Ref

NBS
Publi-
cations

NAT'L INST. OF STAND & TECH R.I.C.
A11104 577164

NBSIR 79-1713

Final Report on the "BFIRES/Version 1" Computer Simulation of Emergency Egress Behavior During Fires: Calibration and Analysis

Fred I. Stahl

Environmental Design Research Division
Center for Building Technology
National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

October 15, 1978

Issued March 1979

Prepared for the Center for Fire Research, in support of the
HEW-NBS Fire/Life Safety Program, Sponsored by:
U.S. Public Health Service
Department of Health, Education and Welfare
Washington, DC 20203

QC
100
.U56
79-1713

National Bureau of Standards
MAY 14 1979

NBSIR 79-1713

FINAL REPORT ON THE "BFIRES/VERSION 1" COMPUTER SIMULATION OF EMERGENCY EGRESS BEHAVIOR DURING FIRES: CALIBRATION AND ANALYSIS

Fred I. Stahl

Environmental Design Research Division
Center for Building Technology
National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

October 15, 1978

Issued March 1979

Prepared for the Center for Fire Research, in support of the
HEW-NBS Fire/Life Safety Program, Sponsored by:
U.S. Public Health Service
Department of Health, Education and Welfare
Washington, DC 20203

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*
Jordan J. Baruch, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

PREFACE

The Environmental Design Research Division, Center for Building Technology, National Bureau of Standards, is developing a more comprehensive understanding of pedestrian movement within buildings. The responses of building occupants during fire emergencies is an important part of this overall effort.

This report is the final product of a specific effort to develop and analyze a computer simulation of human egress behavior during fires. This project was one component of a research program undertaken jointly by the Department of Health, Education and Welfare, and the Center for Fire Research of the National Bureau of Standards. In addition to the behavior of institutionalized populations during fire situations, this program considered the problems of design analysis, fire and smoke detection, smoke movement and control, and automatic extinguishment.

The author gratefully acknowledges Drs. Edward Arens, Francis Ventre, Robert Glass, and Messrs. George Turner and James Harris, of the Center for Building Technology, and Dr. Bernard Levin and Mssrs. Harold Nelson and Jeffery Shibe, of the Center for Fire Research, for their critical reviews of this report. The author is especially grateful to Dr. Stephen Margulis of the Center for Building Technology, for his assistance in interpreting data obtained during this study. A special debt of gratitude is owed the Center for Building Technology Word Processing Center, whose staff prepared the final manuscript.

ABSTRACT

This report documents computer simulation experiments designed to calibrate and analyze BFIRES/VERSION 1, a computer program which simulates building occupants' egress behavior during fires. This report demonstrates that emergency egress behavior under certain specified conditions can be systematically conceptualized, and simulated through the use of a digital computer. Important findings concerning the calibration and sensitivity of BFIRES are also discussed. In particular, it is shown that: (a) a variety of general egress situations may be simulated through the application of BFIRES; (b) every such event is unique, and is defined by the set of user-supplied input parameter values which describe the building, the threat, and the occupants; (c) BFIRES may be used in simulated environments of known (or desired) spatial dimension, and events of known (or desired) temporal duration; and (d) BFIRES simulation outcomes are sensitive to variations in a number of parameters of immediate interest to the building design and regulatory communities.

FINAL REPORT ON THE "BFIRES/VERSION 1" COMPUTER SIMULATION OF EMERGENCY EGRESS BEHAVIOR DURING FIRES: CALIBRATION AND ANALYSIS

1.0 INTRODUCTION

1.1 LONG RANGE GOALS

The research reported here was guided by two main goals. The first was to provide a framework for identifying parameters for and testing relationships deemed important in defining building fire events, and thereby to increase our overall understanding of occupants' emergency egress behavior. The second goal was to develop a basis from which predictive design and regulatory tools may eventually be refined.

1.2 OBJECTIVES OF THE PROJECT

This project consisted of four tasks. These were to: (1) develop a theoretical model of occupants' egress behavior during fire events; (2) simulate such behavior by means of a computer program derived from the theoretical model; (3) calibrate the computer program to enable the simulation of "real-world" conditions; and (4) examine the internal validity of the program, particularly the sensitivity of simulation outcomes to variations in input parameters.

The first two of these tasks were conducted during the project's initial phase, and have been documented elsewhere (Stahl, 1978). The final phase of the project dealt primarily with the later two tasks, although it also included an effort to refine certain aspects of the computer program written during task (2).

1.3 PURPOSE AND SCOPE OF THIS REPORT

The primary objective of this report is to document computer simulation experiments which lead to the calibration and analysis of BFIRES/VERSION 1 (or simply, BFIRES), the computer program specially written to simulate occupants' egress behavior during fires*. In addition, this report includes complete documentation of the BFIRES program. Finally, since it may not always be convenient for readers to first peruse the project's Interim Report (Stahl, 1978), a brief overview of the approach is presented below in Section 1.4.

Determining whether BFIRES can replicate actual historial fire events, or whether it can predict the outcomes of future ones, was outside the scope of this project. Consequently, this report includes no case studies in which comparisons are drawn between simulated versus real-world events.

---

* Research continually results in modifications to BFIRES. The computer program presented in this report was current at the time of printing. Prospective users may wish to contact the author regarding the program's currency at some future date. A "user manual" is expected to be available for BFIRES/VERSION 2, in progress.

Similarly, simulating flame and smoke migration, and actually applying computer simulations to design and regulatory practice, posed special problems which were outside the scope of the project. As a result, detailed consideration of these issues was excluded from the report.

1.4 OVERVIEW OF THE TECHNICAL APPROACH

1.4.1 Model of Egress Behavior

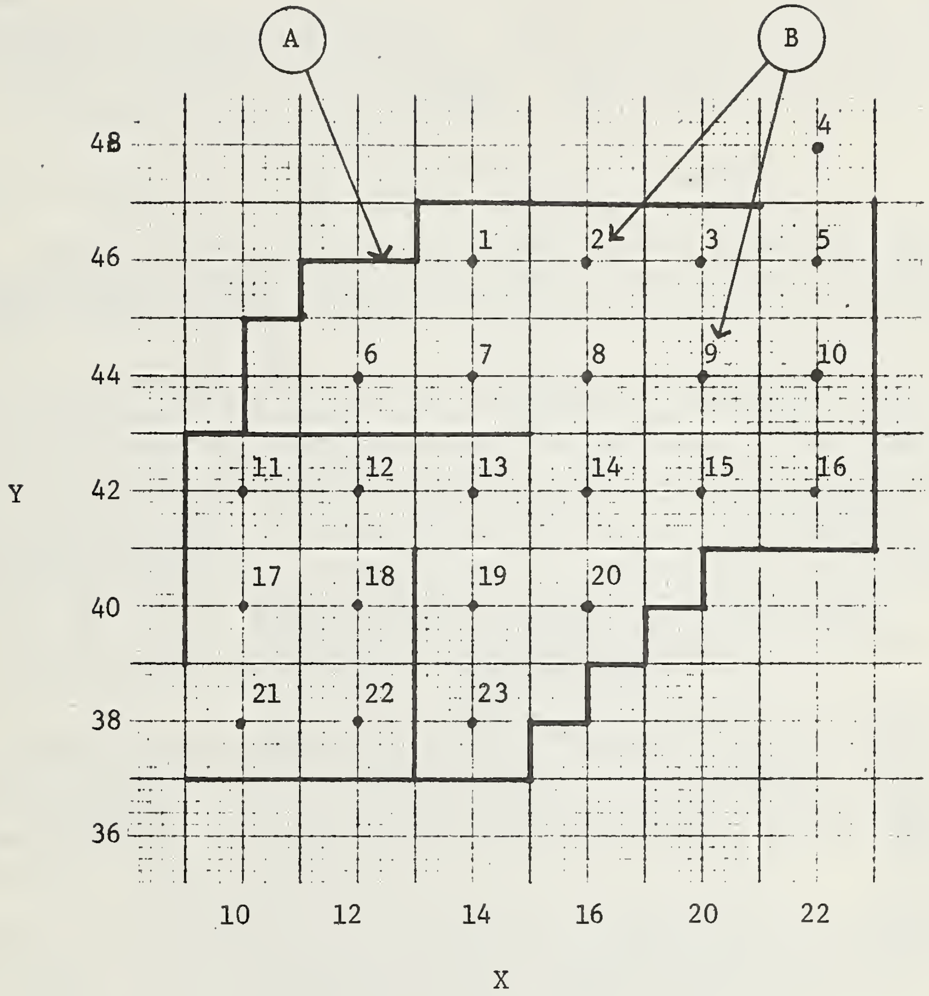
In its most basic form, BFIRES is derived from an "information processing" model of human behavior. Accordingly, a building occupant moves about through an architectural environment as a result of movement decisions he makes during some period of time. A particular path of travel results from a "chain" of movement decisions. Each incremental decision is derived through a process in which the individual interprets information he has gathered from the environment in light of his unique movement objectives.

The environmental information field consists of elements external to the individual. For present purposes, we may limit the discussion to such items as other occupants, building elements (e.g., walls, doors), and fire-based stimuli. These elements are not static. Rather, contents of the information field change over time. For example: the spatial location of other occupants is constantly changing; the location or severity of life-threatening stimuli may change; and physical features of the architectural environment may change as a result of human interference (opening and closing of doors) or pyrological destruction.

As an illustration of these processes, consider a planar surface which has been overlaid with an orthogonal ("x, y") grid. Further consider that spatial boundaries (i.e., a floor plan) have been laid out on this grid, and that persons in this field are permitted only to occupy grid points (i.e., the intersection of two orthogonal grid lines). Refer to Figure 1.1. As time advances incrementally, persons move from one grid point to another. Their decisions to move to specific points are based on interpretations of information they have obtained concerning the degree to which a given move alternative will help achieve some predetermined spatial objective.

The model described here does not assume that movement decisions are entirely determined by some information processing procedure. Rather, the process leading to a "decision" is construed as one in which various move alternatives are weighed, and from which the probability that each alternative will be selected is derived. Accordingly, information processing biases movement behavior; it does not determine it. Since the information field changes over time, the magnitude and direction of the biasing phenomenon changes over time as well.

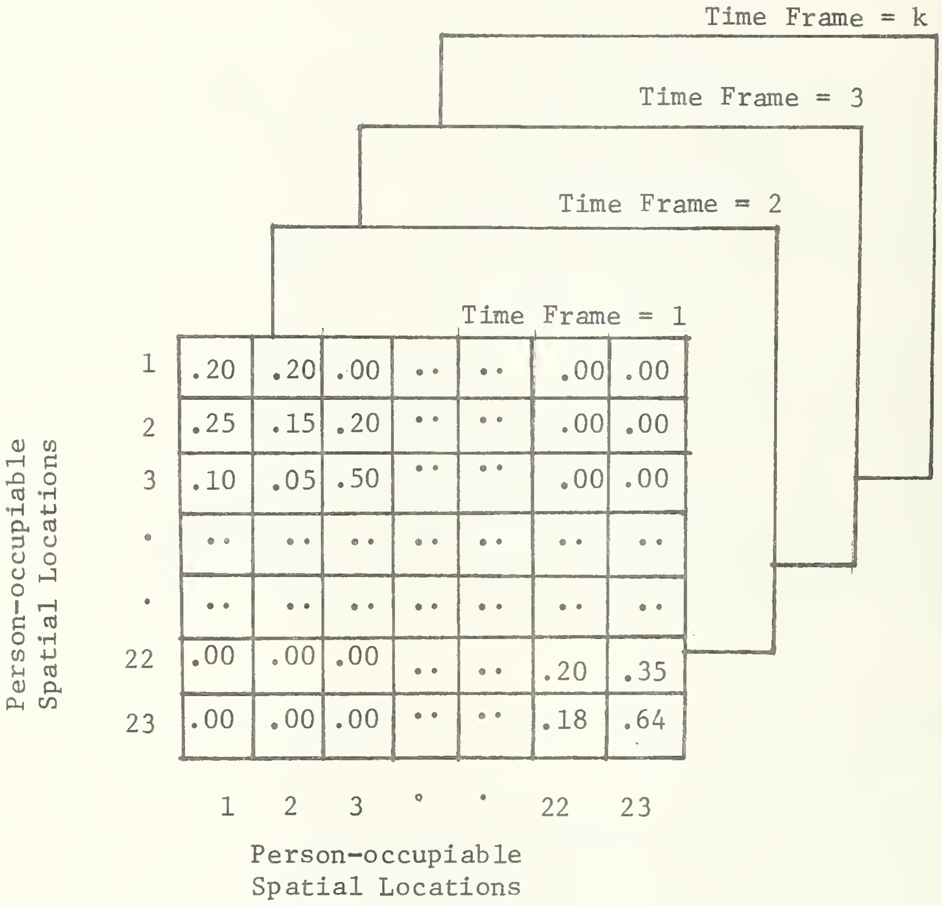
Figure 1.2 illustrates the movement probability concept by means of a matrix of spatial locations. The cells contain values of P_{ij}, denoting the probability that an occupant at location i will, during the current



A: Walls defining floor plan

B: Person-occupiable spatial locations

Figure 1.1 Orthogonal Grid Laid Over Floor Plan



	1	2	3	°	•	22	23
1	.20	.20	.00	••	••	.00	.00
2	.25	.15	.20	••	••	.00	.00
3	.10	.05	.50	••	••	.00	.00
•	••	••	••	••	••	••	••
•	••	••	••	••	••	••	••
22	.00	.00	.00	••	••	.20	.35
23	.00	.00	.00	••	••	.18	.64

Probability values in cells are
generated by BFIRES, and are updated
each time frame to reflect changing conditions.

Figure 1.2 Time Dependent Relocation Probability Matrices time increment, relocate to point j. For any given time increment, each occupant generates his own P_{ij} matrix, M. Since factors which influence values of P_{ij} vary over time, the occupant regenerates such a matrix at the onset of each succeeding time increment. This process may be considered a nonstationary Markov model (Stahl, 1978).

1.4.2 Dynamic Simulation of the Model by Comptuer: BFIRES

The BFIRES computer program was developed specifically for the purpose of simulating the model described above. BFIRES was written in FORTAN-V for the UNIVAC 1108 computer located at the National Bureau of Standards*.

The central feature of BFIRES is the "individual occupant loop". This loop enables occupants of a floor plan to individually exercise their decisionmaking procedures, during a single time increment. The occupant loop consists of three main components: (1) an information gathering component which scans the information field; (2) an information interpretation/processing component which compares available information with predetermined objectives, biases spatial behavior, and establishes values of P_{ij}; and (3) an action component which probabilistically selects the actual move to be undertaken, and relocates the occupant. Figure 1.3 illustrates the individual occupant loop.

Figure 1.4 locates the occupant loop within the next higher level of BFIRES: the "time loop". The time loop enables the iteration of individual occupant decision procedures over the span of a fire event, on the assumption that the event may be subdivided into a finite number of discrete units of equal duration.

All occupants in the simulation are "processed" during each successive iteration of the time loop. Each time loop iteration is referred to as a "time frame". In Chapter 2.0 of this report, the conversion of time frames to real time units (i.e., seconds) is discussed.

Finally, the time loop is nested with the "replication loop". This loop enables the experimenter to run any number of replications of a simulated fire event, under a single set of input parameter values. As the highest level of the program, the replication loop is also the BFIRES executive routine. Refer to Figure 1.5.

1.4.3 Facility-Specific Characteristics of BFIRES

In general, BFIRES can be run on any digital computer of adequate capacity. In its current form, the program requires approximately 29,000 36-bit words of memory. On a 32-bit word machine, approximately 32,300 words are required.

---

* Because BFIRES/VERSION 1 has not been fully validated, its description here does not imply endorsement as a design tool by either NBS or the Department of Health, Education and Welfare (the sponsor).

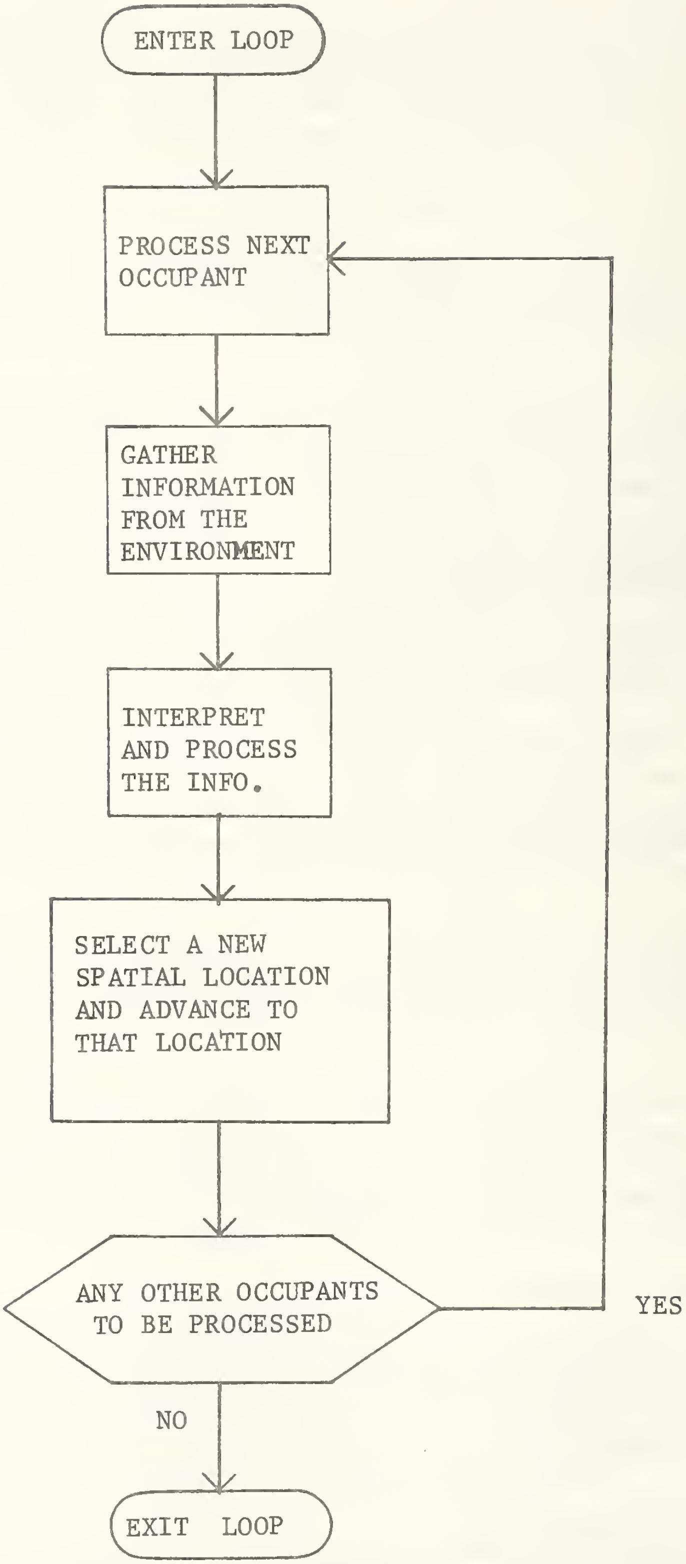


Figure 1.3 Individual Occupant Loop

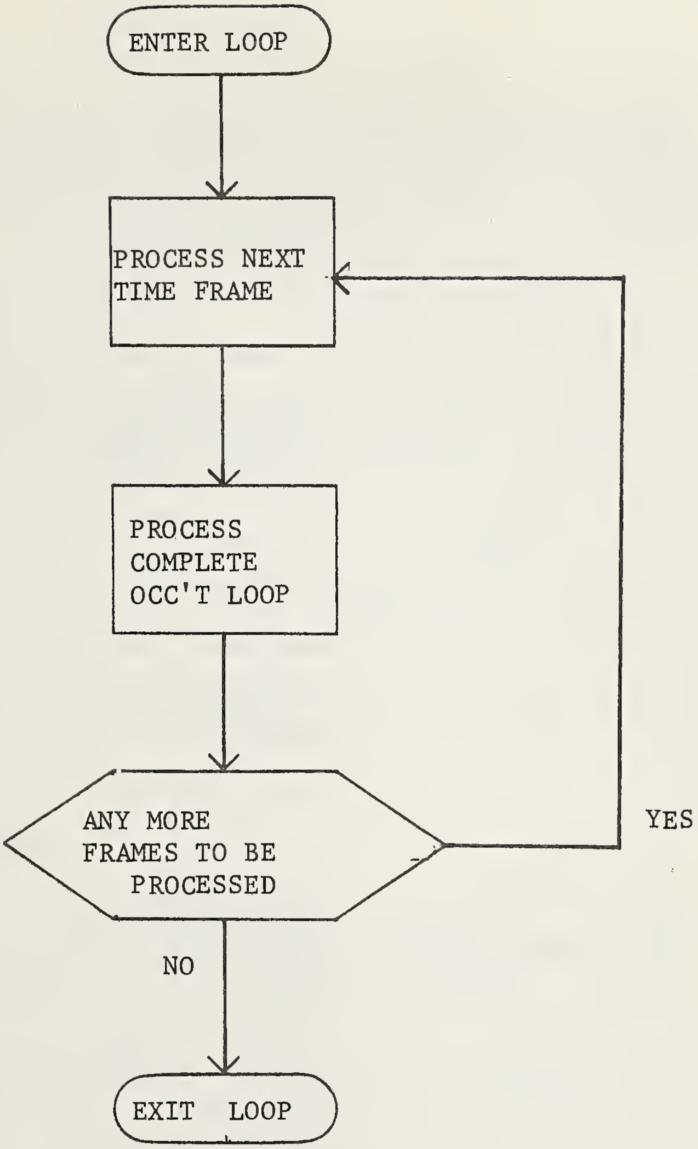


Figure 1.4 Time Loop

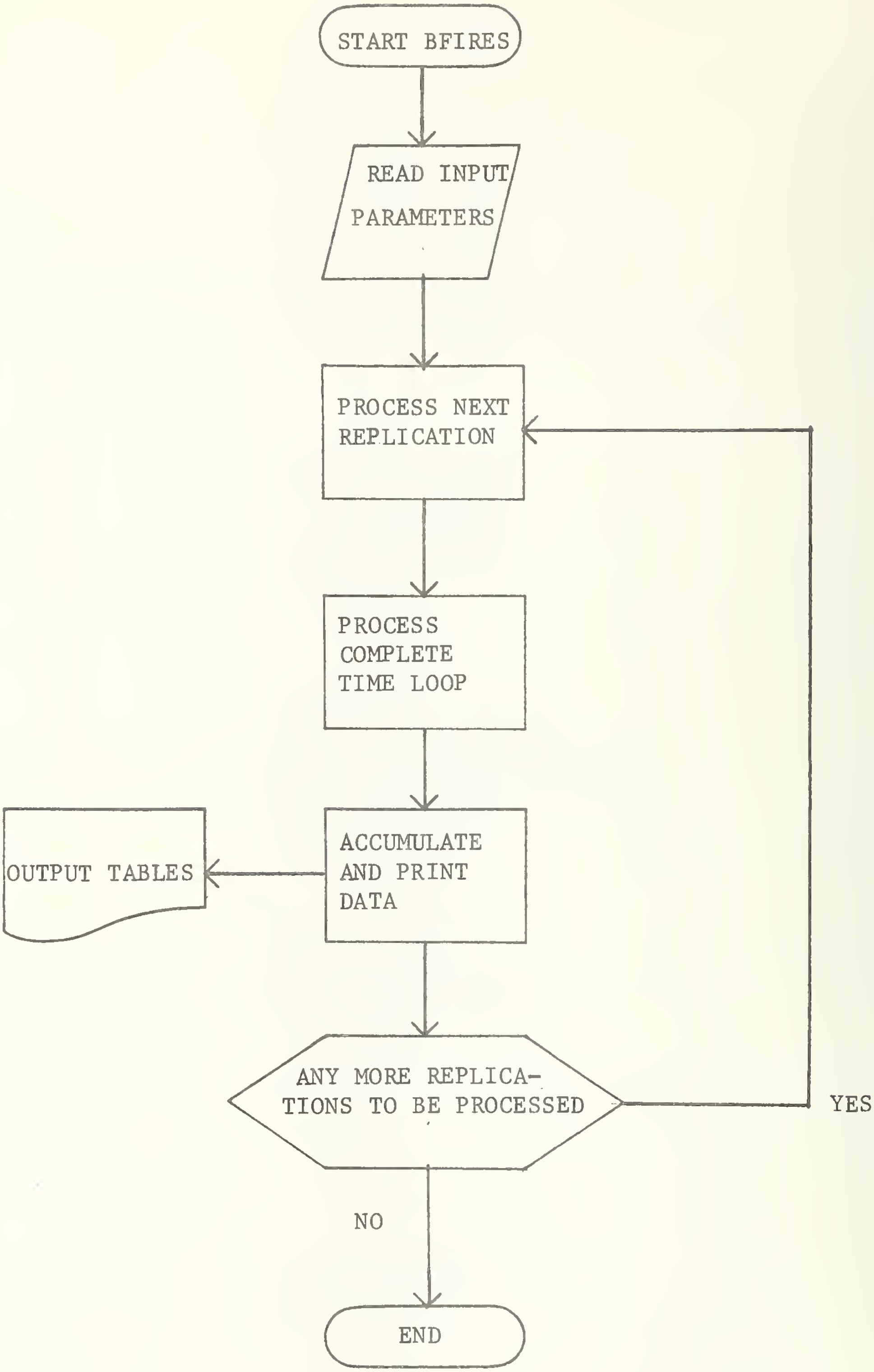


Figure 1.5 Replication Loop: BFIRES Executive

Stochastic functions are executed by comparing BFIRES-generated probability values (such as P_{ij} discussed above) against random numbers. Uniform distributions of random numbers are produced by special subroutines (random number generators). Most "canned" generators are of the so-called power-residue type, and are specifically written on the basis of computer word size. Accordingly, a random number generator written for a 32-bit processor will not function on a 36-bit machine.

To cope with this problem and thereby make BFIRES more universally applicable, two versions were prepared. BFIRES/32 uses a random number generator operable on 32-bit computers (e.g., Interdata 7/32 or 8/32 minicomputers; IBM 360/370 systems). This subroutine is contained within the BFIRES source code. Users of 36-bit machines, such as the UNIVAC 1108, will run the BFIRES/36 version. This version contains no random number subroutine, but rather calls an external subroutine from the facility library. At the National Bureau of Standards, for example, this subroutine is known as RANDNU. Within BFIRES/36, the statement X=RANDNU(0) causes a random number to be generated by the external subroutine, and then assigns the value of this number (between 0 and 1.00) to the variable labeled X. A user of BFIRES/36 may have to modify the program's source code to reflect the requirements of a specific computer facility.

1.5 SUMMARY OF KEY FINDINGS

Results from this research effort demonstrate that emergency egress behavior under certain specified conditions can be systematically conceptualized, and simulated through the use of a digital computer. Although the intent of this project was not to test the simulation's ability to predict real-world fire outcomes, results have suggested its applicability to problems of immediate interest to building designers and regulators (e.g., what is the life safety impact of variations in floor plan configuration or exit arrangement?). Thus, the way has been paved for future validation research, and for applications exercises.

In addition to demonstrating both the "simulability" of occupants' egress behavior and the value of such a facility, important technical findings concerning the simulation program's calibration and sensitivity were also realized. In particular, this report shows that:

(1) A variety of general egress situations may be simulated through the use of BFIRES.

(2) Every such event is unique, and is defined by the set of user-supplied input parameter values which describe the building, the threat, and the occupants.

(3) Although BFIRES was not designed to operate in real time, and while it deals with imaginary spatial units, it is easily calibrated to standard measures of time and space (i.e, seconds and feet or meters.)

Thus, BFIRES may be readily used to simulate environments of known (or desired) spatial dimension, and events of known (or desired) duration.

(4) BFIRES simulation outcomes are sensitive to variations in parameters of immediate interest to designers and regulators. These include: (a) floor plan configuration, (b) occupants' spatial locations at the onset of the emergency event, (c) the existence of any impairments to occupants' mobility, (d) occupants' familiarity with the building layout, and (e) permissible levels of occupant density.

1.6 DIRECTIONS FOR FUTURE RESEARCH

1.6.1 Program Enhancements

In the current version of BFIRES, direct effects of flame and smoke migration are assumed to be felt only outside the area under study. For example, when the user wishes to examine occupants' egress responses from a particular floor of a multistory building, he must assume that the actual fire is occurring on some other floor, and that the occupants he is studying have some degree of information about the existence and location of that event. An obvious enhancement of immediate interest, then, is the inclusion of subroutines enabling BFIRES to simulate occupants' behavioral patterns in spaces actually infiltrated by fire products.

Another problem is that BFIRES presently makes no provision for rescue activities, important during many emergencies. An additional enhancement of BFIRES will be necessary, enabling the program to simulate such behavior. Enhancements such as these are presently under development at the National Bureau of Standards.

Other less critical enhancements may be desired, as well. For example, the interfacing of BFIRES with a validated simulation of fire and smoke migration should ultimately yield more authentic egress simulations. Also, the interacting of BFIRES with a real-time graphics facility should enable users to apply the simulation more creatively, and to apply its results to design problems more directly and efficiently.

1.6.2 Program Streamlining

As BFIRES undergoes more intensive use, it will be applied to an increasingly wider array of conditions and contexts. As this process continues, more will be learned about the senstivity of simulation outcomes to variations in parameter values. Eventually, variation in some parameters may be found to have no significant impact on simulation results. At some point, therefore, it will be possible (and desirable) to streamline BFIRES by deleting such parameters.

1.6.3 External Validation

This problem may be viewed on two levels: face validity, and predictive validity. In the case of face validity, we are content with the conclusion that behaviors generated by the computer program "feel right"; they seem, according to conventional wisdom or common sense, to concur with our general knowledge of the actual phenomenon. Ascertaining predictive validity, however, requires a more rigorous exercise, since we want to know the degree to which simulated outcomes are indicative of what might happen in a real fire under a very specific set of conditions.

To a great extent, the reader can review the experiments in Chapter 3.0 of this report, and make judgements about the face validity of BFIRES output. To some degree, of course, these judgments will vary according to the reader's own experience and professional background. In the future, investigators may wish to examine the program's predictive validity. This will be extremely difficult to assess directly, however, since the actual conditions leading up to an surrounding real fire events are not often easy to forecast. Accordingly, it will be necessary to conduct an indirect analysis, in which the convergence of results from several techniques is sought. Among the possible techniques are Turing's Test (Turing, 1950), in which experienced experts attempt to distinguish simulated scenarios from real ones, and replicative tests, in which the investigator attempts to replicate actual historical fire outcomes with the simulation program.

2.0 CALIBRATION OF BFIRES/VERSION 1, AND LIMITATIONS TO THE PROGRAM'S APPLICABILITY

2.1 INTRODUCTION

The BFIRES simulation program produces tabular output in various forms. By analyzing this output, the user can draw inferences about building fire events. The actual output itself, of course, possesses none of the physical characteristics of a fire event; it is merely a symbolic representation. The degree to which the computer output represents a real-world event is an important and complex problem, and generally refers to the external validity of the simulation (a problem outside the current scope). Here, however, we are concerned with factors which influence this degree of representation. In particular, there are two factors which largely determine the similarity between simulated events and their real-world referents: (1) the correctness of the simulation model, and (2) the deployment and application of the model to a given case.

Recall that BFIRES constructs a complex network of interrelated variables, or parameters. Some of these are computed, varied, or fixed internally, and are thus outside the user's immediate control. As such, these parameters relate directly to the "correctness" of the simulation model; incorrect parameter values detract from the model's correctness. The values of others, however, are chosen and input by the user, in his attempt to match simulated conditions to those expected during hypothetical real-world events (or to those actually known to have occured, as in the case of historical simulations). This process of aligning program parameters with those describing the actual event is what we will refer to here as calibration.

Calibration and external validity are closely related. When the user compares simulated with real-event data and finds some degree of variance between the two sets, he will attempt to adjust input parameters until a minimum variance is achieved. If the variance is still unacceptably high, or if low variance could only be achieved at the expense of using obviously unrealistic parameter values, then the user may justifiably conclude that the model underlying BFIRES is inappropriate to the case under study.

In this report, we are not concerned with techniques for fine-tuning a simulation in the presence of comparison data from a real fire event (part of the event validation process, beyond the present scope). Rather, our objective is to introduce the user to parameters handled within BFIRES, so that he will understand the program's range of application, and so that he will be able to conduct a tuning exercise once the program is in fact applied to an actual case. There are three classes of parameters with which the user must become familiar: (1) internal constants; (2) internal dynamic processes; and (3) user-supplied variable values.

2.2 INTERNAL CONSTANTS

2.2.1 Consensus Exit of Choice

Subroutines GROUP, OTHERS, and AGREE establish for a given occupant the social environment through which he gathers certain information necessary for making egress movement decisions. An important example involves the situation in which several occupants inhabiting a space have different opinions about the best exit from that space. The model underlying this small package of routines suggests that: (1) whenever all such occupants hold the same opinion, the choice of exit is clear-cut; but (2) where a difference of opinion exists, a consensus will have the effect of winning all occupants over to the majority view. But just how should "consensus" be defined: 51% of all occupants in the space? 67%? The literature on human behavior in fires (or fire drills) provides no guidance. For practicality, however, the cut-off line was drawn at 60%: if 60% (or more) of the occupants inhabiting a space favor a particular exit from the space, they will "convince" the remaining occupants of the quality of their opinion, and all the occupants will seek that exit. When occupants have differing opinions and no consensus exists, BFIRES simulates a state of confusion in which occupants "lose faith" in their originally-held beliefs. Confusion reigns until a consensus is eventually achieved.

2.2.2 Penalty Thresholds

Subroutine EVAL20 simulates an occupant's evaluation of his current "safety status" by comparing his egress progress to date against the total elapsed time he has spent in the danger zone. When evaluating his status with respect to the egress goal (final exit), he seeks to ascertain that the distance separating himself from the goal is not so great as to preclude his reaching it before the "critical time" is reached (point at which life support becomes untenable). Similarly, when evaluating his status with respect to the location of the fire, he seeks to ascertain that the distance between himself and the fire is sufficiently large to permit escape prior to the critical time.

BFIRES establishes thresholds (with respect to both threat evasion and goal seeking), or criteria against which occupants make these evaluations. For example, if an occupant is farther from the exit than permissible at time t, EVAL20 will return a negative status evaluation. This will also occur if the occupant is closer to the fire than permissible at time t.

As the simulation progresses, the criteria become more difficult to satisfy, since the critical time is continually being approached. Accordingly, the "penalty thresholds" may be viewed as equations which relate distance and time. In the absence of empirical data, these functions were assumed to be linear. For practical purposes, BFIRES assumes an intercept of 0, and a slope of 1 for the threat penalty threshold, and an intercept equal to the critical time with a slope of -1 for the exit goal penalty threshold (see Figure 2.1).

The consensus and threshold constants may not be manipulated at execution time. The user may wish to alter their values, however, to reflect new empirical findings or to suit special conditions. This will require modifications to the program source code. Should a particular application of BFIRES necessitate frequent variation of these values, the user may wish to establish them as input variables.

2.3 Internal Dynamic Processes

Certain variables within BFIRES take on a new value at the start of each time frame. However, these are determined entirely by internal processes, and are outside the user's immediate control. The most critical example is P(K), the probability that an occupant will, during a given time frame, select some move alternative, K. The actual values of P(K) are computed within subroutines EQUALZ, TBIAS, EBIAS, ASSIGN, or DOORS1, depending upon the biasing mode selected in subroutine ASSIGN and the door-opening behavior generated by subroutine DOORS1.

To date, it has not been possible to calibrate computed values of P(K) against data from actual fire situations. This is because no data on human behavior during fires exist to describe emergency decisionmaking processes at so fine a level of detail. Considerable research will be

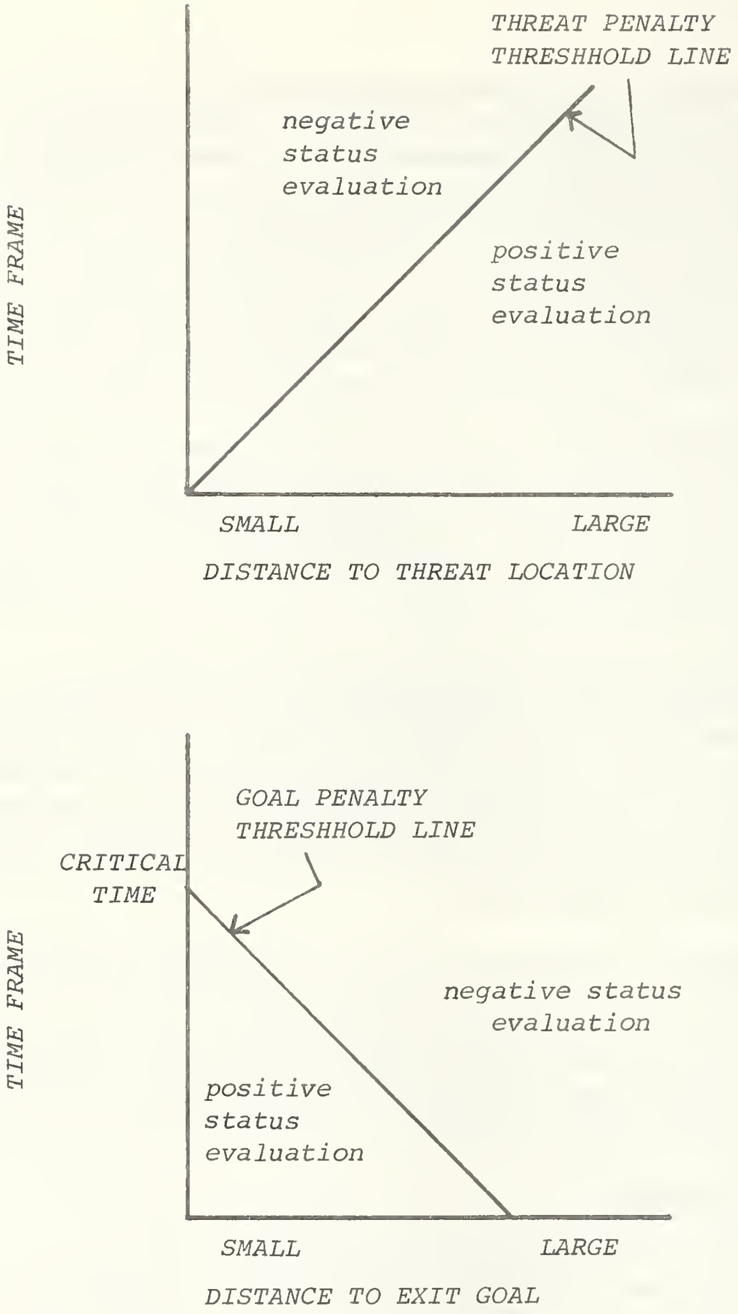


Figure 2.1 Calibration of Penalty Thresholds in Subroutine EVAL20

necessary to understand the mechanism by which people under emergency conditions perceive alternative courses of action, relate such alternatives to broader egress strategies, and then select appropriate actions. As new data becomes available, however, the user may wish to incorporate new hypotheses about decision biasing or probability value computation. This will require modifying the program source code.

2.4 USER SUPPLIED VARIABLE VALUES

Parameters describing most of the important initial conditions are determined by the user, and are input at program execution time. There are four broad categories of input parameters: (1) fire descriptors; (2) occupant descriptors; (3) building descriptors; and (4) system descriptors.

2.4.1 Fire Descriptors

The current version of BFIRES permits the user to define only the initial spatial location of the fire threat (input variables XT and YT). As BFIRES does not simulate any form of threat migration, the initial location specified by the user will remain constant throughout the simulation run. This factor may, however, be used as the basis for a number of realistic fire cases, e.g.: (1) simulation of egress from compartment while fire and smoke are confined to another compartment elsewhere on the same floor; (2) simulation of egress from one floor while fire and smoke are confined to another floor elsewhere within the building; and (3) simulation of egress during a fire drill, in which one exit has been blocked-off due to "mock fire" conditions.

When specifying the initial location of the threat, the user in effect blocks-off one of the available exits from the floor; he must assume that the fire (occurring elsewhere on the floor or within the building) has effectively rendered that exit non-useable. When using BFIRES to test egress time requirements from floor plans, the user may establish exits wherever desired, and run simulations for any blocking condition (threat location) he chooses.

2.4.2 Occupant Descriptors

The model underyling BFIRES suggests that a variety of factors may interact to predispose occupants to respond in certain ways to the emergency environment. Principal factors include: (1) the number of occupants involved in a given fire event; (2) the initial spatial location of each; (3) the tolerance of each occupant to interruptions to goal-seeking behavior; (4) each individual's initial state of knowledge concerning the location of the best exit from the floor; (5) each occupant's initial mobility status (e.g., impaired versus non-impaired mobility); and (6) each occupant's predisposition toward opening and closing doors encountered along the egress route.

When preparing a given BFIRES simulation run, the user must determine values for each of these parameters. If the user wishes to simulate a hypothetical fire in an actual facility, he must be careful to estimate the likely spatial positions of occupants, as well as calibrate each on the various parameters enumerated above. Spatial locations may usually be estimated on the basis of information known about the building (or building type) under study, e.g., work stations, relative locations of beds, etc. A nighttime fire at a nursing home, for example, would be simulated with all patients at bed locations, one or two staff members at their station, and perhaps a single staff member in a corridor. A daytime event in an office wing might find all occupants initially at their predefined work stations.

It should also be possible to "guesstimate" values for other occupant parameters. Consider predispositions toward opening and closing doors. These are input in the form of probabilities: i.e., the variable POPEN is the probability that an occupant opens a closed door he confronts; the variable PCLOSE is the probability that an occupant closes a (manual-type) door he has just passed through. In the nursing home example, the user could preset POPEN and PCLOSE for staff members to reflect a particular training program; and preset these variables for patients to reflect a lack of knowledge; cognitive impairment due to sedation, etc, (perhaps using the value of 0.50 for each variable). The user might wish to evaluate variations in door-manipulation behavior exhibited by staff members which result from different training philosophies. Several BFIRES runs may be conducted for each of several values of PCLOSE and POPEN, and the varying effects (if any) of door-manipulation upon egress time or number of persons evacuated can be studied.

Similarly, the mobility status of occupants, and the exit knowledge of each, should be estimable from prior knowledge of the facility under study. Other paramters, however, such as interruption tolerance, are presently not estimable on the basis of existing data from building fire cases. Here again, data will be required which describe occupants decisionmaking procedures during emergency conditions.

2.4.3 Building Descriptors

BFIRES constructs building floor plans on a two-dimensional plane by laying walls out as orthogonal vectors on an x, y grid. Doorways are represented as breaks in wall lines. Such openings may or may not have doors installed within them. When doors are present, they may be either manually- or automatically-closing. The user is free (within certain limitations) to enter into the computer a floor plan of almost any configuration. This is accomplished by reading in the x, y coordinates of points defining walls and doors. The principal limitation is that all walls must lie along orthogonal vectors (i.e., they must be parallel to either the x or the y axis). Accordingly, angular or curvelinear walls must be entered as "steps" (refer to Figure 2.2).

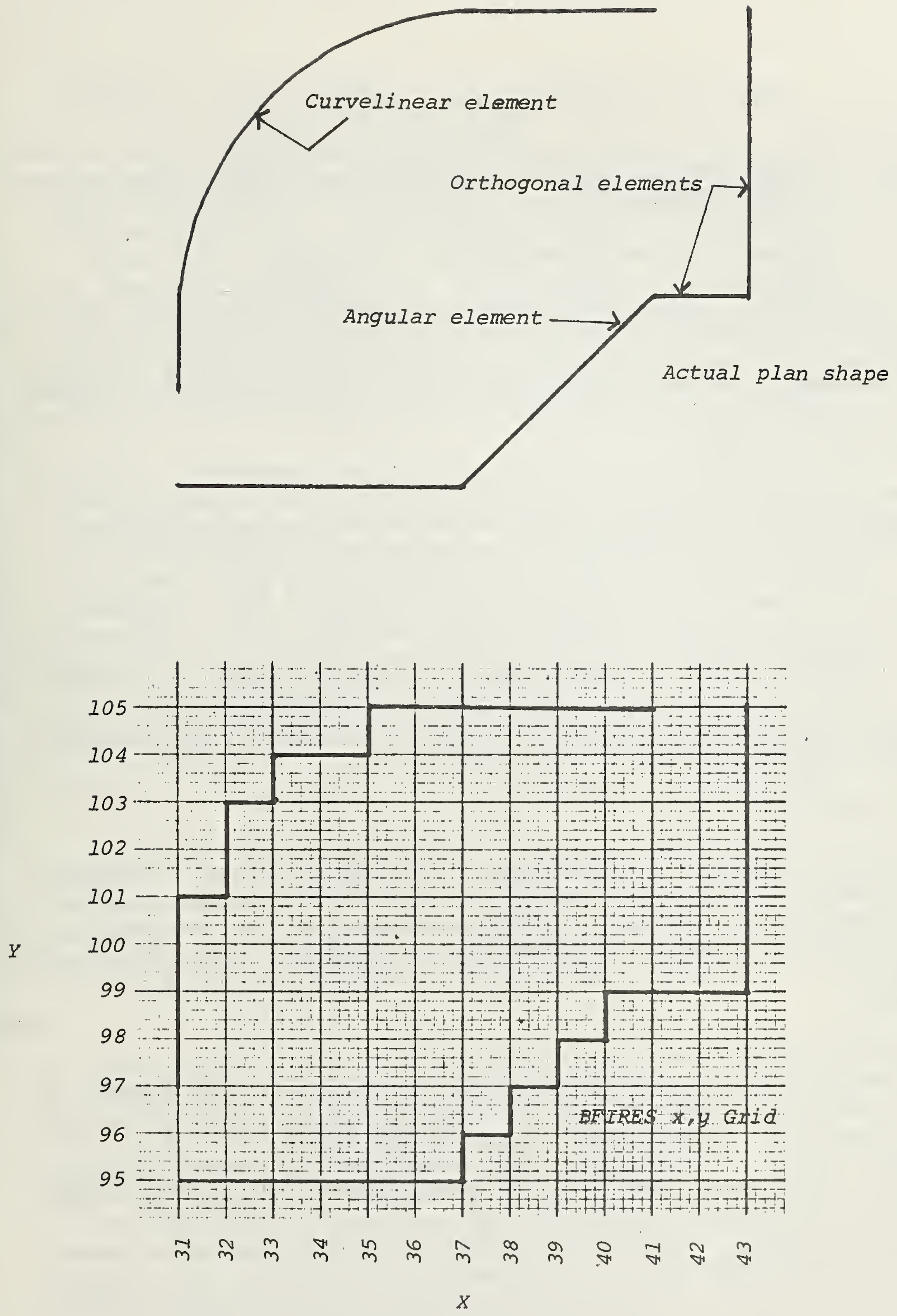


Figure 2.2 Translating Orthogonal, Curvelinear, and Angular Wall Elements into BFIRES-readable Form

The severity of this "stepping" condition is reduced as the size of the x, y grid units decrease. But this additional sensitivity comes at the cost of increased computer memory requirements. For example, a floor plan laid out on a 10 x 10 grid requires storage for no more than 100 points (wall, door, and person-occupiable locations). A much more sensitive simulation will result if this plan is laid out on, say, a 50 x 50 grid (e.g., much finer changes in occupants' incremental movement will be generated with each passing time frame). However this arrangement will require storage for 2,500 points...a 25-fold increase. Note the examples in Part 3.0 of this report. In Case Study A, a floor plan is laid out on a 5.0 foot grid. In Case Study B, a more sensitive 2.5 foot grid is used.

The user is free to use almost any size grid he feels is appropriate, (provided be does not exceed program array limits), considering the degree of sensitivity desired, and the amount of computer memory available. Once a grid has been laid over the floor plan (which may be "idealized" to meet the orthogonal vector criterion), wall designator points are entered through input variable IBAR (IS, I, J). Information concerning door location, operating type, and initial position position (i.e., open or closed) is entered via input variable IDOOR (I, J). Of course, the user can vary the location of walls and doors (i.e., alter the floor plan) between simulation runs, and study the study variations in egress phenomena.

2.4.4 System Descriptors

Several input parameters are available which permit the user to establish system-wide rules. The number of replications of a given simulation is specified by NUMREP. If NUMREP is preset to "5", for example, the computer will generate five completely independent events which are identical in all respects - except for the outcome of stochastic processes.

The user must also preset the desired length of the simulation run. TOTIME specifies the number of interactions within each replication, in time frames. When comparing simulation outcomes with real-world events, it is necessary to convert time frames to real time units (i.e., seconds). Table 2.1 illustrates such conversions for several typical situations. When using this table, the user must: (1) make an assumption about the mean walking speed of all occupants in the event, and (2) use a mean grid* step which conforms to the grid size he has superimposed over his floor plan. For example, if we assume a mean walking speed of 4.5 ft/s (1.37 m/s), and a mean grid step of 3.02 ft. (0.92m), then a single time frame will equal about 0.67 seconds, and it will require about 90 time frames to simulate one minute real time.

$$* \text{ mean grid step} = \frac{\text{(length of orthogonal step)} + \text{(length of diagonal step)}}{2}$$

TABLE 2.1 TIME FRAME/REAL TIME CONVERSIONS, FOR THREE VALUES OF WALKING SPEED

$$\text{MEAN WALKING SPEED (V)} = \frac{\text{Mean Step Length}}{\text{Unit Time (second)}}$$

		4 ft/s (1.22 m/s)	4.5 ft/s (1.37 m/s)	5 ft/s (1.53 m/s)
MEAN GRID STEP (D) = (Orth D + Diag D)/2	3.02 ft	TF = 0.76 s	TF = 0.67 s	TF = 0.60
	(0.92 m)	TF/min = 79*	TF/min = 90	TF/min = 100
	6.4 ft	TF = 1.51 s	TF = 1.34 s	TF = 1.21 s
	(1.84 m)	TF/min = 40	TF/min = 45	TF/min = 50
	12.07 ft	TF = 3.02 s	TF = 2.68 s	TF = 2.41 s
	(3.68 m)	TF/min = 20	TF/min = 23	TF/min = 25

* time frames per minute, rounded to the next higher frame

Where:

TF = Time Frame in "real time" seconds = $\frac{D}{V}$

Orth D = length of orthogonal step

Diag D = length of Diagonal step

Figure 2.3 provides a convient graphic conversion chart, which permits conversion either from time frames to seconds, (how many seconds are simulated by a run of predetermined length?), or from seconds to time frames (how long must a simulation run in order to represent a desired period of real time?).

Note that "grid step" is not meant to imply walking stride. It merely refers to the mean distance between person-occupiable grid locations. The user can, however, select his x, y grid to assure that "grid step" is quite similar to mean walking stride. But again, this may require a large expenditure of computer memory.

Another system-wide parameter preset for a given simulation run is the crowding factor, input via variable IALLOW. IALLOW specifies that maximum number of occupants permited to inhabit any person-occupiable grid location during a single time frame. The value of IALLOW can easily be converted to a measure of maximum allowable density (persons per unit area) as follows:

$$\text{Maximum Allowable Density} = \frac{\text{IALLOW}}{\text{area of a grid square}}$$

Finally, the user must predetermine the likelihood that occupants will, during the simulated event, experience a "backtrack" interruption, a "remain-in-place" interruption, or no interruption at all (these are detailed within Appendix A, under discussions of Subroutines INTRPT and BACKUP). The probability of a backtrack interruption is input via variable PI2, and the probability of experiencing no interruption at all is input through variable PI0. The probability of experiencing a remain-in-place interruption is computed internally as the difference between PI2 and PI0.

2.5 SUMMARY

Part 2.0 dealt with the calibration of the BFIRES simulation program. A variety of parameters were considered, and particular attention was paid to the problem of aligning these with parameters which describe real-world fire events. Three broad categories of parameters were discussed. Values of internal constants and internal dynamic processes are written into, or are determined by the BFIRES source code, and are therefore outside the user's direct control. Important parameters which describe the fire, the occupants, the building, and other aspects of the simulation event are user supplied at execution time.

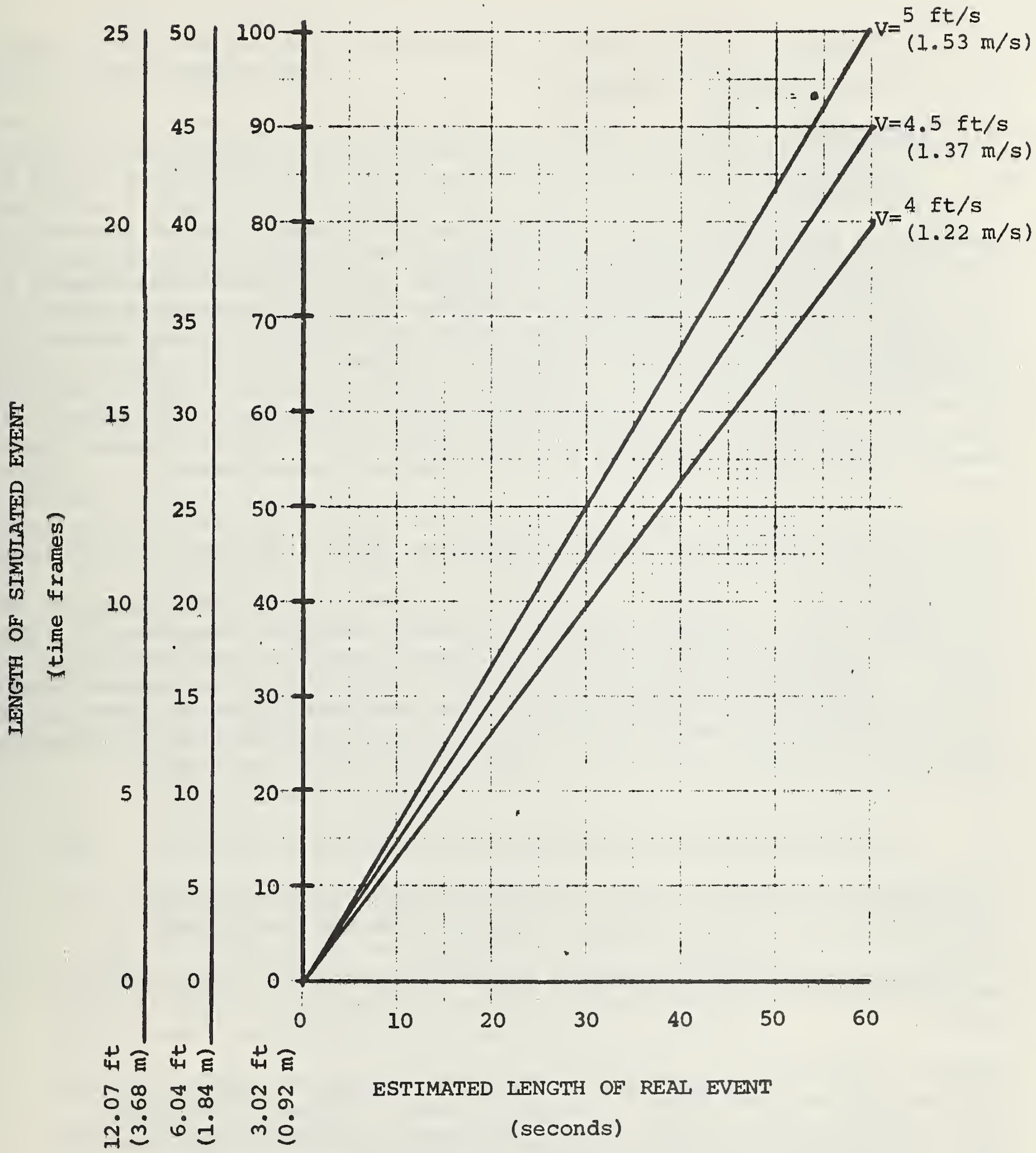


Figure 2.3 Time Frames to Seconds Conversion Chart

3.0 PROGRAM SENSITIVITY ANALYSIS

3.1 INTRODUCTION

3.1.1 Rationale

Sensitivity analysis is an important step in the overall validation of computer simulation programs such as BFIRES. Generally speaking, sensitivity analysis helps the simulation program writer to determine whether the "cause-and-effect" relationships (often expressed as "if...then..." statements) which comprise the underlying process model are in fact demonstrated when the computer simulation is run. Another way of expressing this problem is by asking how variation in simulation parameter values impacts the results of computer runs, and whether these results conform with hypotheses derived from the program underlying model.

Remember that sensitivity analysis yields no information about whether the underlying model (i.e., the set of "if...then..." statements) correctly reflects "reality". Similarly, it does not tell us whether the most important or useful parameters (from an applications point of view) have been selected for study. However, sensitivity analyses provide a considerable amount of information about the interal consistency of the modeling and simulation design processes. This is accomplished through the examination of specific hypotheses (derived from the model) about causal relationships, making use of data from computer simulation exercises.

3.1.2 Overview of the Technical Approach

BFIRES enables the user to simulate any number of situations. This is accomplished by adjusting the BFIRES input parameters to reflect a particular set of initial occupant and environmental conditions. The complete set of parameters defines the initial state of a given event, and they may be altered by changing the values assigned to input parameters.

Computer simulations are useful because they help us to make causal predictions (of the "if...then..." variety), and to evaluate differences among outcomes from initially dissimilar events. Accordingly, we would expect differences in initial occupant and environmental conditions to yield variations in simulated emergency egress outcomes. For example, we would expect occupants initially located near a safe exit (and at the same time located far from the threatened zone) to leave the building or floor before occupants located at a greater distance from the exit. Similarly, we would anticipate that occupants who are familiar with the building, and who knew the location of exits, to escape faster (and use a more direct path) than occupants who have no such familiarity. In a final example, we might expect that mobility-impaired occupants will require more time to leave the building or floor than will occupants with no such impairments.

The principal questions for sensitivity analysis is, then, whether variations in event-defining input parameters produce the expected variations in BFIRES egress behavior? This question was studied by establishing base fire scenarios, manipulating input parameters, and then measuring differences between simulated egress outcomes (e.g., egress time and path length). According to this rationale, we may conclude that BFIRES is sensitive to variation in a particular parameter if, while holding all other parameter values constant, we find a significant difference between outcomes from simulations run under two or more different values of test parameters. For example, if occupants of a floor with dead end corridors require significantly more time to escape than do occupants on a floor without dead ends, then we may conclude that BFIRES is sensitive to variation in one aspect of "floor plan configuration". Similarly, if we find that occupants with no familiarity with exit locations traverse significantly longer paths than do occupants who do possess exit knowledge, then we will have determined that BFIRES is sensitive to variation in "exit knowledge" or "building familiarity".

The following list contains input parameters manipulable by the BFIRES user. To reiterate, the user presets the initial state of a fire event by assigning values to these variables. He differentiates between events by varying the values of one or more parameters. Parameters marked with an asterisk (*) were the subjects of specific sensitivity analyses reported later in this chapter:

*(1) initial threat location;

*(2) placement of interior doors and floor (or building) exits;

*(3) spatial configuration (involving: layout, corridor arrangement, access to exits, shape of spaces);

*(4) number of spatial subdivisions contained within a floor plan;

(5) number and location of occupants on the floor;

(6) occupants' knowledge of initial threat location;

*(7) occupants' familiarity with the floor or building (i.e., their knowledge of a "best exit");

*(8) occupants' mobility status;

*(9) permissible occupant density (or crowding factor);

(10) door type (i.e., manually versus automatically closing);

(11) initial door position (i.e., open versus closed);

(12) probability that an occupant will open a closed door he encounters;

(13) probability that an occupant will close a door he has passed through;

(14) probability that an occupant will encounter either a remain-in-place or a backtrack interruption.

These parameters were specially selected for user manipulation because of their practical appeal to building designers, regulators, and managers, and to professionals interested in evaluating the effects of training programs. We now turn to analyses of two hypothetical cases.

3.2 ANALYSIS "A"

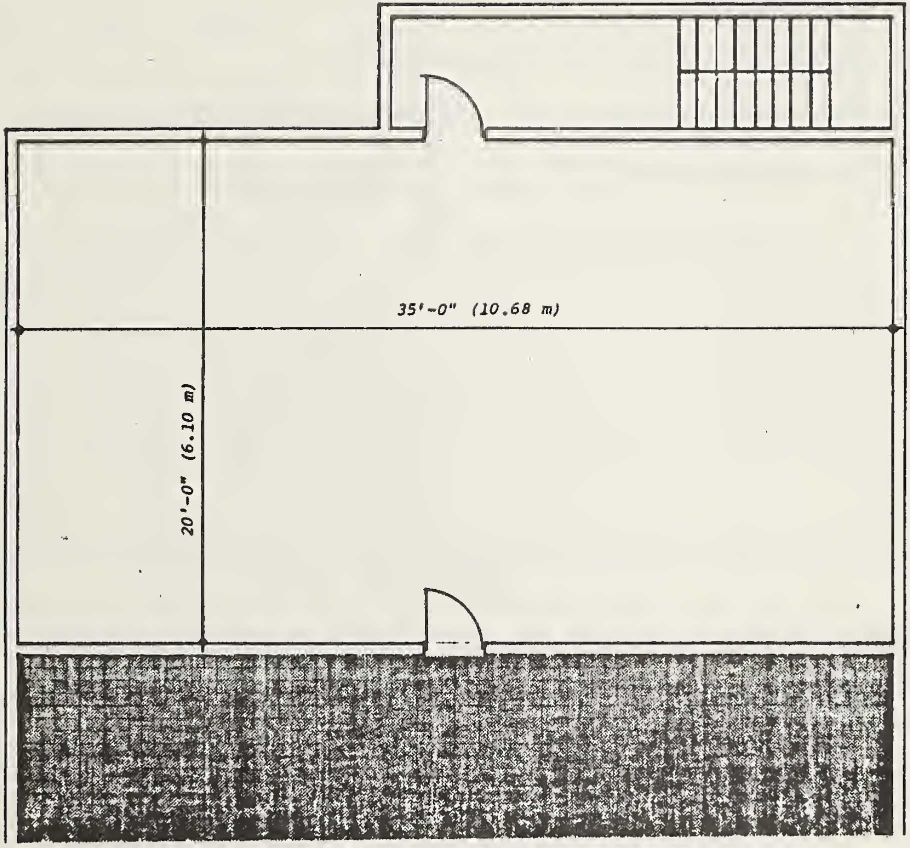
3.2.1 Description and Objectives

Description: Fire events were simulated on a rectangular zone measuring 20 feet by 35 feet (6.10 m by 10.68 m). Two exits from the zone were provided, one at the center of each long wall. One exit provided a direct escape to a place of refuge; the other connected the zone under study with another section of the floor. During all simulations in Analysis "A", this later exit was assumed to lead directly to life-threatening agents (fire and smoke). Accordingly, although the zone under investigation had two potential exits, one was assumed to have been rendered impassible prior to the onset of the simulation.

Simulations were conducted under various values of the spatial configuration, and interior door placement parameters (refer to Figures 3.1, 3.3, 3.5, and 3.7). These conditions simulated different ways of subdividing the original zone into smaller functional units. These may represent variations in bedroom or service space configurations in, say, an addition to a small nursing unit or group home.

Each simulation run involved 12 occupants. These were initially located at points shown in Figures 3.2, 3.4, 3.6, and 3.8. At the start of each run, all occupants were assumed to have been alerted to the existence of the fire, and to the fact that a particular exit was already blocked and should therefore not be used. In all cases, occupants were assumed to be "ordinary residents"; no staff persons or other individuals with specialized training or knowledge (e.g., to affect rescue activities) were assumed to be present. All occupants were assumed to be fully mobile with external assistance.

Objectives: The primary objective of this analysis was to detemine whether BFIRES is sensitive to differences in floor plan configuration (more specifically, degree of spatial subdivision). Secondary objectives of the analysis were to determine whether program is sensitive to variations in permissible occupant density, and whether it produces an interaction effort between spatial organization and permissible density.



Shaded portion denotes area infiltrated by fire or smoke

Figure 3.1 Un-subdivided Spatial Zone (One-Space Plan)

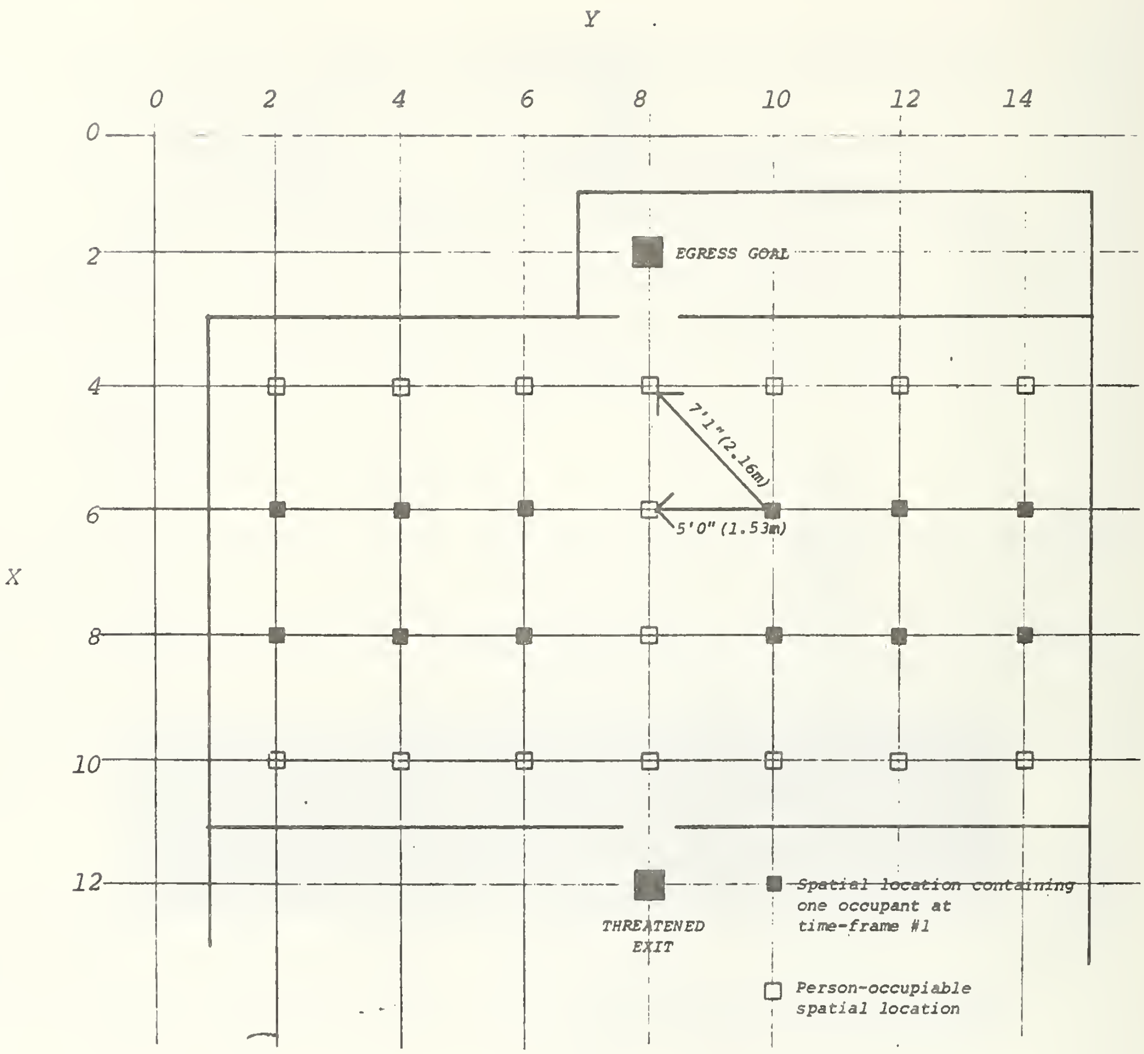
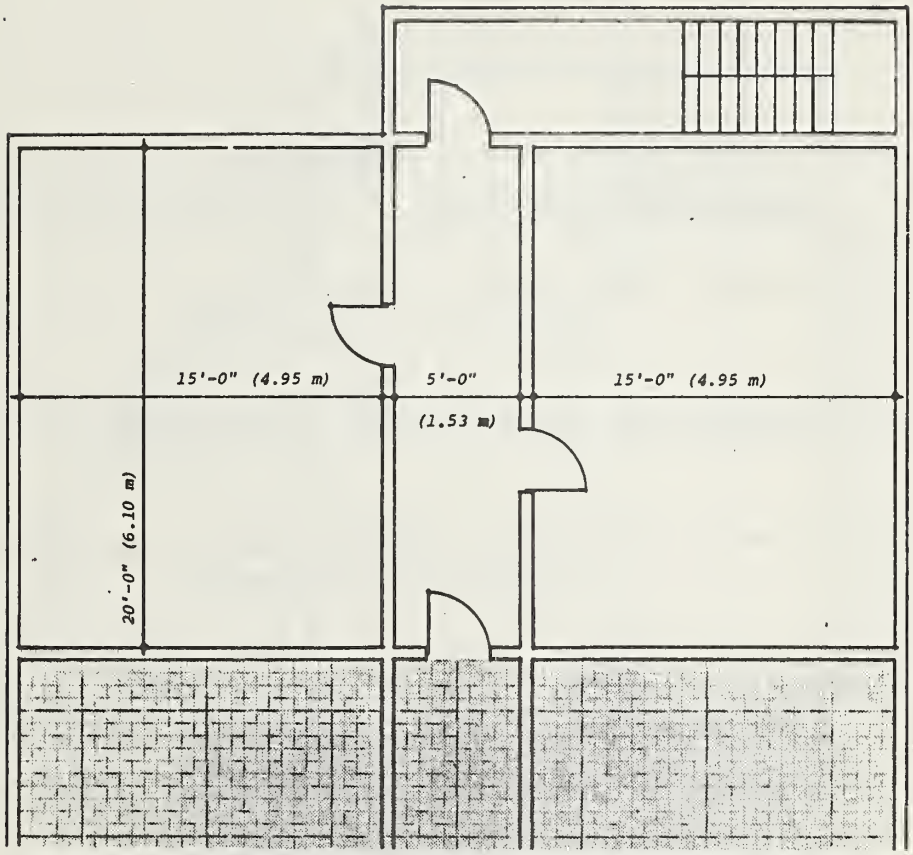


Figure 3.2 One-Space Plan in BFIRES Grid Form



Shaded portion denotes area
infiltrated by fire or smoke

Figure 3.3 Spatial Zone Subdivided Into Three Units (Three-Space Plan)

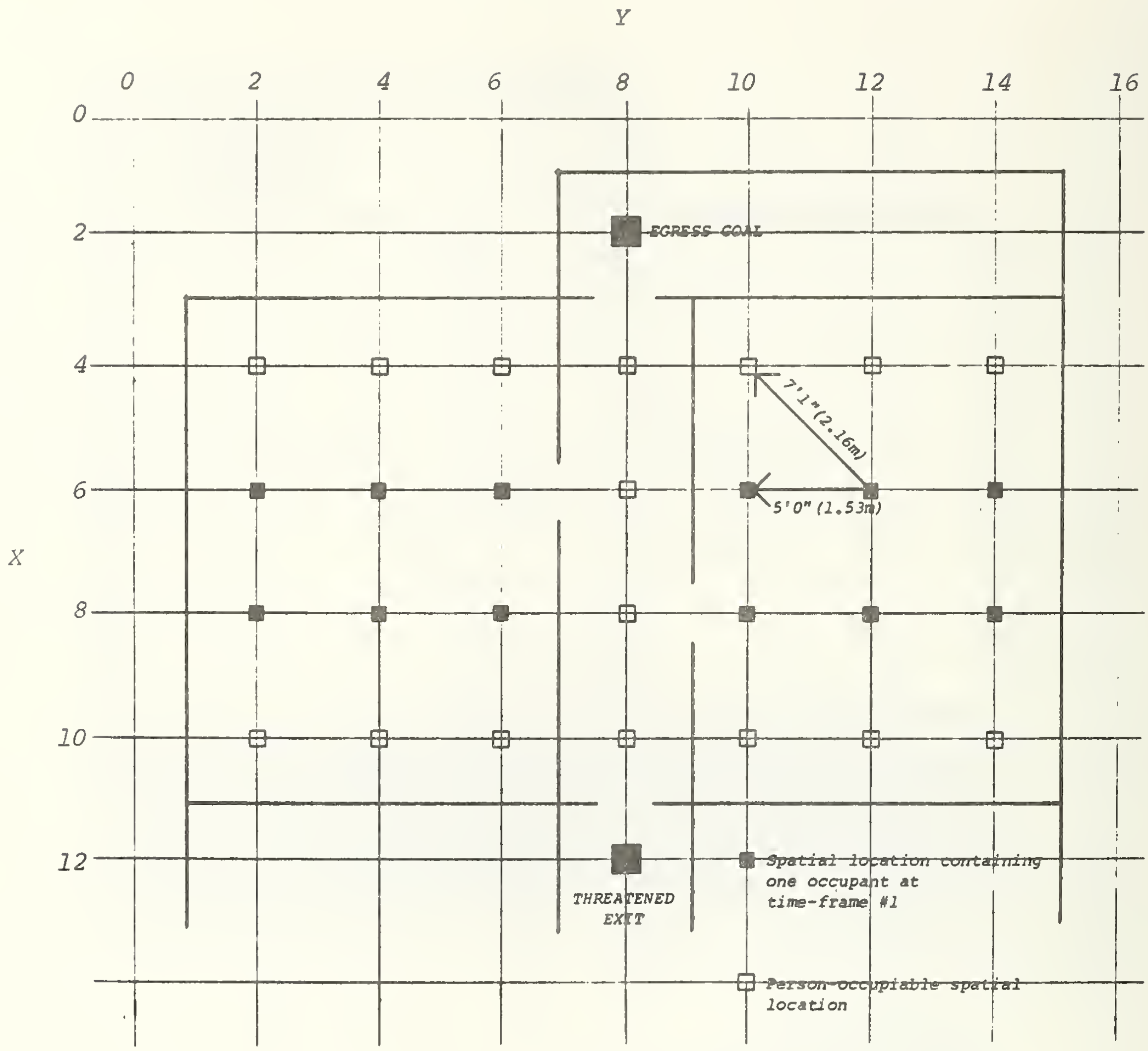
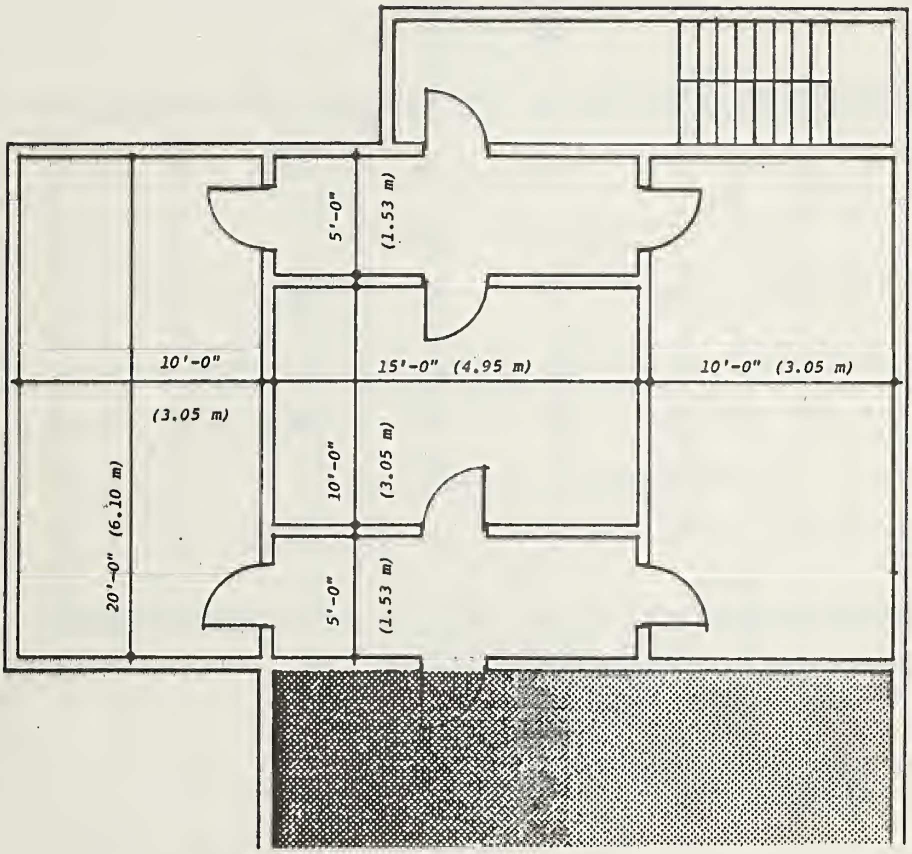


Figure 3.4 Three-Space Plan in BFIRES Grid Form



Shaded portion denotes area infiltrated by fire or smoke

Figure 3.5 <u>Spatial Zone Subdivided Into Five Units (Five-Space Plan)</u>

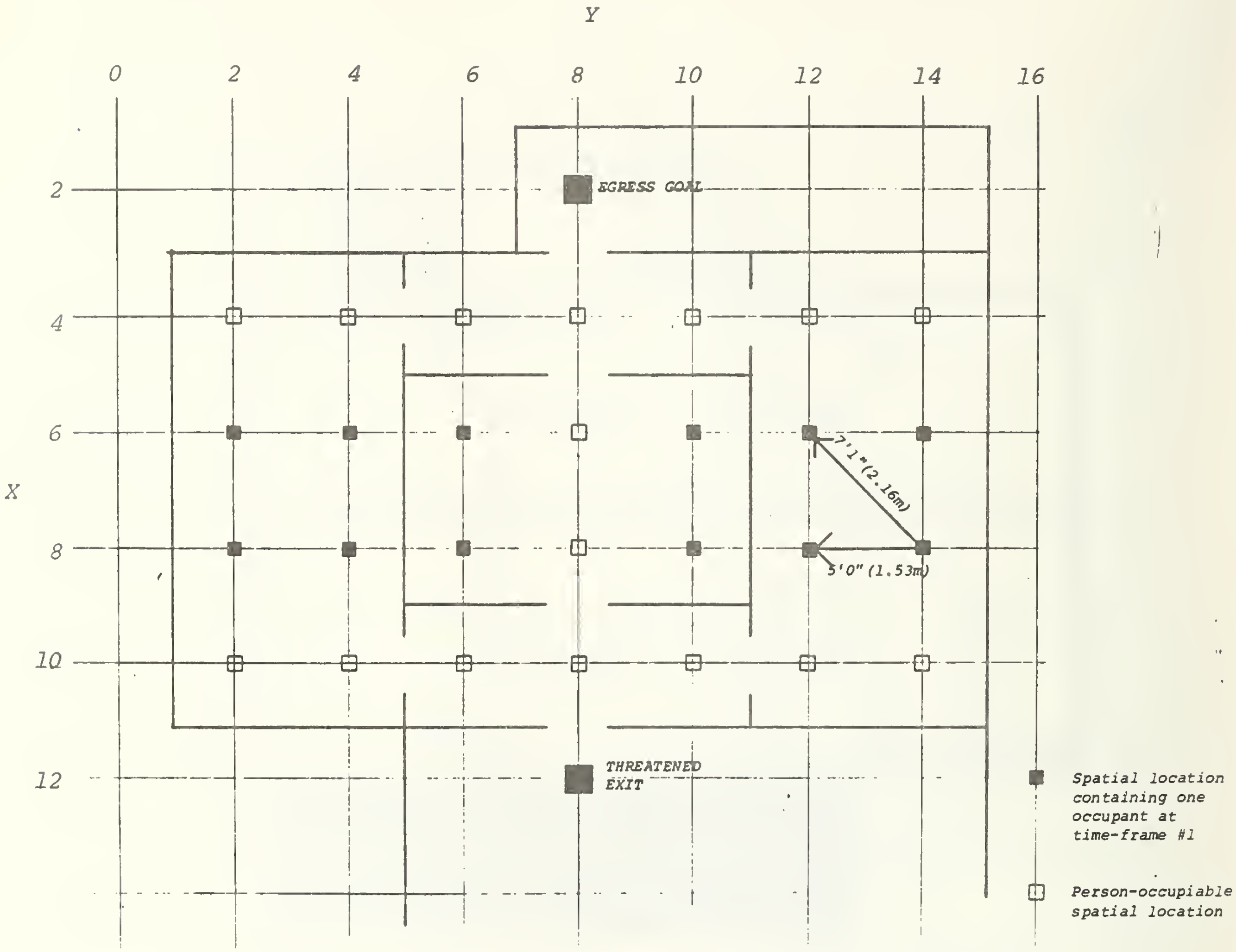
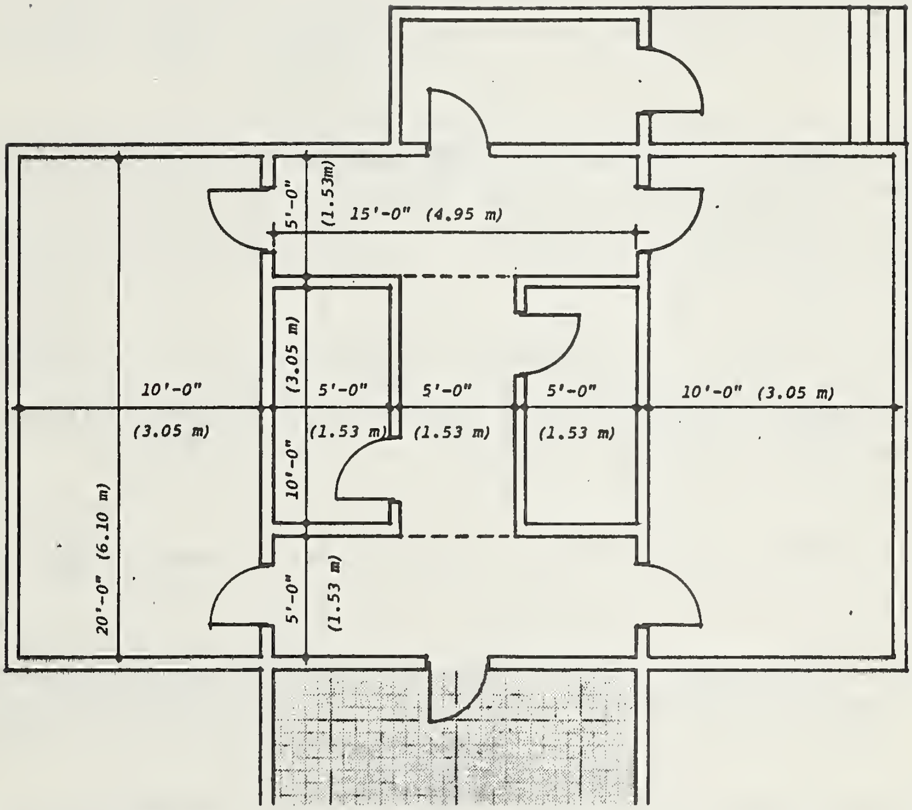


Figure 3.6 Five-Space Plan in BFIRES Grid Form



Shaded portion denotes area
infiltrated by fire or smoke

Figure 3.7 Spatial Zone Subdivided Into Seven Units (Seven-Space Plan)

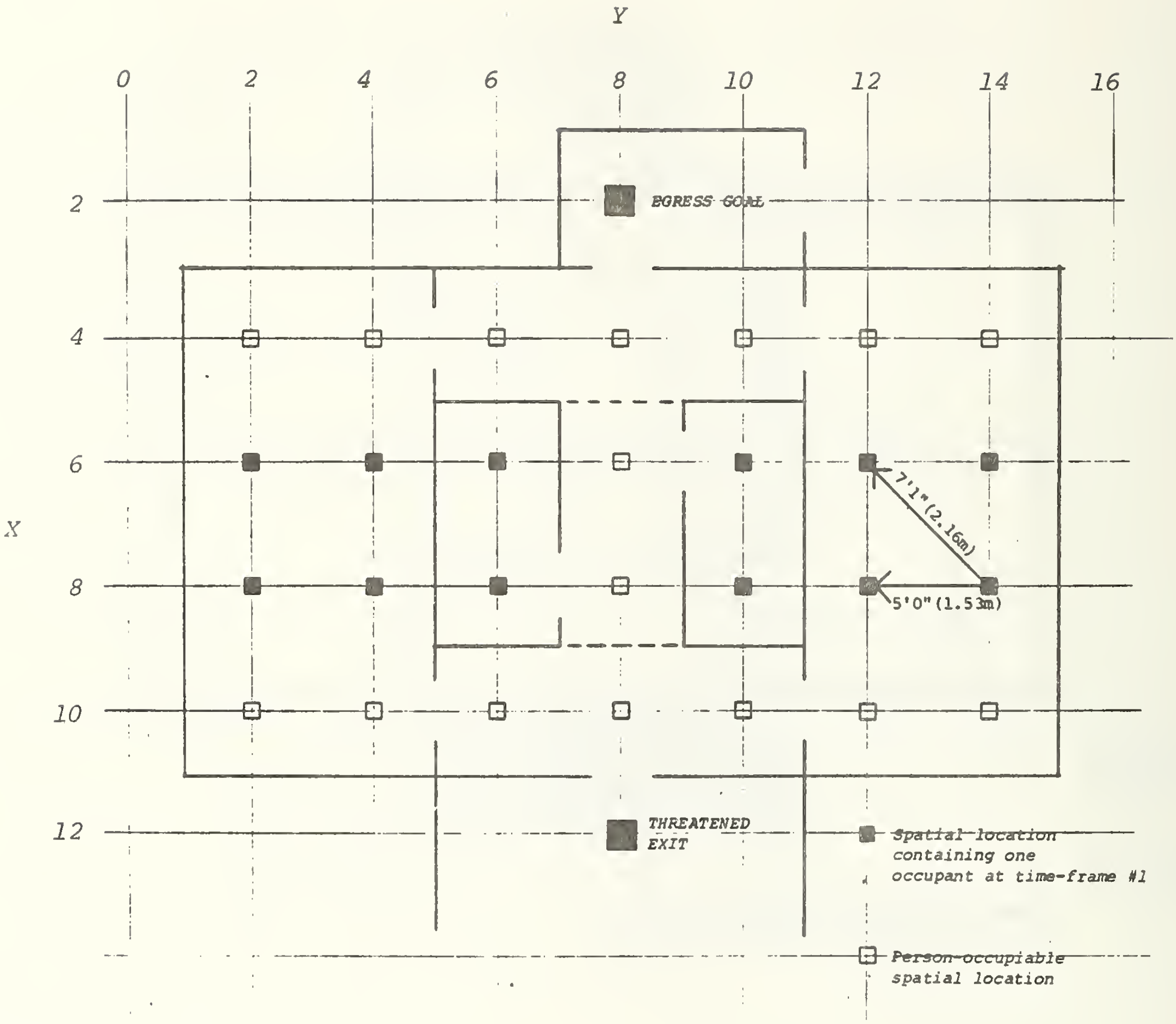


Figure 3.8 Seven-Space Plan in BFIRES Grid Form

3.2.2 Experimental Design

Independent variables: A two-way factorial design was constructed to test the effects of spatial subdivision (the actual number and size of spaces, or "rooms", constructed within the basic rectangular zone) and permissible occupant density (the maximum number of occupants permitted to inhabit a single person-occupiable location at any point in time). The 4 x 3 design is shown in Figure 3.9.

The study of these variables was warranted for certain practical reasons. For example, fire safety regulations address the design of access to exitways, and the "directness" of egress paths, without actually evaluating the costs and benefits of alternative designs. A simulation program sensitive to various aspects of spatial configuration could help fill this regulatory gap.

Dependent variables: The two variables measured were occupants' escape scores, and their total numbers of spatial displacements ("steps"). Escape score is the ratio of time required for escape versus the total length of the simulated event, and is computed by BFIRES as follows:

$$E = \frac{t - f}{t}$$

where,

E = occupant's escape score
t = total length of the simulated event in time frames
f = total number of frames the occupant actually spent on the floor of study, prior to escape.

Accordingly, if a simulation was run for a total of 100 time frames, and an occupant escaped during the 50th frame, then his escape score is computed to be 0.50. If the occupant never escapes during the run, his score will be 0.00. The higher the escape score, the earlier during the simulated event did escape occur.

The total number of spatial displacements made by an occupant during a simulated fire event, and the extent of deviation from the minimum number of steps actually required, may be used as indicators of egress path directness and complexity.

Hypotheses: The following hypotheses were examined:

(1) Escape score varies as a function of the extent of spatial subdivision, and in general, for a zone of given gross area, as the number of subdivisions increases, the mean escape score increases.

(2) Total spatial displacement varies as a function of the extent of spatial subdivision, and in general, as the number of subdivisions increases, the number of steps taken decreases.

SPATIAL CONFIGURATION

(defined as subdivision of a basic spatial zone)

1 space *area = 700 ft^2 ($65.15\ m^2$)*			
3 spaces *mean area 200 ft^2 ($19.36\ m^2$)*			
5 spaces *mean area=142 ft^2 ($12.78\ m^2$)*			
7 spaces *mean area=108 ft^2 ($9.72\ m^2$)*			
	density thresh.=1 *0.04 pers/ft^2* *0.43 pers/m^2*	*density thresh.=3* *0.12 pers/ft^2* *1.29 pers/m^2*	*density thresh.=5* *0.20 pers/ft^2* *2.15 pers/m^2*

PERMISSIBLE OCCUPANT DENSITY

Figure 3.9 <u>4x3 Factorial Design for Analysis "A"</u>

These expectations are deduced from the model underlying BFIRES, which suggests that before selecting a particular move, occupants first scan the available alternatives, and weigh the relative costs and benefits of each. Further, the model implies that as the number of alternatives available to an occupant at time t increases, the likelihood that he will in fact select the biased move decreases. As a result, we should expect more frequent goal-directed movement decisions, and hence a more direct egress route (i.e., higher escape score and fewer displacements), in cases providing the fewest movement alternatives.

(3) Escape score varies as a function of permissible occupant density, and in general, the higher the permissible density, the higher the escape score.

(4) Total spatial displacement varies as a function of permissible occupant density, and in general, the higher the density, the fewer displacements will be made.

The notion that occupant density (or, "crowding") impacts egress time and escape route is also deduced from the model underlying BFIRES. Similarly, the idea that the effects of density vary as a function of spatial configuration also stems from the model. While scanning alternative target locations, occupants are thought to assess the viability of each with respect to certain criteria. The first criterion an alternative target location must pass is its possibility of being reached. Accordingly, theoretical targets which are blocked by walls cannot be reached in a single step, and are thus deleted from the occupants' array of alternatives during time t. Similarly, targets perceived by the occupant as "crowded" will also be ruled out.

Although the reduction of alternatives has the effect of increasing the likelihood of selecting a goal-directed alternative, it also has the effect of reducing the actual number of alternatives leading toward a specified goal. This may influence egress behavior. For example, when occupying a large open space, an individual will often have nine movement alternatives available to him (the maximum possible) at a given point in time. Consider a situation in which the occupant perceives three of these alternatives as adaptive (i.e., as being highly goal-directed). If he notes that one of these will lead to a crowded location, he will drop it from his list of alternatives. However, there is still a high probability that the occupant will select one of the remaining two goal-directed moves.

But consider an individual occupying a more confined space, and that at time t there are only four movement alternatives available. Consider further that the occupant perceives that only one of these alternatives will satisfy his objective. If the target location of this move is perceived to be crowded, then less adaptive movement behavior will result (e.g., remaining in place, or meandoring), and valuable time will be wasted.

(5) The effect of occupant density is dependent upon the extent of spatial subdivision, such that density has the greatest impact where spatial zones are more highly subdivided into smaller areas.

The meaning of the interaction between spatial subdivision and occupant density can now be discussed. In larger spaces, an occupant will often have large numbers of move alternatives (up to nine) to choose from.

More than one of these will usually be perceived as goal-directed, and so the overcrowding of any single key location need not result in nonadaptive movement behavior. Therefore, the likelihood of successful escape from larger spaces should depend very little upon the crowding threshold (permissible number of occupants) for individual spatial locations.

In floor plans subdivided into many smaller spaces, however, the occupant will usually have relatively few move alternatives to choose from at any point in time. Often, only one of these will be perceived as goal-directed, and hence the crowding of key locations will lead to nonadaptive movement behavior. Therefore, the likelihood of successful escape from highly subdivided zones should depend directly upon the crowding threshold for individual spatial locations. In such cases, higher thresholds should "forestall" the perception of crowding, by simply endowing occupants with a greater tolerance for being crowded. The five hypotheses discussed above are summarized in Figure 3.10.

Data collection and analysis: The spatial subdivision and occupant density parameters were examined at the levels indicated in Figure 3.9. Variation in spatial subdivision was defined as the extent to which the original 700 square foot (65.15 m^2) zone was subdivided into smaller spaces, as follows:

Level 1: one space; area equals 700 square feet (65.15 m^2).

Level 2: three spaces; mean spatial area equals 200 square feet (19.36 m^2).

Level 3: five spaces; mean spatial area equals 142 square feet (12.78 m^2).

Level 4: seven spaces; mean spatial area equals 108 square feet (9.72 m^2).

Variation in occupant density was defined in terms of the maximum number of persons permitted to occupy any spatial location at a given point in time. In Analysis "A", a person-occupiable spatial location represented an imaginary envelope of 25 square feet (2.25 m^2). Therefore:

Level 1: density threshold equals 1; maximum allowable density equals 0.04 persons per square foot (0.43 persons per m^2).

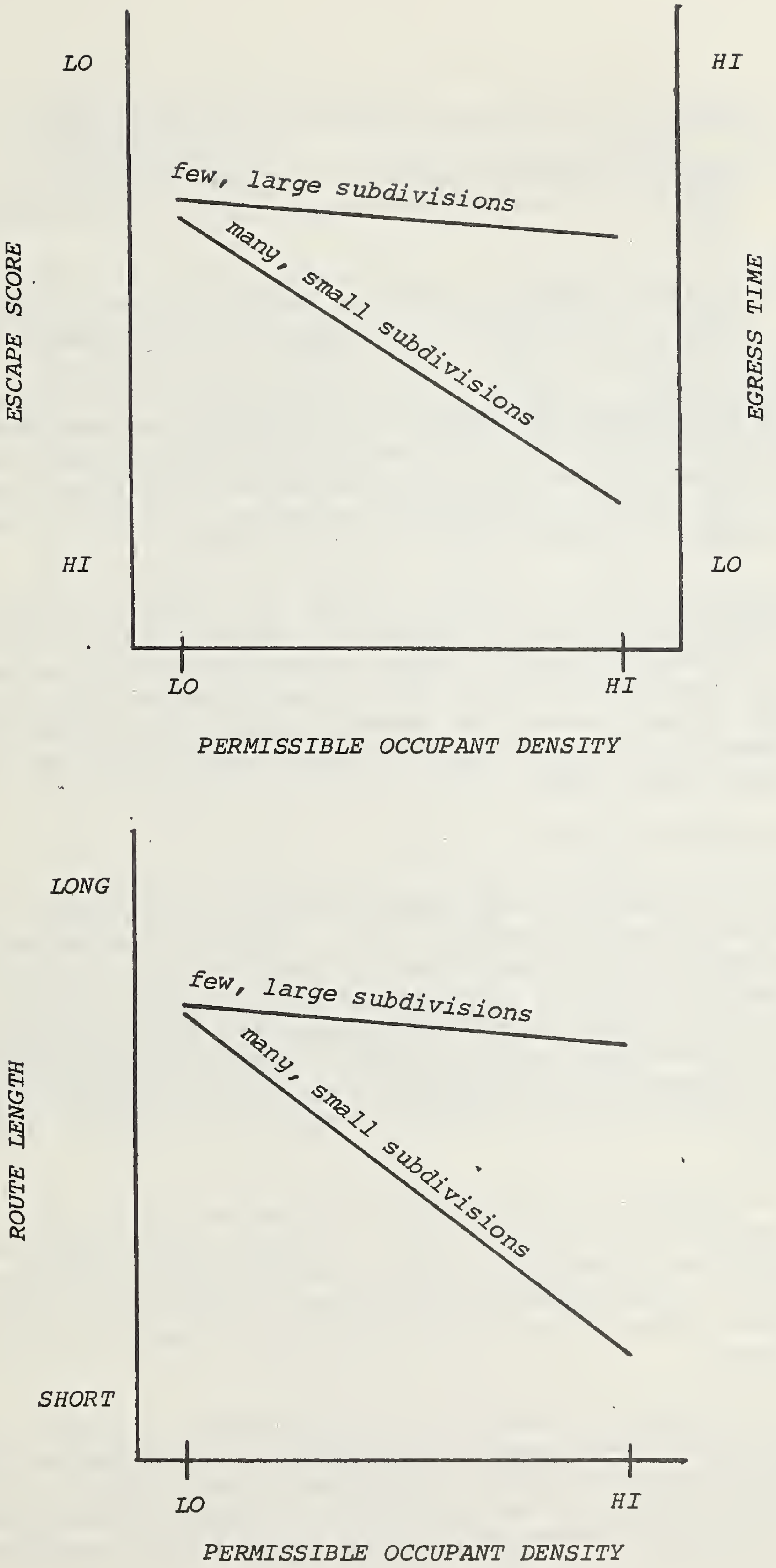


Figure 3.10 Graphic Summary of Hypotheses (1) - (5)

Level 2: density threshold equals 3; maximum allowable density equals 0.12 persons per square foot (1.29 persons per m^2).

Level 3: density threshold equals 5; maximum allowable density equals 0.20 persons per square foot (2.15 persons per m^2).

The 4 x 3 factorial design was replicated 10 times. For each cell, values of both mean escape score and mean spatial displacement (across the replications) were recorded. Separate analyses of variance were conducted for each of the two dependent variables, in order to assess the effects of spatial subdivision and occupant density.

The random effects analysis of variance model was chosen, in which the interaction mean square is used to compute F values for the main effects. This model was employed since the levels of the independent variables actually studied could, at least in theory, have been selected randomly from some larger range. Use of the random effects model permits inferences to be drawn from the particular findings to all levels of the variables, within such a range.

3.2.3 Findings and Discussion

Mean outcomes from simulation runs assuming density thresholds of one, three, and five are shown in Tables 3.1, 3.2, and 3.3, respectively. Each table indicates mean escape scores and route lengths (in number of "steps") aggregated across all 12 occupants within each replication. Hence, the grand means were computed by aggregating across occupants and replications, for each level of the spatial subdivision variable. These data are shown graphically in Figures 3.11 and 3.12. Analyses of variance for escape score and step totals are summarized in Tables 3.4 and 3.5, respectively.

Escape score: Hypotheses (1), (3), and (5) presented above were supported by simulated escape score data. In particular; BFIRES was found to be sensitive to variation in both spatial subdivision and occupant density, in the predicted directions. Moreover, the predicted interaction effect between these variables was also found to be statistically significant.

Route length: Hypotheses (2) and (4) were supported by simulated data on route length (total steps taken by occupants). In particular, the program was found to be sensitive to variation in both spatial configuration and occupant density, in the predicted directions. However, no statistically significant interaction effect between these variables was found.

Discussion: Two important conclusions are suggested by these findings. First, under the experimental conditions described above, the BFIRES computer program faithfully replicated theoretical relationships about

Table 3.1 Mean Outcomes From Simulations Based on a Density Threshold of 1

Replication	1-Space Plan		3-Space Plan		5-Space Plan		7-Space Plan	
	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps
1	.27	16.50	.18	16.92	.19	17.17	.38	12.58
2	.31	14.50	.28	14.58	.36	12.42	.35	11.42
3	.26	17.08	.33	13.83	.26	14.83	.31	12.50
4	.33	14.58	.22	16.25	.28	14.33	.30	13.25
5	.32	14.67	.20	16.50	.26	15.00	.36	10.58
6	.22	16.50	.26	14.25	.42	10.25	.36	12.92
7	.41	13.58	.27	16.42	.29	14.50	.27	13.67
8	.34	14.17	.24	15.58	.32	13.67	.29	13.00
9	.35	13.58	.17	17.17	.27	14.92	.36	11.83
10	.42	12.75	.22	15.42	.27	15.08	.27	14.58
GRAND MEANS	.32	14.79	.24	15.69	.29	14.22	.33	12.63

Table 3.2 Mean Outcomes From Simulations Based on a Density Threshold of 3

	1-Space Plan		3-Space Plan		5-Space Plan		7-Space Plan	
Replication	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps
1	.18	19.58	.34	13.75	.56	10.25	.49	10.75
2	.39	13.83	.39	14.75	.53	10.67	.55	9.17
3	.49	11.25	.34	13.58	.45	12.33	.51	9.83
4	.38	14.17	.34	15.17	.35	15.33	.46	10.50
5	.43	13.33	.31	13.67	.47	11.17	.49	11.00
6	.32	14.17	.26	16.58	.38	13.25	.29	15.08
7	.42	13.25	.24	16.33	.47	11.83	.58	8.75
8	.33	15.67	.27	16.58	.39	13.83	.56	8.67
9	.39	13.58	.41	13.67	.56	9.08	.45	12.17
10	.39	13.58	.32	15.75	.55	9.33	.54	10.25
GRAND MEANS	.37	14.24	.32	14.98	.47	11.71	.49	10.62

Table 3.3 Mean Outcomes From Simulations Based on a Density Threshold of 5

Replication	1-Space Plan		3-Space Plan		5-Space Plan		7-Space Plan	
	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps	Mean Escape Score	Mean Steps
1	.46	12.17	.32	14.92	.34	14.33	.44	12.92
2	.46	13.17	.20	17.58	.50	10.17	.52	9.50
3	.45	13.00	.38	12.92	.59	8.50	.51	10.33
4	.26	17.08	.40	13.08	.52	10.50	.50	10.33
5	.47	12.00	.21	17.33	.53	10.00	.66	6.25
6	.36	14.83	.27	16.33	.56	9.00	.40	13.58
7	.26	16.83	.35	14.00	.41	12.33	.44	11.58
8	.34	15.08	.42	11.83	.49	10.50	.56	9.58
9	.34	14.67	.26	16.92	.64	7.67	.62	8.67
10	.41	13.75	.29	15.50	.37	13.33	.42	12.92
GRAND MEANS	.38	14.26	.31	15.04	.49	10.63	.46	10.57

spatial subdivision and occupant density which are contained within the program's underlying model. Thus, our confidence in the internal validity and consistency of BFIRES is strengthened. Second, when simulating certain kinds of fire events, users should expect to find BFIRES capable of distinguishing among variations in such important environmental and occupancy factors as spatial subdivision and occupant density.

3.3 ANALYSIS "B"

3.3.1 Description and Objectives

Description: Fire events were simulated on a single story of a dormitory-type facility. The floor under study consisted of a double-loaded corridor with four rooms on each side. The corridor was divided into two segments by a wall, and the segments were connected by a doorway. Two egress stairs were provided. One stairway lead to a place of refuge; the other was assumed to be smoke-logged, due to a fire already burning on another floor of the building.

Simulations were conducted under two different floor plan configuration conditions. In the first condition, stairways were located at the extreme ends of the corridor (refer to Figure 3.13). In the second, the stairways were located closer toward the center of the building, leaving dead ends of 15 feet (4.58 m) at each end of the corridor (see Figure 3.15).

Each simulation run involved 20 occupants. These were initially located at points shown in Figures 3.14 and 3.16. At the start of each run, all occupants were assumed to have been alerted to the existence of a fire elsewhere within the building. All occupants were assumed to be "ordinary residents", and as in Analysis "A", no staff persons or other individuals with specialized training were present.

Simulations were conducted under several different occupant conditions. Comparisons were made between simulations in which occupants knew which stair was blocked and which was safe, and those in which occupants had no such direct knowledge. In addition, comparisons were made between simulations in which occupants were fully mobile, and those in which they were mobility-impaired.

Objectives: The objective of Analysis "B" was to determine whether BFIRES is sensitive to differences in floor plan configuration (specifically, the presence or absence of dead end corridors), and to variation in such occupant parameters as mobility and knowledge about exit utility. An additional objective was to study the sensitivity of BFIRES to variation in occupant density.

3.3.2 Experimental Design

Independent variables: A four dimensional factorial design was employed to test the effects of floor plan configuration, occupant mobility,

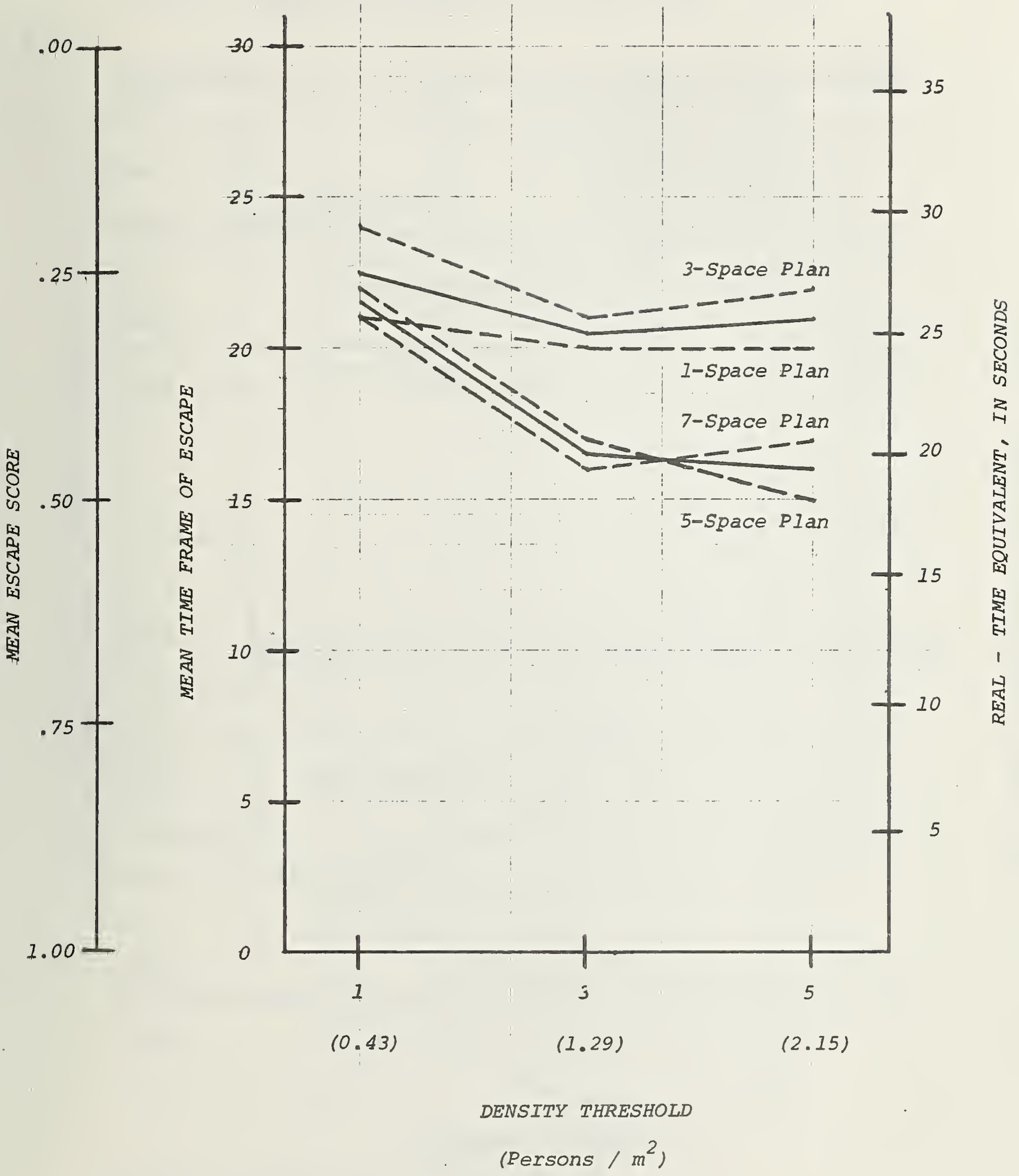


Figure 3.11 Effects of Spatial Subdivision and Occupant Density on Escape Score

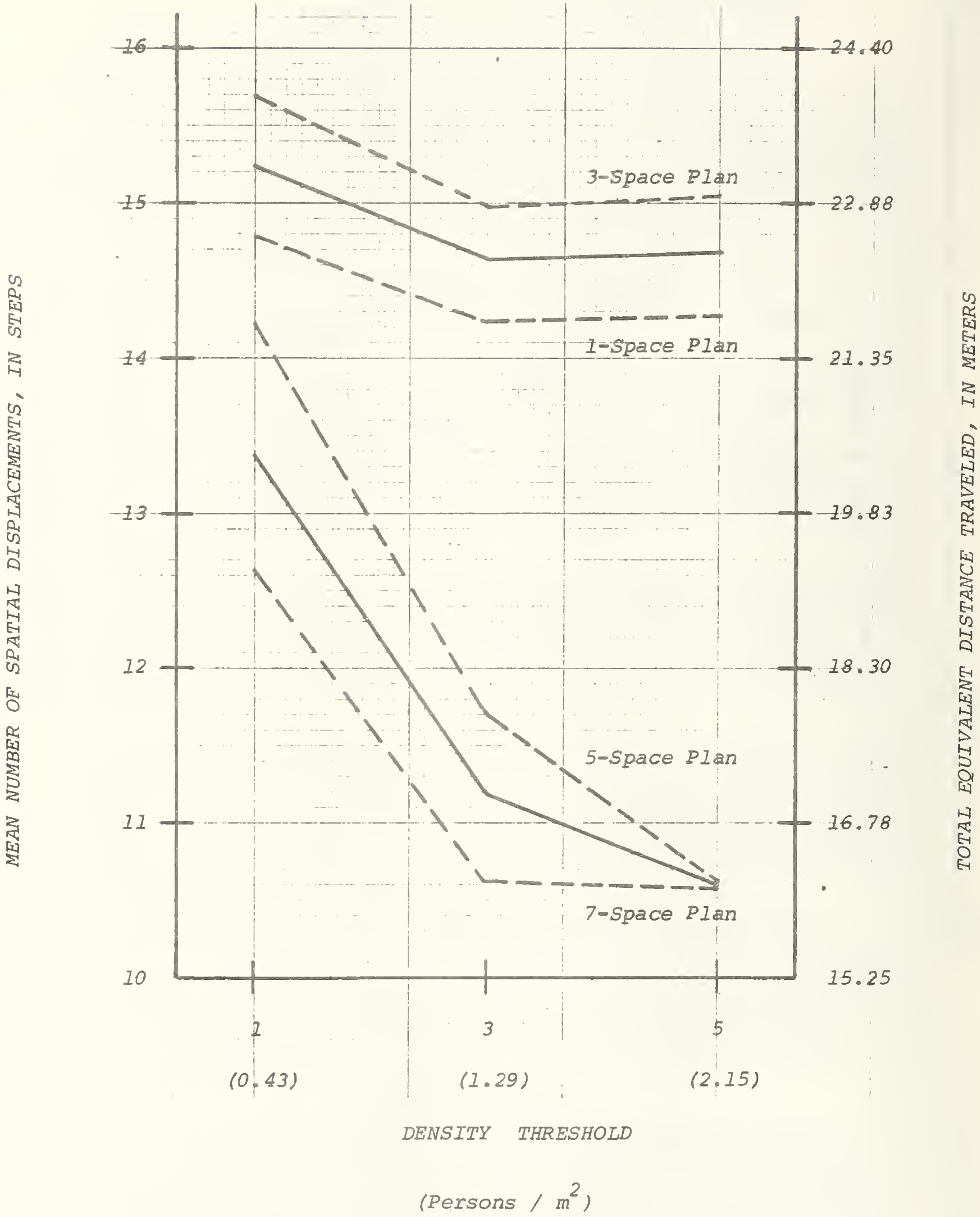


Figure 3.12 Effects of Spatial Subdivision and Occupant Density on Route Length

Table 3.4 Analysis of Variance for Escape Score (N=120)

SOURCE	D.F.	S.S.	M.S.	F
Density (D)	2	.415	.207	12.936[2]
Number of Spaces (S)	3	.417	.139	8.688[1]
D x S	6	.097	.016[3]	3.027[2]
Within	108	.577	.005	
Total	119	1.506		

Table 3.5 Analysis of Variance for the Total Number of Steps Taken (N=120)

SOURCE	D.F.	S.S.	M.S.	F
Density (D)	2	69.874	34.937	6.660[1]
Number of Spaces (S)	3	314.167	104.722	19.962[2]
D x S	6	31.478	5.246[3]	1.619
Within	108	349.912	3.240	
Total	119	765.431		

Notes: (1) significant at the .05 level
(2) significant at the .01 level
(3) in the random effects model, the D x S interaction mean square is ued to compute values of *F* for the main effects

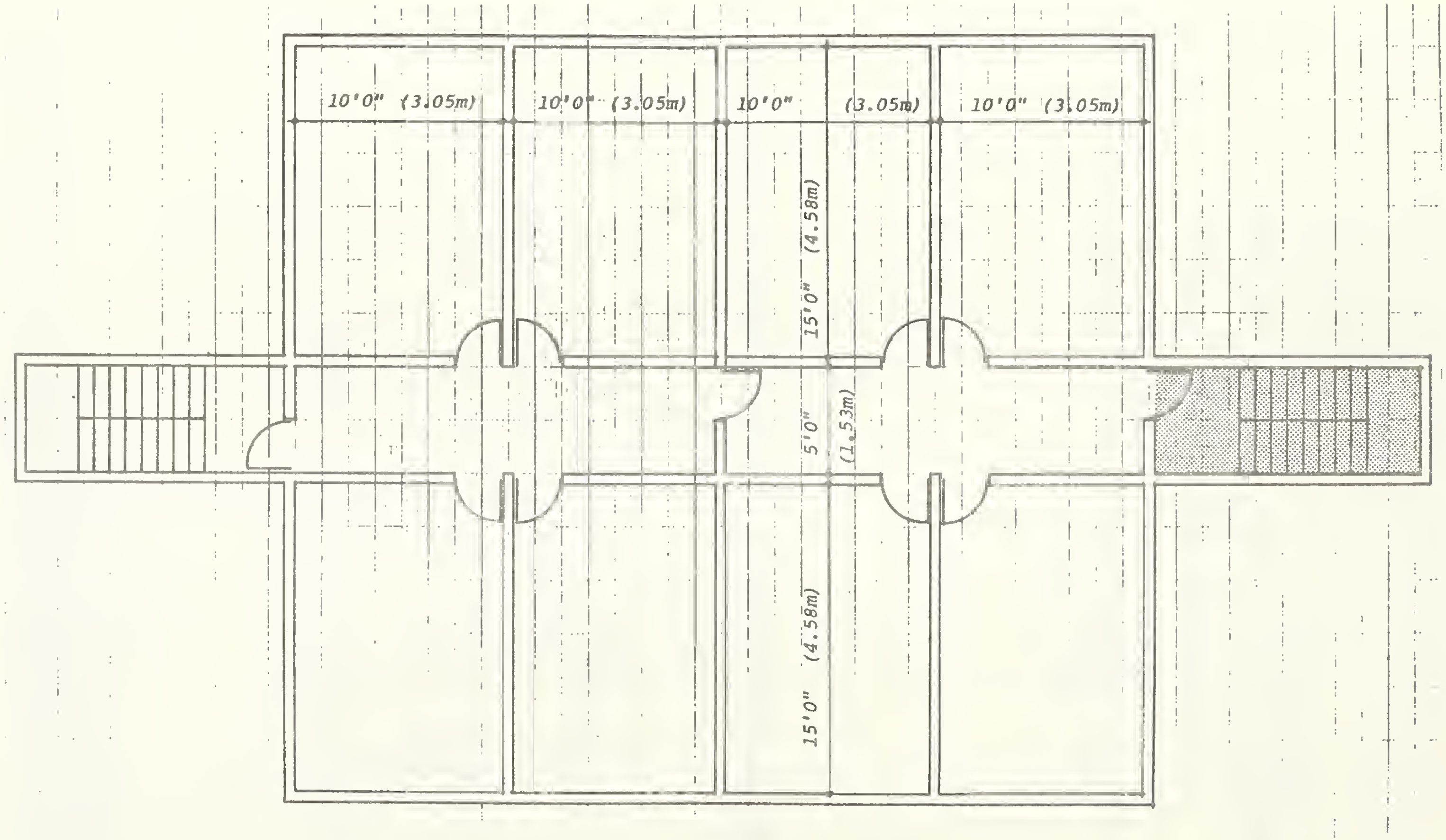


Figure 3.13 Non Dead-End Floor Plan

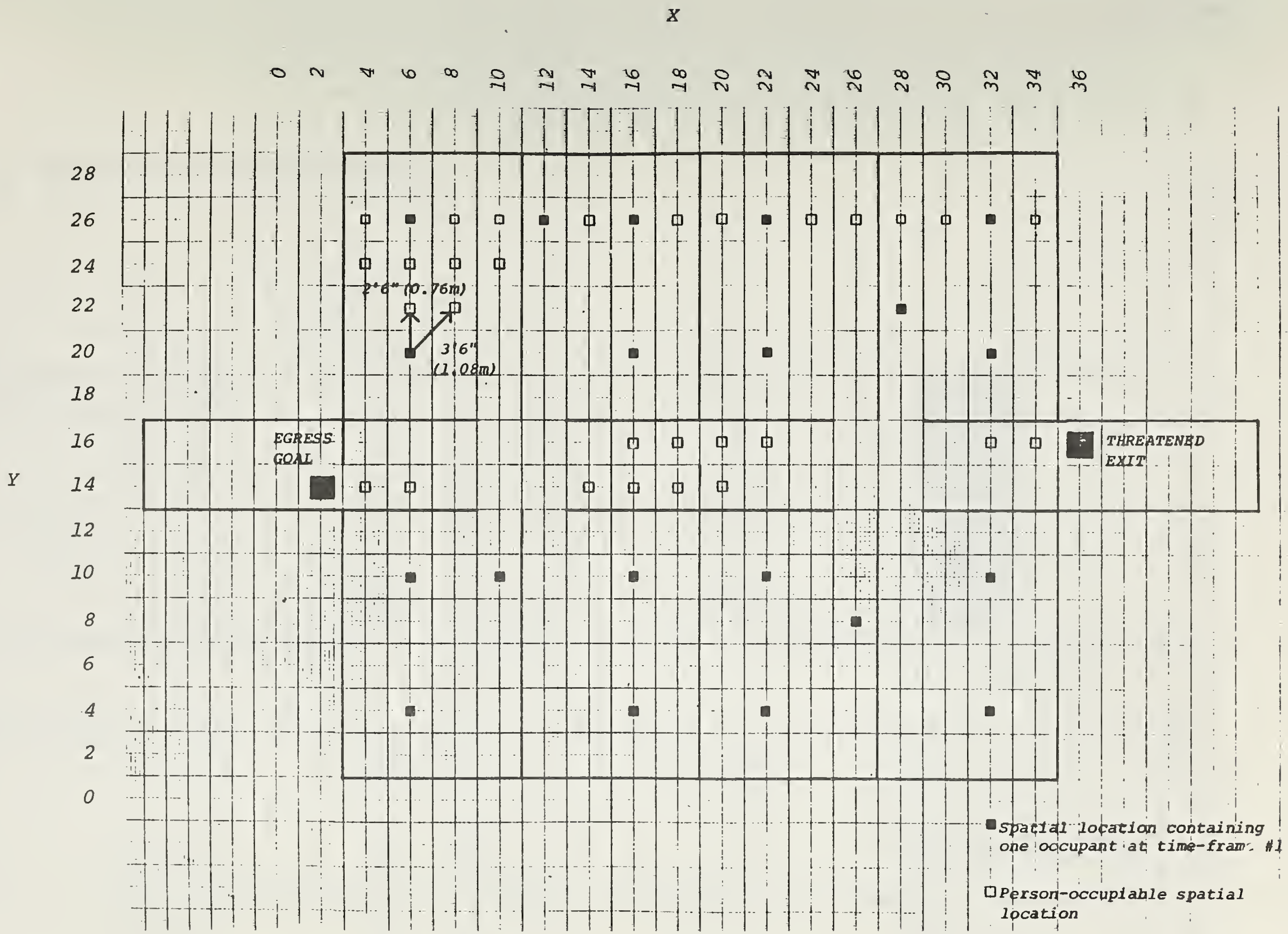


Figure 3.14 Non Dead-End Floor Plan in BFIRES Grid Form

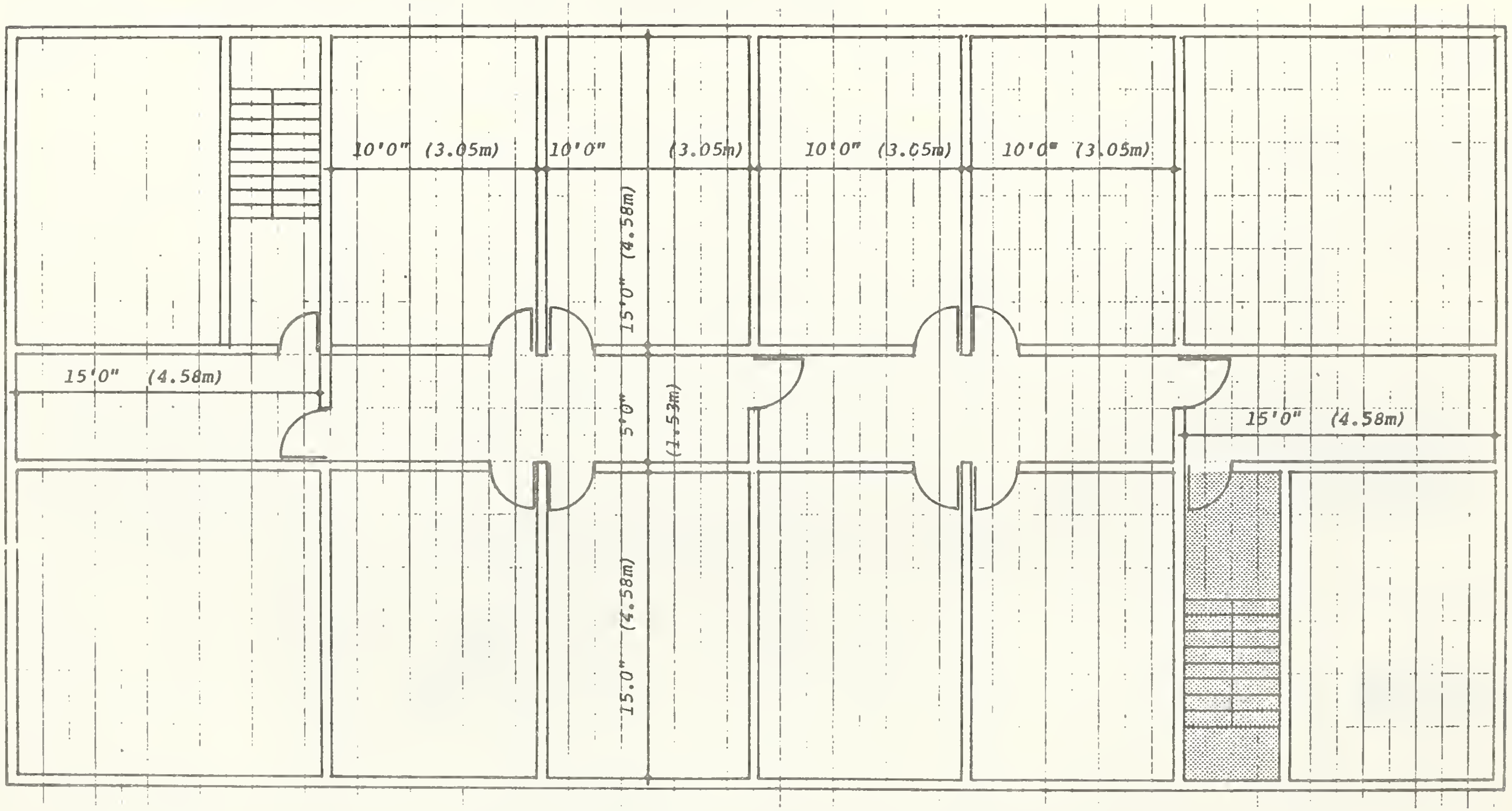


Figure 3.15 Dead-End Spatial Configuration

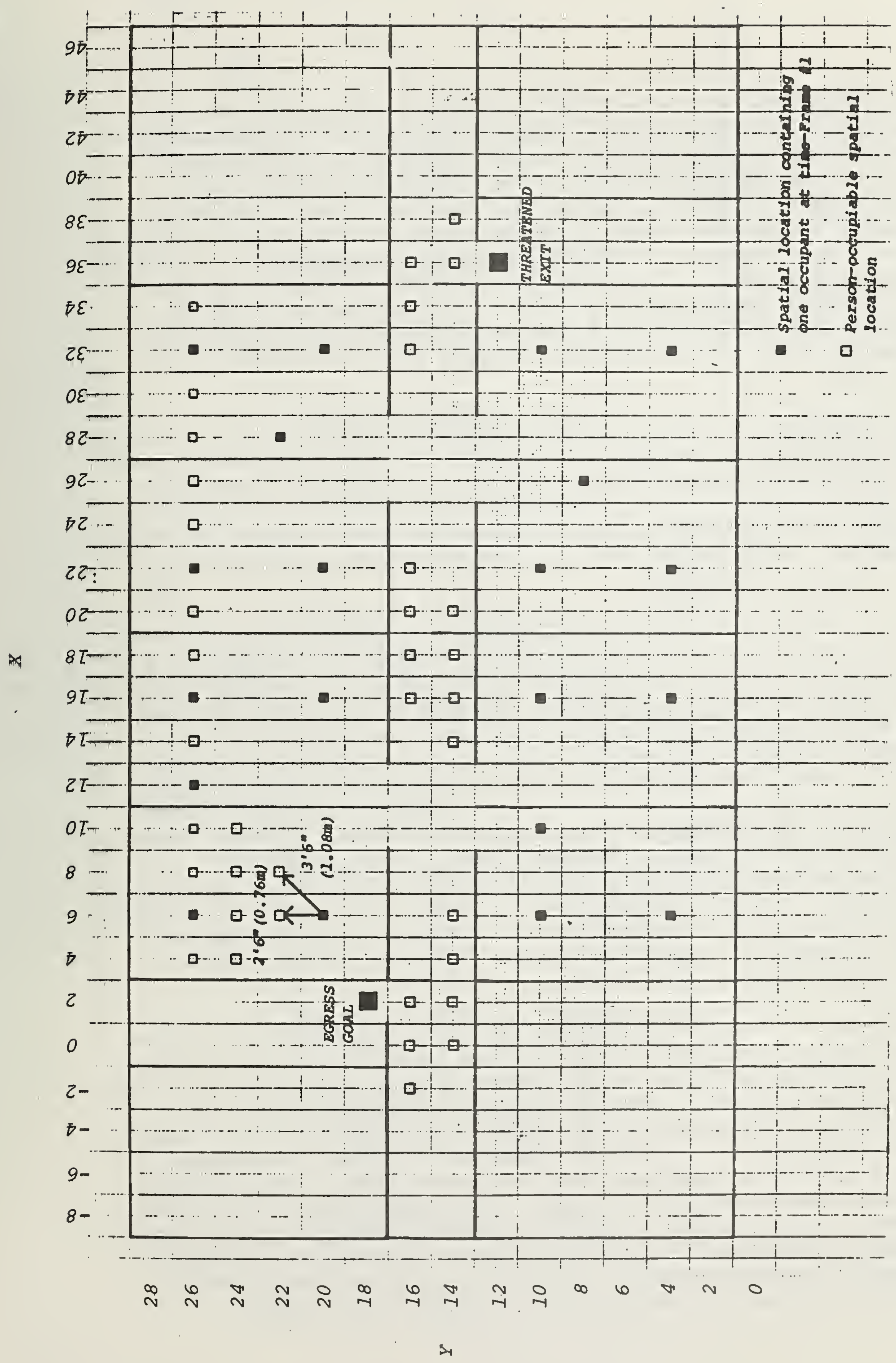


Figure 3.16 Dead-End Floor Plan in BFIRES Grid Form

occupants' knowledge of the safe exit location, and occupant density threshold. The 2x2x2x2 design is shown in Figure 3.17. Examination of these variables is important for a number of reasons. For example, Analysis "A" suggested the sensitivity of BFIRES to variation in a particular aspect of building design, spatial subdivision. Floor plan configuration is another aspect of design which is under the immediate control of the architect. If BFIRES can assist the architect in evaluating differences between alternative floor plan arrangements, it will be deemed a valuable design tool. Similarly, the ability of BFIRES to distinguish among occupants who differ on various characteristics will strengthen its value as a facility management and occupant (or staff) training tool.

Dependent variables: Measures of four dependent variables were recorded: (a) the total number of occupants who escaped the floor by the end of an event of arbitrarily selected length; (b) the difference between occupants' initial distances from the safe exit and their final distances; (c) occupants' escape scores; and (d) occupants' total numbers of spatial displacements. Variables (c) and (d) have already been described in detail in Section 3.2.2 above.

Variable (a), the total number of occupants escaping the floor, is self explanatory. This provides a somewhat gross measure of the overall outcome of a fire event: at the end of a given period of time, how many people escaped the floor under study? Variable (b), on the other hand, provides a finer measure of occupant performance during a particular event. When we curtail a simulated event at some arbitrarily chosen point, it is quite likely that many occupants who would have eventually escaped are still found on the floor. It is therefore useful to have some measure of the progress of the remaining occupants, without having to actually trace the complete movement paths of each individual (although BFIRES does permit the user to conduct such tracing exercises). The "difference" variable accommodates this need. The output is computed for each occupant, and is defined as the difference in straight-line distance separating the individual and the safe exit location between the initial and terminal time frames.

If the difference output for occupant i is zero, for example, then this individual was neither nearer to, or farther from, the safe exit at the terminal time frame as he was at the initial frame. This does not necessarily mean that occupant i remained in place throughout the entire event. It simply means that all his activity resulted in no net change in distance relative to the safe exit location. Indeed, an occupant with a zero difference value may also have experienced a large number of spatial displacements during the event. This combination would suggest that movement decisionmaking occurred in an environment virtually devoid of information (about, say, the location of the safe exit). It would also suggest that decisionmaking occurred in a confused environment, in which multiple sources of conflicting information were present.

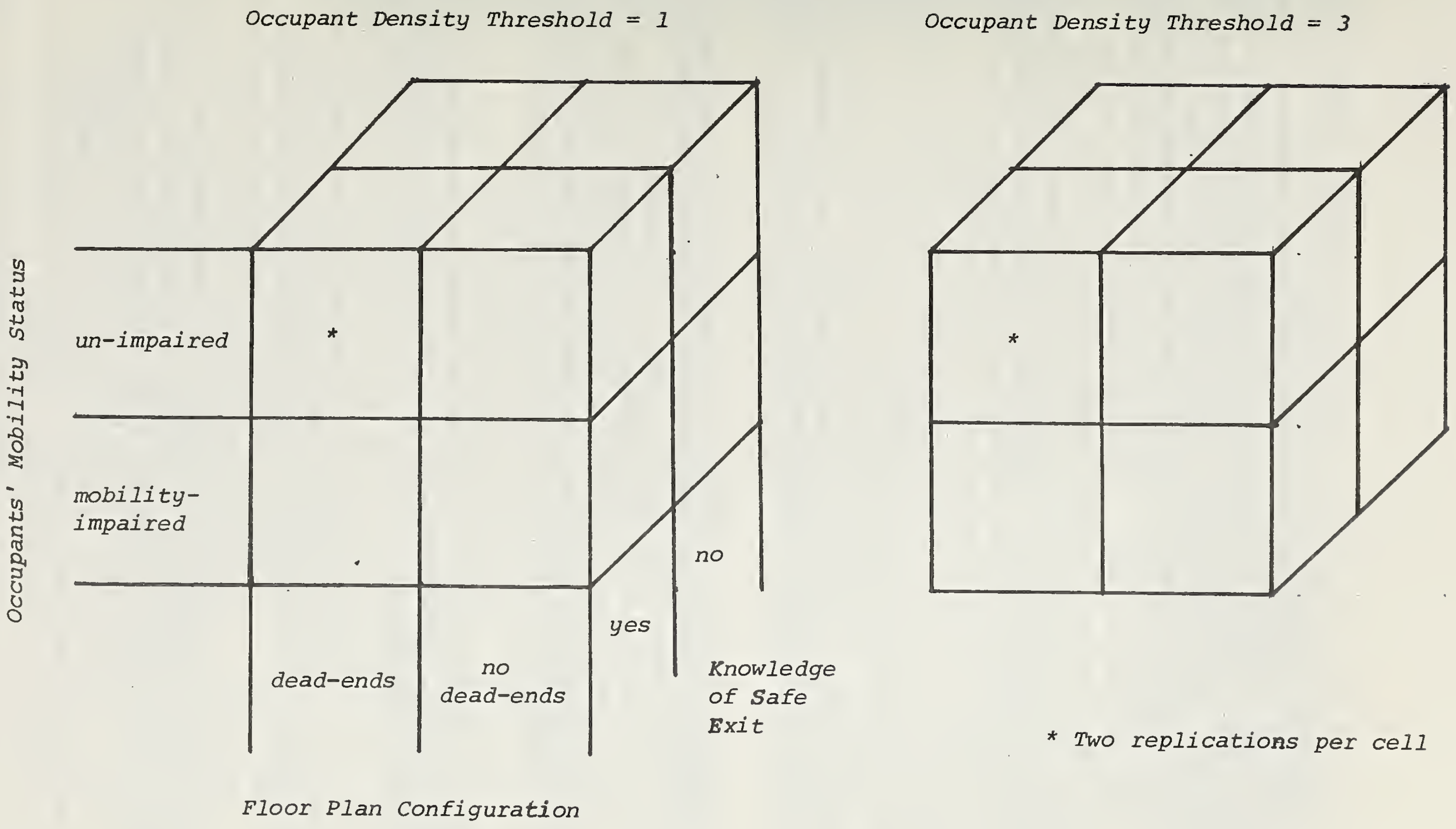


Figure 3.17 Four-Dimensional Factorial Design for Analysis "B"

Alternatively, difference values may be either positive or negative. Positive values indicate that the occupant is nearer to the safe exit at the terminal time frame; negative values indicate that he is farther. Consider two examples: An occupant with a high positive difference value and relatively small displacement output was probably making movement decisions on the basis of "good" information, and is obviously on his way toward reaching the safe exit. Had the simulation been run for another few time frames, he may very well have attained his exit goal.

On the other hand, an individual with a high negative difference value is likely to be operating under an erroneous idea of the safe exit's location. A high negative difference may also result when both the safe and threatened exits are very close to each other.

Hypotheses: Several hypotheses were evaluated:

(6) Permissible occupant density will have no effect on the dependent variables, nor will it interact with knowledge of safe exit location, the presence of dead end corridors, or occupant mobility.

We found during Analysis "A" that variation in occupant density produced changes in event outcomes depending upon the extent to which a spatial zone was subdivided into smaller and smaller units. In Analysis "B", occupant density was varied while spatial subdivision and size remained constant. Under these conditions, the model underlying BFIRES predicts no variation in event outcomes. Moreover, neither theoretical nor logical links are suggested between occupant density and safe exit knowledge, the presence of dead end corridors, or occupant mobility.

(7) In general, a larger portion of those occupants possessing knowledge of the safe exit location will escape the floor than those without exit location knowledge.

Exit-seeking is the most important objective processed within BFIRES. In order to work toward the exit objective, an occupant must, by definition, possess knowledge of its location. Given a knowledge of the safe exit's location, the occupant is able to route his way through any network of spatial subdivisions. Without any knowledge of the safe exit's location, the occupant must resort to satisfying the second-echelon objective: increasing his distance from the threat. In BFIRES, however, this may result in "meandoring", during which the safe exit may be found only by chance (and not as a result of conscious planning and movement). On the average, then, we expect most occupants with safe exit knowledge to escape the floor within the time allowed. Similarly, we expect very few individuals possessing no exit knowledge to escape.

(8) Regardless of floor plan configuration, more occupants with unimpaired mobility will escape the floor than will those with a mobility impairment.

BFIRES defines mobility impairment in terms of a reduction in movement velocity. This is accomplished by forcing impaired occupants (say, elderly, arthritic, etc.) to remain in place during every other time frame. The overall effect is a velocity reduction of about 50% (the user may wish to adjust the program source code to produce other levels of reduction). Because of this speed reduction effect, fewer mobility-impaired occupants are expected to reach the exit objective by the terminal time frame.

(9) By the terminal time frame, occupants with a knowledge of the safe exit will have moved closer to the exit objective than will individuals with no exit location knowledge. This will occur irrespective of floor plan configurations.

Refer to the discussion of hypothesis (7), above. It is assumed here that many fully able and knowledgable occupants would have escaped the floor by the terminal time frame, had the simulation been run for a longer period (say, 150 instead of 100 frames). Accordingly, we expect such individuals to increase the difference considerably between their initial and final positions, and that their movement behavior will be directed toward the exit objective.

(10) The effect predicted by hypothesis (9) will be greater for unimpaired occupants than for those with mobility impairment.

Refer to the discussion of hypothesis (8).

(11) Occupants with knowledge of the safe exit location will achieve higher escape scores than will those with no exit knowledge.

Escape score is an index which indicates not only whether an occupant has escaped by the terminal time frame (any non-zero value), but also how quickly (the higher the value, the earlier the escape). Exit knowledge equips the occupant with the highest priority goal, and persons working toward this goal are expected to escape earliest. Refer also to the discussions of hypotheses (7) and (9), above.

(12) Occupants with unimpaired mobility will achieve higher escape scores than will mobility-impaired individuals.

According to BFIRES, mobility-impaired occupants will require about twice as much escape time as unimpaired individuals. Since escape score is a direct measure of escape time*, scores for impaired individuals

---

* $ET = FL\ [T(1-ES)]$

Where: ET = escape time, in seconds
FL = length of a single frame, in seconds
T = total number of frames run
ES = occupant's escape score

will - by definition - be significantly lower than those achieved by fully able occupants.

(13) Occupants with knowledge of the safe exit location will traverse a shorter egress route (i.e., fewer "steps") than will individuals with no exit knowledge.

Occupants with the exit objective clearly in mind should have relatively little difficulty in planning their escape routes. These routes will be as direct and as linear as possible, with deviations resulting only from random variation and either cognitive or environmental interruptions.

(14) Unimpaired occupants will traverse longer paths during the simulated event than will those with mobility-impairments.

By definition, unimpaired occupants will take about twice as many "steps" as impaired individuals. Deviations may result from either random variation among occupants, or from interruptions, as in the case of hypothesis (13).

Data collection and analysis: The floor plan configuration, occupant mobility, exit knowledge, and occupant density parameters were examined at the levels indicated in Figure 3.17, and discussed in Section 3.3.1 (Description). Variation in occupant density was defined in terms of the maximum number of persons permitted to occupy any spatial location at a given in time. In Analysis "B", a person-occupiable spatial location represented and imaginary envelope of 6.25 square feet (0.56 m^2).

Therefore:

Level 1: density threshold equals 1; maximum allowable density equals 0.16 persons per square foot (1.79 persons per m^2).

Level 2: density threshold equals 3; maximum allowable density equals 0.48 persons per square foot (5.36 persons per m^2).

The 2x2x2x2 factorial design was replicated twice. For each cell, values of total number of escapees, locational difference, escape score, and spatial displacement were recorded. Separate fixed-effects analyses of variance were conducted for each dependent variable.

3.3.3 Findings and Discussion

Mean outcomes from simulation runs are shown in Table 3.6. The values recorded are aggregations of the original data from the 20 occupants in each replication. The data were further aggregated across the two replications. These data are displayed graphically in Figures 3.18 through 3.25. Analyses of variance for the four dependent variables studied are shown in Tables 3.7 through 3.10.

Table 3.6 Mean Data From Simulated Fire Events

CASE	PLAN[a]	DT[b]	MOB[c]	KNOW[d]	# ES[e]	DIFF[f]	SCOR[g]	STEP[h]
1	1	1	0	0	0	1.45	.00	81.38
2	0	1	0	0	0	1.00	.00	80.63
3	0	1	0	1	14.5	15.30	.30	55.68
4	1	3	0	0	0	0.70	.00	82.75
5	0	1	1	0	0	0.10	.00	40.13
6	1	1	1	1	4.0	5.60	.06	37.33
7	0	3	0	0	0	0.60	.00	82.43
8	0	3	0	1	14.5	15.35	.31	55.90
9	0	3	1	1	5.5	11.75	.05	40.63
10	0	3	1	0	0	-0.20	.00	40.98
11	1	3	1	1	5.5	9.85	.07	38.85
12	0	1	1	1	4.0	7.60	.05	40.18
13	1	3	0	1	13.0	15.65	.30	59.93
14	1	3	1	0	0	0.20	.00	42.18
15	1	1	0	1	10.5	13.50	.19	63.95
16	1	1	1	0	0	1.05	.00	40.70

Notes: (a) floor plan configuration:
0 = dead-end plan
1 = non-dead-end plan
(b) occupant density threshold:
value indicates actual number of occupants permitted per person-occupiable spatial location
(c) occupants' mobility status:
0 = all occupants were unimpaired
1 = all occupants were impaired
(d) occupants' knowledge of the safe exit location:
0 = no occupants possessed knowledge of the safe exit location
1 = all occupants possessed knowledge of the safe exit location
(e) number of occupants who escaped the floor by the 100th time frame
(f) occupants' final locations relative to their initial locations, in grid steps*
(g) occupants' escape scores
(h) total number of actual spatial displacements, in grid steps*

* mean grid step = 3.5 feet (1.08 m)

TABLE 3.7 ANALYSIS OF VARIANCE FOR THE TOTAL NUMBER OF OCCUPANTS WHO ESCAPE

N = 32

Source	df	SS	MS	F
Floor plan configuration (FP)	1	3.781	3.781	3.27
Density threshold (DT)	1	3.781	3.781	3.27
Mobility status (MS)	1	140.281	140.281	121.33*
Exit knowledge (K)	1	639.031	639.031	522.68*
DT x FP	1	.781	.781	.68
DT x MS	1	.031	.031	.03
DT x K	1	3.781	3.781	3.27
FP x MS	1	3.781	3.781	3.27
PF x K	1	3.781	3.781	3.27
MS x K	1	140.281	140.281	121.33*
2nd-order interactions	4			
3rd-order interaction	1			
Error	16	18.500	1.156	
Total	31	963.969		

* Significant at the .001 level

TABLE 3.8 ANALYSIS OF VARIANCE FOR THE TOTAL NUMBER OF SPATIAL DISPLACEMENTS ("STEPS" TAKEN)

N=32

Source	df	SS	MS	F
Floor plan configuration (FP)	1	7.078	7.078	.68
Density threshold (DT)	1	.057	.057	.01
Mobility Status (MS)	1	7120.717	7120.717	685.44*
Exit knowledge (K)	1	1293.496	1293.496	124.51*
MS x K	1	961.959	961.959	92.60*
Other 1st-order interactions	5			
2nd-order interactions	4			
3rd-order interaction	1			
Error	16	166.216	10.389	
Total	31	9658.441		

* Significant at the .001 level

TABLE 3.9 ANALYSIS OF VARIANCE FOR ESCAPE SCORE

Source	df	SS	MS	F
Floor plan configuration (FP)	1	.001	.001	.76
Density threshold (DT)	1	.002	.002	1.28
Mobility status (MS)	1	.092	.092	55.82*
Exit knowledge (K)	1	.218	.218	131.50*
MS x K	1	.092	.092	55.82*
Other 1st-order interactions	5			
2nd-order interactions	4			
3rd-order interaction	1			
Error	16	.026	.002	
Total	31	.450		

* Significant at the .001 level

TABLE 3.10 ANALYSIS OF VARIANCE FOR OCCUPANTS' FINAL POSITIONS RELATIVE TO THEIR INITIAL POSITIONS

N = 32

Source	df	SS	MS	F
Floor plan configuration (FP)	1	2.205	2.205	4.31
Density threshold (DT)	1	10.125	10.125	19.78***
Mobility Status (MS)	1	93.161	93.161	182.00***
Exit knowledge (K)	1	1019.261	1019.261	1991.25***
DT x FP	1	.361	.361	.71
DT x MS	1	3.920	3.920	7.66*
DT x K	1	19.845	19.845	38.77***
FP x MS	1	.125	.125	.24
FP x K	1	6.125	6.125	11.97**
MS x K	1	66.701	66.701	130.31***
DT x MS x K	1	5.445	5.445	10.64**
Other 2nd-order interactions	3			
3rd-order interaction	1			
Error	16	8.190	.512	
Total	31	1238.799		

* Significant at the .05 level
** Significant at the .01 level
*** Significant at the .001 level

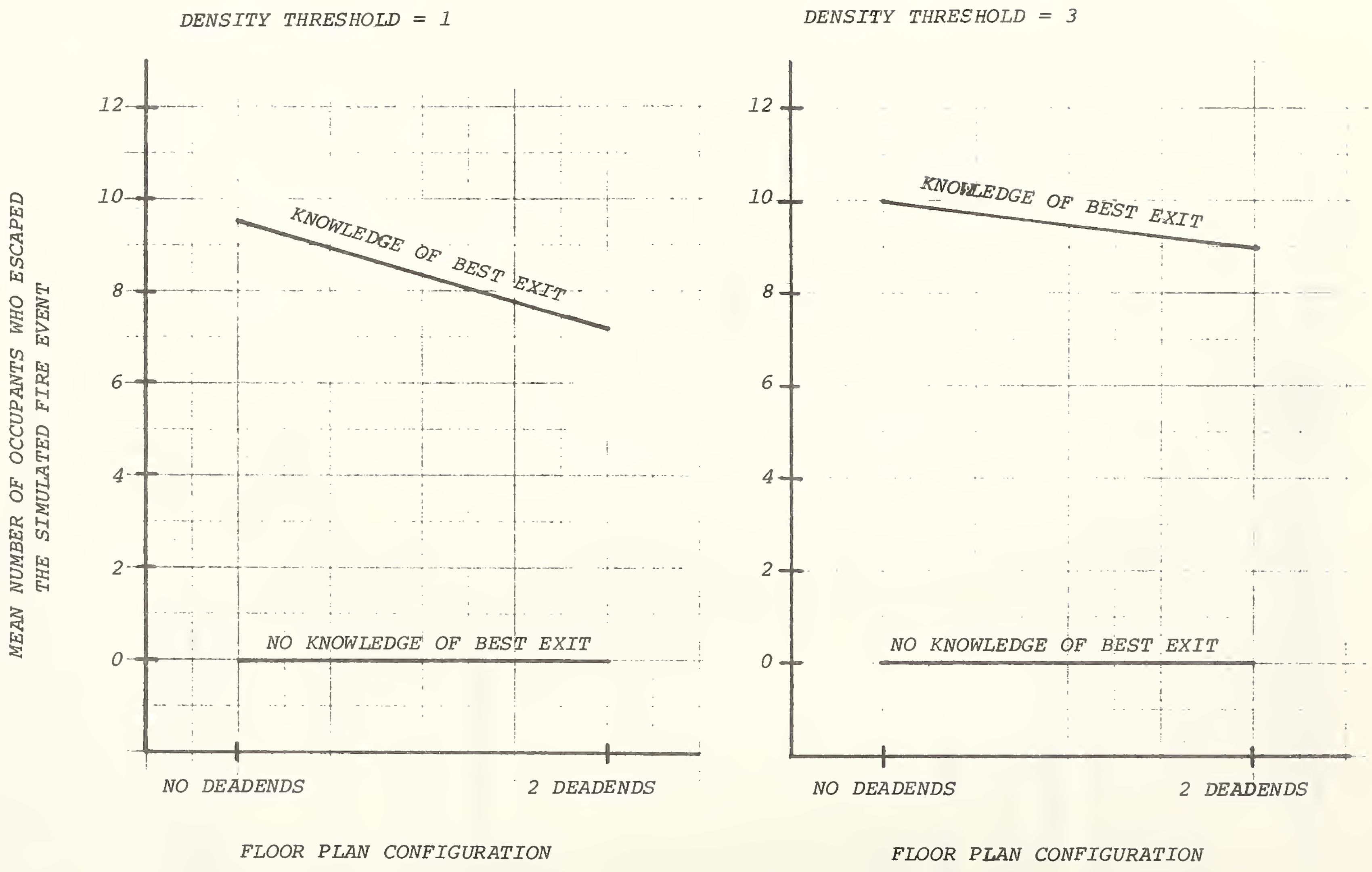


Figure 3.18 Effects of Knowledge of Best Exit Location, Floor Plan Configuration, and Occupant Density on the Mean Number of Occupants Escaping the Floor

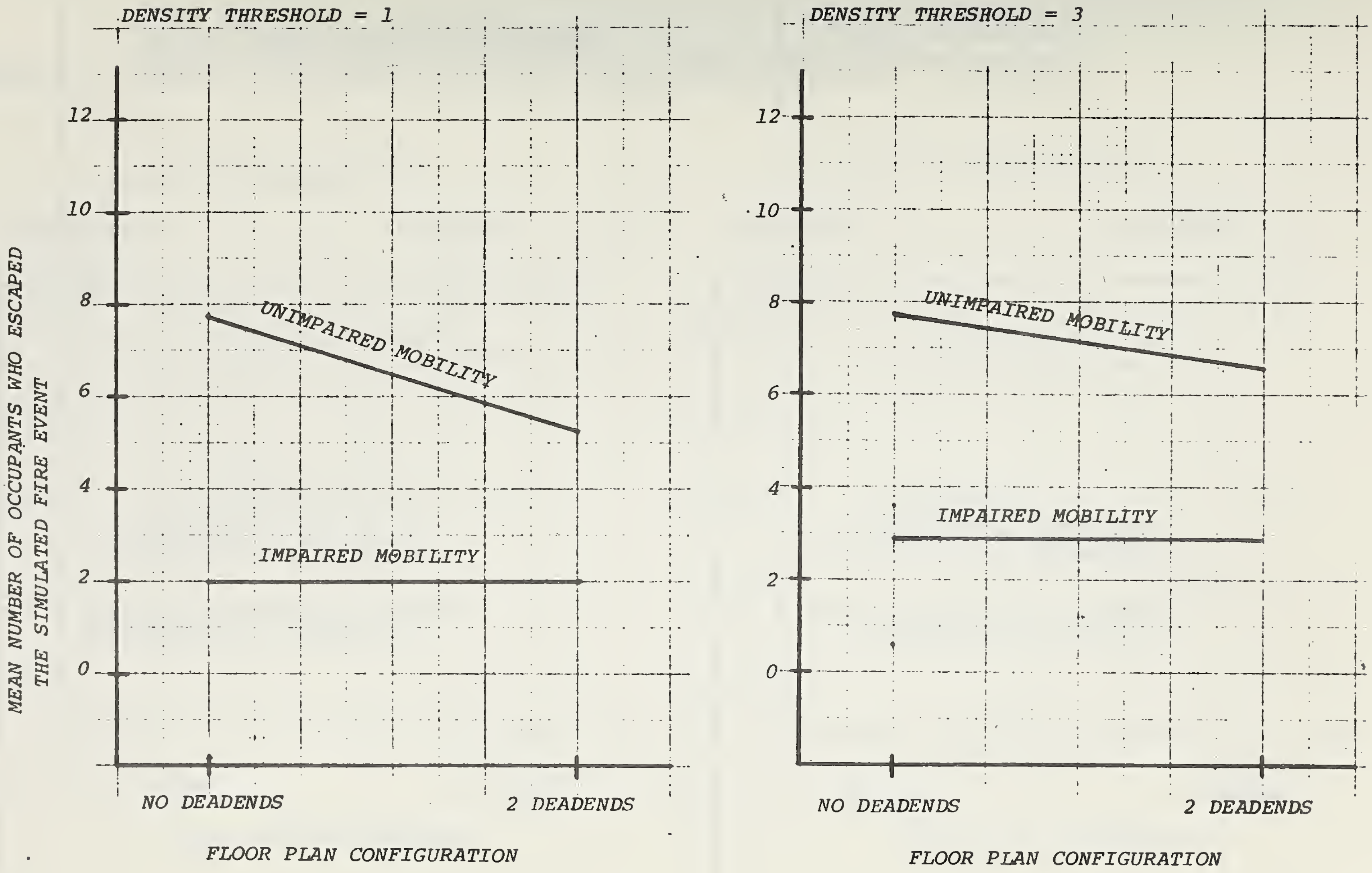


Figure 3.19 Effects of Occupant Mobility, Floor Plan Configuration, and Occupant Density on the Mean Number of Occupants Escaping the Floor

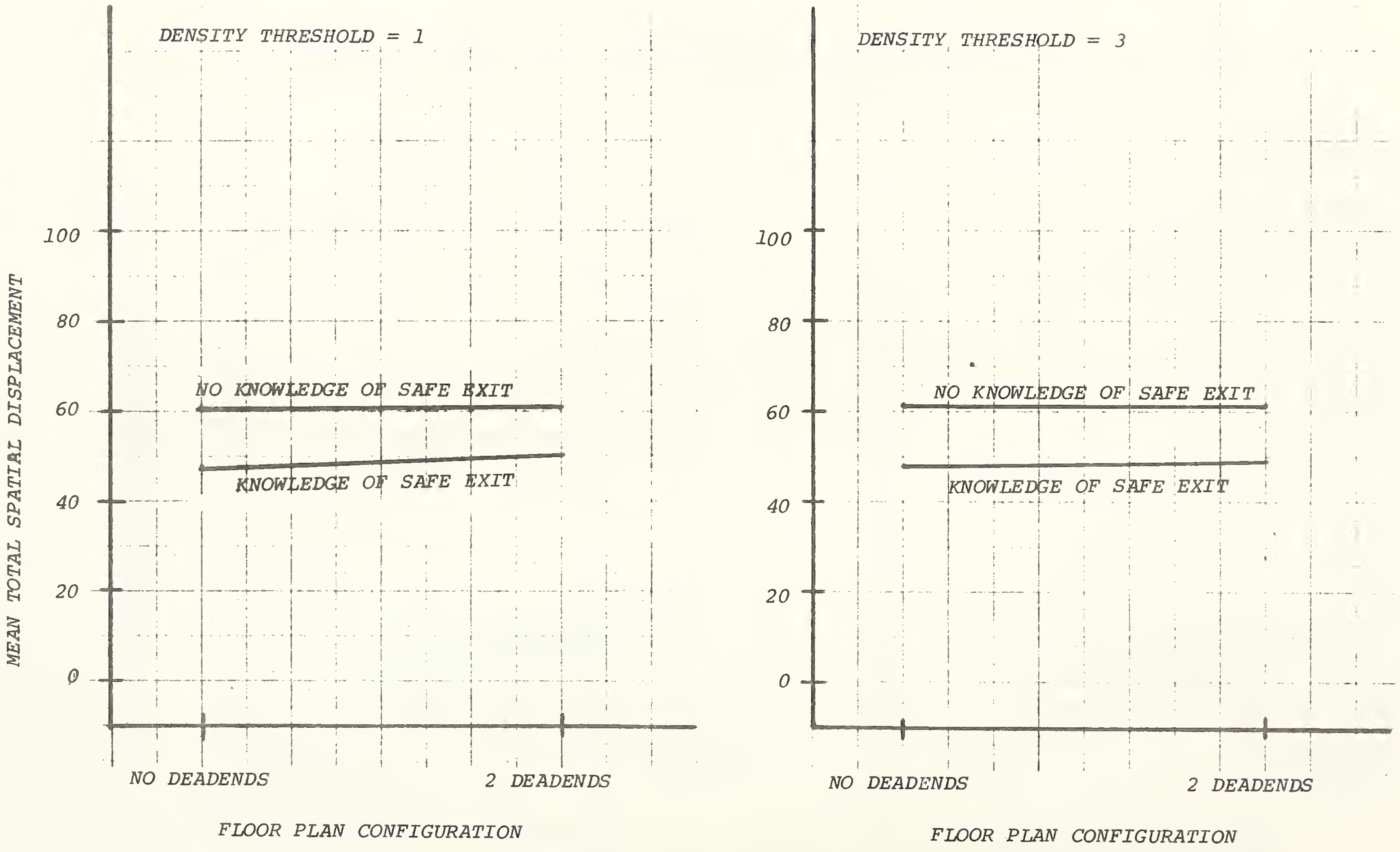


Figure 3.20 Effects of Knowledge of Safe Exit, Floor Plan Configuration, and Occupant Density on Mean Spatial Displacement

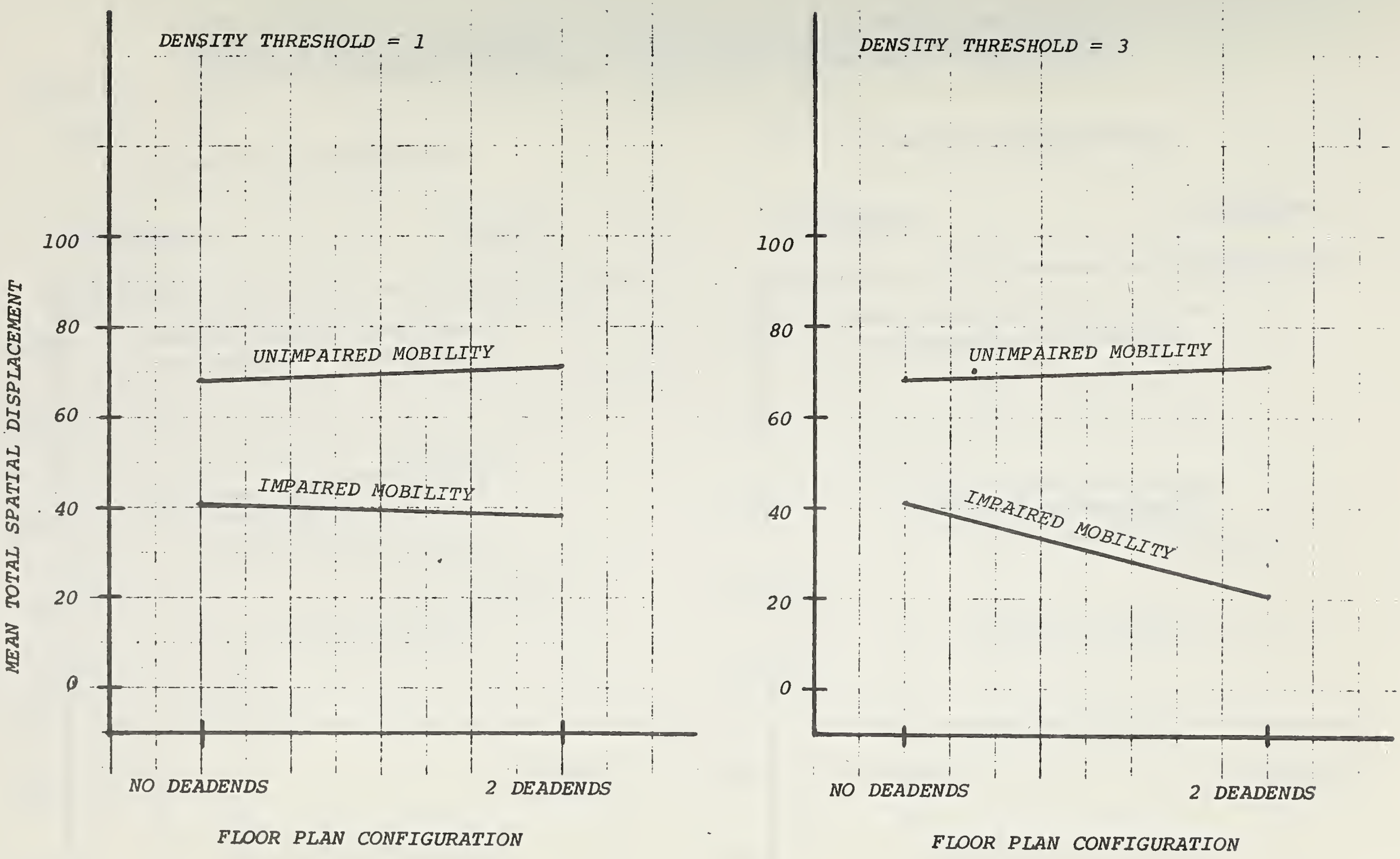


Figure 3.21 Effects of Occupant Mobility, Floor Plan Configuration, and Occupant Density on Mean Spatial Displacement

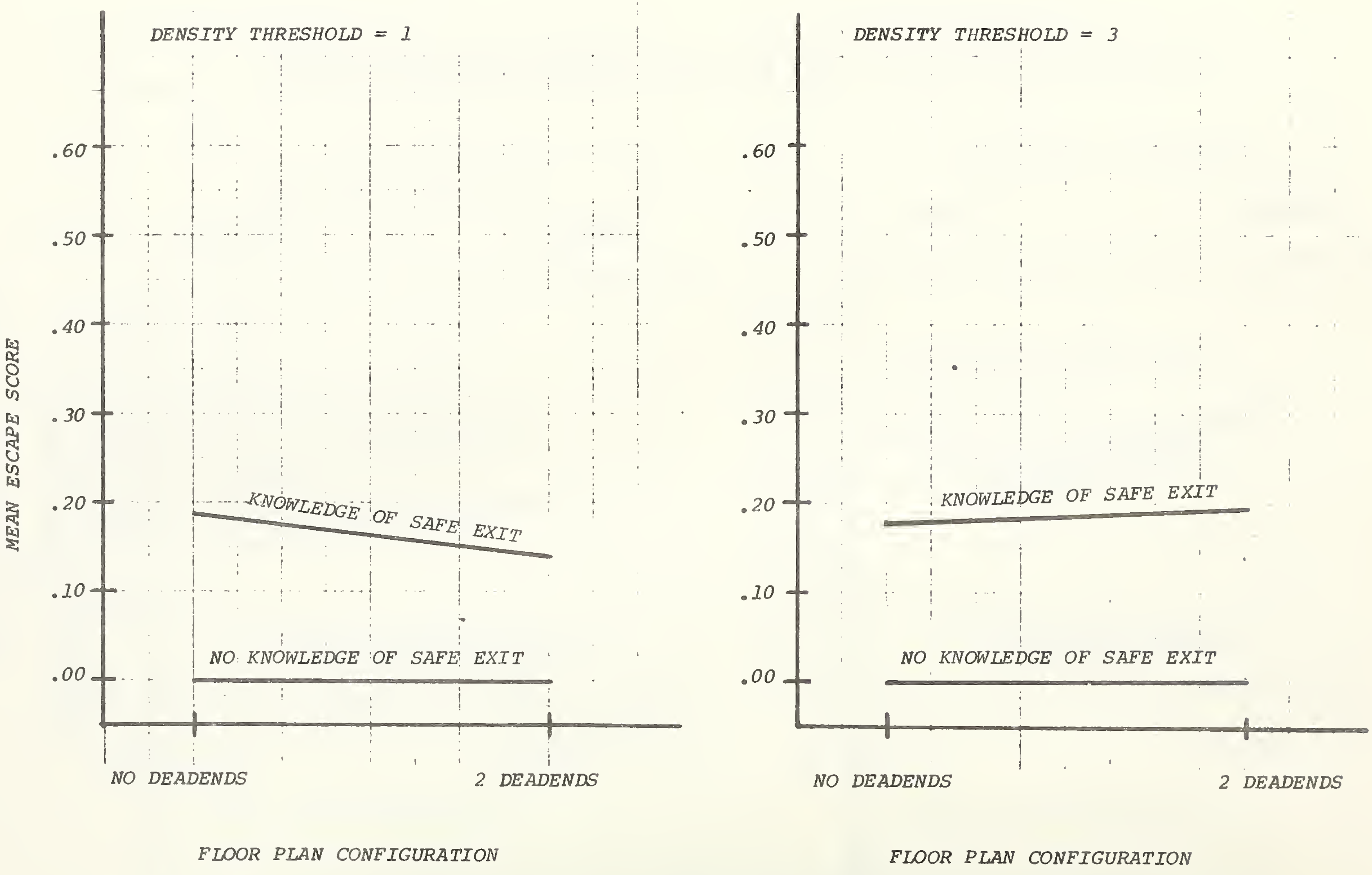


Figure 3.22 Effects of Knowledge of Safe Exit, Floor Plan Configuration, and Occupant Density on Mean Escape Score

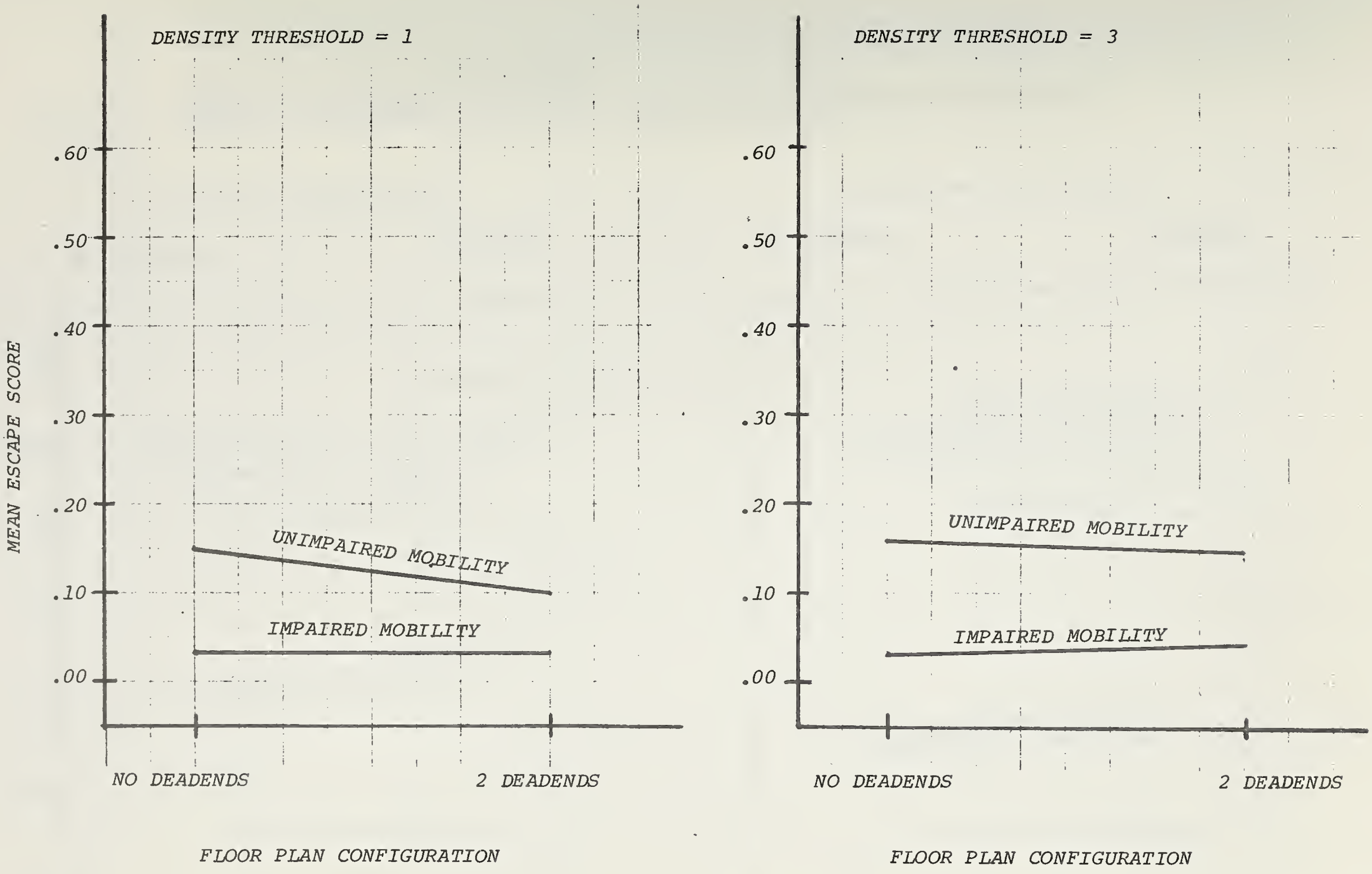


Figure 3.23 <u>Effects of Occupant Mobility, Floor Plan Configuration, and Occupant Density on Mean Escape Score</u>

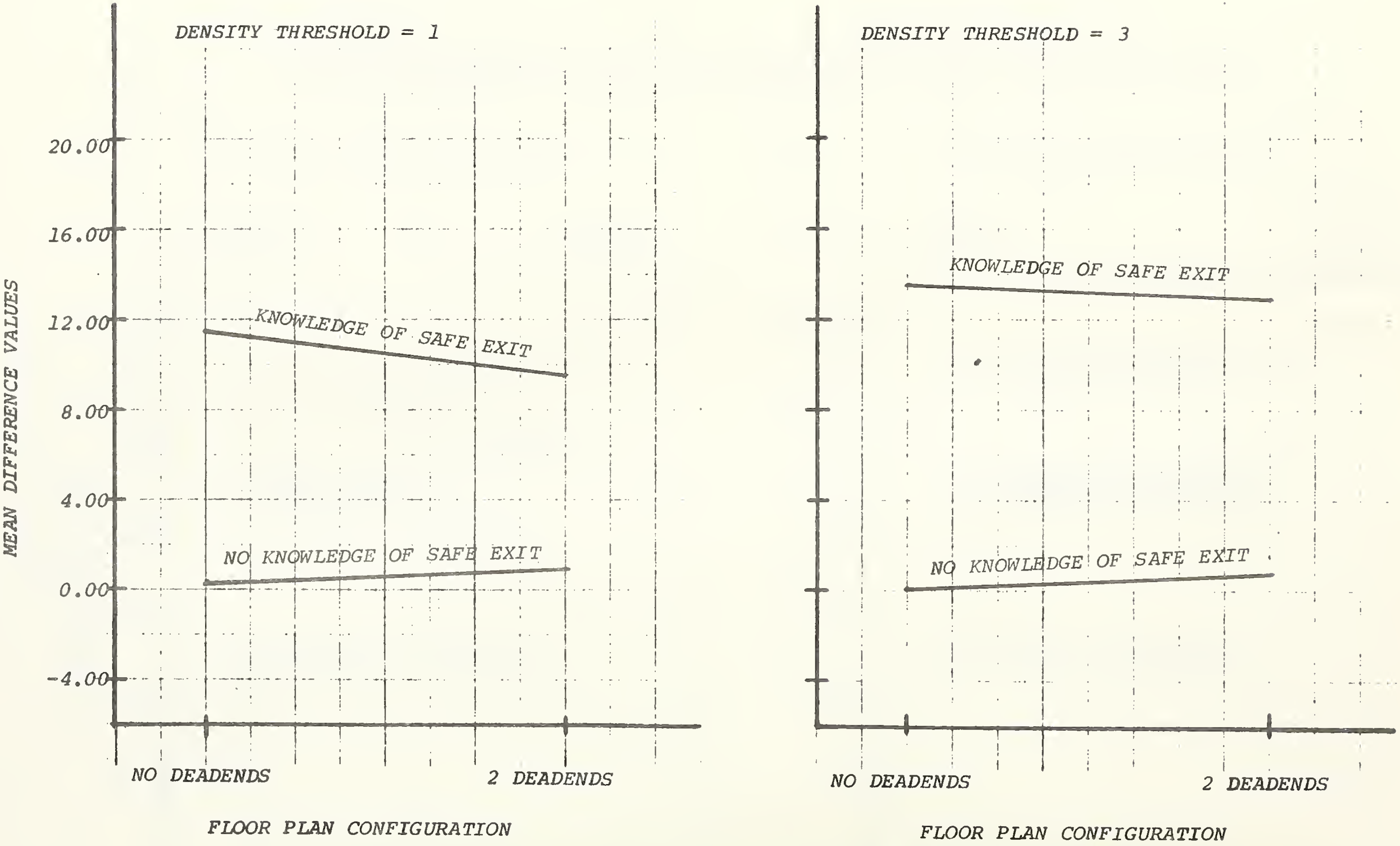


Figure 3.24 Effects of Knowledge of Safe Exit, Floor Plan Configuration, and Occupant Density on Mean Difference Values

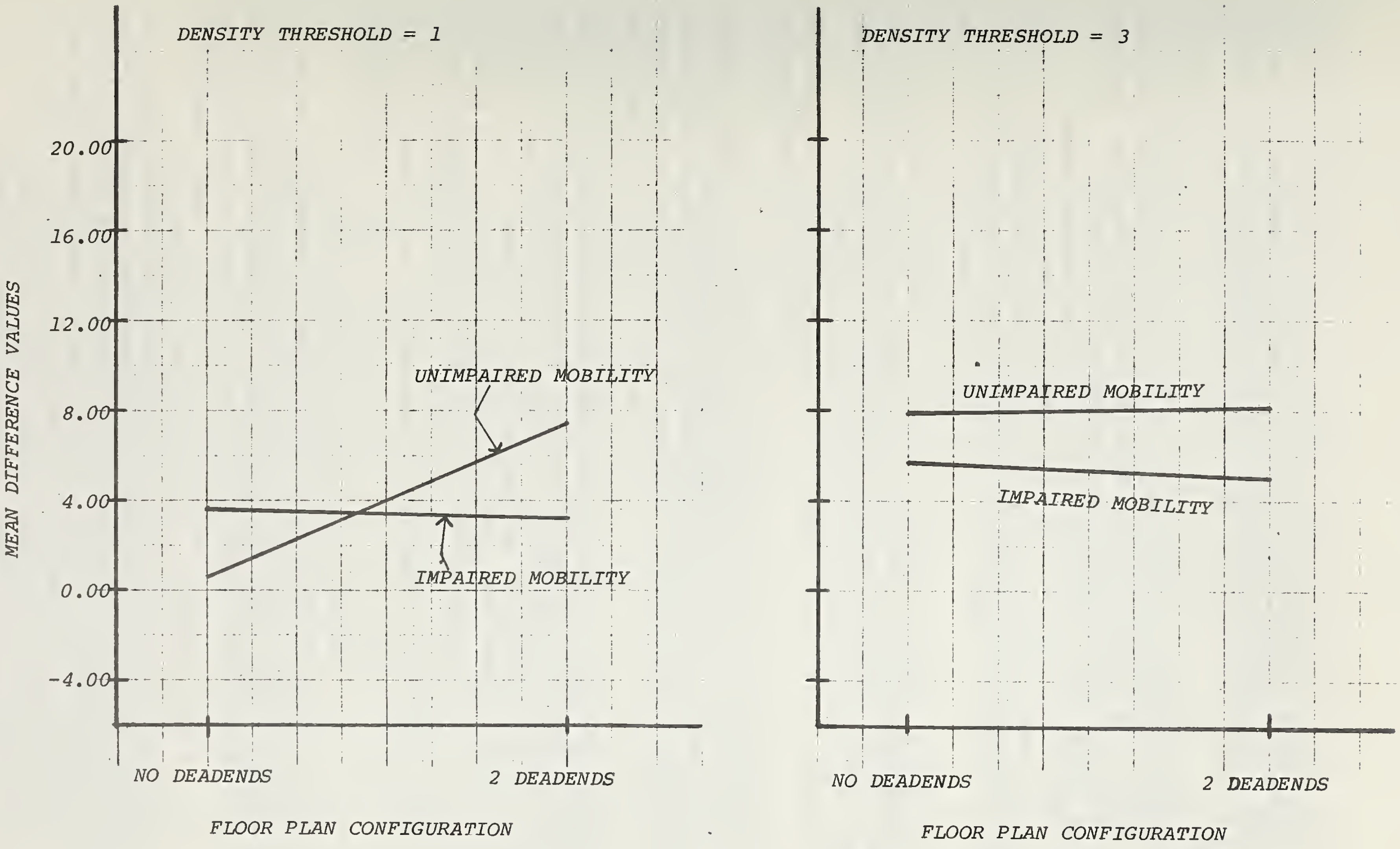


Figure 3.25 Effects of Occupant Mobility, Floor Plan Configuration, and Occupant Density on Mean Difference Values

Main effect of floor plan configuration: For all dependent variables studied, variation in floor plan configuration (i.e., the presence or absence of dead end corridors) produced no significant change in simulation outcomes.

Main effect of occupant density: Variation in occupant (i.e., whether the density threshold was 1 or 3) had no significant effect upon simulation outcomes for total number of occupants escaping, total spatial displacement, and escape score. Variation in density did, however, have a significant effect upon occupants' final positions relative to their initial ones, as follows: On the average, occupants in the case permitting higher density were one "step" closer to the exit goal than were individuals in the low density case. This distance translates to 3.5 feet (1.08 m).

Main effect of occupant mobility: Variation in occupant mobility (i.e., whether occupants could move during every, or every other time frame) had a significant effect upon simulation outcomes for all dependent measures recorded. In all cases, the effect was in the predicted direction.

Main effect of knowledge of the safe exit location: Variation in safe exit knowledge (i.e., whether or not an occupant knew the location of the safe exit at the onset of the event) significantly effected event outcomes for all dependent measures. In each case, the effect was in the predicted direction:

Interaction effects: For each of the four dependent variables studied, the occupant mobility-by-exit knowledge interaction was signficantly large. The analysis of variance for final relative to initial location yielded a number of other significant interaction effects. These included the first order interactions between occupant density and mobility, density and exit knowledge, and floor plan and exit knowledge.

Moreover, the second order effect between density, mobility, and exit knowledge was significantly large.

Discussion: We shall first consider the analyses for number escaping, escape score, and spatial displacement, since these appear to establish a consistent pattern of results. The analysis for final relative to initial location produced results falling far outside this pattern. We will therefore consider that analysis separately.

In discussing the first three analyses, we note that the mobility and knowledge main effects, and the mobility-by-knowledge interactions, were all statistically significant. The main effects by themselves lend ample support for the sensitivity hypotheses enumerated in Section 3.3.2 above. This is, occupants' escape behavior, under the experimental conditions established in Section 3.3.1, are impacted by variation in levels of occupant mobility and safe exit location knowledge. Moreover, in comparison to these "personal trait" variables, variation in both allowable density and floor plan configuration have negligible effects.

However, the interaction of occupant mobility with safe exit knowledge must be considered if we are to make a case for the sensitivity of BFIRES to variation in these two parameters. Clearly, the finding that BFIRES produces interactions among certain input parameters is of critical importance, and permits us to qualify our statement about the program's sensitivity. In particular, sensitivity to exit knowledge is contingent upon the level of occupant mobility considered (the reverse also being true). We note that although occupants require a knowledge of the safe exit location in order to escape the floor:

(1) those who are knowledgeable are more likely to escape if they are not mobility-impaired; and

(2) those who are knowledgeable will escape more quickly if they are not mobility-impaired. Moreover:

(3) mobility-impaired occupants traverse the fewest steps, but for the case of non-impaired individuals, full exit knowledge results in fewer steps than does a lack of knowledge.

As discussed earlier in Chapter 3.0, these effects are consistent with the model underlying BFIRES.

Initial relative to final occupant locations: The analysis of variance for this variable produced results falling far outside the pattern discussed above. Recall that this "difference value" was defined as the difference between an occupant's initial linear distance from the exit goal, and his final distance measured at the terminal time frame. This variable was expected to tell us whether those occupants whose attainment of the exit goal was terminated prematurely (by the arbitrary selection of the simulation end point) had otherwise made substantial progress toward the escape objective. Accordingly, a pattern of results similar to that produced by the analysis of the total number of occupants escaping was anticipated. Portions of this pattern were, indeed, found in the analysis of difference values: occupant mobility and exit knowledge main effects, and the first order interaction between these parameters. However, the occupant density main effect was also found to be significantly large, as were a number of other first and second order interactions. These clearly complicate the analysis.

It may be that these effects are indeed predictable from the model underlying BFIRES, but that they involve relationships so complex as to require additional analyses. Such analyses would involve observing the variables studied here at other levels, as well as considering additional variables. This task is clearly beyond the current scope.

But perhaps these effects cannot be traced to the model underlying the computer program. In that case, the program may not have been consistently deduced from the model, or alternatively, the inconsistent findings may be artifacts of the particular sample of cases studied. Again, the solution of these problems will be tasks for future research.

3.4 SENSITIVITY TO ENVIRONMENTAL VERSUS OCCUPANT PARAMETERS

3.4.1 An Overall Comparison Between Analyses "A" and "B"

In Analysis "A", all replications involved occupants who were fully knowledgeable of the safe exit location, and who were not mobility-impaired. Under these conditions, event outcomes for various levels of two environmental parameters (occupant density and spatial subdivision) were examined. The analysis concluded that, under the conditions established for study, BFIRES may be considered sensitive to variation in both environmental parameters.

In Analysis "B", however, two occupant-based parameters (mobility impairment and knowledge of safe exit location) were investigated in conjunction with the environmental variables studied in the former case. Occupants in Analysis "B" varied in level of mobility impairment and exit knowledge, as well as on the basis of which environmental system they inhabited. This analysis concluded that, when individuals vary on the basis of occupant parameters, BFIRES is sensitive only to variation in these parameters; under these conditions, the effects of variation in environmental parameters disappear.

This finding is critical for two important reasons. First, it helps define the ranges of conditions under which we should expect BFIRES to be sensitive to various parameters. Second, it raises an important theoretical question very worthy of future investigation: is the likelihood of safe escape dependent upon the extent of occupants' mobility, emergency preparedness and emergency alert, while not at all dependent on the physical design of the building?

3.5 SUMMARY OF SENSITIVITY RESULTS

In cases where all occupants knew the safe exit location, and where no occupants were mobility-impaired, experiments using the BFIRES computer simulation program yield results suggesting that:

(1) Escape score varies as a function of the extent to which a spatial zone is subdivided into smaller segments. For a zone of given gross area, the mean escape score for all occupants should increase as the number of spatial subdivisions is increased.

(2) Total spatial displacement by occupants varies inversely as a function of the extent of spatial subdivision. As a zone is subdivided into more spaces, the number of steps taken by occupants should decrease.

(3) Escape score varies as a function of permissible occupant density. With a higher permissible density, a higher mean escape score should be found for all occupants on the floor.

(4) Total spatial displacement varies inversely as a function of permissible occupant density. At higher densities, fewer spatial displacements should be found.

(5) The effect of permissible occupant density is dependent upon the extent of spatial subdivision. Density appears to have the greatest impact where spatial zones are subdivided into a larger number of smaller areas.

Under conditions where occupants varied in their knolwedge of safe exit location, and their levels of mobility impairment, BFIRES experiments yielded results suggesting that:

(6) Floor plan configuration (specifically, the presence or absence of dead end corridors) has no effect on emergency egress outcomes.

(7) In general, egress outcomes will not be influenced by variations in permissible occupant density.

(8) Egress outcomes vary as a function of occupant mobility. Unimpaired occupants are more likely to escape the floor within a given time period, will escape more quickly, and will traverse shorter routes than will their mobility-impaired counterparts.

(9) Egress outcomes vary as a function of occupants' knowledge of the safe exit location. Knowledgeable occupants are more likely to escape the floor, will escape more quickly, and will traverse shorter routes than will uninformed individuals.

(10) The effect of exit knowledge is dependent upon occupants' mobility. In general, occupants never informed as to the location of the safe exit may never escape within the time allowed. However, occupants who _do_ know the safe exit's location will escape faster and along more direct routes if they are not mobility-impaired.

4.0 CONCLUSIONS

4.1 KEY FINDINGS

This effort demonstrated the feasibility and utility of systematically conceptualizing the emergency egress behavior of building occupants under certain specified conditions, and of simulating this behavior on a digital computer. Although the ability of the simulation model to predict or replicate real-world fire events has not yet been tested, results to date do suggest that the computer program is applicable to problems of immediate interest to building designers and regulators. At the very least, this project has paved the way for future validation research, and for applications exercises.

In addition to demonstrating both the "simulability" of occupants' egress behaviors and the value of this capability, important technical findings were also noted. In particular, this report showed that:

(1) A variety of general egress situations could be simulated by means of the BFIRES computer program.

(2) Every such situation is unique, and is defined by the set of user-supplied input parameter values which describe the building, the threat, and the occupants.

(3) BFIRES output is readily interpretable in terms of familiar units of space and time. Thus, the program is capable of simulating environments of known (or desired) spatial dimensions, and events of known (or desired) temporal duration.

(4) BFIRES was shown to be sensitive to variations in parameters of immediate interest to building designers and regulators. These included: (a) several aspects of floor plan configuration, (b) the existence of impairments to occupants' mobility, (c) occupants' familiarity with the building layout, and (d) levels of occupant density.

4.2 APPLICABILITY OF AVAILABLE DATA TO THE MODEL-BUILDING PROCESS

As discussed in Chapter 1.0, BFIRES resulted from a deductive exercise, in which a particular model of emergency egress was derived from a much more general and basic system: an information-processing theory of human behavior. The deductive approach was favored over empirical model-building chiefly because of unresolved difficulties which characterize the available data on emergency egress. Several of these are summarized below.

First, available data shed virtually no light on the cognitive processes at work during building fire emergencies. For example, while Wood (1972) and Bryan (1977) attempted to identify action sequences, neither described specific processes through which such sequences were determined. Accordingly, there remains no direct knowledge of: (a) occupants' perception of the building-scale emergency environment; (b) mechanisms for gathering and interpreting information about the emergency situation; (c) mechanisms for evaluating alternative action patterns; and (d) strategies for making decisions about action in or upon the emergency environment. Since BFIRES deals specifically with these factors, use of this data to formulate or test systemic relationships was not possible.

Second, the literature is characterized by several important methodological shortcomings. Taken as a whole, for example, the body of research on egress behavior and human responses during fires was not guided by any single set of objectives. Consequently, individual efforts were neither cumulative nor purposefully directed toward theory development. What we do have is a collection of discrete studies in which it is often difficult to even compare results for ostensibly similar variables. Moreover, many of the studies discussed above suffer problems or reliability and validity. Included are the following:

(1) Often, such complex constructs as "egress behavior" were operationalized in terms of pedestrian flow measures (e.g., velocity, flow rate, density). Variance due to social and cognitive factors could not be assessed, and variance attributed to physical design features may therefore have been overrated.

(2) With few exceptions (experiments by Peschl (1971) and Henderson (1971), field investigations of the carrying capacity of egress ways were characterized by a lack of experimental controls. In fact, most studies involved no tests of explicit hypotheses, and may consequently be viewed as exercises in data collection technique.

(3) Even where meaningful trends might have been found in the carrying capacity data, investigators rarely attempted to quantify these in a statistically rigorous fashion.

(4) Surveys of fire survivors consisted of scalar, structured, and open ended items. The reliability and validity of the various protocols employed has not, to date, been examined.

(5) Survey researchers never systematically controlled for effects arising from the temporal proximity of the interview and the actual experience. Where too long a period lapsed, respondents' impressions of the event may have changed due to media reports and interactions with other victims. Moreover, the emotional impact of the event may, over time, have altered the individual's memory of the fire experience.

Conversely, if the event was traumatic, too short a time lapse could have resulted in distorted reports. For the available data base, the extent of such effects - and hence the validity of findings - are largely indeterminate.

(6) Finally, when properly conducted an interview may yield much insight into behavioral processes which result in safe escape during a building fire. Since those who do not survive can never be interviewed, our knowledge of processes leading to failure can only be based on indirect inference.

For a more detailed treatment of the literature on human behavior in building fires, refer to the review by Stahl and Archea (1977).

4.3 GENERAL SUMMARY

This report documented computer simulation experiments designed to calibrate and analyze BFIRES, a computer program which simulates building occupants' egress behavior during certain fire conditions. The investigation demonstrated that emergency egress behavior can be systematically conceptualized, and that the computer simulation of this phenomenon would be useful. In general, experimental results suggested that BFIRES is sensitive to variation in a number of parameters of immediate concern to building designers and regulators. Finally, the applicability of available research data on human behavior in fires to the simulation-modeling process was briefly discussed.

REFERENCES

Bryan, J. L., Smoke as a Determinant of Human Behavior in Fire Situations: Project People. Washington, D.C.: U.S. Dept. of Commerce, National Bureau of Standards, NBS GCR 77-94, 1977.

Henderson, L. F., The Statistics of Crow Fluids. Nature, 1971, 229, 381-383.

Peschl, I., Passage Capacity of Door Openings in Panic Situations. Bowen (Construction), January 9, 1971, 62-67.

Stahl, F. I., A Computer Simulation of Human Behavior in Fires: Interim Report. Washington, D.C.: U.S. Dept. of Commerce, National Bureau of Standards, NBSIR 78-1514, 1978.

Stahl, F. I. and Archea, J., An Assessment of the Technical Literature on Emergency Egress from Buildings. Washington, D.C.: U.S. Dept. of Commerce, National Bureau of Standards, NBSIR 77-1313, 1977.

Turing, A. M., Computing Machinery and Intelligence. Mind, 1950, 59, 236, 433-460.

Wood, P. G., The Behavior of People in Fires. London, U.K.: Dept. of the Environment and Fire Officers' Committee, Joint Fire Research Organization, November, 1972.

APPENDIX A: "BFIRES" PROGRAM DOCUMENTATION

INTRODUCTION

This appendix provides documentary material which describes the BFIRES computer program. The program is presented as a "package" composed of a network of interrelated subroutines. These are linked through the EXECUTIVE program, as shown in Figure A.1. For each unit, the following information is provided:

(1) program or subroutine name;

(2) loop within which the program functions;

(3) description of the program's purpose of function;

(4) description of computational formulas, if any;

(5) description of program logic by means of flow diagrams*;

(6) FORTRAN listing.

Subroutines comprising BFIRES/VERSION 1 are outlined in Table A.1.

---

* Not included with I/O and non-behavioral subroutines.

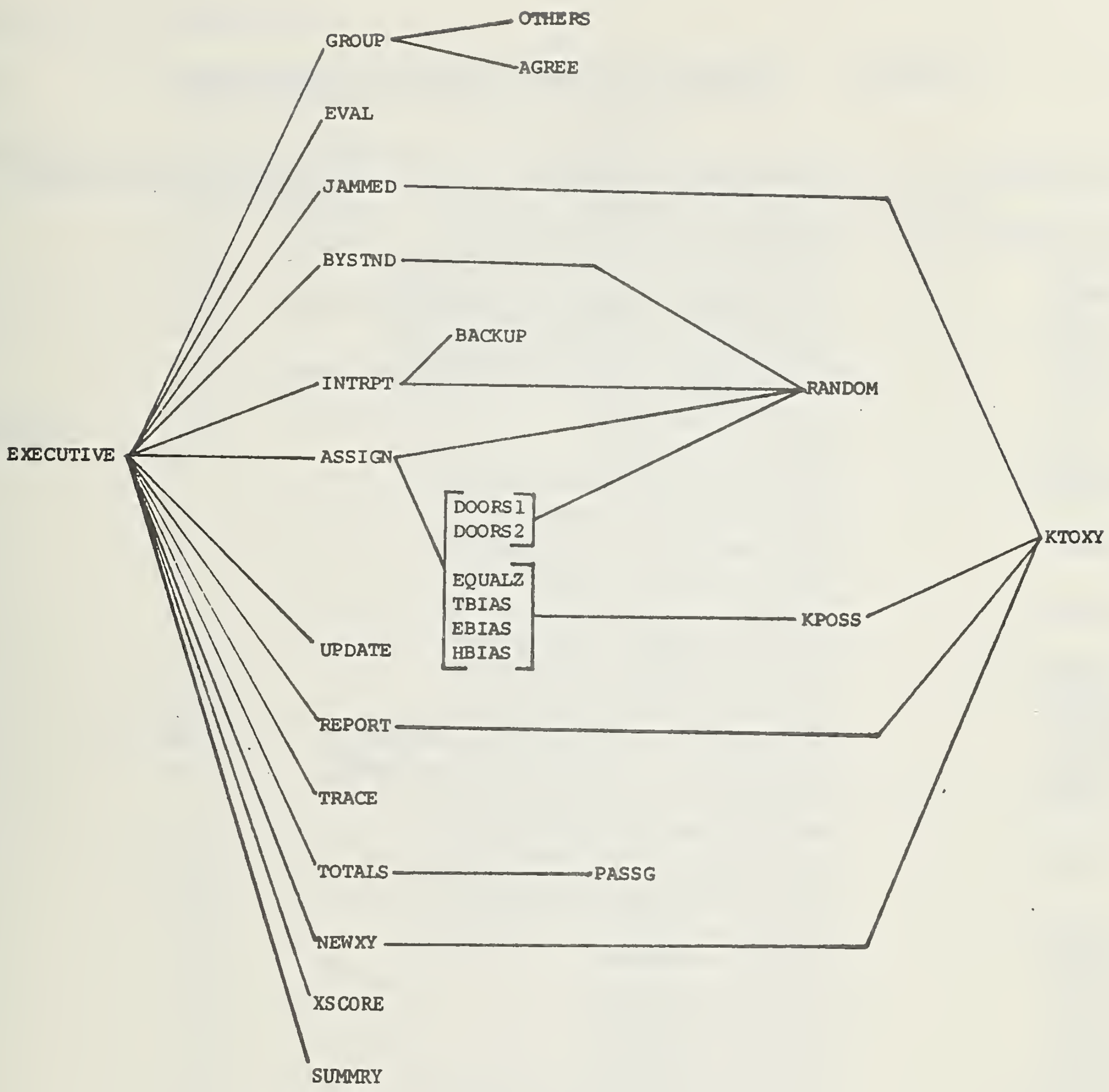
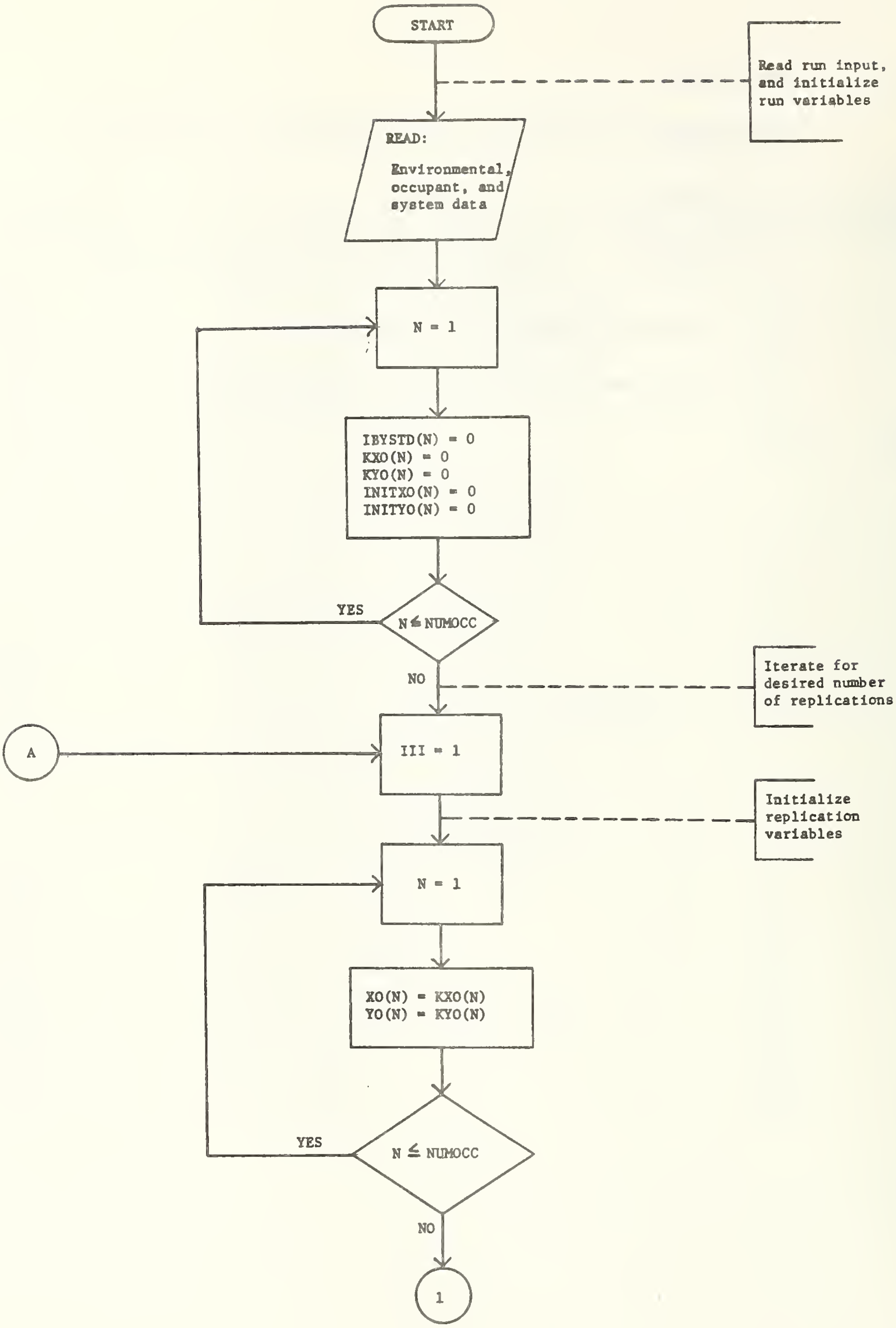


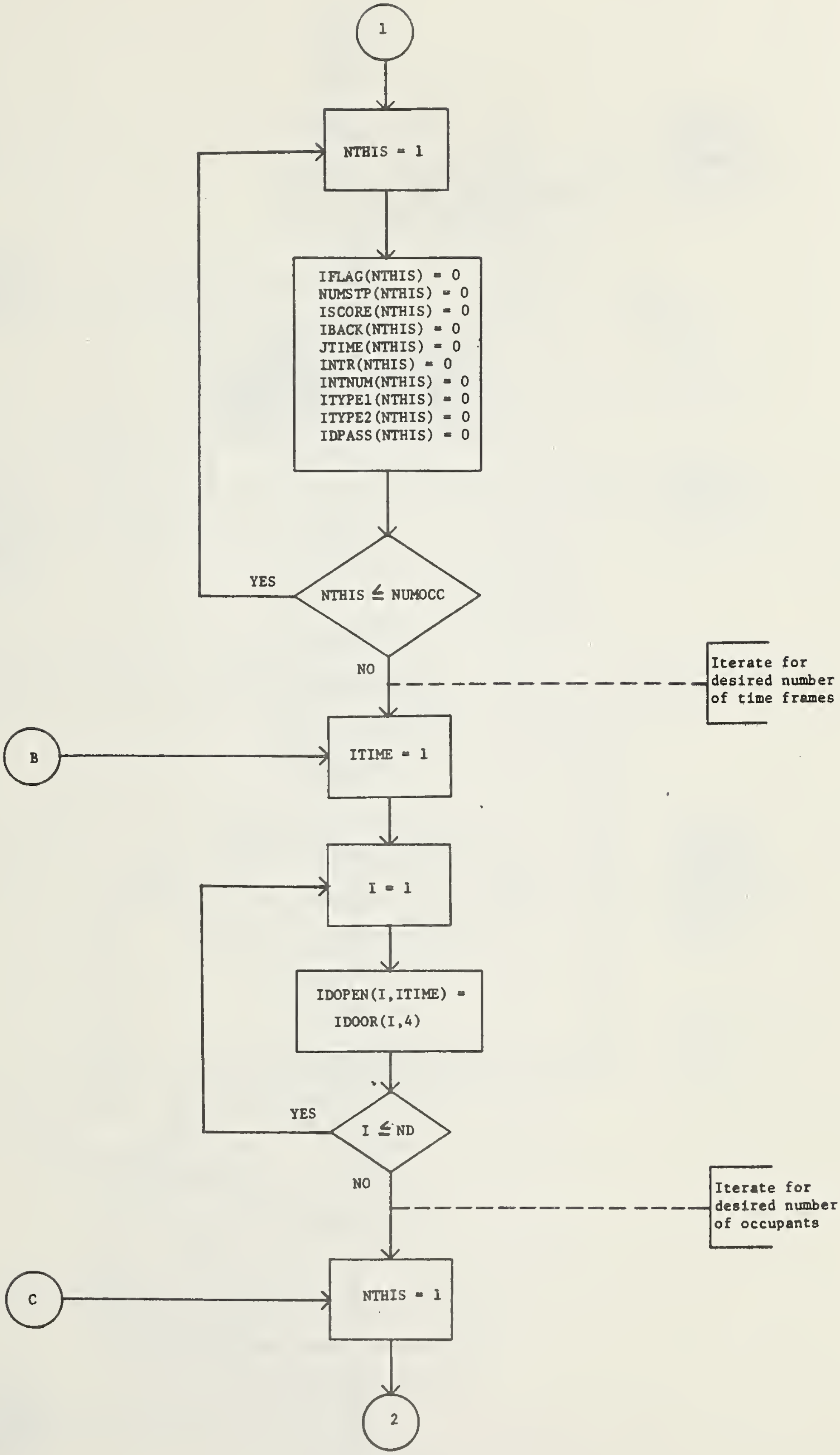
Figure A.1 Subroutine Network and Flow of Control

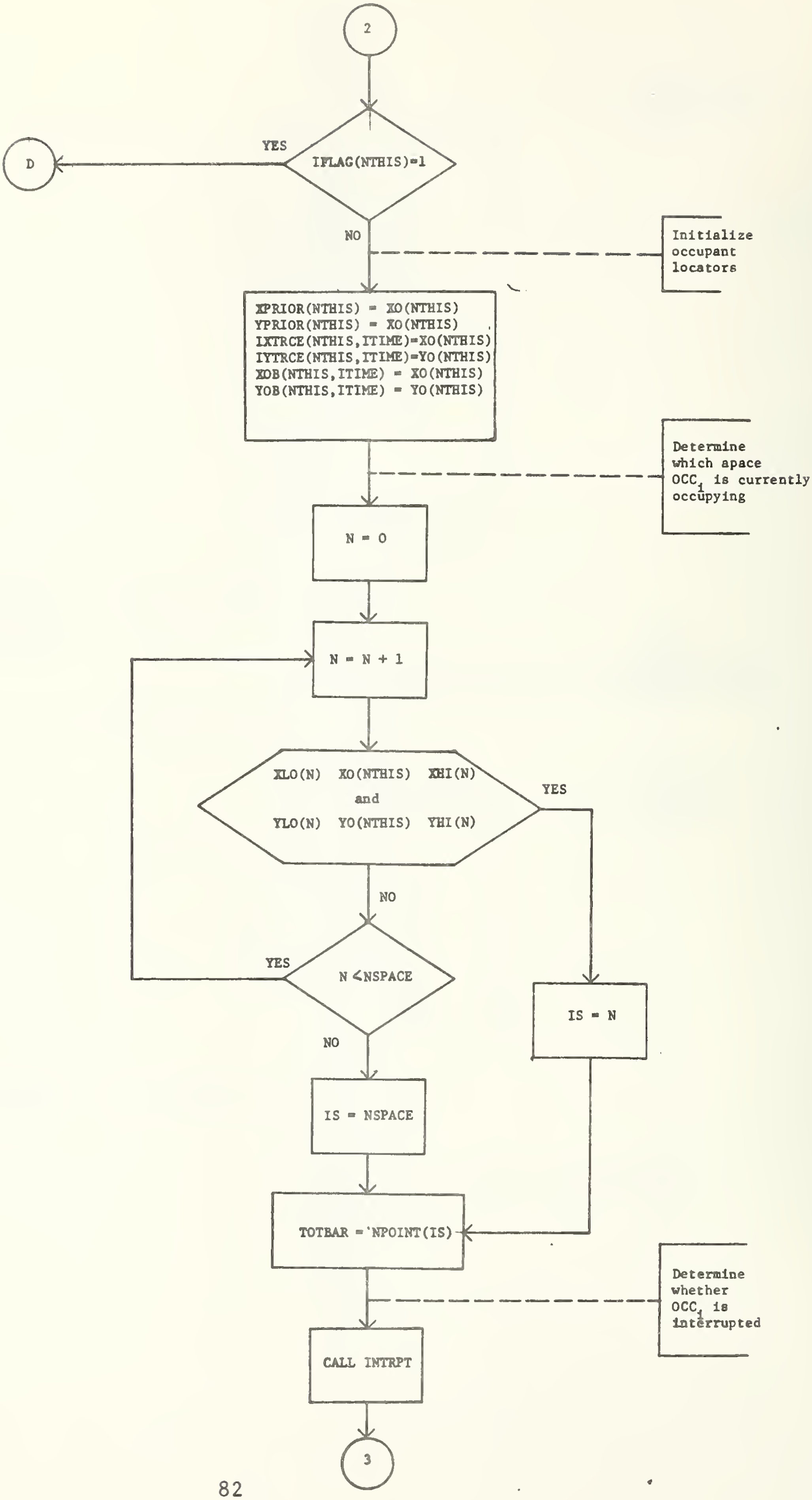
Table A.1 Summary of BFIRES/VERSION 1 Subroutines

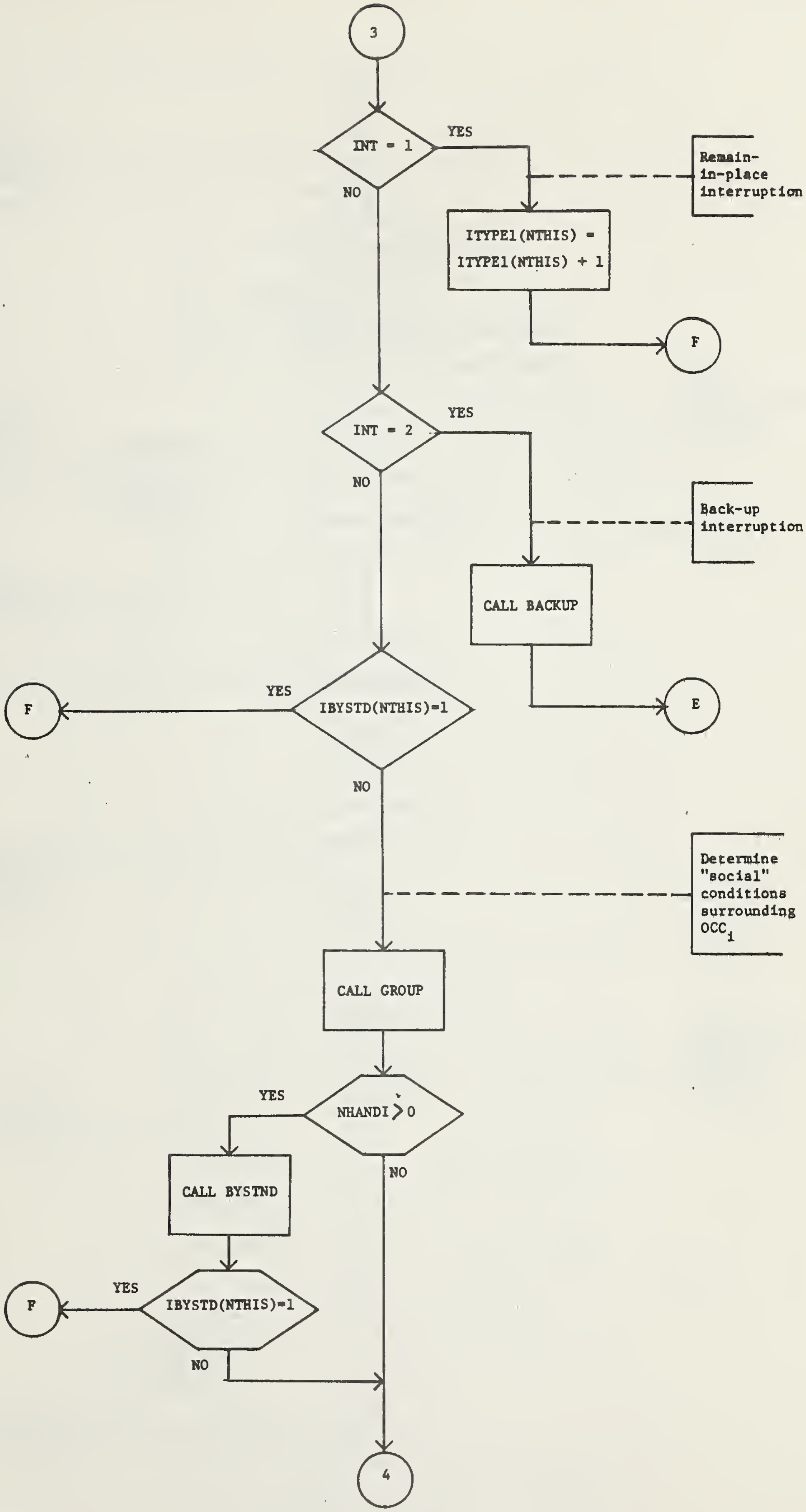
Subroutine	Functional Category	User Options Available?
EXECUTIVE	Central calling program	no
KPOSS	Perceptual process simulator	no
GROUP	Perceptual process simulator	no
OTHERS	Perceptual process simulator	no
AGREE	Perceptual process simulator	no
KTOXY	Perceptual process simulator utility program	no
JAMMED	Perceptual process simulator	no
EQUALZ	Information processing and decisionmaking simulator	no
TBIAS	Information processing and decisionmaking simulator	no
EBIAS	Information processing and decisionmaking simulator	no
DOORS1	Decisionmaking simulator	no
DOORS2	Decisionmaking simulator	no
EVAL8	Information processing simulator	yes
EVAL20	Information processing simulator	yes
INTRPT	Information processing and decisionmaking simulator	no
BACKUP	Information processing and decisionmaking simulator	no
ASSIGN	Movement behavior simulator	no
UPDATE	Utility program	no
NEWXY	Utility program	no
XSCORE	Utility program	no
STEPS	Utility program	no
PASSG	Utility program	no
SUMMARY	Input/output (I/O) program	yes
REPORT	I/O Program	yes
TRACE	I/O Program	yes
TOTALS	I/O Program	yes

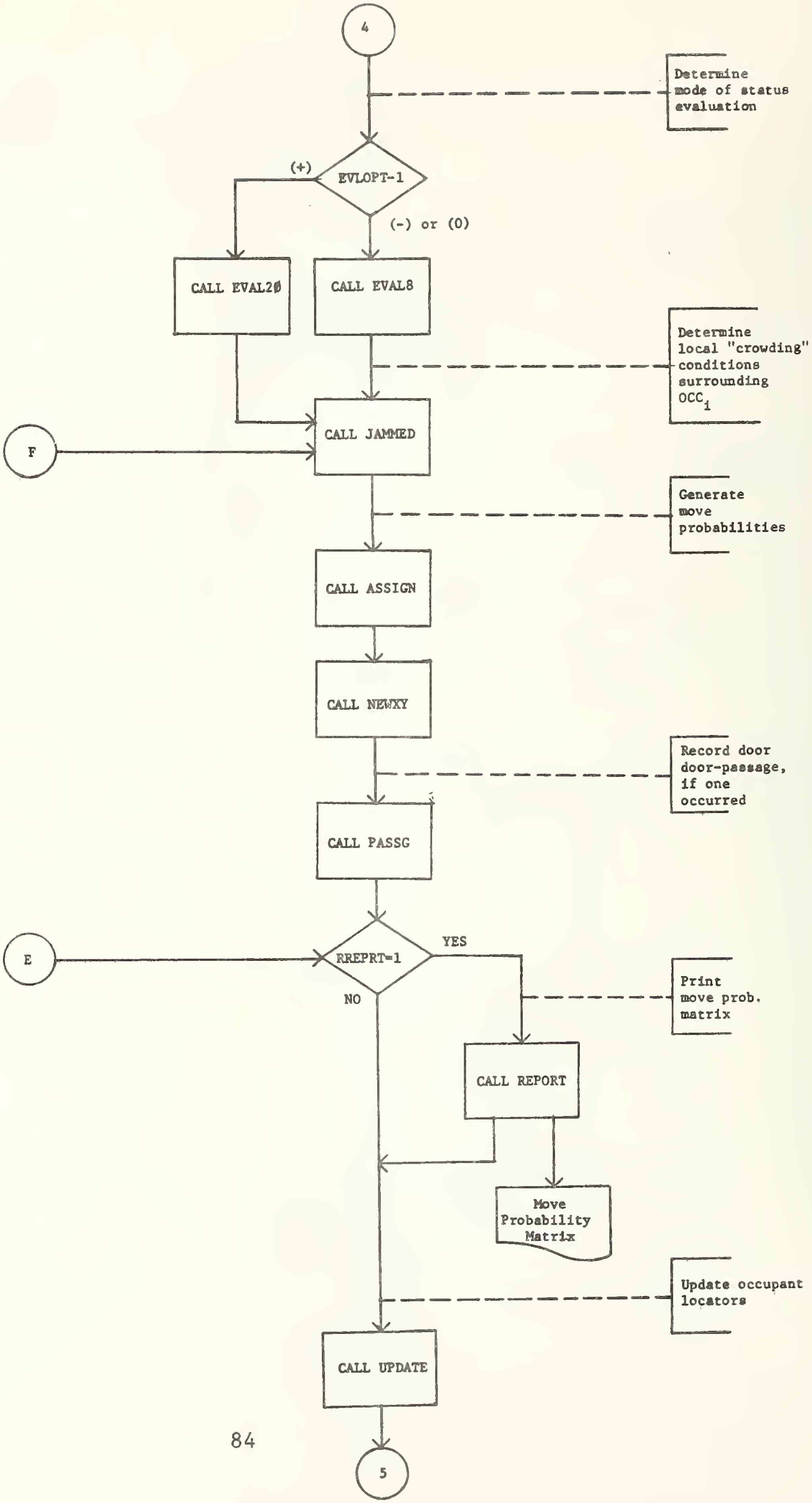
Routine	EXECUTIVE
Loop	Replication
Purpose	(1) Reads-in input data files; (2) processes complete replications of building fire events; (3) accumulates event outcome data; (4) summarizes outcome data in tabular form.
Formulas	n/a

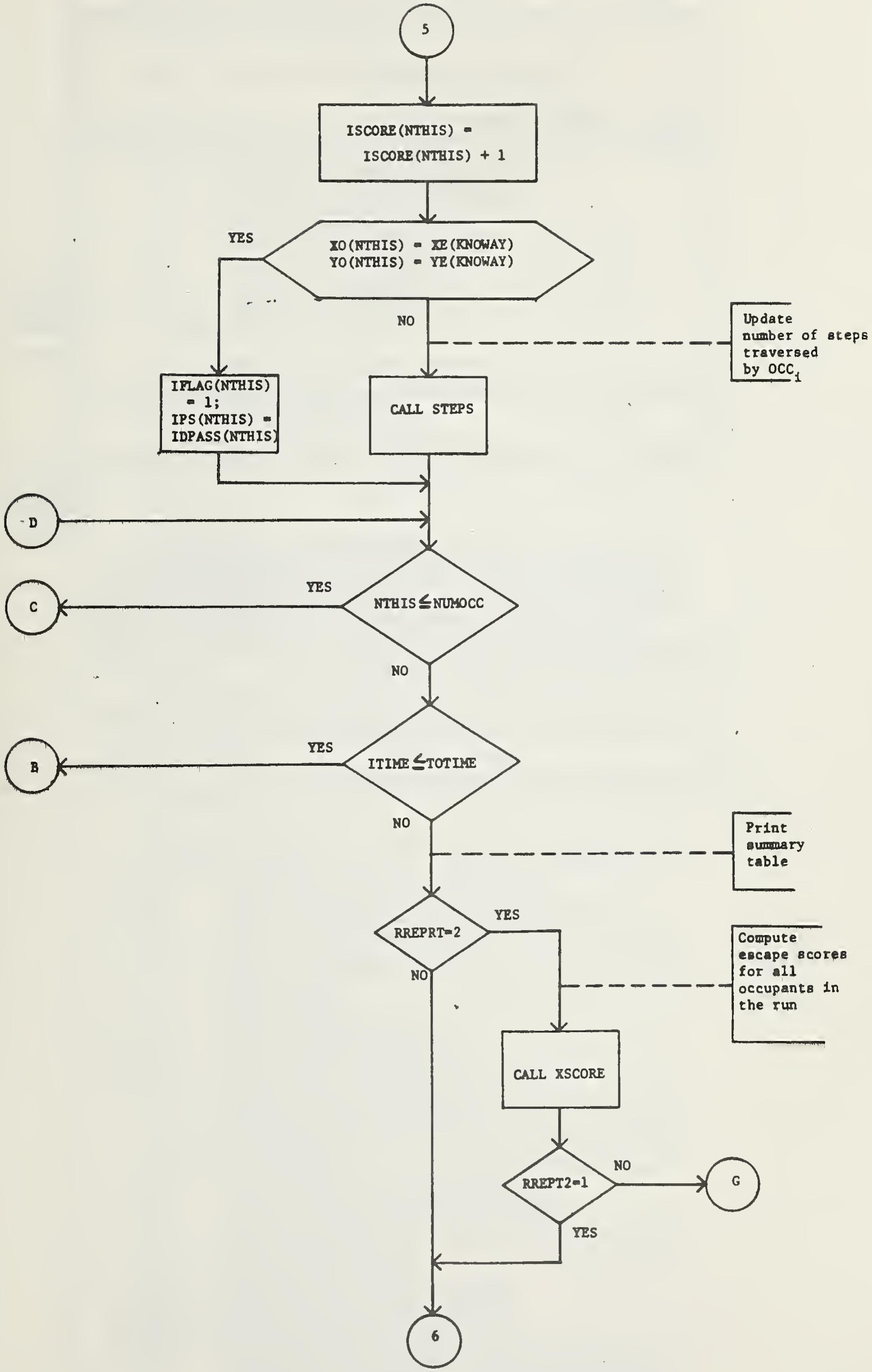

START
Read run input, and initialize run variables
READ: Environmental, occupant, and system data
N = 1
IBYSTD(N) = 0
KXO(N) = 0
KYO(N) = 0
INITXO(N) = 0
INITYO(N) = 0
YES
N ≤ NUMOCC
NO
Iterate for desired number of replications
A
III = 1
Initialize replication variables
N = 1
XO(N) = KXO(N)
YO(N) = KYO(N)
YES
N ≤ NUMOCC
NO
1

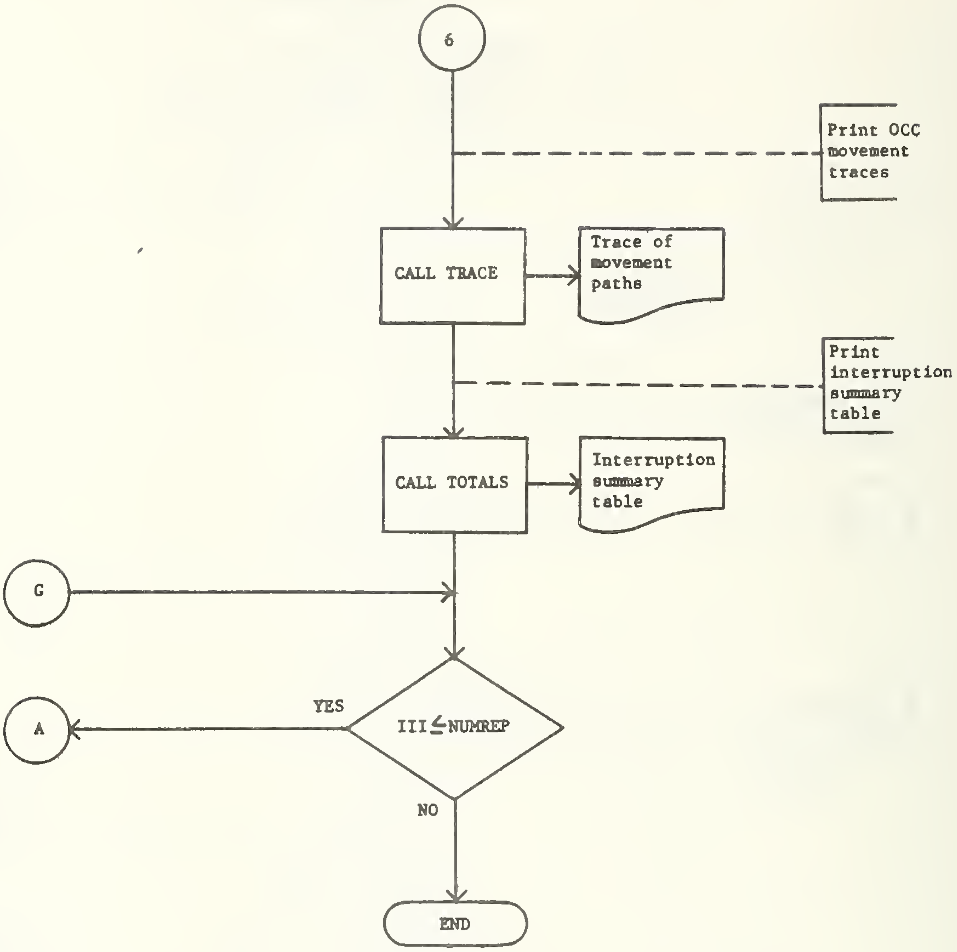

1
NTHIS = 1
IFLAG(NTHIS) = 0
NUMSTP(NTHIS) = 0
ISCORE(NTHIS) = 0
IBACK(NTHIS) = 0
JTIME(NTHIS) = 0
INTR(NTHIS) = 0
INTNUM(NTHIS) = 0
ITYPE1(NTHIS) = 0
ITYPE2(NTHIS) = 0
IDPASS(NTHIS) = 0
YES
NTHIS ≤ NUMOCC
NO
Iterate for desired number of time frames
B
ITIME = 1
I = 1
IDOPEN(I,ITIME) = IDOOR(I,4)
YES
I ≤ ND
NO
Iterate for desired number of occupants
C
NTHIS = 1
2


2
IFLAG(NTHIS)=1
YES
D
NO
Initialize
occupant
locators
XPRIOR(NTHIS) = XO(NTHIS)
YPRIOR(NTHIS) = XO(NTHIS)
IXTRCE(NTHIS,ITIME)=XO(NTHIS)
IYTRCE(NTHIS,ITIME)=YO(NTHIS)
XOB(NTHIS,ITIME) = XO(NTHIS)
YOB(NTHIS,ITIME) = YO(NTHIS)
Determine
which apace
OCC$_i$ is currently
occupying
N = 0
N = N + 1
XLO(N) XO(NTHIS) XHI(N)
and
YLO(N) YO(NTHIS) YHI(N)
YES
NO
N <NSPACE
YES
NO
IS = N
IS = NSPACE
TOTBAR = 'NPOINT(IS)
Determine
whether
OCC$_i$ is
interrupted
CALL INTRPT
3


3
INT = 1
YES
NO
Remain-in-place interruption
ITYPE1(NTHIS) = ITYPE1(NTHIS) + 1
F
INT = 2
YES
NO
Back-up interruption
CALL BACKUP
E
F
YES
IBYSTD(NTHIS)=1
NO
Determine "social" conditions surrounding OCC$_i$
CALL GROUP
YES
NHANDI > 0
NO
CALL BYSTND
F
YES
IBYSTD(NTHIS)=1
NO
4


4
Determine mode of status evaluation
EVLOPT-1
(+)
(-) or (0)
CALL EVAL20
CALL EVAL8
Determine local "crowding" conditions surrounding OCC_i
F
CALL JAMMED
Generate move probabilities
CALL ASSIGN
CALL NEWXY
Record door door-passage, if one occurred
CALL PASSG
E
RREPRT=1
YES
NO
Print move prob. matrix
CALL REPORT
Move Probability Matrix
Update occupant locators
CALL UPDATE
5


5
ISCORE(NTHIS) = ISCORE(NTHIS) + 1
YES
XO(NTHIS) = XE(KNOWAY)
YO(NTHIS) = YE(KNOWAY)
NO
Update number of steps traversed by OCC$_i$
IFLAG(NTHIS) = 1; IPS(NTHIS) = IDPASS(NTHIS)
CALL STEPS
D
YES
C
NTHIS ≤ NUMOCC
NO
YES
B
ITIME ≤ TOTIME
NO
Print summary table
RREPRT=2
YES
NO
Compute escape scores for all occupants in the run
CALL XSCORE
RREPT2=1
NO
G
YES
6


6
Print OCC movement traces
CALL TRACE
Trace of movement paths
Print interruption summary table
CALL TOTALS
Interruption summary table
G
YES
A
III ≤ NUMREP
NO
END

```
C
C*****  THIS VERSION IS FOR THE INTERDATA 7/32 AND OTHER 32-BIT UNITS  *********
C
C*******************************************************************************
C*******************************************************************************
C*                                                                             *
C*                                                                             *
C*       BFIRES -- HUMAN EGRESS BEHAVIOR DURING BUILDING FIRES                 *
C*                                                                             *
C*                                                                             *
C*******************************************************************************
C*******************************************************************************
C*                                                                             *
C*       WRITTEN BY FRED I. STAHL, RESEARCH PSYCHOLOGIST                       *
C*                  ARCHITECTURAL RESEARCH PROGRAM                             *
C*                  ENVIRONMENTAL DESIGN RESEARCH DIVISION                     *
C*                  CENTER FOR BUILDING TECHNOLOGY,NEL                         *
C*                  NATIONAL BUREAU OF STANDARDS                               *
C*                  WASHINGTON, DC  20234                                      *
C*                                                                             *
C*       FOR        PROGRAM FOR DESIGN CONCEPTS                                *
C*                  CENTER FOR FIRE RESEARCH,NEL                               *
C*                  NATIONAL BUREAU OF STANDARDS                               *
C*                                                                             *
C*       IN SUPPORT OF THE                                                     *
C*                                                                             *
C*                  NBS/HEW FIRE-LIFE SAFETY PROGRAM                           *
C*                                                                             *
C*******************************************************************************
C*                                                                             *
C*                  REVISED  AUGUST 30,1978                                    *
C*                                                                             *
C*******************************************************************************
C*******************************************************************************
C
C
C
C
C        THE BFIRES PROGRAM SIMULATES HUMAN EGRESS BEHAVIOR DURING BUILDING
C   FIRES.  BFIRES IS A DISCRETE TIME STOCHASTIC SIMULATION BASED ON A NON-
C   STATIONARY MARKOV MODEL OF THE BUILDING FIRE PROCESS.  ACCORDING TO THIS
C   MODEL, FIRES MAY BE UNDERSTOOD IN TERMS OF THREE INTERACTING COMPONENTS.
C   THESE ARE  (1) THE FIRE AND ITS BI-PRODUCTS,  (2) THE BUILDING ENCLOSURE,
C   AND  (3) THE HUMAN OCCUPANTS.  EACH POSSESSES UNIQUE CHARACTERISTICS,
C   AND THE BEHAVIOR OF EACH CONTRIBUTES TO THE OVERALL OUTCOME OF ANY FIRE
C   EVENT (I.E., HOW MANY PEOPLE ESCAPED, HOW MUCH TIME WAS REQUIRED FOR ESCAPE,
C   ETC.).
C
C        EXEC2 IS THE SECOND VERSION OF THE BFIRES EXECUTIVE ROUTINE.  THE
C   PURPOSE OF EXEC2 IS TO READ-IN ALL USER-SUPPLIED DATA, AND THEN TO RUN A
C   FIRE EVENT FOR A GIVEN PERIOD OF TIME.  IN ADDITION, EXEC2 PERMITS THE USER


C   TO CONDUCT A NUMBER (UP TO 20) OF REPLICATIONS OF A GIVEN FIRE EVENT, IN A
C   SINGLE COMPUTER RUN.
C
C
C        THE FOLLOWING DATA MUST BE PROVIDED BY THE USER.  THESE DESCRIBE THE
C   FIRE, THE BUILDING ENCLOSURE, AND THE OCCUPANTS FOR THE COMPUTER.
C
C     XT,YT        X,Y COORDINATES OF INITIAL THREAT LOCATION
C     NUMEXT       NUMBER OF EXITS FROM THE FLOOR (NOT MORE THAN 2)
C     MXTIME       OCCUPANTS' PERCEIVED TIME FOR EGRESS(LESS THAN TOTIME)
C     NSPACE       NUMBER OF SPATIAL SUBDIVISIONS ON THE FLOOR (NOT MORE THAN
C                    20)
C     EVLOPT       STATUS EVALUATION OPTION SELECTOR
C     MK           PRESET TO ZERO
C     C            PRESET TO ZERO
C     IALLOW       SPATIAL CROWDING FACTOR
C     ND           NUMBER OF DOORS ON THE FLOOR (NOT MORE THAN 30)
C     RREPRT       SUMMARY TABLE OPTION SELECTOR
C     RREPT2       SUMMARY TABLE OPTION SELECTOR
C     XE,YE        X,Y COORDINATES OF EXITS FROM THE FLOOR
C     NE           NUMBER OF EXITS FROM A SPATIAL SUBDIVISION
C     NPOINT       NUMBER OF POINTS COMPRISING WALLS WHICH ENCLOSE A SPATIAL
C                    SUBDIVISION (NOT MORE THAN 75)
C     IBAR(IS,1,J) X COORDINATE OF THE JTH POINT OF A WALL WHICH ENCLOSES
C                    SUBDIVISION IS
C     IBAR(IS,2,J) Y COORDINATE OF THE JTH POINT OF A WALL WHICH ENCLOSES
C                    SUBDIVISION IS
C     IGOALX       X COORDINATE OF AN EXIT FROM A SUBDIVISION
C     IGOALY       Y COORDINATE OF AN EXIT FROM A SUBDIVISION
C     XLO,XHI      RANGE OF X COORDINATES OF POINTS COMPIRISING WALLS WHICH
C                    ENCLOSE A SUBDIVISION
C     YLO,YHI      RANGE OF Y COORDINATES OF POINTS COMPRISING WALLS WHICH
C                    ENCLOSE A SUBDIVISION
C     IDOOR(1,J)   X COORDINATE OF LOCATION OF JTH DOOR
C     IDOOR(2,J)   Y COORDINATE OF LOCATION OF JTH DOOR
C     IDOOR(3,J)   DOOR-TYPE IDENTIFIER FOR JTH DOOR
C     IDOOR(4,J)   DOOR POSITION IDENTIFIER FOR JTH DOOR
C     NUMOCC       NUMBER OF OCCUPANTS IN THE EVENT (NOT MORE THAN 20)
C     TOTIME       TOTAL NUMBER OF SIMULATED TIME FRAMES TO BE RUN (I.E.,
C                    LENGTH OF THE FIRE EVENT -- NOT MORE THAN 100 FRAMES)
C     IRAND        RANDOM NUMBER SEED (NECESSARY FOR 32 BIT COMPUTER ONLY), ANY
C                    5 DIGIT ODD NUMBER.   FOR UNIVAC-1108 VERSION, INSERT ANY
C                    5 DIGIT DUMMY NUMBER.
```

```
C     NUMREP        TOTAL NUMBER OF REPLICATIONS DESIRED
C     P12           PROBABILITY OF A TYPE-2 INTERRUPTION
C     P10           PROBABILITY OF NO INTERRUPTION
C     INTLIM        OCCUPANTS' INTERRUPTION LIMIT
C     LBYSTD        OCCUPANTS' INTERVENTION LIMIT
C     IHANDI        OCCUPANTS' MOBILITY STATUS
C     KNOWAY        OCCUPANTS' INITIAL KNOWLEDGE OF BEST EXIT
C     XO,YO         X,Y COORDIATES OF OCCUPANTS' INITIAL SPATIAL LOCATIONS
C     POPEN         PROABILITY THAT OCCUPANT WILL OPEN A CLOSED DOOR
C     PCLOSE        PROBABILITY THAT OCCUPANT WILL CLOSE AN OPEN DOOR
C

C   THESE DATA ARE ENTERED IN THE FOLLOWING SEQUENCE...
C
C        TITLE  (ANY 80 CHARACTER COMMENT)
C             (20A4)
C        IFMT  (USER SUPPLIED FORMAT STATEMENT)
C             (20A4)
C        JFMT  (USER SUPPLIED FORMAT STATEMENT)
C             (20A4)
C        KFMT  (USER SUPPLIED FORMAT STATEMENT)
C             (20A4)
C        XT,YT,NUMEXT,MXTIME,NSPACE,EVLOPT,MK,C,IALLOW,ND,RREPRT,RREPT2
C             (5(I2,1X),2(I1,1X),F1.0,1X,2(1X,I2),2(1X,I1))
C        XE,YE     ALL XC OORDINATES FOLLOWED BY ALL YC OORDINATES
C             (IFMT)
C
C        REPEAT THE FOLLOWING SEQUENCE FOR EACH SPATIAL SUBDIVISION
C
C           NE,NPOINT
C             (IFMT)
C           IBAR(IS,1,J)  COORDIATES 1-NPOINT IN ADJACENT FIELDS
C             (JFMT)
C           IBAR(IS,2,J) C OORDINATES I-NPOINT IN ADJACENT FIELDS
C             (JFMT)
C           IGOALX,IGOALY     ALL X COORDINATES, FOLLOWED BY ALL Y COORDINATES
C             (IFMT)
C           XLO,XHI,YLO,YHI
C             (IFMT)
C
C        IDOOR(1,J)    (COORDINATES 1-ND IN ADJACENT FIELDS)
C             (JFMT)
C        IDOOR(2,J)    (COORDINATES 1-ND IN ADJACENT FIELDS)
C             (JFMT)
C        IDDOR(3,J)    (IDENTIFIERS I-ND IN ADJACENT FIELDS)
C             (JFMT)
C        IDOOR(4,J)    (IDENTIFIERS I-ND IN ADJACENT FIELDS)
C             (JFMT)
C        NUMOCC,TOTIME,IRAND,NUMREP,PI2,PI0
C             (2(I2,1X),I5,1X,I2,2(1X,F4.2))
C
C        REPEAT THE FOLLOWING LINE FOR EACH OCCUPANT IN THE RUN...
C
C           INTLIM,LBYSTD,IHANDI,KNOWAY,XO,YO,POPEN,PCLOSE
C             (KFMT)
C
C
C
C
C
      DIMENSION ITYPE1(20),ITYPE2(20),IDPASS(20),IPS(20)
      DIMENSION IXTRCE(20,100),IYTRCE(20,100)
      DIMENSION IBACK(23),JTIME(20),INITYO(20),INITXO(20)
      DIMENSION INTR(20),INTNUM(20),TITLE(20)
      DIMENSION IFMT(20),JFMT(20),KFMT(20),IENTER(9)
      DIMENSION IBAR(20,75,2),LBYSTD(20),IHANDI(20),KNOWAY(20)


      DIMENSION INTLIM (20),IBYSTD(20),NE(20),NPOINT(20)
      DIMENSION PTDIST(20),PEDIST(20),P(9)
      DIMENSION IGOALX(20,10),IGOALY(20,10),KXO(20),KYO(20)
      DIMENSION POPEN(20),PCLOSE(20),IDOOR(30,4),IDOPEN(30,100)
      DIMENSION IFLAG(20),ISCORE(20),NUMSTP(20)
       INTEGER XPRIOR(20),YPRIOR(20),SCORE(20)
      INTEGER XT,YT,XO(20),YO(20),XE(10),YE(10),TOTBAR,TOTIME
      INTEGER XLO(20),XHI(20),YLO(20),YHI(20),EVLOPT
      INTEGER XOB(20,100),YOB(20,100),RREPRT,RREPT2
C
C  READ RUN INPUT AND INITIALIZE RUN VARIABLES
      READ (5,101) TITLE
C
      READ (5,101) IFMT
      READ (5,103) JFMT
      READ (5,104) KFMT
C
C: INITIALIZE THE SIMULATION...
C:  (1) ENVIRONMENTAL PARAMETERS:
      READ (5,100) XT,YT,NUMEXT,MXTIME,NSPACE,EVLOPT,MK,C,
     I   IALLOW,ND,RREPRT,RREPT2
      READ (5,IFMT) (XE(I),I=1,NUMEXT),(YE(I),I=1,NUMEXT)
      DO 10 IS=1,NSPACE
      READ (5,IFMT) NE(IS),NPOINT(IS)
      NEXIT=NE(IS)
      TOTBAR=NPOINT(IS)
      READ (5,JFMT)(IBAR(IS,I,1),I=1,TOTBAR)
      READ (5,JFMT)(IBAR(IS,I,2),I=1,TOTBAR)
      READ (5,IFMT)(IGOALX(IS,JEXIT),JEXIT=I,NUMEXT),
     1   (IGOALY(IS,JEXIT),JEXIT=1,NUMEXT)
```

```
10    READ (5,IFMT) XLO(IS),XHI(IS),YLO(IS),YHI(IS)
      READ (5,JFMT) (IDOOR(I,1),I=1,ND)
      READ (5,JFMT) (IDOOR(I,2),I=1,ND)
      READ (5,JFMT) (IDOOR(I,3),I=1,ND)
      READ (5,JFMT) (IDOOR(I,4),I=1,ND)
C:  (2) SYSTEM PARAMETERS:
      READ (5,102) NUMOCC,TOTIME,IRAND,NUMREP,PI2,PI0
      DO 40 I=1,NUMOCC
      IBYSTD(I)=0
40    CONTINUE
C:  (3) OCCUPANT PARAMETERS:
      DO 45 N=1,NUMOCC
      READ (5,KFMT) INTLIM(N),LBYSTD(N),IHANDI(N),KNOWAY(N),XO(N),YO(N)
     1    ,POPEN(N),PCLOSE(N)
      KXO(N)=XO(N)
      KYO(N)=YO(N)
      INITXO(N)=XO(N)
      INITYO(N)=YO(N)
45    CONTINUE
C
C ** EXECUTE THE SIMULATION EXPERIMENT **
C
C  ITERATE FOR DESIRED NUMBER OF REPLICATIONS
      DO 90 III=1,NUMREP

C  INITIALIZE REPLICATION VARIABLES
      DO 91 N=1,NUMOCC
      XO(N)=KXO(N)
91    YO(N)=KYO(N)
C
      DO 92 NTHIS=1,NUMOCC
      IFLAG(NTHIS)=0
      NUMSTP(NTHIS)=0
      ISCORE(NTHIS)=0
      IBACK(NTHIS)=0
      JTIME(NTHIS)=0
      INTR(NTHIS)=0
      INTNUM(NTHIS)=0
      ITYPE1(NTHIS)=0
      ITYPE2(NTHIS)=0
92    IDPASS(NTHIS)=0
C
C  ITERATE FOR DESIRED NUMBER OF TIME FRAMES
C
      DO 50 ITIME=1,TOTIME
C
      DO 501 I=1,ND
501   IDOPEN(I,ITIME)=IDOOR(I,4)
C
C  ITERATE FOR DESIRED NUMBER OF OCCUPANTS
      DO 60 NTHIS=1,NUMOCC
      IF (IFLAG(NTHIS).EQ.1) GO TO 60
C  INITALIZE OCCUPANT LOCATORS
      XPRIOR(NTHIS)=XO(NTHIS)
      YPRIOR(NTHIS)=YO(NTHIS)
      IXTRCE(NTHIS,ITIME)=XO(NTHIS)
      IYTRCE(NTHIS,ITIME)=YO(NTHIS)
      XOB(NTHIS,ITIME)=XO(NTHIS)
      YOB(NTHIS,ITIME)=YO(NTHIS)
C  DETERMINE WHICH SPACE THE OCCUPANT IS CURRENTLY OCCUPYING
      N=0
15    N=N+1
      IF (((XLO(N).LT.XO(NTHIS)).AND.
     1    (YLO(N).LT.YO(NTHIS))).AND.
     2    ((XHI(N).GT.XO(NTHIS)).AND.
     3    (YHI(N).GT.YO(NTHIS)))) GO TO 25
      GO TO 20
25    IS=N
      GO TO 26
20    IF (N.LT.NSPACE) GO TO 15
      IS=NSPACE
26    TOTBAR=NPOINT(IS)
C  DETERMINE WHETHER THE OCCUPANT IS INTERRUPTED
      CALL INTRPT (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1    XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2    IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER,
     3    X,INTLIM,INTR,INTNUM,PI2,PI0)
      IF (INT.EQ.1) GO TO 27
      IF (INT.EQ.2) GO TO 30


      GO TO 31
C  REMAIN-IN-PLACE INTERRUPTION
27    ITYPE1(NTHIS)=ITYPE1(NTHIS)+1
      GO TO 70
C  BACK-TRACK INTERRUPTION
30    CALL BACKUP (IBACK,XO,YO,INITXO,INITYO,XOB,YOB,
     1    ITIME,NTHIS,NEWXO,NEWYO,INTR,JTIME)
      ITYPE2(NTHIS)=ITYPE2(NTHIS)+1
      IF(INTR(NTHIS).EQ.0) GO TO 31
      GO TO 71
31    CONTINUE
      IF (IBYSTD(NTHIS).EQ.1) GO TO 70
C  DETERMINE SOCIAL CONDITIONS SURROUNDING THE OCCUPANT
      CALL GROUP (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,NKNOW,NAGREE,
     1    IAGREE)
```

```
      IF (NNANDI.GT.0) GO TO 65
      GO TO 67
65    CALL BYSTND (IBYSTD,NTHIS)
      IF (IBYSTD(NTHIS).EQ.1) GO TO 70
C  DETERMINE MODE OF STATUS EVALUATION
67    IF (EVLOPT-1) 68,68,69
68    CALL EVAL8(XO,YO,XT,YT,XE,YE,NTHIS,IAGREE,ITIME,IEVAL,
     1   PTDIST,TDIST,PEDIST,EDIST,IS,IGOALX,IGOALY)
      GO TO 70
69    CALL EVAL20 (MDTIME,MK,XO,YO,XE,YE,NTHIS,IAGREE,
     1   ITIME,C,IEVAL,TOTIME)
C  DETERMINE LOCAL CROWDING CONDITIONS SURROUNDING THE OCCUPANT
70    CALL JAMMED (ITIME,NTHIS,INANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,IRAND,
     2   P,MOVE,XK,YK,K,IALLOW,NUMOCC,IENTER)
C  GENERATE MOVE PROBABILITIES
      CALL ASSIGN (ITIME,NTHIS,INANDI,INT,IBYSTD,IEVAL,
     1   XO.YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2   IRAND,P,MOVE,XK,YK.K,L,IS,IGOALX,IGOALY,IENTER,
     3   X,IDOOR,POPEN,ND,MDOOR,PCLOSE)
      CALL NEWXY (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2   IRAND,P,MOVE,XK,YK,K,NEWXO,NEWYO)
C  RECORD DOOR-PASSAGE, IF ONE OCCURRED
      CALL PASSG (IDPASS,IDOOR,XO,YO,NTHIS,ND,NEWXO,NEWYO)
71    IF (RREPRT.EQ.1) GO TO 72
      GO TO 61
C  PRINT MOVE PROBABILITY MATRIX, IF THIS OPTION IS SELECTED
72    CALL REPORT (ITIME,NTHIS,INANDI,INT,IBYSTD,IEVAL,
     1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE.XE,YE,IAGREE,
     2  IRAND,P,MOVE,XK,YK,K,NUMEXT,NUMOCC,TOTIME,INTLIM,
     3  LBYSTD,KNOWAY,PTDIST,TDIST,PEDIST,EDIST,NEWXO,NEWYO,
     4   EVLOPT,IDOOR,IDOPEN,ND,INTR)
C  UPDATE OCCUPANT LOCATORS
61    CALL UPDATE (XO,YO.NTHIS,NEWXO,NEWYO)
      ISCORE(NTHIS)=ISCORE(NTHIS)+1
      IF ((XO(NTHIS).EQ.XE(KNOWAY)).AND.
     1   (YO(NTHIS).EQ.YE(KNOWAY))) GO TO 62
      GO TO 66


62    IFLAG(NTHIS)=1
      IPS(NTHIS)=IDPASS(NTHIS)
      GO TO 60
C  UPDATE NUMBER OF STEPS TRAVERSED BY THE OCCUPANT
66    CALL STEPS (XPRIOR,YPRIOR,XO,YO,NUMSTP,NTHIS)
60    CONTINUE
50    CONTINUE
C  PRINT SUMMARY TABLE, IF THIS OPTION IS SELECTED
      IF (RREPRT.EQ.2) GO TO 63
      GO TO 64
C  COMPUTE ESCAPE SCORES FOR ALL OCCUPANTS IN THE RUN
63    CALL XSCORE (TOTIME,ISCORE,NUMOCC,SCORE)
      CALL SUMMRY (INITXO,INITYO,INTLIM,LBYSTD.IHANDI,KNOWAY,POPEN,
     1   PCLOSE,SCORE,NUMSTP,IPS,III,NUMREP,NUMOCC,TOTIME,XO,YO,XE,YE,
     2   TITLE)
      IF (RREPT2.EQ.1) GO TO 64
      GO TO 90
64    CONTINUE
C  PRINT OCCUPANT MOVEMENT RACES, IF THIS OPTION IS SELECTED
      CALL TRACE (IXTRCE,IYTRCE,NTHIS.ITIME,NUMOCC,TOTIME)
C  PRINT INTERRUPTION SUMMARY TABLE, IF THIS OPTION IS SELECTED
      CALL TOTALS (IDPASS,ITYPE1,ITYPE2,NTHIS,NUMOCC)
90    CONTINUE
C
C: INPUT FORMATING
C
100   FORMAT (5(I2,1X),2(I1,1X),F1.0.1X.I2,1X,I2,2(1X,I1))
101   FORMAT (20A4)
102   FORMAT (2(I2,1X),I5,1X,I2,2(1X,F4.2))
103   FORMAT (20A4)
104   FORMAT (20A4)
      END
-
```

Routines GROUP, OTHERS, and AGREE

Loop Occupant

Purpose This is a collection of subprograms which establishes the social environment of occupants as they progress through the simulated fire event. By calling upon the routines OTHERS and AGREE, the GROUP package informs a given occupant:

(1) whether any other occupants co-occupy the space with him;

(2) whether any of the others in the space possess information currently unknown to him;

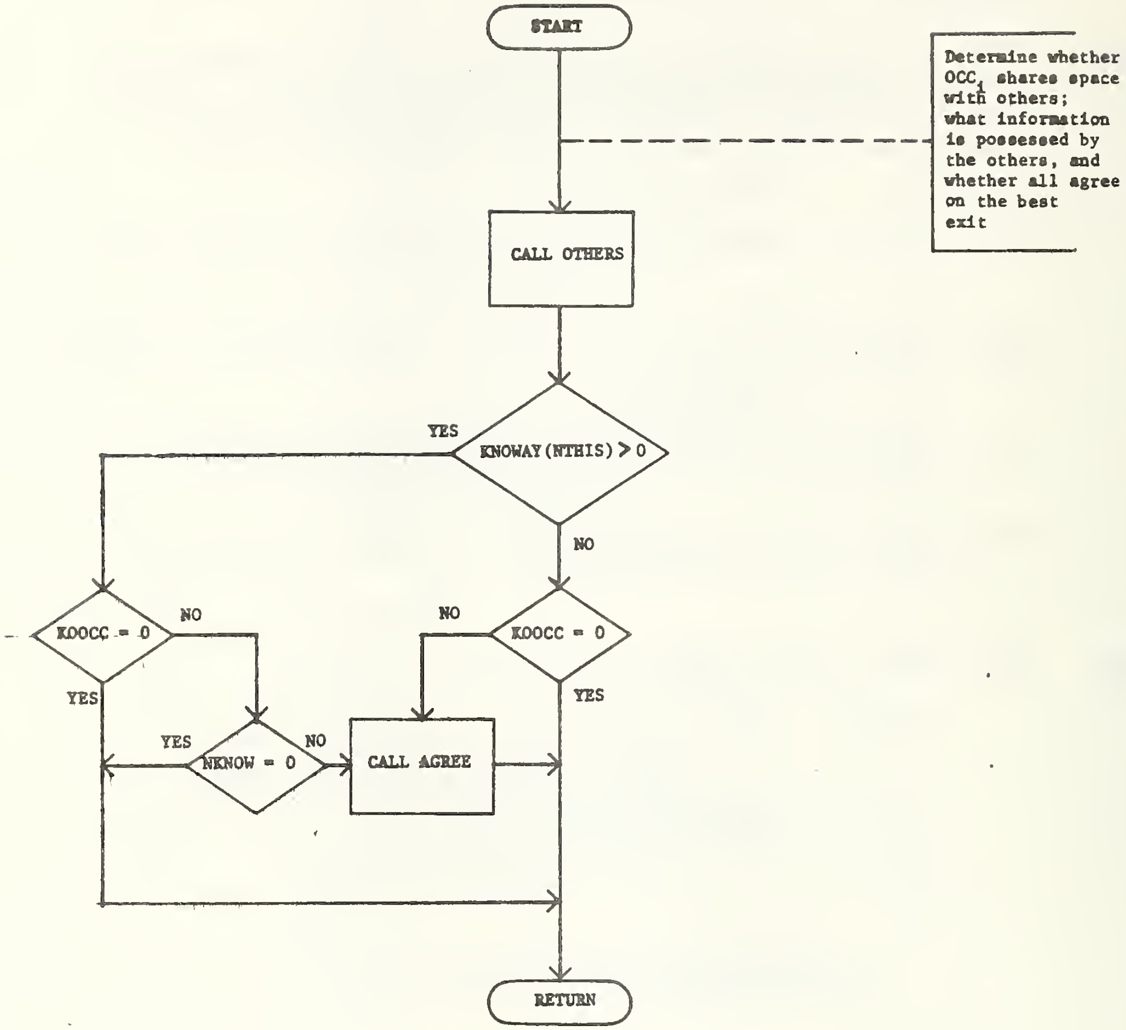
(3) whether any of the others in the space is injured or otherwise in need of assistance; and

(4) whether all the occupants in the space are able to agree upon an effective exit route.

Formulas (1) $\mathrm{PSUM} = 0.60 * \mathrm{SUM}$

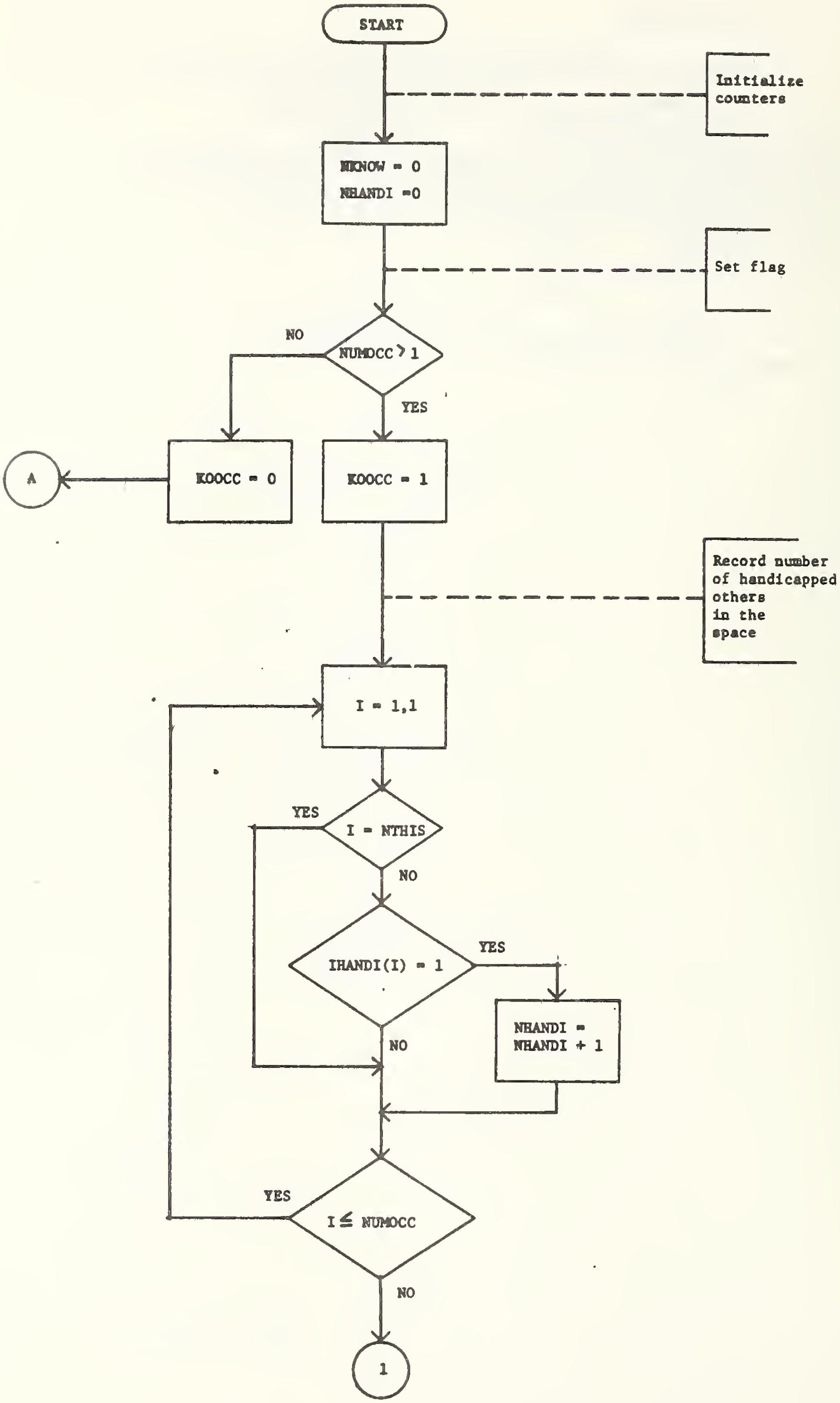
where: PSUM = the minimum number of occupants who must agree upon a single exit;

SUM = the total number of occupants impacting the consensus process.

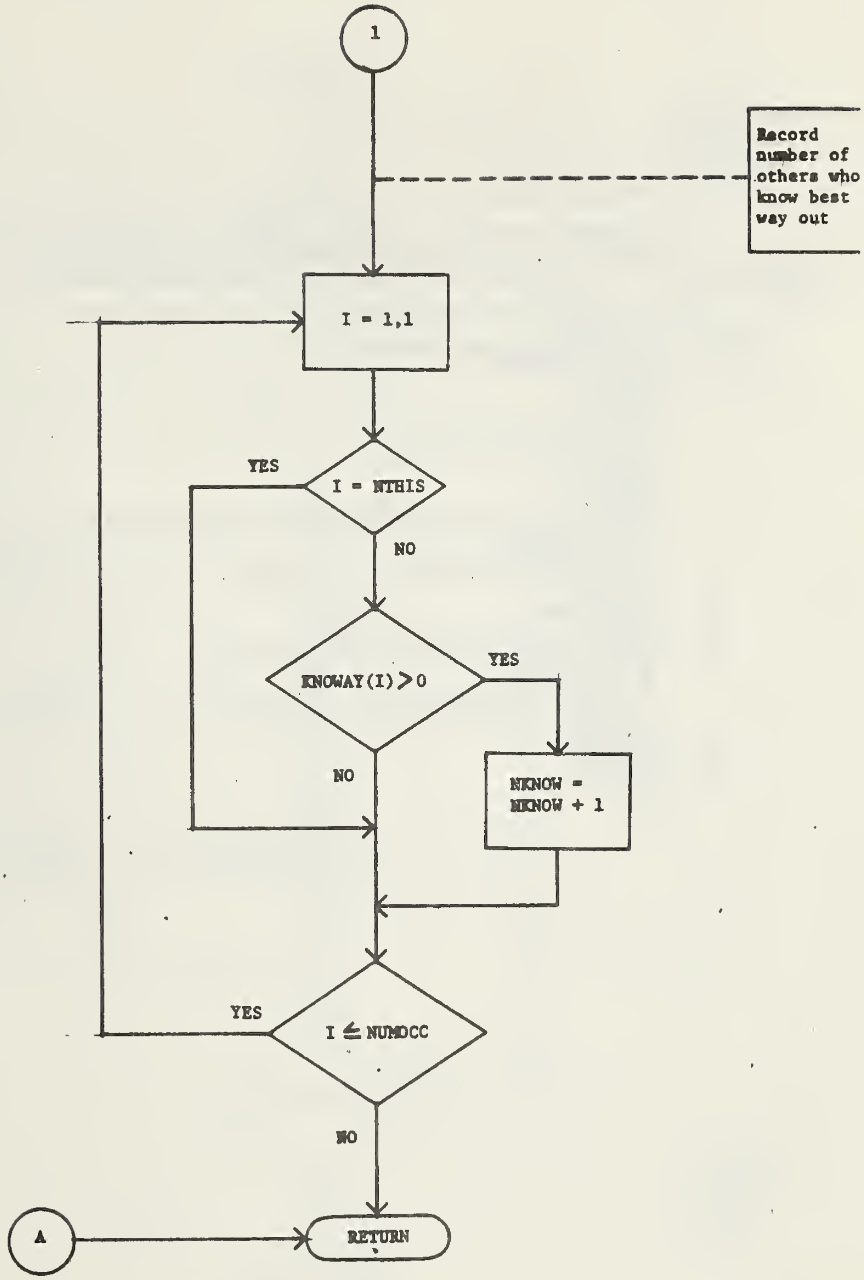


Subroutine GROUP

```
C
C
C
C
C
C   SUBROUTINE GROUP
C
C   THE PURPOSE OF GROUP IS TO ESTABLISH AND UPDATE THE SOCIAL ENVIRONMENT OF
C   OCCUPANTS AS THEY PROGRESS THROUGH THE SIMULATED FIRE EVENT.
C
      SUBROUTINE GROUP (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,
     1   NKNOW,NAGREE,IAGREE)
      DIMENSION KNOWAY(20)
C   DETERMINE WHETHER THE OCCUPANT SHARES THE SPATIAL SUBDIVISION WITH OTHER
C   OCCUPANTS, WHAT INFORMATION IS POSSESSED BY THE OTHERS, AND WHETHER ALL
C   SUBDIVISION AGREE ON THE BEST EXIT
      CALL OTHERS (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,NKNOW)
      IF (KNOWAY(NTHIS).GT.0) GO TO 1
      IF (KOOCC.EQ.0) GO TO 993
      GO TO 2
1     IF (KOOCC.EQ.0) GO TO 999
      IF (NKNOW.EQ.0) GO TO 999


2     CALL AGREE (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,
     1  NKNOW,NAGREE,IAGREE)
999    RETURN
      END
```

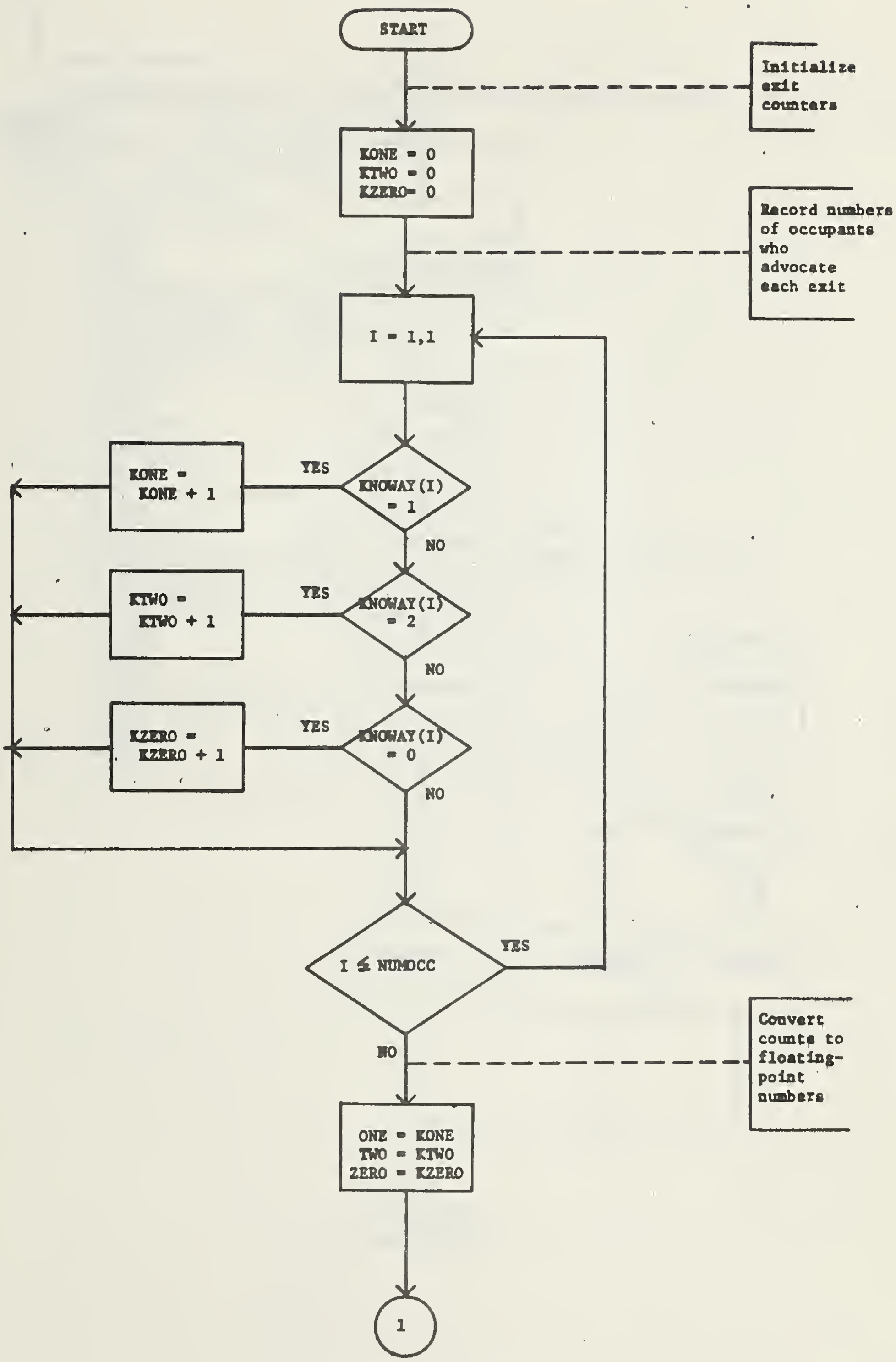


Subroutine OTHERS

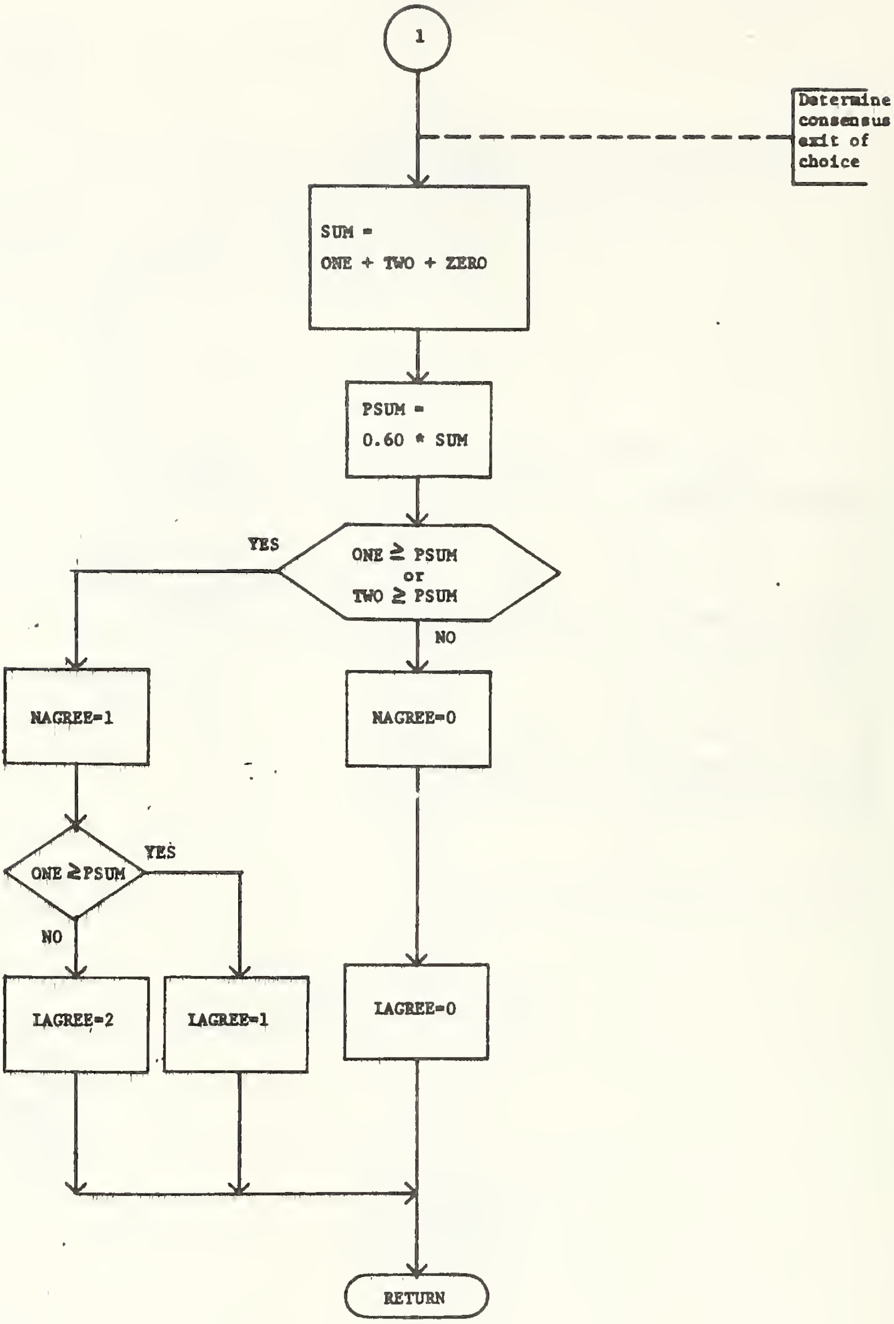


Subroutine OTHERS

```
C
C
C
C
C
C   SUBROUTINE OTHERS
C
C   THE PURPOSE OF OTHERS IS TO RECORD THE NUMBER OF OTHER OCCUPANTS IN THE
C   SUBDIVISION.  OTHERS ESTABLISHES SEPARATE RECORDS FOR THE NUMBER OF MOBILITY
C   -IMPAIRED (HANDICAPPED) OTHERS, AND FOR THOSE KNOWING THE WAY OUT.
C
      SUBROUTINE OTHERS (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,
     1   NKNOW)
      DIMENSION IHANDI(20),KNOWAY(20)
C   INITIALIZE COUNTERS
      NKNOW=0
      NHANDI=0
C   SET FLAG
      IF (NUMOCC.GT.1) GO TO 1
      KOOCC=0
      GO TO 999
1     KOOCC=I
C   RECORD NUMBER OF MOBILITY-IMPAIRED OTHERS IN THE SUBDIVISION
      DO 50 I=1,NUMOCC
      IF (I.EQ.NTHIS) GO TO 50
      IF (IHANDI(I).EQ.I) GO TO 51
      GO TO 50
51    NHANDI=NHANDI+I
50    CONTINUE
C   RECORD THE NUMBER OF OTHERS WHO KNOW THE BEST EXIT
      DO 60 I=I,NUMOCC
      IF (I.EQ.NTHIS) GO TO 60
      IF (KNOWAY(I).GT.0) GO TO 61
      GO TO 60
61    NKNOW=NKNOW+I
60    CONTINUE
999   RETURN
      END
```



Subroutine AGREE



Subroutine AGREE

```
C
C
C
C
C
C     SUBROUTINE AGREE
C
C     THE PURPOSE OF AGREE IS TO DETERMINE A CONSENSUS-EXIT-OF-CHOICE AMONG ALL
C     OCCUPANTS OF A GIVEN SPATIAL SUBDIVISION
C
      SUBROUTINE AGREE (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,
     1  NHANDI,NKNOW,NAGREE,IAGREE)

      DIMENSION KNOWAY(20)
C    INITIALIZE EXIT COUNTERS
      KONE=0
      KTWO=0
      KZERO=0
C    RECORD NUMBERS OF OCCUPANTS WHO ADVOCATE EACH EXIT
      DO 50 I=I,NUMOCC
      IF (KNOWAY(I).EQ.1) GO TO 51
      IF (KNOWAY(I).EQ.2) GO TO 52
      IF (KNOWAY(I).EQ.0) GO TO 53
      GO TO 50
51    KONE=KONE+I
      GO TO 50
52    KTWO=KTWO+I
      GO TO 50
53    KZERO=KZERO+I
50    CONTINUE
C    CONVERT COUNTS TO FLOATING POINT NUMBERS
      ONE=KONE
      TWO=KTWO
      ZERO=KZERO
C    DETERMINE CONSENSUS EXIT OF CHOICE
      SUM=ONE+TWO+ZERO
      PSUM=.60*SUM
      IF ((ONE.GE.PSUM).OR.(TWO.GE.PSUM)) GO TO I
      NAGREE=0
      IAGREE=0
      GO TO 2
I     NAGREE=1
      IF (ONE.GE.PSUM) GO TO 3
      IAGREE=2
      GO TO 2
3     IAGREE=I
2     RETURN
      END
```

Routine KPOSS

Loop Occupant

Purpose As an occupant moves through a bounded environment, motion in certain directions may be possible, while in others it may be constrained. When he arrives at a particular point in space, the individual begins looking ahead and scanning possibilities for the next move decision. He requires a perceptual apparatus which permits him to distinguish open paths from those constrained by walls or other physical barriers. As Subroutine GROUP provides the occupant with means of perceiving the *social* environment, Subroutine KPOSS provides "eyes" through which to discern his immediate *physical* environment. Namely, as the occupant scans each potential move alternative, k, he determines which are physically possible to attain, and which are blocked. Blocking by architectural features (e.g., walls) is illustrated in Figure A.2. KPOSS also responds to inputs from Subroutine JAMMED. A spatial location which is crowded beyond an occupant's level of acceptance will be treated as though it was blocked off by an inanimate physical barrier: the individual will eliminate that alternative, k, from the array of possibilities available at time frame t.

Formulas n/a

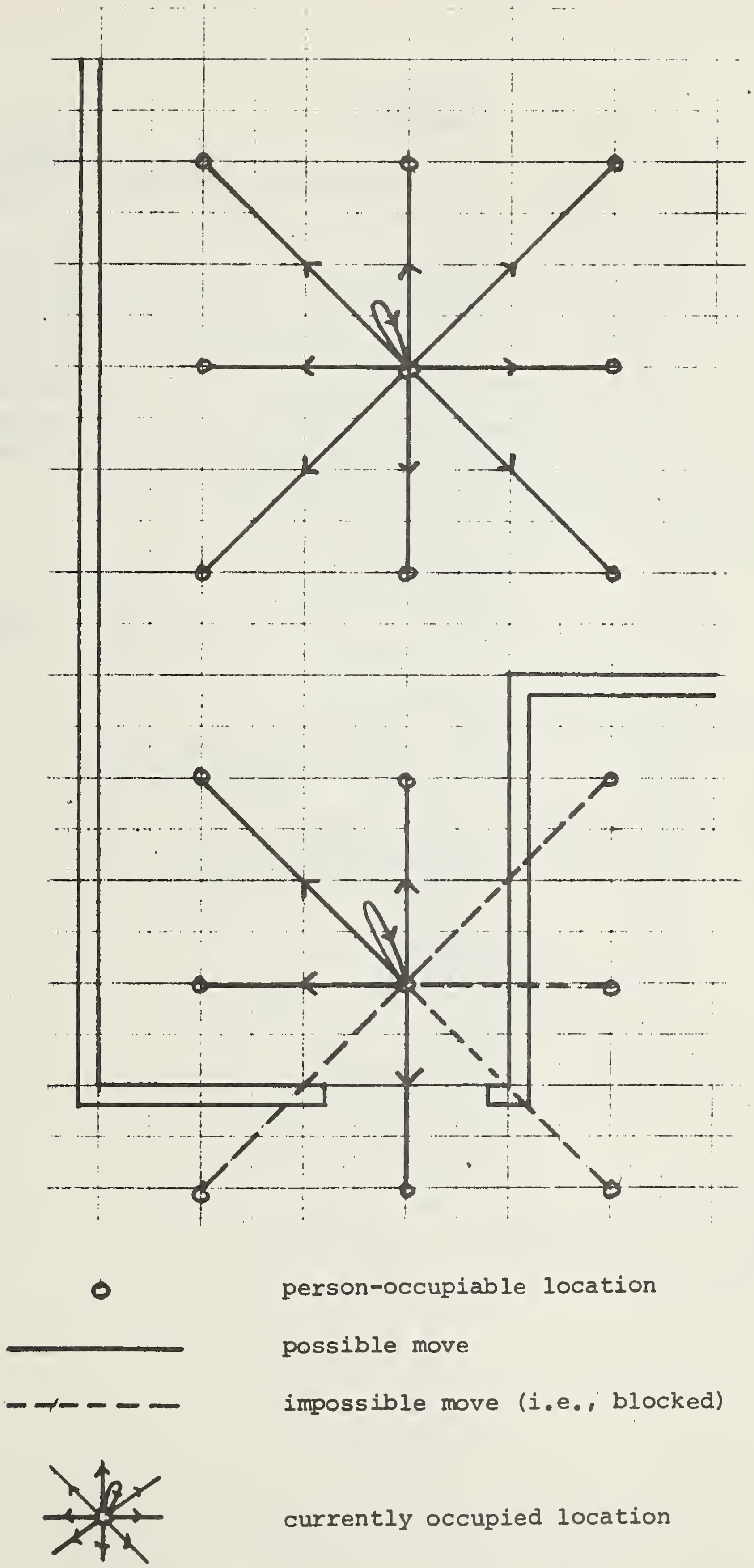
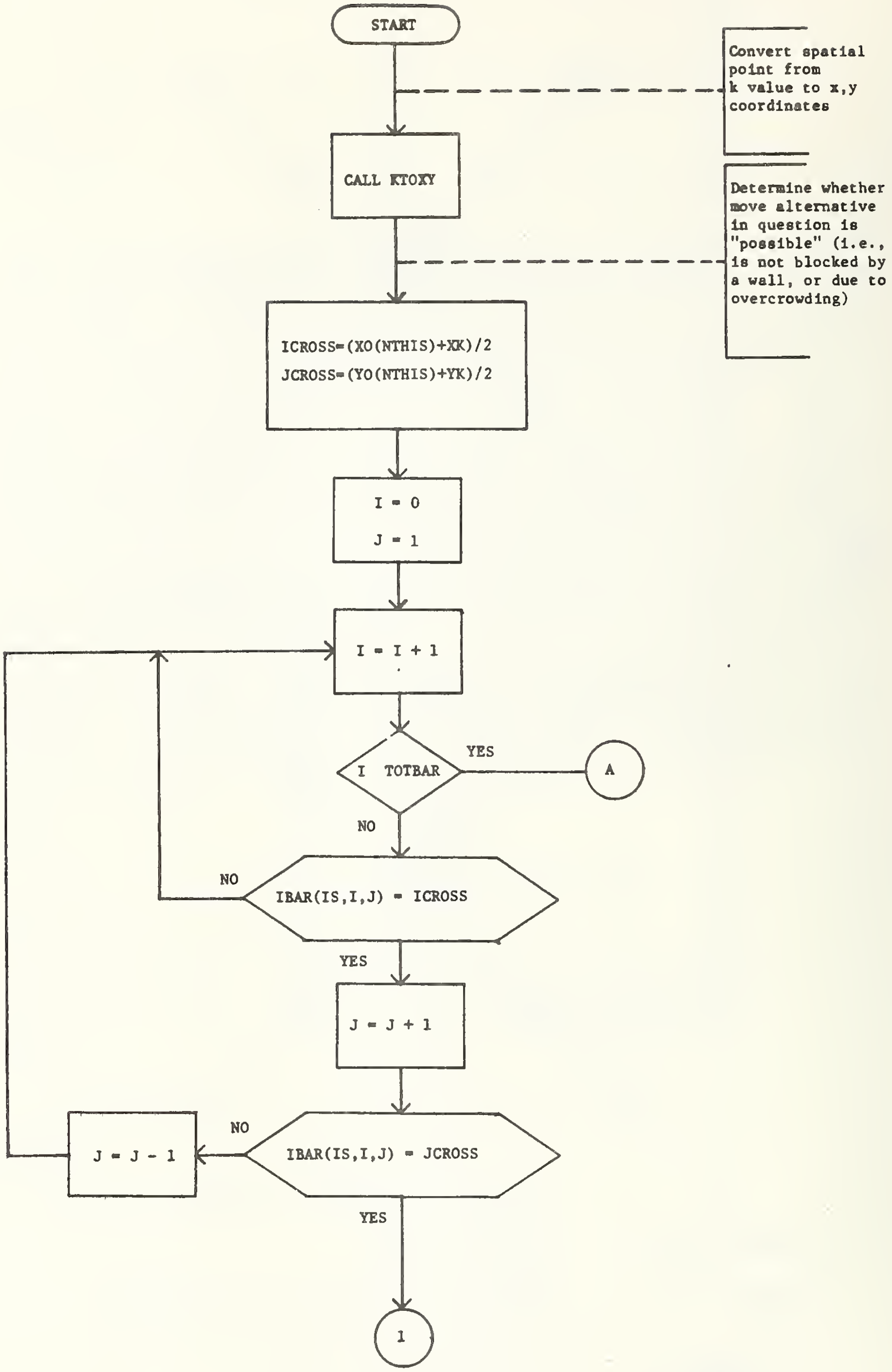
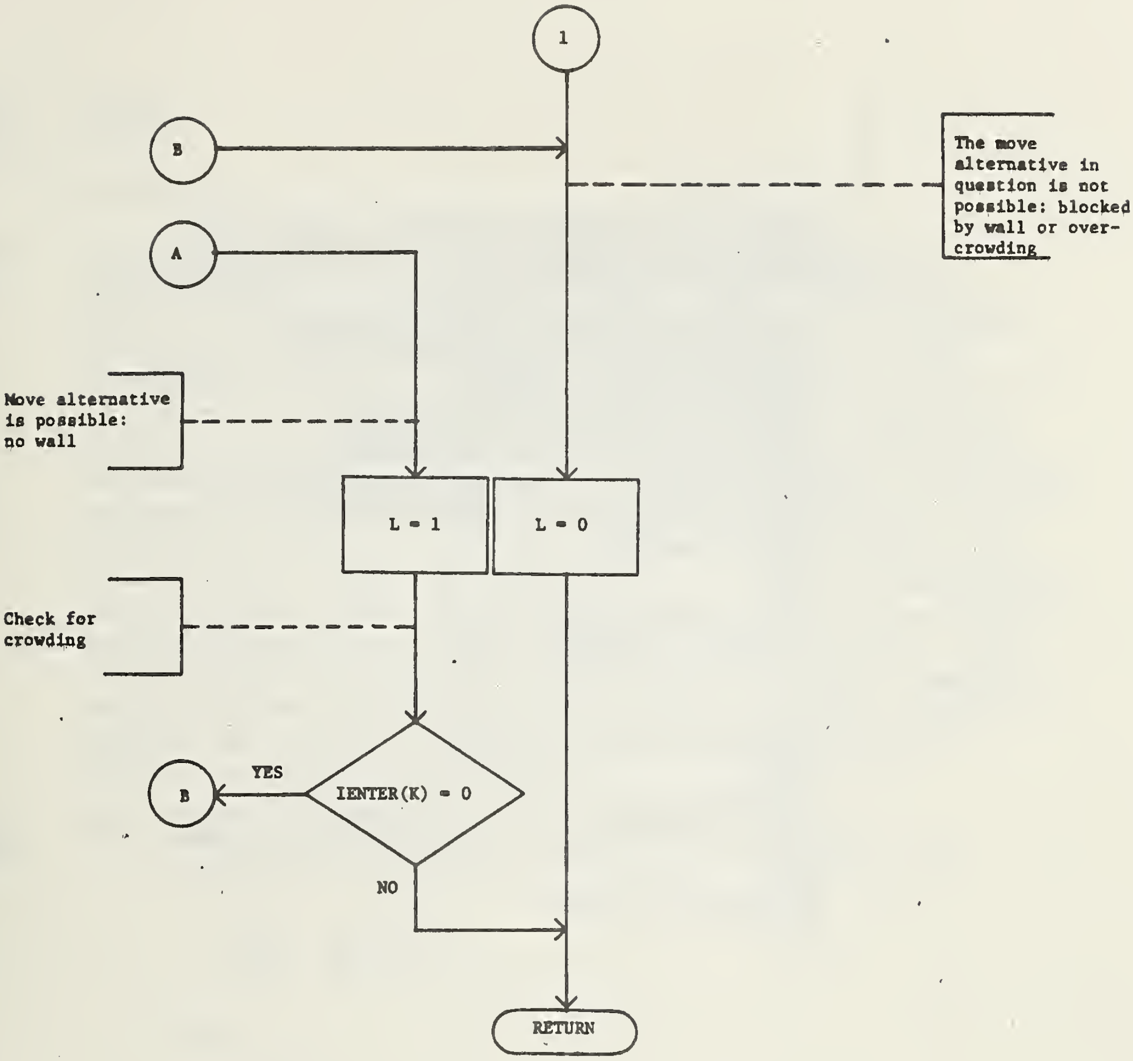


FIGURE A.2 Possible vs. Impossible Spatial Movements



Subroutine KPOSS



Subroutine KPOSS

```
C
C
C
C
C
C     SUBROUTINE KPOSS
C
C     THE PURPOSE OF KPOSS IS TO SCAN THE OCCUPANT'S IMMEDIATE PHYSICAL
C     ENVIRONMENT, AND TO DETERMINE WHETHER A MOVE ALONG ANY DIRECTION IS
C     RENDERED IMPOSSIBLE BECAUSE OF EITHER A PHYSICAL CONSTRAINT (WALL) OR
C     OVERCROWDING BY OTHER OCCUPANTS
C
        SUBROUTINE KPOSS (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
       1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,IRAND,
       2  P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER)
        DIMENSION IBAR (20,75,2),IENTER(9)
        INTEGER XO(20),YO(20),XK,YK,TOTBAR
C     CONVERT SPATIAL POINT FROM K VALUE TO X,Y COORDINATES
        CALL KTOXY (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
       1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,IRAND,
       2  P,MOVE,XK;YK,K)
C     DETERMINE WHETHER THE MOVE ALTERNATIVE UNDER REVIEW IS POSSIBLE,
C     I.E., IS NOT BLOCKED BY A WALL, OR DUE TO OVERCROWDING
        ICROSS=(XO(NTHIS)+XK)/2
        JCROSS=(YO(NTHIS)+YK)/2
        I=0
        J=1
1       I=I+1
        IF (I.GT.TOTBAR) GO TO 5
        IF (IBAR(IS,I,J).EQ.ICROSS) GO TO 2
        GO TO 1


2       J=J+1
        IF (IBAR(IS,I,J).EQ.JCROSS) GO TO 4
        J=J-1
        GO TO 1
4        CONTINUE
C     THE MOVE ALTERNATIVE UNDER REVIEW IS NOT POSSIBLE...IT IS BLOCKED BY A WALL
C     OR BECAUSE OF OVERCROWDING
        L=0
        GO TO 6
5       L=1
        IF (IENTER(K).EQ.0) GO TO 4
6       RETURN
        END
```

Routine KTOXY

Loop Occupant

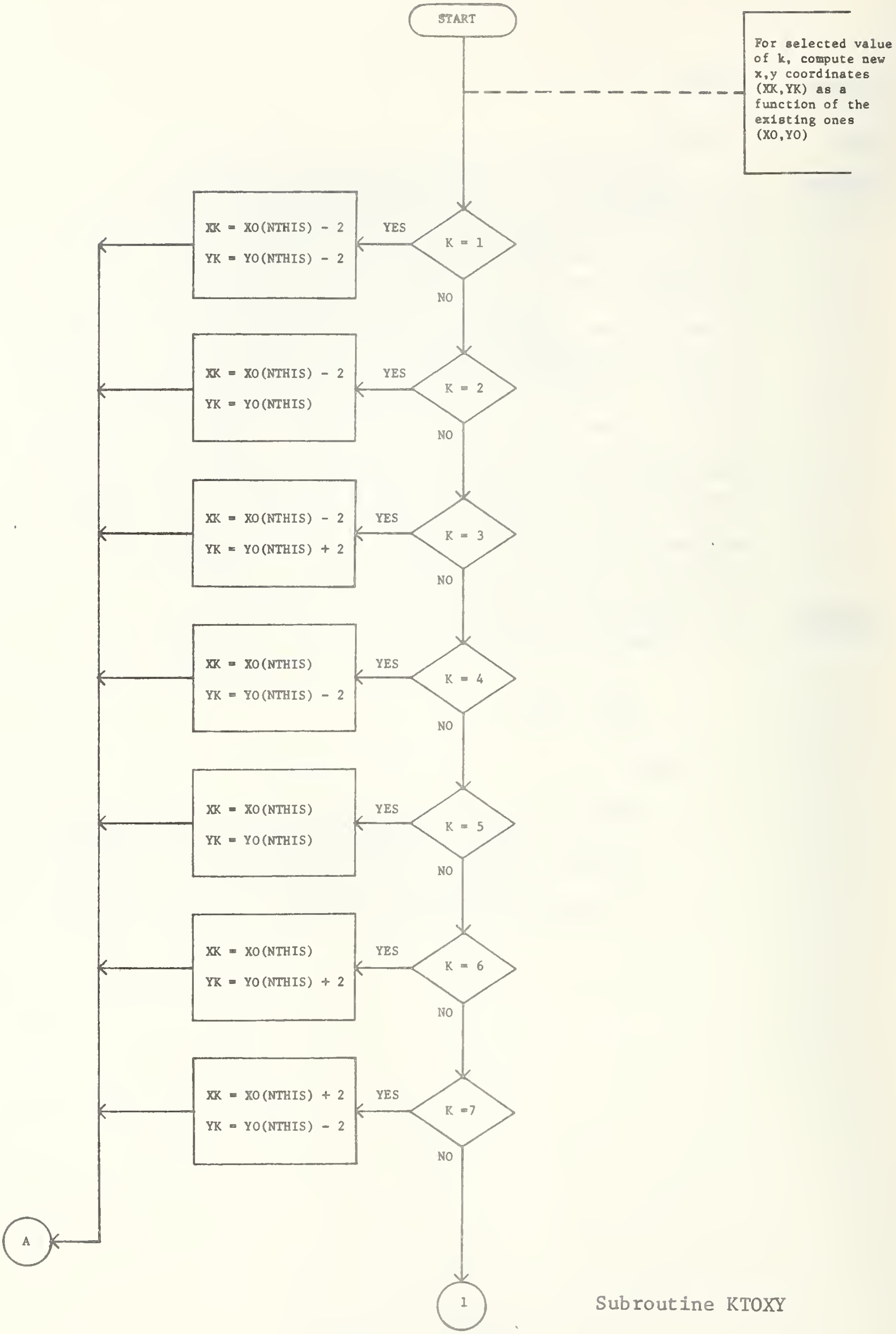
Purpose Two spatial notations systems are employed by BFIRES: The orthogonal x,y coordinate system keeps track of the spatial locations of wall and door elements, and occupants. The k-grid system is used in connection with the move alternative selection process. The k-grid may be thought of in terms of a compass dial, with eight vectors radiating outward from a central point (note Figure A.2). This point denotes the current location of occupant n, while the vectors represent potential movement paths. A ninth vector also exists to denote the condition of remaining-in-place. Each vector on the k-grid is designated by a number (1 through 9). As an occupant moves about through space, he "carries" his personal k-grid along with him, such that the central point (k=5) always coincides with his current location. Execution of the various subroutines often requires transformations between the x,y and k-grids. This is accomplished by Subroutine KTOXY ("k to x,y").

Formulas (1) general form for computing an x,y coordinate when k-number is known:

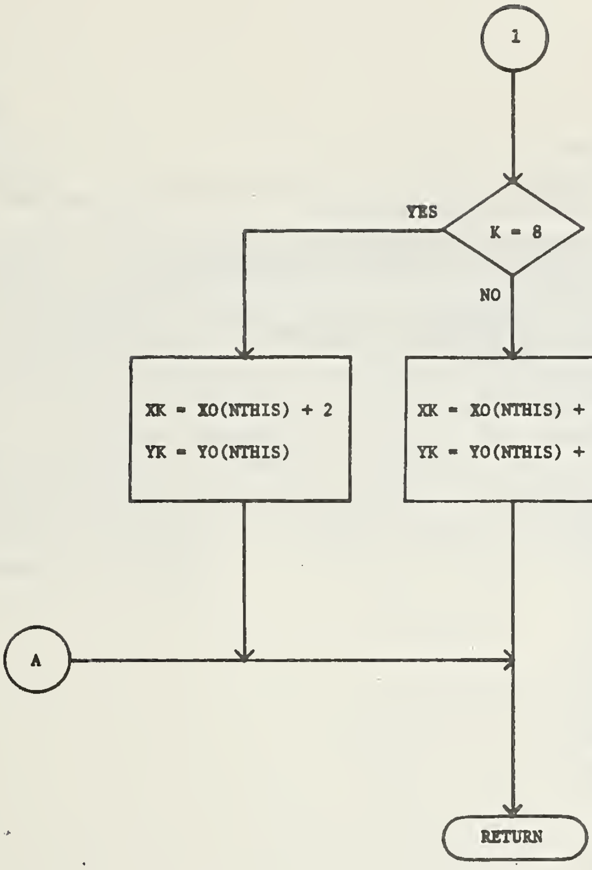
$$XK = X0 + c$$
$$YK = Y0 + c$$

Where:

XK; YK = x and y coordinates of a new point which would be reached if vector k is selected;
X0, Y0 = current x and y coordinates describing occupant_n's location;
c = constant required to produce locational shift.



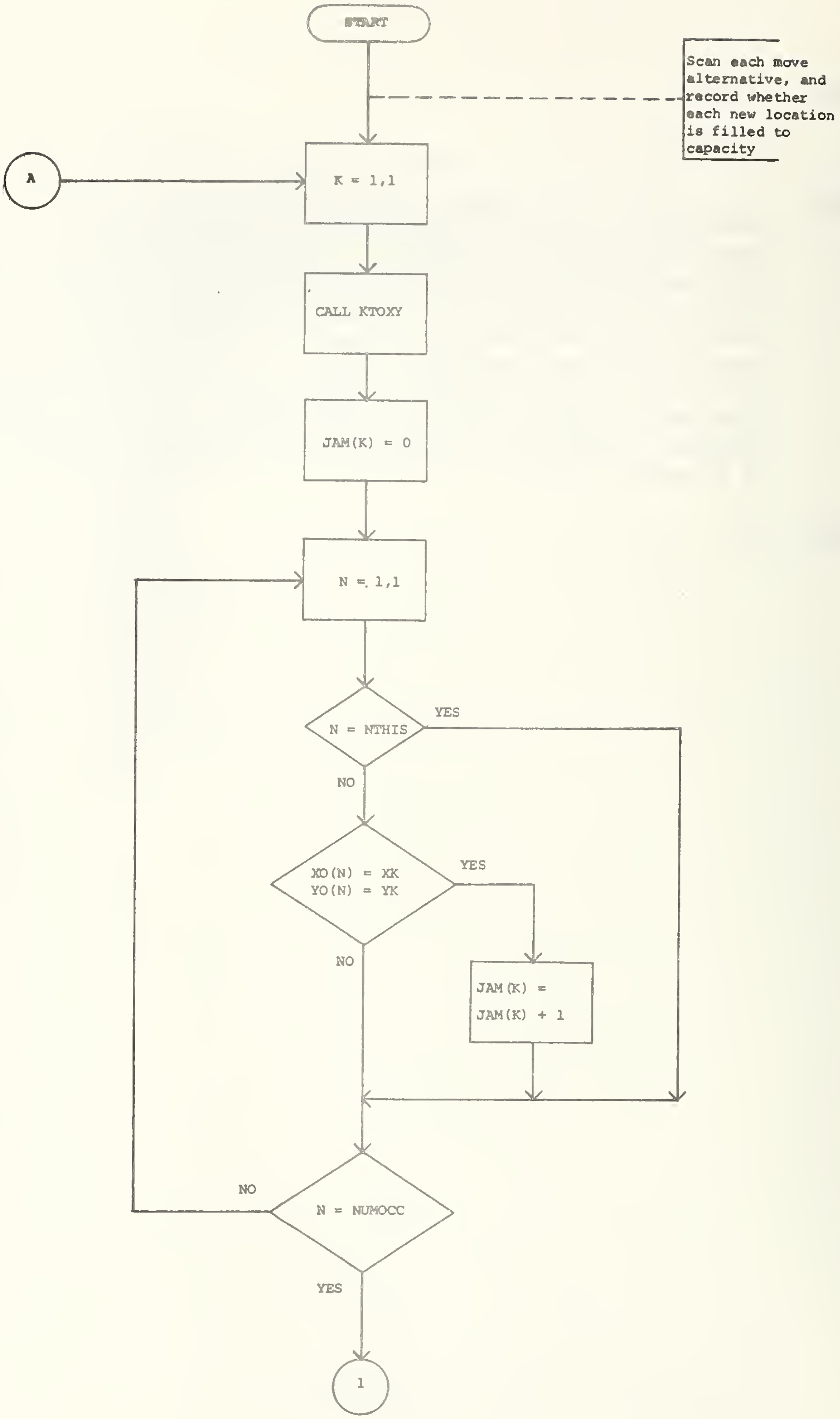
Subroutine KTOXY



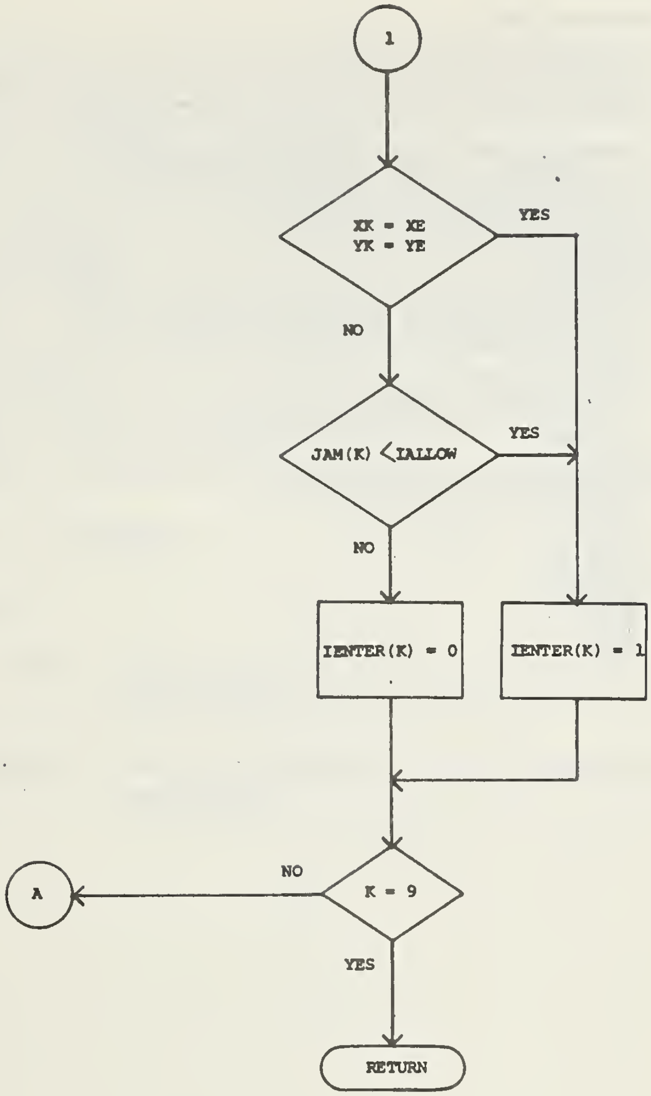
Subroutine KTOXY

```
C
C
C
C
C
C     SUBROUTINE KTOXY
C
C     THE PURPOSE OF KTOXY ('K TO X,Y') IS TO CONVERT SPATIAL LOCATIONS FROM
C     K-GRID DESIGNATIONS TO X,Y COORDINATES
C
        SUBROUTINE KTOXY(ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
       1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,IRAND,
       2  P,MOVE,XK,YK,K)
        INTEGER XO(20),YO(20),XK,YK
C     FOR THE VALUE OF K UNDER REVIEW, COMPUTE NEW X,Y COORDINATES (XK,YK)
C     AS A FUNCTION OF THE EXISTING ONES (XO,YO)
        GO TO (1,2,3,4,5,6,7,8,9),K
1       XK=XO(NTHIS)-2
        YK=YO(NTHIS)-2
        GO TO 10
2       XK=XO(NTHIS)-2
        YK=YO(NTHIS)
        GO TO 10
3       XK=XO(NTHIS)-2
        YK=YO(NTHIS)+2
        GO TO 10
4       XK=XO(NTHIS)
        YK=YO(NTHIS)-2
        GO TO 10
5       XK=XO(NTHIS)
        YK=YO(NTHIS)
        GO TO 10
6       XK=XO(NTHIS)
        YK=YO(NTHIS)+2
        GO TO 10
7       XK=XO(NTHIS)+2
        YK=YO(NTHIS)-2
        GO TO 10
8       XK=XO(NTHIS)+2
        YK=YO(NTHIS)
        GO TO 10

9       XK=XO(NTHIS)+2
        YK=YO(NTHIS)+2
10      RETURN
        END
```

Routine	JAMMED
Loop	Occupant
Purpose	As occupants move about during a simulated fire, the population density of the different spatial locations varies. Some mechanism is necessary to enable an occupant to gather information about the density, or degree of physical crowding, of locations he may wish to enter. JAMMED satisfies this need. As an occupant looks ahead and scans the alternative target locations available to him, he counts the number of other individuals already occupying each. If, for any given alternative location, this number is greater than the preset crowding tolerance, he rejects that alternative from his array of movement choices.
Formulas	n/a



Subroutine JAMMED



Subroutine JAMMED

```
C
C
C
C
C
C    SUBROUTINE JAMMED
C
C    THE PURPOSE OF JAMMED IS TO ENABLE THE OCCUPANT TO GATHER INFORMATION ABOUT
C    THE DEGREE OF 'CROWDING' OF LOCATIONS HE MAY WISH TO ENTER...AS THE
C    OCCUPANT SCANS THE ALTERNATIVE TARGET LOCATIONS AVAILABLE TO HIM, HE
C    DETERMINES WHETHER EACH IS NON-ENTERABLE DUE TO OVERCROWDING
C
      SUBROUTINE JAMMED (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,IRAND,
     2   P,MOVE,XK,YK,K,IALLOW,NUMOCC,IENTER)
      INTEGER XO(20),YO(20),XK,YK,XE,YE
      DIMENSION JAM(9),IENTER(9)
C    SCAN EACH MOVE ALTERNATIVE, AND RECORD WHETHER EACH NEW LOCATION IS FILLED
C    TO CAPACITY
      DO 100 K=1,9
      CALL KTOXY (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,IRAND,
     2   P,MOVE,XK,YK,K)
      JAM(K)=0
      DO 200 N=1,NUMOCC
      IF (N.EQ.NTHIS) GO TO 200
      IF ((XO(N).EQ.XK).AND.(YO(N).EQ.YK)) GO TO 1
      GO TO 200
1     JAM(K)=JAM(K)+1
200   CONTINUE
      IF ((XK.EQ.XE).AND.(YK.EQ.YE)) GO TO 2
      IF (JAM(K).LT.IALLOW) GO TO 2
      GO TO 3
2     IENTER(K)=1
      GO TO 100
3     IENTER(K)=0
100   CONTINUE
      RETURN
      END
```

Routine EQUALZ

Loop Occupant

Purpose EQUALZ is one of the biasing routines available to ASSIGN. The function of EQUALZ is to satisfy the condition of no bias, that is, the situation in which the probability values of available move alternatives are equalized. An occupant enters a state of confusion whenever he is mobile and uninterrupted, makes a negative safety status evaluation, and is unable to discern an effective egress route. He will remain in this condition until he:

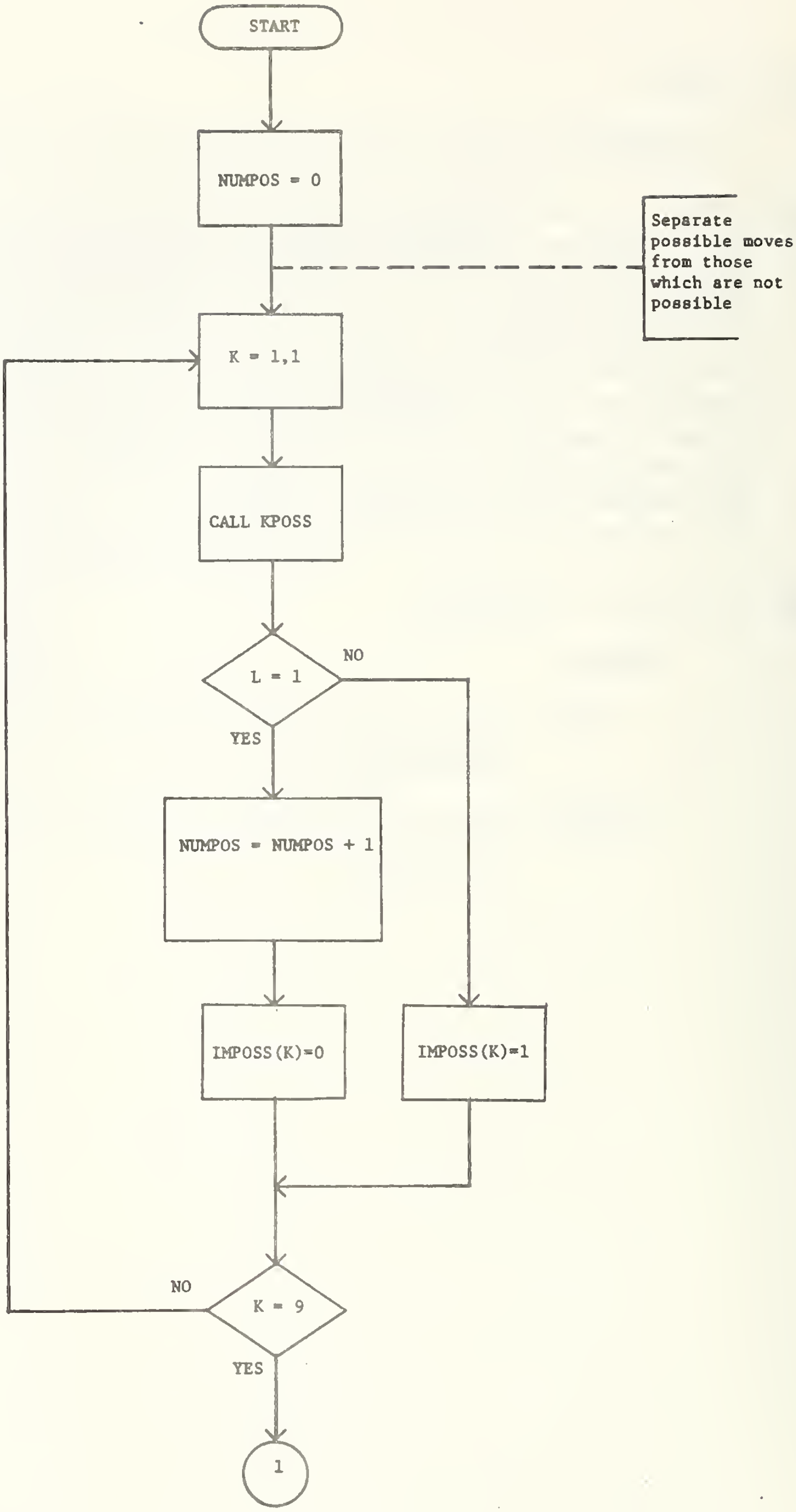
(1) makes a positive safety status evaluation;
(2) learns of an effective route; or
(3) decides to enter the backtracking interruption mode.

Formulas (1) $P(K) = 1.0/NUMPOS$

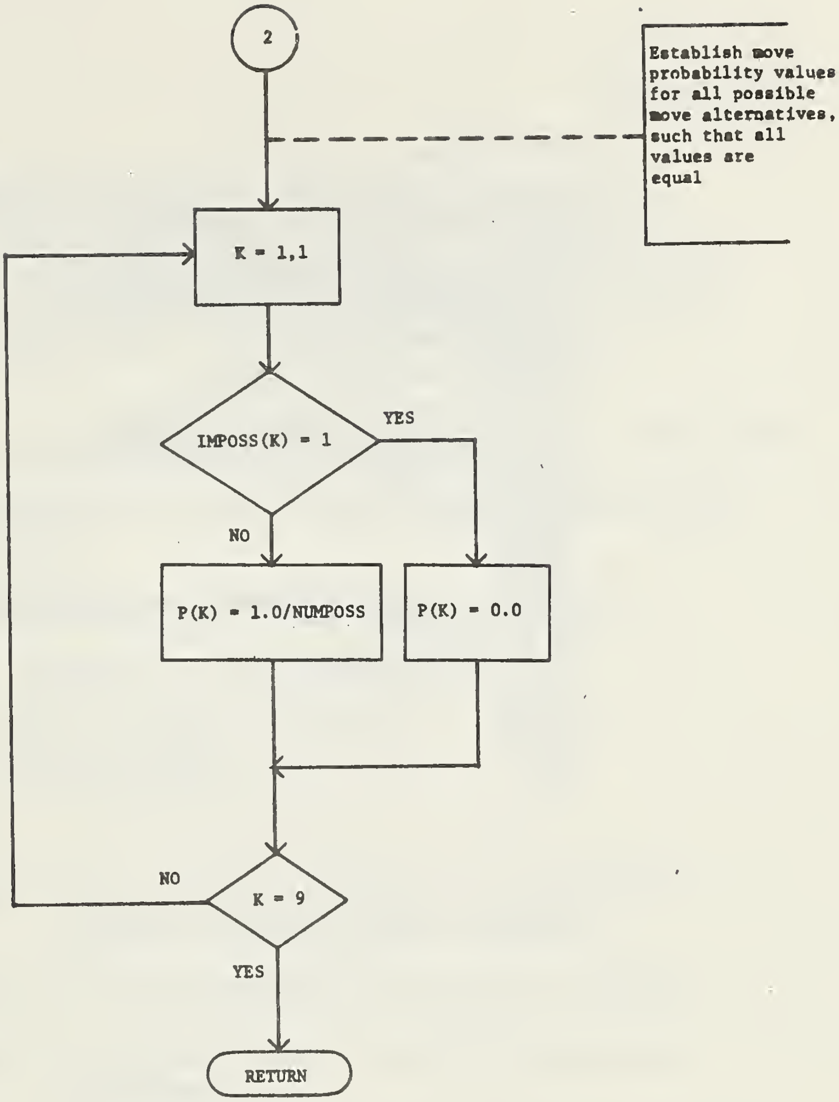
Where:

$P(K)$ = the probability of selecting the kth move alternative;

NUMPOS = the total number of possible alternatives available.



Subroutine EQUALZ



Subroutine EQUALZ

```
C
C
C
C
C
C    SUBROUTINE EQUALZ
C
C    THE PURPOSE OF EQUALZ IS TO SATISFY THE CONDITION OF NO DECISION BIAS
C    (INDECISION). THAT IS. THE CONDITION UNDER WHICH THE PROBABILITY VALUES OF
C    AVAILABLE MOVE ALTERNATIVES ARE ALL EQUALIZED
C
      SUBROUTINE EQUALZ(ITIME,NTHIS.INANDI.INT.IBYSTD.IEVAL,
     1  XO.YO.IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2  IRAND.P,MOVE.XK,YK,K.L.IS.IGOALX.IGOALY,IENTER)
      INTEGER XO(20),YO(20),XK,YK
      DIMENSION IMPOSS (9), P (9)
      NUMPOS=0
C    IDENTIFY ALL POSSIBLE MOVE ALTERNATIVES
      DO 1 K=1,9
      CALL KPOSS (ITIME.NTHIS.IHANDI.INT.IBYSTD.IEVAL.
     1  XO.YO.IBAR,TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
     2  IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER)
      IF (L.EQ.1) GO TO 2
      GO TO 3
2     NUMPOS=NUMPOS+1
      IMPOSS(K)=0
      GO TO 1
3     IMPOSS(K)=1
1     CONTINUE
C    ESTABLISH MOVE PROBABILITY VALUES FOR ALL POSSIBLE MOVE ALTERNATIVES.
C    SUCH THAT ALL VALUES ARE EQUAL
      DO 4 K=1,9
      IF (IMPOSS(K).EQ.1) GO TO 5
      P(K)=1.0/FLOAT(NUMPOS)
      GO TO 4
5     P(K)=0.0
4     CONTINUE
      RETURN
      END
```

Routine TBIAS

Loop Occupant

Purpose Subroutine TBIAS effectuates "threat evasion" movement behavior. Whenever this biasing routine is assigned, it establishes move selection probability values which "favor" moves that maximize the occupant's distance from the fire threat (threatened exit). TBIAS is assigned if the occupant:

(1) is mobile and uninterrupted during the current time frame;

(2) is operating under a positive perception of his current safety status;

(3) has no exit route in mind; and

(4) knows the location of the threat.

Formulas (1) $DIST_k = SQRT((XT-XK)^2 + (YT-YK)^2)$
(2) $P(K) = DIST(K)/TOTDST$

where:

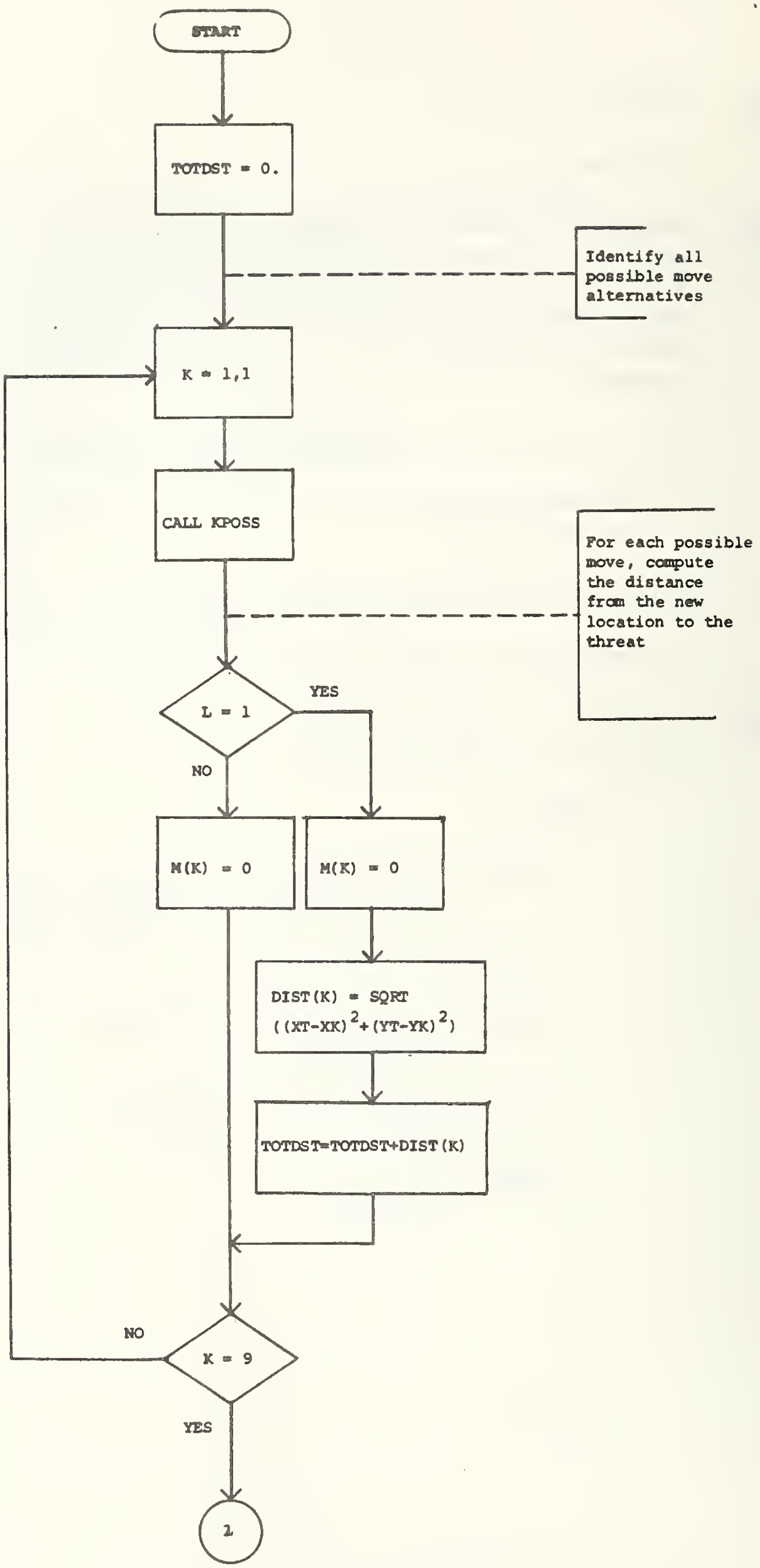
$DIST_k$ = linear distance between an alternative location and the threat location;

XY,YT = x,y coordinates of the threat location;

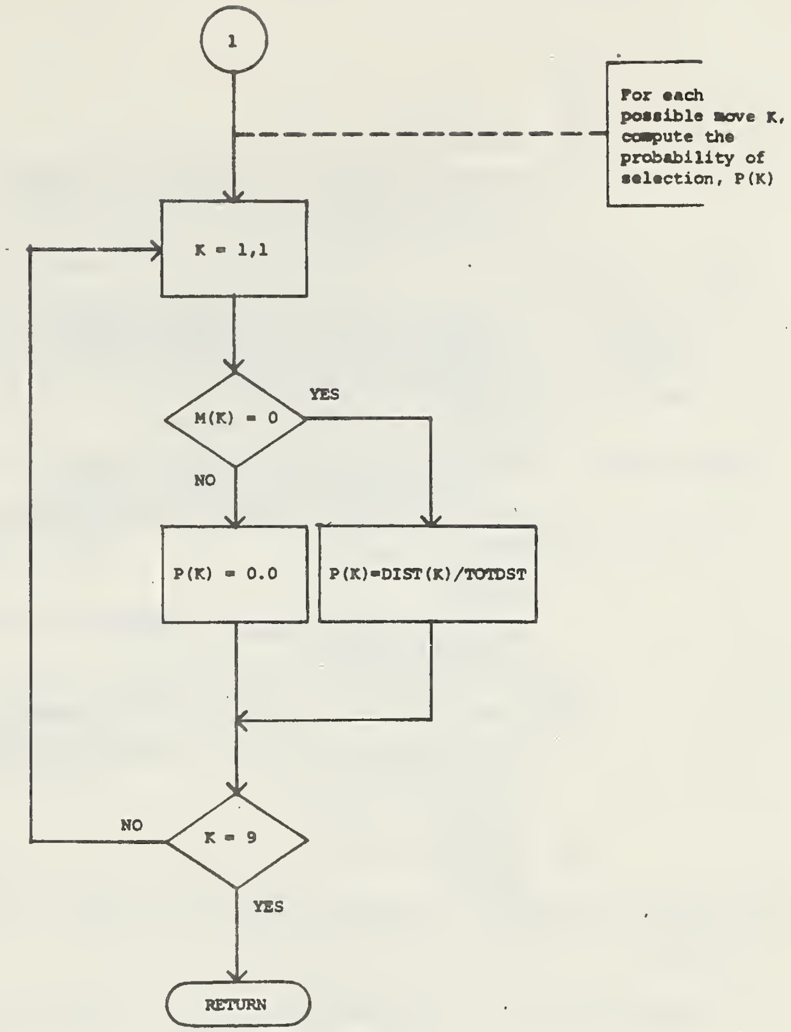
XK,YK = x,y coordinates of the kth alternative location;

P(K) = probability of selecting the kth alternative;

$TOTDST = \sum_{k=1}^{9} DIST_k$



Subroutine TBIAS



Subroutine TBIAS

```
C
C
C
C
C
C    SUBROUTINE TBIAS
C
C    THE PURPOSE OF TBIAS IS TO EFFECTUATE 'THREAT EVASION' MOVEMENT BEHAVIOR.
C    WHENEVER TBIAS IS ASSIGNED, MOVE PROBABILITY VALUES ARE ESTABLISHED IN SUCH
C    A WAY AS TO 'FAVOR' MOVES WHICH MAXIMIZE THE OCCUPANT'S DISTANCE FROM
C    THREATENING STIMULI


C
      SUBROUTINE  TBIAS (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     1  IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER)
      INTEGER XO(20),YO(20),XT,YT,XK,YK
      DIMENSION M(9),DIST(9),P(9)
      TOTDST=0.
C    IDENTIFY ALL POSSIBLE MOVE ALTERNATIVES
      DO 10 K=1,9
      CALL KPOSS (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2  IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER)
C    FOR EACH POSSIBLE MOVE, COMPUTE THE DISTANCE FROM THE NEW LOCATION TO THE
C    THREAT
      IF (L.EQ.1) GO TO 1
      M(K)=1
      GO TO 10
1     M(K)=0
      DIST(K)=SORT(FLOAT((XT-XK)**2+(YT-YK)**2))
      TOTDST=TOTDST+DIST(K)
10    CONTINUE
C
C: FOR EACH POSSIBLE MOVE, COMPUTE THE MOVE-PROB., P(K):
C
C    FOR EACH POSSIBLE MOVE, COMPUTE THE PROBABILITY OF SELECTION, P(K)
      DO 15 K=1,9
      IF (M(K).EQ.0) GO TO 2
      P(K)=0.
      GO TO 15
2     P(K)=DIST(K)/TOTDST
15    CONTINUE
      RETURN
      END
```

Routine EBIAS

Loop Occupant

Purpose For all move alternatives available to an occupant at a given point in time, Subroutine EBIAS weights move selection probabilities to favor moves which minimize the occupant's distance from an exit goal point. An occupant's decision making strategy is routed through Subroutine EBIAS if he:

(1) is mobile and uninterrupted during the current time frame;

(2) is operating under a positive perception of his current safety status; and

(3) has a specific egress route in mind.

Formulas

(1) $DIST(K) = SQRT((IGOALX - XK)^2 + (IGOALY - YK)^2)$
(2) $P(K) = A(K)/SUMA$
(3) $A(K) = TOTDST/DIST(K)$
(4) $P(K)^* = 1.0/ZERO$

Where:

DIST(K) = linear distance from new location designated by k, to the agreed-upon exit from space$_i$;

IGOALX,IGOALY = x,y coordinates of the agreed-upon exit from space$_i$;

XK,YK = x,y coordinates of the spatial location denoted by k;

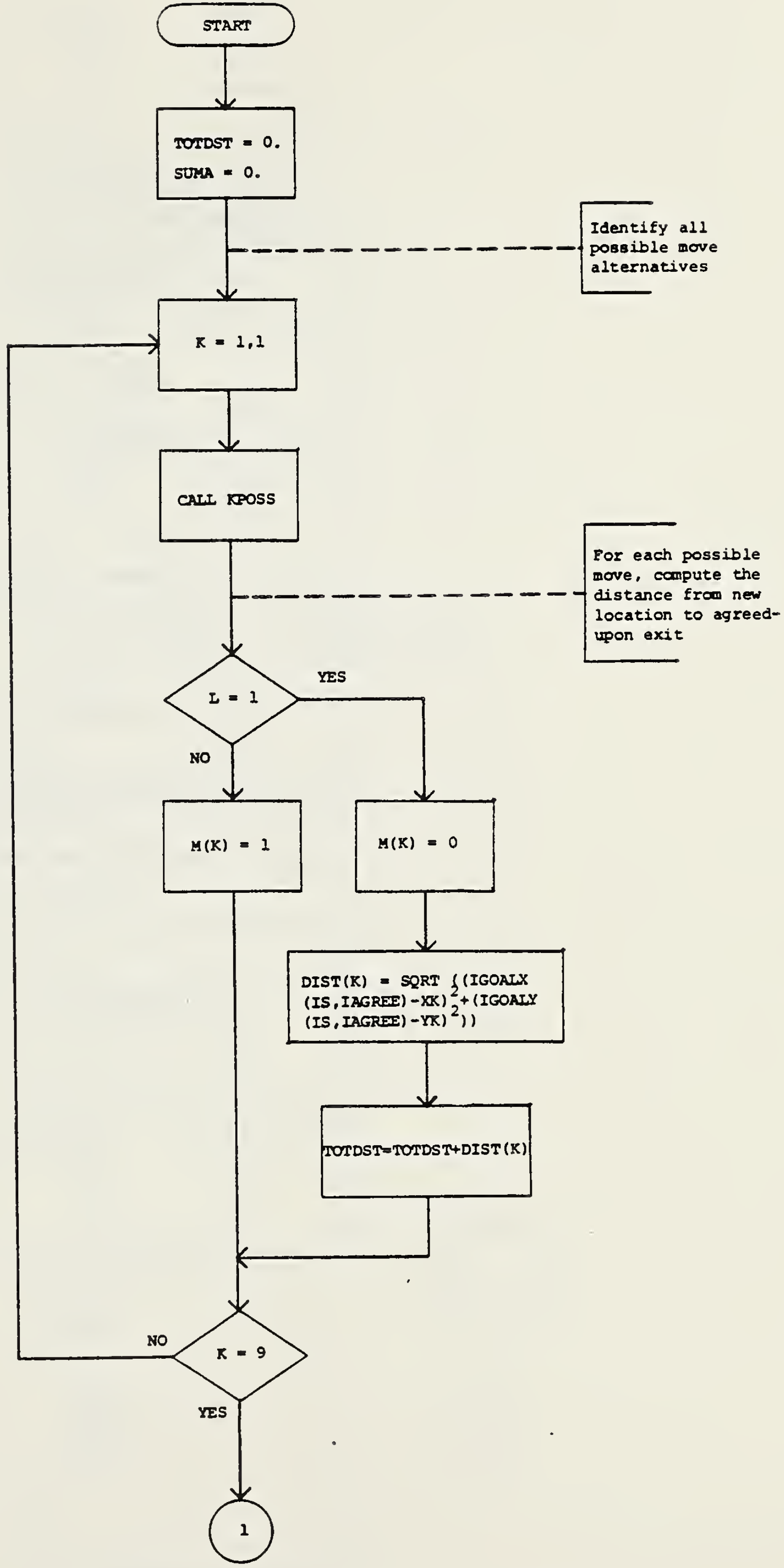
P(K) = the probability of selecting the kth move alternative, under the condition that not more than one alternative leads directly through an exit from space$_i$, during t;

$$TOTDST = \sum_{k=1}^{9} DIST(K)$$

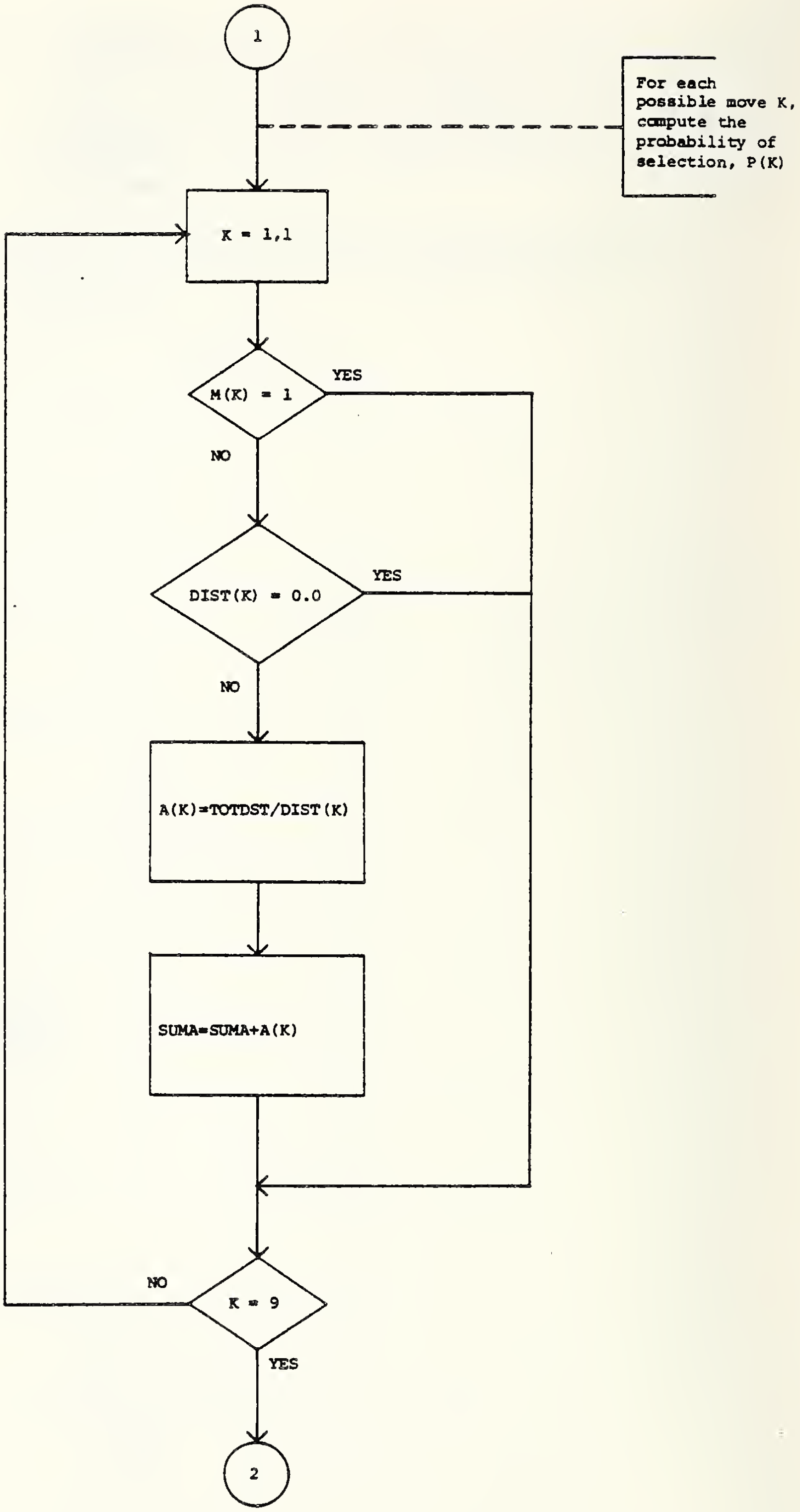
$$SUMA = \sum_{k=1}^{9} A(K)$$

P(K)* = the probability of selecting an alternative which leads directly through an exit from $space_i$, only under one condition that more than one alternative leads through such an exit;

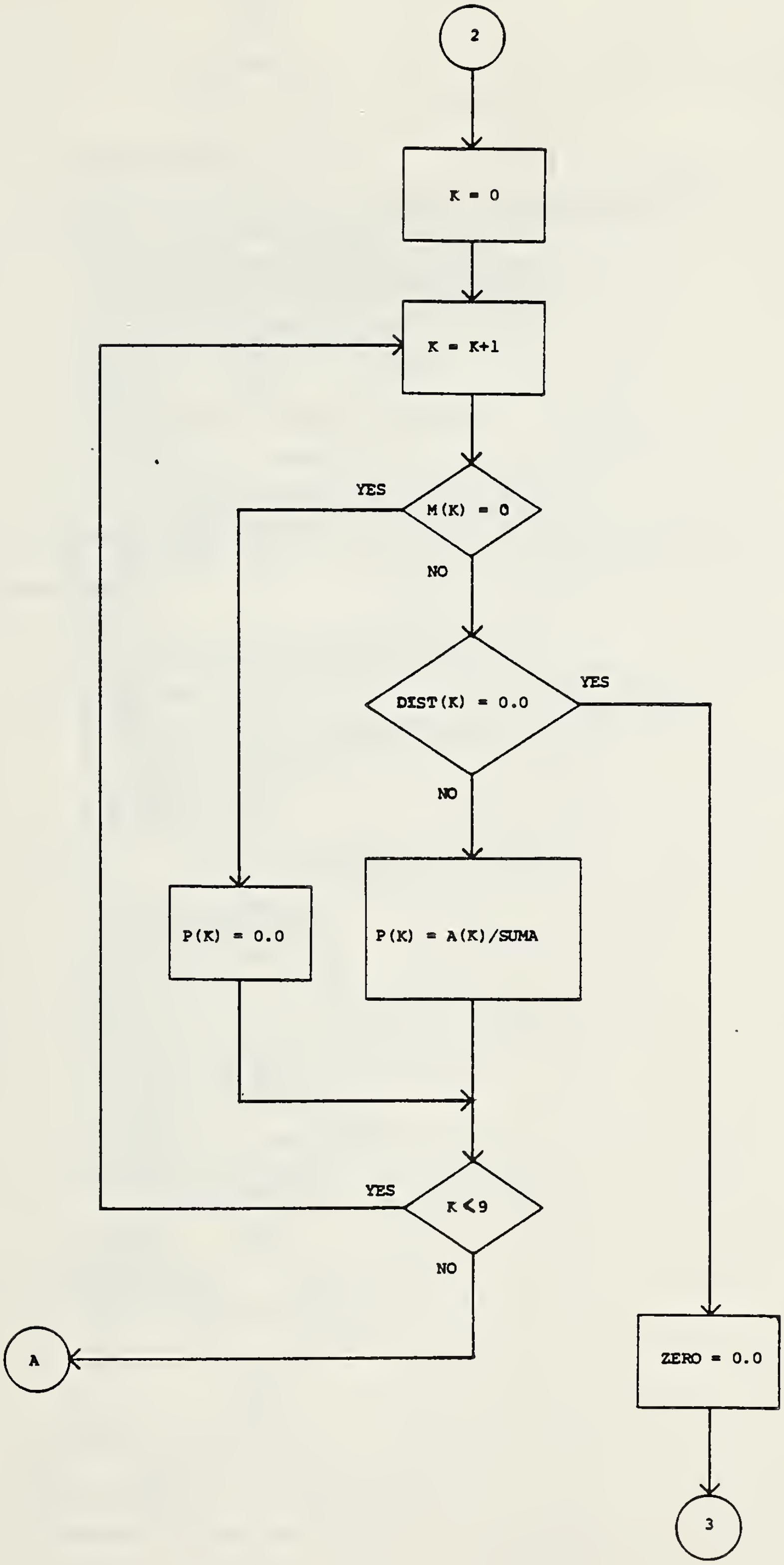
ZERO = the total number of alternatives leading directly through an exit from $space_i$ during t.



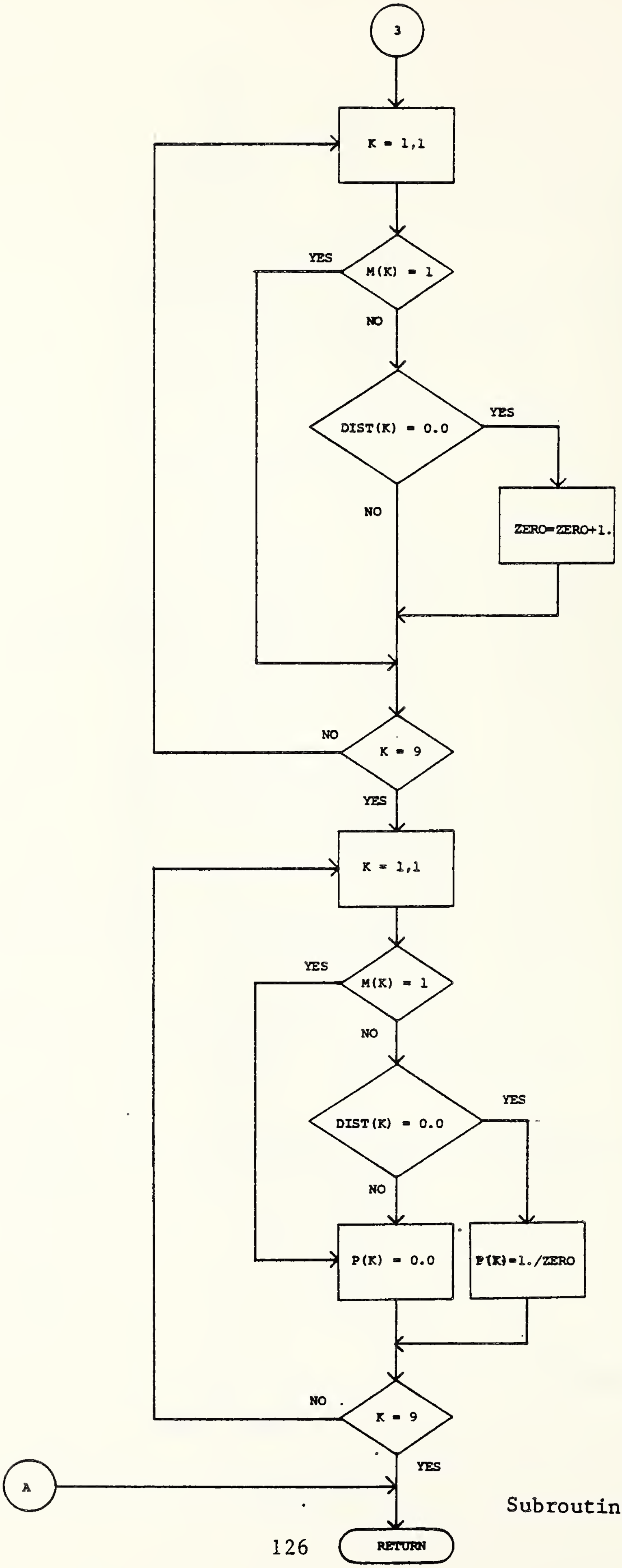
Subroutine EBIAS



Subroutine EBIAS



Subroutine EBIAS



Subroutine EBIAS

```
C
C
C
C
C
C    SUBROUTINE EBIAS
C
C    THE PURPOSE OF EBIAS IS TO EFFECTUATE GOAL SEEKING MOVEMENT BEHAVIOR.
C    EBIAS WEIGHTS MOVE SELECTION PROBABILITIES TO 'FAVOR' MOVES WHICH
C    MINIMIZE THE OCCUPANT'S DISTANCE TO AN EXIT GOAL
C
      SUBROUTINE EBIAS(ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2  IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER)
      INTEGER XO(20),YO(20),XE(10),YE(10),XK,YK
      DIMENSION M(9),DIST(9),A(9),P(9)
      DIMENSION IGOALX(20,10),IGOALY(20,10)
      TOTDST=0.
      SUMA=0.
C    IDENTIFY ALL POSSIBLE MOVE ALTERNATIVES
      DO 10 K=1,9


      CALL KPOSS (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2  IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER)
C    FOR EACH POSSIBLE MOVE, COMPUTE THE DISTANCE FROM THE NEW LOCATION TO THE
C    AGREED-UPON-EXIT
      IF (L.EQ.I) GO TO I
      M(K)=1
      GO TO 10
1     M(K)=0
      DIST(K)=SQRT(FLOAT((IGOALX(IS,IAGREE)-XK)**2+
     1   (IGOALY(IS,IAGREE)-YK)**2))
      TOTDST=TOTDST+DIST(K)
10    CONTINUE
C    FOR EACH POSSIBLE MOVE, COMPUTE THE PROBABILITY OF SELECTION, P(K)
      DO 15 K=I,9
      IF (M(K).EQ.I) GO TO 15
      IF (DIST(K).EQ.0.) GO TO 15
      A(K)=TOTDST/DIST(K)
      SUMA=SUMA+A(K)
15    CONTINUE
C
      K=0
2     K=K+1
      IF (M(K).EQ.I) GO TO 3
      IF (DIST(K).EQ.0.) GO TO 5
      P(K)=A(K)/SUMA
      GO TO 4
3     P(K)=0.
4     IF (K.LT.9) GO TO 2
      RETURN
5     ZERO=0.
      DO 20 K=1,9
      IF(M(K).EQ.I) GO TO 20
      IF (DIST (K).EQ.0.) GO TO 6
      GO TO 20
6     ZERO=ZERO+I.
20    CONTINUE
      DO 25 K=1,9
      IF (M(K).EQ.I) GO TO 707
      IF (DIST(K).EQ.0.) GO TO 7
707   P(K)=0.0
      GO TO 25
7     P(K)=1./ZERO
25    CONTINUE
      RETURN
      END
```

Routines DOORS1 and DOORS2

Loop Occupant

Purpose As a part of its move selection function, subroutine ASSIGN controls the manipulation of doors by occupants. For example, when an individual encounters a closed door, there is some probability he will open it, and some chance that he will not. If he chooses not to open the door, the through-door move alternative is deleted, and the probility values of remaining alternatives are adjusted so as to maintain a sum of unity. This function is controlled by Subroutine DOORS1. Moreover, if the occupant indeed passes through an open door, he may or may not close it behind him. Subroutine DOORS2 controls this behavior.

Formulas (1) $SUM = SUM + P(K)$
(2) $DIFF = 1.0 - SUM$
(3) $SHARE = DIFF/NPOSS$
(4) $P(K)^* = P(K) + SHARE$

Where:

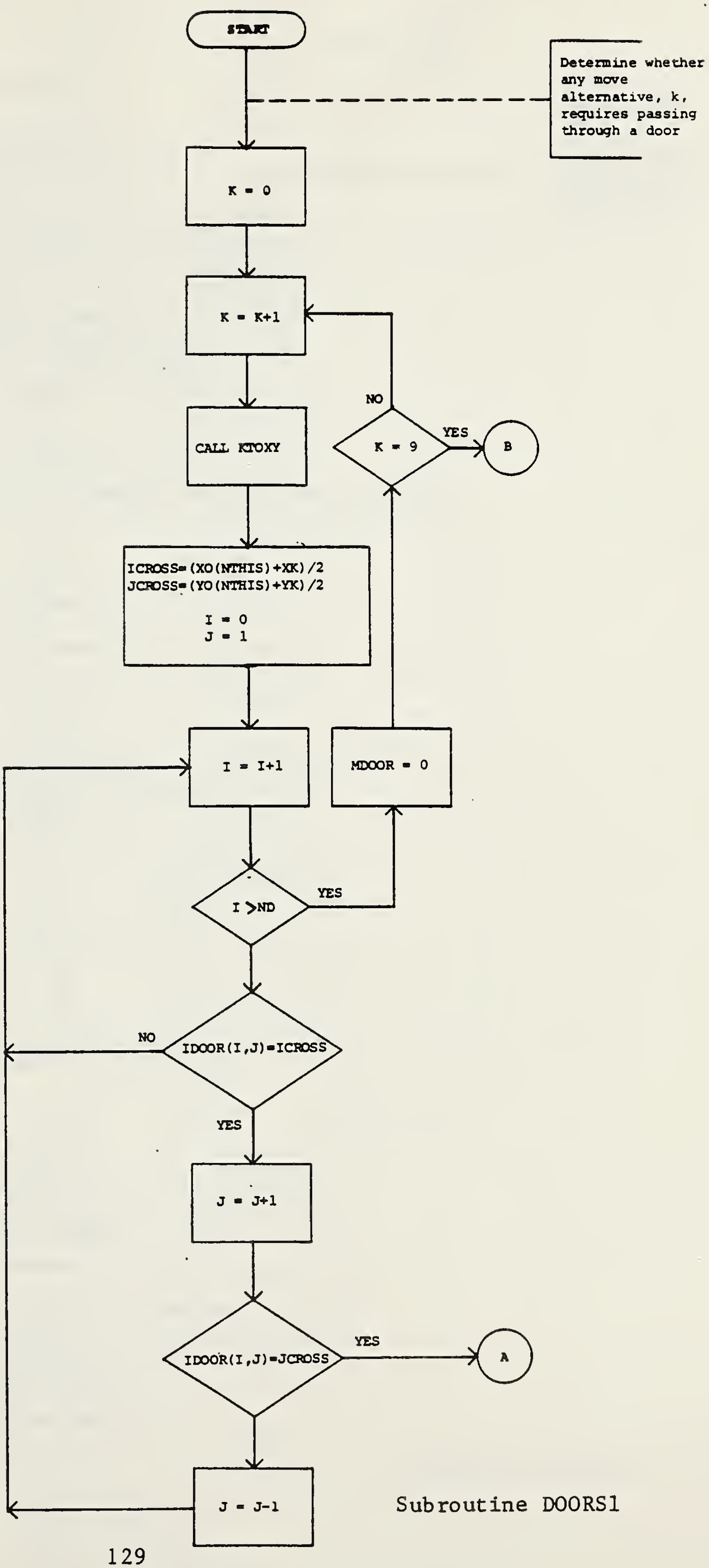
SUM = cumulative sum of probability values for all k vectors;

P(K) = likelihood of selecting move k;

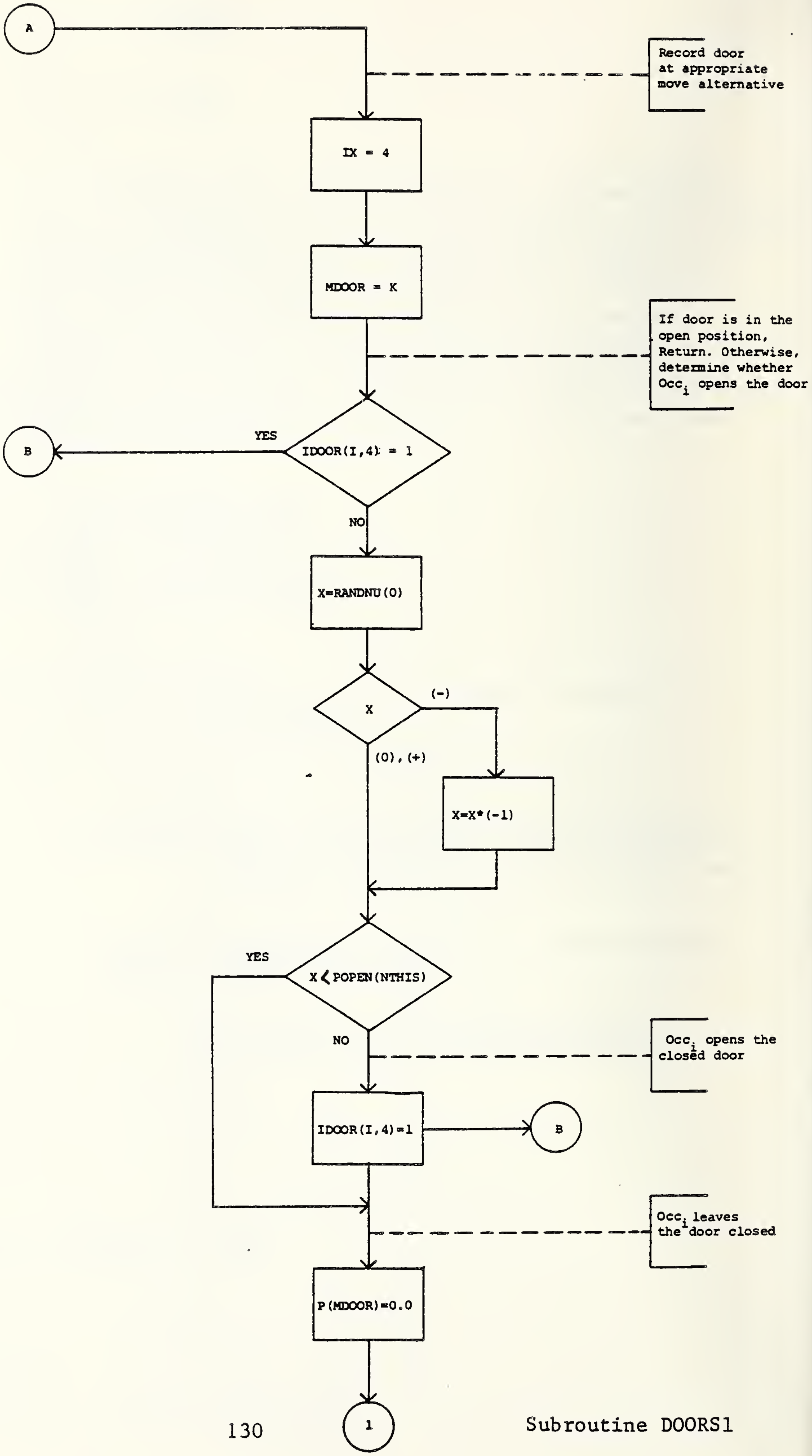
Share = proportion of cumulative probility which must be redistributed under the condition that the through-door alternative has been deleted;

NPOSS = total number of possible moves available during t;

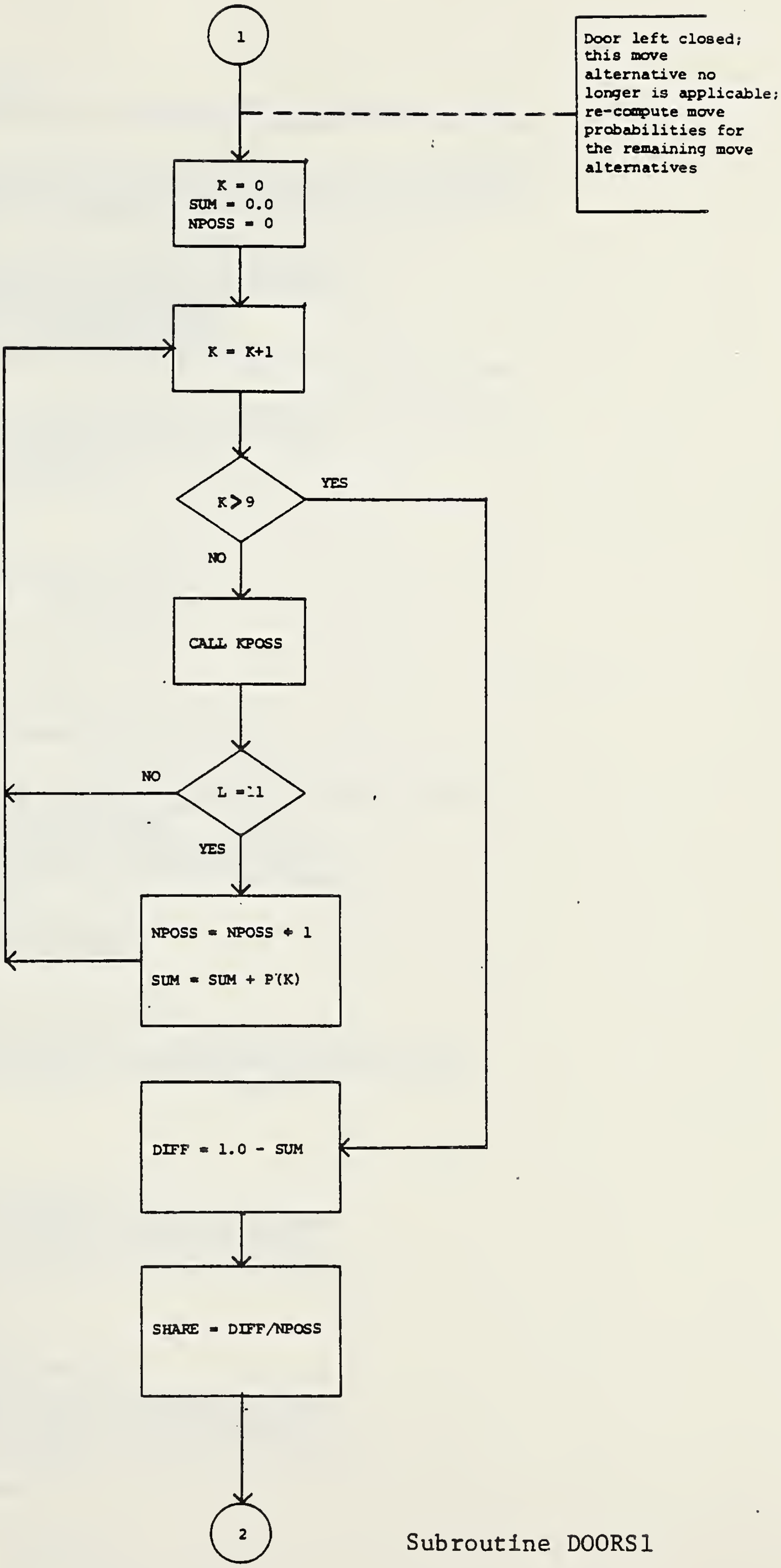
P(K)* = new value of P(K), after cumulative probability has been redistributed.



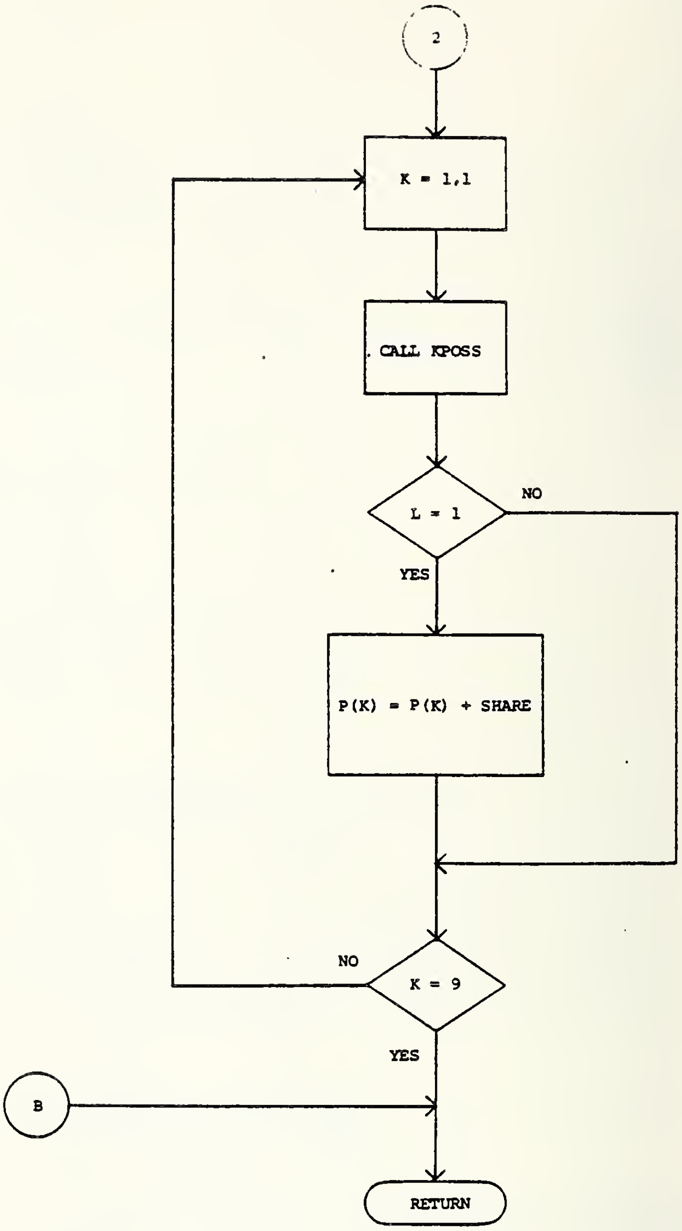
Subroutine DOORS1



Subroutine DOORS1

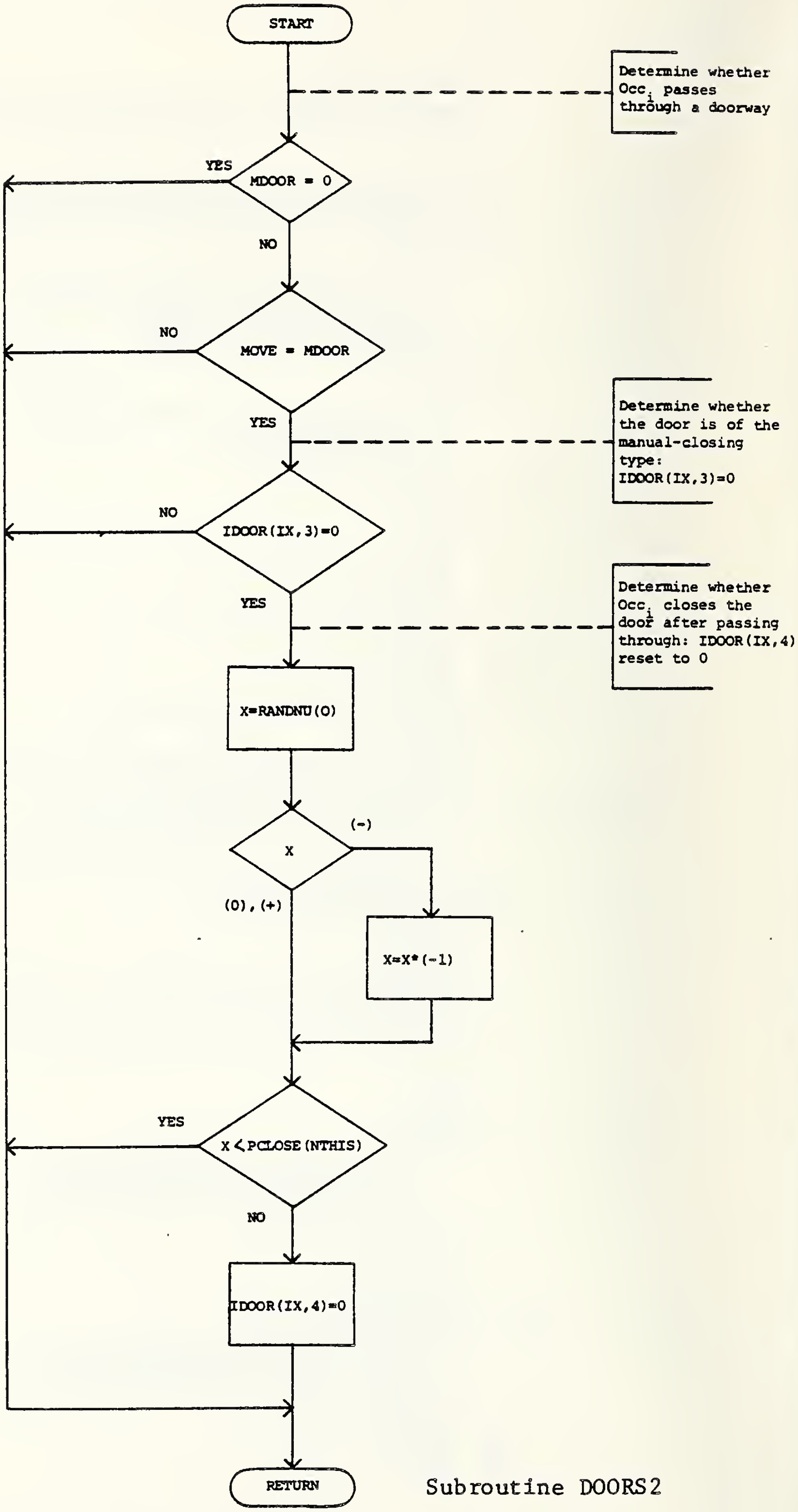


Subroutine DOORS1



Subroutine DOORS1

```
C
C
C
C
C
C     SUBROUTINE DOORSI
C
C     THE PURPOSE OF DOORSI IS TO DETERMINE WHETHER THE OCCUPANT WILL OPEN A
C     CLOSED DOOR WHICH IS ALONG AN ALTERNATIVE MOVEMENT PATH AVAILABLE TO HIM...


C     OPENING THE DOOR DOES NOT GUARANTEE THAT THE OCCUPANT WILL PASS THROUGH IT
C     ...IF HE DECIDES TO LEAVE THE DOOR CLOSED. HOWEVER, THE THRU-DOOR MOVE
C     ALTERNATIVE WILL BE CANCELED, AND THE MOVE PROBABILITIES WILL BE
C     RECOMPUTED
C
        SUBROUTINE DOORSI (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
       1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
       2   IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER,
       3   X,IDOOR,POPEN,ND,MDOOR,PCLOSE,IX)
        DIMENSION P(9),IDOOR(30,4),POPEN(20)
        INTEGER XO(20),YO(20),XK,YK,TOTBAR
C     DETERMINE WHETHER ANY MOVE ALTERNATIVE REQUIRES PASSING THROUGH A DOOR
        K=0
5       K=K+1
6        CALL KTOXY (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL, .
       1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
       2   IRAND,P,MOVE,XK,YK,K)
        ICROSS=(XO(NTHIS)+XK)/2
        JCROSS=(YO(NTHIS)+YK)/2
        I=0
        J=0
        J=1
3       I=I+1
        IF (I.GT.ND) GO TO 1
        IF (IDOOR(I,J).EQ.ICROSS) GO TO 2
        GO TO 3
2       J=J+1
        IF (IDOOR(I,J).EQ.JCROSS) GO TO 4
        J=J-1
        GO TO 3
1       MDOOR=0
        IF (K.EQ.9) GO TO 999
        GO TO 5
C     RECORD DOOR AT APPROPRIATE MOVE ALTERNATIVE
4       IX=I
        MDOOR=K
C     IF DOOR IS IN THE OPEN POSITION (IDOOR(I,4)=1)), RETURN...OTHERWISE,
C     DETERMINE WHETHER THE OCCUPANT OPENS THE DOOR
        IF (IDOOR(I,4).EQ.1) GO TO 999
        CALL RANDOM (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
       1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
       2   IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER,X)
        IF (X) 55,56,56
55      X=X*(-1)
56      IF (X.LT.POPEN(NTHIS)) GO TO 6
C     THE OCCUPANT OPENS THE DOOR
        IDOOR(I,4)=1
        RETURN
        GO TO 999
C     THE OCCUPANT LEAVES THE DOOR CLOSED
6       P(MDOOR)=0.0
C     THE DOOR HAS BEEN LEFT CLOSED...THIS MOVE ALTERNATIVE IS NO LONGER
C     APPLICABLE...RECOMPUTE MOVE PROBABILITIES FOR THE REMAINING MOVE
C     ALTERNATIVES


        K=0
        SUM=0.0
        NPOSS=0
7       K=K+1
        IF (K.GT.9) GO TO 9
        CALL KPOSS (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
       1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
       2   IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER)
        IF (L.EQ.1) GO TO 8
        GO TO 7
8       NPOSS=NPOSS+1
        SUM=SUM+P(K)
        GO TO 7
9       DIFF=1.0-SUM
        SHARE=DIFF/FLOAT(NPOSS)
        DO 25 K=1,9
        CALL KPOSS (ITIME,NTHIS,IHANDI,INT,IBYSTD, IEVAL,
       1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
       2   IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER)
        IF (L.EQ.1) GO TO 10
        GO TO 25
10      P(K)=P(K)+SHARE
25      CONTINUE
999     RETURN
        END
```



Subroutine DOORS2

```
C
C
C
C
C
C    SUBROUTINE DOORS2
C
C    THE PURPOSE OF DOORS2 IS TO DETERMINE WHETHER THE OCCUPANT CLOSES A DOOR
C    BEHIND HIM, ONCE HE HAS PASSED THROUGH (ONLY APPLICABLE FOR THE CASE OF
C    MANUALLY-OPERATED DOORS)
C
      SUBROUTINE DOORS2 (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2   IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,IENTER,
     3   X,IDOOR,POPEN,ND,MDOOR,PCLOSE,IX)
      DIMENSION IDOOR(30,4),PCLOSE(20)
      IF (MDOOR.EQ.0) GO TO 999
      IF (MOVE.EQ.MDOOR) GO TO 1
      GO TO 999
C    DETERMINE WHETHER THE DOOR IS OF THE MANUALLY-OPERATING TYPE, I.E.,
C    IDOUR(IX,3)=0
1     IF (IDOOR(IX,3).EQ.0) GO TO 2
      GO TO 999
C    DETERMINE WHETHER THE OCCUPANT CLOSES THE DOOR AFTER PASSING THROUGH,
C    IN WHICH CASE, IDOOR(IX,4) IS RESET TO 0, DENOTING THE CLOSED POSITION
2     CALL RANDOM (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2   IRAND,P,MOVE,XK,YK,K,L,IS,IGOALX,IGOALY,
     3   IENTER,X)

      IF (X) 55,56,56
55    X=X*(-1)
56    IF (X.LT.PCLOSE(NTHIS)) GO TO 999
      IDOOR(IX,4)=0
999   RETURN
      END
```

Routines EVAL8 and EVAL 20

Loop Occupant

Purpose The direction of move probability biasing frequently depends upon an occupant's current evaluation of his own safety status (his spatial location with respect to the locations of the exit goal and the threat, if these are known to him). Evaluations may be positive or negative: A positive evaluation results whenever an occupant perceives his status to have improved between time t-1 and t. BFIRES provides two user-called options for the evaluation of safety status: EVAL8 and EVAL20.

EVAL8 constructs evaluation outcomes purely on the bases of straight-line distance measurements between an occupant's current location and the locations of threats and exits. A positive evaluation results whenever the occupant's perceive status at t time is better than that at time t-1 (i.e., he is nearer to an exit goal, and/or farther from the threat).

EVAL20 on the other hand, evaluates egress progress relative to the total elapsed time an occupant has spent in the threatening environment. A move in a seemingly threatening direction may not be perceived as negative, if the occupant thinks (on the whole) he still has an ample amount of time left to escape safely.

Formulas EVAL8

(1) TDIST = SQRT $((XO-XT)^2 + (YO-YT)^2)$
(2) PTDIST = TDIST
(3) TCHANG = TDIST - PTDIST
(4) EDIST = EDIST
(5) PEDIST = EDIST
(6) ECHANG = EDIST - PEDIST

Where:

TDIST = distance between occupant$_n$ and the threat;

XO,YO = x,y coordinates of occupant$_n$'s current location;

XT,YT = x,y coordinates of the threat location;

PTDIST = distance between occupant$_n$ and the threat at time frame t-1;

TCHANG = change in distance between occupant$_n$ and the threat, between time frames t-1 and t;

EDIST = distance between occupant$_n$ and the agreed-upon exit from space$_i$;

IGOALX,IGOALY = x,y coordinates of the agreed-upon exit from space$_i$;

PEDIST = the distance between occupant$_n$ at the agreed-upon exit from space$_i$, at time frame t-1;

EXCHANG = change in distance between occupant$_n$ and the agreed-upon exit from space$_i$, between time frames t-1 and t.

Formulas

EVAL20:

(1) $TEST = SQRT((XO-XE)^2 + (YO-YE)^2)$
(2) $TDIST = TTIME - TIME$
(3) $TDIST^* = TTIME - MXTIME$
(4) $QDIST = SQRT\ ((XO-XT)^2 + (YO-YT)^2)$
(5) $TDIST^{**}=TIME$

Where:

TEST = distance between $occupant_n$'s current location and the agreed-upon exit from floor;

XO,YO = x,y coordinates of $occupant_n$'s current location;

XE,YE = x,y coordinates of agreed-upon exit from the floor;

TDIST = time distance factor with respect to the exit location, under the condition that the elapsed time is greater than the critical time;

TTIME = total number of time frames in the event;

Time = current time frame (i.e., elapsed time);

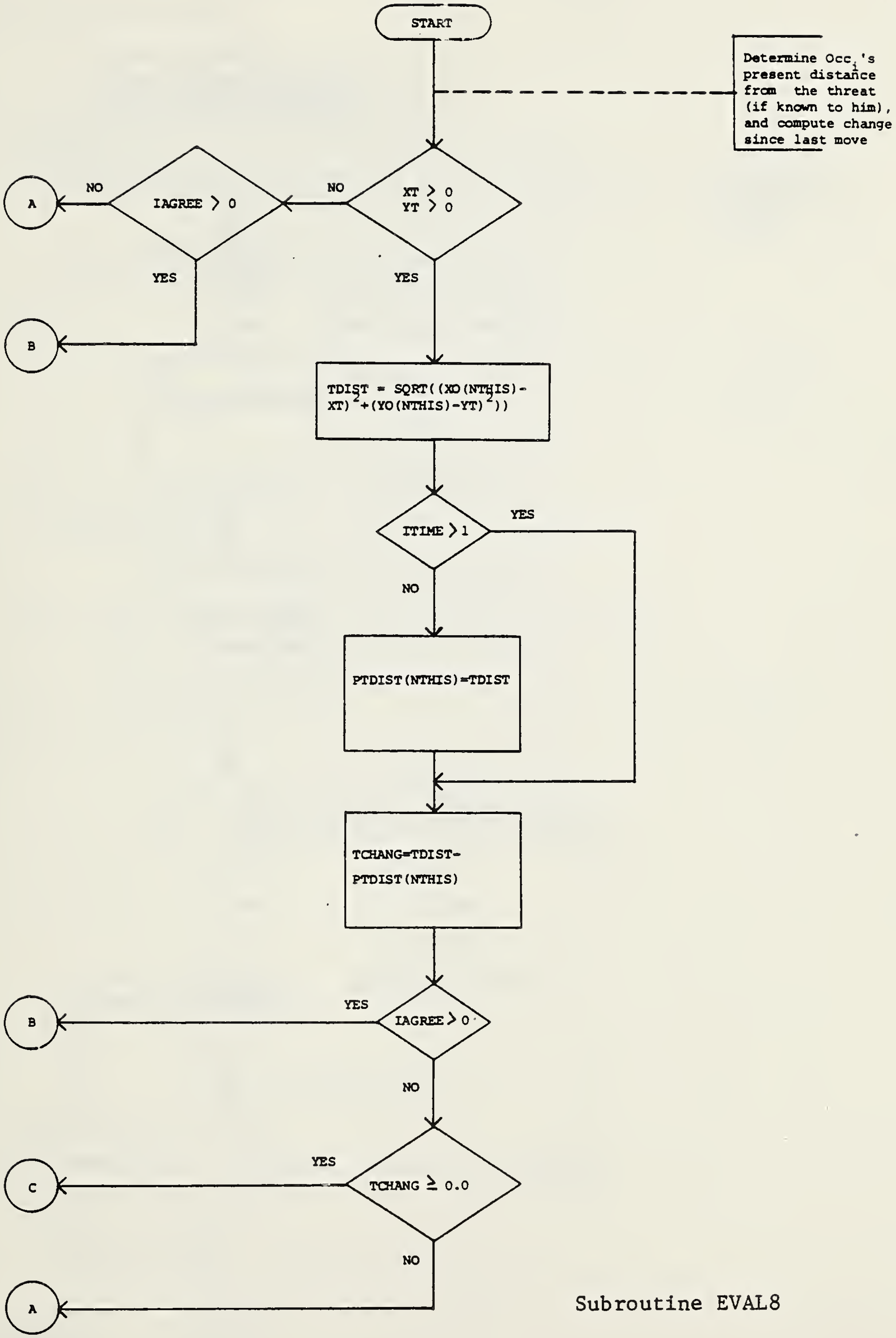
TDIST* = time distance factor with respect to the exit location under the condition that the elapsed time is less than the critical time;

MXTIME = critical time;

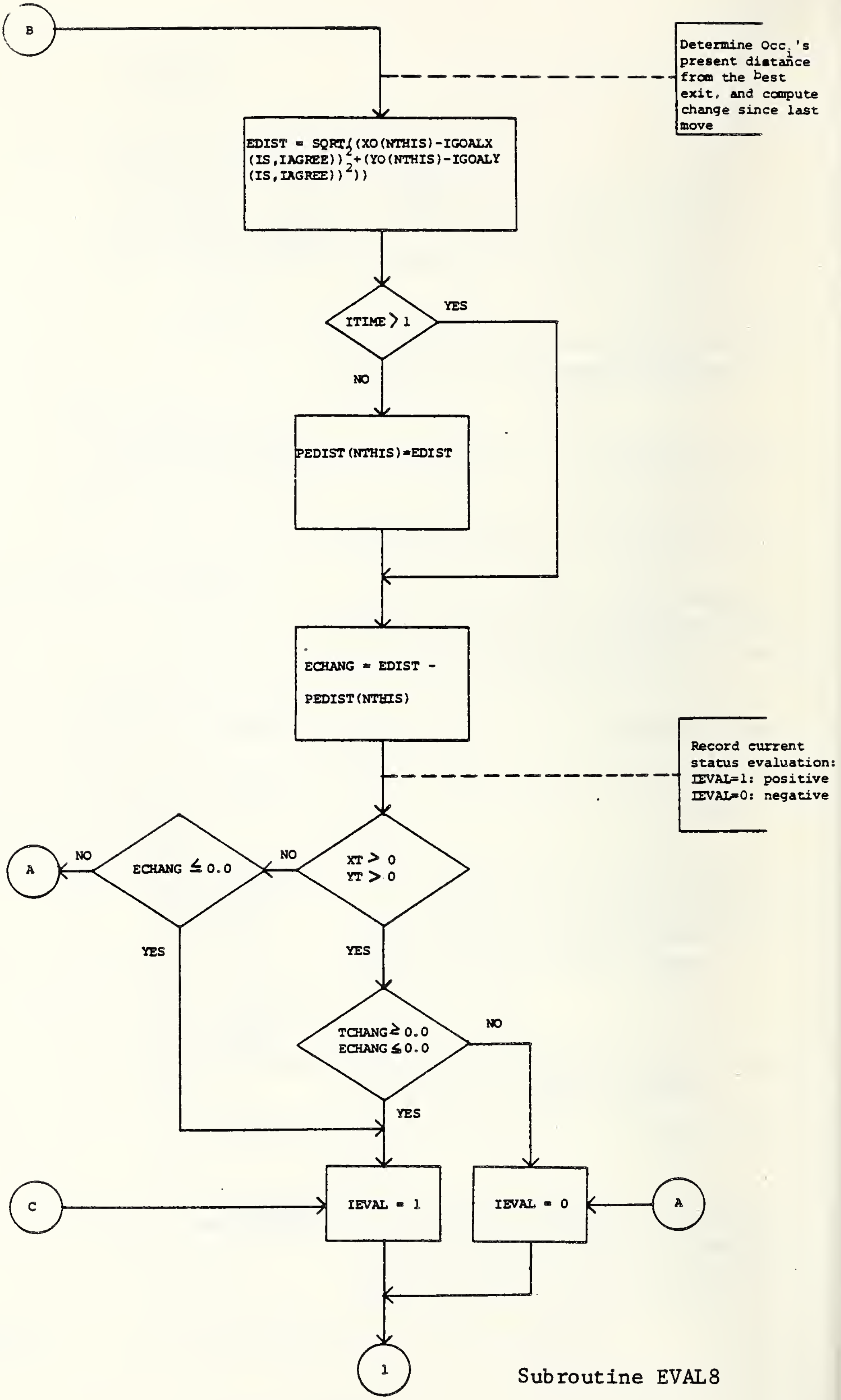
QDIST = distance between $occupant_n$'s current location and threat location;

XT,YT = x,y coordinates of the threat location;

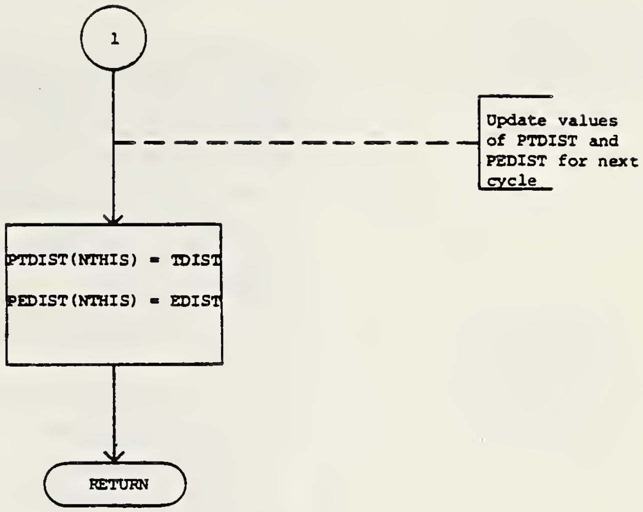
TDIST** = time distance factor with respect to the threat location, under the condition that the elapsed time is less than the critical time.



Subroutine EVAL8

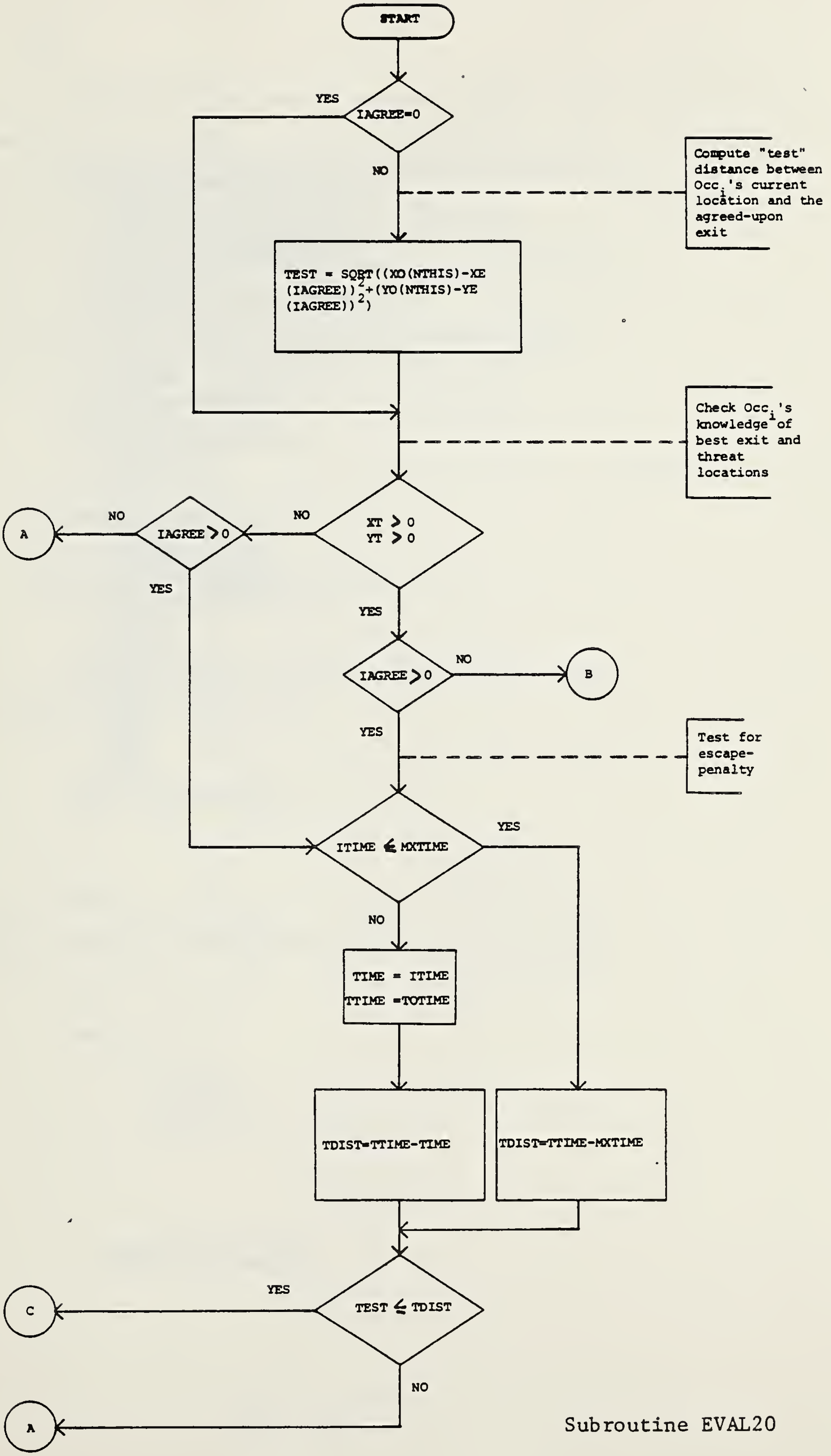


Subroutine EVAL8



Subroutine EVAL8

```
C
C
C
C
C
C     SUBROUTINE EVAL8
C


C     THE PURPOSE OF EVAL8 IS TO ENABLE THE OCCUPANT TO PROCESS DISTANCE
C     INFORMATION, AND THEREBY DETERMINE HIS CURRENT  'SAFETY STATUS'...EVAL8
C     CONDUCTS STATUS EVALUATIONS PURELY ON THE BASIS OF STRAIGHT-LINE DISTANCE
C     MEASUREMENTS BETWEEN THE OCCUPANT'S CURRENT LOCATION, AND THE LOCATIONS OF
C     THREATS AND EXITS...A POSITIVE STATUS EVALUATION RESULTS WHENEVER THE
C     OCCUPANT'S PERCEIVED STATUS AT TIME T IS 'BETTER' THAN IT WAS AT TIME T-1...
C     OTHERWISE, HIS EVALUATION IS NEGATIVE
C
        SUBROUTINE EVAL8 (XO,YO,XT,YT,XE,YE,NTHIS,
      1   IAGREE,ITIME,IEVAL,PTDIST,TDIST,PEDIST,
      1   EDIST,IS,IGOALX,IGOALY)
        INTEGER XO(20),YO(20),XE(10),YE(10),XT,YT
        DIMENSION PTDIST(20),IGOALX(20,10),IGOALY(20,10)
        DIMENSION PEDIST(20)
C     DETERMINE THE OCCUPANT'S PRESENT DISTANCE FROM THE THREAT (IF KNOWN TO HIM),
C     AND COMPUTE CHANGE SINCE LAST MOVE
        IF ((XT.GT.0).AND.(YT.GT.0)) GO TO 1
        IF (IAGREE.GT.0) GO TO 2
        GO TO 6
1       TDIST=SQRT(FLOAT((XO(NTHIS)-XT)**2+
      1   (YO(NTHIS)-YT)**2))
        IF (ITIME.GT.1) GO TO 50
        PTDIST(NTHIS)=TDIST
50      TCHANG=TDIST-PTDIST(NTHIS)
        IF (IAGREE.GT.0) GO TO 2
        IF (TCHANG.GE.0.) GO TO 5
        GO TO 6
C     DETERMINE THE OCCUPANT'S PRESENT DISTANCE FROM THE BEST EXIT, AND COMPUTE
C     CHANGE SINCE LAST MOVE
2       EDIST=SQRT(FLOAT((XO(NTHIS)-IGOALX(IS,IAGREE))**2
      1   +(YO(NTHIS)-IGOALY(IS,IAGREE))**2))
        IF (ITIME.GT.1) GO TO 55
        PEDIST(NTHIS)=EDIST
55      ECHANG=EDIST-PEDIST(NTHIS)
C     RECORD CURRENT STATUS EVALUATION, IEVAL=1 (POSITIVE), IEVAL=0 (NEGATIVE)
        IF ((XT.GT.0).AND.(YT.GT.0)) GO TO 3
        IF (ECHANG.LE.0.) GO TO 5
        GO TO 6
3       IF ((TCHANG.GE.0.).AND.(ECHANG.LE.0.)) GO TO 5
        GO TO 6
5       IEVAL=1
        GO TO 7
6       IEVAL=0
C     UPDATE VALUES OF PTDIST AND PEDIST FOR THE NEXT CYCLE
7       PTDIST(NTHIS)=TDIST
        PEDIST(NTHIS)=EDIST
        RETURN
        END
```

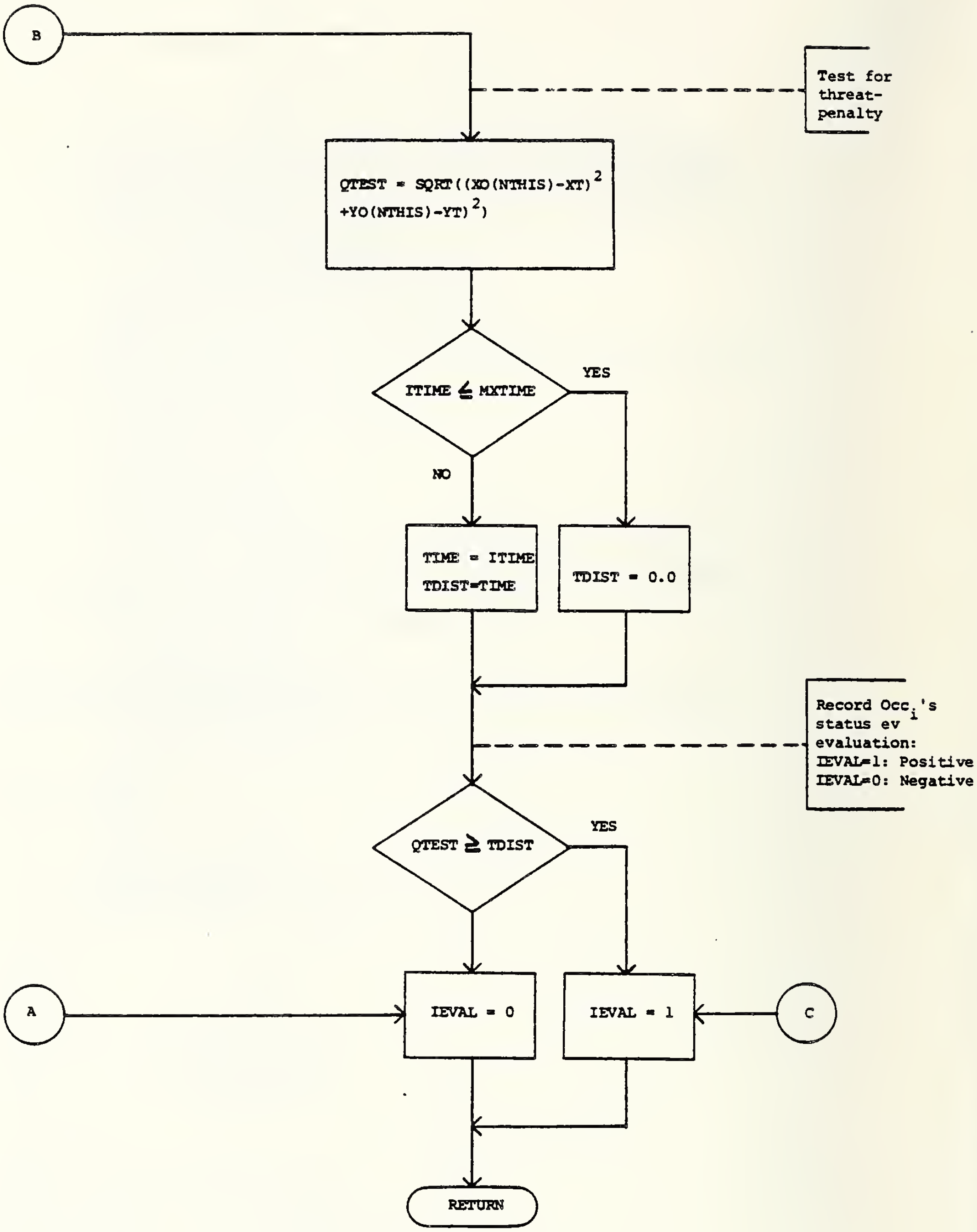


Compute "test" distance between Occ$_i$'s current location and the agreed-upon exit

Check Occ$_i$'s knowledge of best exit and threat locations

Test for escape-penalty

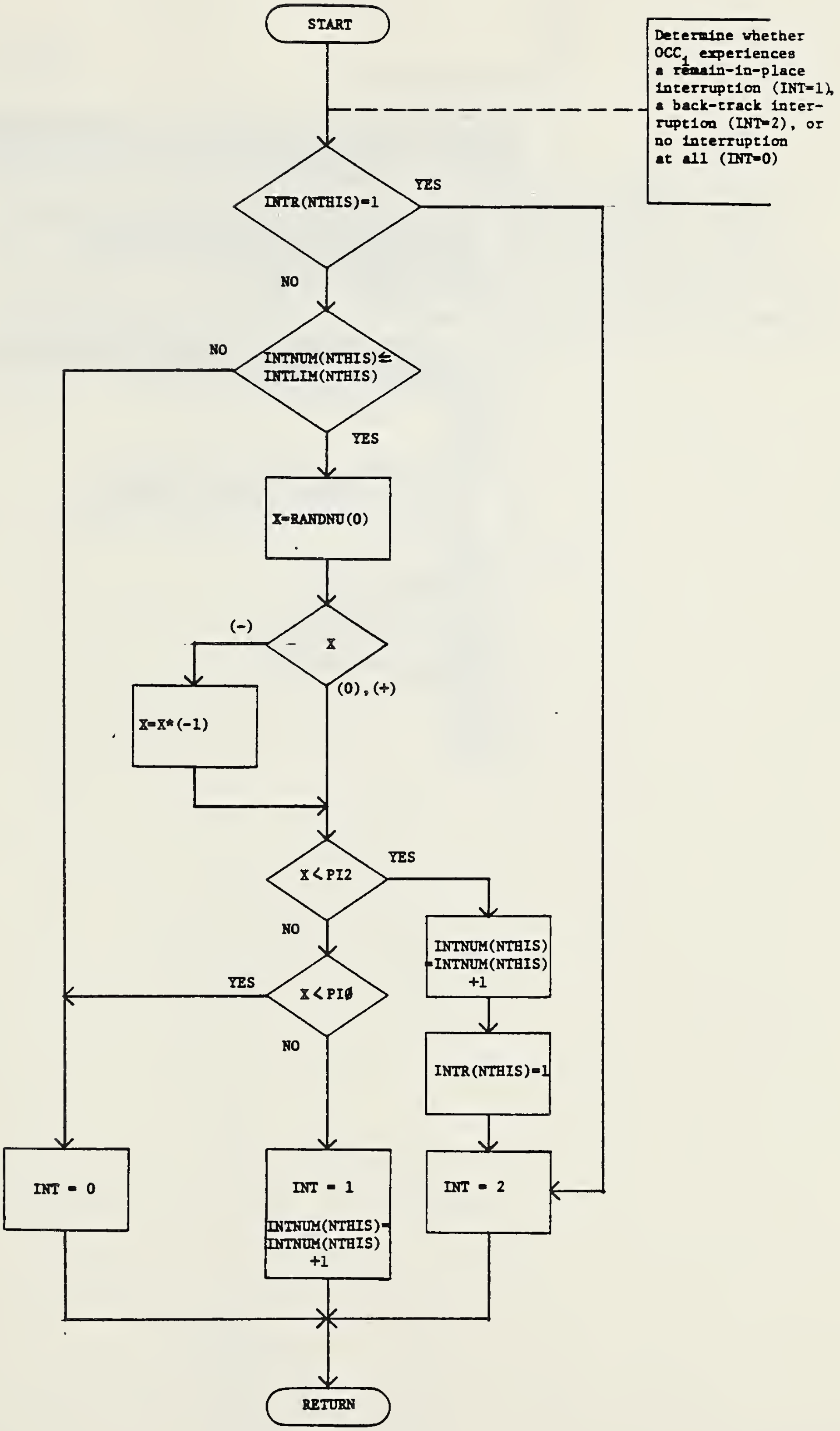
Subroutine EVAL20



Subroutine EVAL20

```
C
C
C
C
C
C   SUBROUTINE EVAL20


C
C   THE PURPOSE OF EVAL20 IS TO ENABLE THE OCCUPANT TO EVALUATE HIS
C   'SAFETY STATUS' BY COMPARING EGRESS PROGRESS AGAINST TOTAL ELAPSED TIME
C   SPENT IN THE DANGER ZONE
C
      SUBROUTINE EVAL20 (MXTIME,MK,XO,YO,XE,YE,NTHIS,IAGREE,
     1   ITIME,C,IEVAL,TOTIME)
      INTEGER XO(20),YO(20),XE(10),YE(10),XT,YT,TOTIME
      IF (IAGREE.EQ.0) GO TO 5
C   COMPUTE TEST DISTANCE BETWEEN THE OCCUPANT'S CURRENT LOCATION AND THE
C   AGREED-UPON EXIT
      TEST=SQRT(FLOAT((XO(NTHIS)-XE(IAGREE))**2+
     1   (YO(NTHIS)-YE(IAGREE))**2))
5     CONTINUE
C   CHECK THE OCCUPANT'S KNOWLEDGE OF BEST EXIT AND THREAT LOCATIONS
      IF ((XT.GT.0).AND.(YT.GT.0)) GO TO 10
      IF (IAGREE.GT.0) GO TO 20
      GO TO 50
10    IF (IAGREE.GT.0) GO TO 20
      GO TO 30
C   TEST FOR ESCAPE PENALTY
20    IF (ITIME.LE.MXTIME) GO TO 21
      TIME=ITIME
      TTIME=TOTIME
      TDIST=TTIME-TIME
      GO TO 22
21    TDIST=TTIME-(FLOAT(MXTIME))
22    IF (TEST.LE.TDIST) GO TO 51
      GO TO 50
C   TEST FOR THREAT PENALTY
30    QTEST=SQRT(FLOAT((XO(NTHIS)-XT)**2+
     1   (YO(NTHIS)-YT)**2))
      IF (ITIME.LE.MXTIME) GO TO 31
      TIME=ITIME
      TDIST=TIME
      GO TO 32
31    TDIST=0.0
C   RECORD THE OCCUPANT'S STATUS EVALUATION, IEVAL=1 (POSITIVE), IEVAL=0
C   (NEGATIVE)
32    IF (QTEST.GE.TDIST) GO TO 51
50    IEVAL=0
      RETURN
51    IEVAL=1
      RETURN
      END
```

Routine	INTRPT
Loop	Occupant
Purpose	This subroutine probabilistically determines whether an occupant's goal-directed behavior will be interrupted during time frame t. The two modes of interruption are remaining-in-place and backtracking. Occupants are assigned probabilities of encountering such interruptions. Each occupant is also assigned an interruption limit. If, during the course of the simulated event, an occupant has experienced a number of interruptions equal to his limit, he will not "tolerate" any more, and hence ignore future interruptions.
Formulas	n/a



Subroutine INTRPT

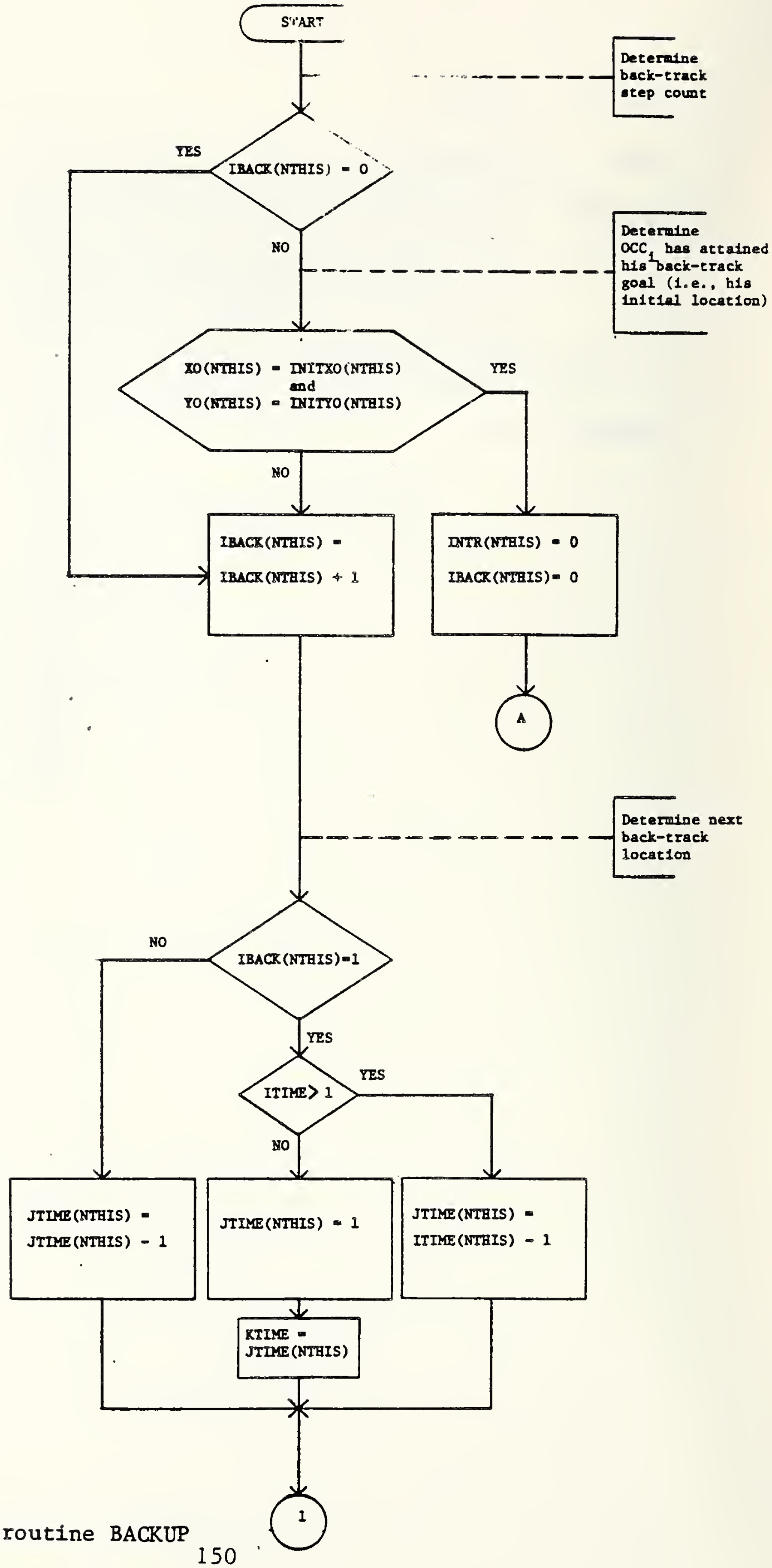
```
C
C
C
C
C
C     SUBROUTINE INTRPT
C
C     THE PURPOSE OF INTRPT IS TO PROBABILISTICALLY DETERMINE WHETHER THE
C     OCCUPANT'S GOAL-DIRECTED BEHAVIOR WILL BE INTERRUPTED DURING TIME FRAME T.
C     TWO MODES OF INTERRUPTION ARE AVAILABLE. REMAINING-IN-PLACE AND
C     BACKTRACKING.  INTRPT DETERMINES WHETHER AN INTERRUPTION WILL OCCUR. AND
C     WHICH MODE WILL CONTROL.
C
        SUSROUTINE INTRPT (ITIME.NTHIS.IHANDI.INT.IBYSTD.IEVAL.
       1   XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
       2   IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER.
       3   X.INTLIM.INTR.INTNUM.P12.P10)
        DIMENSION INTNUM(20).INTLIM(20)
        DIMENSION INTR(20)


C     DETERMINE WHETHER THE OCCUPANT EXPERIENCES A REMAIN-IN-PLACE INTERRUPTION
C     (INT=1). A BACKTRACK INTERRUPTION (INT=2). OR NO INTERRUPTION AT ALL (INT=0)
        IF (INTR(NTHIS).EQ.1) GO TO 1
        IF (INTNUM(NTHIS).LE.INTLIM(NTHIS)) GO TO 2
        INT=0
        RETURN
1       INT=2
        RETURN
2       CALL RANDOM (ITIME.NTHIS.IHANDI.INT.IBYSTD.IEVAL.
       1   XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
       2   IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER.
       3   X)
        IF (X) 5.6.6
5       X=X*(-1)
6       CONTINUE
        IF (X.LT.P12) GO TO 3
        IF (X.LT.P10) GO TO 4
        INT=1
        INTNUM(NTHIS)=INTNUM(NTHIS)+1
        RETURN
3       INTNUM(NTHIS)=INTNUM(NTHIS)+1
        INTR(NTHIS)=1
        INT=2
        RETURN
4       INT=0
        RETURN
        END
```

Routine BACKUP

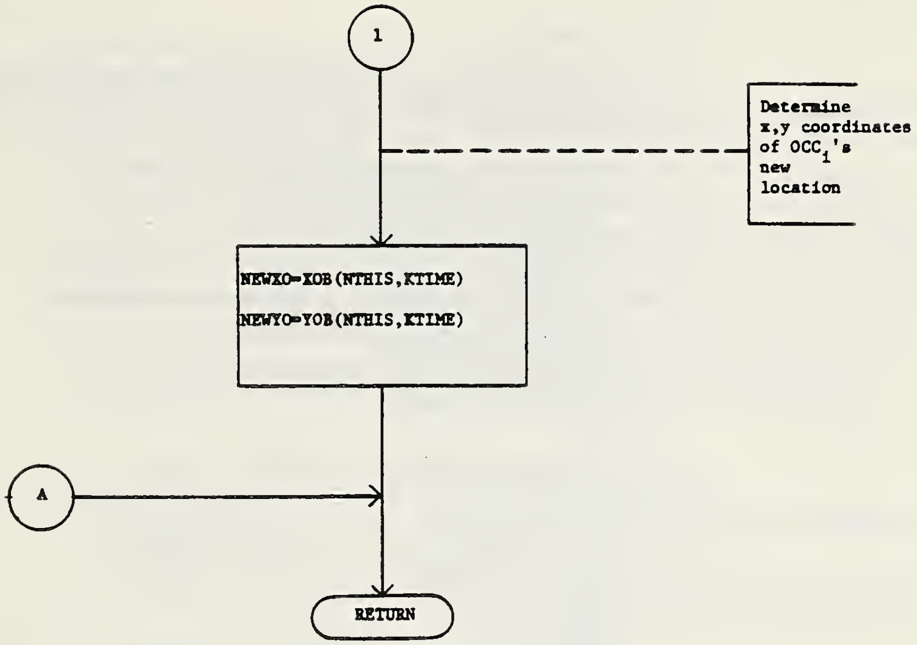
Loop Occupant

Purpose If a backtracking interruption is evoked by Subroutine INTRPT, then BACKUP is called. BACKUP processes occupants who have entered into this mode by retracing their steps back toward their initial starting location. Once the occupant has returned to this point, he is removed from the backtracking mode, and he resumes the normal decisionmaking and goal seeking processes.

Formulas n/a



Subroutine BACKUP



Subroutine BACKUP

```
C
C
C
C
C
C     SUBROUTINE BACKUP
C
C     THE PURPOSE OF BACKUP IS TO PROCESS OCCUPANTS THRUST INTO THE BACKTRACK
C     INTERRUPTION MODE.  BACKUP RETRACES THEIR STEPS BACK TOWARD THEIR INITIAL
C     STARTING LOCATIONS.  ONCE AT THIS LOCATION, OCCUPANTS REENTER THE NORMAL
C     GOAL-SEEKING MODE.
C
        SUBROUTINE BACKUP (IBACK,XO,YO,INITXO,INITYO,XOB,YOB,
     1   ITIME,NTHIS,NEWXO,NEWYO,INTR,JTIME)
        DIMENSION IBACK(20),INITXO(20),
     1   INITYO(20),JTIME(20),INTR(20)
        INTEGER XOB(20,100),YOB(20,100),XO(20),YO(20)
C     DETERMINE BACKTRACK STEP COUNT
        IF (IBACK(NTHIS).EQ.0) GO TO 1
C     DETERMINE WHETHER THE OCCUPANT HAS ATTAINED HIS BACKTRACK GOAL
        IF ((XO(NTHIS).EQ.INITXO(NTHIS)).AND.
     1   (YO(NTHIS).EQ.INITYO(NTHIS))) GO TO 3
1       IBACK(NTHIS)=IBACK(NTHIS)+1
C     DETERMINE THE NEXT BACKTRACK LOCATION
        IF (IBACK(NTHIS).EQ.1) GO TO 2
        JTIME(NTHIS)=JTIME(NTHIS)-1
        GO TO 4


2       IF (ITIME.GT.1) GO TO 21
        JTIME(NTHIS)=1
        GO TO 4
21       JTIME(NTHIS)=ITIME-1
4       KTIME=JTIME(NTHIS)
C     DETERMINE X,Y COORDINATES OF THE OCCUPANT'S NEW LOCATION
        NEWXO=XOB(NTHIS,KTIME)
        NEWYO=YOB(NTHIS,KTIME)
        RETURN
3       INTR(NTHIS)=0
        IBACK(NTHIS)=0
        RETURN
        END
```

Routine ASSIGN

Loop Occupant

Purpose BFIRES assumes that an individual's decisionmaking behavior will be biased, and that the direction of bias will be determined by his immediate perception of the fire situation. The primary function of ASSIGN is to "recall" for each occupant all those factors which comprise his current perception (e.g., current evaluation of success, knowledge of exit locations, interruption status, etc.). It then assigns his decisionmaking task to an appropriate biasing subroutine. The following directions are accommodated within the current version of BFIRES:

(1) threat evasion (Subroutine TBIAS);
(2) exit goal seeking (Subroutine EBIAS);
(3) interruption mode fulfillment (Subroutines INTRPT and/or BACKUP);
(4) confusion, or no specific bias (Subroutine EQUALZ).

Formulas (1) $\mathrm{CUM}(K) = P(K)$
(2) $\mathrm{CUM}(K) = P(K) + \mathrm{CUM}(K-1)$
(3) $\mathrm{RAND} = \mathrm{CUM}(K) - X$

Where:

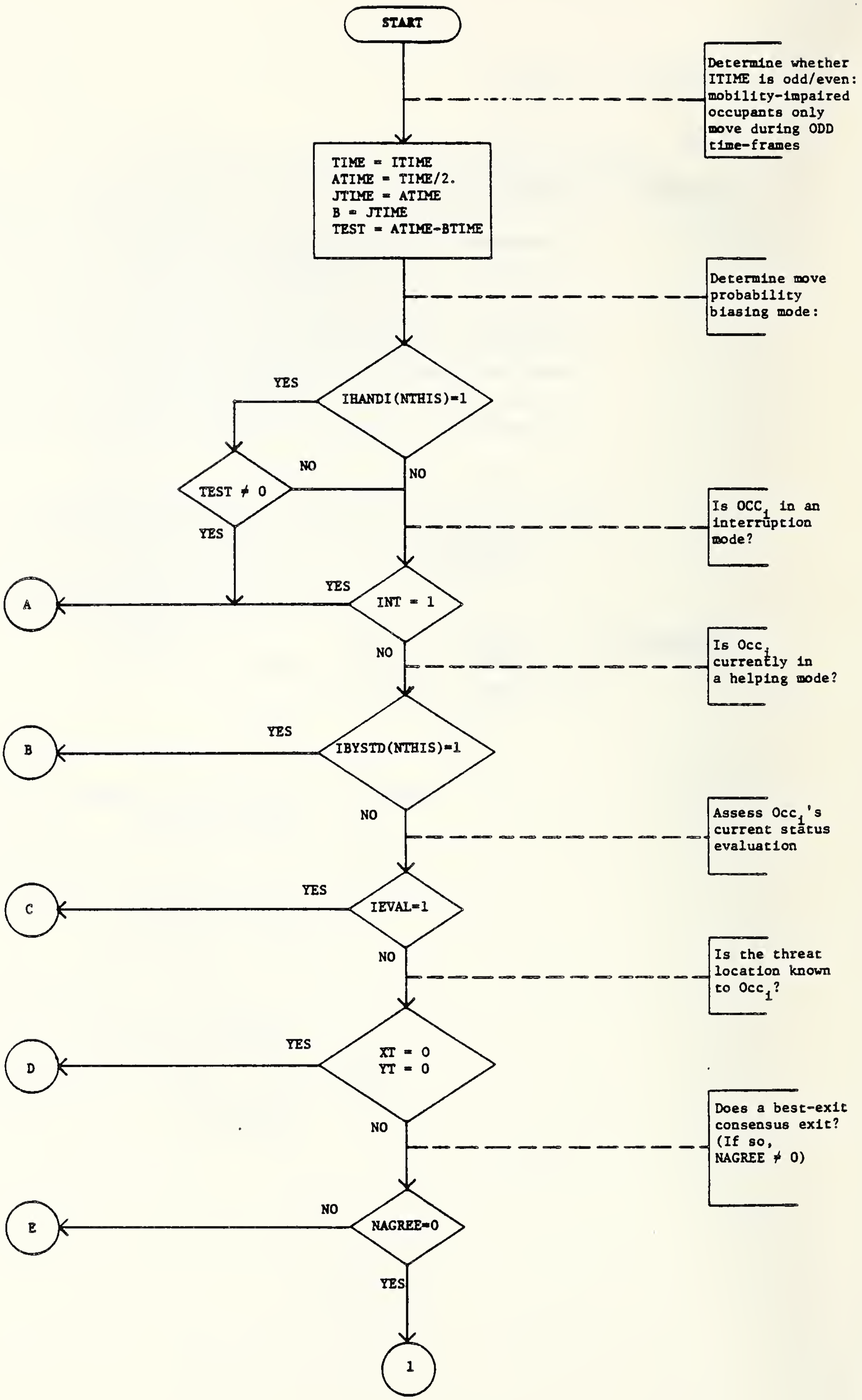
$\mathrm{CUM}(K)$ = cumulative probability of selecting the kth move;

$P(K)$ = the computed probability fo selecting the kth move;

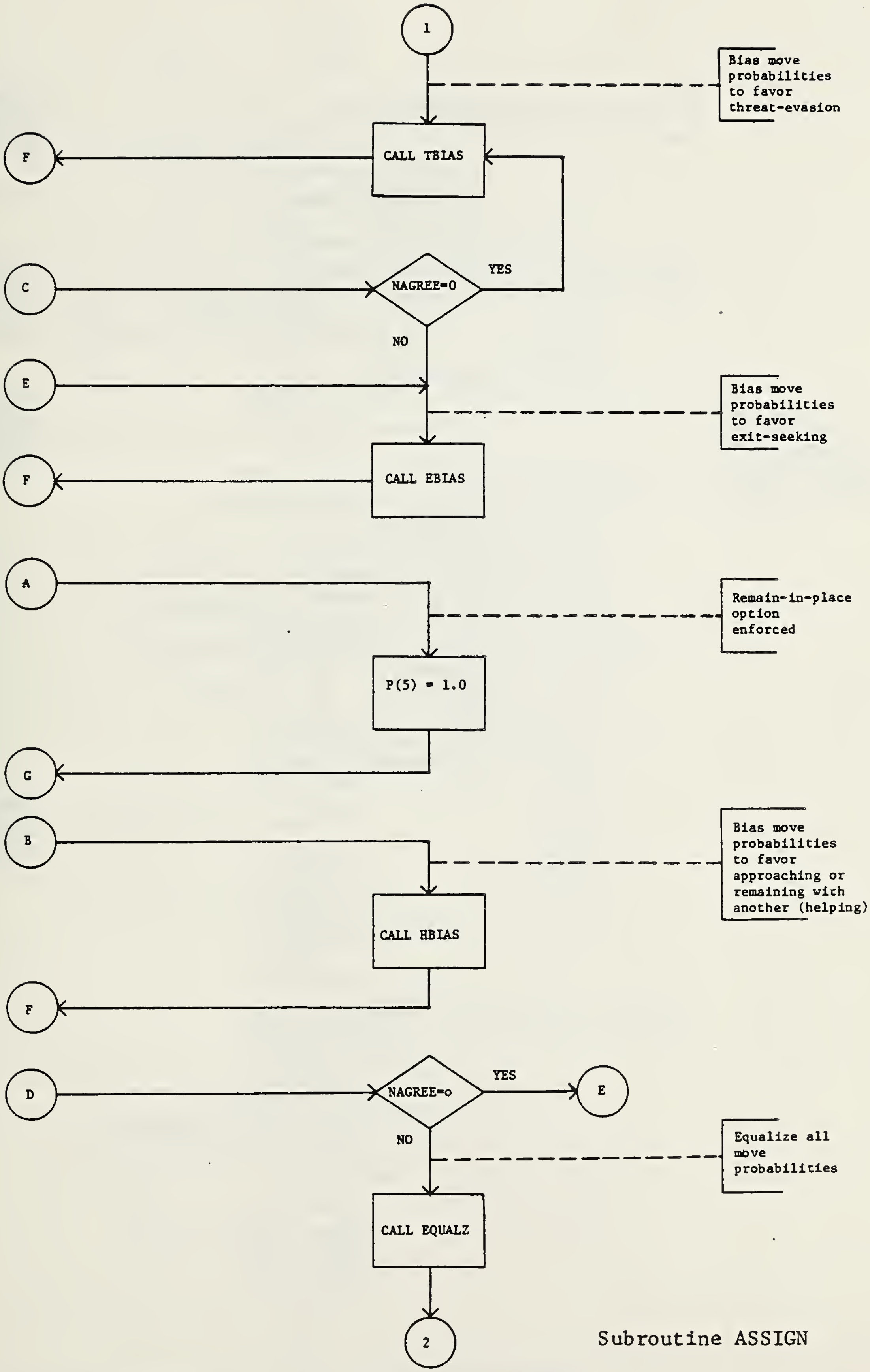
K = move identifier;

X = a uniformly distributed random number between 0 and 1;

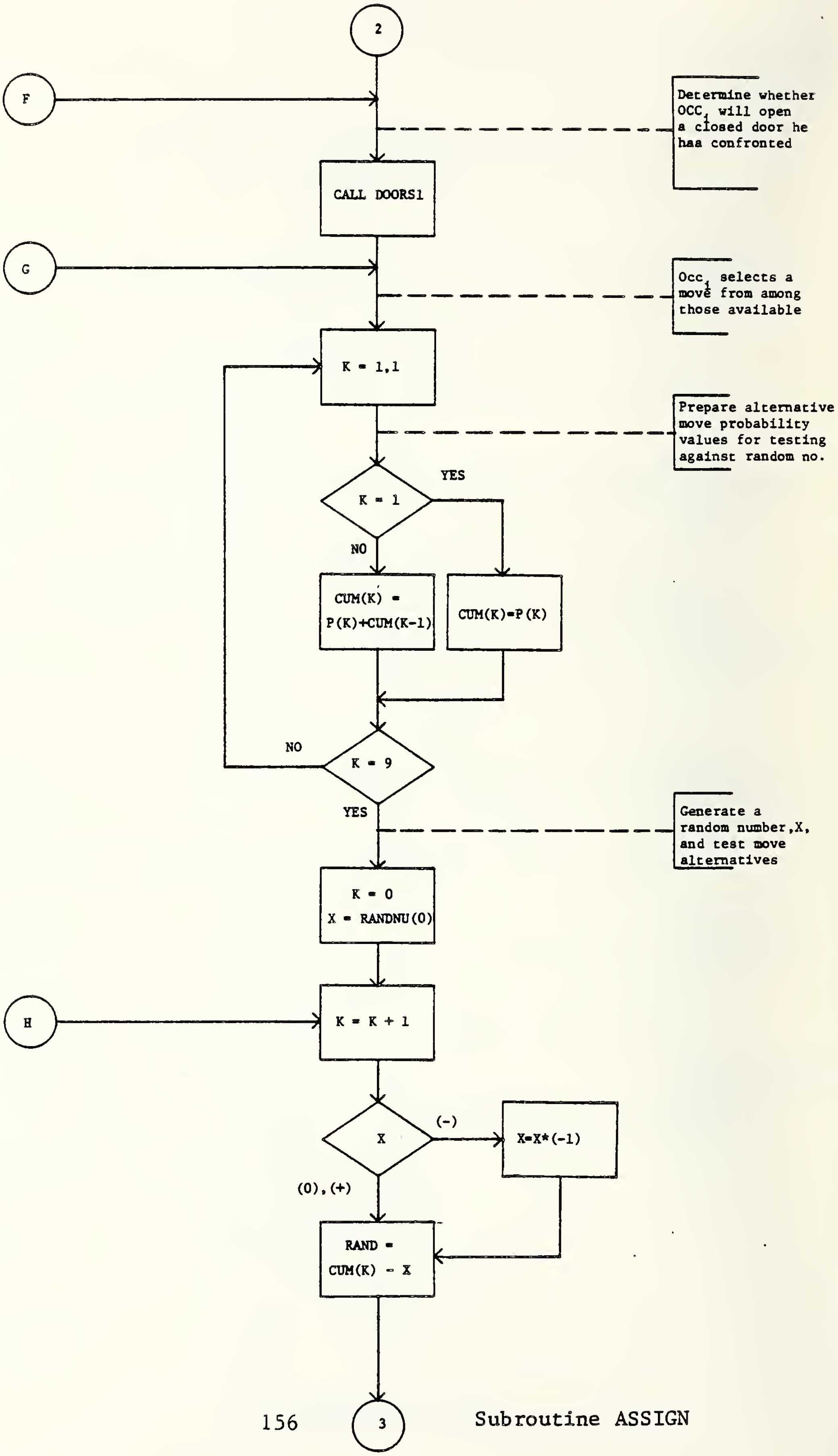
RAND = Test number for stochastic selection process.



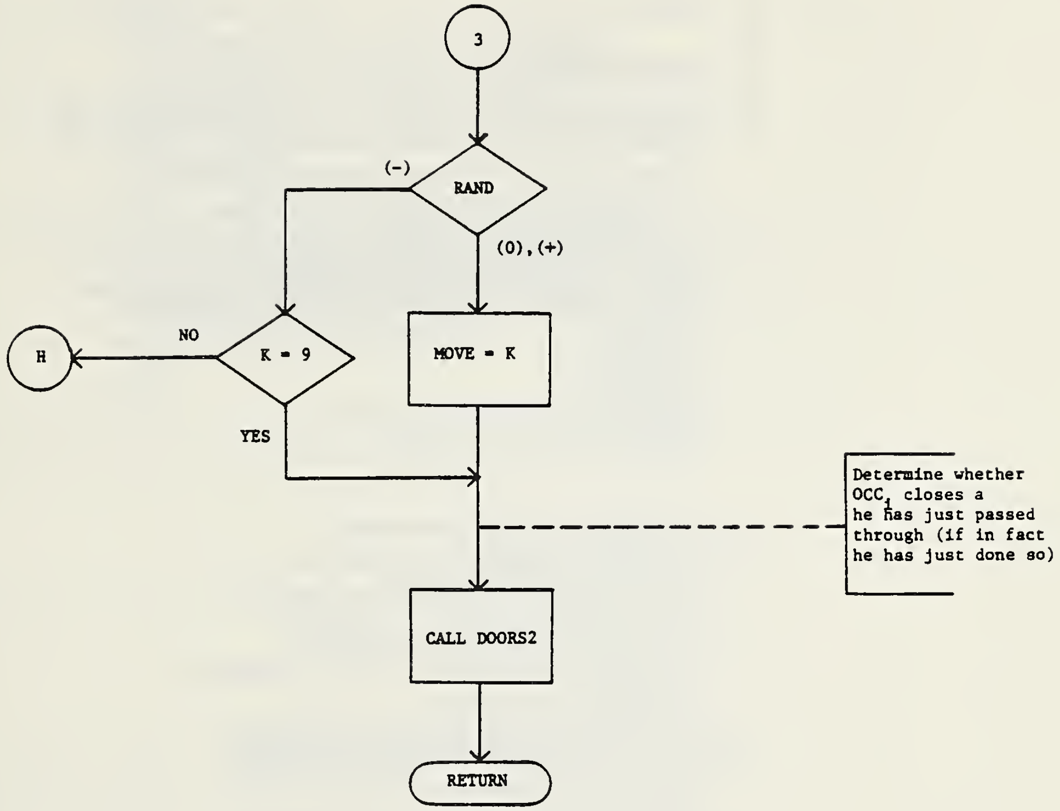
Subroutine ASSIGN



Subroutine ASSIGN



Subroutine ASSIGN



Subroutine ASSIGN

```
C
C
C
C
C
C    SUBROUTINE ASSIGN
C
C    THE PURPOSE OF ASSIGN IS TO CONSIDER ALL FACTORS COMPRISING THE OCCUPANT'S
C    CURRENT PERCEPTION OF NIS SITUATION. AND THEN TO SWITCH CONTROL FOR
C    DECISION-MAKING TO THE APPROPRIATE BIASING ROUTINE.
C
      SUBROUTINE ASSIGN (ITIME.NTHIS.IHANDI.INT.IBYSTD.IEVAL.
     I   XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
     2   IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER.
     3   X.IDOOR.POPEN.ND.MDOOR.PCLOSE)
      DIMENSION IHANDI(20).IBYSTD(20).P(9).CUM(9)
      INTEGER XO(20).YO(20).XE(10).YE(10).XT.YT
C    DETERMINE WHETHER ITIME. THE CURRENT TIME-FRAME. IS ODD OR EVEN...
C    MOBILITY-IMPAIRED OCCUPANTS ONLY MOVE DURING ODD TIME-FRAMES
      TIME=ITIME
      ATIME=TIME/2.
      JTIME=ATIME
      BTIME=JTIME
      TEST=ATIME-BTIME
C    DETERMINE MOVE PROBABILITY BIASING MODE
      IF (IHANDI(NTHIS).EQ.I) GO TO 1
      GO TO 1I


1     IF (TEST.NE.0.) GO TO 2
C    IS THE OCCUPANT IN AN INTERRUPTION MODE
11    IF (INT.EQ.I) GO TO 2
C    IS THE OCCUPANT CURRENTLY IN A HELPING MODE
      IF (IBYSTD(NTHIS).EQ.I) GO TO 3
C    ASSESS THE OCCUPANT'S CURRENT STATUS EVALUATION
      IF (IEVAL.EQ.I) GO TO 4
C    IS THE THREAT LOCATION KNOWN TO THE OCCUPANT
      IF ((XT.EQ.0).AND.(YT.EQ.0)) GO TO 5
C    DOES A BEST-EXIT CONSENSUS EXIST (IF SO. NAGREE.NE.0)
      IF (NAGREE.EQ.0) GO TO 404
      GO TO 504
C    BIAS MOVE PROBABILITIES TO FAVOR THREAT-EVASION
404   CALL TBIAS (ITIME.NTHIS.INANDI.INT.IBYSTD.IEVAL.
     I  XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
     2  IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER)
      GO TO 6
4     IF (NAGREE.EQ.0) GO TO 404
C    BIAS MOVE PROBABILITIES TO FAVOR EXIT-SEEKING
504   CALL EBIAS (ITIME.NTHIS.INANDI.INT.IBYSTD.IEVAL.
     1  XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
     2  IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER)
      GO TO 6
C    REMAIN-IN-PLACE OPTION ENFORCED
2     P(5)=1.0
      DO 50 K=1.4
50    P(K)=0.0
      DO 5I K=6.9
5I    P(K)=0.0
      GO TO 60I
C    BIAS MOVE PROBABILITIES TO FAVOR APPROACNING OR REMAINING WITH A MOBILITY-
C    IMPAIRED OTHER
3     CALL HBIAS (ITIME.NTHIS.IHANDI.INT.IBYSTD.IEVAL.
     I  XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
     2  IRAND.P)
      GO TO 6
5     IF (NAGREE.NE.0) GO TO 504
C    EQUALIZE ALL MOVE PROBABILITIES
      CALL EQUALZ (ITIME.NTHIS.INANDI.INT.IBYSTD.IEVAL.
     1  XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
     2  IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER)
C    DETERMINE WHETHER THE OCCUPANT WILL OPEN A CLOSED DOOR HE NAS CONTRONTED
6     CALL DOORS1 (ITIME.NTHIS.IHANDI.INT.IBYSTD.IEVAL.
     1   XO.YO.IBAR.TOTBAR.XT.YT. NAGREE.XE.YE.IAGREE.
     2   IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER.
     3   X.IDOOR.POPEN.ND.MDOOR.PCLOSE.IX)
60I   CONTINUE
C    THE OCCUPANT SELECTS A MOVE FROM AMONG THE ALTERNATIVES AVAILABLE
      DO 100 K=I.9
C    PREPARE ALTERNATIVE MOVE PROBABILITY VALUES FOR TESTING AGAINST A RANDUM
C    NUMBER
      IF (K.EQ.1) GO TO 200
      CUM(K)=P(K)+CUM(K-I)
      GO TO 100
```

```
200    CUM(K)=P(K)
100    CONTINUE
C   GENERATE A RANDOM NUMBER. X. AND THEST THE MOVE ALTERNATIVES
       K=0
       CALL RANDOM (ITIME.NTHIS.IHANDI.INT.  IBYSTD.IEVAL.
     1  XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.IRAND.
     2  P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER.X)
7      K=K+1
       IF (X) 71.72.72
71     X=X*(-1)
72     RAND=CUM(K)-X
       IF (RAND) 52.53.53
53     MOVE=K
       GO TO 8
52     IF (K.LT.9) GO TO 7
C   DETERMINE WHETHER THE OCCUPANT CLOSES A DOOR JUST PASSED THROUGH (IF IN
C   FACT HE HAS JUST DONE SO)
8      CALL DOORS2(ITIME.NTHIS.IHANDI.INT.IBYSTD.IEVAL.
     1   XO.YO.IBAR.TOTBAR.XT.YT.NAGREE.XE.YE.IAGREE.
     2   IRAND.P.MOVE.XK.YK.K.L.IS.IGOALX.IGOALY.IENTER.
     3   X.IDOOR.POPEN.ND.MDOOR.PCLOSE.IX)
12     RETURN
       END
```

Routines UPDATE, NEWXY, XSCORE, STEPS, PASSG (Utility Programs)

Loops Occupant and Replication

Purposes UPDATE:

This subroutine changes the x,y coordinates denoting occupant locations to reflect movement actions of each during the just-completed time frame.

NEWXY:

This program converts spatial locations from k-grid designators to x,y coordinates, using Subroutine KTOXY, in those cases where KTOXY is not called directly.

XSCORE:

This subroutine computes each occupant's escape score for the entire event.

STEPS:

The purpose of STEPS is to keep track of the total number of spatial displacements ("steps") actually made by each occupant during the fire event. Remaining-in-place is not recorded as a step.

PASSG:

PASSG keeps track of door-passage behavior exhibited by occupants.

<u>Formulas</u> XSCORE:

(1) SCORE = (SUMTIM-E)/SUMTIM)

Where:

SCORE = occupant_n's overall escape score;

SUMTIM = total number of time frames available;

E = time frame at which escape occured[1].

---

[1] If the occupant never escapes, E = SUMTIM

```
C
C
C
C
C
C   SUBROUTINE UPDATE
C
C   THE PURPOSE OF UPDATE IS TO CHANGE THE X,Y COORDINATES OF OCCUPANT LOCATIONS
C   TO REFLECT MOVEMENT ACTIONS OF EACH DURING THE JUST-COMPLETED TIME FRAME
C
      SUBROUTINE UPDATE (XO,YO,NTHIS,NEWXO,NEWYO)
      INTEGER XO(20),YO(20)
      XO(NTHIS)=NEWXO
      YO(NTHIS)=NEWYO
      RETURN
      END
```

```
C
C
C
C
C
C   SUBROUTINE NEWXY
C
C   THE PURPOSE OF NEWXY IS TO CONVERT SPATIAL LOCATIONS FROM K-GRID
C   DESIGNATORS TO X,Y COORDINATES, USING SUBROUTINE KTOXY, IN THOSE
C   CASES WHERE KTOXY IS NOT CALLED DIRECTLY
C
      SUBROUTINE NEWXY (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2.  IRAND,P,MOVE,XK,YK,K,NEWXO,NEWYO)
      INTEGER XK,YK
      CALL KTOXY (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2   IRAND,P,MOVE,XK,YK,K)
      NEWXO=XK
      NEWYO=YK
      RETURN
      END
```

```
C
C
C
C
C
C   SUBROUTINE XSCORE
C
C   THE PURPOSE OF XSCORE IS TO COMPUTE EACH OCCUPANT'S ESCAPE SCORE FOR THE
C   ENTIRE EVENT, I.E., SCORE=(TOTAL TIME AVAILABLE - CURRENT TIME FRAME)
C   DIVIDED BY THE TOTAL TIME AVAILABLE
C
      SUBROUTINE XSCORE (TOTIME,ISCORE,NUMOCC,SCORE)
      DIMENSION ISCORE(20),SCORE(20)

      INTEGER TOTIME
      SUMTIM=TOTIME
      DO 10 NTHIS=1,NUMOCC
      E=ISCORE(NTHIS)
C   COMPUTE THE OCCUPANT'S ESCAPE SCORE FOR THE ENTIRE EVENT
10    SCORE(NTHIS)=(SUMTIM-E)/SUMTIM
      RETURN
      END
```

```
C
C
C
C
C
C   SUBROUTINE STEPS
C
C   THE PURPOSE OF STEPS IS TO KEEP TRACK OF THE TOTAL NUMBER OF SPATIAL
C   RELOCATIONS ('STEPS') ACTUALLY MADE BY EACH OCCUPANT DURING THE FIRE EVENT
C   ...A STEP IS DEFINED AS A SPATIAL RELOCATION, AND THEREFORE, REMAINING-IN-
C   PLACE IS NOT RECORDED AS A STEP
C
      SUBROUTINE STEPS (XPRIOR,YPRIOR,XO,YO,NUMSTP,NTHIS)
      INTEGER XPRIOR(20),YPRIOR(20),XO(20),YO(20)
      DIMENSION NUMSTP(20)
C   RECORD WHETHER THE OCCUPANT MOVED DURING THE TIME FRAME JUST ENDED, THAT IS,
C   WHETHER (XPRIOR.NE.XO).AND.(YPRIOR.NE.YO)
      IF ((XPRIOR(NTHIS).EQ.XO(NTHIS)).AND.(YPRIOR(NTHIS).EQ.YO(NTHIS)))
     1 GO TO 999
C   UPDATE THE TOTAL NUMBER OF STEPS TAKEN BY THE OCCUPANT DURING THE EVENT
      NUMSTP(NTHIS)=NUMSTP(NTHIS)+1
999   RETURN
      END
```

```
C
C
C
C
C
C    SUBROUTINE PASSG
C
C    THE PURPOSE OF PASSG IS TO KEEP TRACK OF DOOR-PASSAGE BEHAVIOR EXHIBITED BY
C    OCCUPANTS
C


      SUBROUTINE PASSG (IDPASS,IDOOR,XD,YD,NTHIS,
     1   ND,NEWXD,NEWYD)
      DIMENSION IDPASS(20),IDOOR(30,4)
      INTEGER XD(20),YD(20)
C    DETERMINE WHETHER THE OCCUPANT PASSED THROUGH A DOORWAY DURING THE TIME-
C    FRAME JUST ENDED
      IXPASS=(NEWXD+XD(NTHIS))/2
      IYPASS=(NEWYD+YD(NTHIS))/2
      DO 10 I=1,ND
      IF ((IDOOR(I,1).EQ.IXPASS).AND.
     1   (IDOOR(I,2).EQ.IYPASS)) GO TO 5
      GO TO 10
C    UPDATE THE TOTAL NUMBER OF DOOR PASSAGES MADE BY THE OCCUPANT DURING THE
C    FIRE EVENT
5     IDPASS(NTHIS)=IDPASS(NTHIS)+1
10    CONTINUE
      RETURN
      END
```

Routines SUMMARY, REPORT, TRACE, TOTALS (Input/Output Programs)

Loop Occupant and Replication

Purposes SUMMARY:

This program prints a summary table for each replication. Output are values for various dependent measures computed by BFIRES. These values are "grand means" taken across occupants and time frames, and report aggregated scores and final status at the end of the last time frame for each replication. Initial conditions are also printed, for comparison against final states.

REPORT:

This subroutine prints a summary table for each time frame within a given replication. Each table reports results of the decision process for each occupant in the run. Data include move probability values, and x,y coordinates for occupants' locations at times t-1 and t.

TRACE:

TRACE prints a summary table for each occupant in a given replication. Each table traces the spatial displacement of the occupant across the entire simulated event (in terms of changes in x,y coordinates).

TOTALS:

This routine prints summary tables reporting total numbers of door passages and interruptions for each occupant in the event. Door passages are also reported by Subroutine SUMMARY.

```
C
C
C
C
C
C     SUBROUTINE SUMMRY
C
C     THE PURPOSE OF SUMMRY IS TO PRINT-OUT A SUMMARY TABLE FOR EACH REPLICATION
C     RUN...OUTPUT VALUES ARE 'GRAND MEANS' TAKEN ACROSS OCCUPANTS AND TIME-
C     FRAMES, AND REPORT AGGREGATED SCORES AND FINAL STATUS AT THE END OF THE
C     LAST TIME FRAME FOR EACH REPLICATION
C
        SUBROUTINE SUMMRY (INITXO,INITYO,INTLIM,LBYSTD,IHAND1,KNOWAY,
     1    POPEN,PCLOSE,SCORE,NUMSTP,IPS,III,NUMREP,NUMOCC,TOTIME,
     2    XO,YO,XE,YE,TITLE)
       DIMENSION INITXO(20),INITYO(20),INTLIM(20),LBYSTD(20),IHAND1(20),
     1  KNOWAY(20),POPEN(20),PCLOSE(20),SCORE(20),NUMSTP(20),IPS(20)
       DIMENSION NUMBER(20),SMEAN(20),DMEAN(20),DIST(20),DEINIT(20),
     1    DIFF(20),DFMEAN(20),TITLE(20)
       REAL NMEAN(20),IMEAN(20)
       INTEGER TOTIME,XO(20),YO(20),XE(10),YE(10)
       DIFTOT=0.0
       DTOTAL=0.0
       STOTAL=0.0
       NTOTAL=0
       ITOTAL=0
       NSUM=NUMOCC*NUMREP
       SUM=NSUM
       AN=NUMOCC
       WRITE (6,100)
       WRITE (6,134) TITLE
       WRITE (6,119)
       WRITE (6,102)
       WRITE (6,103)
       WRITE (6,119)
       WRITE (6,104) III,NUMREP,TOTIME
       WRITE (6,102)
       WRITE (6,119)
       WRITE (6,105)
       WRITE (6,119)
       WRITE (6,106)
       DO 200 N=1,20
       NUMBER(N)=N
200    CONTINUE
       WRITE (6,107) (NUMBER(N),N=1,20)
       WRITE (6,101)


       DO 55 K=1,NUMOCC
55     DEINIT(K)=SQRT(((INITXO(K)-XE(1))**2)+((INITYO(K)-YE(1))**2))
       WRITE (6,131) (DEINIT(K),K=1,NUMOCC)
       WRITE (6,108) (INITXO(K),K=1,NUMOCC)
       WRITE (6,109) (INITYO(K),K=1,NUMOCC)
       WRITE (6,110) (INTLIM(K),K=1,NUMOCC)
       WRITE (6,111) (LBYSTD(K),K=1,NUMOCC)
       WRITE (6,112) (IHAND1(K),K=1,NUMOCC)
       WRITE (6,113) (KNOWAY(K),K=1,NUMOCC)
       WRITE (6,114) (POPEN(K),K=1,NUMOCC)
       WRITE (6,115) (PCLOSE(K),K=1,NUMOCC)
       WRITE (6,102)
       WRITE (6,119)
       WRITE (6,116)
       WRITE (6,119)
       WRITE (6,106)
       WRITE (6,107) (NUMBER(N),N=1,20)
       WRITE (6,101)
C..COMPUTE REPLICATION MEANS...
       DO 20 K=1,NUMOCC
       DIST(K)=SQRT(((XE(1)-XO(K)) **2)+((YE(1)-YO(K))**2))
       DTOTAL=DTOTAL+DIST(K)
       STOTAL=STOTAL+SCORE(K)
       NTOTAL=NTOTAL+NUMSTP(K)
20     ITOTAL=ITOTAL+IPS(K)
       SMEAN(III)=STOTAL/AN
       NMEAN(III)=FLOAT(NTOTAL)/AN
       IMEAN(III)=FLOAT(ITOTAL)/AN
       DMEAN(III)=DTOTAL/AN
C
       DO 201 K=1,NUMOCC
       DIFF(K)=DEINIT(K)-DIST(K)
       DIFTOT=DIFTOT+DIFF(K)
201    NUMSTP(K)=NUMSTP(K)+1
       WRITE (6,127) (XO(K),K=1,NUMOCC)
       WRITE (6,128) (YO(K),K=1,NUMOCC)
       WRITE (6,129) (DIST(K),K=1,NUMOCC)
       WRITE (6,132) (DIFF(K),K=1,NUMOCC)
       WRITE (6,117) (SCORE(K),K=1,NUMOCC)
       WRITE (6,118) (NUMSTP(K),K=1,NUMOCC)
       WRITE (6,120) (IPS(K),K=1,NUMOCC)
C. COMPUTE NESCAP...
       NESCAP=NUMOCC
       DO 300 L=1,NUMOCC
       IF (SCORE(L).LE.0.001) GO TO 301
       GO TO 300
301    NESCAP=NESCAP-1
300    CONTINUE
       WRITE (6,126) NESCAP
       WRITE (6,102)
       WRITE (6,122) NUMOCC
       WRITE (6,130) DMEAN(III)
       DFMEAN(III)=DIFTOT/AN
       WRITE (6,133) DFMEAN(III)
```

```
      WRITE (6,123) SMEAN(III)
      WRITE (6,124) NMEAN(III)
      WRITE (6,125) IMEAN(III)
      WRITE (6,102)
      WRITE (6,121)
      WRITE (6,102)
100   FORMAT ('1')
101   FORMAT (130('*'))
102   FORMAT (130('*'),/,130('*'))
103   FORMAT (57X,'SIMULATION SUMMARY')
104   FORMAT (3X,'REPLICATION',I5,'   OF',I5,70X,'RUN FOR',I4,
     1   ' TIME FRAMES')
105   FORMAT (57X,'INITIAL CONDITIONS')
106   FORMAT (63X,'OCCUPANT NUMBER')
107   FORMAT (11X,20(I2,3X))
108   FORMAT (3X,'INITXO',1X,29(I3,2X),I3)
109   FORMAT (3X,'INITYO',1X,29(I3,2X),I3)
110   FORMAT (3X,'INTLIM',1X,29(I3,2X),I3)
111   FORMAT (3X,'LBYSTD',1X,29(I3,2X),I3)
112   FORMAT (3X,'IHANDI',1X,29(I3,2X),I3)
113   FORMAT (3X,'KNOWAY',1X,29(I3,2X),I3)
114   FORMAT (3X,'POPEN ',1X,29(F3.2,2X),F3.2)
115   FORMAT (3X,'PCLOSE',1X,29(F3.2,2X),F3.2)
116   FORMAT (58X,'OUTCOMES')
117   FORMAT (3X,'SCORE ',1X,20(F4.2,1X))
118   FORMAT (3X,'STEPS ',1X,20(I3,2X))
120   FORMAT (3X,'PASSES',1X,20(I3,2X))
119   FORMAT (' ')
121   FORMAT (57X,'END OF REPLICATION')
122   FORMAT (9X,'MEANS COMPUTED ACROSS',I3,' OCCUPANTS...')
123   FORMAT (20X,'MEAN SCORE = ',F4.2)
124   FORMAT (20X,'MEAN STEPS = ',F6.2)
125   FORMAT (20X,'MEAN PASSES =',F6.2)
126   FORMAT (3X,'NUMBER ESCAPED',5X,I3)
127   FORMAT (3X,'FIN X ',1X,20(I3,2X))
128   FORMAT (3X,'FIN Y ',1X,20(I3,2X))
129   FORMAT (3X,'DIST  ',1X,20(F4.1,1X))
130   FORMAT (20X,'MEAN DIST  = ',F4.1)
131   FORMAT (3X,'INIT D',1X,20(F4.1,1X))
132   FORMAT (3X,'DIFF D',   20(F5.1))
133   FORMAT (20X,'MEAN DIFF D =',F4.1)
134   FORMAT (1X,'RUN TITLE/  ',20A4)
      RETURN
      END
```

```
C
C
C
C
C
C   SUBROUTINE REPORT
C
C   THE PURPOSE OF REPORT IS TO PRINT-OUT A SUMMARY TABLE FOR EACH TIME-FRAME
C   OF A GIVEN REPLICATION...EACH TABLE REPORTS RESULTS OF THE DECISION
C   PROCESS FOR EACH OCCUPANT IN THE TIME FRAME. PARTICULARLY MOVE PROBABILITY


C   VALUES ASSIGNED TO EACH AVAILABLE MOVE ALTERNATIVE AT THAT POINT IN TIME
C   ...X,Y COORDINATES ARE ALSO SHOWN FOR BOTH TIMES T AND T+1. FOR EACH
C   OCCUPANT IN THE TIME FRAME
C
      SUBROUTINE REPORT(ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2  IRAND,P,MOVE,XK,YK,K,NUMEXT,NUMOCC,TOTIME,INTLIM,
     3  LBYSTD,KNOWAY,PTDIST,TDIST,PEDIST,EDIST,NEWXO,NEWYO,
     4   EVLOPT,IDOOR,IDOPEN,ND,INTR)
      DIMENSION IBAR (20,75,2),INTLIM(20),LBYSTD(20),IHANDI
     1  (20),KNOWAY(20),IBYSTD(20),P(9),INTR(20)
      DIMENSION IDOOR(30,4),IDOPEN(30,100)
      INTEGER XE(10),YE(10),XO(20),YO(20),XT,YT,TOTIME,
     1  XK,YK,EVLOPT
C
      IF ((ITIME.GT.1).OR.(NTHIS.GT.1)) GO TO 1
C
C: ECHO:CHECK INPUT PARAMETERS*
C:  (1) ENVIRONMENTAL:
C
      WRITE (6,100)
      WRITE (6,101) XT,YT
      WRITE (6,102) NUMEXT
      WRITE (6,104)
      WRITE (6,105) (XE(I),I=1,NUMEXT)
      WRITE (6,106) (YE(I),I=1,NUMEXT)
C
C:  (2) SYSTEM:
C
      WRITE (6,109) NUMOCC
      WRITE (6,110) TOTIME
      WRITE (6,111) IRAND
C
C:  (3) OCCUPANT:
C
      WRITE (6,112)
      WRITE (6,113) (INTLIM(I),I=1,NUMOCC)
      WRITE (6,114) (LBYSTD(I),I=1,NUMOCC)
      WRITE (6,115) (IHANDI(I),I=1,NUMOCC)
      WRITE (6,116) (KNOWAY(I),I=1,NUMOCC)
      WRITE (6,117)
C
1     CONTINUE
C
      IF (NTHIS.NE.1) GO TO 2
C
C: IF NTHIS=1, PRINT CURRENT TIME MARKER AND COLUMN HEADINGS:
C
      WRITE (6,118)
      WRITE (6,119) ITIME
      WRITE (6,118)
      WRITE (6,120)
      WRITE (6,118)
C


C
2      IF (INTR(NTHIS).EQ.1) GO TO 22
C
C: WRITE OUTPUT MATRIX:
       IF (EVLOPT-1) 20,20,21
20     CONTINUE
       WRITE (6,121) NTHIS,XO(NTHIS),YO(NTHIS),INT,IBYSTD(NTHIS),IAGREE,
     1 TDIST,EDIST,(P(K),K=1,9),NEWXO,NEWYO
       GO TO 23
21     WRITE (6,123) NTHIS,XO(NTHIS),YO(NTHIS),INT,IBYSTD(NTHIS),
     1   IAGREE,(P(K),K=1,9),NEWXO,NEWYO
       GO TO 23
22     WRITE (6,127) NTHIS,XO(NTHIS),YO(NTHIS),INT,
     1   NEWXO,NEWYO
23     CONTINUE
       IF (NTHIS.EQ.NUMOCC) GO TO 3
       GO TO 4
3      WRITE (6,118)
4      IF ((ITIME.EQ.TOTIME).AND.(NTHIS.EQ.NUMOCC)) GO TO 5
       GO TO 6
5      WRITE (6,118)
       WRITE (6,124)
       WRITE (6,118)
       WRITE (6,125)
       WRITE (6,118)
       DO 30 I=1,ND
       WRITE (6,126) I,IDOOR(I,1),IDOOR(I,2),IDOOR(I,3),
     1   (IDOPEN(I,ITM),ITM=1,TOTIME)
```

```
30    CONTINUE
      WRITE (6,118)
      WRITE (6,122)
      WRITE (6,118)
      GO TO 6
C
C: OUTPUT FORMATING:
C
100   FORMAT (1X.120('*').//.55X.'ECHO-CHECK INPUT PARAMETERS'.//.120
     1 ('*').//.1X.'(1) ENVIRONMENTAL:'./)
101   FORMAT (24X.'THREATENED EXIT: X= '.12.4X.'Y='.I2)
102   FORMAT (24X.'NUMBER OF EXITS:  = '.I2)
103   FORMAT (24X.'NO. OF BARRIER PTS='.13./)
104   FORMAT (24X.'COORDINATES OF EXITS:  1  2  3  4  5  6  7  8  9 10'.
     1 /)
105.  FORMAT (43X;'X: '.10(12.1X))
106   FORMAT (43X.'Y: '.10(I2.1X)./)
107   FORMAT (1X.'BARRIER-POINT MATRIX:'./)
108   FORMAT (2X.'X:'.38(12.1X)./.2X.'Y:'.38(I2.1X)./)
109   FORMAT (1X.'(2) SYSTEM'./.24X.'NUMBER OF OCCUPANTS IN THE SPACE ='
     1 .13)
110   FORMAT (24X.'TOTAL NO. OF TIME INCREMENTS ='.I3)
111   FORMAT   (24X.'RANDOM NUMBER STARTER          ='.13./)
112   FORMAT (1X.'(3) OCCUPANT:'./.12X.'PARAMETER'.5X.'OCC NO  1  2  3
     1 4  5  6  7  8  9 10 11 12 13 I 4 15 16 17 18 19 20'./)
113   FORMAT (12X.'INTLIM'.15X.20(12.1X))


114   FORMAT (12X.'LBYSTD'.15X.20(12.1X))
115   FORMAT (12X.'IHAND1'.15X.20(12.1X))
116   FORMAT (12X.'KNOWAY'.15X.20(12.1X)./)
117   FORMAT (2(1X.120('*')./))
118   FORMAT (1X.120('*')./)
119   FORMAT (1X.'TIME = '.13./)
120   FORMAT (6X.'PRIOR'.18X.'EXIT'.89X.'NEW'./.1X.'OCC'.2X.'LOCAT'.17X.
     1'AGREED'.87X.'LOCAT'./.IX.'NUM'.2X.'XO YO  INT    IBYSTD   UPON
     2  PTDIST TDIST   PEDIST EDIST   P(1)  P(2)  P(3)  P(4)  P(5)  P(6)
     3 P(7)  P(8)  P(9)'.6X.'XO YO'./)
121   FORMAT (1X.I2.3X.12.1X.I2.4X.I1.6X.I1.6X.12.3X.2(7X.F6.3.2X).
     1 9(F5.3.1X).4X.I2.1X.I2)
122   FORMAT (50X.'END OF SIMULATION'./)
123   FORMAT (1X.I2.3X.I2.1X.12.4X.I1.6X.I1.6X.
     1    I2.33X.9(F5.3.IX).4X.I2.1X.12)
124   FORMAT (50X.'DOOR STATUS SUMMARY'./)
125   FORMAT (1X.'DOOR'.4X.'X  Y'.5X.'TYPE'.5X.'T= 1  2  3  4  5
     1  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
     2  24 25 26 27 28 29 30'./)
126   FORMAT (2X.12.5X.I2.1X.I2.7X.I1.8X.30(I2.1X))
127   FORMAT (1X.12.3X.12.1X.I2.4X.I1.106X.I2.1X.I2)
6     RETURN
      END
```

```
C
C
C
C
C
C    SUBROUTINE TRACE
C
C    THE PURPOSE OF TRACE IS TO PRINT-OUT A SUMMARY TABLE FOR EACH OCCUPANT IN
C    A GIVEN REPLICATION...EACH SUCH TABLE TRACES THE SPATIAL DISPLACEMENT
C    (CHANGE IN X,Y COORDINATES) OF EACH OCCUPANT ACROSS THE ENTIRE SIMULATED
C    EVENT
C
      SUBROUTINE TRACE (IXTRCE,IYTRCE,NTHIS,ITIME,NUMOCC,
     1   TOTIME)
      DIMENSION IXTRCE(20,100),IYTRCE(20,100)
      INTEGER TOTIME
      WRITE (6,1)
      DO 25 I=1,NUMOCC
      WRITE (6,2) I
      DO 24 J=1,TOTIME
      WRITE (6,3) J,IXTRCE(I,J),IYTRCE(I,J)
24    CONTINUE
      WRITE (6,4)
25    CONTINUE
      WRITE (6,5)
1     FORMAT (1X,120('*'),//,48X,
     1   'OCCUPANT MOVEMENT TRACES',//,1X,120('*'))
2     FORMAT (1X,120('*'),//,1X,'OCCUPANT NUMBER:',I4,/,
     1   10X,'TIME',/,10X,'FRAME',10X,'X',5X,'Y',/,
     2   1X,120('*'))
3     FORMAT (12X,I2,18X,I2,4X,I2)


4     FORMAT (1X,120('*'))
5     FORMAT (1X,120('*'),//,55X,'END OF TRACES',//,
     1   1X,120('*'))
      RETURN
      END
```

```
C
C
C
C
C
C    SUBROUTINE TOTALS
C
C    THE PURPOSE OF TOTALS IS TO PRINT-OUT SUMMARY TABLES REPORTING TOTAL
C    NUMBERS OF DOOR PASSAGES AND INTERRUPTIONS (OF EACH TYPE) FOR EACH
C    OCCUPANT IN THE EVENT
C
      SUBROUTINE TOTALS (IDPASS,ITYPE1,ITYPE2,NTHIS,NUMOCC)
      DIMENSION IDPASS(20),ITYPE1(20),ITYPE2(20)
      DIMENSION IOCC(20)
      DO 25 I=1,NUMOCC
25    IOCC(I)=I
      WRITE (6,1)
      WRITE (6,2) (IOCC(I),I=1,NUMOCC)
      WRITE (6,3) (ITYPE1(NTHIS),NTHIS=1,NUMOCC)
      WRITE (6,31) (ITYPE2(NTHIS),NTHIS=1,NUMOCC)
      WRITE (6,4)
      WRITE (6,5) (IOCC(I),I=1,NUMOCC)
      WRITE (6,6) (IDPASS(NTHIS),NTHIS=1,NUMOCC)
      WRITE (6,7)
      WRITE (6,8)
1     FORMAT (1X,120('*'),//,45X,
     1   'OCCUPANTS INTERRUPTION TOTALS:',//,38X,
     2   'REPORTS TOTAL NUMBER OF FRAMES SPENT IN MODES',
     3   //,1X,120('*'))
2     FORMAT (1X,'INTRPT',20X,'OCCUPANT',/,2X,'TYPE',
     1   10X,20(I3))
3     FORMAT (1X,120('*'),/,4X,'1',11X,20(I3))
31    FORMAT (4X,'2',11X,20(I3),/,1X,120('*'))
4     FORMAT (1X,120('*'),//,50X,'DOOR PASSAGE TOTALS',
     1   //,1X,120('*'),/,55X,'OCCUPANT')
5     FORMAT (30X,20(I3),/,1X,120('*'))
6     FORMAT (30X,20(I3),/,1X,120('*'))
7     FORMAT (1X,120('*'),//,52X,'END OF TOTALS',//,1X,
     1   120('*'))
8     FORMAT (1X,120('*'),//,55X,'END OF RUN',//,1X,120('*'))
      RETURN
      END
```

FEDERAL INFORMATION PROCESSING STANDARD SOFTWARE SUMMARY

01. Summary date
Yr. 78 Mo. 11 Day 08

02. Summary prepared by (*Name and Phone*)
Fred I. Stahl (301) 921-2627

03. Summary action
New ☐ Replacement ☒ Deletion ☐
Previous Internal Software ID

04. Software date
Yr. 78 Mo. 08 Day 30

05. Software title
Computer Simulation of Human Behavior in Building Fires

06. Short title BFIRES

07. Internal Software ID

08. Software type
☐ Automated Data System
☒ Computer Program
☐ Subroutine/Module

09. Processing mode
☐ Interactive
☒ Batch
☐ Combination

10. Application area

General
☐ Computer Systems Support/Utility
☒ Scientific/Engineering
☐ Bibliographic/Textual
☐ Management/Business
☐ Process Control
☐ Other

Specific
Computer simulation of human behavior

11. Submitting organization and address

Architectural Research Program
Environmental Design Research Division
Center for Building Technology
National Bureau of Standards
Washington, DC 20234

12. Technical contact(s) and phone

Fred I. Stahl (301) 921-2627

13. Narrative

BFIRES aids the prediction of escape times and escape routes of building occupants during fires. The program executes a descrete time stochastic simulation of human movement within bounded physical spaces, in response to specified fire conditions. The simulation is based on a non-stationary Markov model of building fire events. Input/output is via punched cards and line printer, or via terminal.

14. Keywords

Building fires; computer-assisted building design; fire research; fire safety; human performance simulation.

15. Computer manuf'r and model
UNIVAC 1108

16. Computer operating system
EXEC 8

17. Programing language(s)
FORTRAN V

18. Number of source program statements

19. Computer memory requirements
28.62 K 36-bit words

20. Tape drives

21. Disk/Drum units

22. Terminals

23. Other operational requirements

24. Software availability
Available ☐ Limited ☐ In-house only ☒

25. Documentation availability
Available ☒ Inadequate ☐ In-house only ☐

contact: Fred I. Stahl
(301) 921-2627

26. FOR SUBMITTING ORGANIZATION USE

185-101

Standard Form 185
1974 July
U.S. Dept. of Commerce—NBS
(FIPS. Pub. 30)

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 79-1713	2. Gov't. Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Final Report on the "BFIRES/VERSION 1" Computer Simulation of Emergency Egress Behavior During Fires: Calibration and Analysis

5. Publication Date
March 1979

6. Performing Organization Code

7. AUTHOR(S) Fred I. Stahl

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.
7430504

11. Contract/Grant No.

12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

National Bureau of Standards
Department of Commerce
Washington, D.C. 20234

U.S. Public Health Service
Dept. of H.E.W.
Washington, D.C. 20203

13. Type of Report & Period Covered
FINAL

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☒ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report documents computer simulation experiments designed to calibrate and analyze BFIRES, a computer program which simulates building occupants' egress behavior during fires. This report demonstrates that emergency egress behavior under certain specified conditions can be systematically conceptualized, and simulated through the use of a digital computer. Important findings concerning the calibration and sensitivity of BFIRES are also discussed. In particular, it is shown that: (a) a variety of general egress situations may be simulated through the application of BFIRES; (b) every such event is unique, and is defined by the set of user-supplied input parameter values which describe the building, the threat, and the occupants; (c) BFIRES may be used in simulated environments of known (or desired) spatial dimension, and events of known (or desired) temporal duration; and (d) BFIRES simulation outcomes are sensitive to variations in a number of parameters of immediate interest to the building design and regulatory communities.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Architectural Research; building fires; computer-aided design; environmental psychology; fire research; fire safety; human performance; modeling technique; programming; sensitivity analysis; simulation.

18. AVAILABILITY ☒ Unlimited ☐ For Official Distribution. Do Not Release to NTIS ☐ Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003- ☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PRINTED PAGES 178
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $9.00