.18 Qualitative Changes. Although it is possible that future changes in threat of nuclear, chemical, or biological weapons may make present concepts of sheltering inadequate or even entirely obsolete, they will not greatly affect the elements of the movement as outlined in this study, if that process is undertaken. The rate at which a population can be sheltered naturally does not depend on subsequent conditions of damage.

Problems of Management

6.19 The sheltering process depicted in this study is a relatively ideal limiting case. In order to facilitate the analytical problem in this study perfect conditions of management, information flow, public training, and command and control in general have been assumed. Obviously, degradation in any of these aspects would produce degradation in the ability to respond adequately to an alert. Nevertheless, over a broad range of conditions it may be asserted that the general sheltering program that is more effective under perfect conditions will also be more effective under the real conditions of an actual alert.

6.20 Information. The most important assumption in this treatment of the sheltering process has been the assumption of perfect information. Without the knowledge of the nearest shelter, which was assumed in this study, the movement of the population would be reduced to a random flow and the filling of shelters to chance arrivals. Although no attempt was made to analyze this condition, it is clear that the filling of shelters would be accomplished in the cities analyzed only in terms of days rather than minutes and hours. The need for information to utilize shelters adequately is quite crucial when the number of shelters is large, whereas the distribution of them differs markedly from the distribution of persons to be sheltered. This is the situation in most urban areas, and it is questionable whether knowledge of nearest shelter locations is widespread at present.

6.21 The results of the analysis of the movement process in Milwaukee and Salt Lake City indicated that between 30 and 50 percent of the population of these cities could reach the present shelters in less than 30 min after the sounding of a warning to move. In Tampa, where shelter distribution in conformity with the population was assumed, 100 percent of the population was sheltered in less than 30 min. It should be stressed that these are highly optimistic results and are probably close to the limits of performance of a trained, disciplined, and informed population. It is clear that most of the gains possible through increasing the number or improving the distribution of present shelters can only be realized by a population informed of these improvements and trained to respond rapidly and with order to an alert. Only marginal improvement will be possible merely by constructing more shelter spaces without concomitant information and training programs.

APPENDIX A

REVIEW OF RELATED STUDIES

A.1 The purpose of this appendix is to provide brief reviews of various studies relating to the subjects of warning and reaching shelter. The studies are examined for the area of interest and the results and conclusions achieved. Where appropriate, passages have been excerpted for their focus on one or more of the problems covered in this study. The included group is by no means exhaustive as such an undertaking would have been infeasible under our contractual limitations. Furthermore, much of the work on this subject is outdated and relates to conventional weapon threats or aircraft delivery means.

<u>A Comparison of Two Methods of Calculating Evacuation Movements,</u>
SRI Project No. IU-1947, IV E
Stanford Research Institute
Menlo Park, California
November 1957

A.2 This report compares an SRI developed method for evacuation analysis with one developed by Wilbur Smith and Associates. Both methods consider long-distance evacuations that are now incompatible with the shortened warning times. Further, these methods use area or location units that are too large to be sensitive to short movements within the city proper.

Operation Green Light
Disaster Relief and Civil Defense Department
Portland, Oregon
December 1955

A.3 Operation Green Light covers the preparation and carrying out of a civil defense exercise to evacuate a portion of downtown Portland. It provides much useful information on the reactions and attitudes of people in a test, but does not predict actual conditions. Of special interest is the section on traffic and how it moved, which provides some clue as to the ease with which people might move within a city under attack. Since total evacuation was the aim of this exercise, little attention was given to the time sequences involved, leaving that information gap still unfilled.

A Study of the Public Response to Evacuation Orders
SRI Project No. IU 1947, III B
Stanford Research Institute
Menlo Park, California
August 1957

A.4 This study attempts to describe the time sequence of a city population's response to a warning. Predictions are made with respect to the total number responding and the time taken by them to perform various activities prior to leaving for shelter. These figures are presented for three cases of cities whose responses are good, fair, and poor. Since the whole population of the city is characterized in the applied numbers, there is no possibility for differentiating between areas of the city or times of day. The work done in deriving these results was influenced by the evacuation concepts then in force, and could not be expected to consider the criticality of small changes in the response pattern either by locale or time of day.

Analysis of the Evacuation Schemes for FCDA Region IV
SRI Project No. IU 1947, IV A
Stanford Research Institute
Menlo Park, California
October 1957

A.5 The major effort of this study is the calculation for a group of 19 cities in FCDA Region IV of the time required for their partial evacuation. It is significant that the lowest time required was 6 hr and that

80 percent of South Bend, Indiana's population of 205,000 was removed. It took 8 hr to remove 60 percent of Flint, Michigan's 271,000 people. These numbers certainly preclude such evacuations under our current warning times of $\frac{1}{2}$ hr or less. Further, moderate fallout carried to any of the evacuation destinations would find an almost totally unprotected population.

<u>Operations Walkout, Rideout, and Scat</u>
Committee on Disaster Studies
National Academy of Sciences
National Research Council
Washington, D. C., 1955

A.6 These three operations, like Operation Green Light, were preplanned evacuations of portions of various cities. In each case, the public had been intensively forewarned and some instances of prealarm evacuations were observed. There could be few conclusions drawn from public reaction during these evacuations, since the element of surprise certainly was not present. Operation Walkout in Spokane, Washington, required people to walk out of a 50 square block downtown area to peripheral bus depots where buses loaded and transported them out of town. Twelve minutes were needed to evacuate those who were going, but many did not respond.

A.7 Operation Rideout occurred in Bremerton, Washington, where automobiles were used to evacuate the city. It took 22 min to clear the only large industry, and 40 min to clear traffic from the city itself. One very interesting result was that "except for family units, most of the cars (estimated 80%) had but one or two occupants." It was also noted that "evacuation by automobile would seem . . . to be a most promising Civil Defense Technique." This was modified by the disclosure that traffic entered the movement stream at very few points and "traffic control was exercised at every intersection on each evacuation . . . . It has already been implied that the absence of an officer at one designated point could readily lead to chaotic interruption of the flow of traffic."

A.8 Operation Scat was a "drive out" evacuation of part of Mobile, Alabama. It was well publicized and total participation was urged. The influence of ethnic backgrounds was readily observable as the white population was generally uncooperative, whereas the negro population conformed almost completely. In evaluating available transportation, it was said that "there was ample evidence that the public transportation facilities were inadequate. The large number of people who left early plus the 'car pools' organized for the drive out served to mitigate the inadequacy....In terms of actual unannounced disaster, this failure would be very grave."

A.9 In all three of these studies, there was no analysis of the time sequence of reaction to the alert, there was no study of the origin or destination of drivers in Mobile, and very little of this in Bremerton.

<u>Warning Times and Protection Factors for Local Civil Defense Planning</u>
Research Triangle Institute, Durham, North Carolina
March 1962

A.10 This report is an attempt to use probability and confidence limits to determine the estimated time of arrival of fallout at any point in the U. S. A. It also examines the possibility of reducing fallout protection factor requirements commensurate with attack results as predicted by the developed risk analysis. Warning time predictions are also outputs of this analysis. "Various studies indicate that a protection factor of 100 should protect against serious radiation effects in any area sufficiently remote from the center of a nuclear blast to avoid effects of heat and overpressure.... However, it is quite likely that there are areas in which protection factors less than 100 would have a high probability of giving the necessary protection against fallout expected for that area....in some of the less hazardous areas, a PF of 50 provides a higher probability of survival than a 100 PF shelter adjacent to a primary target."

A.11 "Without going into aspects of expected warning times prior to the first attack on the United States, it appears that a planned allowance of 30 minutes for taking shelter against fallout is an appropriate minimum for preliminary local planning."

<u>Community Operations Plan for Shelter Occupancy</u>
Research Triangle Institute
Durham, North Carolina
March 1962

A.12 "The objective of this procedural description is to present typical applications of the national fallout shelter survey data in assisting local CD planning." This report describes survey outputs, provides guides on mapping of data, and outlines plan for population analysis and future shelter location.

Air Raid Warning in the Missile Era
Operations Research Office
The Johns Hopkins University
Bethesda, Maryland
July 1960

A.13 "Army units. . . experience delays up to about 15 minutes in the reception of their warning."

A.14 "The concept of two tactical alternatives, one for hours of warning and the other for minutes of warning, originated several years ago when the only seriously threatening means of enemy weapon delivery were subsonic aircraft. This concept is now outmoded."

A.15 "A decade of experience in living with the threat (Atomic war) has demonstrated that the American public fails to comprehend the nature of modern civil defense requirements and that most persons would be relatively unprepared if an attack occurred today, next year, or the year after."

A.16 "No study is known in the literature on the perception of unalerted subjects."

A.17 "Much of the siren response by unalerted observers . . . apparently stems from the interaction of individuals with one another, plus the fact that any alarm that persists for a sufficiently long time is likely to attract attention merely through its nuisance characteristic . . . Hence if a siren sound continues for a long period - perhaps for a minute or for a few minutes - it will ultimately evoke a spread reaction through person-to-person diffusion."

A.18 (Telephone Survey results) "The results of the sleep survey indicate that an alarm system comparable in stimulus to that of a telephone bell in the same room can produce a 90% probable reaction in about 24 seconds for healthy individuals. . . .thus, in a city completely served by such an alarm system with only one unit per household, 90% waking of all inhabitants could possibly run to several minutes."

Task Silence
Institute for Cooperative Research
University of Pennsylvania
Philadelphia, Pennsylvania
September 1962.

A.19 This is a description and analysis of the events following the release to the atmosphere of a large quantity of anyhydrous ammonia, which occurred at a dock on the Illinois River just south of Peoria, Illinois, on 1 August 1961.

A.20 As the emergency developed, warnings were sounded by siren, radio, telephone, and in person. Evacuation in the face of the spreading ammonia cloud took place in some of the adjacent communities with people going to shelters, relatives, friends, or gathering points at high ground. Human behavior and community reaction are analyzed and discussed.

A.21 The most valuable commentaries of this report concern the efficiency of various warning methods, the maintaining of information channels, and the reaction of the population of the emergency. The following quotations have been extracted to provide the major points presented in those areas:

> "Initial dump occurred approximately 12:15. . . ."
> "F.D. (fire department) called at 12:20 . . . . "
> "Warning action at 12:45 . . . . "
> "Warning initiated at 1:15 in nearby town. . . ."
> "Warning was initiated by call to F.D. &
> phone 'news tip' to radio station. . . ."

A.22 "Sirens, both fixed and mounted on vehicles, were used almost continuously throughout the emergency period. . . they effectively cleared a path for emergency vehicles, and they summoned the members of the various volunteer fire departments to the fire stations. But as warning to the general public, they were generally less than adequate. Some people reported sleeping undisturbed while sirens wailed continuously nearby. Many who heard the sirens had no reason to believe that any warning was being directed at them and reported various interpretations of the sirens to mean fires, ambulances, police, etc. There seems to be little doubt that the general public has been thoroughly conditioned over the years to associate sirens with certain specific hazards and that general emergency or threat to the community is not one of these hazards. Sirens did not appear to be an adequate means of communication with the general public in this emergency. . . .Loudspeakers mounted on vehicles were used effectively to arouse and alert residents.

A.23 "Door-to-door knocking, individual person-to-person telephone and personal warnings, and announcements by loudspeaker trucks aroused those not awakened, or whose curiosity had not been sufficiently aroused by the sirens to turn on the radio, which was reporting the incident and the evacuation. . . .There were numerous reports of persons knocking on doors, telephoning, driving to a friend's or a relative's house to see if this car was gone, or being picked up by a friend or acquaintance."

A.24 "(Evacuation) Movement was generally radially away from the site of the accident, though no definite pattern of movement was established. It does not appear that police officers and sheriff's deputies were given any specific instructions as to channeling the traffic. The principal activities seem to have been to slow it down. Although it appears from comments that people were 'bent on getting out,' only one very minor accident was reported."

A.25 "Lack of highway congestion was reported, with the comment that people did not all evacuate at once....When an all clear was announced over the radio stations, the roads became clogged with most evacuees trying to return home at one time."

A.26 "City officials were genuinely disturbed by the 'assumption of authority' over their citizens by outsiders. They resented the evacuation advice, which they felt was given by some radio announcer who took it upon himself to make the decision. . .they carried on a prolonged telephone battle with radio station personnel and other officials during the emergency. . . . The investigators feel that the lack of real community ties was reflected in the lack of coordination displayed during the emergency. This suggests that a similar reaction pattern might be expected from the officials and residents of the many other 'package development' communities springing up around the country."

A.27 "The public quickly realized that the radio was their only source of information, and they utilized it. Nearly everyone reported listening to a home or car radio during the emergency, and they followed radio instructions unhesitatingly. Two of the evacuation centers filled within minutes after they were announced to be open and emptied very quickly when the 'all clear' was announced over the radio.

A.28 "Nearly everyone who was initially alerted or awakened by some other means reported turning on the radio for information. Most followed the evacuation instructions without hesitation or question. However, nearly everyone took the time to check on neighbors, relatives, or pets before departing."

A.29 "The use of fixed fire sirens as a system for warning the communities of hazard or disaster late at night was generally inadequate. A number of residents of the communities either did not hear the sirens, or were not sufficiently aroused to investigate the cause of their being sounded. It is concluded that reliance cannot be placed on fire sirens to arouse sleeping communities for evacuation and that disaster plans should include effective warning systems."

"What is a Realistic Civil Defense Shelter Program for the U.S.A.?"
George W. McLaughlin, 8796A Colonel, U.S.A.F.
Air War College Thesis No. 1638 Air University
Maxwell Air Force Base, Alabama
March 1959

A.30 This is a study of the large issues impinging on civil defense policy making. The author weighs the broad aspects of the strategic, economic, political, and lifesaving features of our air defenses and the various shelter and evacuation plans that had been advanced by 1959.

A.31 His first area of discussion is the active defense measures that have been or will be taken against bomber or missile attack. The strongest points cited concern the probability that 70 percent or more of an enemy bomber attack should reach its target, and the probability is even greater for missiles.

A.32 This strong a possibility of attack success coupled with the gigantic effects of nuclear weapons leads the author to conclude that there is no way of preventing almost the whole population from experiencing the effects of an attack.

A.33 Having evaluated our active defense capability, the author turns to passive defense measures such as underground factories and shelters, and evacuation. He spotlights the difficulty of short-term mass evacuation by saying that: "Officials talk glibly of evacuating the city (Philadelphia) on anything from one to six hours warning. No staff officer in his right mind would undertake to move two million disciplined soldiers any considerable distance in less than three days. Considering a heterogeneous crowd in haphazard vehicles, bearing the sick, infants, children, and aged, it appears that mass evacuation is an infallible prescription for a colossal catastrophe."

<u>A Report on Recommended Procedures for Conducting Civil Defense Reception and Care Studies</u>
Public Administration Service
Chicago, Illinois
1956

A.34 The purpose of this work is the development of methodology for analyzing evacuee reception areas. Its scope includes the composition of evacuating groups, their minimum survival needs, and means for describing an area's ability to receive evacuees. The latter two topics do not pertain to ORI's current work, and the composition of evacuating groups was not treated in sufficient detail to shed any new light on the topic for ORI.

<u>Project East River</u>
Associated Universities, Inc.
New York, New York
June to October 1952

A.35 "Project East River was initiated ...to evaluate and recommend the optimum combination on non-military measures which will assist (1) the FCDA in discharging its responsibilities for preparing to minimize the effects of attack by atomic, biological, chemical, or other weapons on the population and industry of the United States; (2) the NSRB in discharging its responsibilities of advising the President concerning the strategic location of industries, services, government, and economic activities, the continuous operation of which is essential to the nation's security; and (3) the Department of Defense in collaborating with FCDA and NSRB in discharging their responsibilities." The above purpose is carried out in ten parts, each of which covers a particular area of importance. These areas range from the destructiveness of atomic weapons to the measures needed to make civil defense manageable. Naturally, much has changed since 1952, but the conclusions drawn in this report are still of great value in civil defense planning. For instance, the following passage from Part V, page 15a still applies: "Warning time is an important controlling factor in the shelter program. Thus, it was obvious that (a) if no warning were given, shelters would be of little or no use; (b) if only 5 or 10 minutes warning were given, people would not have time to dress and travel any distance to shelter; and (c) public shelters would be feasible only if a half-hour or more warning time could be anticipated."

A.36 Another cogent observation concerns metropolitan decentralization: "The optimum pattern for metropolitan decentralization is one consisting of a core city performing principally specialized functions and surrounded by satellite or functionally nucleated developments which perform most manufacturing functions and provide noncentral specialized services for the metropolitan area."

A.37 The obvious implications is that urban populations cannot be made to move in a smooth stream over long distances, and should therefore only be expected to move short distances avoiding the formation of large moving streams. In speaking of deep shelters and underground factories, the author says that the cost of such defense could not and would not be borne by the economy without a radical change in public attitude. He concludes that fallout shelters are the only practical defense and that programs for shelter building and public civil defense education should be accelerated.

A.38 "In connection with the planning by those cities, it was felt that in the areas of greatest concentration the evacuation speed on foot would be two miles per hour with vehicle travel only slightly faster."

A.39 "On the occasion of the evacuation of Washington by designated people, to include all personnel from the Pentagon, confusion reigned. Again, all were waiting the signal, and yet in 20 minutes time, hundreds of people on the fifth floor had not moved out of their own corridors and were jammed up waiting to pass through the door."

A.40 "In considering human behavior under an atomic bombardment threat we must remember that one quarter of the population are children. About a tenth of the adults are emotionally unstable even without external provocation. About six percent of the population in every large city has a tendency to be criminals. Does this all make for an orderly departure once the real alert comes?"

A.41 Part IX, entitled "Information and Training for Civil Defense," contains the following passage: "To the extent that training is feasible, it stands as the surest single preventive measure against panic. It is the device used effectively in combat training - the implanting of habitual estimates of danger situations and of habitual responses in consequence of such estimates....Even if the individual is untrained in reactions to emergency, his behavior may be directed effectively by external guidance, if this is <u>immediately</u> and <u>impressively</u> available to him. In fact, if he lacks the training to assess and usefully react to the threat, his need for authoritative assessment and direction from others is exceedingly urgent....Effective civil defense planning must, therefore, provide for leaders in each area where people may congregate...."

Shelter
John F. Devaney
OCDM-SA-61-12
Operations Research Office
OCDM, June 1961

A.42 This study is an important analysis of the effectiveness of current shelter schemes and some future possibilities. It does not concentrate solely on fallout protection, but also considers blast shelter and mixes of the two. Mr. Devaney distinguishes between metropolitan and nonmetropolitan areas when speaking of shelter availability, warning time, nature of threat, and expected casualties.

A.43 Cost effectiveness is a major consideration of this study. This evaluation yardstick is applied to blast vs fallout shelter vs active defense, and is on regional as well as metropolitan and non-metropolitan bases.

A.44 One of Mr. Devaney's most important points concerns the need for educating the public to use makeshift shelter, primarily that found in basements. He says: "When we subject people in basements at random to the four standard attacks, we find that survival has increased...2 to 12% of the population....Where there is more basement space - of all categories - than is needed, survival can be improved by marking enough spaces giving the better protection. If this is accompanied by a program of public education, it can change the distribution of people by shelter category....The number of survivors added by marking would amount to 3 to 18 million." Since 1961 when these statements were made, warning times have not changed, but weapon strength has. This change in situation will undoubtedly affect the total casualty figures, but the mix of survivors in various shelters will probably remain the same.

A.45 Another area of prime importance in this paper is blast shelter and how it would be used. The author points out that, "To protect against immediate effects, blast shelter obviously must be occupied before the weapon bursts. This means that positive warning of the approach of the weapon must be had in time for the shelter to be occupied." This is in contrast to the fallout shelter that can still be entered safely in the interim between weapon burst and fallout arrival. Though current policy does not include the building of blast shelters, Mr. Devaney's conclusions indicate that this area deserves further inspection.

REVIEW OF EVACUATION PLANS

A.46 During the course of this tactical movement study, examinations and reviews of city and region plans were accomplished. However, most aspects of these plans did not provide for the short warning times inherent to a tactical movement situation and hence are not specifically pertinent to the scope of this study. Accordingly, they are not included in this review, although many of the principles contained in these plans are valid and provided for in the basic analysis. After the basic analysis was completed, the SRI plans for Boston,1/ San Diego,2/ and Montgomery County, Maryland,3/ were published but received too late for incorporation in this report.

1/ Leland H. Towle and John G. Gregory, Development of a Shelter Allocation and Use Plan for Boston, Stanford Research Institute, January 1963.

2/ Edwin E. Boughton, Frederick D. Witzel, and Nicholas A. Rosa, Planning for Shelter Use in San Diego, Stanford Research Institute, June 1963.

3/ Leland H. Towle and Keith E. Duke, Shelter Utilization Planning in Montgomery County, Stanford Research Institute, 30 June 1963, and Stanford Research Institute, Toward Effective Civil Defense in Montgomery County, Maryland, 30 June 1963.

APPENDIX B

METHOD

POPULATION ANALYSIS

B.1 The objective of the population analysis is to determine the time-dependent distribution of postures over the analyzed area. For this purpose the calculations should, if done on an electronic computer, be performed at the finest level possible, i. e., by census tracts. If the calculations are to be made manually, as they were in this study, it is necessary to group census tracts of similar character into subareas. However the subareas are chosen, their boundaries should correspond to census tracts in order to utilize census data.

Basic Data

B.2 The following items of information are required:

p_i = resident population (i^{th} subarea)

p_i^s = school attending resident population (i^{th} subarea)

p_i^e = employed resident population (i^{th} subarea)

A_{ij} = land area of the j^{th} usage-type (i^{th} subarea)

A_i = total land area (i^{th} subarea)

k_{ij} = land-use factor for j^{th} usage-type (i^{th} subarea)

T = total number of jobs held in analyzed area

Cm = number of jobs held by residents in the m^{th} employment category.

B.3 The population has been divided into two major segments, one of which is considered to be in its resident subarea, and the other is distributed over the whole area to be analyzed. Each distributed segment is associated with some identifiable land-use type, and a population density is computed for each of them by dividing the total number of persons in a particular category by the total land area with which that segment is associated. The number of persons in a particular posture allocated to a subarea is the product of the area of appropriate land-use type within that subarea and the population density for that posture. Naturally not all urban areas in any one broad category have the same population density; to allow for this it was found necessary to introduce the matrix k_{ij}, the components of which were estimated from detailed land-use maps. Since they enter into both the numerator and denominator of the expression for the numbers of persons in the m^{th} posture in the j^{th} subarea, the absolute value of any one has no significance. However, it is necessary that the ratios of the adjustment factors for two plots approximate the ratios of their population densities.

B.4 The first breakdown of the population is done directly from census data with the aid of the two following functions:

$g^e(t)$ = fraction of the employed population actually at work at time t

$g^s(t)$ = fraction of school attending population actually at school at time t.

These two functions are assumed to be independent of subarea of residence or employment category.

Major Segments

B.5 The three major segments into which the resident population of a subarea is divided are:

$P_i^e(t)$ = persons resident in subarea i at work at time t;

$P_i^s(t)$ = persons resident in subarea i at school at time t;

$P_i^f(t)$ = "free population" subarea i residents, neither at work nor at school at time t.

B.6 It follows from census data and the distribution mentioned in paragraph B.4 that

$$P_i^e(t) = g^e(t)p_i^e,$$

$$P_i^s(t) = g^s(t)p_i^s,$$

$$P_i^f(t) = p_i - P_i^e(t) - P_i^e(t).$$

Employment

B.7 Since the distributed workers include both residents and nonresidents, it is necessary to obtain an estimate of the total employment in each occupational category. The nonresident employees are assumed to be distributed into occupations in the same ratio as the resident employees are. Let e_m^t be the total number of employed persons in the m^{th} occupational category, resident and nonresident:

$$e_m^t = \frac{T}{\sum_m e_m} e_m .$$

Let $E_m^t(t)$ equal total number of employed persons at work at time t:

$$E_m^t(t) = g^e(t)e_m^t.$$

B.8 The employed persons are then allocated to the various employment locations (e. g., industrial outdoors, business indoors). Let b_m^k be the fraction of employees in the m^{th} occupational category allocated to the k^{th} employment location (assumed independent of time and resident subarea) and let $W_k(t)$ be the total number of employees in the k^{th} occupational location at time t:

$$W_k(t) = \sum_m b_{mk} E_m^t(t).$$

Free Population

B.9 Let $c_k(t)$ equal the fraction of free population remaining in its resident subarea in the k^{th} posture at time t; $d_k(t)$, the fraction of free population in the k^{th} posture to be distributed over the entire area; $F_k^d(t)$, the number of free persons distributed in the k^{th} posture; $F_{ik}^r(t)$, the number of free persons remaining in the i^{th} subarea in the k^{th} posture:

$$F^r_{ik}(t) = c_k(t)\, P^f_i(t)$$

$$F^d_k(t) = d_k(t) \sum_i P^f_i(t).$$

Determination of Densities

B.10 If $K_{ij}A_{ij}$ is the adjusted land area of the j^{th} usage type in the i^{th} subarea; and P_{jm}, the fraction of land of the j^{th} usage type relevant to the m^{th} posture, then

$$A^p_{im} = \sum_j P_{jm} k_{ij} A_{ij},$$

$$A^p_m = \sum_i A^p_{im},$$

where A^p_{im} is the adjusted area relevant to the m^{th} posture in the i^{th} subarea, and A^p_m is the total adjusted area relevant to the m^{th} posture. The general urban density of persons in the m^{th} posture is given by

$$D_m(t) = \frac{F^d_m(t) + W_m(t)}{A^p_m}.$$

Final Allocations

B.11 The number of persons allocated to the i^{th} subarea in the m^{th} posture at time t is given by the product of the general urban density of the m^{th} posture and the amount of land in subarea i relevant to that posture:

$$F^a_{im} = A^p_{im}\, D_m(t).$$

B.12 The total number of persons in the i^{th} subarea in the m^{th} posture is equal to the sum of those allocated to the subarea in the m^{th} posture and those remaining in the subarea in the m^{th} posture.

$$Q_{im}(t) = F^a_{im}(t) + F^r_{im}(t)$$

$$N_i(t) = \sum_m Q_{im}(t).$$

B.13 The fraction of persons in subarea i in the m^{th} posture at time t is given by

$$p_{im}(t) = \frac{Q_{im}(t)}{N_i(t)} .$$

MOVEMENT MODEL

B.14 The movement model is concerned with the process of movement towards a destination and is concerned with the <u>associated area</u> of that destination. In this application the destinations were taken to be either shelters or points of assembly for relocation to more remote shelters. The associated area of the shelter is the land area over which persons are distributed for whom that shelter will be a destination. In this study the associated area of a shelter was taken to consist of all points closer to it than to any other shelter.

B.15 Input data consist of φ_{mk}, fraction of persons in m^{th} posture departing for shelter in the time interval $(k-1)\Delta t \geq t < k\Delta t$; A_i, area associated with i^{th} destination; V_i, (constant)[1] velocity of travel towards shelter; π_{im}, fraction of persons in i^{th} subarea in the m^{th} posture;[2] μ_i, population density of the i^{th} subarea;[2] z_i, velocity adjustment for street patterns.

Assumptions

B.16 The boundaries of the associated area are assumed to be circular with the destination at its center. The total population, $A_i \mu_i$, and the number of persons in each posture, $A_i \mu_i \pi_{im}$, are assumed to be uniformly distributed over the subarea.

ANALYSIS

B.17 Consider the associated area to be divided into annuli by a series of concentric circles, with the boundaries of the k^{th} annulus so chosen that it contains within it all those points that can be reached in the time interval $[(k-1)\Delta t, k\Delta t)$ from the center of the associated area by a person moving with velocity $z_i v_i$. The radius of the k^{th} concentric circle will be given by

$$r_{ik} = k z_i v_i \Delta t .$$

1/ For discussion of the use of a velocity distribution, see paragraph B.20.

2/ For a discussion of the relation of these two quantities to the quantities $Q_i(t)$ and $p_{im}(t)$ of the population analysis, see paragraph B.21.

Let P^a_{ik} be the population of the k^{th} annulus, and A_{in} be the number of persons arriving at destination during the n^{th} time interval.

$$A_{in} \approx \sum_{j=1}^{k} P^a_{i,n+1-j} f_{ij}$$

Where f_{ij} is the fraction of persons departing in the j^{th} time interval,

$$f_{ij} = \sum_m \pi_{im} \varphi_{mj} .$$

If N_{ik} is the number of persons having arrived at destination by the end of the k^{th} time interval,

$$N_{ik} = \sum_{n=1}^{k} A_{in} \approx \sum_{n=1}^{k} \sum_{j=1}^{k} P^a_{i,n+1-j} f_{ij} .$$

If P^c_{ip} is taken to be the population of the p^{th} concentric circle,

$$N_{ik} \approx \sum_{p=1}^{k} P^c_{i,k+1-p} f_{ip}.$$

<u>Determination of P^c_{ij}</u>

B.18 Two cases must be distinguished: (a) A_j, area of the j^{th} concentric circle, less than a_i and (b) A_j greater than a_i.

$$P^c_{ij} = \begin{cases} \mu_i A_j, & A_j \le a_i \\ \mu_i a_i, & A_j \ge a_i . \end{cases}$$

It follows that

$$P^c_{ij} = \mu_i c_{ij}$$

where

$$c_{ij} = \min\left\{\pi r^2_{ij}, a_i\right\}$$

$$= \pi v_i^2 z_i^2 \Delta t_i^2 \min\left\{j^2, \frac{a_i}{\pi v_i^2 z_i^2 \Delta t^2}\right\} .$$

Determination of N_{ik}

B.19 It follows that

$$N_{ik} \approx \pi \mu_i v_i^2 z_i \Delta t^2 \sum_{j=1}^{k} d_{ij} f_{ij}$$

where $$d_{ij} = \min\left\{ (k+1-j)^2, \frac{a_i}{\pi v_i^2 z_i^2 \Delta t^2} \right\}.$$

Velocity Distribution

B.20 The extension of this formula to the case of a distributed velocity is quite straightforward. If $\omega(v)$ is the velocity distribution and M_{ik}, the number sheltered by the end of the k^{th} time interval, then

$$M_{ik} = \int_0^\infty \omega(v)\, N_{ik}\, dv \ .$$

Determination of π_{im} and μ_i

B.21 The assumption of uniform distribution within a subarea allows the determination of π_{im} and μ_{im} in the following manner:

$$\mu_i = \frac{Q_i(t)}{A_i}$$

$$\pi_{im} = a_i \mu_i p_{im}(t) \ .$$

APPENDIX C

COMPUTATIONS AND RESULTS

C.1 This appendix contains the detailed computations of the population and movement analysis for Salt Lake City, Utah, and gives the results of the computations for Tampa, Florida, and Milwaukee, Wisconsin. For a general treatment of the concepts of this analysis, consult Sections III and IV of this report. Appendix B contains the mathematical formulation of the methods used in this appendix. For a discussion of the results of the analysis of Salt Lake City, Tampa, and Milwaukee, consult Section V.

C.2 The day on which the alert occurred in this analysis was assumed to be a weekday when school was in session. Weather conditions were not considered to be such as would produce any major obstacles to population movement. Three specific times were chosen: 11:00 a.m., to illustrate a typical midmorning condition with high population densities in business, commercial, and industrial areas; 5:30 p.m., taken as representative of a time with a large in-transit population; 2:30 a.m., typical of nighttime, mainly residential, population distributions.

SALT LAKE CITY

Population Analysis

C.3 Subarea Basic Data. Table C.1 contains the basic data on the analyzed subareas. For a map of the subareas, see Figure 4.

C.4 Area Resident Working Force. Table C.2 contains the breakdown into the occupational categories of the employed residents of the analyzed area.

C.5 Employment Allocation. Table C.3 contains the factors used to allocate members of the various categories to different locations.

C.6 Area Working Force Distributions. Table C.4 contains the estimated total resident and nonresident working force and allocates this total working force to employment locations on the basis of factors from the previous table.

C.7 Distribution of Major Population Segments. Table C.5 presents the fractions of subarea residents allocated to the three major population segments—(a) employed, (b) school, and (c) free—at the three times of day.

C.8 Subarea Residents at Work, at School, and Free. Table C.6 presents the number of subarea residents in each of the three major population segments at the three times of day.

C.9 Free Population Allocations. Tables C.7 to C.9 contain the detailed breakdown of the free population based on the allocation factors in Table C.5.

C.10 Employment by Categories. Table C.10 contains the total number of resident and nonresident employees actually at work at the three times of day by employment categories. These are obtained by multiplying the total employment by categories from Table C.4 by the allocation factors from Table C.5.

C.11 Population Segment Allocation. Table C.11 contains fractions of the various previously computed population segments allocated to various postures and remaining in subarea of residence.

C.12 Population Segment Distribution. Tables C.12 to C.14 contain the numbers of persons in various population segments allocated to postures and remaining in the subarea of residence. These are obtained by multiplying the totals in the appropriate categories from Tables C.7 to C.10 by the allocation factors from Table C.11.

C.13 Population Densities. Table C.15 contains the population densities for the three times of day. The density in persons per square mile is determined by dividing the total number of persons allocated to various employment categories by the total urban land area relevant to that employment category.

C.14 Undistributed Population Segments. Table C.16 contains the number of subarea residents remaining within their subarea, classified by activity.

C.15 Posture Distributions. Tables C.17 to C.27 contain the result of the posture analysis. For each subarea and for the three times of day are presented (a) the number of persons in each posture, (b) the total population, and (c) the fraction of population in each posture.

Movement Analysis

C.16 Basic Movement Inputs. Table C.28 summarizes the basic inputs to the movement model.

C.17 Distribution of Departure Times. Table C.29 contains the fraction of persons in each posture departing for shelter in each 1-min interval after the sounding of warning.

C.18 Distribution of Departures, by Subarea. Tables C.30 to C.33 contain the fraction of persons in each subarea departing for shelter in each time interval after the alert. The fraction of persons departing in any one time interval is determined by multiplying the fraction of persons in each posture from Tables C.17 to C.27 by the fraction in that posture departing in the given time interval and summing over all postures.

C.19 Initial Arrivals at Shelter. From this point onward, calculations are presented in detail only for the shelters in subareas B, C, and J. The arrivals at shelter are calculated by means of the following formula

$$N_{ik} = \frac{16}{\pi} n_i \mu_i v_i^2 \Delta t^2 \sum_{j=1}^{k} d_{ij} f_{ij} ,$$

where,

N_{ik} = number of persons who have arrived at assembly point in the i^{th} subarea at the end of the k^{th} time interval.

n_i = number of assembly points (Table C.28)

μ_i = population density (Table C.28)

v_i = average movement velocity (Table C.28)

Δ_t = time interval chosen for analysis (1 min)

f_{ij} = fraction of persons departing for shelter in the j^{th} minute after warning (Tables C.30 to C.33)

$$d_{ij} = \min \left\{ (k + 1 - j)^2 \frac{\pi a_i}{16 v_i^2 \Delta_t^2} \right\}$$

a_i = associated area (Table C.28).

C.20 Initial Arrivals in Subareas B and J. Table C.34 contains for each time interval the number of arrivals at shelters in subareas B and J, the number of arrivals that are sheltered in these subareas, and the number that are directed to subarea C.

C.21 Redistributions Data. Table C.35 contains the data needed to calculate the relocations, i.e., the redistribution of people when the shelters in their subarea are filled. The initial arrivals in subareas B and J that are directed to subarea C will have their times of arrival displaced by their relocation time.

C.22 Movement to Shelter with Redistribution. Table C.36 contains the arrivals at shelter in subarea C as a sum of three components: direct arrivals from subarea C and persons redirected from subareas B and J. Figures C.1 to C.7 present a plot of this calculation for each subarea. For Salt Lake City as a whole see Figure 8, Section 4.

MILWAUKEE AND TAMPA

C.23 The same analysis was performed on Milwaukee and Tampa. The results of this analysis are presented in Figures 7 and 9, Section 4.

TABLE C.1

SALT LAKE CITY, SUBAREA BASIC DATA

Sub-Area 1/	Residents 2/			Area, sq mi 3/				Shelter Data 4/	
	Total	At School	Em-ployed	Bus. & Com.	Indus-trial	Local Bus & Shop.	Total 5/	No.	Capacity
A	7,477	1,822	2,816	.253	.499	.033	4.1	13	2,680
B	10,947	2,671	4,584	-	-	.011	1.8	9	1,609
C	3,597	1,862	1,138	.213	-	-	3.3	77	15,677
D	34,104	6,255	15,505	.681	-	.235	2.7	425	103,586
E	33,649	8,749	12,194	.505	.552	.331	8.3	13	6,473
F	10,893	3,685	3,553	-	.031	.026	1.6	-	-
G	1,650	485	519	.021	.346	.143	7.8	1	283
H	46,993	11,897	19,595	.081	-	.114	4.8	35	7,632
J	18,827	6,514	7,151	-	-	.075	3.5	9	944
K	5,859	1,900	2,199	.056	-	.179	1.5	8	843
L	15,458	4,556	6,126	.015	-	.056	2.4	3	117
Total	189,454	50,396	75,380	1.825	1.428	1.203	41.8	593	139,844

1/ The subareas are made up of census tracts, as follows: A-1,2, 7; B-9, 10, 12; C-13, 14; D-8, 11, 15, 17, 19, 20, 21, 22, 23; E-6, 24, 25, 26, 27, 28, 29; F-4, 5; G-3; H-16, 18, 30, 31, 32, 33, 34, 35, 36, 37, 38; J-39, 40, 41, 42, 43; K-44, 45, 46; L-47, 48, 49.

"Census tracts are small areas into which large cities and adjacent areas have been divided for statistical purposes. (A) tract... (is) generally designed to be relatively uniform with respect to population characteristics....The Bureau of the Census tabulates population and housing information on each tract." (U.S. Bureau of the Census, U.S. Censuses of Population and Housing: 1960, Census Tracts, Final Report PHC(1)-132, p. 1, 1961.

2/ Ibid., Tables P-1 and P-3.

Page 4, "School enrollment is shown for persons 5 to 34 years old. Persons were included as enrolled in school if they were reported as attending or enrolled in a 'regular' school or college at any time between February 1, 1960, and the time of the enumeration."

"Employed persons comprise all civilians 14 years old and over who were either (a) 'at work'...or (b) were 'with a job but not at work'—those who did not work and were not looking for a job but had a job or business from which they were temporarily absent because of bad weather, industrial dispute, vacation, illness, or other personal reasons."

3/ Business and commercial area, industrial area, and local business and shopping area were measured from local maps and have been adjusted for land-use factors. Uninhabited areas on the boundaries of subarea A and B have been removed from the total land area.

4/ National Fallout Shelter Survey, Phase II.

5/ Total land area includes residential and undeveloped areas.

TABLE C.2

SALT LAKE CITY, RESIDENT WORKING FORCE
BY OCCUPATIONS

Occupation	Resident Working Force*
Mining	1,230
Construction	4,278
Manufacturing	11,834
Railroad and railway express services	2,063
Other transportation	2,480
Communication, utility, & sanitary services	2,422
Wholesale trade	4,446
Eating and drinking places	2,223
Other retail trade	10,880
Business and repair services	2,165
Private households	1,303
Other personal services	3,065
Hospitals	2,979
Educational services	5,050
Other professional and related services	4,719
Public administration	5,153
Other industries	9,090
Total	75,380

*U.S. Bureau of the Census, op. cit., Table P-3, "The data on... (this) subject...are for employed persons....The occupation... statistics presented here are based on the detailed systems developed for the 1960 census; see 1960 Classified Index of Occupations and Industries, Government Printing Office, Washington 25, D.C." (ibid., p 5).

TABLE C.3

SALT LAKE CITY, EMPLOYMENT
ALLOCATION MATRIX

Occupation	Allocation Factor*				
	Indus., Indoors	Indus., Outdoors	Business, Indoors	Business, Outdoors	Pub. Pl., Indoors
Mining	.50	.50			
Construction		.40		.60	
Manufacturing	.88	.02	.10		
R. R. & rail exp serv	.60	.30	.05	.05	
Other transportation	.10	.20	.15	.55	
Comm, util, & serv	.05	.15	.20	.60	
Wholesale trade					1.00
Eating & drinking places					1.00
Other retail trade					1.00
Business & repair serv					1.00
Private households					1.00
Other personal services	.20		.80		
Hospitals	.20		.60		.20
Educational services	.10		.60		.30
Other professional serv	.10		.80		.10
Public administration			1.00		
Other	.40	.10	.40	.10	

*It is assumed for an occupation, the allocation factor under any location heading is the fraction of the total number of persons in that category who are allocated to that location.

TABLE C.4

SALT LAKE CITY, AREA WORKING FORCE DISTRIBUTIONS

Occupation	Resident Working Force[1]	Resident and Nonresident Working Force: Total[2]	Employment Location[3]: Indus., Indoors	Indus., Outdoors	Business, Indoors	Business, Outdoors	Pub.Pl, Indoors
Mining	1,230	1,584	793	793			
Construction	4,278	5,514		2206		3308	
Manufacturing	11,834	15,253	13,423	305	1,525		
R.R. & rail exp serv	2,063	2,659	1,595	793	133	133	
Other transportation	2,480	3,196	320	639	479	1758	
Comm, util, & san	2,422	3,121	156	468	624	1873	
Wholesale trade	4,446	5,730					5,730
Eating & drinking pl	2,223	2,866					2,866
Other retail	10,880	14,025					14,025
Bus. & repair	2,165	2,791					2,791
Priv households	1,303	1,680					1,680
Other personal serv	3,065	3,951	791		3,160		
Hospitals	2,979	3,840	768		2,304		768
Education serv	5,050	6,509	651		3,905		1,953
Other profess. serv	4,719	6,083	608		4,867		608
Public admin	5,153	6,642			6,642		
Other	9,090	11,716	4,686	1172	4,686	1172	
Total[4]	75,380	97,160	23,791	6381	28,325	8244	30,421

1/ Source: Table C.2.

2/ Source: 1.288 x (resident working force).
The number 1.288 (nonresident factor) is the total number of jobs held in Salt Lake City divided by the total number of jobs held in Salt Lake City by residents. The total number of jobs held was estimated as follows:

Total jobs = no. of SLC residents employed in Salt Lake City
+ no. of remainder of SLC SMSA residents employed in SLC + No. of non-SMSA residents employed in SLC.

The source for the first two components is the Census Report PHC (1)-132, Table P-3. The last component was assumed to be equal to the number of Salt Lake City residents employed outside of the SMSA. This figure was checked against the figures of "those who worked outside of county of residence" for the surrounding counties in the <u>County and City Data Book</u>, 1962, Table 2, Item 48.

3/ Source: (Total resident and nonresident working force) x (appropriate factors from Table C.3).

4/ Because of rounding, these numbers may not add exactly.

TABLE C.5

SALT LAKE CITY, TIME DISTRIBUTION OF MAJOR POPULATION SEGMENTS*

Time	Employed Pop.		School Pop.		Free Population					
	At Work	Free	At School	Free	At Home Awake	At Home Asleep	At Recreation	In Stores	In Transit	On Streets
11:00 a.m.	.80	.20	.93	.07	.7200	.0300	.0250	.1250	.0500	.0500
5:30 p.m.	.30	.70	.00	1.00	.6400	.0100	.0175	.0525	.2100	.0700
2:30 a.m.	.03	.97	.00	1.00	.0100	.9800	.0040	.0025	.0025	.0010

* Source: assumed.

TABLE C.6

SALT LAKE CITY, SUBAREA RESIDENTS AT WORK, AT SCHOOL, AND FREE

Subarea	Total Resid Pop. 1/	Number of Subarea Residents Allocated								
		11:00 a.m.			5:30 p.m.			2:30 a.m.		
		At Work 2/	At School 3/	Free 4/	At Work 2/	At School 3/	Free 4/	At Work 2/	At School 3/	Free 4/
A	7,477	2,253	1,694	3,530	845	0	6,632	85	0	7,392
B	10,947	3,667	2,484	4,796	1,375	0	9,572	138	0	10,809
C	3,597	910	1,732	955	341	0	3,256	34	0	3,563
D	34,104	12,404	5,817	15,883	4,652	0	29,452	465	0	33,639
E	33,649	9,755	8,137	15,757	3,658	0	29,991	366	0	33,283
F	10,893	2,842	3,427	4,624	1,066	0	9,827	107	0	10,786
G	1,650	415	451	784	156	0	1,494	16	0	1,634
H	46,993	15,676	11,064	20,253	5,879	0	41,114	588	0	46,405
J	18,827	5,721	6,058	7,048	2,145	0	16,682	215	0	18,612
K	5,859	1,759	1,767	2,333	660	0	5,199	66	0	5,793
L	15,458	4,901	4,237	6,320	1,838	0	13,620	184	0	15,274
Total	189,454	60,303	46,868	82,283	22,615	0	166,839	2264	0	187,190

1/ Source: Table C.1.

2/ Source: (Employed residents from Table C.1) x (appropriate factors from Table C.5).

3/ Source: (School residents from Table C.1) x (appropriate factors from Table C.5).

4/ Source: (Total resident population) - (residents at work) - (residents at school).

TABLE C.7

SALT LAKE CITY, FREE POPULATION ALLOCATION, 11:00 A.M.

Sub-area	Total Free Pop.1/	Number of Persons2/					
		At Home, Awake	At Home, Asleep	At Recreation	In Stores	In Transit	On Street
A	3,530	2,541	106	88	441	177	177
B	4,796	3,453	144	120	599	240	240
C	955	687	29	24	119	48	48
D	15,883	11,436	476	397	1,986	794	794
E	15,757	11,345	473	394	1,969	788	788
F	4,624	3,329	139	116	578	231	231
G	784	564	24	20	98	39	39
H	20,253	14,582	608	506	2,531	1013	1013
J	7,048	5,075	211	176	882	352	352
K	2,333	1,680	70	58	291	117	117
L	6,320	4,550	190	158	790	316	316
Total	82,283	59,242	2470	2057	10.234	4115	4115

1/ Source: Table C.6, free population, 11:00 a.m.

2/ Source: (Total free population) x (appropriate factors from Table C.5).

TABLE C.8

SALT LAKE CITY, FREE POPULATION ALLOCATION, 5:30 P.M.

Sub-area	Total Free Pop.1/	Number of Persons 2/					
		At Home, Awake	At Home, Asleep	At Rec-reation	In Stores	In Transit	On Street
A	6,632	4,245	66	116	348	1,393	464
B	9,572	6,126	96	168	502	2,010	670
C	3,256	2,083	33	57	171	684	228
D	29,452	18,849	295	515	1546	6,185	2,062
E	29,991	19,194	300	525	1575	6,298	2,099
F	9,827	6,289	98	172	516	2,064	688
G	1,494	956	15	26	78	314	105
H	41,114	26,313	411	720	2159	8,633	2,878
J	16,682	10,676	167	292	876	1,168	1,168
K	5,199	3,327	52	91	273	1,092	364
L	13,620	8,717	136	238	715	2,861	953
Total	166,839	106,775	1669	2920	8759	32,702	11,679

1/ Source: Table C.6, free population, 5:30 p.m.

2/ Source: (Total free population) x (appropriate factors from Table C.5).

TABLE C.9

SALT LAKE CITY, FREE POPULATION ALLOCATION, 2:30 A.M.

Sub-area	Total Free Pop.1/	Number of Persons 2/					
		At Home, Awake	At Home, Asleep	At Recreation	In Stores	In Transit	On Street
A	7,392	74	7,244	29	19	19	7
B	10,809	108	10,593	43	27	27	11
C	3,563	36	3,491	14	9	9	4
D	33,639	336	32,967	134	84	84	34
E	33,283	333	32,617	134	83	83	33
F	10,786	108	10,570	43	27	27	11
G	1,634	16	1,602	6	4	4	2
H	46,405	464	45,477	186	116	116	46
J	18,612	186	18,240	73	47	47	19
K	5,793	58	5,677	22	15	15	6
L	15,274	153	14,968	62	38	38	15
Total	187,190	1872	183,446	746	469	469	188

1/ Source: Table C.6, free population, 2:30 a.m.

2/ Source: (Total free population) x (appropriate factors from Table C.5).

TABLE C.10
SALT LAKE CITY, EMPLOYMENT BY CATEGORIES

Employment Location	Total Employed 1/	At Work 2/		
		11:00 a.m.	5:30 p.m.	2:30 a.m.
Industrial worker, indoors	23,791	19,033	7137	714
Industrial worker, outdoors	6,381	5,105	1914	191
Business worker, indoors	28,325	22,660	8498	850
Business worker, outdoors	8,244	6,595	2473	247
Public place employed, indoors	30,421	24,335	9126	913

1/ Source: Table C.4, total.

2/ Source: (Total employed) x (appropriate factors from Table C.5).

TABLE C.11
SALT LAKE CITY, POPULATION SEGMENT, ALLOCATION MATRIX

Population Segment	Allocation Factors*						
	Remain-ing in Sub-area	Bus., Indoors	Indus., Indoors	Pub. Place, Indoors	Pub. place, outdoors		
					Bus.	Indus.	Other
Bus. worker, indoors		1.00					
Bus. worker, outdoors					1.00		
Indus. worker, indoors			1.00				
Indus. worker, outdoors						1.00	
Pub. place, indoors				1.00			
In stores				1.00			
In transit	.50						.50
At recreation	.75			.25			
On streets	.25						.75
At home, asleep	1.00						
At home, awake	1.00						
At school	1.00						

* Source: assumed.

TABLE C.12

SALT LAKE CITY, POPULATION SEGMENT
DISTRIBUTION, 11:00 A.M.

Population Segment	Total 1/	Remaining in Sub-area	Distributed Population 2/					
			Business, Indoors	Indus., Indoors	Pub. Place, Indoors	Pub. Place, Outdoors		
						Bus.	Indus.	Other
Bus. worker, indoors	22,660		22,660					
Bus. worker, outdoors	6,595					6595		
Indus. worker, indoors	19,033			19,033				
Indus. worker, outdoors	5,105						5105	
Pub. place, indoors	24,335				24,335			
In stores	10,284				10,284			
In transit	4,115	2,058						2057
At recreation	2,057	1,543			514			
On street	4,115	1,029						3086
At home, asleep	2,470	2,470						
At home, awake	59,242	59,242						
At school	46,868	46,868						
Total	206,879	113,210	22,660	19,033	35,133	6595	5105	5143

1/ Source: Tables C.7 and C.10.

2/ Source: (Total distributed population) x (appropriate factors from Table C.11).

TABLE C.13

SALT LAKE CITY, POPULATION SEGMENT DISTRIBUTION, 5:30 P.M.

Population Segment	Total 1/	Remain-ing in Sub-area	Distributed Population 2/					
			Business, Indoors	Indus, Indoors	Pub. Place, Indoors	Pub.Place, Outdoors		
						Bus.	Indus.	Other
Bus. worker, indoors	8,498		8498					
Bus. worker, outdoors	2,473					2473		
Indus. worker, indoors	7,137			7137				
Indus. worker, outdoors	1,914						1914	
Pub. place, indoors	9,126				9,126			
In stores	8,759				8,759			
In transit	35,037	17,518						17,518
At recreation	2,920	2,190			730			
On street	11,679	2,920						8,759
At home, asleep	1,669							
At home, awake	106,775	106,775						
At school	0	0						
Total	195,987	131,072	8498	7137	18,615	2473	1914	26,278

1/ Sourcé: Tables C.8 and C.10.

2/ Source: (Total distributed population) x (appropriate factors from Table C.11).

TABLE C.14

SALT LAKE CITY, POPULATION SEGMENT
DISTRIBUTION, 2:30 A.M.

Population Segment	Total 1/	Remaining in Sub-area	Distributed Population 2/					
			Business, Indoors	Indus., Indoors	Pub. Place, Indoors	Pub. Place, Outdoors		
						Bus.	Indus.	Other
Bus. worker, indoors	850		850					
Bus. worker, outdoors	247					247		
Indus. worker, indoors	714			714				
Indus. worker, outdoors	191						191	
Pub.place, indoors	913				913			
In stores	469				469			
In transit	469	235						234
At recreation	746	559			187			
On street	188	47						141
At home, asleep	183,446	183,446						
At home, awake	1,872	1,872						
At school	0	0						
Total	190,105	186,159	850	714	1569	247	191	375

1/ Source: Tables C. 9 and C. 10.

2/ Source: (Total distributed population) x (appropriate factors from Table C.11).

TABLE C.15

SALT LAKE CITY, POPULATION DENSITIES

Population Segment	Area,[1] sq mi	11:00 a.m.		5:30 p.m.		2:30 a.m.	
		Number[2]	Density[3]	Number[2]	Density[3]	Number[2]	Density[3]
Bus. worker, indoors	1.825	22,660	12,416	8,498	4,656	850	465
Indus. worker, indoors	1.427	19,033	13,338	7,137	5,001	714	500
Pub. place, employed, indoors	1.204	35,133	29,180	18,615	15,460	1569	1303
Pub. place, outdoors							
Bus. worker	1.825	6,595	3,614	2,473	1,355	247	135
Indus. worker	1.427	5,105	3,577	1,914	1,341	191	133
Other	4.456	5,143	1,154	26,278	5,897	375	84

[1] Source: Table C.1. Business workers are distributed over business and commerical area; industrial workers, over industrial area; public place employed, over local business and shopping area. Public place, others are distributed over all three land-use categories.

[2] Source: Totals, Tables C.12 to C.14.

[3] Source: (Number of persons) ÷ (area).

TABLE C.16

SALT LAKE CITY, UNDISTRIBUTED POPULATION SEGMENTS

Subarea	11:00 a.m. 1/			5:30 p.m. 2/			2:30 a.m. 3/		
	In Transit	On Street	At Recreation	In Transit	On Street	At Recreation	In Transit	On Street	At Recreation
A	88	44	66	696	116	87	10	2	22
B	120	60	90	1005	168	126	14	3	32
C	24	12	18	342	57	43	4	1	10
D	397	198	298	3092	516	386	42	8	100
E	394	197	296	3149	525	393	42	8	100
F	116	58	87	1032	172	129	14	3	32
G	20	10	15	157	26	20	2	0	4
H	506	253	380	4316	720	540	58	12	140
J	176	88	132	1752	292	219	24	5	55
K	58	29	44	546	91	68	8	2	16
L	158	79	118	1430	238	178	19	4	46

1/ Source: In transit, on street, and at recreation components from Table C.7 multiplied by appropriate factors from Table C. 11.

2/ Source: In transit, on street, and at recreation components from Table C.8 multiplied by appropriate factors from Table C. 11.

3/ Source: In transit, on street, and at recreation components from Table C.9 multiplied by appropriate factors from Table C. 11.

TABLE C.17

SALT LAKE CITY, POSTURE DISTRIBUTION * OF SUBAREA A

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	106	.0056	66	.0043	7244	.9136
At home, awake	2,541	.1344	4,245	.2823	74	.0093
At school	1,694	.0896	0	.0000	0	.0000
Bus. worker, indoors	3,141	.1661	1,178	.0783	118	.0148
Indus. worker, indoors	6,656	.3521	2,495	.1659	250	.0315
Pub. place, indoors	963	.0509	510	.0339	43	.0054
Pub. place, outdoors	3,802	.2011	6,540	.4350	200	.0252
In transit	88		696		10	
On streets	44		116		2	
At recreation	66		87		22	
Bus. worker, outdoors	914		343		34	
Indus. worker, outdoors	1,785		669		66	
Other	905		4,629		66	
Total	18,903		15,034		7929	

* Source: At home, asleep - Tables C.7 to C.9.
At home, awake - Tables C.7 to C.9.
At school - Table C.6.
Business workers, indoors: (Density of business workers, indoors, Table C.15) x (business and commercial area of subarea, Table C.1).
Industrial workers, indoors: (Density of industrial worker indoors, Table C.15) x (industrial area of subarea, Table C.1).
Public place, indoors: (Density of public place, employed, indoors, Table C.15) x (local business and shopping area of subarea, Table C.1).
Public place, outdoors: Sum of the following six components.
In transit: Table C.16.
On streets: Table C.16.
At recreation: Table C.16.
Business workers, outdoors: (Density of business workers, outdoors, Table C.15) x (business and commercial area of subarea, Table C.1).
Industrial workers, outdoors: (Density of industrial workers, outdoors, Table C.15) x (industrial area of subarea, Table C.1).
Others: (Density of public place, others, Table C.15) x (sum of industrial, business, and local business areas of subarea, Table C.1).

TABLE C.18

SALT LAKE CITY, POSTURE DISTRIBUTION*
OF SUBAREA B

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	144	.0215	96	.0123	10,593	.9840
At home, awake	3453	.5165	6126	.7898	108	.0100
At school	2484	.3715	0	.0000	0	.0000
Bus. worker, indoors	0	.0000	0	.0000	0	.0000
Indus. worker, indoors	0	.0000	0	.0000	0	.0000
Pub. place,indoors	321	.0480	170	.0219	14	.0013
Pub. place,outdoors	283	.0423	1364	.1758	50	.0046
In transit	120		1005		14	
On streets	60		168		3	
At recreation	90		126		32	
Bus. worker, outdoors	0		0		0	
Indus. worker, outdoors	0		0		0	
Other	13		65		1	
Total	6685		7756		10,765	

* Same as footnote in Table C.17.

TABLE C. 19

SALT LAKE CITY, POSTURE DISTRIBUTION
OF SUBAREA C

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	29	.0047	33	.0064	3491	.9466
At home, awake	687	.1114	2083	.4088	36	.0098
At school	1732	.2810	0	.0000	0	.0000
Bus. worker, indoors	2645	.4291	992	.1947	99	.0268
Indus. worker, indoors	0	.0000	0	.0000	0	.0000
Pub. place, indoors	0	.0000	0	.0000	0	.0000
Pub. place, outdoors	1070	.1736	1987	.3899	62	.0168
In transit	24		342		4	
On street	12		57		1	
At recreation	18		43		10	
Bus. worker, outdoors	770		289		29	
Indus. worker, outdoor	0		0		0	
Other	246		1256		18	
Total	6163		5095		3688	

* Same as footnote in Table C.17.

TABLE C.20

SALT LAKE CITY, POSTURE DISTRIBUTION*
OF SUBAREA D

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	476	.0127	295	.0081	32,967	.9627
At home, awake	11,436	.3053	18,849	.5197	336	.0098
At school	5,817	.1553	0	.0000	0	.0000
Bus. worker, indoors	8,455	.2257	3,171	.0874	317	.0093
Indus. worker, indoors	0	.0000	0	.0000	0	.0000
Pub. place, indoors	6,857	.1830	3,633	.1001	306	.0089
Pub. place, outdoors	4,411	.1177	10,319	.2845	319	.0093
In transit	397		3,092		42	
On streets	198		516		8	
At recreation	298		386		100	
Bus. worker, outdoors	2,461		923		92	
Indus. worker, outdoors	0		0		0	
Other	1,057		5,402		77	
Total	37,452		36,267		34,245	

*Same as footnote in Table C.17.

TABLE C. 21

SALT LAKE CITY, POSTURE DISTRIBUTION *
OF SUBAREA E

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	473	.0095	300	.0069	32,617	.9510
At home, awake	11,345	.2290	19,194	.4422	333	.0097
At school	8,137	.1642	0	.0000	0	.0000
Bus. worker, indoors	6,270	.1265	2,351	.0541	234	.0068
Indus. worker, indoors	7,363	.1486	2,761	.0636	276	.0080
Pub. place, indoors	9,659	.1949	5,117	.1179	431	.0126
Pub. place, outdoors	6,289	.1269	13,676	.3151	408	.0119
In transit	394		3,149		42	
On streets	197		525		8	
At recreation	296		393		100	
Bus. worker, outdoors	1,825		684		68	
Indus. worker, outdoors	1,975		740		73	
Other	1,602		8,185		117	
Total	49,536		43,399		34,299	

* Same as footnote in Table C. 17.

TABLE C. 22

SALT LAKE CITY, POSTURE DISTRIBUTION *
OF SUBAREA F

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	139	.0163	98	.0113	10,570	.9800
At home, awake	3329	.3914	6289	.7266	108	.0100
At school	3427	.4029	0	.0000	0	.0000
Bus. worker, indoors	0	.0000	0	.0000	0	.0000
Indus.worker, indoors	413	.0485	155	.0179	16	.0015
Pub. place, indoors	759	.0892	402	.0464	34	.0032
Pub. place, outdoors	438	.0514	1711	.1976	58	.0054
In transit	116		1032		14	
On streets	58		172		3	
At recreation	87		129		32	
Bus.worker, outdoors	0		0		0	
Indus.worker, outdoors	111		42		4	
Other	66		336		5	
Total	8505		8655		10,786	

* Same as footnote in Table C. 17.

TABLE C. 23

SALT LAKE CITY, POSTURE DISTRIBUTION
OF SUBAREA G

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	24	.0019	15	.0017	1602	.7683
At home, awake	564	.0469	956	.1097	16	.0077
At school	451	.0375	0	.0000	0	.0000
Bus.worker, indoors	261	.0217	98	.0112	10	.0048
Indus.worker, indoors	4,615	.3841	1730	.1985	173	.0830
Pub. place, indoors	4,173	.3474	2211	.2537	186	.0892
Pub. place, outdoors	1,924	.1601	3702	.4249	98	.0470
In transit	20		157		2	
On streets	10		26		0	
At recreation	15		20		4	
Bus.worker, outdoors	76		28		3	
Indus.worker, outdoors	1,238		464		46	
Other	565		3007		43	
Total	12,012		8712		2085	

* Same as footnote in Table C. 17.

TABLE C.24

SALT LAKE CITY, POSTURE DISTRIBUTION*
OF SUBAREA H

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	608	.0188	411	.0115	45,477	.9808
At home, awake	14,582	.4522	26,313	.7370	464	.0100
At school	11,064	.3431	0	.0000	0	.0000
Bus. worker, indoors	1,006	.0311	377	.0105	38	.0008
Indus. worker, indoors	0	.0000	0	.0000	0	.0000
Pub. place, indoors	3,327	.1031	1,762	.0493	149	.0032
Pub. place, outdoors	1,657	.0513	6,836	.1914	237	.0051
In transit	506		4,316		58	
On streets	253		720		12	
At recreation	380		540		140	
Bus. worker, outdoors	293		110		11	
Indus. worker, outdoors	0		0		0	
Other	225		1,150		16	
Total	32,244		35,699		46,365	

*Same as footnote in Table C.17.

TABLE C.25

SALT LAKE CITY, POSTURE DISTRIBUTION*
OF SUBAREA J

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	211	.0150	167	.0113	18,240	.9799
At home, awake	5,075	.3621	10,676	.7258	186	.0092
At school	6,058	.4322	0	.0000	0	.0000
Bus. worker, indoors	0	.0000	0	.0000	0	.0000
Indus. worker, indoors	0	.0000	0	.0000	0	.0000
Pub. place, indoors	2,188	.1561	1,160	.0788	98	.0052
Pub. place, outdoors	483	.0344	2,705	.1839	90	.0048
In transit	176		1,752		24	
On streets	88		292		5	
At recreation	132		219		55	
Bus. worker, outdoors	0		0		0	
Indus. worker, outdoors	0		0		0	
Other	87		442		6	
Total	14,015		14,708		18,614	

*Same as footnote in Table C.17.

TABLE C. 26

SALT LAKE CITY, POSTURE DISTRIBUTION*
OF SUBAREA K

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	70	.0069	52	.0060	5677	.9386
At home, awake	1,680	.1673	3327	.3880	58	.0095
At school	1,767	.1760	0	.0000	0	.0000
Bus. worker, indoors	695	.0692	261	.0304	26	.0042
Indus. worker, indoors	0	.0000	0	.0000	0	.0000
Pub. place, indoors	5,223	.5202	2767	.3227	233	.0385
Pub. place, outdoors	604	.0601	2167	.2527	54	.0089
In transit	58		546		8	
On streets	29		91		2	
At recreation	44		68		16	
Bus. worker, outdoors	202		76		8	
Indus. worker, outdoors	0		0		0	
Other	271		1386		20	
Total	10,039		8574		6048	

*Same as footnote in Table C. 17.

TABLE C. 27

SALT LAKE CITY, POSTURE DISTRIBUTION*
OF SUBAREA L

Posture	11:00 a.m.		5:30 p.m.		2:30 a.m.	
	No.	Fraction	No.	Fraction	No.	Fraction
At home, asleep	190	.0168	136	.0112	14,968	.9797
At home, awake	4,550	.4030	8,717	.7219	153	.0100
At school	4,237	.3753	0	.0000	0	.0000
Bus. worker, indoors	186	.0164	70	.0057	7	.0004
Indus. worker, indoors	0	.0000	0	.0000	0	.0000
Pub. place, indoors	1,634	.1447	866	.0717	73	.0047
Pub. place, outdoors	491	.0434	2,285	.1892	77	.0050
In transit	158		1,430		19	
On streets	79		238		4	
At recreation	118		178		46	
Bus. worker, outdoors	54		20		2	
Indus. worker, outdoors	0		0		0	
Other	82		419		6	
Total	11,288		12,074		15,278	

*Same as footnote in Table C. 17.

TABLE C. 28

SALT LAKE CITY, MOVEMENT INPUTS

Subarea	Area, sq mi 1/	Number of Assembly Points 1/	Associated Area, 2/ sq mi	Velocity, 3/ mph	11:30 a.m.		5:30 p.m.		2:30 a.m.	
					Pop. 4/	Density 5/	Pop. 4/	Density 5/	Pop. 4/	Density 5/
A	4.1	13	.777	4	18,903	4,610	15,034	3,667	7,929	1,934
B	1.8	9	1.044	4	5,685	3,714	7,756	4,309	10,765	5,981
C	3.3	77	.0935	4	6,163	1,868	5,095	1,544	3,688	1,118
D	2.7	425	.00635	4	37,452	13,871	36,267	13,432	34,245	12,683
E	8.3	13	.638	4	49,536	5,968	43,399	5,229	34,299	4,132
F	1.6	1	1.600	4	8,505	5,316	8,655	5,409	10,786	6,741
G	7.8	1	7.800	4	12,012	1,540	8,712	1,117	2,085	267
H	4.8	35	.137	4	32,244	6,717	35,699	7,437	46,365	9,659
J	3.5	9	.389	4	14,015	4,004	14,708	4,202	18,614	5,318
K	1.5	8	.188	4	10,039	6,693	8,574	5,716	6,048	4,032
L	2.4	3	.800	4	11,288	4,703	12,074	5,031	15,278	6,366

1/ Source: Table C.1.

2/ Source: (Area) / (number of assembly points).

3/ Source: Assumed.

4/ Source: Totals, Tables C.17 to C.27.

5/ Source: (Population) / (area).

TABLE C. 29

SALT LAKE CITY, DISTRIBUTION OF DEPARTURE TIMES 1/

Posture	Time Interval, min														
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
At home, asleep	.00	.00	.00	.00	.00	.00	.00	.01	.06	.32	.34	.22	.05	.00	.00
At home, awake	.00	.00	.09	.22	.43	.22	.04	.00	.00	.00	.00	.00	.00	.00	.00
At school	.00	.03	.17	.38	.31	.10	.01	.C0	.00	.00	.00	.00	.00	.00	.00
Bus. worker, indoors	.00	.00	.00	.00	.00	.01	.04	.09	.17	.22	.22	.14	.08	.02	.01
Indus. worker, indoors	.00	.00	.00	.00	.00	.03	.08	.17	.26	.24	.14	.06	.02	.00	.00
Pub. place, indoors	.00	.00	.00	.00	.01	.02	.09	.18	.27	.23	.13	.06	.01	.00	.90
Pub. place, outdoors	.03	.22	.49	.23	.03	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

1/ The entry for a given posture and time interval is equal to the fraction of persons in that posture departing for shelter in that time interval after the beginning of an alert.

Source: assumed.

TABLE C. 30

SALT LAKE CITY, DISTRIBUTION OF DEPARTURES, SUBAREAS A, B, C

Time Interval	Subarea								
	A 1/			B 2/			C 3/		
	11:00 a.m.	5:30 p.m.	2:30 a.m.	11:00 a.m.	5:30 p.m.	2:30 a.m.	11:00 a.m.	5:30 p.m.	2:30 a.m.
1	.000	.000	.000	.000	.000	.000	.000	.000	.000
2	.000	.000	.000	.000	.000	.000	.000	.000	.000
3	.000	.000	.000	.000	.000	.000	.000	.000	.000
4	.006	.013	.001	.001	.005	.000	.005	.012	.000
5	.047	.097	.006	.020	.039	.001	.047	.086	.004
6	.127	.240	.013	.130	.157	.003	.144	.229	.009
7	.113	.164	.008	.265	.215	.003	.177	.182	.006
8	.096	.138	.005	.339	.347	.004	.146	.191	.005
9	.053	.070	.003	.152	.174	.002	.059	.093	.002
10	.045	.030	.004	.029	.033	.000	.024	.024	.001
11	.082	.040	.016	.009	.004	.010	.037	.017	.012
12	.131	.063	.067	.014	.006	.059	.071	.032	.061
13	.133	.064	.304	.018	.009	.316	.093	.043	.309
14	.093	.045	.319	.013	.007	.336	.093	.043	.329
15	.048	.023	.206	.008	.004	.217	.059	.027	.212
16	.021	.010	.048	.002	.000	.049	.033	.015	.049
17	.003	.002	.000	.000	.000	.000	.008	.004	.001
18	.002	.001	.000	.000	.000	.000	.004	.002	.000
19	.000	.000	.000	.000	.000	.000	.000	.000	.000
20	.000	.000	.000	.000	.000	.000	.000	.000	.000

1/ Source: (Distribution of postures, Table C.17) x (appropriate factors from Table C.29).

2/ Source: (Distribution of postures, Table C.18) x (appropriate factors from Table C.29).

3/ Source: (Distribution of postures, Table C.19) x (appropriate factors from Table C.29).

TABLE C. 31

SALT LAKE CITY, DISTRIBUTION OF DEPARTURES,
SUBAREAS D, E, F

Time Interval	Subarea								
	D 1/			E 2/			F 3/		
	11:00 a.m.	5:30 p.m.	2:30 a.m.	11:00 a.m.	5:30 p.m.	2:30 a.m.	11:00 a.m.	5:30 p.m.	2:30 a.m.
1	.000	.000	.000	.000	.000	.000	.000	.000	.000
2	.000	.000	.000	.000	.000	.000	.000	.000	.000
3	.000	.000	.000	.000	.000	.000	.000	.000	.000
4	.004	.009	.000	.004	.010	.000	.002	.006	.000
5	.031	.063	.002	.033	.070	.003	.023	.044	.001
6	.113	.187	.005	.112	.196	.007	.130	.163	.003
7	.157	.182	.004	.146	.172	.005	.253	.206	.003
8	.189	.235	.005	.161	.204	.005	.298	.319	.004
9	.091	.118	.002	.078	.103	.003	.131	.162	.002
10	.039	.033	.002	.045	.035	.002	.031	.035	.001
11	.052	.025	.012	.070	.036	.014	.023	.011	.011
12	.086	.041	.062	.110	.056	.062	.036	.017	.060
13	.093	.043	.312	.109	.054	.311	.036	.018	.315
14	.075	.034	.331	.075	.037	.328	.023	.012	.334
15	.044	.019	.214	.039	.019	.212	.011	.006	.217
16	.020	.008	.049	.015	.007	.048	.003	.001	.049
17	.004	.002	.000	.002	.001	.000	.000	.000	.000
18	.002	.001	.000	.001	.000	.000	.000	.000	.000
19	.000	.000	.000	.000	.000	.000	.000	.000	.000
20	.000	.000	.000	.000	.000	.000	.000	.000	.000

1/ Source: (Distribution of postures, Table C.20) x (appropriate factors from Table C.29).

2/ Source: (Distribution of postures, Table C.21) x (appropriate factors from Table C.29).

3/ Source: (Distribution of postures, Table C.22) x (appropriate factors from Table C.29).

TABLE C.32

SALT LAKE CITY, DISTRIBUTION OF DEPARTURES, SUBAREAS G, H, J

Time Interval	Subarea								
	G			H			J		
	11:00 a.m.	5:30 p.m.	2:30 a.m.	11:00 a.m.	5:30 p.m.	2:30 a.m.	11:00 a.m.	5:30 p.m.	2:30 a.m.
1	.000	.000	.000	.000	.000	.000	.000	.000	.000
2	.000	.000	.000	.000	.000	.000	.000	.000	.000
3	.000	.000	.000	.000	.000	.000	.000	.000	.000
4	.005	.013	.001	.002	.006	.000	.001	.006	.000
5	.036	.095	.012	.022	.042	.001	.021	.040	.001
6	.090	.222	.023	.125	.160	.003	.124	.156	.003
7	.063	.124	.012	.243	.206	.003	.254	.203	.003
8	.042	.064	.006	.305	.324	.004	.295	.319	.004
9	.034	.036	.006	.137	.164	.002	.127	.162	.002
10	.065	.043	.015	.032	.034	.001	.032	.036	.001
11	.129	.080	.037	.021	.010	.010	.027	.014	.011
12	.197	.119	.091	.033	.015	.060	.041	.021	.060
13	.176	.107	.287	.035	.017	.316	.039	.021	.315
14	.103	.062	.287	.026	.013	.335	.025	.014	.335
15	.047	.028	.181	.014	.007	.216	.012	.007	.216
16	.013	.007	.042	.004	.002	.049	.002	.001	.049
17	.000	.000	.000	.001	.000	.000	.000	.000	.000
18	.000	.000	.000	.000	.000	.000	.000	.000	.000
19	.000	.000	.000	.000	.000	.000	.000	.000	.000
20	.000	.000	.000	.000	.000	.000	.000	.000	.000

1/ Source: (Distribution of postures, Table C.23) x (appropriate factors from Table C.29).

2/ Source: (Distribution of postures, Table C.24) x (appropriate factors from Table C.29).

3/ Source: (Distribution of postures, Table C.25) x (appropriate factors from Table C.29).

TABLE C.33

SALT LAKE CITY, DISTRIBUTION OF DEPARTURES, SUBAREAS K, L

Time Interval	Subarea					
	K[1/]			L[1/]		
	11.00 a.m.	5:30 p.m.	2:30 a.m.	11.00 a.m.	5:30 p.m.	2:30 a.m.
1	.000	.000	.000	.000	.000	.000
2	.000	.000	.000	.000	.000	.000
3	.000	.000	.000	.000	.000	.000
4	.002	.008	.000	.001	.006	.000
5	.019	.056	.002	.021	.042	.001
6	.076	.161	.005	.122	.158	.003
7	.121	.145	.004	.244	.203	.003
8	.138	.179	.005	.295	.318	.004
9	.067	.093	.003	.130	.161	.002
10	.057	.045	.004	.033	.035	.001
11	.098	.060	.016	.027	.013	.011
12	.149	.091	.067	.041	.020	.060
13	.134	.081	.311	.041	.021	.315
14	.084	.050	.325	.027	.014	.335
15	.042	.024	.210	.014	.007	.216
16	.011	.006	.048	.004	.002	.049
17	.001	.001	.000	.000	.000	.000
18	.001	.000	.000	.000	.000	.000
19	.000	.000	.000	.000	.000	.000
20	.000	.000	.000	.000	.000	.000

1/ Source: (Distribution of postures, Table C.26) x (appropriate factors from Table C.29).

2/ Source: (Distribution of postures, Table C.27) x (appropriate factors from Table C.29).

TABLE C.34

SALT LAKE CITY, INITIAL ARRIVALS IN SUBAREAS B AND J, 11:00 A.M.

Time After Alert, min	Subarea					
	B			J		
	Arrivals at Shelter	Number Sheltered	Number Directed to C	Arrivals at Shelter	Number Sheltered	Number Directed to C
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	7	7	0	7	7	0
6	62	62	0	65	65	0
7	277	277	0	290	290	0
8	822	822	0	848	848	0
9	1824	1609	215	1,868	944	924
10	3242	1609	1633	3,398	944	2,454
11	4727	1609	3118	5,433	944	4,489
12	5818	1609	4209	7,817	944	6,873
13	6234	1609	4625	10,063	944	9,119
14	6353	1609	4744	11,614	944	10,670
15	6439	1609	4830	12,358	944	11,414
16	6534	1609	4922	12,810	944	11,866
17	6608	1609	4999	13,230	944	12,286
18	6654	1609	5045	13,597	944	12,653
19	6673	1609	5004	13,843	944	12,899
20	6685	1609	5076	13,968	944	13,024
21	6685	1609	5076	14,013	944	13,069
22	6685	1609	5076	14,015	944	13,071

TABLE C.35

SALT LAKE CITY, REDISTRIBUTION DATA

Deficit Subarea	Receiving Subarea	Average Relocation Distance, miles	Average Relocation Velocity, mph	Relocation Time, min
A	D	2.7	4	40
B	C	1.4	4	21
E	D	1.8	4	27
F	D	3.0	4	45
G	--	---	-	--
H	D	1.6	4	24
J	C	2.0	4	30
K	--	---	-	--
L	--	---	-	--

TABLE C.36

SALT LAKE CITY, MOVEMENT TO SHELTER WITH REDISTRIBUTION, SUBAREA C, 11:00 A.M.

Time After Alert, min	Arrivals at Shelter From Subarea C	Persons Received From Subarea B	Persons Received From Subarea J	Total Sheltered
1	0			0
2	0			0
3	0			0
4	6			6
5	82			82
6	436			436
7	1231			1,231
8	2213			2,213
9	3013			3,013
10	3427			3,427
11	3635			3,635
12	3898			3,898
13	4334			4,334
14	4897			4,897
15	5446			5,446
16	5834			5,834
17	6048			6,048
18	6127			6,127
19	6153			6,153
20	6163			6,163
30	6163	0		6,163
31	6163	215		6,378
32	6163	1633		7,766
33	6163	3118		9,281
34	6163	4209		10,372
35	6163	4625		10,788
36	6163	4774		10,937
37	6163	4830		10,993
38	6163	4922		11,085
39	6163	4999		11,162
40	6163	5045	924	12,132
41	6163	5064	2454	13,681
42	6163	5076	4489	15,677
43	6163	5076	6873	15,677

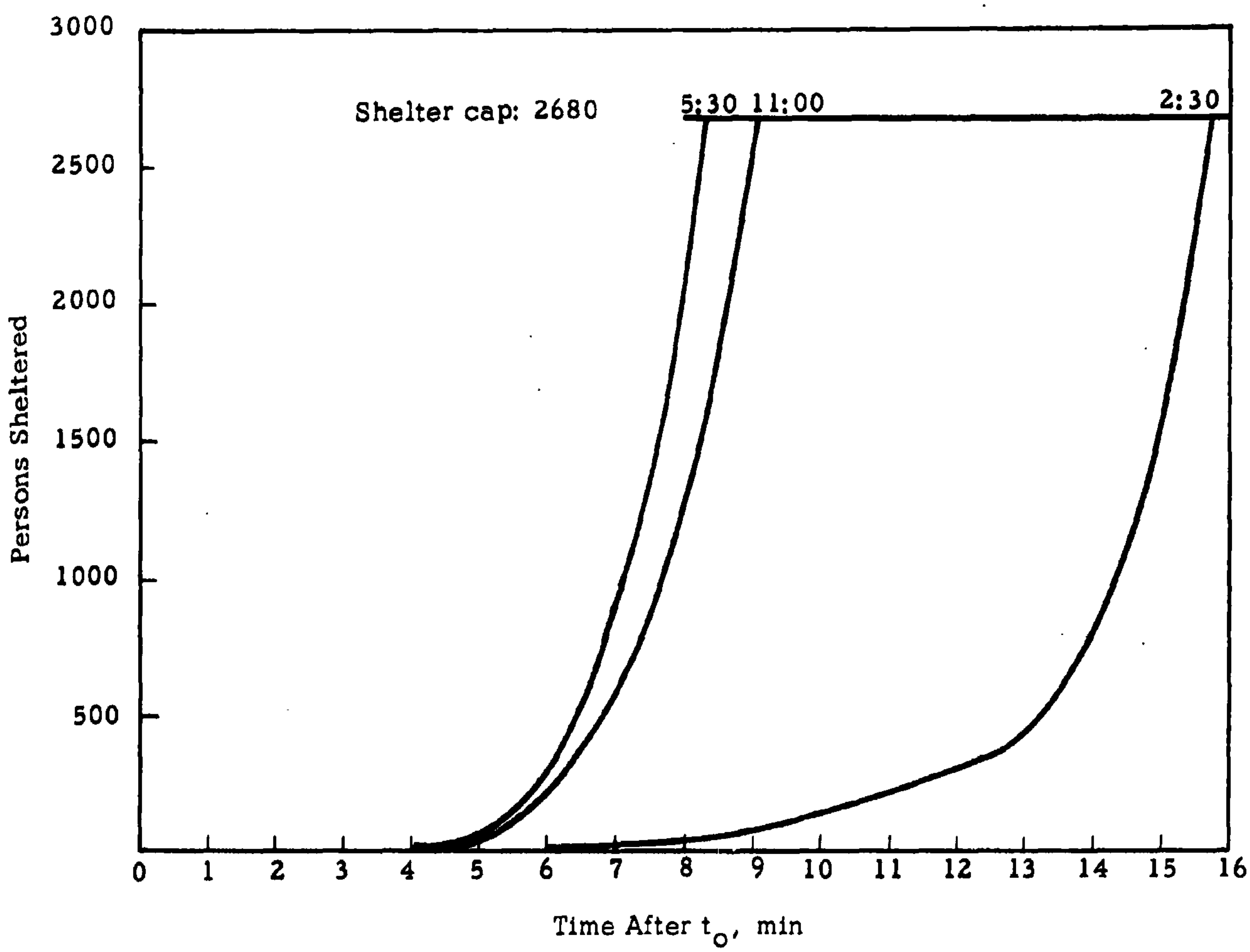


FIGURE C.1. NUMBER OF PERSONS SHELTERED IN SALT LAKE CITY, SUBAREA A

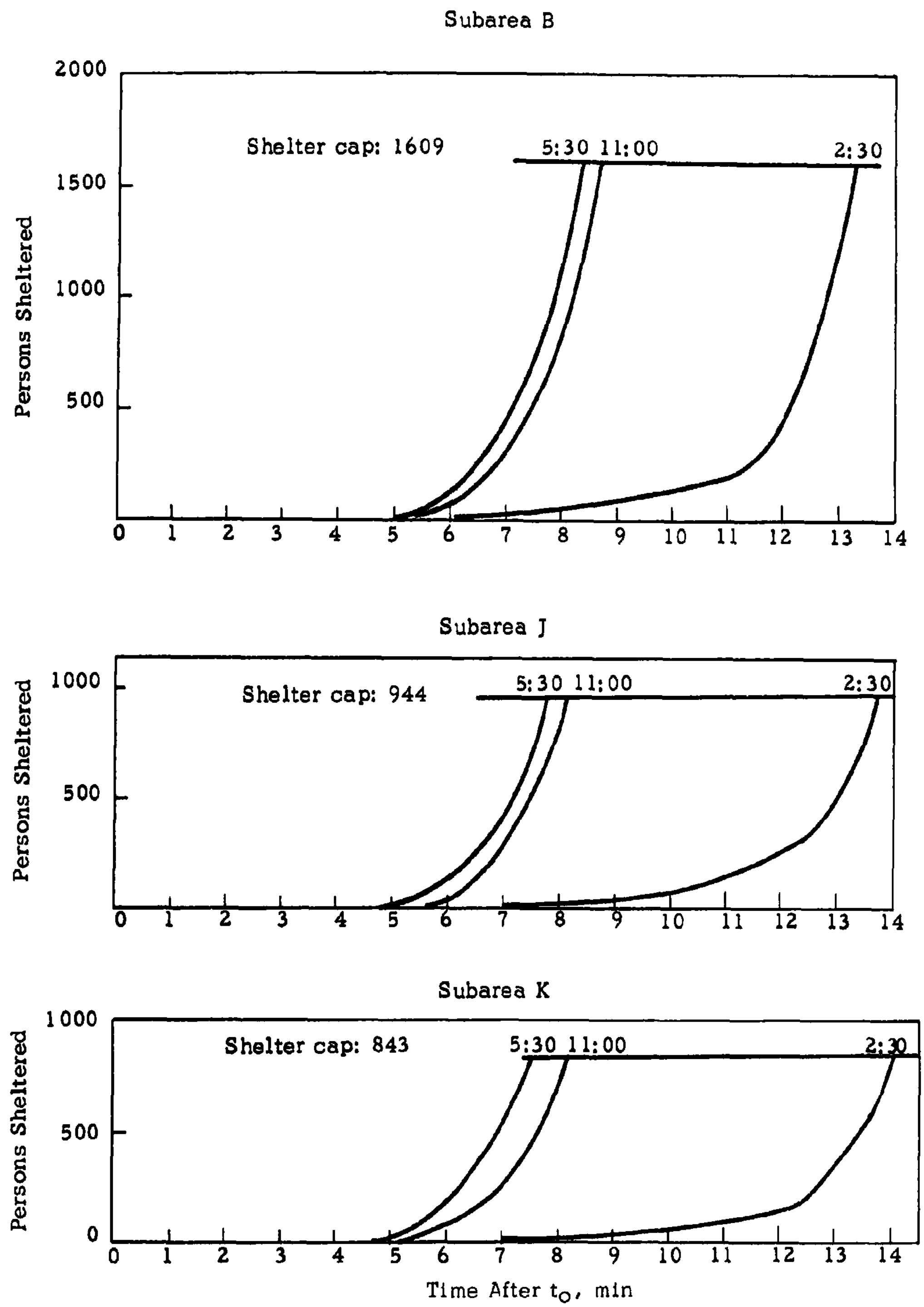


FIGURE C.2. NUMBER OF PERSONS SHELTERED IN SALT LAKE CITY, SUBAREAS B, J, AND K

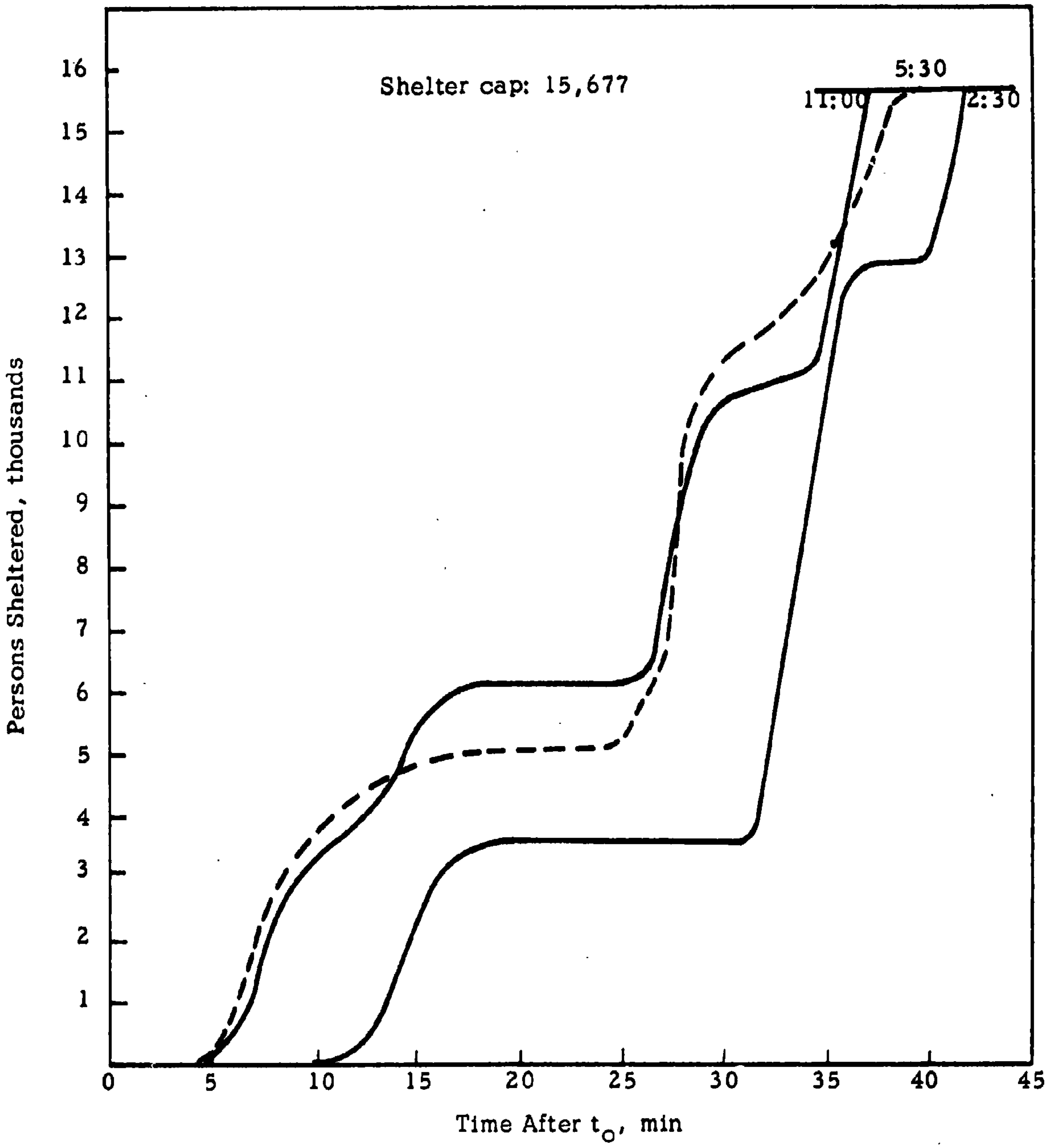


FIGURE C.3. NUMBER OF PERSONS SHELTERED IN SALT LAKE CITY, SUBAREA C

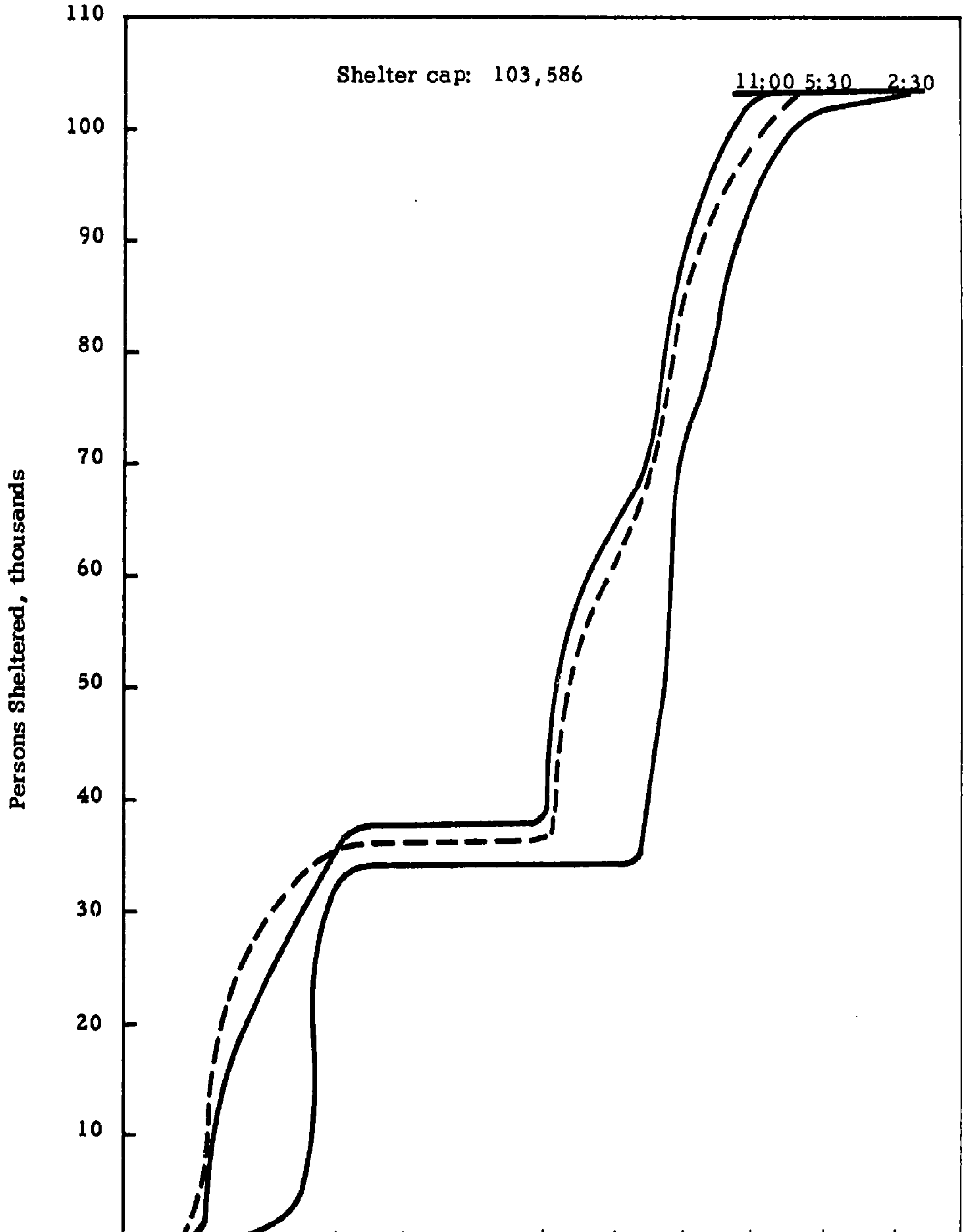


FIGURE C.4. NUMBER OF PERSONS SHELTERED IN SALT LAKE CITY, SUBAREA D

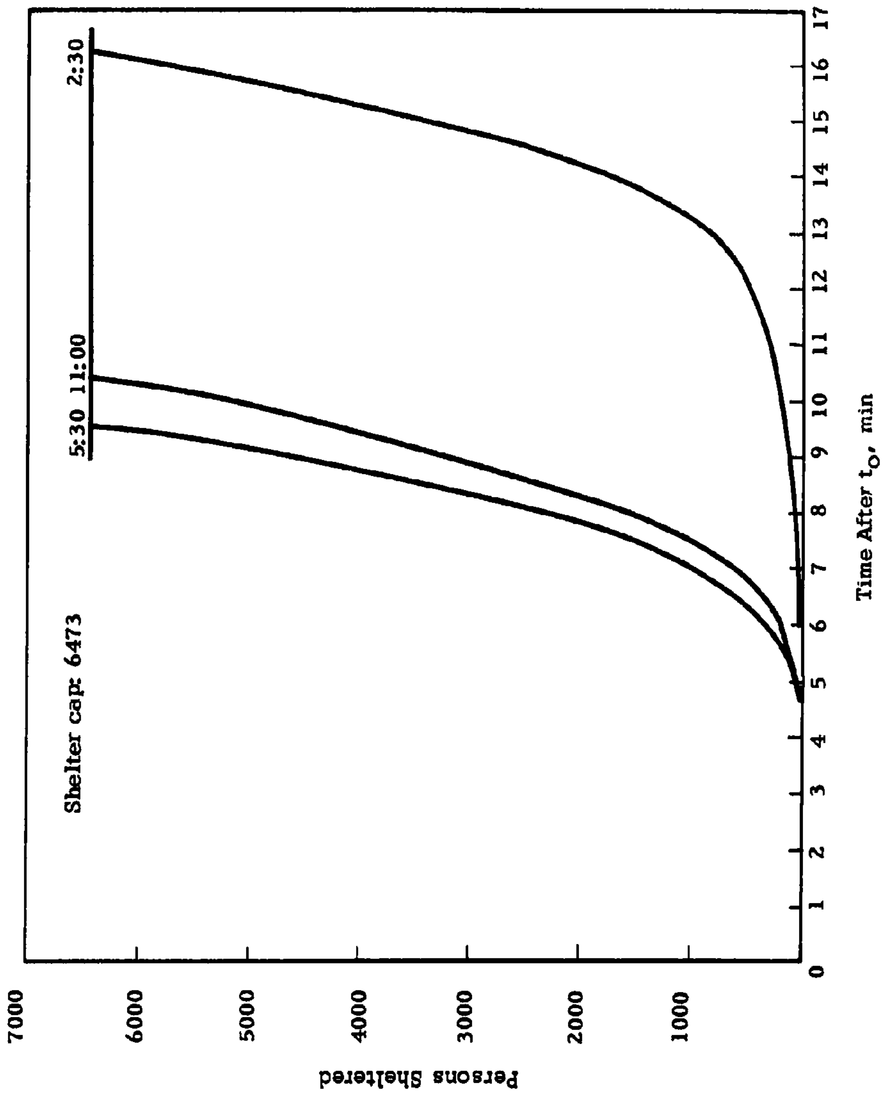


FIGURE C.5. NUMBER OF PERSONS SHELTERED
IN SALT LAKE CITY, SUBAREA E

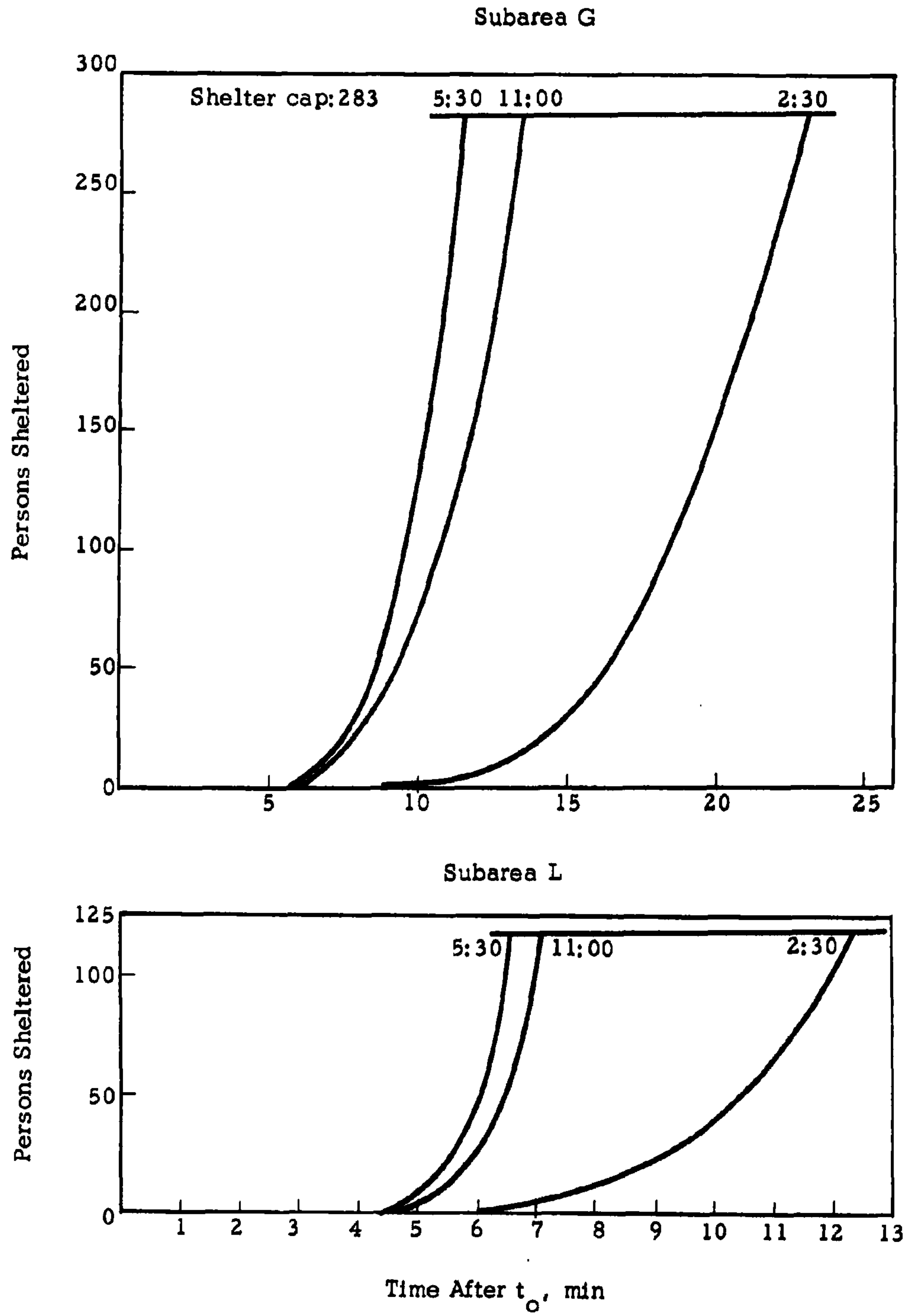


FIGURE C.6. NUMBER OF PERSONS SHELTERED IN SALT LAKE CITY, SUBAREAS G AND L

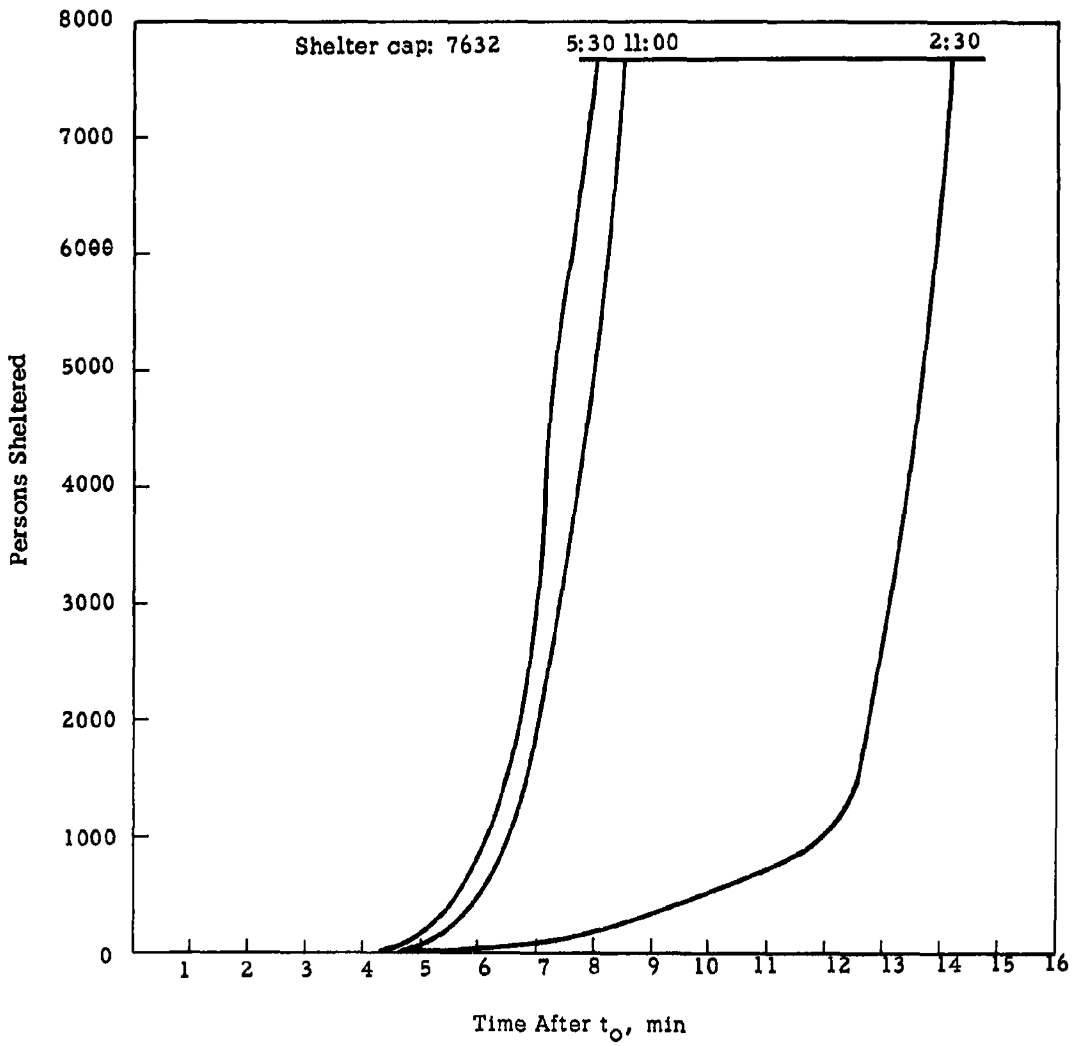


FIGURE C.7. NUMBER OF PERSONS SHELTERED IN SALT LAKE CITY, SUBAREA H

APPENDIX D

DATA REQUIREMENTS

D.1 Data requirements for the computation of movement to shelter may be categorized into four areas.

a. Population data

b. Geographical data

c. Fallout shelter data

d. Miscellaneous input data.

D.2 An attempt has been made in the origination of this model to adhere closely to the requirement that data be of such nature that they are easily available to local officials as well as to research personnel. The description and primary source of the input data requirements will be discussed in terms of the four categories.

D.3 The required population characteristics are:

a. Total resident population,

b. Total census tract resident population,

c. Total members of employment categories,

d. Total school-age population by census tract.

D.4 The data were taken directly from "U.S. Censuses of Population and Housing; 1960" for the pertinent standard metropolitan statistical area under study. Also available from this source are various summations of the employment data that allow the calculation of the total number of jobs held in the metropolitan area. The data concerning the school population may also be obtained from local school boards in the area under study. Although the Census Bureau does not provide updated population estimates, this information usually is obtainable from local planning commissions or government sources.

D.5 The required geographical characteristics are:

a. Total area by census tract,

b. Total industrial area by census tracts,

c. Total local shopping area by census tract,

d. Total commercial business area by census tract, and

e. Distances from tract to tract.

D.6 The data in this category are usually available through current land area maps or publications of the local governmental offices. The intertract distances may be scaled from a large-scale map of the area under study. Emphasis is placed on the acquisition of land-use maps rather than zoning maps, as significant inconsistencies are usually apparent in the comparison of the two.

D.7 The required fallout shelter information is:

a. Number of shelters by census tract

b. Total shelter spaces by census tract.

D.8 This information is documented in detail by OCD and available from the Demographic Operation Division of the Bureau of the Census in the form of "Phase II, Fallout Shelter Survey."

D.9 The required miscellaneous input data are:

a. Movement to shelter velocity,

b. Redistribution velocity,

c. Percentage of workers remaining home from work, and

d. Percentage of school children remaining home from school.

D.10 This category of data may be supplied through experienced judgment and evaluation of local characteristics. The school children will, of course, all remain home in the summer time, and local school boards usually maintain adequate records to determine the percentage required for d. Local manufacturing centers may provide assistance in the determination of c.

APPENDIX E

EXPERIMENTAL MEASUREMENT OF THE TIME REQUIRED FOR AN AT-HOME SLEEPING POPULATION TO PREPARE FOR MOVEMENT TO A CIVIL DEFENSE FALLOUT SHELTER

INTRODUCTION

E.1 Research is being conducted by Operations Research Incorporated to provide OCD with a means of evaluating evacuation concepts and procedures in order to improve civil defense planning.

E.2 Field and controlled experiments utilizing volunteer families were conducted in the Atlanta Metropolitan Area in order to measure the distribution of times required for an at-home sleeping population to prepare to move to shelter under surprise warning conditions. The volunteers were obtained with the assistance of the Atlanta Metropolitan Area of Civil Defense through the Atlanta Parent Teachers Association.

E.3 The sample is not purported to represent the time to prepare to move for the general populace. This is because the sample consists wholly of volunteers and has been selected from within a particular group, namely the PTA. It is felt, however, that the data provide useful information, particularly with respect to the impact that size of family and young children have on the prepare-to-move time.

E.4 The distribution of prepare-to-move time is approximated graphically in Figure E.1. It is based on the sample distribution of time to move for 96 volunteer families.

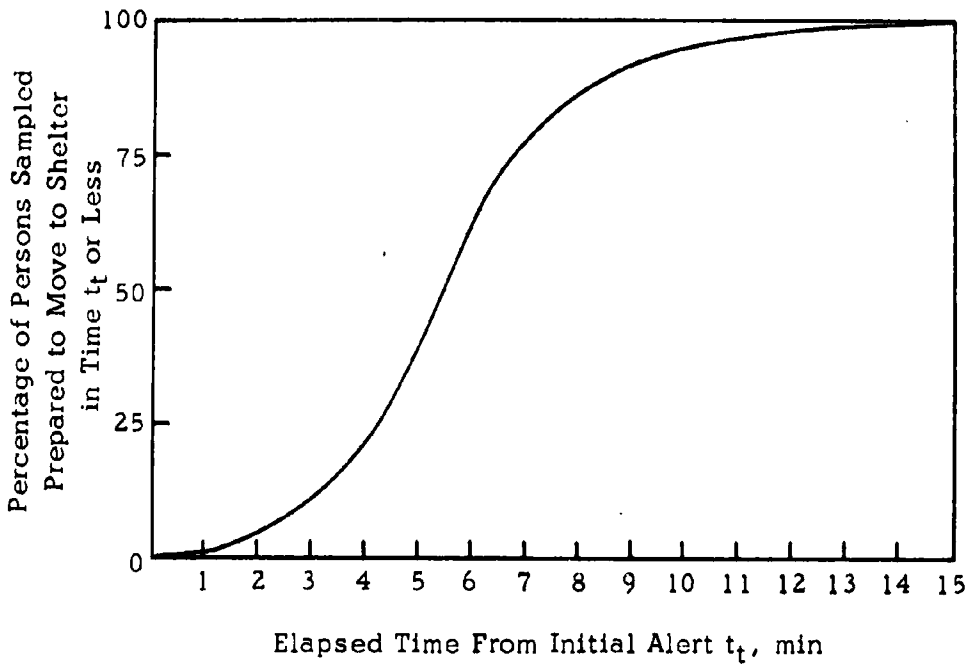


FIGURE E.1. CUMULATIVE DISTRIBUTION OF TIME TO PREPARE TO DEPART FOR SHELTER t_t

E.5 Two basic time elements comprise the total time to prepare to depart to shelter: the time to become aware of an alert and the time to prepare for departure after becoming aware of the alert. It was determined that the time to prepare to depart after becoming aware of an alert comprises the major portion of the total time, generally over 90 percent when the alerting stimulus is an audio signal similar to the ring of a telephone.

E.6 It was determined that a significant variable in the time required to prepare to depart for shelter is the number of young children within the family. Only one child under 6 years of age was in the range of families with time values less than the median; whereas 17 children under 6 years of age were in the range of families with time values greater than the median. Fifty-four controlled experiments conducted with 13 families also indicated that the number of young children significantly influences the time to prepare to depart for shelter.

E.7 All information obtained in the experiments is included in detailed summary form in the annexes. By considering certain factors outlined in this appendix, the data can be applied to various population distributions to obtain indications of the distribution of times required for an at-home sleeping population to prepare to move to shelter under surprise warning conditions, in order that results can be compared or integrated with similar or related studies conducted in other parts of the United States.

Background

E.8 As world power blocs increase the destruction capacity and the delivery efficiency of their weapons systems, the ability of a nation to effectively survive initial and subsequent attacks by hostile powers gains increased significance.

E.9 In evaluating evacuation concepts and procedures, a significant factor is time, its various components, and its relation to other factors. Although some time data exist from previous research conducted with certain segments of daytime populations, no prior data exist for nighttime populations. This appendix describes and presents the results of experiments conducted to generate and collect data pertaining to nighttime populations. Specifically, the distribution of times for an at-home sleeping population to prepare to move to shelter is included. Future research will be concerned with the time to travel to shelter when preparations are complete. Since advance attack warning conditions must be assumed to be of so short a duration that they are classified as surprise, it was necessary that the data be applicable to surprise conditions.

Statement of Objectives

E.10 The main objective of the study is to measure by experiment the distribution of time for an at-home sleeping population to prepare to depart for shelter under surprise warning conditions. The time for preparing to depart or move is defined for the purposes of this study as the elapsed time from initial alert until the persons concerned are prepared to depart.

E.11 Corollary objectives are to determine the activities included in the prepare-to-move time and to gain a more complete general understanding of the behavior response of a nighttime population.

Formulation of the Problem

E.12 The process of preparing to move to shelter consists of two steps: becoming aware of the need for movement and preparing for the move. The first step results in a time interval, which is the span of time between the sounding of a warning signal and the point at which an individual recognizes the need for movement to shelter. Once an individual is alert to impending attack and decides that action must be taken, he begins preparing to move to shelter. The span of time devoted to this preparation begins with the decision to take shelter and ends as the individual starts overt movement to a shelter.

E.13 The problem then becomes one of determining and combining the distribution of times for these two steps.

Scope of the Study

E.14 The scope of this study is limited to presentation and discussion of the findings within the sample and experimental groups who volunteered their services. Interferences based on this study relative to distribution of prepare-to-move times for the general populace is not necessarily valid.

Approach to the Problem

E.15 Three types of experiments were conducted to complete the objectives of the study.

a. To determine the distribution of times for individuals to become alert to the need for movement to shelter, 100 telephone numbers were selected at random from the Atlanta Metropolitan Area Telephone Directory. Individual numbers were dialed on various dates during the sleeping hours 0:01 a.m. to 5:00 a.m. The time of the first ring was recorded, the time the telephone was answered was recorded, and the lapse between first ring and answer was computed.

b. To determine the distribution of times for individuals to prepare to move to shelter once they have been alerted, 96 field experiments were conducted utilizing volunteers solicited through the PTA of the Atlanta Metropolitan Area School Systems. The volunteer families were awakened during the sleeping hours 0:01 a.m. to 7:00 a.m. They then prepared to depart for shelter in accordance with a standard procedure. The time that the simulated alert was acknowledged was recorded, the time that all preparations were completed was recorded, and the elapsed time for preparing to move was computed.

c. To obtain more detailed data pertaining to the activities included in the prepare-to-move time and to obtain more complete information for determining the correlation between number and ages of persons in the family and elapsed times for preparing to move, 54 controlled experiments utilizing 18 volunteer families were conducted. Families were grouped according to various size and age categories. The elapsed time for preparing to move to shelter was measured for each category.

DESIGN OF THE PROJECT

General

E.16 The time for preparing to move to shelter may be expressed mathematically as follows:

$$t_t = t_w + t_p$$

where t_t = the total time to prepare to move,
t_w = the time to become aware of an alert, and
t_p = the time to prepare to move to shelter after becoming aware of the alert.

Determination of t_w

E.17 The time to become alert to the need for movement t_w is the span of time between the sounding of a warning signal (stimulus) and the point at which an individual recognizes the need for movement to shelter. The major factors affecting t_w are the nature and strength of the stimulus, the individual's preconditioning to the stimulus, and his state of awareness or preoccupation when the stimulus is applied. The interaction of these factors along with others such as international tensions provides a timed action sequence and distribution to recognize warning signals.

E.18 Since mass populace warning systems are generally associated with a type of audio signal, an experiment was designed in which the telephone was used to initiate a simulated warning.

E.19 To incorporate the element of surprise within a representative nighttime population, residential numbers were selected at random from the Atlanta Metropolitan Telephone Directory and dialed during the hours 0:01 a.m. to 5:00 a.m.

E.20 To obtain an indication of the distribution of times for t_w, the following time span within the experiments was arbitrarily assigned as t_w:

t_w = the time span from the first telephone ring until the first word was spoken in the answer process.

Determination of t_p

E.21 The time to prepare to move to shelter t_p is the span of time beginning with the decision to take shelter and ending when all preparations are complete. The following activities are included within t_p:

a. Gather family,

b. Get dressed,

c. Gather personal belongings, supplies, and special medicines, and

d. Secure residence; i.e., turn off appliances, lock up, etc.

E.22 An experiment was designed in which volunteer families were utilized in field experiments to provide indications of the distribution of t_p. A procedure was developed for the field experiments to ensure uniformity of conduct. The experiments were conducted during the sleeping hours 0:01 a.m. to 7:00 a.m. and incorporated the element of surprise. The distribution of t_p for the volunteer families was obtained by continuous time study.

E.23 It was expected that values of t_p would be influenced by the number and ages of persons within the family and consequently the distribution of t_p would be influenced by the distribution of families by number and age types within the volunteer population.

E.24 Controlled experiments were designed to verify the expected effect of numbers and ages of persons within the family. These experiments utilized volunteer families residing in a student and faculty apartment dwelling[1/] of the Georgia Institute of Technology. All experiment conditions were held constant except for the number of small children participating, and resultant values of t_p were measured by continuous time study.

Determination of t_t

E.25 The distribution of times for preparing to move to shelter t_t was approximated for the volunteer population by combining the measured values of t_w and t_p, which was accomplished by adding the mean of the measured values of t_w to the distribution of t_p.

E.26 The experimental data are included in the annexes in detailed form in the event it should be desirable in later phases of the project to statistically analyze the distributions of t_w and t_p or to apply the data to

[1/] Callaway Apartments.

different population distributions. The detailed experiment data for t_p include the following classifications: identification of PTA group, location, date and time conducted, total persons in family and ages, number of rooms in the dwelling, race, and measured values of t_p.

FIELD EXPERIMENTS

Introduction

E.27 Ninety-six field experiments were conducted to provide data for determining the distribution of prepare-to-move times t_p. The volunteer families utilized in the conduct of the experiments were distributed geographically throughout the Atlanta Metropolitan Area as follows:

Number of Calls	Section of Atlanta Metropolitan Area
43	Northeast
17	Southeast
31	Southwest
9	Northwest

E.28 To determine the distribution of t_w, 100 random telephone numbers were dialed during the sleeping hours. The geographical distribution of the addresses corresponding to the randomly selected numbers was as follows:

Number of Families	Section of Atlanta Metropolitan Area
49	Northeast
16	Southeast
13	Southwest
18	Northwest

Procedure

E.29 Procurement of Volunteers. Volunteers for the field experiments were obtained through the Atlanta PTA with the cooperation of the Atlanta Metropolitan Area of Civil Defense. A letter from the Director of the Atlanta Metropolitan Area of Civil Defense was distributed through selected PTA groups to prospective volunteers. This letter along with a list of instructions informed the prospective volunteers of the purpose, nature, and procedure for the tests. These forms are included in Annexes E1 and E2. The volunteers were requested to complete a questionnaire, which provided pertinent information regarding the volunteer family. The questionnaire form is shown in Annex E3.

E.30 In order to include the element of surprise, the volunteer families were requested to conduct the test on any of three specified evenings, the particular date to be selected by ORI. Exceptions were sometimes made to this rule in the interest of obtaining as large a total sample as possible.

E.31 Exceptions were also made in some instances in regard to the time that the volunteer family would be awakened. In those instances where a family would not volunteer to be awakened at a random time during the sleeping hours but would volunteer to be awakened 30 min to 1 hr prior to its normal awakening time, the family was allowed to participate, again in the interest of obtaining the largest total sample possible.

E.32 Method of Conduct. The experiments were conducted in the following manner:

a. Each volunteer family was alerted during the sleeping hours by a trained observer, who called at the home in the most appropriate manner.

b. The volunteers were requested to begin the test.

   1. The time that the message was completed and acknowledged was recorded.

c. The volunteers prepared to depart in accordance with the instructions listed in Annex E2.

   1. The time that all preparations were completed was recorded.

   2. Other pertinent information was recorded.

d. Values of t_p were computed.

E.33 A sample of the form used in collecting the data is included in Annex E4.

E.34 The activities included in t_p, which were listed in paragraph E.21, are discussed as follows:

E.35 Activity a., gather family, is straightforward and leaves little chance for variation in interpretation. However, there are numerous possible interpretations of activities b., c., and d., each of which could influence the results of t_p. The pace at which each of the activities is conducted is also a factor that can influence the values of t_p. These points were resolved in the following manner.

E.36 For activity b., get dressed, it was assumed that the practice alert was occurring on the date of the test and the volunteers dressed appropriately for the current season.

E.37 For activity c., gather personal belongings, supplies, and special medicines, it was assumed that basic supplies, such as food, water, and bedding, were stocked in the shelters. It was further assumed that personal supplies, such as clothing and special medicines, were prepacked in a shelter kit with the shelter kit stored within the home for use in the event of evacuation. An empty suitcase was used as a dummy shelter kit and was a requirement for each volunteer participant. Four field experiments were conducted in which the families actually packed suitcases with blankets, clothing, and other personal supplies. The results of these tests provide a valuable indication of the times that could be expected if prepacked shelter kits are not included in proposed shelter programs.

E.38 For activity d., secure residence; i.e., turn off appliances, lock up, etc., the volunteers were requested to make the same preparations in regard to securing the residence that would be made in advance of an expected 2-week absence from the home.

E.39 It was assumed that sufficient time was available to complete all the required activities, and that no time was available for nonrequired activities.

E.40 The distribution of t_W was obtained by:

a. Randomly selecting residential telephone numbers, utilizing a table of random numbers.

   1. Recording geographical section of addresses corresponding to the numbers.

b. Dialing the number.

   1. Recording the time of the first ring, and

   2. Recording the time that the first word was spoken by the party answering the phone.

c. Computing t_W.

E.41 It was determined through trial and error that 8 min was an adequate maximum time to wait for an answer, and after this interval it was assumed that no one was at the location being called. This precluded the persons residing at the location being included in an at-home sleeping population and the number was not included in the sample. There were three calls that fell in this category.

Results

E.42 Obtaining Volunteers. The cooperation of the ten participating school PTA groups was good, and a total of 144 volunteer families was obtained; however, only 103 of these volunteer families actually participated in the field experiments. The reasons for nonparticipation after volunteering were:

a.	No response to call at the door:	28
b.	Refusal to participate after answering the door; reason not given:	8
c.	Unforeseen occurrences, such as death or illness, creating a necessity for withdrawal:	5

E.43 The data of three of the experiments were not included owing to a failure to comply with the test procedure.

E.44 Four of the volunteer families departed from the prescribed procedure by packing their simulated shelter kits. The data from these experiments are included in this appendix but are segregated from the other data.

E.45 Determination of t_p. The results of the 96 field experiments conducted to obtain an indication of the distribution of t_p are listed in detail in Annex E5. The measured values of the sample distribution range from 1.25 to 13.42 min with a median of 4.71 min. The mean value was calculated as 4.88 min and the standard deviation as 2.29 min. The sample distribution is skewed (positive). A histogram of the sample data is presented in Figure E.2.

E.46 Figure E.3 is a cumulative distribution curve for the total sample population that was graphically approximated.

E.47 The results of the four field experiments conducted in which the simulated shelter kits were packed are listed in detail in Annex E6. The mean value of t_p for these experiments was calculated as 10.20 min.

E.48 Determination of t_w. The results of the 100 experiments conducted to obtain an indication of the distribution of t_w are listed in detail in Annex E7. The measured values of the sample distribution range from 0.06 to 6.84 min with a median of 0.23 min. The mean value was calculated as 0.33 min. Excluding the value of 6.84 min, which is much greater than the time taken for the others, the mean value for the remaining 99 families is 0.27 min. The distribution is skewed (positive). A histogram of the sample data is presented in Annex E8.

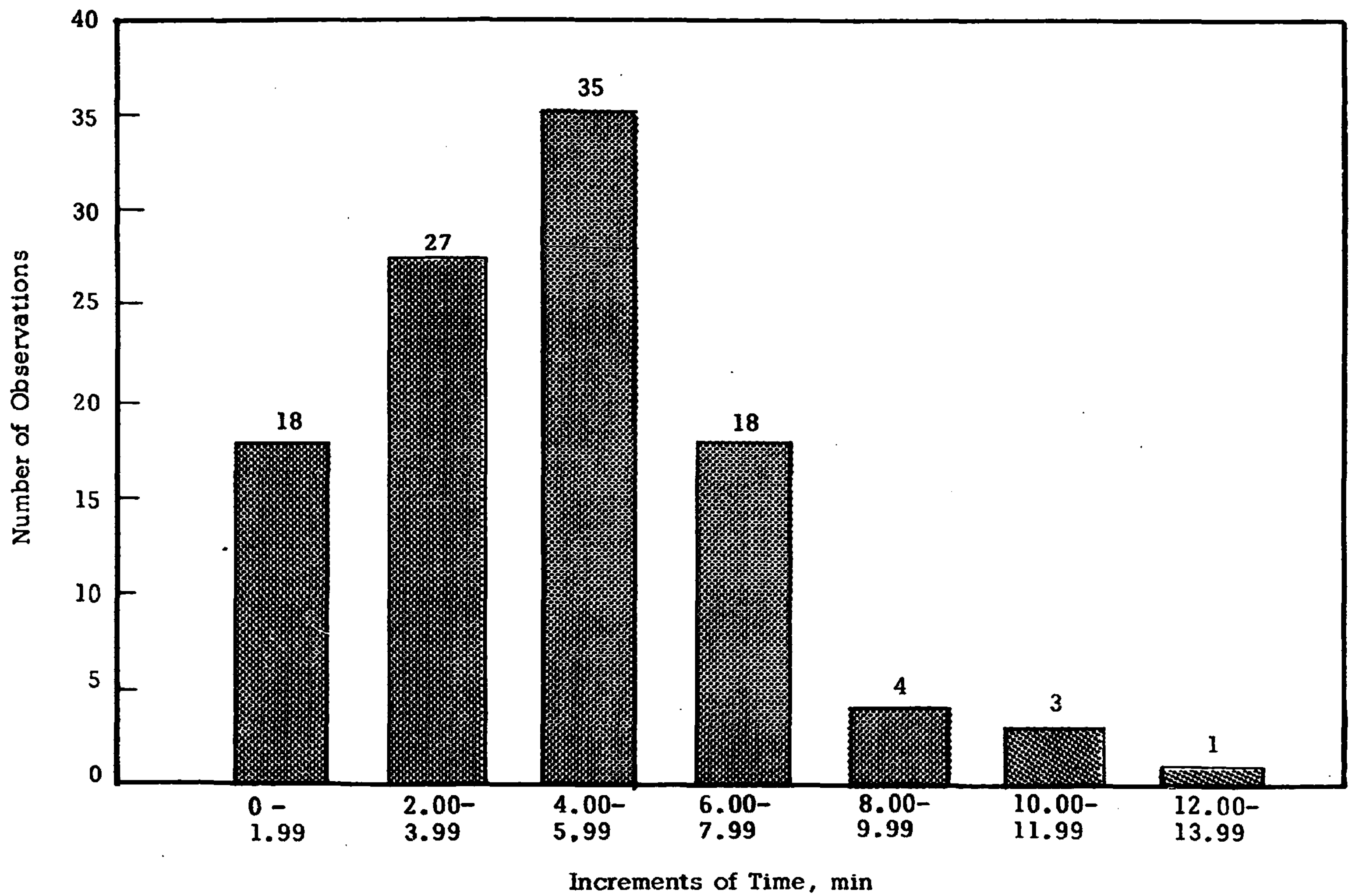


FIGURE E.2. HISTOGRAM OF MEASURED VALUES OF TIME TO PREPARE TO MOVE AFTER RESPONDING TO AN ALERT t_p

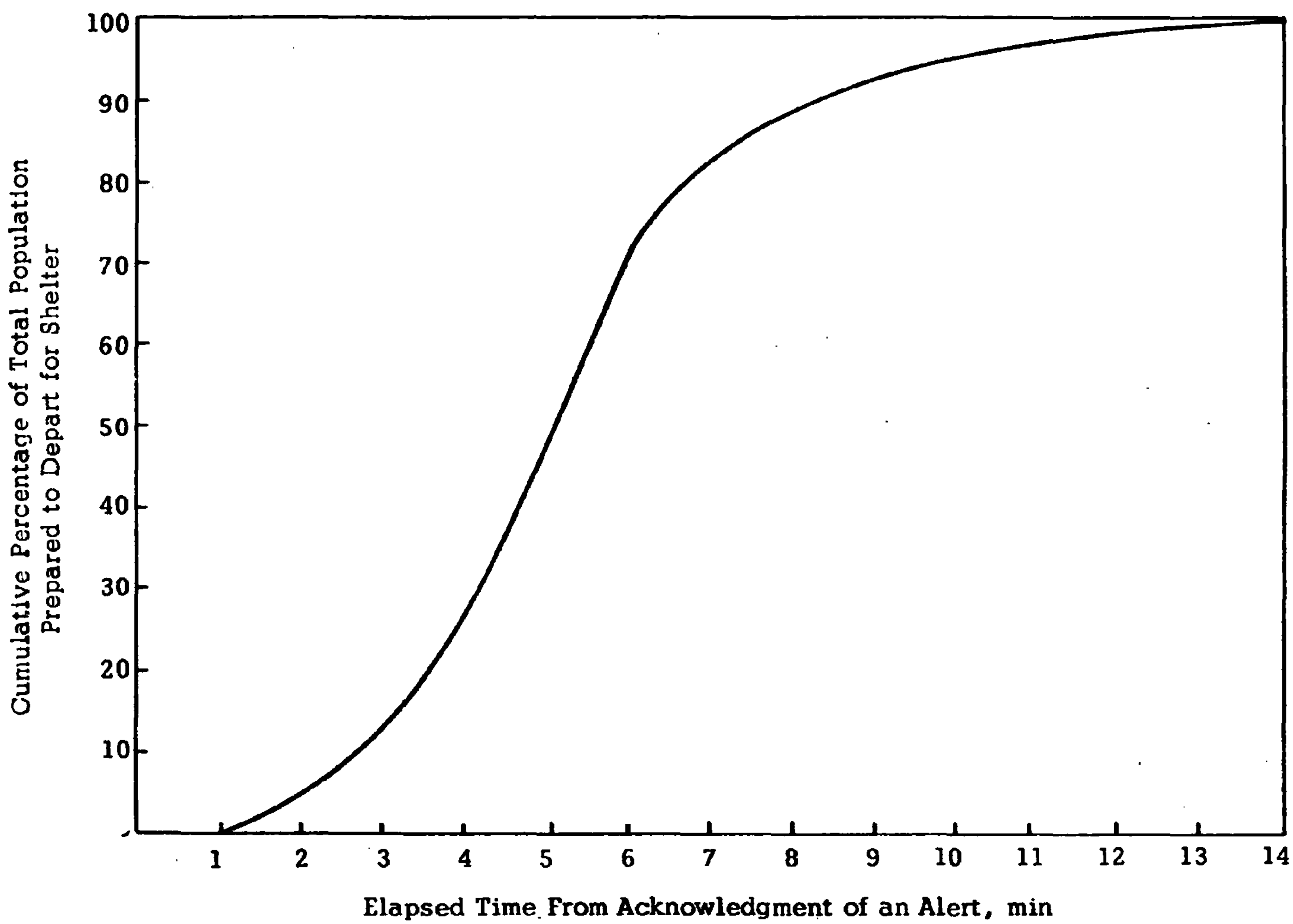


FIGURE E.3. CUMULATIVE DISTRIBUTION OF t_p

E.49 A graphical approximation of a cumulative distribution curve for the sample data is presented in Figure E.4.

E.50 Determination of t_t. Since the mean and variance of t_w are small with respect to the mean and variance of t_p, the mean value of the distribution t_w was added to the distribution of t_p to obtain an approximation of the distribution of t_t. A graphical approximation of the distribution of t_t is presented in Figure E.1.

CONTROLLED EXPERIMENTS

Introduction

E.51 The purpose of this portion of the project is to provide additional information to be used in conjunction with the results of the field experiments in determining times required to prepare to move to a shelter. The controlled experiments were concerned with the response of an at-home sleeping population to a simulated alert. The primary objective of the controlled experiments was to determine the influence of family size, particularly the number of young children, on the times required to prepare to move to shelter. A secondary objective was to provide basic data for the distribution of prepare-to-move times in the event that the field experiments did not yield sufficient data.

E.52 College students and their families comprised the population from which the controlled experiments were made. These families reside in the Callaway Apartments on the campus of the Georgia Institute of Technology in Atlanta, Georgia. This group provided an excellent means for determining the influence of the number of small children on prepare-to-move times for families. Additionally, the variable of dwelling size was reasonably controlled in these experiments, since the only difference between apartments was the number of bedrooms. The families included in the experiments lived in either one- or two-bedroom apartments.

E.53 In the following paragraphs, the procedure and the results of the controlled experiments are described. The actual times for each trial and characteristics of the families are included in Annex E9.

Procedure

E.54 Design of the Experiments. It was assumed that the prepare-to-move times would be influenced by, among other variables, the number of children who could not completely care for themselves. For the purpose of

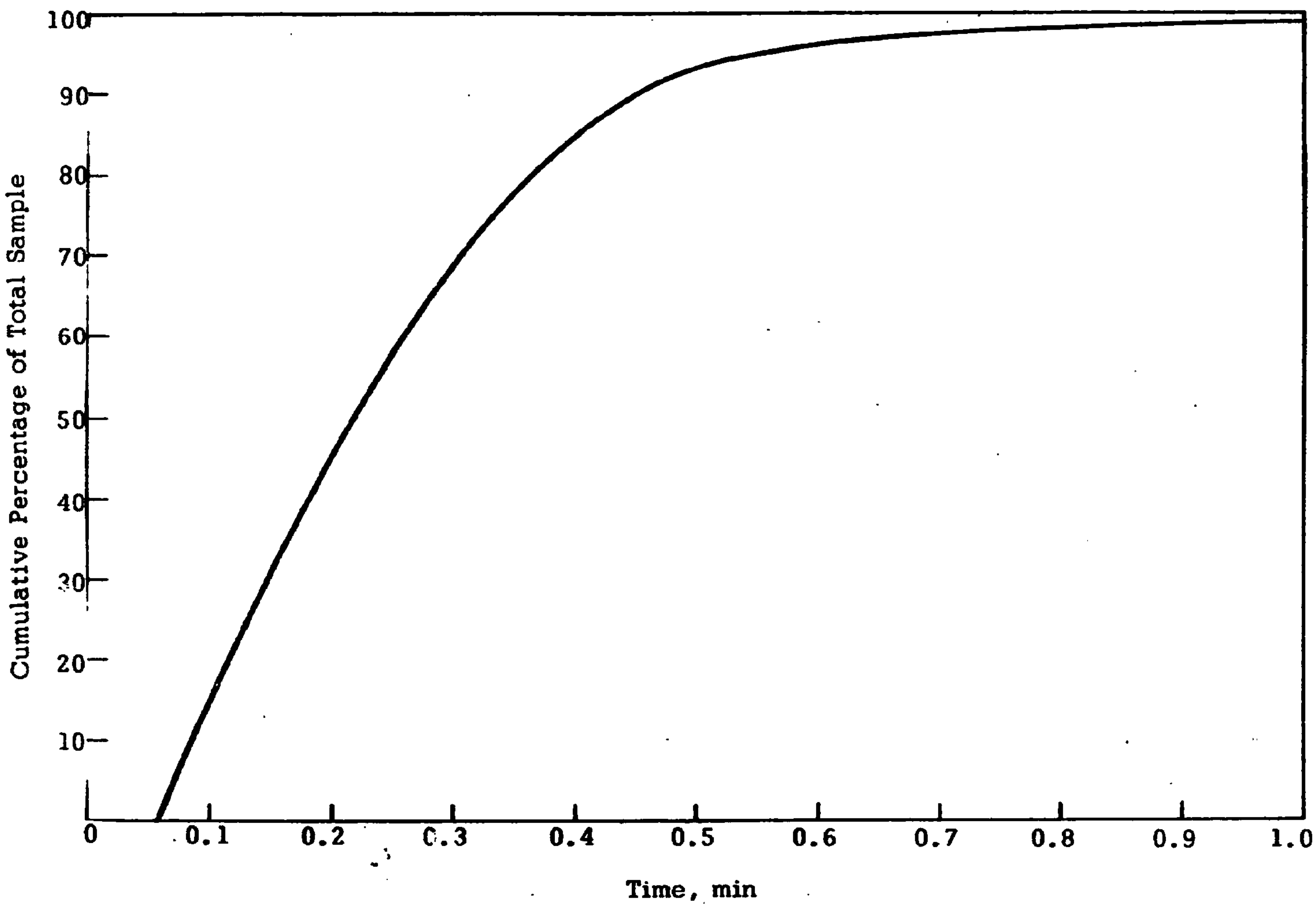


FIGURE E.4. CUMULATIVE DISTRIBUTION OF TIME TO RESPOND TO AN ALERT t_w

these experiments it was assumed that children under 8 years of age would need help in getting dressed. Consequently, the experiment was designed to include data on families in the following five groups.

Family Group	Children Under 8 Years
I	0
II	1
III	2
IV	3
V	4 and more

Contacts were made among the student families to obtain five families in each of these five groups. However, there were no student families in the last two groups so the controlled experiments were conducted on 18 families from the first three groups.

E.55 Method. Each family that participated was informed about the purpose of the project and the procedure to be used in responding to the alert. The controlled experiments were conducted between the hours of seven and nine in the evening and the participants were instructed to dress for bed and to retire, thus simulating a sleeping population. The prepare-to-move time began when the ORI representative rang the doorbell or knocked at the door. When the door was opened, the words, "This is an alert. Prepare to move to a shelter," were pronounced and the preparations began. The family dressed in street clothes appropriate for the season, closed the windows, turned off appliances, and obtained empty suitcases for each member of the family to simulate shelter kits. The prepare-to-move time ended when all members of the family were out of the apartment and the front door was closed. The observation form used in the controlled experiments is shown in Annex E10. Each family made three trials to provide some idea of the consistency with which small children affect the prepare-to-move time.

Results

E.56 Differences in t_p Between Family Groups. The average time to prepare to move to shelter after being alerted t_p for each of the family groups is as follows:

Family Group	t_p, min
I	1.76
II	2.33
III	2.75

These results indicate a definite relation between the number of children under eight in a family and the prepare-to-move times. The times ranged from 1.05 to 3.90 min with an overall average of 2.23 min. Note that the time to become aware of the alert t_w is not included in these results.

E.57 The complete results of the controlled experiments are shown in Annex E11. Generally, the second and third trials of the controlled experiment required less time than the first.

ANALYSIS AND CONCLUSIONS

E.58 The cumulative distribution curve in Figure E.1 indicates that within 5 min after the initial sounding of an alert, 40 percent of the sample population is prepared to depart for shelter; within 10 min, 90 percent; and within 15 min, 100 percent.

E.59 The field and controlled experiments indicate that the number of young children within a family significantly influences the distribution of times for preparing to move to shelter after becoming aware of an alert t_p. Table E.1 shows that the average number of children under 6 years of age per family with a measured value of t_p less than the median for the field experiment distribution is 0.02, whereas the average per family with measured values greater than the median is 0.33. This can be further stated as follows: for every child under six included in the range of families with measured values of t_p less than the sample median values of t_p, there are 17 children under six in the range of families with values of t_p greater than the median.

TABLE E.1

INFLUENCE OF FAMILY SIZE ON PREPARE-TO-MOVE TIME

(1)	(2)	(3)	(4)
Category	Average per Family for Total Observations With Values Less Than Median Value of t_p	Average per Family for Total Observations With Values Greater Than Median Value of t_p	Ratio of Column (3) to Column (2)
Persons per family	3.15	4.29	1.36
Children under twelve	0.69	1.60	2.32
Children under eight	0.19	0.75	3.95
Children under six	0.02	0.33	16.50

E.60 The cumulative distribution curve in Figure E.4 reveals that the response by an at-home sleeping population to an audio signal (similar to the telephone) is almost instantaneous. Within 0.6 min or 36 sec from the first ring, more than 90 percent of the total sample had responded. Only two calls out of the sample population of one hundred had a response time greater than 1 min (1.1 and 6.8 min).

E.61 The ratio of the first time element, t_w, to the second, t_p, within the total prepare-to-move time t_t is small. The ratio of the mean values t_w/t_p within t_t is small. The ratio of the mean values t_w/t_p is 0.05; the ratio of the median values t_w/t_p is 0.07.

E.62 The measured values of t_p for the controlled experiments were generally lower than those of similar-sized families in the field experiments. This can be attributed to at least two factors:

- a. The controlled experiments did not contain the element of surprise.
- b. The controlled experiments did not deal with an actual sleeping population.

E.63 The mean value of t_p for the four experiments conducted in which the families actually packed their shelter kits was 10.20 min. All these families contained children 6 years of age or under. The mean value of t_p for all families with children 6 years of age in the 96 field experiments, in which it was assumed that shelter kits were packed in advance, was 7.65 min.

E.64 The cumulative distribution curve for t_p in Figure E.3 is an approximation of the distribution that could be expected from similar populations. However, in applying the results to other similar or to nonsimilar distributions, several limitations of the study should be considered.

- a. Climate. Both the field and controlled experiments were conducted during the months of September and October. The weather during this period was generally mild. The volunteers for both the field and the controlled experiments dressed appropriately for the current weather conditions, which did not require supplementary exterior clothing, such as coats or sweaters. Cold and inclement weather would probably increase the time required to complete the activity, get dressed, and hence increase the values of t_p. A time factor, probably on the order of 1 or 2 min, should be included for inclement or extreme low temperature conditions.

b. <u>Number and Ages of Persons Within the Family</u>. The number of small children within a particular family significantly influences the value of t_p. Annex E12 is a comparison by family size and number and ages of children of the field experiment population distribution and national population distribution.

ANNEX E1
LETTER TO POTENTIAL VOLUNTEERS

THE ATLANTA METROPOLITAN AREA OF CIVIL DEFENSE

MUNICIPAL AUDITORIUM
30 COURTLAND STREET, S. E.
ATLANTA 3, GEORGIA

ELLIOTT R. JACKSON, DIRECTOR
MEMBER
U. S. CIVIL DEFENSE COUNCIL

TELEPHONE JAckson 5-4843

September 20, 1962

TO: PTA MEMBERS

You -- and your family -- are being asked to participate in a nationwide study- the purpose of which is to provide a more effective means of planning for Civil Defense in the event of a nuclear conflict. This study in which you are asked to participate may help to save millions of lives - including your own, and your children's.

The phase of the overall study in which you are requested to participate is concerned with the time required for a sleeping population to prepare to depart from home for a shelter. In this study, you will not have to leave your own home. You will be awakened during your normal sleeping hours to dress and be ready to leave your home as soon as possible - but you will not be asked to leave your home.

The Atlanta study is a part of a national study. Other phases of the overall study are being made in other cities. When completed, all phases will be "tied" together to afford Civil Defense with information about the movement of "night time" population - especially in residential areas.

Certain selected school areas are being studied. This is with concurrence of the CD School Coordinators (Messrs. John Lewis, Lewis Cook, Sam Moss and Tom Morgan). Your school is one selected for the study -- and we ask your cooperation. About 25 families are needed from each selected school area.

Your cooperation with your local School CD Chairman will be appreciated.

Thank you and your family.

Sincerely,

Elliott R. Jackson

Elliott R. Jackson

ERJ/vh

P. S. Operations Research is working on this special study for the Federal Government. Personnel of this organization will conduct the study and contact you at your home - if you participate.

Serving all Communities in DeKalb and Fulton Counties

ANNEX E 2

INSTRUCTIONS FOR VOLUNTEERS PARTICIPATING
IN FIELD EXPERIMENT FOR CIVIL DEFENSE STUDY

1. During one of the evenings on which you have volunteered, a civil defense representative will call at your home during the sleeping hours (0:01 a.m. to 5:00 p.m.).
2. As a means of identification, the representative will wear a civil defense arm band and will carry a letter of authorization.
3. On answering the door, you will be requested to begin the exercise.
4. You will then awaken the other members of your family, and every one will dress in street clothes appropriate for current seasonal conditions.
5. An empty suitcase or a reasonable substitute will be obtained for each member of the family (these items will represent shelter kits and should be stored in a fairly convenient location).
6. All appliances that you would not leave on during an extended absence from the house should be turned off and all windows closed.
7. When all preparations are complete, all members of the family will assemble with their suitcases in the room nearest the front entrance of the house.
8. Notify the representative, who will be waiting at the front entrance, that your preparations are complete.
9. Assume that adequate time is available for you to complete your preparations; however, do not waste time.
10. You will not be required to leave your home.
11. The civil defense representative will not enter your home.

ANNEX E3
VOLUNTEER QUESTIONNAIRE

THE ATLANTA METROPOLITAN AREA OF CIVIL DEFENSE

MUNICIPAL AUDITORIUM
30 COURTLAND STREET, S. E.
ATLANTA 3, GEORGIA

ELLIOTT R. JACKSON, DIRECTOR
MEMBER
U. S. CIVIL DEFENSE COUNCIL

TELEPHONE JAckson 5-4843

Date ____________________

NAME ______________________________ Phone ____________________

ADDRESS ______________________________

CITY ______________________________

1) Number of persons in family: ______________________________
2) Please circle age of children in family 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 11 - 12 - 13 - 14 - 15 - 16 - 17 - 18 - 20 - 21.
3) Number of adults in family: ______________________________
4) Will all members of family participate? ____________________
5) Select three (3) dates in the week of ____________________ family will be willing to participate.
6) Awaken anytime during sleeping hours. ____________________

Serving all Communities in DeKalb and Fulton Counties

ANNEX E4

DATA-COLLECTION FORM

PROJECT CD-1A

Observer:

Date:

Time:

Observation Sheet - Field Experiment

1. Family name:

   Address:

2. Type of dwelling:

   No. of rooms:

3. Recorded times:

Element	C	E	Check List
Knock or ring			No. of adults:
Door opened			No. of children and ages
Message completed			Participants were: (check one)
Family assembled			a. Asleep
			b. Awake

4. Was everyone adequately clothed and prepared?

Note:

ANNEX E5

SUMMARY OF FIELD EXPERIMENT DATA, t_p

No.	School PTA Group 1/	Section of Atlanta 2/	Date and Hour of Conduct, a.m. 3/	Race 4/	Number of Rooms in Dwelling	Ages of Persons Participating	Total Persons Participating 5/	Measured Time, t_p min 6/
1	F	NE	10/11,6	W	7	A,16,15,7	4	1.25
2	C	NE	10/9,6	W	7	A,A	2	1.33
3	F	NE	10/10,5	W	7	A,A	2	1.33
4	B	SW	9/26,1	N	4	A,8	2	1.50
5	A	NW	10/11,6	W	9	A,A,11,10,7	5	1.58
6	H	SE	10/10,4	W	4	A	1	1.67
7	B	SW	9/24,2	N	5	A,A,A,13,6	5	1.92
8	H	SE	10/13,5	W	4	A,A	2	1.92
9	F	NE	10/10,6	W	11	A,15	2	2.08
10	J	NW	10/11,4	W	4	A,A	2	2.16
11	B	SW	9/21,1	N	3	A,A	2	2.37
12	F	NE	10/10,6	W	9	A,A	2	2.57
13	G	NE	10/11,7	W	7	A,13,9	3	2.63
14	I	NW	10/13,4	W	5	A,A	2	2.67
15	E	NE	10/5,5	W	4	A,A,8	3	2.75
16	B	SW	9/21,2	N	4	A,10,9	3	2.83
17	D	NE	10/9,7	W	8	A,A,10,8	4	2.93
18	B	SW	9/24,0	N	6	A,A,9	3	2.95
19	F	NE	10/11,5	W	5	A,A,6	3	3.00
20	I	NW	10/13,3	W	6	A,A	2	3.00

No.	School PTA Group 1/	Section of Atlanta 2/	Date and Hour of Conduct, a.m. 3/	Race 4/	Number of Rooms in Dwelling	Ages of Persons Participating	Total Persons Participating 5/	Measured Time, t_p, min 6/
21	H	SE	10/9,6	W	7	A,A	2	3.00
22	E	NE	10/4,6	W	6	A,19,13,11	4	3.23
23	H	SE	10/10,4	W	6	A,12	2	3.25
24	B	SW	9/21,1	N	7	A,A,A,9,8	5	3.30
25	G	NE	10/10,6	W	6	A,A	2	3.33
26	B	SW	9/21,3	N	5	A,A,12,10	4	3.33
27	B	SW	9/29,1	N	5	A,10	2	3.45
28	F	NE	10/11,6	W	8	A,A,15,13,11	5	3.45
29	H	SE	10/10,5	W	7	A,A	5	3.50
30	G	NE	10/11,6	W	6	A,A,9	3	3.52
31	G	NE	10/10,5	W	7	A,A	2	3.62
32	G	NE	10/10,5	W	6	A,15,9	3	3.70
33	H	SE	10/9,5	W	7	A,A	2	3.77
34	B	SW	9/29,0	N	6	A,A,12,10	4	3.80
35	H	SE	10/10,5	W	7	A,A	2	3.92
36	B	SW	9/24,1	N	3	A,16,10	3	4.03
37	H	SE	10/9,6	W	6	A,A	2	4.03
38	E	NE	10/5,5	W	5	A,A,12	3	4.08
39	J	NW	10/11,3	W	7	A,A,15	3	4.16
40	C	NE	10/9,5	W	6	A,A,12,10,6	5	4.33

No.	School PTA Group 1/	Section of Atlanta 2/	Date and Hour of Conduct, a.m. 3/	Race 4/	Number of Rooms in Dwelling	Ages of Persons Participating	Total Persons Participating 5/	Measured Time, t_p, min 6/
41	C	NE	10/9,6	W	7	A,14,11,8,6,6	6	4.38
42	H	SE	10/10,5	W	6	A,A,15,13,12,10,6,3	8	4.42
43	F	NE	10/10,7	W	7	A,A	2	4.55
44	G	NE	10/12,6	W	6	A,A,A	3	4.58
45	J	NW	10/11,2	W	8	A,A,14,13,9	5	4.67
46	J	NW	10/11,3	W	6	A	1	4.67
47	J	NW	10/11,4	W	7	A,A,16,14,13	5	4.67
48	E	NE	10/4,5	W	7	A,A,17,10	4	4.67
49	A	NW	10/11,5	W	9	A,A	2	4.75
50	G	NE	10/12,6	W	9	A,11,9	3	4.75
51	F	NE	10/10,7	W	6	A,A,14	3	4.78
52	G	NE	10/10,5	W	7	A,A,13,10,5	5	4.82
53	A	NW	10/11,5	W	4	A,A,9	3	4.83
54	E	NE	10/4,6	W	6	A,A,11	3	4.88
55	B	SW	9/26,0	N	6	A,A,12,11,9,6	6	4.90
56	G	NE	10/10,6	W	9	A,12,10,9	4	4.90
57	E	NE	10/4,5	W	6	A,A,A,12	4	4.90
58	I	NW	10/13,2	W	6	A,A,6,3	4	4.95
59	G	NE	10/12,6	W	7	A,A	2	5.00
60	J	NW	10/11,2	W	7	A,A,A,17,13,11	6	5.16
61	D	NE	10/9,6	W	4	A,7	2	5.18
62	G	NE	10/11,6	W	7	A,A,14,12,9	5	5.20
63	H	SE	10/9,4	W	7	A,A	2	5.25
64	F	NE	10/11,6	W	6	A,12	2	5.28
65	H	SE	10/13,5	W	5	A,A,14,11,7	5	5.33

No.	School PTA Group 1/	Section of Atlanta 2/	Date and Hour of Conduct, a.m. 3/	Race 4/	Number of Rooms in Dwelling	Ages of Persons Participating	Total Persons Participating 5/	Measured Time, t_p, min 6/
66	H	SE	10/13,5	W	3	A,13,10,8	4	5.58
67	F	NE	10/11,5	W	6	A,A,10,6	4	5.67
68	G	NE	10/11,6	W	7	A,A,9,5	4	5.67
69	A	NW	10/11,6	W	8	A,A,16,13,9,6	6	5.70
70	A	NW	10/11,6	W	9	A,A,12,10,7	5	5.78
71	B	SW	9/24,2	N	5	A,A,A,15,14,13,6	7	6.03
72	E	NE	10/6,6	W	5	A,A,5	3	6.08
73	E	NE	10/6,4	W	7	A,A,10,8,6	5	6.10
74	H	SE	10/13,4	W	5	A,A,14,7	4	6.10
75	B	SW	9/21,1	W	7	A,A,A,9	4	6.15
76	A	NW	10/11,5	W	7	A,A,14,13,9	5	6.20
77	C	NE	10/9,4	W	7	A,A,15,10	4	6.30
78	G	NE	10/10,5	W	8	A,A,12,11,6	5	6.33
79	E	NE	10/5,6	W	6	A,13,11,6	4	6.42
80	H	SE	10/9,5	W	9	A,A,14,11,8	5	6.42
81	H	SE	10/9,5	W	5	A,A,A,15,9,3	6	6.67
82	G	NE	10/10,7	W	8	A,A,9,6,3	5	6.68
83	G	NE	10/12,4	W	8	A,A,13,9	4	6.75
84	D	NE	10/9,5	W	5	A,A,7,6,2	5	6.80
85	F	NE	10/10,6	W	10	A,A,14,12,11,9,5	7	7.08
86	F	NE	10/10,6	W	6	A,A,17	3	7.42
87	G	NE	10/12,5	W	9	A,A,13,10,8,6	6	7.50
88	I	NW	10/13,4	W	8	A,A,6,5	4	7.67
89	E	NE	10/6,5	W	6	A,A,11,6	4	8.27
90	I	NW	10/13,3	W	5	A,A,A,16	4	8.67

No.	School PTA Group 1/	Section of Atlanta 2/	Date and Hour of Conduct, a.m. 3/	Race 4/	Number of Rooms in Dwelling	Ages of Persons Participating	Total Persons Participating 5/	Measured Time, t_p, min 6/
91	H	SE	10/9,6	W	7	A,A,8,5,	4	9.13
92	E	NE	10/6,3	W	8	A,A,A,4,3,	5	9.30
93	D	NE	10/9,6	W	7	A,A,7,5,3,1	6	10.33
94	J	NW	10/11,3	W	6	A,A,10,8,4	5	11.72
95	G	NE	10/12,6	W	8	A,A,10,9	4	11.92
96	F	NE	10/11,7	W	6	A,A,7,5	4	13.42

1/ School PTA group
- A = E. Rivers Elementary School
- B = E. R. Carter Elementary School
- C = Winnona Park Elementary School
- D = Fifth Avenue Elementary School
- E = S. M. Inman School
- F = Briafcliff High School
- G = W. D. Thompson School
- H = Lakewood Heights Elementary School
- I = Roswell Elementary School
- J = Roswell High School

2/ Section of Atlanta
- NE = Northeast
- SE = Southeast
- SW = Southwest
- NW = Northwest

3/ Date and hour of conduct, a. m.
10/11,6 = 10th month, 11th day, 6 a. m. to 7 a.m.

4/ Race
- N = Nonwhite
- W = White

5/ Ages of persons participating
A = Adult

6/ Measured time, t_p,
t_p = The time lapse from acknowledgment of commence test until all preparations are complete.

SUMMARY OF FIELD EXPERIMENT DATA, t_p, FOR FAMILIES WHO PACKED SHELTER KITS

No.	School PTA Group 1/	Section of Atlanta 2/	Date and Hour of Conduct, a.m. 3/	Race 4/	Number of Rooms in Dwelling	Ages of Persons Participating	Total Persons Participating 5/	Measured Time, t_p, min 6/
1	G	NE	10/10,6	W	7	A,9,8,4	5	9.33
2	G	NE	10/10,6	W	9	A,A,9,3	4	9.42
3	G	NE	10/10,6	W	7	A,9,6	3	10.33
4	D	NE	10/9,5	W	6	A,A,7,5,1	5	11.72

1/ School PTA group

D = Fifth Avenue Elementary School

G = W. D. Thompson School

2/ Section of Atlanta

NE = Northeast

3/ Date and hour of conduct, a. m.

10/10,6 = 10th month, 10th day, 6 a. m. to 7 a. m.

4/ Race

W = White

5/ Ages of persons participating

A = Adult

6/ Measured time, t_p,

t_p = The time lapse from acknowledgment of commence test until all preparations are complete.

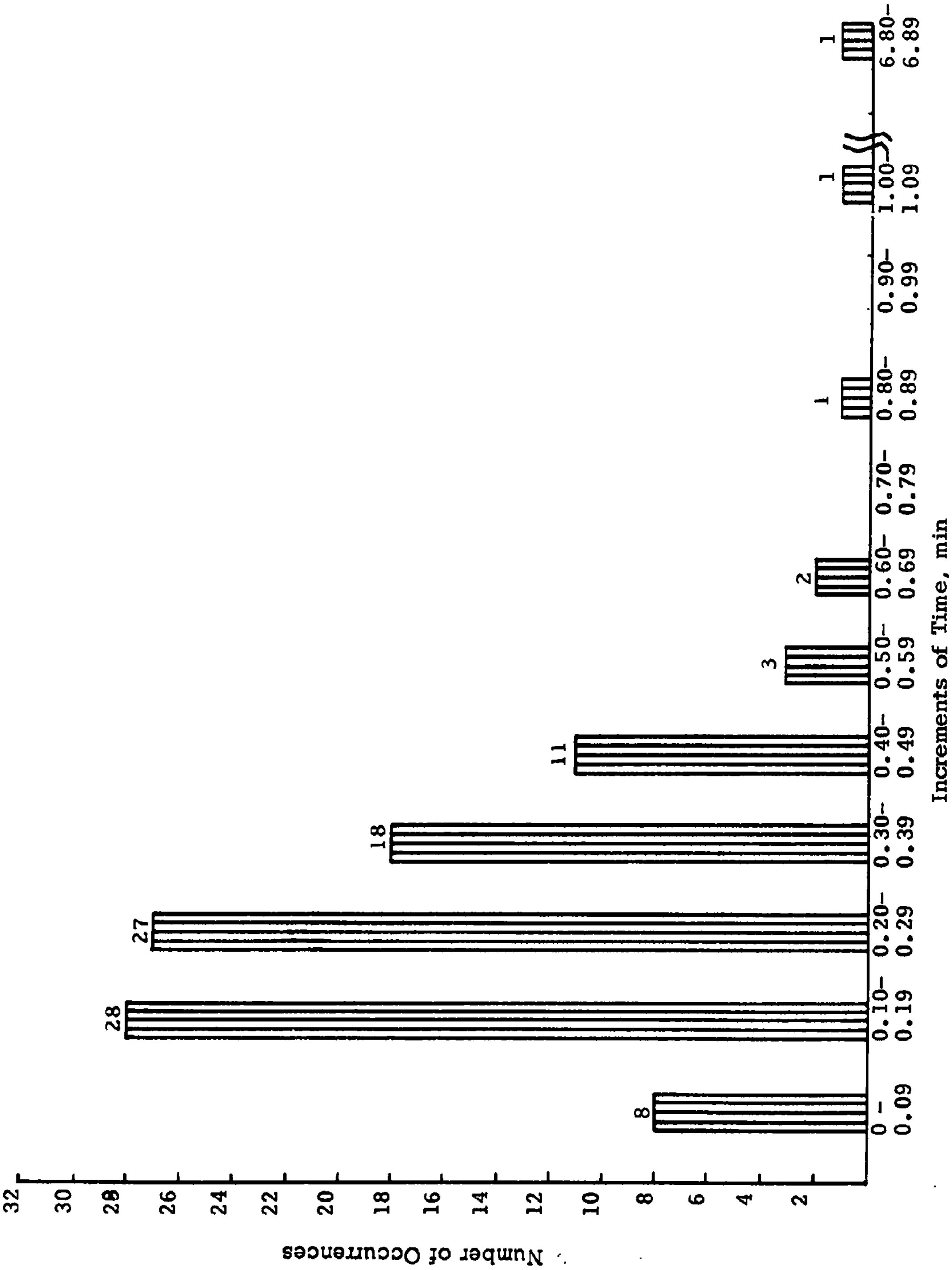
ANNEX E7

SUMMARY OF FIELD EXPERIMENT DATA, t_w

No.	Date of Call	Hour of Call, a.m.	Section of Atlanta	Measured time, min
1	10/10	3	SW	0.06
2	9/20	4	SW	0.06
3	10/10	3	NW	0.07
4	10/10	3	NE	0.07
5	10/2	1	NE	0.08
6	10/10	3	NE	0.08
7	10/10	3	NE	0.08
8	10/10	3	SW	0.08
9	9/10	0	NE	0.10
10	10/2	1	NE	0.10
11	10/10	0	NW	0.10
12	10/10	3	SW	0.10
13	10/10	3	NE	0.10
14	10/10	3	NE	0.10
15	9/19	2	SW	0.11
16	9/12	1	SW	0.12
17	10/10	0	NE	0.12
18	10/11	1	NE	0.12
19	10/12	3	NE	0.13
20	10/10	3	SW	0.13
21	9/19	2	NE	0.13
22	10/10	3	SW	0.14
23	10/10	3	NE	0.14
24	9/19	2	SW	0.15
25	10/2	1	NW	0.17
26	10/2	1	SW	0.17
27	10/10	0	NE	0.17
28	10/10	3	SE	0.17
29	9/12	1	SW	0.17
30	9/27	3	SE	0.17
31	9/27	3	SE	0.17
32	9/20	4	SW	0.18
33	10/12	3	NE	0.18
34	10/10	0	SW	0.18
35	9/10	0	NE	0.18
36	10/10	3	NE	0.19

No.	Date of Call	Hour of Call, a.m.	Section of Atlanta	Measured time, min
37	9/20	4	SW	0.20
38	9/20	4	SW	0.20
39	9/20	4	SW	0.20
40	10/12	3	NE	0.20
41	10/10	0	SE	0.20
42	10/10	0	NE	0.20
43	10/10	3	SW	0.20
44	9/27	3	NE	0.20
45	9/10	0	SW	0.21
46	9/10	0	SE	0.21
47	10/10	3	NW	0.22
48	10/2	1	NE	0.22
49	10/10	0	NE	0.22
50	9/19	2	NE	0.23
51	9/19	2	NE	0.23
52	10/10	0	SW	0.23
53	10/10	3	SE	0.24
54	10/10	3	NE	0.24
55	9/27	3	NE	0.24
56	9/10	0	SW	0.25
57	9/10	0	NE	0.25
58	9/12	1	NE	0.25
59	9/27	3	SW	0.25
60	10/12	3	SW	0.25
61	10/10	3	NW	0.25
62	9/19	2	SE	0.27
63	10/10	3	NE	0.29
64	10/2	1	SE	0.30
65	10/12	3	NW	0.30
66	9/27	3	NE	0.31
67	10/10	0	NW	0.32
68	10/10	3	SW	0.32
69	10/10	0	SE	0.33
70	10/2	0	NE	0.33
71	10/10	3	NE	0.33
72	10/10	3	NW	0.33
73	9/19	2	NE	0.35
74	10/10	3	NE	0.35
75	9/20	4	NE	0.36

No.	Date of Call	Hour of Call, a.m.	Section of Atlanta	Measured time, min
76	10/10	0	SW	0.37
77	9/20	4	NE	0.37
78	9/27	3	NE	0.38
79	10/12	3	SE	0.38
80	10/11	1	SW	0.38
81	10/11	1	SE	0.38
82	9/19	2	SW	0.40
83	10/10	0	SE	0.40
84	9/20	4	SE	0.40
85	10/2	1	SW	0.40
86	9/27	3	NE	0.41
87	10/10	0	NE	0.42
88	10/2	1	NE	0.45
89	9/12	1	NE	0.45
90	9/19	2	SE	0.45
91	9/20	4	NE	0.47
92	9/19	2	NE	0.48
93	9/10	0	SE	0.52
94	10/11	1	SE	0.52
95	9/10	0	SE	0.61
96	10/10	0	SW	0.63
97	10/2	1	NW	0.63
98	10/10	3	SW	0.80
99	9/27	3	SW	1.03
100	9/10	0	SW	6.84



HISTOGRAM OF MEASURED TIMES TO BECOME AWARE OF AN ALERT t_w

SUMMARY OF CONTROLLED EXPERIMENT DATA TIMES FOR PREPARE TO MOVE AFTER BEING ALERTED t_p

Families		Bdrms in Apts	Ages of Persons Participating	t_p by Trials, sec			t_p Averages	
Group	No.			First	Second	Third	sec	min
I	1	1	A,*A	147	163	160	157	2.61
	2	1	A,A	102	82	76	87	1.45
No	3	2	A,A	71	60	58	63	1.05
children	4	1	A,A	133	98	75	102	1.70
under 8	5	2	A,A	130	102	88	107	1.78
	6	2	A,A	108	95	99	101	1.68
	7	2	A,A,14	141	113	118	124	2.07
							741	
Average:	t_p for Group I = $\frac{741}{7}$ = 106 sec or 1.76 min per family							
II	1	2	A,A,9,8,1.5	182	167	142	164	2.73
	2	1	A,A,1	213	139	174	175	2.92
One	3	2	A,A,2	146	146	118	137	2.28
child	4	1	A,A,1	96	92	75	88	1.47
under 8	5	2	A,A,3	208	174	153	178	2.97
	6	2	A,A,2	96	95	93	95	1.58
							837	
Average:	t_p for Group II = $\frac{837}{6}$ = 140 sec or 2.33 min per family							
III	1	2	A,A,7.5,5	146	133	124	134	2.23
	2	1	A,A,0.4,0.4	151	163	165	160	2.67
Two	3	2	A,A,5,3	172	199	200	190	3.17
children	4	2	A,A,7,5	113	105	105	108	1.80
under 8	5	2	A,A,3,1	302	186	215	234	3.90
							826	
Average:	t_p for Group III = $\frac{826}{5}$ = 165 sec or 2.75 min per family							

*Ages for adults (A) were not recorded.

ANNEX E10

DATA-COLLECTION FORM FOR CONTROLLED EXPERIMENTS

PROJECT CD-1A

Observer:
Date:

Observation Sheet – Controlled Experiments

1. Family name and address:

2. Children's names: ages:
   1.
   2.
   3.
   4.
   5.

3. Type of dwelling:

4. Recorded times:

	(1)		(2)		(3)		
Element	C	E	C	E	C	E	AE
Knock or ring							
Door opened							
Message completed							
Family assembled							

5. Notes (use back of observation sheet and space below):

ANNEX E11

CONTROLLED EXPERIMENT RESULTS GROUPED TO PROVIDE FOR THE CUMULATIVE FREQUENCY DISTRIBUTION OF PREPARE-TO-MOVE TIMES t_p

Time Intervals, min	Average t_p, min	Families per Interval	Percentage of Total Families	Cumulative Percentages
0.00 - 0.50	-	0	-	-
0.51 - 1.00	-	0	-	-
1.01 - 1.50	1.05 1.45 1.47	3	16.7	16.7
1.51 - 2.00	1.70 1.78 1.68 1.58 1.80	5	27.8	44.5
2.01 - 2.50	2.23 2.28 2.07	3	16.7	61.2
2.51 - 3.00	2.61 2.73 2.92 2.97 2.67	5	27.8	89.0
3.01 - 3.50	3.17	1	5.5	94.5
3.51 - 4.00	3.90	1	5.5	100.0
Total		18	100.0	

ANNEX E12

COMPARISON OF FAMILY SIZES OF FIELD EXPERIMENT POPULATION DISTRIBUTION AND NATIONAL POPULATION DISTRIBUTION, 1960 1/

No. of Persons	Field Experiment Population Distribution, Percentage of Total Families	National Population Distribution, Percentage of Total Families
	Size of Family	
1 2/	2.1	0.0
2	24.0	47.1
3	17.7	24.0
4	24.0	13.5
5	21.9	6.9
6	7.2	4.3
7 or more	3.1	4.2
Total	100.0	100.0
	Related Children Under 18	
0	22.9	40.1
1	20.8	19.7
2	24.0	18.7
3	24.0	11.5
4 or more	8.3	10.0
Total	100.0	100.0
	Children Under 6 3/	
0	84.4	83.4
1	12.5	9.0
2 or more	3.1	7.6
Total	100.0	100.0

1/ Statistical abstract of the United States 1961, U.S. Dept. of Commerce, Bureau of the Census.

2/ The Bureau of the Census classifies an individual as nonfamily.

3/ It was assumed that all children under six participating in the field experiments were "own" children.

APPENDIX F

METHOD FOR ANALYZING MOVEMENT TO SHELTER

INTRODUCTION

F.1 The effectiveness of any shelter system in protecting a population against enemy attack will depend on many factors, only a few of which are under the control of the civil defense planner. These factors have to do with the number and location of shelter spaces, the configuration of the population when warning of an attack is received, the doctrine and means for assuming a defensive posture, the nature of the attack, and the warning time given. Knowledge of the relations among the factors is required to guide future decisions in implementation and improvement of the shelter program and in selection of doctrine for assuming a defensive posture. This study examines one aspect of this program, viz., the movement of people from where they are at time of warning to a location where they may be sheltered.

F.2 An important concern of the planner is that part of the shelter program involving the protection of populations of metropolitan areas. The manner in which the structures of such areas evolve depends primarily on political and economic forces, and is influenced only slightly by civil defense considerations. Furthermore, such considerations appear to have little or no effect on the day-to-day activities of the people within the areas, and will probably continue to have no effect unless a nuclear attack is known to be imminent. Because an enemy will try to achieve as much surprise as possible in carrying out initial attacks, knowledge that an attack is imminent may come only after the enemy has launched its missiles. The maximum possible warning time from detected launchings of strategic missiles to their descent on targets is on the order of half an hour. For some elements of the population, the time between realization that an attack is in progress and the impact of weapons may be appreciably shorter. Therefore, an important problem faced by OCD involves the sheltering of a population that receives warning while going about its normal activities, and where the warning time is so short that individuals must take shelter, if possible, in the same general locality in which they receive the warning.

F.3 Many shelters already exist in cities throughout the U.S., and it is the responsibility of OCD to determine whether the existing populations under the conditions just described can actually move to these shelters in time. If they cannot, OCD may well ask what is required to improve movement capabilities, or whether the problem must be solved through the improvement and expansion of present shelters and the provision of new shelters. To assist OCD in this task, ORI has developed a method by which the movement-to-shelter system can be analyzed. The method is designed to permit its application to any metropolitan area without requiring either an excessive amount of special data preparation for the specific area being examined or the use of costly simulation techniques. Furthermore, the method will allow some flexibility as to the precision of input data used and the kinds of factors considered.

F.4 The method was developed specifically for use in analyzing the movement of people into shelters located within the same general area as the population served. The objectives of the method are the following:

a. To estimate, for a typical range of population configurations and for different types and levels of attack, how well the movement-to-shelter system can be carried out, both from the standpoint of the entire metropolitan area and with respect to particular subareas.

b. To determine where weaknesses in the system lie with respect to shelter locations and capacities, and to obtain an indication of how such weaknesses might be effectively and economically reduced by addition to or modification of the system.

c. To evaluate the effect of proposed additions to or modifications of the system.

F.5 The purpose of this appendix is to describe the method for analyzing the movement of a population to a shelter system. It also gives a brief overall description of the method, including the general assumptions that have been made, shows the detailed mathematical development, and discusses briefly how the method is to be used.

GENERAL DESCRIPTION OF THE METHOD

F.6 The principal result to be obtained by the method is a curve or set of curves showing the estimated fraction of the population of a metropolitan area that will have entered shelters, expressed as a function of time from some event such as an initial warning. Similar results can also be obtained separately for various parts of the area. Such curves may be affected by the following factors that have been taken into account:

a. Shelter distribution and density.

b. Shelter capacities.

c. Population distribution and density.

d. Individual delays in receiving warning and in departing for shelter.

e. Available means of transportation.

F.7 Factors under c., d., and e. may vary with the configuration of the population at the time of warning. Therefore, to determine the effectiveness of the movement to a given shelter system, the method should be applied to a typical range of configurations, such as those occurring at night, during a weekday, and during a holiday.

F.8 Since these factors and output curves describe the population and its state of movement to shelters as a function of place and time, they can be used to estimate the consequences of bomb attacks and spreading fallout at various times during the movement operation. These consequences will depend not only on population movement and shelter information, but on the type, size, time, and location of the attack, and would be calculated using damage-assessment factors obtained from other OCD studies.

Input Data

F.9 The first step in the method of analyzing the movement-to-shelter system of a metropolitan area is to partition this area into a number of subareas in the following way. Each subarea defined should have a population that is more or less uniformly distributed over the entire subarea. It would be useful if the same types of activity were carried on throughout a subarea, but this restriction is not essential. Subareas should be made as large as possible, so that as few as possible are required to completely cover the metropolitan area. However, uniformity of population must not be sacrificed to increase subarea size.

F.10 After subareas have been defined, the following information about each must be obtained:

a. Distribution of shelter locations within the subarea.

b. Distribution of shelter capacities.

c. Population density at initial time.

d. Distribution of individual delays in departure for a shelter.

e. Distribution of individual travel speeds, either fixed or varying with time.

f. Information about the system of thoroughfares connecting adjacent subareas, including estimates of the capacities of these thoroughfares.

F.11 Items c. through e. will vary with time of day and day of week, and perhaps with weather as well. Therefore a range of representative values of each must be obtained.

General Assumptions

F.12 It is assumed that the initial distribution of the population of a particular subarea is uniform, regardless of the distributions of travel speed and delay in departure for a shelter. The population density can, of course, be different for the same subarea at different times of the day and week.

F.13 It is assumed that each person in a subarea goes first to the shelter that is located nearest to him. Under this assumption, the area containing all people going first to the same shelter is called the "area associated with the shelter." Annex A1 presents a method for estimating the distribution of areas associated with the shelters located within a given subarea of a city.

F.14 The method of analysis considers the possibility that an individual will not be accepted at the nearest shelter (because the shelter is full), and must be directed to another. It is assumed that each shelter has a definite capacity, and that shelter officials are capable of redirecting new arrivals after the shelter is full. Shelter capacities in a subarea will be described by a distribution function.

F.15 It is tentatively assumed that the distribution of area associated with shelters in a subarea is independent of the distribution of shelter capacities. The validity of this assumption can be checked by statistical tests on shelter data, and if the assumption is found to be invalid in some cases, the analytic method can be modified accordingly.

F.16 It is assumed that every person turned away from a full shelter will be directed to the nearest shelter that is expected to have vacant space.

F.17 A special norm (i.e., definition of travel distance between two points) has been used in the method of analysis. Because of the generally rectangular structure of street networks in most U.S. cities, and because movement patterns in a city ordinarily must follow the streets, the distance between the points (x_1, y_1) and (x_2, y_2) is assumed to be[1/]

$$|x_1 - x_2| + |y_1 - y_2| .$$

F.18 In the analysis of population movement within a subarea, it is assumed that edge effects can be neglected.

[1/] If desired, another norm could be used without basically changing the method of analysis.

Outline of Method

F.19 Movement to Shelters Within a Subarea, Special Case. Consider the movement of people initially located within a city subarea to a shelter system located within the same subarea. The problem is to estimate the number of people in the subarea that will be sheltered, expressed as a function of time. First, a special case is considered in which it is assumed that everyone starts for shelter at the same time and travels at the same speed.

F.20 Movement in the subarea is separated into two or more phases. The first deals with people going to the nearest shelter and being either accepted or turned away, according to the capacity of the shelter and the number of prior arrivals. In the first phase, therefore, there is the threefold problem:

a. How many people will have been sheltered by time t in the first shelter they reach?

b. How many will have been turned away by time t?

c. How many vacancies will be left in the various shelters after the first phase?

Expressions are derived in paragraph F.25 and following for obtaining these values with respect to the first phase.

F.21 The second phase deals with people who have been turned away from the first shelter they reach (at various times), and who are directed to the nearest shelter still expected to have vacancies. Additional phases will be required if people are turned away from two or more shelters. Of course, in the second and any subsequent phases one can no longer consider people's starting times to another shelter to be all the same. Therefore, a more general analysis is required, and consideration of the second phase must be postponed until this analysis has been discussed.

F.22 Movement to Shelters Within a Subarea, General Case. In the more general case of the movement problem described in the preceding paragraphs, distributions of starting time and travel speed have been considered. Otherwise, the problem remains essentially the same. Expressions for obtaining values similar to those described in paragraph F.20 hold for all phases of movement.

F.23 Note that there will be a dependence between travel speeds and starting times for people starting for a second shelter. This fact could be arrived at intuitively, since the speed at which people move will affect their chances of being accepted at the first shelter they reach. In other words, slow people arrive late at the first shelter and are more likely to be turned away.

F.24 The general approach has resulted in an iterative method that will enable one to calculate the number of people sheltered as a function of time in a city subarea. This function, together with the distribution of starting times to the first shelter, also permits a determination of the number of people in transit at any given time.

MATHEMATICAL DEVELOPMENT

F.25 The following paragraphs present a detailed mathematical development of the method of analysis described previously. As indicated in the general description, an iterative approach has been taken in this development. The first iteration (or phase) has to do with the movement of people to the shelters nearest them at the time of warning. Some of these people will be turned away because the shelters at which they arrive are full. The second iteration involves the movement of such people to other shelters that may still receive them. If people are turned away from more than one shelter, additional iterations will be required. Note that successive iterations do not correspond to a sequence of time intervals, since movements involving two or more iterations will often occur simultaneously.

F.26 The following notation is used to describe certain basic factors related to the movement of people to shelters in a city subarea:

t = elapsed time from the event that initiates movement to shelters (i.e., time from initial warning).

ρ = population density of the subarea.

S = total number of shelters in the subarea.

$g_V(v)$ = probability density function describing the travel speeds v of individuals in the subarea.

$g_O(t_O)$ = probability density function describing the times t_O at which individuals in the subarea start for shelter.

$h(k)$ = density function describing the capacities k of shelters located within the subarea.

F.27 The "area associated with a shelter" is defined as the area of the locus of points that are closer to the given shelter than to any other. The fraction of shelters in a subarea having associated areas less than or equal to η is represented by a distribution function $F(\eta)$. Annex A1 describes a method for estimating this function.

F.28 One may infer from the assumption made in paragraph F.12 that people in a subarea having the same delay in departure and the same travel speed will be distributed uniformly over the subarea. Let

$A(v, t-t_o)$ = the area that could be occupied initially by people who start for a given shelter at time t_o, travel at a speed v, and who arrive at the shelter by time t.

It is apparent that $A(v, t-t_o)$ is the area enclosed by a circle that has a radius equal to the distance that can be traveled in the time $(t-t_o)$ at a speed v.

F.29 For the norm defined in paragraph F.17, a "circle" assumes the shape of a square whose diagonals are parallel to the coordinate axes (i.e., to the directions of the streets), as shown in Figure F.1. The radius of such a circle equals half the length of a diagonal, and is $v(t-t_o)$ when expressed in terms of speed and travel time. Therefore,

$$A(v, t-t_o) = 2v^2(t-t_o)^2 \qquad \text{(F.1)}$$

for the assumed norm, where $t \geq t_o$.

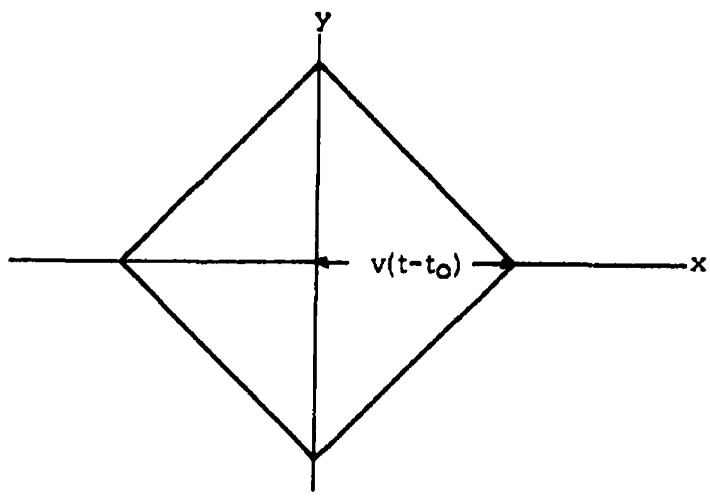


FIGURE F.1. SHAPE OF A CIRCLE UNDER THE ASSUMED NORM

Arrival at Nearest Shelter, Special Case

F.30 Consider now the first iteration of the method, viz., the movement of people in a subarea to the shelter nearest them at the time of warning. Furthermore, consider the special case in which everyone starts for the nearest shelter as soon as warning is given (t_o is zero for everyone), and everyone travels at the same speed v.

F.31 A new variable, ξ, is introduced for this special case. It is defined by the expression:

$$\xi = k/\rho, \tag{F.2}$$

and will be referred to as the area "served" by a shelter of capacity k. The density function $\omega(\xi)$, describing the areas served by shelters located within the subarea, is obtained by the relation:

$$\omega(\xi) = \rho h(\rho\xi). \tag{F.3}$$

F.32 For a particular shelter, the values of the served area ξ relative to that of the associated area η will have an important bearing on what occurs at the shelter. Note that the area A(v,t), defined in paragraph F.28, will increase monotonically with time until it is equal to η. After this time it is defined but will have no meaning since all people in the associated area will have arrived at the shelter. Now, if $\eta > \xi$ for the shelter, then:

a. The shelter will accept all new arrivals until $A(v,t) = \xi$.

b. The shelter will turn away all new arrivals during the time interval when $\xi < A(v,t) \leq \eta$.

c. The shelter, being full, will not be involved in any further iteration.

On the other hand, if $\eta \leq \xi$, then:

a. The shelter will accept all new arrivals until $A(v,t) = \eta$.

b. The shelter will have unfilled space at this time, and will accept people turned away from other shelters during a second iteration.

F.33 Let

$N_1(t) =$ expected number of people in a subarea actually sheltered by time t in the first shelter reached.

Also let

$$\Phi(\xi) = \int_0^{\xi} \varphi(\lambda)\, d\lambda , \qquad \text{(F.4)}$$

the fraction of shelters having served areas less than or equal to ξ.

F.34 From the discussion in paragraph F.32, it is apparent that the fraction of shelters in the subarea still accepting people at time t is just the fraction of shelters for which both ξ and η are greater than or equal to $A(v,t)$. This fraction is

$$\left[1 - F(A)\right]\left[1 - \Phi(A)\right] .$$

The number of people going to their first shelter who arrive at a particular shelter during the time interval $[t, t+dt]$ is

$$\rho \frac{dA}{dt}\, dt .$$ [2/]

Consequently,

$$N_1(t) = S\rho \int_0^t \left[1 - F(A)\right]\left[1 - \Phi(A)\right] \frac{dA}{d\tau} d\tau . \qquad \text{(F.5)}$$

F.35 Let

$R_1(t) =$ expected number of people in a subarea who reach the nearest shelter by time t and are turned away.

The fraction of shelters in the subarea turning away people at time t is just the fraction of shelters for which

$$\xi < A(v,t) < \eta .$$

This fraction is

$$\left[1 - F(A)\right] \Phi(A).$$

2/ The total derivative dA/dt is used in this case since v is assumed to be constant.

Consequently,

$$R_1(t) = S\rho \int_0^t \left[1 - F(A)\right] \Phi(A) \frac{dA}{d\tau} d\tau . \qquad \text{(F.6)}$$

F.36 A shelter will have unfilled space after the first iteration only if $\xi > \eta$, and the amount of such space will be precisely

$$\rho(\xi - \eta) = k - \rho\eta .$$

The probability that a shelter with an associated area η will be unfilled after the first iteration, but will have fewer than k_1 units of space left is

$$\Pr\left\{0 < (k - \rho\eta) < k_1\right\} = \Pr\left\{\rho\eta < k < (\rho\eta + k_1)\right\}$$
$$= H(\rho\eta + k_1) - H(\rho\eta);$$

where

$$H(k) = \int_0^k h(\lambda) d\lambda . \qquad \text{(F.7)}$$

Let

$H_1(k_1)$ = fraction of all shelters that will remain unfilled after the first iteration, but will have fewer than k_1 units of space left.

Then[3/]

$$H_1(k_1) = \int_\eta f(\eta)\left[H(\rho\eta + k_1) - H(\rho\eta)\right] d\eta, \qquad \text{(F.8)}$$

where

$$f(\eta) = \frac{dF(\eta)}{d\eta} . \qquad \text{(F.9)}$$

Arrival at Nearest Shelter, General Case

F.37 Consider again the first iteration of the method. Now, however, suppose that the times t_o at which people leave for shelters are described by the density function $g_o(t_o)$ and the speeds v with which they travel are described by the density function $g_v(v)$.

[3/] An integral involving a density function can be replaced by a summation wherever the density function is expressed as a set of discrete values.

F.38 The concepts of associated area and shelter capacity still have meaning for this general case since they have nothing to do with time or speed. However, the concept of served area is no longer valid since it depends on a population having uniform characteristics of starting time and travel speed. Furthermore, the function $A(v, t-t_o)$ must now be considered as a function of v and t_o, as well as of t, and can no longer be related to the population as a whole. As before, this function has no meaning when its value exceeds the associated area of a shelter.

F.39 Let

$\nu_1(t,\eta)$ = expected number of people arriving at a shelter by time t, where this is the first shelter they reach.

$\nu_1(t,\eta)$ refers to a shelter having an associated area η. Then

$$\nu_1(t,\eta) = \int_{t_o}\int_{v} \rho g_o(t_o) g_v(v) \inf \left\{\eta, A(v, t-t_o)\right\} dt_o dv. \qquad \text{(F.10)}$$

F.40 Now let

$M_1(t)$ = expected number of people in a subarea reaching their nearest shelter by time t, regardless of whether they are accepted or turned away.

$M_1(t)$ is obtained by integrating $\nu_1(t,\eta)$ over all shelters in the subarea; that is,

$$M_1(t) = S\int_{\eta} f(\eta)\,\nu_1(t,\eta)\,d\eta\,. \qquad \text{(F.11)}$$

F.41 Consider those shelters in the subarea that have associated areas in the interval $[\eta, \eta+d\eta]$. Of these shelters, the fraction at time t that have a capacity less than $\nu_1(t,\eta)$ is

$$\int_0^{\nu_1(t,\eta)} h(k)dk = H\left[\nu_1(t,\eta)\right].$$

On the supposition that the ratio of the variance of the number of people arriving at these shelters to $[\nu_1(t,\eta)]^2$ is small, $H[\nu_1(t,\eta)]$ is approximately equal to the fraction of shelters that are full by time t. The rate at which people are arriving at shelters, including full ones, is

$$\frac{\partial \nu_1(t,\eta)}{\partial t}\,.$$

Then

$$R_1(t) \approx S\int_0^t\int_\eta f(\eta)\ \frac{\partial\nu_1(\tau,\eta)}{\partial t}\ H\Big[\nu_1(\tau,\eta)\Big]\,d\eta\, d\tau . \qquad \text{(F.12)}$$

F.42 By combining Equations (F.11) and (F.12), one obtains the expected number of people sheltered in the subarea by time t:

$$N_1(t) \approx M_1(t) - R_1(t)\ . \qquad \text{(F.13)}$$

F.43 The distribution of vacancies in shelters after the first iteration is the same in the general case as in the special case, and is given by Equation (F.8). This is true because $H_1(k_1)$ depends only on the capacities and associated areas of shelters, and not on movement time.

Redirection to Another Shelter

F.44 Everyone who is turned away from the first shelter he reaches is directed to the nearest shelter expected to have unfilled space. The second iteration of the method involves the movement of people toward a second shelter. The purpose of this part of the appendix is to obtain expressions for $M_2(t)$, $R_2(t)$, $N_2(t)$, and $H_2(k_2)$, which correspond in the second iteration to $M_1(t)$, $R_1(t)$, $N_1(t)$, and $H_1(k_1)$ in the first.

F.45 Assume that the spatial distribution of people turned away from shelters is uniform with regard to the people's starting points for new shelters.

F.46 Also assume that the distribution of areas η_1 associated with shelters having unfilled space after the first iteration is related to the original distribution of associated areas in the following manner:

$$f_1(\eta_1)\,d\eta_1 = f(\eta)\,d\eta\ , \qquad \text{(F.14)}$$

where

$$\eta_1 = \eta/(1-\theta), \qquad \text{(F.15)}$$

θ being the fraction of shelters filled during the first iteration. Combining Equations (F.14) and (F.15), one obtains

$$f_1(\eta_1) = (1-\theta)\,f\Big[(1-\theta)\,\eta_1\Big]\ . \qquad \text{(F.16)}$$

The value of θ is found by the relation:

$$\theta = \int_\eta f(\eta)\ H(\rho\eta)\,d\eta\ . \qquad \text{(F.17)}$$

F.47 In the first iteration, the expression

$$\rho g_O(t_O) g_V(v)\, dt_O\, dv$$

gives the number of people per unit area starting for a shelter in the time interval $[t_O, t_O + dt_O]$ with speeds in the interval $[v, v+dv]$. The equivalent expression for the second iteration, i.e., the number of people per unit area starting for a second shelter in the time interval $[t_1, t_1 + dt_1]$ with speeds in the interval $[v, v+dv]$, is the following:

$$v(t_1, v)\, dt_1 dv \approx \frac{S}{\alpha} \int_{\eta} f(\eta) \frac{\partial u(t_1, \eta)}{\partial t_1} H\Big[\nu_1(t_1, \eta)\Big] d\eta\, dt_1\, dv, \qquad \text{(F.18)}$$

where

α = area of the whole subarea,

and

$$u(t_1, \eta) = \int_{t_O} \rho g_O(t_O) g_V(v) \inf \Big\{\eta, A(v, t_1 - t_0)\Big\}\, dt_O. \qquad \text{(F.19)}$$

The expression $\mu(t_1, \eta)$ is the expected number of people who travel at speeds in the interval $[v, v+dv]$ and arrive at their nearest shelter by time t_1.

F.48 By changing t_O to t_1, η to η_1, and replacing $\rho g_O g_V$ by v in Equation (F.10), one obtains

$$\nu_2(t, \eta_1) = \int_{t_1}\int_{v} v(t_1, v) \inf \Big\{\eta_1, A(v, t - t_1)\Big\}\, dt_1 dv, \qquad \text{(F.20)}$$

where $\nu_2(t, \eta_1)$ is defined in exactly the same way for the second iteration as $\nu_1(t, \eta)$ is for the first.

F.49 Using Equations (F.11), (F.12), and (F.13) for guidance, the following relations can be written directly:

$$M_2(t) = S \int_{\eta_1} f_1(\eta_1)\, \nu_2(t, \eta_1)\, d\eta_1\,; \qquad \text{(F.21)}$$

$$R_2(t) \approx S \int_0^t \int_{\eta_1} f_1(\eta_1) \frac{\partial \nu_2(\tau, \eta_1)}{\partial \tau} H_1\Big[\nu_2(\tau, \eta_1)\Big] d\eta_1 d\tau; \qquad \text{(F.22)}$$

$$N_2(t) \approx M_2(t) - R_2(t)\,. \qquad \text{(F.23)}$$

F.50 To obtain an expression for $H_2(k_2)$, the density of people in the subarea who are involved in the second iteration must be found. This density will be denoted by ρ_1. The expected total number of people turned away from shelters in the first iteration is

$$R_1(\infty) = S \int_k \int_{(k/\rho)}^{(k_{max}/\rho)} (\rho\eta - k) f(\eta) h(k) d\eta\, dk . \qquad \textbf{(F.24)}$$

Then

$$\rho_1 = \frac{R_1(\infty)}{\alpha} . \qquad \textbf{(F.25)}$$

Using ρ_1 and H_1 in place of ρ and H, the expression for $H_2(k_2)$ is derived in exactly the same way as the expression for $H_1(k_1)$. Therefore, referring to Equation (F.8), one obtains

$$H_2(k_2) = \int_{\eta_1} f_1(\eta_1) \Big[H_1(\rho_1 \eta_1 + k_2) - H_1(\rho_1 \eta_1) \Big] d\eta_1 . \qquad \textbf{(F.26)}$$

F.51 If more than two iterations are to be made, the mathematical expressions required are obtained in exactly the same way as for the second iteration. The total number of people in the subarea that are sheltered by time t is

$$N(t) = \sum_i N_i(t), \qquad \textbf{(F.27)}$$

where i is the number of the iteration.

Dependence of Associated Area on Shelter Capacity

F.52 Thus far it has been assumed that the distribution of areas associated with shelters in a subarea does not depend on the distribution of shelter capacities. Suppose now that a dependence does exist, and that it is expressed by the density function $f(k,\eta)$. Define a function, $f(k|\eta)$, so that

$$f(k,\eta) = f(\eta)\, f(k|\eta),$$

where $f(\eta)$ is defined as before. This dependence of associated area on shelter capacity will now be considered for the general case of the first iteration.

F.53 The first change required in the method of analysis involves relations shown in paragraph F.41. The integral

$$\int_0^{\nu_1(t,\eta)} h(k)dk$$

must be replaced by

$$\int_0^{\nu_1(t,\eta)} f(k|\eta)\,dk.$$

By using this new integral in Equation (F.12), one obtains

$$R_1(t) = S\int_0^t \int_\eta f(\eta)\ \frac{\partial \nu_1}{\partial \tau}\ \int_0^{\nu_1(\tau,\eta)} f(k|\eta)\,dk\,d\eta\,d\tau$$

$$= S\int_0^t \int_\eta \int_0^{\nu_1(\tau,\eta)} f(k,\eta)\,dk\,d\eta\,d\tau\ .$$

F.54 The only other change required involves Equation (F.8) which becomes

$$H_1(k_1) = \int_\eta f(\eta)\Big[\int_0^{\rho\eta+k_1} f(k|\eta)dk - \int_0^{\rho\eta} f(k|\eta)dk\Big]d\eta$$

$$= \int_\eta \int_{\rho\eta}^{\rho\eta+k_1} f(k,\eta)\,dk\,d\eta\,.$$

Sheltering in a Different Subarea

F.55 If a subarea contains fewer shelter spaces than people, then eventually certain people will have to move out of the subarea and into one that has a surplus of space. A method for obtaining an estimate of how such movement between subareas would affect the sheltering of a population is described in the following paragraphs. This method is based on the premise that a foreknowledge of the subareas having deficits and surpluses of space allows the predetermination of shelterer redistribution paths and destinations.

F.56 After a certain number of iterations of the method of analysis just described, the number of people sheltered in a subarea having a deficit of space will be equal to the number of spaces available. At this stage, the people who remain unsheltered must be directed to other subareas. The distribution of such people with respect to the time at which they leave for shelters in other subareas and the speed with which they travel is obtained from Equation (F.18) or an equivalent expression for the particular iteration involved. Not all the people leaving a subarea need move to the same new subarea; a certain fraction may go to one, another fraction to another, etc. It is assumed, however, that each such group leaving will be described by the same distribution of leaving times and travel speeds.

F.57 Consider now the people who move from subarea A to subarea B. An estimate is first made of the average distance these people must travel to reach shelter in subarea B, and it is assumed that every person in the group travels just this distance. By combining this distance with the distribution of starting times and travel speeds for the group, one can easily obtain a function $N_{AB}(t)$, which is the number of people from subarea A sheltered in subarea B by time t. This and similar functions [e.g., $N_{CB}(t)$, $N_{DB}(t)$, etc.], can then be added to the value of N(t) obtained for shelter B by Equation (F.27), to give a new value of N(t) that includes shelterers from outside the subarea.

F.58 If some sort of barrier lies between subareas A and B (e.g., a river), which limits the rate of flow of people moving between the subareas, then the average distance traveled from subarea A to the barrier and from the barrier to subarea B should be estimated, together with the expected delay in crossing the barrier. This expected delay may be a function of the number of people waiting to cross. The procedure described in the preceding paragraph is then modified by separating the movement of people from subarea A to subarea B into three stages: to the barrier, across the barrier, and from the barrier. It should not be difficult, using the information available, to obtain time and speed distributions for people arriving at and leaving the barrier.

F.59 Instead of waiting until all shelters are full in a subarea, it might be desirable to direct people to another subarea after they have been turned away from a specified number of shelters in their own subarea. No change would be required in the method just described if this procedure were followed, and it might be worthwhile to use the method to compare the values of different procedures.

USE OF THE METHOD

F.60 The method of analysis described in this appendix has been designed primarily for estimating the effectiveness of movement-to-shelter systems in metropolitan areas for any given system of shelters, whether actually existing or planned. Effectiveness is considered as a function of capacity and location of shelters. In addition, the method will provide an indication as to how such systems could best be improved by changing these factors. As observed earlier, the distribution and movement of people in a metropolitan area, and hence the effectiveness of the shelter system, will vary with time of day and day of week. They will also vary with warning time, the nature of an attack, and other factors. It is especially important to examine those situations in which a population is likely to be most vulnerable, whether or not such situations occur frequently.

F.61 If it is desired to study the problem of where new shelters should be located and what their capacities ought to be, two approaches should be taken, both employing the method of analysis. The first approach is to apply the method directly to particular cities. Separate studies would be made of movement to shelters within the various subareas of a city for a range of different conditions, followed by a study of any movement between subareas. The second approach is to carry out a series of theoretical studies to determine what, generally, is the most desirable relation between shelter capacity and spacing for different conditions of population density, travel speed, reaction time, and warning time. The results of the first approach will indicate the nature and general location of weaknesses in a particular shelter system that are attributable to movement factors. The results of the second approach could then be used as guidelines in determining how the system should be improved. As a final step, the method of analysis should again be used to test proposed changes in the shelter system and provide estimates of how much improvement can be expected. It must be emphasized that any recommendations for system improvement based on the use of the method will pertain to the general size and distribution of shelters in a subarea, rather than to the activation or construction of specific shelters.

F.62 In developing the method of analysis it was necessary to consider the influence of many factors, in addition to shelter size and location, that have bearing on the effectiveness of a shelter system. As a result the scope of the method is somewhat broader than that originally conceived. In particular, use of the method can help to define quantitatively problems related to control, communications, and transportation, and to give an indication of the impact of these problems on system effectiveness. Furthermore, it will provide an estimate of the degree to which the system would be utilized in various situations, and an indication of some of the training problems that will be encountered.

F.63 The problem of control is especially important. Detailed plans for directing the movement of people to shelters must be made in advance and must consider that the relation between population and shelter configurations can change from hour to hour and from day to day. If people are turned away from full shelters, officials must know where to redirect them (even to other sections of the city), so that as much of the population as possible will be sheltered in as short a time as possible. Application of the method of analysis to a city will provide the planner with information as to where deficits and surpluses of shelter space are likely to exist throughout the city at representative times during the day and week, and will give him a means of evaluating alternative plans for directing movement, particularly between different sections of the city.

ANNEX F1

DISTRIBUTION OF AREAS ASSOCIATED WITH SHELTERS

F1.1 An important input function required for the analysis of movement to local shelters is the distribution of areas associated with shelters located in each subarea of a city. The problem is to devise a simple means of estimating this function for any locality, using existing civil defense data.

F1.2 The best data available for this purpose are published in the NBS National Fallout Shelter Survey. This survey lists all potential shelters and their characteristics, grouped by standard location. Each standard location in a city covers a small area, and it is expected that a number of standard locations will be included in each city subarea defined for the present method of analysis.

F1.3 The procedure recommended for determining the distribution of associated areas is the following.

Let

α_i = area of the i^{th} standard location in a city subarea

n_i = number of shelters located in the i^{th} standard location

η_i = α_i / n_i = average area per shelter in the i^{th} standard location

n = $\sum n_i$ = total number of shelters in the city subarea

f_i = n_i / n_i = fraction of shelters located in the i^{th} standard location.

Assume that η_i is the associated area of each shelter in the i^{th} standard location. Then, using the η_i, f_i of the standard locations, plot a cumulative curve showing what fraction of shelters in the city subarea have associated areas that are less than or equal to the independent variable η. A simple analytic function fitted to this plot is used to estimate the distribution of associated areas in the city subarea.

F1.4 The same survey data may be used directly to determine the distribution of shelter capacities in a subarea, and to estimate the dependence, if any, of shelter capacity on associated area. Since the survey data are already in a form suitable for computer processing, simple computer routines could be devised for any of these operations.

APPENDIX G

BALANCING POPULATION DENSITIES

G.1 The problem of balancing population distribution in relation to shelter distribution is illustrated in Figure G.1. This figure is an idealized and, perhaps, exaggerated plot of the distribution of population and shelter space densities as a function of distance from the city's center. Curve A is a typical daytime distribution of population densities, and curve B represents a common distribution of density of shelter spaces, showing the greater concentration of shelters located in the central business district.

G.2 In this study the results obtained by making the distribution of shelters conform with curve A were examined in the case of Tampa. The movement analysis outputs indicated a significantly faster sheltering rate in Tampa than that which occurred in the cases of Salt Lake City and Milwaukee, where actual shelter distributions were used.

G.3 The question arises, What is the effect of changing the distribution of shelters to approach a uniformly low density of shelter spaces over a wide region? This would render the population less vulnerable to the blast effects by eliminating large concentrations of population in shelters.

G.4 The effect that the distribution of persons sheltered has on survival capabilities will differ depending on the nature of the threat. If the threat consists of fallout only, which may be assumed to be reasonably

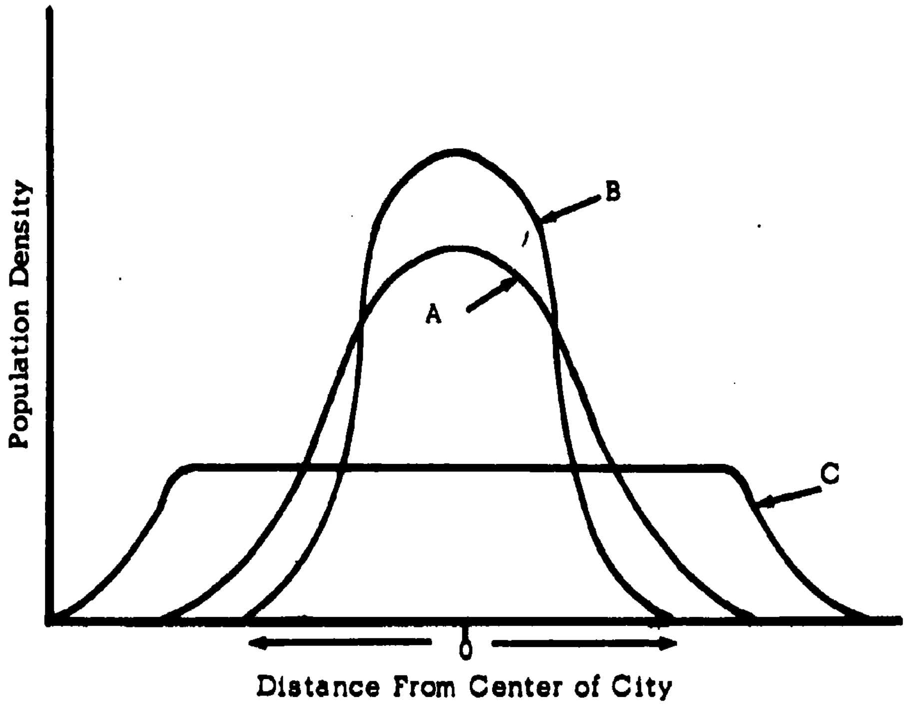


FIGURE G.1. ILLUSTRATIVE VARIATIONS OF POPULATION DENSITIES WITHIN AN URBAN AREA

uniform over a large area, it is clear that the existence of large concentrations of sheltered persons would not adversely affect the survival probabilities. A uniform distribution of persons, as depicted by curve C, will significantly increase survival probability under blast and fire effects only if the region of direct blast damage is small compared to the region over which persons are distributed and weapon accuracy is high.

G.5 In relation to sheltering time, it is clear that a distribution of shelters illustrated by curve A will produce the most direct and rapid sheltering of the population, and that any change that would produce a more uniform distribution of shelters than of people would impede the sheltering process timewise.

G.6 The decision to implement a shelter distribution like that of curve C would involve a complete reversal of present shelter policy and would render obsolete a large portion of presently marked and stocked shelters. Since buildings in which shelters can be located for a relatively small expenditure are not plentiful in the fringe regions of most urban areas, a program of this type would entail a considerable amount of shelter construction. Further, these newly constructed shelters would have to have a high degree of blast resistance to secure the advantage of this distribution.

G.7 In the light of this consideration it may be concluded that any attempt to secure a uniform shelter distribution of this latter type would not produce significant improvements in survival probabilities under most attack patterns and would very likely be infeasible on a cost basis.

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