NBSIR 78-1514

A Computer Simulation of Human Behavior in Building Fires: Interim Report

Fred I. Stahl

Environmental Design Research Division
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

March 13, 1978

Issued September 1978

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, D.C. 20203

NBSIR 78-1514

A COMPUTER SIMULATION OF HUMAN BEHAVIOR IN BUILDING FIRES: INTERIM REPORT

Fred I. Stahl

Environmental Design Research Division
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

March 13, 1978

Issued September 1978

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, D.C. 20203

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

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

This report is an interim product of the joint effort of the Department of Health, Education and Welfare and the Center for Fire Research of the National Bureau of Standards. This joint effort consists of products in the areas of decision analysis, fire and smoke detection, smoke movement and control, automatic extinguishment, and the behavior of institutionalized populations in fire situations. This report is an element of the human behavioral area.

The author wishes to acknowledge the administrative support of Mr. Harold Nelson and Dr. Bernard Levin, of the Center for Fire Research. The author also thanks Drs. Gary Winkel and Susan Saegert of the City University of New York, and Dr. Dane Harwood of the National Bureau of Standards, for their assistance in matters concerning psychological and behavioral theory. The extremely capable technical assistance of Mr. Lawrence Kaetzl in matters involving the use of the Center for Building Technology's INTERDATA 7/32 minicomputer is greatfully acknowledged. Finally, Drs. Edward Arens and Robert Glass, and Mr. James Harris, all of the Center for Building Technology, are acknowledged for their critical reviews of drafts of this report.

ABSTRACT

This interim report presents the conceptual development, structure, and function of BFIRES, a computer program designed to simulate human movement behavior during building fires. The basic model underlying BFIRES is derived from a non-stationary, discrete time Markov Process. This model postulates that occupants construct their emergency responses and behavioral decisions dynamically, in response to continually changing social and environmental information fields. The simulation of this process is accomplished through BFIRES, a computer program written in FORTRAN-V. Directions for further study are discussed.

Key Words: Architectural psychology; architectural research; building fires; computer-aided design; fire computer program; fire research; fire safety; human performance; model documentation; modeling technique; programming; simulation.

A COMPUTER SIMULATION OF HUMAN BEHAVIOR IN BUILDING FIRES: INTERIM REPORT

1. INTRODUCTION

1.1 This Report: Its Function and Use

This interim report documents the conceptual development, structure, and function of BFIRES, a computer program designed to simulate human movement behavior during building fires. In addition to introducing the reader to the BFIRES program, the report suggests avenues for future research.

Although the report is primarily a presentation of the BFIRES program many readers may have very specific interests, and may wish to focus only on certain sections. The following outline provides a guide to the report's contents.

Part one is essentially introductory. The objectives, significance, and scope of the project are described. A review of the most salient literature on the computer simulation of human spatial and emergency behavior is provided, in order to place the current effort in an appropriate perspective.

Part two describes the technical approach taken during the course of this investigation. The question of modeling is considered first, and a formal argument for the adoption of a particular framework is presented. Second, the specific approach to programming the computer simulation is discussed.

Parts three and four describe the specific structure and content of the BFIRES simulation program. Part three considers the various human behavioral attributes of the program. Individual subroutines are presented in full detail, with discussions of their function, background and rationale, and underlying behavioral assumptions. Part four treats the non-behavioral subroutines, which are responsible for the overall system and data-handling operations of BFIRES.

Part five explores directions for further study. First, the simulation exercise is reviewed as a tool which identifies salient literature and data bases in need of future review or expansion. Second, the exercise is reviewed as a tool for identifying key issues and for generating researchable questions.

1.2 Objectives

The project has been guided by the following objectives: (a) to demonstrate the utility of studying building fires by means of computer simulation methodology; (b) to present BFIRES, a simulation model of occupant behavior in building fires; (c) to demonstrate the applicability of available literatures to the modeling process, and (d) to expose hypotheses, inherent in the simulation, for eventual examination.

1.3 Significance

Various difficulties associated with available empirical research on human behavior in fires have been identified by Stahl and Archea (1977). These include the problems of performing controlled field experiments, the lack of verisimulitude between experimental and actual settings, and questions concerning the validity of post-incident survey data.

Models which underlie certain empirical findings, (e.g., those considered by Peschl, 1971, and Henderson, 1971) were also reviewed by Stahl and Archea. Some inadequacies of these models were found by these reviewers to include their apparent focus on the more narrowly defined and easily measured aspects of the problem, and their failure to account for some important behavioral phenomena.

The primary significance of the current study is its emphasis on development of a general model of human behavior in fire situations. In the long term, the value of such a model will be measured on the basis of its ability to (a) demonstrate and explain dynamic interrelationships among systemically linked variables, (b) enable the prediction of behavior patterns occuring during fires, and (c) suggest specific areas requiring intensive empirical investigation.

Of even more practical significance in the long-range is the application of valid and reliable simulation models as building design tools. A vivid example involves the situation in which an architect has ready access to a computer terminal and video display in his office. By calling the simulation program from a central computer facility, and typing in various parameters and data which describe occupancy conditions and emergency scenarios, the architect is enabled to simulate the performance of his design, and to evaluate it from the standpoint of life safety criteria. Moreover, he has at his disposal an objective mechanism for selecting a particular design from among some range of alternatives.

Applications such as the one described above require that the simulation program be "trusted" by practitioners in the field. That is, its ability to predict realistic emergency outcomes reliably must have been demonstrated through rigorous empirical efforts. In this context, I reiterate that the work presented here concerns initial and elementary steps toward this overall, long-range objective.

1.4 Scope

1.4.1 Behavior Patterns

Building regulations concerned with life safety from fire emphasize egress behavior, expressed in terms of the movement of persons from threatened zones to safe ones. Various assumptions about human spatial behavior are implied in these regulations. Although many other kinds of behavior may also be present (e.g., fire-fighting, calling for help, crying), considerations of egress movement have impacted most directly on the design of buildings. The model developed here also emphasized the spatial movement behavior of building occupants. Accordingly, we expect deductions from the model to invite immediate comparison with current regulatory provisions. For example, how does floor-plan layout influence egress movement during a fire? Are present requirements for the provision of exits justified, or do occupants' emergency behavioral patterns suggest other alternatives? How do factors other than building design influence emergency egress behavior?

1.4.2 Life Safety Systems

Caravaty and Haviland (1967) were among the first to identify a "chain" of safety-related events, emphasizing the time-dependent nature of building fire systems. According to these investigators, segments of the fire incident could be identified such that specific reference to event categories should be useful in life safety planning and building design. These event segments, in their assumed sequence of occurrence, were identified to be (1) detection of the life threat, (2) alerting of building occupants to the threat, (3) escape and refuge-seeking actions by occupants, and (4) control and extinguishment of the fire.

Focusing primarily on human behavioral aspects of fire situations, Nelson (1977) structured a similar sequence of events: (1) discovery, (2) alarm, (3) reaction, and (4) evacuation. Other investigators, most notably Wood (1972), Bryan (1977), and Breaux (1977) have, by interviewing fire victims, attempted to elaborate on such structures. "Reaction", for example, has often been found to include such seemingly diverse activities as investigation, helping others, and saving possessions, and not merely exit-seeking.

To the extent that empirical research has actually indicated the existence of such time-dependent categories of events, various structures suggested by several investigators might usefully be summarized as follows: (1) discovery, or the first indication of human awareness of the life threat; (2) alerting, or communication of information about the threat among occupants; (3) decision-making and concomitant action in or on the environment by alerted occupants (which may or may not be adaptive, and which may or may not result in the safe existing of particular occupants).

Assuming this framework, the special focus of the present study is on the third component: decision-making and concomitant action. Accordingly, the remainder of our analysis centers upon cases in which a fire has in fact been discovered, and that varying amounts of information about it (e.g., its location) are already known to at least one of the potentially affected occupants. Our concern shall be, therefore, to model emergency behavior over time, in response to some given information baseline.

1.4.3 Occupancies

For most practical purposes, the discussion presented here is relevant to the study of emergency response across a variety of building types. Our special focus, however, concerns health-care occupancies such as hospitals and nursing homes. These facilities introduce important constraints to our study, arising from the fact that many occupants are perceptually, cognitively and physically impaired, and consequently require some form of assistance at various points during an emergency.

1.5 Previous Research on Simulating Human Spatial Behavior and Reponses to Fire: Literature Review

During the last fifteen years, there has been considerable interest in the application of computer simulation techniques to the study of human cognitive behavior (Feldman, 1962; Luce and Raiffa, 1964; Simon, 1967, 1969; Apter, 1970; Shultz, 1974). Arguments have frequently concerned the ability to simulate human thinking and decision-making (e.g., Neisser, 1963 vs. Simon, 1967), issues of validity, and questions about what to simulate (e.g., processes or outcomes?). Amidst an often confused philosophical climate, computer programs were written, and many simulation-based experiments on human cognitive, motor, and social behavior were conducted (consult the extensive review by Dutton and Starbuck, 1971).

Moreover, interest in the application of the computer simulations to the study of micro-scale person-environment relations has also been evident. Several programs have been written attempting to simulate pedestrian movement behavior within bounded environments, and there have also been attempts to consider human behavior in fires through simulation techniques. Let us review several key examples:

1.5.1 Computer Simulations of Pedestrian Movement Behavior

The chief objective of Krystiniak (1972) was to provide pictorial computer output demonstrating the effect of floor-plan arrangement on pedestrian circulation patterns in buildings. His "pedestrians" were endowed with the physical characteristics of body dimensions (the so-called body ellipse), with individuality of walking speed, and with the ability to sense obstacles and barriers (e.g., walls). Each pedestrian was presumed to have one and only one objective in the building: to get from his randomly selected entrance door to his randomly selected exit door in the least amount of time. Door selections were made prior to the actual simulation, and once these initial and terminal points were present, a deterministic distance-minimization routine took over. Pedestrians then negotiated the floor plan, approaching their objectives, while avoiding collisions with walls or other physical obstacles.

In another example, Studer and Hobson (1973) constructed a model of spatial movement behavior predicated on an operant discrimination learning base. In moving from point to point in a spatial field, individuals were seen to continuously select particular routes from among various available alternatives. When movement along a particular route resulted in some short-term goal attainment, the probability that the reinforced individual would make a similar selection decision in the future was increased.

Baer (1974) investigated the simulation of free-flow pedestrian movement behavior within bounded spaces. In response to difficulties imposed by models which primarily considered input and output conditions, while ignoring the nature of the behavioral system itself, Baer's simulation focused on the behavior of the individual pedestrian during his trip. The model permitted the simultaneous movement of any number of such individuals, at any level of traffic density, to be simulated. Within the spatial system, persons were guided with respect to the physical and behavioral environments by a deterministic procedure which enabled them to alter their speed and direction within any increment of the journey. The model endowed individual pedestrians with goals, motives, and the ability to evaluate obstacles. However, it is not entirely clear how so-called "free flow" behavior is usefully modeled by a non-stochastic process. As Baer begins to expand the scope of his model to include patterns of response to distractions from long-range goals, interpersonal relations, emergency situations, or the psychological effects of crowding, deterministic predictors may not be found to adequately reflect the spontaneity or uncertainty of actual human experience.

Along somewhat different lines, Lozar (1974) discussed a method for simulating spatial behavior in an attempt to determine whether a design influences an individual's attitudes toward the environment. In his program, the likelihood that a simulated person would proceed along a particular path was determined by observing movement behavior in the real world (dining hall). Similarly, the likelihood that a simulated person expressed certain attitudes was derived from correlations between subjective reports and actual behavioral patterns found in the real setting.

1.5.2 Computer Simulations of Human Behavior in Building Fires

Wolpert and Zillmann (1969) made what is perhaps the earliest attempt to simulate by computer the actions of building occupants during a fire. These investigators constructed a computer model of decision-making in a spatial context. Using the theater fire problem as a case for study, the program largely described the individual's selection of, and then movement toward, alternative goals made conspicuous by new information produced by a fire threat that expanded, contracted, or remained stationary. Forced to continuously reassess their location within a spatial context of uncertainty, actors erected barriers, advanced, or retreated, working independently or in groups. Selection from among alternative courses of action depended upon one's location within the space, in relation to the positions of the threat and the various safety zones. This selection process was simulated in a non-stochastic fashion. The Wolpert and Zillmann program operated under the assumption that, during a highly stressful period, occupants were capable of objectively assessing time and distance values which separate themselves from both the threat, and from available refuge areas, at any given moment. Moreover, in considering the theater fire problem in which all relevant events are occuring within the same spatial field, it was presumed that occupants were always in full visual command of the situation. Accordingly, calculated decision making could be considered possible. The model was capable of generating so-called "panic" within any individual, which allegedly resulted when the person realized that attainment of a desired safety goal had become impossible. Individuals in such a state were then presumed to act mal-adaptively, clogging impassible exits rather than seeking other egress possibilities.

Concerned with a somewhat different problem context, the simulation model developed by Edmondo, Hahin and Sinay (1969), and the computer program written by Sinay (1971), featured both stochastic and deterministic characteristics. Conducting research for the U.S. Navy, these investigators dealt with the problem of ship-board emergencies, such as fires, bombardments, collisions, etc. The probabilistic components of their program included establishment of both the time and location of the onset of the emergency, the initial locations of ship crewmen, elapsed time until detection of the emergency, and the selection of a response mode (i.e., aiding others, securing a space, panicking, escaping). The essential deterministic feature was the selection of an escape route, given certain environmental conditions, from a small array of pre-determined possibilities. Accordingly, once an individual understood the situation, his entire escape route (including possible detours, as necessary) became known in advance. Prediction of escape time could then be simply calculated from a knowledge of the route's length, and a simulated crewman's walking speed.

Most recently, the computer simulation of human behavior in building fires has been considered by Korkemas (1977). For simulated fires events, his chief objectives were to plot fire spread over time, plot occupants' movement patterns over time, record the history of occupants' fates, and to record the history of congestion at building exits. As with the exercise by Edmondo, et al., Korkemaz's simulation program utilized both stochastic and deterministic variables including fire migration, rates of increase of toxic substances in the atmosphere, and occupant movement (i.e., spatial displacement) along predefined paths. As time advanced, the fire covered ever-wider territory, and the density of toxic substances in the air increased. These were assumed to have the major effect of slowing the occupant down, as he moved along his pre-set path to a refuge zone or exit. The rate of decrease in movement speed was governed by deterministic equations. If occupants failed to reach their goal before the level of toxicants surpassed their tolerance levels (adjustable by the experimenter), then they were assumed to have been consumed by the fire. In commenting upon his work, Korkemas recommended that future simulation programs would have to account for a "familiarity factor" (i.e., the notion that some people are more familiar than others with circulation paths within the building, and that such familiarity might influence emergency response).

1.5.3 Critique and Summary

Certain limitations to the utility of the simulation programs reviewed above should be noted. First, each of these assumes an environmental-deterministic basis for behavior. For the fire context, it will be demonstrated in this report that it is necessary to view the environment in terms of both physical and social components, and to emphasize the importance of the environment as mediated through perceptual and cognitive processes. Moreover, this report will stress the importance of viewing building occupants as active participants, who continually modify their environment, and are thereby influenced by its changing structure over time.

In addition, each of the simulations discussed avoided the question of how particular paths were created, or why they were followed? We know, of course, that these routes were pre-set, or inserted by the experimenters, who made certain assumptions about emergency egress. The difficulties inherent in such assumptions have already been examined elsewhere (Stahl and Archea, 1977). This report shall stress the importance of simulating occupants' decision-making strategies, and will not assume that persons mechanically respond to stimuli in their environment.

In summary, a variety of simulation approaches are possible when studying human spatial behavior and response to building emergencies. In almost all cases, simulations found in the literature were of the "behavioral-algorithmic" type, in which theoretical descriptions of behavioral sequences were written into computer programs. To varying degrees, such programs were found to exhibit combinations of both deterministic and stochastic attributes. The simulation program presented in the remainder of this report is a stochastic example of the "behavioral-algorithmic" type.

No studies found in the literature exemplified a purely "heuristic" approach, in which the computer would be programmed to simulate human learning, and would then be required to "learn" its way through a novel situation. Moreover, no instances of a "non-behavioral algorithmic" approach were found either. Examples of this type of simulation would include mathematical models of the type generally employed by operations researchers. Connelly (1977) is currently developing the application of operations research techniques to the study of human behavior in building fires.

2. TECHNICAL APPROACH

2.1 A Markov-Based Model of Human Behavior in Building Fires

Figure 2.1 illustrates an interactive state-transition model describing the building fire problem. This model shall serve as our working hypothesis.

Simply stated, the model suggests that:

(a) Actions in or on the emergency environment, at any point in time, have the potential of affecting changes to both its physical and social attributes;

(b) Actions in or on this environment result directly from one's current assessment of available action alternatives;

(c) Such an assessment is contingent upon such factors as:

(1) perceptions of the availability of action alternatives at time t;

(2) specific perceptions about the possible outcome of each alternative;

(3) perceptions of information defining the current state of the emergency environment (i.e., the context for action at time t);

(4) attitudes toward the emergency event, and toward "appropriate" behavior at time t;

(5) familiarity with the physical environment, and/or with formal instructions for behavior during building fires.

It further requires a cognitive analysis of the relative advantages and disadvantages of each action alternative, a process which results in a "cognitive weighting" of the action possibilities during each point in time.

(d) The emergency environment, as altered by a person's actions upon or within it at time t, provides many of the cues, stimuli and information necessary to develope his action decision at time t+1.

Making decisions about action in or on an emergency environment, then, comprises the keystone of the model. Building fire participants continuously gather and evaluate information about their environment, about alternative actions within or upon it, and about the possible consequences of such alternatives. They utilize this information in a process of evaluating and weighing the possible actions, and of deciding what to do - or where to go - next. As the emergency environment undergoes continuous change, perceptions of it change, and as a result, action strategies and behaviors change.

The decision-making process outlined above is not thought to "determine" action outcomes in the mathematical sense. Rather, "cognitive weighting" has the effect of biasing behavior in some particular direction. For example, the behavior of a person fleeing the danger zone might be biased toward stopping to help a disabled other if, e.g., there are no other potential helpers available (from Latane and Darley, 1970). But the helping action is not necessarily certain, since information other than the fact that another individual requires help influences action decision-making (e.g., is there enough time to stop and help, and still reach safety?).

Depending upon the interactive net of information available to an occupant at time t, we may identify some six generic categories of decision bias. Action at time t may be biased toward: (1) threat evasion ("flight"); (2) exit goal seeking; (3) helping others (to include alert or alarm); (4) the demand temporarily imposed by a real-time interruption to goal-seeking behavior (whether cognitive, physiological, or environmental in origin); (5) threat suppression ("fight"); (6) "indecision" (no net biasing effect; equally strong biases).

A detailed discussion of the Markovian basis of the model is provided in Appendix A. A detailed description of both the structural and dynamic characteristics of the model, and an indication of assumptions which underlie it, are presented in Appendix B. For the sake of simplicity, flow diagrams break the model down into a set of "subroutines", each responsible for a different aspect of perception, decision-making, and action by persons in a building fire. The model described is general in scope and purpose (relative to the fire problem), and Appendix A illustrates its current state of development. In studying the diagrams, note that the "executive" routine drives the human behavioral sub-system through a single state-transition (i.e., between time t and t+1). The entire sequence must be repeated each time such a state-transition is made. Also note that whenever a "CALL . . ." statement is encountered, flow of control is routed to the subroutine being called. The results of that subroutine are then inserted back into the calling routine. Figure 2.2 indicates the relationship between subroutine names and the model's structure.

Additional information about the model's dynamics and assumptions is provided through contingency-trace tables (i.e., "truth tables") also found in Appendix B. These permit entire scenarios to be constructed and evaluated, by means of "if . . . then . . ." type statements.

2.2 Programming and Running the Computer Simulation

2.2.1 Programming the Simulation: BFIRES

BFIRES, the computer program written to simulate human behavior in building fires, is modular in form. That is, each subroutine has as its purpose some specific function, second, these functions generally fall into the categories of perception, cognition, and action, relative to the emergency environment. This modular structure provides us with a "skeletal" programming approach (Raser, 1969). If we assume that the most basic elements are present, then additional detail can be added in the future by either adding modules or enriching (or eliminating) existing ones. Such additions, etc., would be predicated upon research findings from both simulation and real-system investigations. Of course, the possibility exists that future research will require us to reconsider the basic organization of the original skeleton.

The various subroutines are linked through an EXECUTIVE, or "main" program. This routine also satisfies the requirements of reading-in external data, iterating the simulated cognitive and behavioral processes for the appropriate numbers of occupants and time-frames (state transitions), and repeating a given simulation experiment any number of times desired. The coding of the EXECUTIVE, therefore, initializes a simulation experiment, and governs the logical flow of events and decisions as these are suggested by the underlying model. Figure 2.3 provides a simplified flow diagram of the EXECUTIVE. The numbers in the left margin key the diagram to a brief description of each program step, given below. Figure 2.4 illustrates the subroutine calling pattern. The complete FORTRAN listing of the EXECUTIVE program and all subroutines is provided in Appendix C.

(1) Read input data. (a) Input environmental descriptors: locations of walls and barriers; boundaries of room subdivisions; door information (location; whether manually or automatically closed; whether initially open or closed); exit goal locations available for each spatial subdivision; location of exits; initial location of fire threat; number of exits available; number of spatial crowding subdivisions in the floor-plan; number of doors in the floor-plan; physical crowding threshhold for each space. (b) Input occupant descriptors: interruption limit for each occupant; bystander intervention limit for each occupant; each occupant's familiarity with emergency exits in the building; initial handicapped/mobility status for each occupant; each occupant's probability of opening a closed door; each occupant's probability of closing an open door; initial location of each occupant in the floor-plan. (c) Input simulation-run descriptors: number of replications desired; total length of each replication (in time-frames); total number of occupants in a given replication; seed number for random-digit generation.

(2) Iterate the simulation experiment for the desired number of replications.

(3) Run each replication for the desired number of time-frames.

(4) Run each occupant through a given time frame.

(5) Identify the spatial sub-division (e.g., room) occupied by each simulated person.

(6,7) Determine probabilistically whether an occupant's goal-directed behavior is influenced by a cognitive or environmental interruption, during the time frame. Determine the mode and outcome of any such interruption.

(8) During the current time-frame, is an occupant in the midst of assisting an injured or handicapped other?

(9) Determine whether an occupant co-occupies a spatial subdivision with one or more other occupants. Determine whether co-occupants of a space will share any information about an effective exit route. Determine whether a "consensus exit or choice" is agreed upon by co-occupants of a space.

(10-12) Determine probabilistically whether the non-handicapped individual assists the handicapped other(s).

(13) Assess for the occupant his distance from the threat (if known to him), and to his current sub-goal (if identified), and determine whether his most recent move or action improved or worsened his situation. Alternatively, assess the occupant's egress progress relative to elapsed time spent in the threatening environment.

(14) Determine whether an occupant will discount or eliminate a particular move alternative on the grounds that it is already occupied by too many other persons (is "crowded").

(15) On the basis of his interruption, intervention, and evaluation status or outcomes, an occupant's next likely move is biased and probabilistically selected to reflect one of the following: threat evasion; exit or goal seeking; bystander intervention; interruption mode fulfillment; confusion.

(17-18) Print-out the progress of the simulation run, by time-frame, including: location of each occupant at time t; move probability values for all move alternatives confronting each occupant, during the given time-frame; selected move by, and resulting location of each occupant at, time t + 1. Also provide status histories and traces for specified variables, for use in subsequent statistical analyses.

(19) Update those parameters for each occupant which describe his current status or condition, and which must be recycled as initial values for the next time-frame.

2.2.3 Operating the Simulation

BFIRES is currently operational on a 32-bit minicomputer at the Center for Building Technology, National Bureau of Standards. Experiments on the program may be conducted at any facility featuring the FORTRAN-V compiler. Approximately 65,000 bytes of storage are required to run the simulation. Instructions for the program's use are provided in Appendix D.

Although the skeletal configuration is frequently being enhanced and modified, the current program is capable of a wide range of experimental applications directed toward validating, expanding upon, or modifying the underlying model of human behavior in fires. In this context, it may be wise to consider a computer, loaded with BFIRES, as a "laboratory" for experimental work. Let us review the features of this laboratory.

Independent Variables

As detailed above, three categories of parameters are adjustable by the researcher: Occupant ("subject") variables, environmental ("setting") variables, and simulation/system variables. By pre-setting the values of these, iterations of the stochastic simulation program will produce distributions of dependent measures. Experimental designs may be of the "analysis of variance", or factorial format, and substantial increases in design complexity may be achieved at relatively little expense.

Dependent Variables: Simulation Outcomes

In its present configuration, BFIRES allows the study of two categories of dependent variables, or simulation outcomes. First, and simplest, is the measure of egress time for occupants. This refers to the number of time-frames required by any simulated occupant to reach a predetermined exit or other place of refuge. Although the problem of calibrating the program has not been dealt with in any detail, preliminary simulation experiments do suggest that a "time-frame" could be construed within the range of 5-10 seconds of real-time. We could run the simulation for any number of time-frames, and record the number of frames actually required by occupants to escape. A straight-forward analysis of variance, in this case, would permit us to evaluate the effects of independent variables, and of their interaction, within the artificial environment of the computer simulation.

Second, the program permits us to trace the history of emergency egress scenarios, as these are generated over time in accordance with the model. Unlike egress time, which is simply measured, scenario development is complex and multi-variate in structure. For example, at least four important components have already been identified during the course of preliminary work with the current program. These include: (1) route (path shape; patterns of route-switching); (2) use of available time (proportion of time spent, e.g., remaining in place, helping others, etc.); (3) manipulation of the physical environment (e.g., opening and/or closing doors); and (4) patterns of communication among occupants (e.g., sharing information about the location of exits, etc.). Evaluation of egress scenario development is seen to require multi-variate analytical techniques.

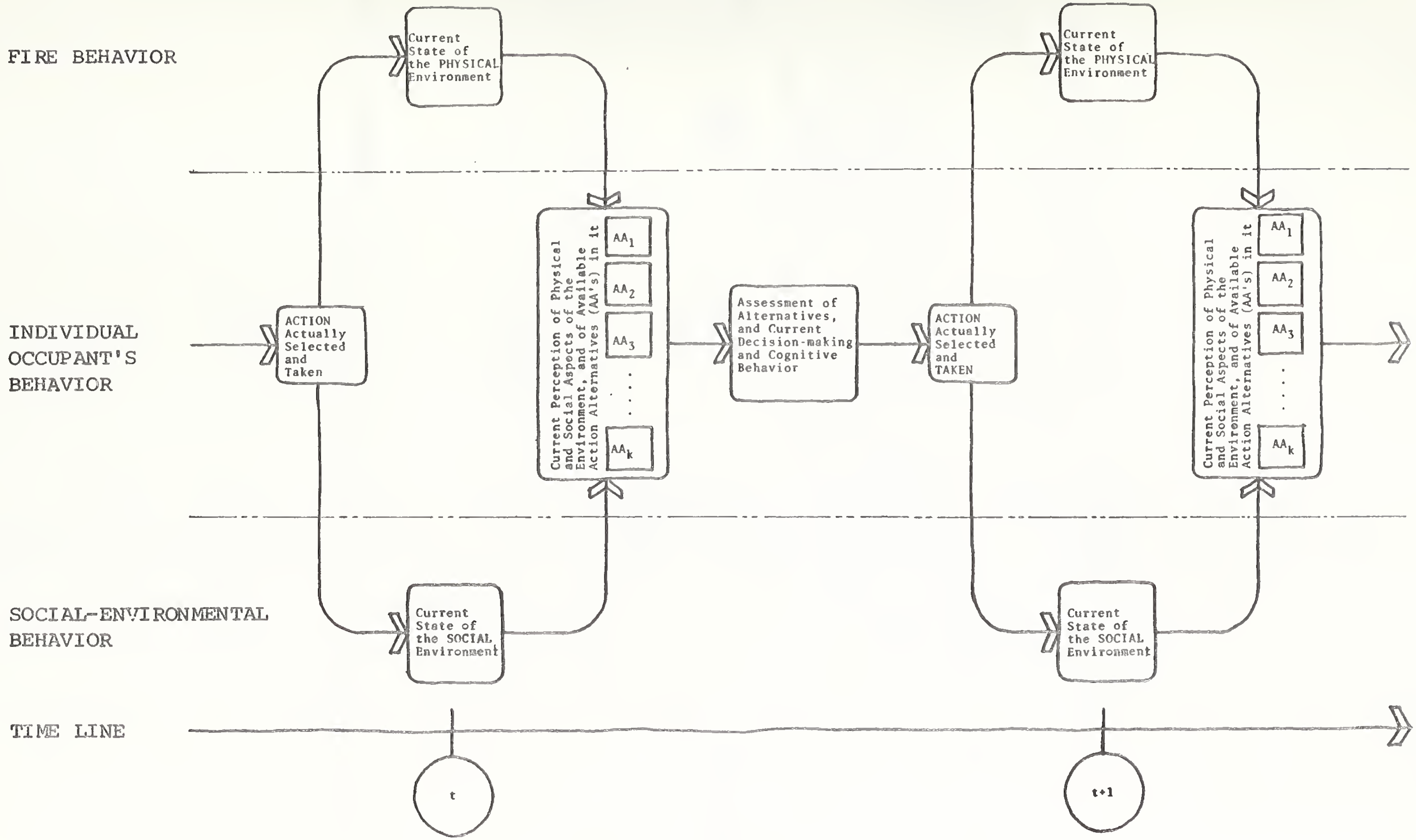


FIGURE 2.1 Conceptual Diagram Illustrating the Interaction of Behavioral Subsystems in Markovian Time/Space

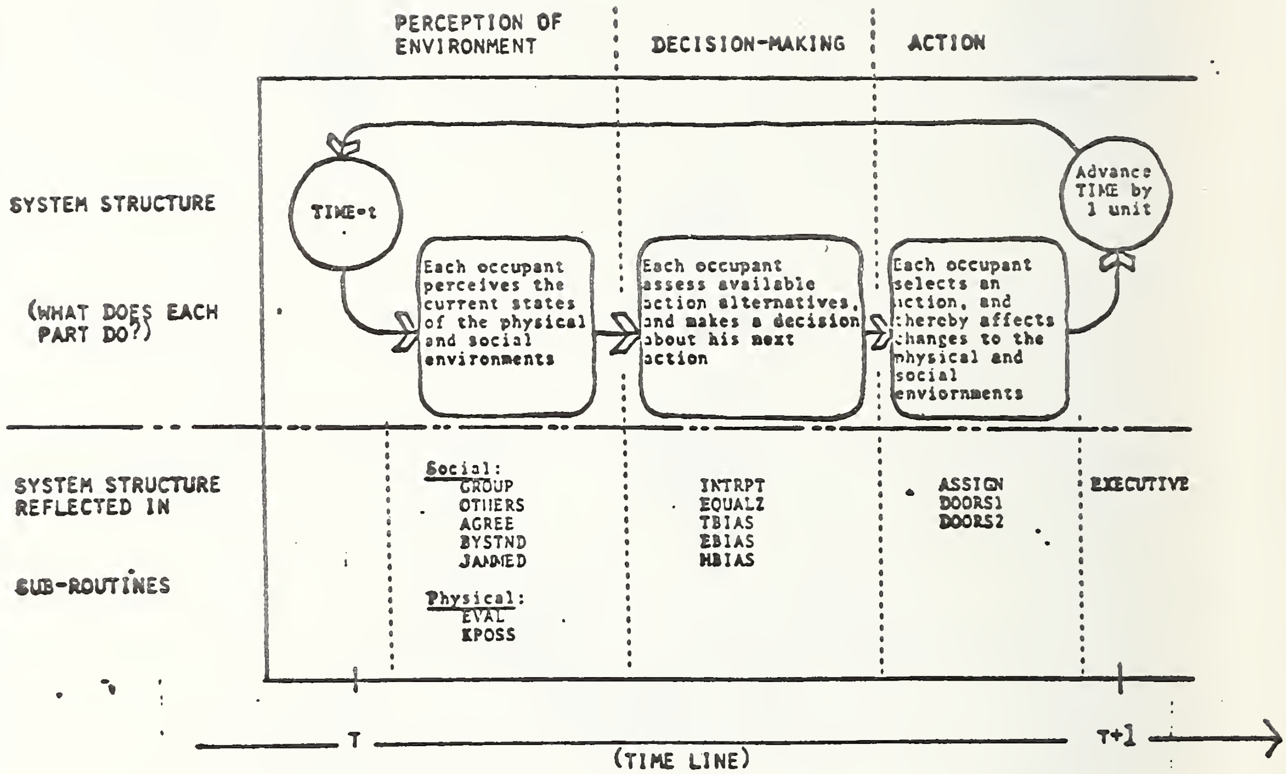


FIGURE 2.2 Relationship Between Subroutines and the Model's Structure

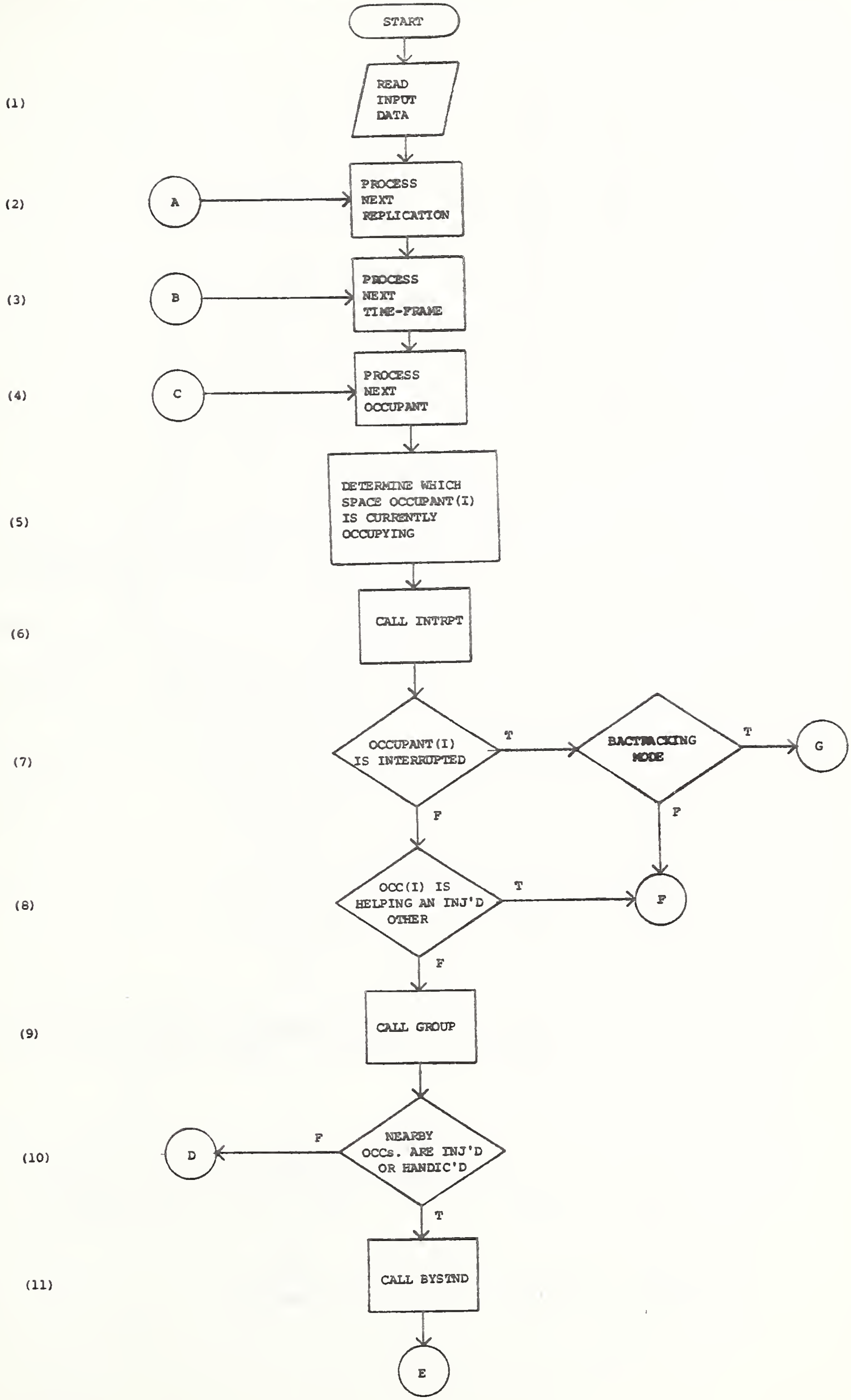


FIGURE 2.3 Event Control by the Executive Program

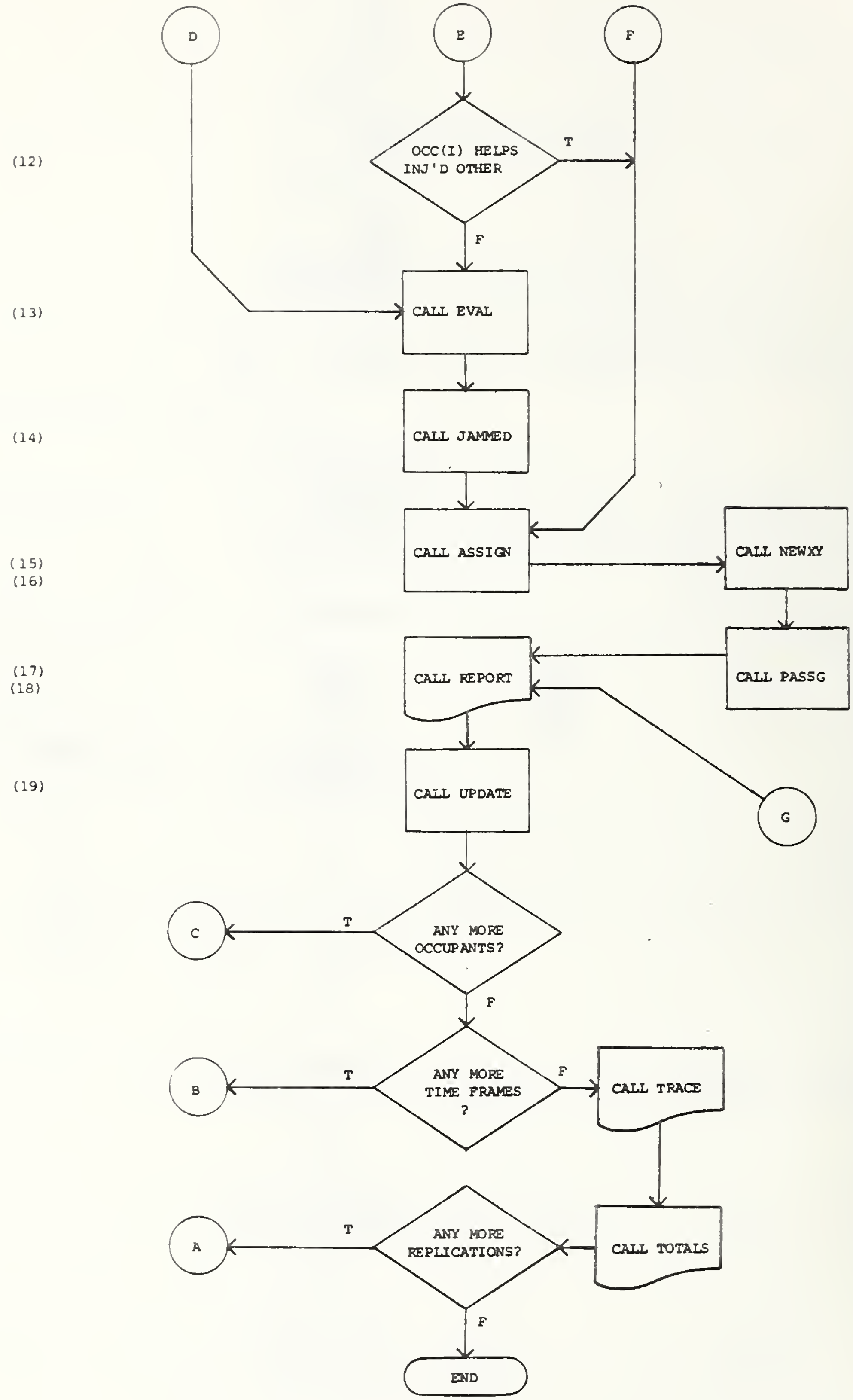


FIGURE 2.3, Continued

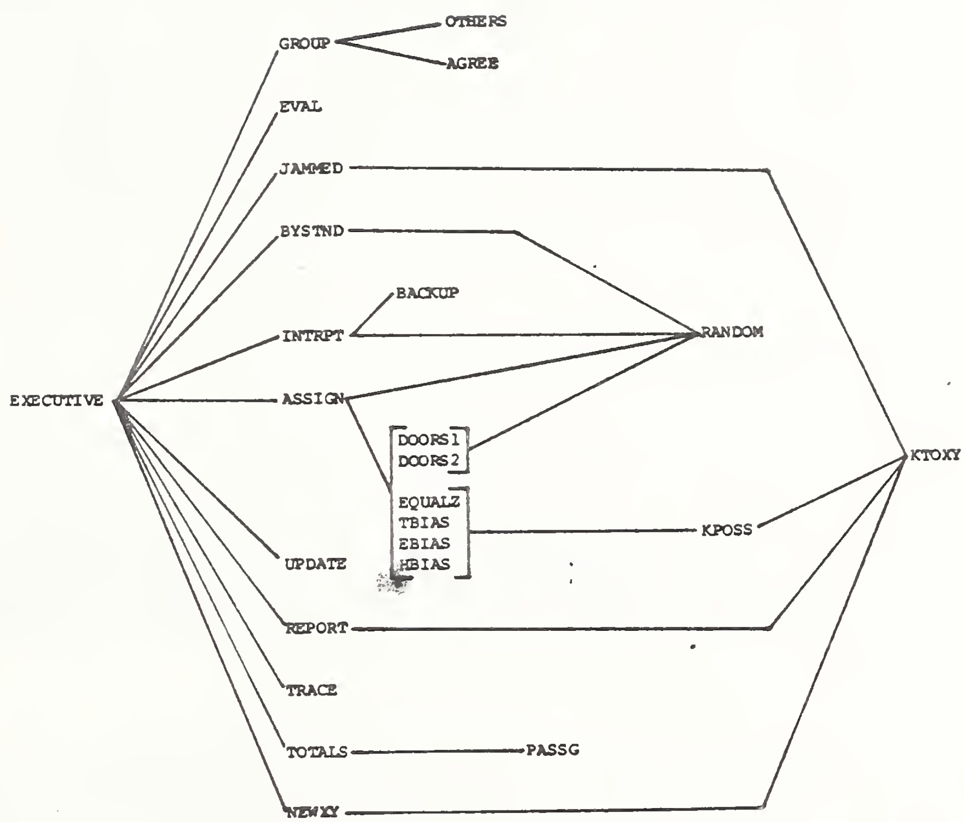


FIGURE 2.4 Subroutine Calling Pattern

3. BEHAVIORAL ATTRIBUTES OF THE COMPUTER PROGRAM

3.1 Overview

In the long-range, the criterion against which the simulation will most frequently be judged will be its ability to accurately and reliably replicate real-life events. But even this criterion is subject to various interpretations. The architect, for example, may be interested in fire outcomes, only: For a building with a given configuration, what is the probability that all occupants will escape injury from a particular fire event? Graphic designers, and professionals charged with the development of emergency public-address messages, however, may have other requirements: During the fire, what is the role of information? What kinds of information are most useful, at which points during the emergency should information be introduced, and how will it influence emergency behavior? Finally, behavioral scientists are likely to approach the building fire problem with yet another set of questions: How do humans cope with life-threatening events? How do they make rational decisions under the stress of a life-threat?

Ideally, any simulation developed as a research and design tool must be sensitive to the diverse needs of its potential users. Toward the achievement of this ideal, the present simulation program contains algorithmic expressions of human processes believed to generate behavioral streams during building fires. The program thereby generates data which enables the architect to study the end-results (outcomes) of fires, and the behavioral scientist to study the contributory processes, as each may require.

However, it would be inappropriate to assume that the results of the current simulation exercise represent such an ideal. For one thing, the available literature on human behavior in fires -- while replete with anecdotal accounts and data on various actions people say they take -- gives extremely little insight into the processes by which occupants gather, utilize, and act upon information during the relatively short period of the fire event. With so little known about the nature of these processes, how can they be written into computer algorithms? The answer to this question lies in the application of available theory and data, and in a substantial dependence upon this researcher's own intuition and conjecture.

A combination of approaches were applied at different levels of the problem. First, a general framework for explaining human behavior was adopted from the "information processing" school of cognitive and perceptual psychology. Accordingly, the entire simulation is based on the notion that the fire environment is the source of information upon which occupants' actions are completely based. This information enables occupants to contemplate and evaluate alternative courses of action which may become available as the fire event progresses over time. As occupants take actions within or upon the fire environment over time, these actions alter the environment, resulting in a continually changing information field. This psychological framework gave rise to the non-stationary Markovian structure of the simulation model and program.

At the less general level of decision-making and response to particular information and stimuli, a probabilistic or "best bet" approach (Brunswik, 1956) was loosely followed. Accordingly, an occupant is thought to "weight" information about certain alternative courses of action more than other ones, on the basis of his perception or knowledge of the overall emergency situation at that point in time. Since, according to Brunswik, neither the available information nor the occupant's perceptions can ever be "perfect", he assigns probabilities to the action choices as a function of information currently on-hand. Finally, the individual samples from among the weighted action alternatives: Given an imperfect system, his choice may be relatively "good" (adaptive, goal-directed action), or it may be "bad".

In at least one instance, specific behavioral mechanisms were programmed by converting psychological models directly into computer algorithms. The chief application of this technique to the current exercise concerns the expression of altruistic behavior (Latane and Darley, 1970).

Most frequently, however, algorithmic expressions of specific perceptual or behavioral mechanisms were programmed on the basis of intuition and qualified speculation. In many cases, this procedure was assisted by anecdotal accounts of real fires. More often, however, these accounts provided a means for checking the "face validity" of _a priori_ conceptualizations.

In sum, then, the simulation program stands as a collection of interrelated hypothetical propositions (i.e., it is a theory) about the manner in which people respond to building fires. Let us now focus on these propositions, as they are "programmed into" the various subroutines comprising the simulation package.

3.2 Subroutines Which Simulate Perception and Information Gathering

3.2.1 Subroutines GROUP, OTHERS and AGREE

Function. Subroutine GROUP is a collection of programs which establishes the social environment of occupants as they progress through the simulated fire event. By calling upon the subroutines 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 the occupant under consideration, (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.

The issue of exit route agreement among co-occupants of a space is managed through Subroutine AGREE. Three conditions are possible: First, all occupants of the space may hold the same perception of the situation, and already agree upon the "best" exit route. Second, none of the occupants in the space may have any notion of an exit route (perhaps because none were informed about the fire's location, because none have any familiarity with the location of exits, or because none have previously come into contact with more knowledgeable individuals). In this case, no single occupant has any special knowledge to share with the rest, and they each continue making decisions in the absence of information about exit routes.

The third condition is less straightforward. In this case, some occupants may have one perception concerning a best exit route, while others have another perception. Where this condition arises, Subroutine AGREE attempts to arrive at a "consensus exit of choice." This consensus is reached if and only if 60% (or more) of the occupants share one of the perceptions. When this rule is satisfied, all the remaining occupants in the space change their perceptions, so that all agree. If this rule is not satisfied, then consensus is not attained, and all occupants in the space lapse into a no-perception state: they no longer know which exit route is best. Moreover, they will continue in this state until they enter into some other group whose occupants are able to force a consensus exit of choice upon them.

Background and Underlying Assumptions. Through its functions of informing the occupant about the existence of other persons within his immediate environment, of providing certain information about these others, and of communicating with them, the GROUP package serves as the occupant's sensory and communicative apparatus. These are highly deterministic routines, in the sense that a given space either is or is not co-occupied by several persons at once, occupants either do or do not possess certain kinds of information, they either are or are not injured or handicapped, etc. The program provides information only in this binary manner, ignoring the possibility that occupants' perceptual mechanisms may occasionally distort the "facts."

Subroutine AGREE, on the other hand, raises issues much more relevant to the interpretation of information from the social environment. For example, when an occupant confronts several others in a space, and each agrees upon the best exit route, then each may interpret such agreement as a reinforcement of his own initial perception. Perhaps he feels "more right" than he did before, since now he finds others who agree with him. But when there is disagreement among co-occupants, who is right? The "consensus" notion written into AGREE assumes that people can be convinced they are wrong, if the pressure to change is sufficiently great. It further assumes that, in those cases where no consensus is attained, a person will develop stress resulting from the inability to replace his eroded perception by a better one. According to AGREE, this stress is manifest in the form of "goal-seeking in the absence of any specific goal," or wandering.

Unfortunately, the literature on human behavior in fires provides no empirical evidence relative to inter-occupant communications during a fire event. Consequently, no means for examining the face validity of the consensus concept, or of the arbitrarily chosen 60% cut-off point, are readily available at this time.

3.2.2 Subroutine BYSTND

Function. If an occupant finds that he co-occupies a space with an injured or handicapped other occupant, then Subroutine BYSTND will be called. The purpose of BYSTND is to determine probabilistically whether he ignores, approaches, or remains to assist the handicapped individual. Subroutine BYSTND is currently under development, and is not included within the version of the program reported here.

Background and Underlying Assumptions. When written and included within the simulation package, BYSTND will fulfill the function expressed by the bystander-intervention model of Latane and Darley (1970). Here, the likelihood that an occupant will intervene will depend upon such factors as (1) the number of other "healthy" individuals in the immediate vicinity, (2) the relationship of the injured person to the bystander, and (3) the bystander's perception of the "cost" (in terms of, e.g., time lost) of the interruption to goal-seeking which may result from helping.

According to Latane and Darley, for example, a bystander may be quite likely to intervene if he is the only other person available. If many potential helpers are present, he may well decide that someone else -- perhaps more qualified than he -- will certainly stop and render assistance, and that it will not be necessary for him to interrupt his own routine. If the bystander knows the injured person, however, he may be compelled to stop (or seek other assistance, etc.), regardless of how many others are present.

3.2.3 Subroutine JAMMED

Function. As occupants move about during a simulated fire, the population density of the different spatial locations varies. Some mechanism is necessary which enables an occupant to gather information about the density, or degree of "crowding," of locations he may wish to enter. Subroutine JAMMED satisfies this function. As an occupant looks ahead and scans the alternative target locations available to him, he counts the number of other persons already occupying each. If, for any alternative location, this number is greater than his pre-set crowding tolerance, he rejects that alternative from his array of movement choices.

Background and Underlying Assumptions. The simulation program contains no "queuing" mechanism, as such, for the purpose of regulating the flow of persons between spatial locations. Queues are used in simulation whenever the number of elements requiring passage through a channel is greater than the channel's capacity. Typically, waiting elements line up in the queue, and remain in line until their turn comes to move into the channel. In the most simple case, once an element has joined a queue, its immediate future is fully determined: it waits its turn, and then moves through the channel.

It is not clear, however, that persons in stressful situations will respond to crowding in so mechanistic a manner, oblivious to events around them. An individual may first seek passage through a particular doorway, but upon finding the vicinity of the door to be heavily crowded, may not join any "queue" at all, but rather seek some other route. Moreover, seeking an alternative egress path may not be a straightforward task, if the occupant is not actually aware of any. If there are no alternatives available, or if the occupant does not perceive any, his level of stress is expected to increase, as is the likelihood he will engage in non-adaptive behavior. The current version of the simulation program manifests such behavior either as goal-less wandering, or remaining "frozen" in place. The latter behavior may continue until the occupant perceives a significant reduction in the crowding of the space leading to his doorway objective.

3.2.4 Subroutine KPOSS

Function. As an occupant moves through a bounded environment, locomotion 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 his 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 his social environment, Subroutine KPOSS provides "eyes" through which to discern his immediate physical environment: Namely, as he scans each potential move alternative, k, he determines which are physically possible to attain, and which are physically constrained. Figure 3.1 illustrates this distinction, as it is defined within the computer-simulated environment.

In addition, KPOSS responds to inputs provided by 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 those available at the current point in time.

Background and Underlying Assumptions. Subroutine KPOSS makes use of a relatively simple stimulus-response function, in which information from the environment results in a specific behavioral outcome: Namely, whenever a move alternative, k, is perceived to be impossible to attain (i.e., it is overcrowded, or blocked by a physical barrier), it is removed from the array of alternatives, and is accorded no further consideration by the occupant during the current time frame. Whenever an alternative is perceived to be possible to attain, the occupant "stores" it away for comparison against other alternatives, and includes information about it in his current decision making task. This function is programmed to remain constant throughout the simulation, and not to alter through interactions with other psychological or environmental processes.

In its present form, moreover, Subroutine KPOSS assumes a clear visual field. Future versions will require a capacity to accommodate such intrusions to the visual field as smoke of varying density. The inclusion of such a vision-reducing medium would result, operationally, in the introduction of a stochastic component to Subroutine KPOSS: the probability of a correct perception of the immediate physical environment would decrease as smoke density increases.

3.3 Subroutines Which Simulate Information Processing and Decision Making

3.3.1 Subroutine INTRPT

Function. INTRPT probabilistically determines whether an occupant's goal-directed behavior will be interrupted during time-frame t. The current version of the program permits two modes of interruption: remaining in place, and backtracking.

If the occupant is currently in the backtracking mode (initiated by some previous interruption), then INTRPT is ignored and he is permitted to return to his origin point uninterrupted (refer to Section 3.3.2: Subroutine BACKUP). For non-backtracking occupants, an interruption of either mode may be initiated when a pseudo-random number is compared with each occupant's interruption probability. Occupants are assigned probabilities of encountering remain-in-place interruptions, backtracking interruptions, and no interruptions at all. These probability values may vary across occupants in the simulation, and for each occupant, the three values must sum to unity. Each occupant is also assigned an interruption limit. If, during the course of the simulated event, an occupant has experienced a number of remain-in-place (or back-tracking) interruptions equal to his limit, he will not "tolerate" -- and hence not experience -- any more; that is, he will ignore future "temptations."

Background and Underlying Assumptions. According to Simon (1967), interruptions to goal-seeking behavior provide useful means for introducing emotional controls over behavior, particularly in a computer-simulated environment. Interruptions, detours, etc., require the individual to temporarily suspend his goal-seeking activity. In a stressful environment, this should lead to increased stress for the occupant, resulting in an increased likelihood of maladaptive behavior, and a decreased likelihood of ultimate success.

Within the fire environment, the causes and effects of interruption may be difficult to specify exactly. The empirical literature on behavior in fires is of virtually no assistance on this subject. Consequently, Subroutine INTRPT is extremely simplistic in its handling of this phenomenon.

Only two forms of interruption are considered. Remaining in place is meant to simulate any response in which the normal decision-making processes are bypassed, and through which an occupant rejects all other move choices available to him. But INTRPT makes no attempt to simulate specific causes of this form of interruption, which may be cognitive, physiological, or environmental in origin. Backtracking is meant to simulate the frequently noticed phenomenon in which an occupant will return to some earlier location to, for example, retrieve valuables, close doors, etc.

In sum, the purpose of Subroutine INTRPT is to introduce the fact of interruption into the simulated environment, so that occupants' responses to such obstacles to goal-seeking may be observed and compared against real-world behavior.

3.3.2 Subroutine BACKUP

Function. 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 (or toward some other, user specified goal). Once an occupant has returned to this point, he is removed from the backtracking mode, and he resumes the normal decision-making and goal-seeking processes.

Background and Underlying Assumptions. The main purpose of Subroutine BACKUP is to "waste an occupant's time" by causing him to temporarily suspend his egress behavior and instead move toward some seemingly irrelevant location on the floor. The current version of the program affects this activity by retracing each and every step the occupant has already taken, until the goal of backtracking has been attained. This is a rather simplistic approach, since once an alternative goal has been selected, the occupant is more likely to determine an effective route through the usual decision-making process, than he is to mechanistically retrace his steps. But even this is an empirical question, for which little guidance exists in the fire literature.

3.3.3 Subroutines ASSIGN, DOORS1 and DOORS2

Function. The model assumes that an individual's decision-making 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 Subroutine 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.), and then to "assign" his decision-making task to an appropriate biasing routine.

For example, if an individual has perfect knowledge of an effective exit route, and if he perceives no social or physical obstacles in his immediate environment, then ASSIGN will shift his decision-making task to a routine which biases him toward seeking his exit goal (see Subroutine EBIAS, below). Similarly, if an unencumbered occupant has no knowledge of an exit route, then his decision-making task may be assigned to a routine which biases him toward threat evasion (see Subroutine TBIAS, below). In its current form, ASSIGN accommodates five biasing objectives:

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

When control of an occupant's decision-making task is assigned to a given biasing routine, there is no certainty that his final move decision will be in the direction of the biased objective. The term "bias" was specifically selected to underscore the probabilistic notion that, under a given set of state-defining conditions at time t, certain move decisions are more likely than are others.

Two additional functions are controlled by Subroutine ASSIGN. One concerns the actual move decision. The biasing routine supplies ASSIGN with a set of probability values. Each value corresponds to the likelihood that a given move alternative will be selected, in accordance with the particular weighting scheme imposed by the biasing routine. Any move alternative perceived by the occupant as impossible to attain is automatically given a zero probability of selection. For each occupant, the sum of the selection probabilities for all alternatives currently available must equal 1. Once the selection probabilities have been established, they are cumulatively compared against a pseudo-random number. This process results in the selection of a unique move. At the conclusion of move selection, control is passed to various "bookkeeping" routines, and a new cycle of perception and decision making begins.

As a part of its move selection function, 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 probability he will not. If he chooses not to open the door, the through-door alternative is deleted, and the probability 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.

Background and Underlying Assumption. The biasing aspect of Subroutine ASSIGN is intended to introduce the concept of weighting, based on perceptions of current events, into the simulation program. The "biased" probability values assigned to move alternatives provide a means for achieving Brunswik's "best bet": in a given situation, a person will probably -- but not certainly -- respond with a particular action. Similarly, the stochastic aspect of ASSIGN assures that in a certain proportion of cases, an occupant will make a wrong decision -- even in the presence of "good" information.

The inclusion of a door manipulation function is a direct response to the frequently raised issue of door-closing during fires. In particular, while doors may provide effective barriers to smoke and fire, they also serve as perceptual barriers which may limit communications and other forms of information flow. The ultimate question of whether doors should best remain open or closed is seen here to remain an empirical one, and it is hoped that its study will be enhanced through the door manipulation routines included in this simulated program.

3.3.4 Subroutine EQUALZ

Function. Subroutine 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 condition in which the probability values of available move alternatives are equalized.

Background and Underlying Assumptions. EQUALZ is called whenever the current events perceived by an occupant make it difficult (or impossible) to decide upon a specific objective (e.g., to evade the threat, to seek an exit, to assist a handicapped other). The principal assumption behind EQUALZ is the notion that certain combinations of information will cause an individual to be (at least momentarily) confused, and that this confusion will make goal oriented decision making difficult.

The program launches such a state of confusion whenever a mobile, uninterrupted individual makes a negative evaluation of his current safety status, and is unable to discern an effective egress route. An occupant will remain in this state until he:

(1) makes a positive evaluation of his current safety status; or

(2) learns about an effective egress route; or

(3) decides to help a handicapped other; or

(4) decides to enter the backtracking interruption mode.

When a "confused" occupant selects a move from among the equalized alternatives, this move is not considered to be toward a particular goal. Rather, it is viewed as "wandering," and this is construed as maladaptive behavior. EQUALZ generates this behavior when a state of insufficient information is coupled with a negative perception of current safety status. Other causes might include "cognitive overload" (Cohen, 1975; Saegert, 1976), in which an individual is forced to respond to more information than he is capable of processing within a given period of time. This problem may be further complicated if there are conflicts within the information field. In the future, routines generating maladaptive behavior will have to accommodate these additional complications.

3.3.5 Subroutine TBIAS

Function. Subroutine TBIAS effectuates "threat evasion" movement behavior. Whenever this biasing routine is assigned, it establishes move selection probability values in such a manner as to "favor" moves which maximize the occupant's distance from threatening stimuli -- fire or smoke.

Background and Underlying Assumptions. As an occupant scans the move alternatives, k's, currently available to him, he "measures" the distance, DIST(k), between each alternative location and the location of the threat. The selection probability of alternative k increases as DIST(k) increases. That is, the more threat-reducing an alternative is perceived to be, the more likely is the occupant to select it.

The program assigns an occupant's decision-making task to Subroutine TBIAS if and only if he:

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

(2) is not currently assisting a handicapped other;

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

(4) has no exit route "in mind"; and

(5) knows the location of the life threat.

With neither a specific egress route objective, nor current perceptual encumbrances, the only remaining goal is seen to be that of threat evasion. TBIAS will bias the individual's movement behavior away from the threat, even at the expense of moving him farther from an exit.

3.3.6 Subroutine EBIAS

Function. 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 or exit goal point. If any of the available alternatives represents final attainment of an egress goal, then this move is automatically selected. If more than one alternative satisfy this criterion, then their probabilities of selection are equalized.

Background and Underlying Assumptions. As an occupant looks ahead to the move alternatives, k's, currently available to him, he "measures" the distance, DIST(k), between each alternative and the location of the next egress objective along his selected route. The selection probability of alternative k increases as DIST(k) decreases. That is, the more goal-directed an alternative is perceived to be, the more likely is the occupant to select it. Note that egress routes are subject to change during the course of the fire event, as the occupant receives new information (e.g., he may change his route, midstream, to conform to a new group consensus). EBIAS establishes move selection probabilities on the basis of an occupant's current route.

An occupant's decision making task is assigned to Subroutine EBIAS if and only if he:

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

(2) is not currently assisting a handicapped other;

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

(4) has a specific egress routine in mind.

3.3.7 Subroutine HBIAS

Function. Subroutine HBIAS has not as yet been developed to the point of inclusion in the current program version. Its function, however, will be to bias an occupant's move selection toward helping handicapped others. The proposed subroutine will effectuate three categories of helping behavior:

(1) movement toward an identified, though distantly located, handicapped (or injured, etc.) other; or

(2) remaining with a handicapped other at a given location; or

(3) assisting a handicapped other to move along an egress path.

HBIAS is assigned if and only if Subroutine BYSTND (the Latane and Darley bystander intervention routine) orders the occupant to, in fact, render some sort of assistance. HBIAS determines the mode of assistance which is likely to be rendered.

Background and Underlying Assumption. The basis for determining a mode of bystander assistance is treated as a function of the relative locations of the helper and the handicapped other, and of the mobility potential of the handicapped other. Where the two occupants are separated spatially by some distance, the decision to help will require movement by the bystander toward the individual needing help. However, where the two persons already occupy the same spatial location, such movement will be unnecessary.

Just what sort of assistance the bystander renders once he reaches the handicapped other will depend upon the other's current abilities. If, for example, he is totally immobile, HBIAS requires the helper to remain with him throughout the duration of the fire event. The version of this routine now under development does not allow the helper to go and seek other assistance, nor does it permit a helper to change the handicapped other's mobility status. In those instances where the handicapped other is mobile to some extent, then HBIAS moves both the two persons -- at half the normal speed -- along a route selected by the helper (all the earlier rules controlling egress route knowledge apply here).

Once developed and included within BFIRES, Subroutine HBIAS will serve general purposes of:

(1) informal rescue of, e.g., a loved one;

(2) more formal helping procedures established within, e.g., health-care facilities; and

(3) vicarious bystander intervention.

3.3.8 Subroutine EVAL (EVAL8, EVAL2Ø)

Function. In certain cases described above, the direction of move probability biasing (i.e., assignment to a particular biasing subroutine) depended upon an occupant's current evaluation of his own safety status. Safety status is here defined as the spatial location of the occupant with respect to the locations of the threat and an effective exit (when these are known to him). Evaluations may be positive or negative: A positive evaluation results whenever an occupant perceives his safety status to have improved, over a specified period of time.

In its present form, BFIRES provides two alternative status evaluation mechanisms. For any given simulation run or experiment, only one of these is actually used. The program's user, however, can call either option. Accordingly, a direct examination of differences between the two definitions of the evaluation process, are possible.

Subroutine EVAL8 constructs evaluation outcomes purely on the basis of straight-line distance measurements between an occupant's current location of threats or exits, or both (depending on which of these latter locations are actually known to him at time t). A positive status evaluation results whenever the occupant's perceived status at time t is "better" than that at time t-1.

Subroutine EVAL2Ø, 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.

Background and Underlying Assumptions: EVAL8. The distance measurement approach is adapted from the simulation by Wolpert and Zillmann (1969). Their study focused on the "theater fire", or more generally, fires in large, single spaces. In these settings, occupants, regardless of their particular locations within the space, are continuously provided unobstructed visual access. Accordingly, the assumption that occupants are able to judge relative distances, and hence may make evaluations based on these judgments, seems a safe one.

Ultimately, however, BFIRES is expected to be useful in a much wider range of problem contexts, and most fires-of-interest subjected for simulation will be in multi-spatial facilities. The question arises, then, as to the ability of occupants to judge distances when visual access to key elements (fire and exits) may in fact be blocked? The major assumption of EVAL8, therefore, is that occupants who have up-to-date information about the location of the key elements form "mental maps" of their environment (see, for example: Moore and Golledge, 1976; Downs and Stea, 1973).

Their judgments of distances derive from these maps, rather than from direct visual experience. When information is not complete, it is less likely that EVAL8 will yield a positive evaluation.

Background and Underlying Assumptions: EVAL2Ø. The approach taken by EVAL2Ø avoids any dependency upon distance estimation, and obviates the need to distinguish between distance judgment through direct visual experience versus by means of a mental map. EVAL2Ø is based on the notion that each occupant has his own perception, or "feelings about" the total amount of time he has to escape the danger zone. This perception may change as the fire event progresses (he may envision more or less time available). Regardless of what actions he may take, he will maintain a positive status evaluation as long as he is well within his perceived time limit. Negative evaluations will result when the occupant approaches his time limit, and realizes that there may not be enough time to reach an identified exit goal.

In this case, a negative evaluation may be interpreted as the frustration one encounters when he realizes he has reached his time limit, but has failed to achieve his goal. By returning a negative status evaluation, EVAL2Ø causes the occupant to respond to this frustration with non-goal directed movement behavior (wandering).

Unlike EVAL8, which faithfully generates incremental status evaluations for each time frame individually, EVAL2Ø implies that the occupant starts off with an overview of his situation: "There is only so much time available to accomplish the egress task; how will I use it, and how much flexibility is there?"

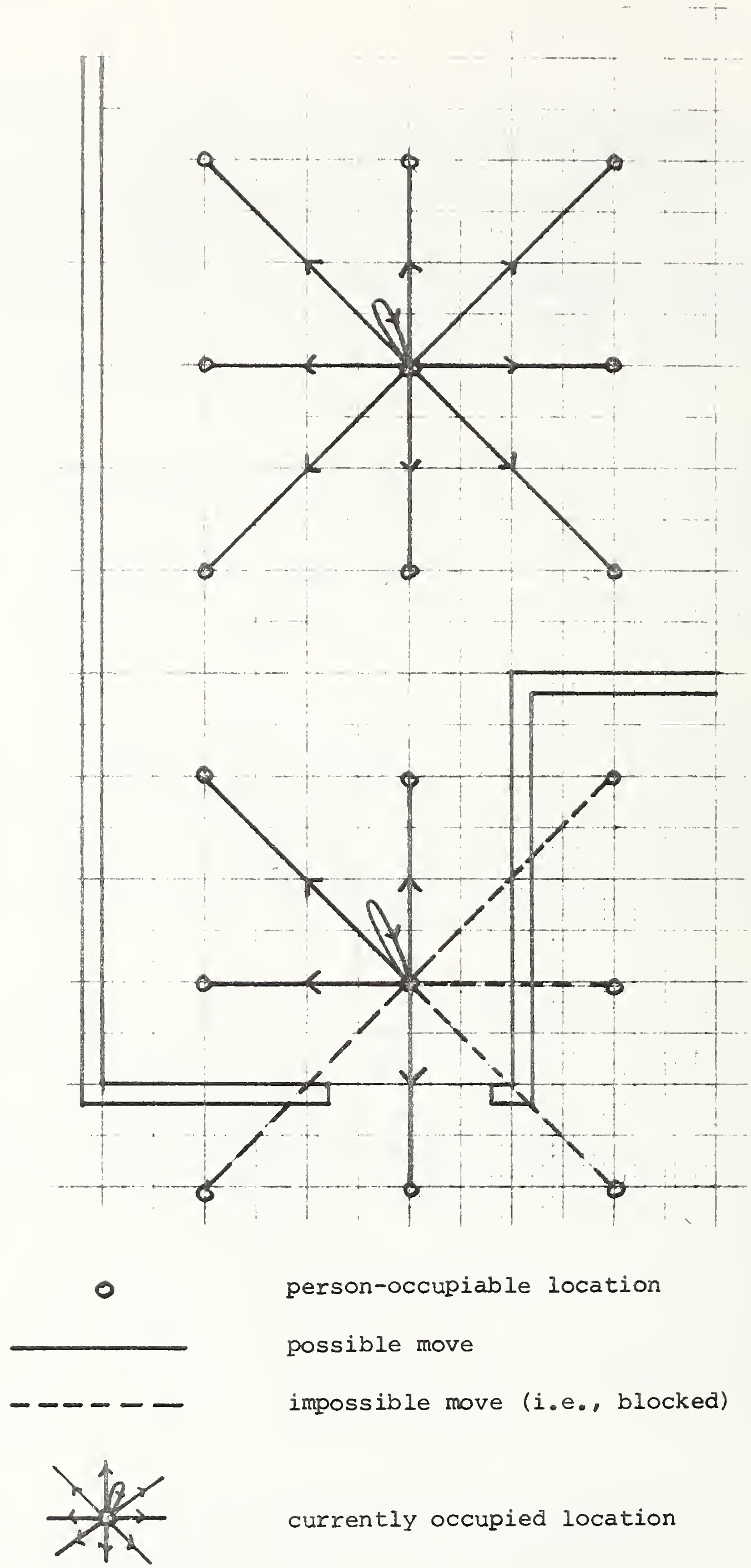


FIGURE 3.1 Possible vs. Impossible Spatial Movements

4. NON-BEHAVIORAL SYSTEM OPERATIONS

4.1 Executive Program

The BFIRES Executive fulfills three principal functions: (1) initialization of simulation parameters; (2) transition of occupants' decision processes from state to state (i.e., time-frame to time-frame); (3) completion of the desired number of replications of a simulated building fire event.

The initialization of simulation parameters involves reading various input data into the computer. Three catagories of data must be input, before any simulation experiment can begin: environmental descriptors; occupant descriptors; system parameters. Environmental descriptors include the layout of walls and doors (expressed in terms of x, y coordinates), special characteristics of doors (whether each is initially opened or closed; whether it is of the manually or automatically closing type), and the initial location of the fire threat.

Occupant descriptors permit the computer to differentiate between individual "persons". Occupants may differ from one another on the basis of their interruption tolerance limits, bystander intervention tolerance limits, initial mobility status, initial knowledge of an effective egress route, predispositons toward opening and closing doors, and initial location on the floor.

Finally, system parameters are initialized. These tell the computer how many replications of a simulated fire are to be executed, the length of each replication (in time-frames), and the number of occupants actually in the simulation. The experimenter also selects a random number seed, and reads this into the machine.

Appendix C provides a guide to organizing input data for FBIRES. A sample data file is also shown.

4.2 Process Updating

As the simulated fire event progresses through a series of time-frames, certain outcomes from the current frame must be used as input for the next frame. In the present version of BFIRES, this is especially true about occupants' locations. A time-frame ends when all occupants have selected new locations, and have moved to them. By changing their positions in space, they have altered the nature of the environment. This new information is an important input to the next round of decision making, during the next time-frame. The conversion of current-frame output into next-frame input is accomplished by Subroutines UPDATE and NEWXY.

4.3 Grid Transformations

Two systems of spatial notations have been referred to in this report. The first is the orthogonal x,y coordinate system, through which the computer keeps track of the relative spatial location of all elements which have been defined for it (e.g., walls, doors, people). Through careful calibration, this coordinate system can be appropriately quantified.

In addition, a "k" system has been referred to, particularly with regard to the direction of alternative moves available to occupants. The "k" system may be thought of in terms of a compass dial, with eight vectors radiating outward from a central point (note Figure 4.1). This central point denotes the current location of an occupant. Each vector denotes a possible movement path, in a given direction, toward a new location. A ninth vector is also possible, when we consider the possibility that the occupant will remain in place. As illustrated in Figure 4.1, each directional vector on the k-grid is designated by a number, 1 through 9. As an individual moves about through space, he "carries" his k-grid along with him, such that the central point (designated as "K=5") always coincides with his current location.

Subroutine ASSIGN, and the various biasing routines, function in the "k" system. That is, whenever a move alternative is considered, it is the k-number (relative to the central point) that is dealt with by the machine. Once a move is actually selected, however, it becomes necessary to convert the new location arrived at by movement in the "k" direction into a point in x,y space. This is accomplished through Subroutine KTOXY ("k-to-x,y").

4.4 Reporting Simulation Results

As simulated building occupants progress through the fire event, various aspects of their experience are monitored and recorded. Three subroutines report the relevant information to the experimenter. These are REPORT, TRACE, and TOTALS.

Subroutine REPORT provides a complete occupant summary for each individual time-frame. For each occupant, this summary includes:

(1) his location at the beginning of the frame,

(2) information about whether he experienced an interruption or bystander intervention during the frame,

(3) what exit goal (if any) he is currently moving toward,

(4) the selection probability values for all move alternatives currently available to him, and

(5) his final location, after a move has been selected.

Figure 4.2 shows a representative sample of output from Subroutine REPORT.

Subroutine TRACE permits the researcher to re-create the movement paths of all occupants over any length of simulated time. TRACE output simply lists, for each occupant, his location in x,y space for each time-frame. With this information, the investigator is readily able to plot the movement paths. An example of TRACE output is provided in Figure 4.3.

After a simulation run, the researcher might wish to know how many times a particular event or experience actually occurred. Subroutine TOTALS keeps track of various events, on an occupant-by-occupant basis. For example, TOTALS output reports the total number of time-frames each occupant actually spent in an interruption or backtracking mode. In addition, it provides the total number of times each occupant passed through a doorway, during the simulated fire event. While Subroutine TOTALS reports door-passage data, Subroutine PASSG monitors door-passage behavior during the simulation. Figure 4.4 shows an example of TOTALS output.

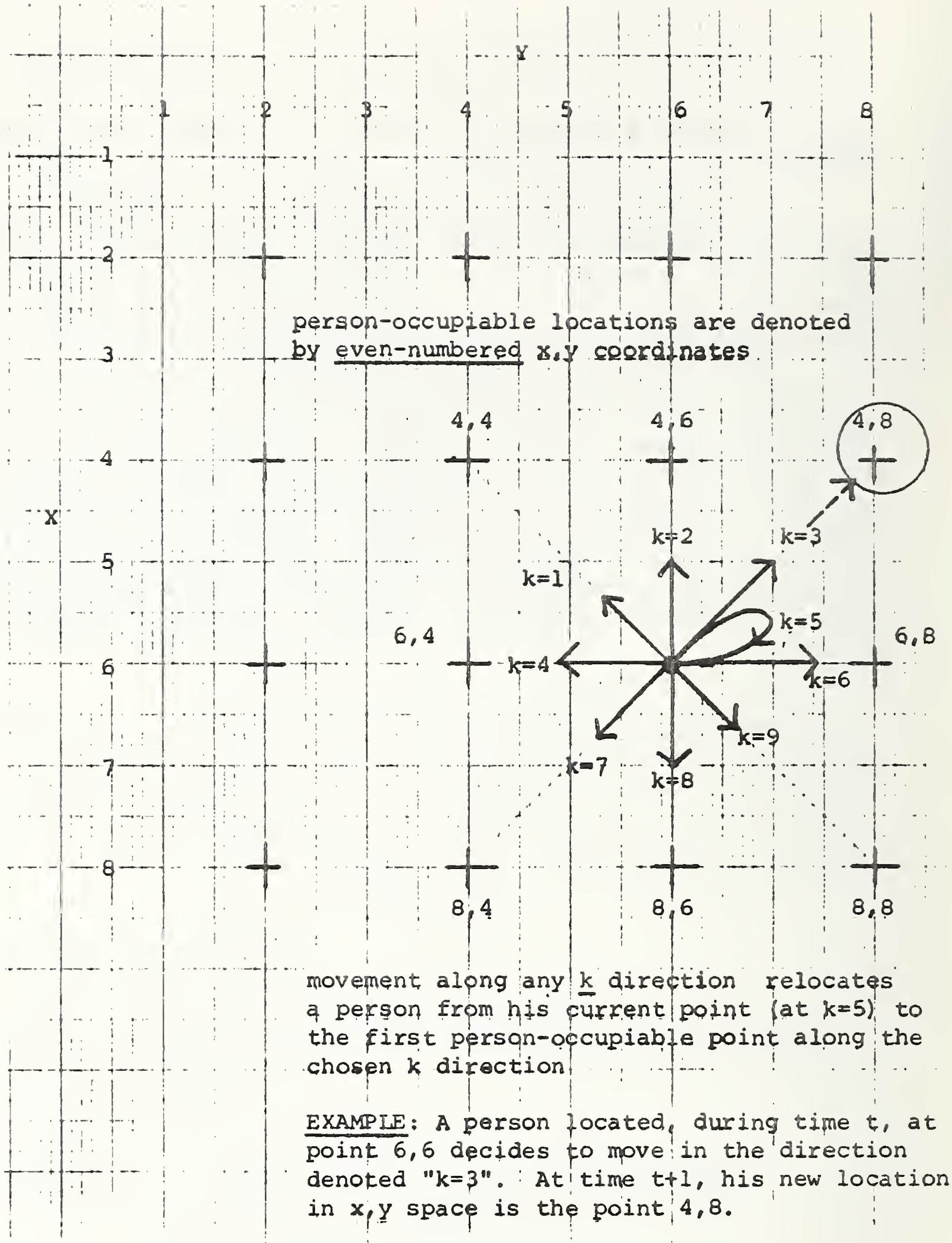


FIGURE 4.1 (a) Relationship Between "X,Y" and "k-Grid" Spatial Coordinate Systems

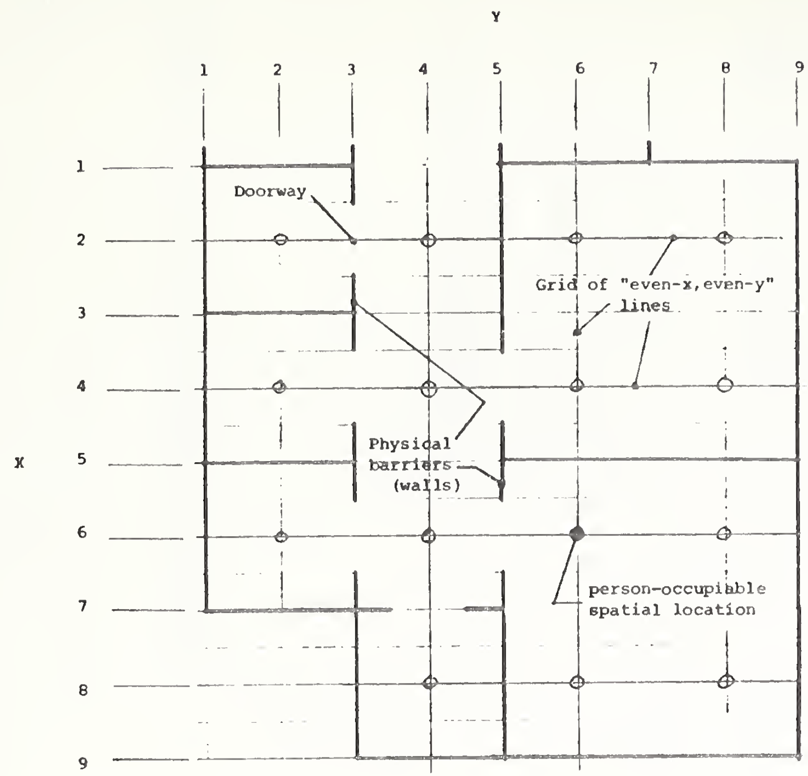


FIGURE 4.1 (b) In the "x,y" Coordinate System, person-occupiable locations occur at the intersection of two even-numbered grid lines.

Physical Barriers (walls) lie on odd-numbered grid lines.

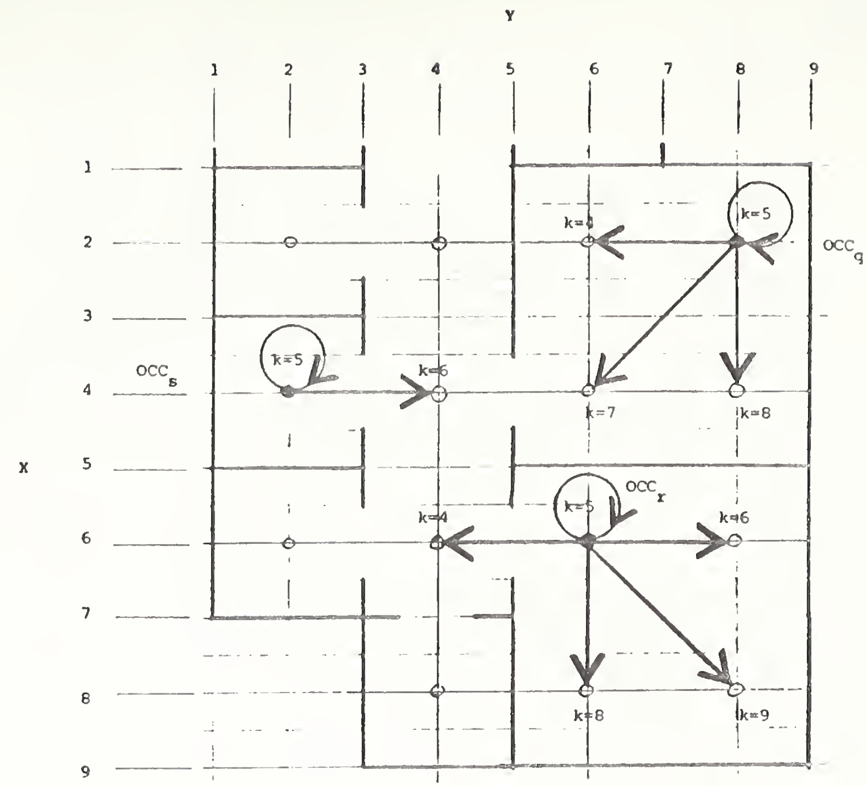


FIGURE 4.1 (c) Physical Barriers (Walls) Preclude Certain Move Alternatives.

Current locations of Occupants q, r, and s are denoted by the "k=5" point. Arrows pointing in various k directions indicate possible moves.

Remaining-in-place (k=5) is always a possible move.

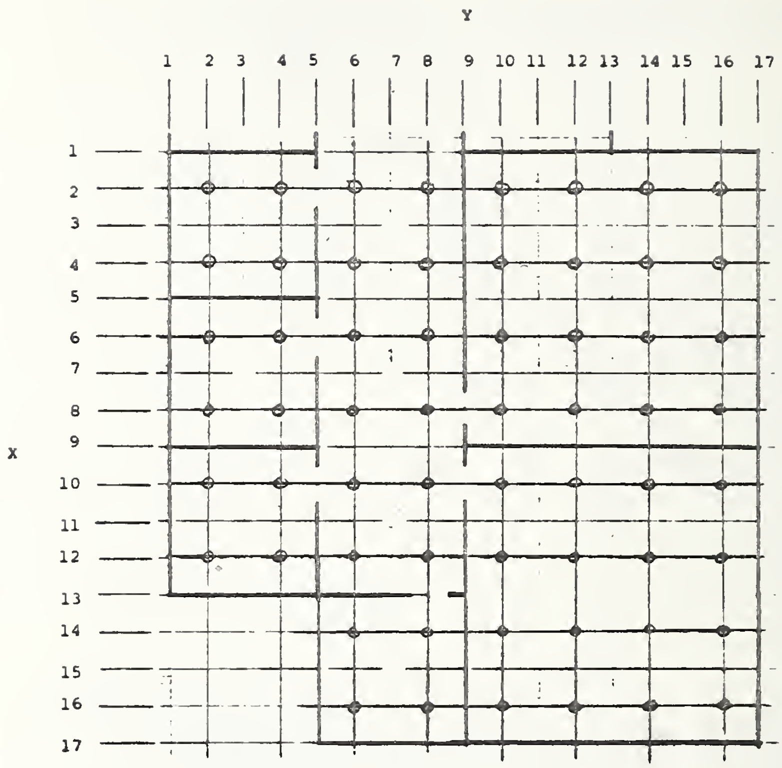


FIGURE 4.1 (d) Spatial Sensitivity May be Improved by Increasing the Number of Person-Occupiable Locations in a Given Space.

This Requires the use of an x,y coordinate grid, which is smaller with respect to room size.

TIME = 5

OCC NUM	PRIOR LOCAT XO	YO	INT	IBYSTD	EXIT AGREED UPON	PTDIST	TDIST	PEDIST	EDIST	P(1)	P(2)	P(3)	P(4)	P(5)	P(6)	P(7)	P(8)	P(9)	NEW LOCAT XO	YO
1	6	4	0	0	1		7.211		0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	6	4
2	4	6	0	0	1		8.246		2.828	0.000	0.124	0.000	0.278	0.196	0.124	0.000	0.278	0.000	6	6
3	6	4	0	0	1		7.211		0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	6	4
4	6	4	0	0	1		7.211		0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	6	4
5	6	4	0	0	1		7.211		0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	6	4
6	8	6	0	0	1		4.472		2.828	0.000	0.278	0.000	0.278	0.196	0.124	0.000	0.124	0.000	8	6
7	8	4	0	0	1		5.657		2.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	8	6
8	16	6	0	0	1		4.472		10.198	0.000	0.300	0.000	0.313	0.387	0.000	0.000	0.000	0.000	14	6
9	4	8	0	0	1		6.000		2.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	4	6
10	2	6	0	0	1		10.198		2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	4	6
11	6	4	0	0	1		7.211		0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	6	4
12	16	4	0	0	1		5.657		2.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	16	6
13	10	8	0	0	1		2.000		2.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	10	6
14	14	4	0	0	1		4.472		2.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	14	6
15	14	6	0	0	1		2.828		8.246	0.000	0.257	0.000	0.204	0.197	0.182	0.000	0.160	0.000	14	6
16	14	8	0	0	1		2.000		2.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	14	6
17	14	6	0	0	1		2.828		8.246	0.000	0.257	0.000	0.204	0.197	0.182	0.000	0.160	0.000	14	4
18	6	4	0	0	1		7.211		0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	6	4
19	12	6	0	0	1		2.000		6.325	0.000	0.277	0.000	0.206	0.196	0.172	0.000	0.150	0.000	12	6
20	6	4	0	0	1		7.211		0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	6	4

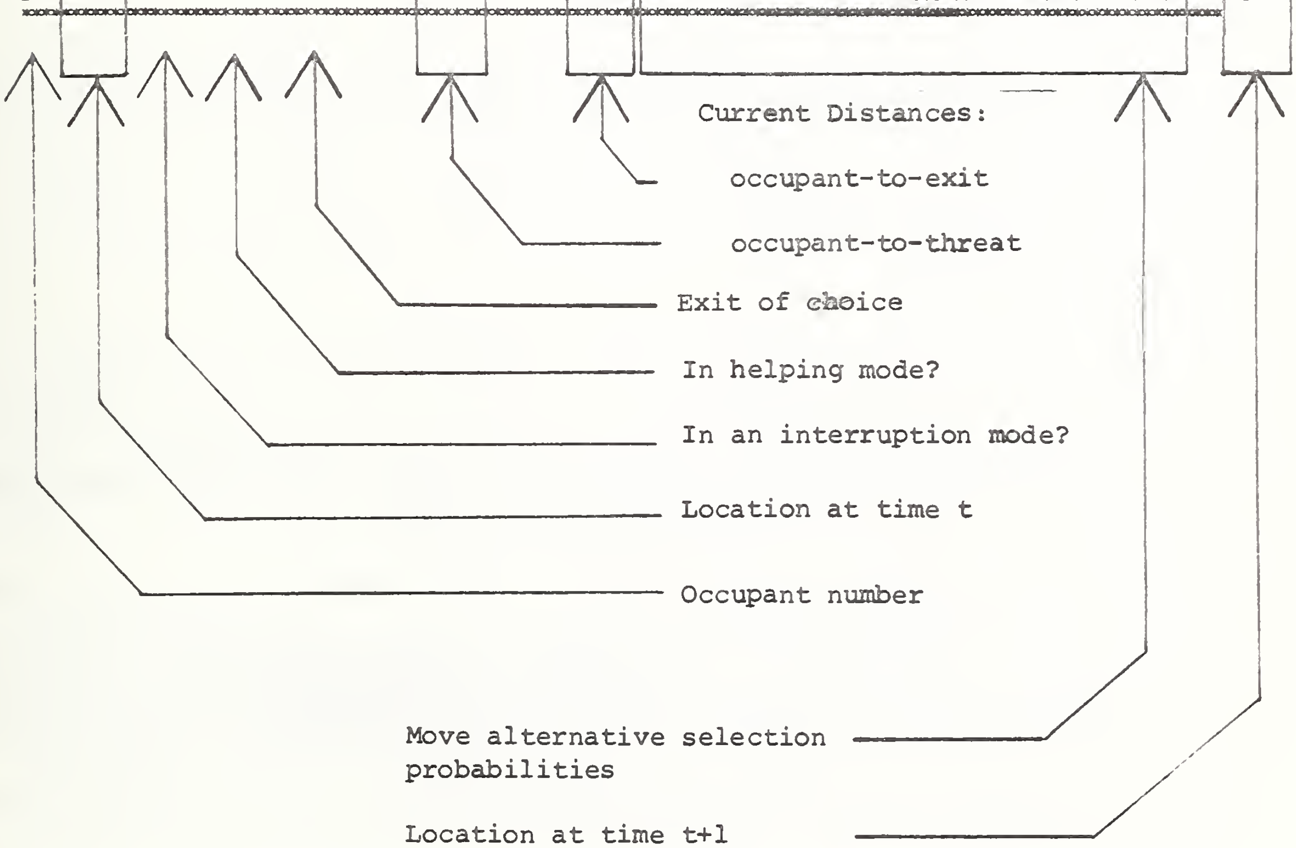


FIGURE 4.2 Output from Subroutine REPORT

OCCUPANT NUMBER: 7

TIME FRAME	X	Y
1	14	2
2	14	4
3	14	2
4	14	2
5	14	4
6	14	2
7	14	4
8	12	4
9	12	4
10	10	4
11	10	6
12	10	6
13	10	4
14	10	2
15	10	2
16	10	2
17	10	2
18	10	2
19	10	4
20	10	6
21	10	6
22	10	4
23	12	4
24	12	4
25	14	4
26	14	2
27	14	4
28	14	4
29	14	4
30	12	4

The figure indicates x,y coordinates locating an exemplary occupant in space, as this location changes from time-frame to time-frame. This sample simulation was run for a period of 30 time-frames (150-300 seconds of real time)

FIGURE 4.3 Output from Subroutine TRACE

OCCUPANTS INTERRUPTION TOTALS:

REPORTS TOTAL NUMBER OF FRAMES SPENT IN MODES

INTRPT TYPE	OCCUPANT 1	2	3	4	5	6	7	8	
1	0	4	2	4	5	5	5	2	Int. Mode #1: remain in place
2	12	0	0	0	5	2	11	14	Int. Mode #2: backtracking

DOOR PASSAGE TOTALS

OCCUPANT 1	2	3	4	5	6	7	8	
2	2	7	2	12	5	9	4	Actual number of passages/occupant

END OF TOTALS

END OF RUN

FIGURE 4.4 Output from Subroutine TOTALS

5. DIRECTIONS FOR FURTHER STUDY

Both short and long range objectives for research, development, and implementation derive from the simulation effort accomplished thus far. In the short range these primarily relate to the heuristic values the simulation development exercise, namely the use of such an exercise to identify literatures and data bases, and to generate researchable questions and issues. Longer range problems (outside the scope of this report), concern the matters of calibrating and validating the BFIRES program, and of implementing it as a building design and regulatory tool.

5.1 The Simulation Exercise as an Identifier of Literatures and Data Bases

In Section 2.2 of this report, the BFIRES program was described as a "skeletal" simulation device. This term was used to suggest that the program expressed a certain core process, even though very little data may actually be available to elaborate that process. Accordingly, the function of the skeleton is to provide a framework for: (1) conceptualizing the problem, (2) hypothesizing relationships among important variables, (3) exposing critical questions which must be addressed in the field, and (4) identifying literatures and data bases which could eventually be tapped.

Focusing on this last point, there are two important objectives of literature and data base identification. First, literatures as yet untapped may be useful in "filling out" (and/or modifying) the initial skeletal program. In terms of program development and expansion, in fact, the application of existing literatures and data bases is an essential first step, preceding the design and conduct of new empirical research.

The second objective of literature and data base identification recognizes the current low level of knowledge in the fire field concerning issues of human response. Namely, even in the absence of a well calibrated or validated simulation program, the exercise of developing such a program exposes literatures expected to be of utility throughout the problem area. Accordingly, the exercise yields an "agenda" of literature review and data base evaluation studies which should be undertaken as precursors to a wide variety of empirical investigations on human behavior in fires.

This report has emphasized the need to consider building fires as complex events which involve interactions between pyrological phenomena, building design and layout, and human response. In this section, literatures concerning the latter two areas shall be treated. This presentation is not intended as a literature survey, review, or critique. Rather, it is offered as a "shopping list" for eventual use in enriching (1) the simulation program, and (2) the current state of knowledge about human behavior in fires. For the most part, the literatures were identified during specific conceptual and program development tasks. Consequently, the direction of literature search may appear somewhat biased toward the general modeling route actually followed.

As a result of the investigation thus far, five superordinate and interrelated categories of literature seem relevant to, and necessary for the expansion of knowledge relative to human behavior in fires. These are the literatures of (1) environmental psychology, (2) cognitive psychology, (3) stress, decision, and judgment under uncertainty, (4) experimental social psychology, and (5) personality psychology. Let us consider the salient aspects of these.

5.1.1 Environmental Psychology

Environmental psychology is a relatively young branch of behavioral science, and it may be considered to combine important aspects of many other branches. It is chiefly concerned with interrelationships between people and the "designed" environment. During its brief history, several schools of thought have developed, leading to a variety of theoretical approaches to the study of person-environment relationships. In the most general terms, person-environment models will be found to stem from psychoanalytic, behavioristic, cognitive-developmental, and transactional foundations.

The BFIRES program embodies various assumptions about the ways building occupants gather information from their physical environment, how they utilize this information, and how they gather additional information through social encounters. A useful point of departure for explicating these assumptions will involve a detailed review of the cognitive and transactional orientations in environmental psychology (Proshansky, et al., 1970, 1976; Ittelson, 1973; Ittleson, et al., 1974).

A positive aspect of research in cognitive and transactional environmental psychology is its utilization of field-based methods, in which the observation of "real world" behaviors in their "real world" settings is heavily stressed. This has resulted in research efforts which have been largely situation-specific, and frequently with a view toward situational - rather than general - theory development. Unfortunately, the array of situations and settings of interest to workers in this area has excluded the special problems of building-scale emergencies.

However, useful perspectives on the subjects of environmental stressors, environmental "pathology", and environment-information overload has begun to emerge from intensive investigation of non-emergency settings. In particular, one should note the work of Saegert (1975) on the effects of crowding and information overload on behavior in and responses to environments; Saegert (1976) on the stress inducing and reducing qualities of environments; and Cohen (1975) on the effects of environment-information overload upon information gathering and processing.

Unfortunately, the remaining literatures do not have as a central theme the "designed" environment. Nevertheless, they may provide enormously rich data bases on psychological processes which operate during building fires.

5.1.2 Cognitive Psychology

The branch of cognitive psychology generally deals with the study of central processes, including thinking, decision-making, and problem solving. Although very recent work in environmental cognition will be found relevant and useful to the special problems of emergency environments, the environmental researchers have not as yet produced a data base sufficient for immediate application. A thorough review of several "traditional" concerns of cognitive psychology is therefore recommended.

Although this field is quite diverse, the simulation effort has suggested a relatively narrow range for focused attention. Reviews of the following specific literatures should prove useful in developing research which explicates the problems of human behavior in building fires, and of simulating such behavior.

Computing machine -- brain function analogy. Perhaps the line between computers as replicators of overt human behavior and computers as models of human brain function is a very fine one. However, the differences have been the source of considerable argument within cognitive psychology, and are relevant to our immediate objectives. Although many details of this dichotomy need not concern us here, it is important to distinguish between the computer simulation of behavior, and artificial intelligence.

Strictly speaking, the computer simulation of behavior requires that complex theories of behavior be faithfully translated, at every level of detail, into computer programs. Equipped with such programs, then, a computer may be thought of as "behaving" as a person would (assuming the validity of the theories written into the programs). The BFIRES program is an example in this direction. As an alternative to building theoretical propositions into computer algorithms, firsthand data about the behavior of actual people is often available and may be utilized. The work of Simon, (1969), Newell, Simon and Shaw, (1965), and Loftus and Loftus (1976) exemplify this general approach, and would form an appropriate basis for literature review.

In contrast, the term artificial intelligence implies that machines can be programmed or equipped to imitate the overt behavior of persons, although no attempts may have been made to simulate those inner processes which result in the overt behavior. This approach has been commonly employed in the automation of industrial processes, where it is necessary to replicate the mechanical task performance of human workers, and where there is little or no need to simulate all the mental processes involved. More recently, unmanned space travel has provided other important examples. In these cases, computing machines are frequently called upon to process information, make judgments or decisions, and to perform various tasks in ways which are most reliable and efficient -- and not necessarily similar to the ways these tasks are performed by humans. The area of artificial intelligence has been explored in great detail by Boden (1977), who has provided an exhaustive review of the literature. Additional perspectives have been offered by Raser (1969) and Dutton and Starbuck (1971).

To the extent that computer methods will be applied to the study of human behavior in fires, it will be important to deal with the dichotomy described above. If our only concern, for example, is to produce machine-generated fire outcomes which imitate those of actual fires, then there need be no search for knowledge on psychological, social, and environmental processes believed to produce or influence those outcomes. However, if we require the facility to examine the ways people internally deal with the fire event as it unfolds, or to test the effects of variations in person-based factors, then it will be necessary to simulate those human psychological processes believed to operate during fires.

The application of artificial intelligence to fire research, therefore, is likely to be limited to those problems in which we want to evaluate physical design influences only. On the other hand, since behavior-simulation focuses directly upon cognitive processes, use of this form of computer application should permit the evaluation of such human-centered influences as level of training, familiarity with the environment, organizational responsibility, etc.

Information processing. The problem of computer-brain analogy, and the use of computer programs to model human cognitive functioning center primarily about information processing theories of cognition. Primary issues in information processing concern (a) perception and information gathering, (b) the mediation or "filtering" of selected stimuli in the environment, (c) the retention of information in short and long term memory, (d) the formulation and use of action strategies, and (e) the evaluation of goal-directed actions. Chapters 2 and 3 of this report have emphasized the importance of such issues in the development of BFIRES. In addition to literature cited earlier in the report, future reviews of this area should emphasize investigations of information retention, recall and application (e.g., Loftus and Loftus, 1976; Atkinson and Shiffrin, 1968, 1971), sensory-cognitive interaction (Palmer, 1975), and information integration (Garner, 1974).

Problem solving. Various aspects of human problem solving are relevant to the problems of occupants' emergency behavior. The BFIRES program itself embodies certain assumptions about the ways people respond to problems they confront in the emergency environment.

Eisenstadt and Kareev (1975) have identified several key components of human problem solving activity, including: (a) scanning behavior (exploratory searching, hypothesis testing, information-checking);

(b) searching through the problem space (state assessment, assessments relative to past and future states, pattern extraction from repetitive events); (c) previewing or planning ahead; (d) action selection (selections which involve extensive previewing, versus "blitz planning" in which little or no previewing is involved); (e) backing up (consideration of new alternatives after a particular strategy has been embarked upon).

5.1.3 Stress, Decision, and Judgment under Uncertainty

Another important product of the simulation exercise has been its emphasis on the need to integrate the influence of stress with decision-making, when studying human behavior in fires. Several references to environmental stress research were cited in Section 5.1.1. In addition, the comprehensive experimental review by Broadbent (1971) provides useful insight into the problems of stimulus detection, arousal, responsiveness, vigilance, selective perception, decision speed, and interaction effects among diverse stressors.

The literature on judgment under uncertainty should also prove useful. Tversky and Kahneman (1974), for example, studied decision-making strategies and dependence upon biases and heuristic devices under conditions of uncertainty.

5.1.4 Experimental Social Psychology

Social processes are believed to be highly relevant to the problem of emergency behavior. Various fire investigations have emphasized this point by reference to actual data (e.g., Wood, 1972, and Bryan, 1977), and certain assumptions about interpersonal behavior were written into BFIRES. The literature and data base in experimental social psychology are quite extensive, and only small segments of these may be referenced here. Future investigators may find the data from the following areas useful in research on human emergency behavior.

In the vast majority of cases, fire will be a uniquely novel experience -- and will provide a uniquely novel environment -- for building occupants. Consequently, it should not be assumed that individuals will have specific adaptive response protocols in mind for immediate application. It is much more likely that each individual will pick up certain cues provided by other persons in the immediate vicinity, and that some form of social learning or vicarious imitation will occur (Miller and Dollard, 1941; Bandura, 1962; Bandura and Walters, 1963).

During a fire emergency, social exchanges may play a key role in the development of effective behavioral response patterns. These exchanges extend far beyond processes of information transmission, to include social reinforcement of one's actions. Homans (1961) and Thibaut and Kelley (1959), for example, postulated that social relationships will continue only as long as the parties involved receive certain benefits from them. Adams and Romney (1959), (1959), on the other hand, found that relationships depend upon the reciprocal reinforcement between people in control and those being controlled. The literature on social-reinforcement exchange would seem highly salient to problems of drills and training plans, evacuation leadership, vocal evacuation systems, and emergency social organization (Dynes and Quarantelli, 1968).

Of further relevance to these problems is the literature on social power. French (1956) and French and Raven (1959), for example, were concerned with those small-group processes which lead to opinion change, and through which certain individuals are "influenced" by the actions of others. These investigators suggested a three-dimensional model of social influence, which involved power patterns, communications patterns, and opinion patterns in the group.

Other salient areas within experimental social psychology which would be worth tapping include: (a) investigations of cooperation and competition (e.g., Deutch, 1949; Grossack, 1954; Gottheil, 1955; Shaw, 1958), (b) the literature on cognitive explanations of social processes (Bruner, 1957; Newell, Simon and Shaw, 1958), and (c) motivational aspects of social behavior (Krech and Crutchfield, 1948).

5.1.5 Personality Psychology.

It would be difficult to develop a design or regulatory tool of general utility if it were based to a significant degree upon individual differences among building occupants. However, where such differences, traits, or characteristics are found to be important, it will be necessary to construct broad-based tools on the basis of well defined distributions. Consequently, a review of individual, or personality psychology is recommended, through which those traits expected to correlate highly with social behavior, environmental response, and decision making under stress can be identified and investigated.

5.2 The Simulation Exercise as a Generator of Researchable Questions

An important value of the simulation development process is its function as an illuminator not only of complex phenomena, but of means for studying them as well. The development of the BFIRES program has already begun to spawn a variety of questions concerning both the explanation and study of human movement behavior during building fires. Certainly, many of the questions introduced below may be asked with specific reference to BFIRES. Indeed, future tasks involving the calibration and validation of this program shall endeavor to address these. The ultimate objective here, however, is to identify questions applicable across a much wider spectrum of research on human behavior in fires.

5.2.1 The Explanation of Occupant Behavior in Fires

Several fundamental questions concerning the need to explain human behavior in fires, and the use of certain models for doing so, will need to be addressed relatively early. The first question is, logically, why develop explanatory models at all? A model-based system for building design and regulation might appear to some individuals as a "given." However, the actual traditions in the fire field have been somewhat different. Namely, new concepts in life safety design have tended to stem from the piecemeal analysis of individual disasters. Although the actual success of the traditional approach may be indeterminate (after all, there is no basis for comparison), there are currently no data available to suggest that a model-based orientation would significantly improve life safety statistics.

To a very real extent, the current investigation represents an attempt to establish the credibility of the model-based approach, and to identify potential values added by it to life safety design and regulation. Additional questions, then, concern the appropriateness of specific models or theoretical orientations. If we wish, for example, to model ongoing human behavioral processes, is the Markov model the most appropriate basis? Moreover, are algorithmic models appropriate for simulating human cognitive functions, or should other, more heuristic alternatives be employed? These questions will require intensive, short range consideration.

Other issues concern the functional and behavioral bases for writing computer simulation programs. In BFIRES, for example, the behavior of the computer is guided largely by loosely constructed theoretical statements and hypotheses about the ways real people would behave under certain circumstances. A very different approach, however, would be to collect massive amounts of empirical data, and then to translate these into simulation scenarios and computer programs. Each approach carries its own implications for research and application: Theory- or model-based simulations may tend to overemphasize occupants' internal cognitive and behavioral processes (rendering the achievement of design and regulatory goals less direct); the data-based simulations may be limited to replicating only gross outcomes of historical fires (making it difficult to assess psychologically-based solutions to life safety problems).

Where the modeling of human behavior in fires is thought desirable, and where computer simulation seems an appropriate technique, questions of scale and system boundaries become salient. It will be necessary to determine the comparative value of general models of human behavior in fires (of which BFIRES is an example) with respect to those which are more situation-specific (focusing on the specialized problems of, say, a single building type). For which classes of problems are each of these directions most appropriate? What forms of modeling and simulation strategy are most effective for each case? What are the relative costs?

Finally, with respect to BFIRES itself, important research problems emerge concerning the appropriateness of assumptions and literatures built into the program, and of variables actually selected for study. These were described in considerable detail in Chapters 2 and 3 of this report, and questions relating to their appropriateness, correctness, etc., will only be answered through the conduct of external validation studies which test the ability of BFIRES to simulate real-world events and behaviors. The entire area of external validation lies outside the current scope. However, if we consider BFIRES to be a composite of interconnected hypotheses, then both the overall model - and the individual hypotheses - are available for immediate empirical analysis in the field. Future developments in the computer simulation of human behavior in fires will depend upon both empirical analysis of the antecedent hypotheses, and on concurrent efforts to externally validate the simulations.

5.2.2 Methods for Investigating Human Behavior in Fires

Although computer simulation is itself one approach to investigating behavior in fires, the simulation exercise underscores certain key problems associated with other (critically interrelated) forms of research in this area. In particular, if future simulation research and applications will require empirically derived inputs, then considerable attention will be required to assure the validity and utility of any data actually obtained. Problems peculiar to the empirical investigation of human behavior in fires have already been enumerated and discussed in great detail by Stahl and Archea (1977), who also identified potentially useful investigatory strategies.

6. SUMMARY

The conceptual development, structure, and function of BFIRES, a computer program designed to simulate human movement behavior during building fires, have been presented. The technical approach leading to the development of BFIRES has involved both theoretical model-building, and computer simulation programming.

The basic model underlying BFIRES is derived from a non-stationary, discrete time Markov process. Essentially, the model postulates that human occupants construct their emergency responses and behavioral decisions on the basis of socially- and environmentally-based information, both of which continually change over time. As the information field changes, so does the basis for individual emergency decision-making. The simulation of this process has been effectuated through BFIRES, a computer program written in FORTRAN-V and currently operational at the Center for Building Technology, National Bureau of Standards.

The specific functions, structures, and underlying assumptions of BFIRES were thoroughly treated in this report. The basic components of the program include mechanisms for initializing simulation experiments, algorithms for simulating human perceptual and cognitive processes, and routines for overall system operations and data accounting.

Finally, directions for further study were discussed. Recommendations for future research chiefly involved reviews of literatures and data bases identified during the simulation development exercise, and empirical research efforts designed to address certain simulation-derived questions about human behavior in fires.

REFERENCES

Adams, J.S. and Romney, A.K. A functional analysis of authority. Psych. review, 1959, 66, 234-251.

Apter, M.J. The computer simulation of human behavior. New York: Harper Colophon Books, 1970.

Atkinson, R.C. and Shiffrin, R.M. Human memory: a proposed system and its control processes. In Spence, K.W. and Spence, J.T. (Eds.), The psychology of learning and motivation: advances in research and theory, Vol. 2. New York: Academic Press, 1968.

Atkinson, R.C. and Shiffrin, R.M. The control of short-term memory. Scientific American, 1971, 225, 82-90.

Baer, A.E. A simulation model of multidirectional pedestrian movement within physically bounded environments. Pittsburgh, Pa.: Carnegie-Mellon Univ., Inst. of Physical Planning, Report #74, June 1974.

Bandura, A. Social learning through imitation. In M.R. Jones (Ed.), Nebraska symposium of motivation: 1962. Lincoln: Univ. of Nebraska Press, 1962, 211-269.

Bandura, A. and Walters, R. Social learning and personality development. New York: Holt, Rinehart and Winston, 1963.

Boden, M.A. Artificial intelligence and natural man. New York: Basic Books, 1977.

Breaux, J. Personal communications. Fire Research Unit, University of Surrey (U.K.), 1977.

Broadbent, D.E. Decision and stress. London: Academic Press, 1971.

Bruner, J.S. On perceptual readiness. Psych. review, 1958, 65, 151-156.

Brunswick, E. Perception and the representative design of psychological experiments. Berkely and Los Angeles: Univ. of California Press, 1956.

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.

Caravaty, R.D. and Haviland, D.S. Life safety from fire: a guide for housing the elderly. Troy, N.Y.: Rensselaer Polythehnic Institute, 1967.

Cohen, S. Environmental load and the allocation of attention. Unpubl. ms., University of Oregon, 1975.

Connelly, E.M. Personal communications. Vienna, Va., 1977.

Deutch, M. A theory of cooperation and competition. Human relations, 1949, 2, 129-152.

Downs, R.M. and Stea, D. Image and environment: cognitive mapping and spatial behavior. Chicago: Aldine, 1973.

Dutton, J.M. and Starbuck, W.H. Computer simulation of human behavior. New York: John Wilen and Sons, 1971.

Dynes, R. and Quarantelli, E. Group behavior under stress. Sociology and social research, 1968, 52, 4, 416-429.

Edmondo, P.M., Hahin, R. and Sinay, J.P. Emergency egress from ships' compartments, Phase II: a systems analysis. Annapolis, Md.: Naval Ship R&D Laboratory, Electrical Laboratory, Report #3203, Nov 1969.

Eisenstadt, M. and Kareev, Y. Aspects of human problem solving: the use of internal representations. In Norman, D.A. and Rumelhart, D.E. (Ed,), Explorations in cognition. San Francisco: W.H. Freeman, 1975, pp. 308-346.

Feldman, J. Computer simulation of cognitive behavior. In Borko, H. (Ed.), Computer applications in the behavioral sciences. Engelwood Cliffs, N.J.: Prentice-Hall, 1962.

French, J.R.P.,Jr. A formal theory of social power. Psych. review, 1956, 63, 181-194.

French, J.R.P.,Jr. and Raven, B. The bases of social power. In Cartwright, D. (Ed.), Studies in social power. Ann Arbor: Inst. for Social Reasearch, 1959, pp. 150-167.

Garner, W.R. The processing of information and structure. Potomac, Md.: Erlbaum Associates, 1974.

Gottheil, E. Changes in social perceptions contingent upon competing or cooperating. Sociometry, 1955, 18, 132-137.

Grossack, M.M. Some effects of cooperation and competition upon small group processes. Journal of abnormal social psychology, 1954, 49, 341-348.

Henderson, L.F. The statistics of crowd fluids. Nature, 229, 1971, 229, 381-383.

Homans, G.C. Social behavior: its elementary forms. Harcourt, Brace, 1961.

Howard, R.A. Dynamic probabilistic systems, Vol. 2: Markov Processes. New York: John Wiley and Sons, 1971.

Ittelson, W.H. Environment and cognition. New York: Academic Press, 1973.

Ittelson, W.H., Proshansky, H.M., Rivlin, L.G. and Winkel, G.H. An introduction to environmental psychology. New York: Holt, Rinehart and Winston, 1974.

Kemeny, J.G. and Snell, J. Mathematical models in the social sciences. Cambridge, Ma.: M.I.T. Press, 1972.

Korkemaz, P.N. A discrete event simulation of a burning occupied building. Unpubl. masters thesis, Univ. of Notre Dame, 1977.

Krech, D. and Crutchfield, R.S. Theory and problems of social psychology. New York: McGraw-Hill, 1948.

Krystiniak, J.A. A stochastic simulation of horizontal pedestrian circulation in buildings. Unpubl. masters thesis, the Penn. State Univ., 1972.

Latane, B. and Darley, J.M. Unreponsive bystander: why doesn't he help? New York: Appleton, Century, Crofts, 1970.

Loftus, G.R. and Loftus, E.F. Human memory: the processing of information. Hillsdale, N.J.: Erlbaum Associates, 1976.

Lozar, R.C. A methodology for the computer simulation of behavior-environment interactions in dining halls. In Carson, D.H. (Gen. Ed.) and Bazjanac, V. (Ed.), Man-environment interactions, Part 10: Computers and Architecture. Stroudsburg, Pa.: Dowden, Hutchinson and Ross, 1974, pp. 211-234.

Luce, R.D. and Raiffa, H. Games and decisions. In Shubik, M. (Ed.), Game theory and related approaches to social behavior. New York: John Wiley, 1964.

Miller, N.E. and Dollard, J. Social learning and imitation. New Haven: Yale Univ. Press, 1941.

Moore, G.T. and Golledge, R.G. Environmental knowing: theories, research and methods. Stroudsburg, Pa.: Dowden, Hutchinson and Ross, 1976.

Neisser, U. The immitation of man by machine. Science, 1963, 139, 193-197.

Nelson, H.E. Personal communications, National Bureau of Standards, 1976.

Newell, A., Simon H.A. and Shaw, J.C. Elements of a theory of human problem solving. Psych. review, 1958, 65, 151-156.

Palmer, S.E. Visual perception and world knowledge: notes on a model of sensory-cognition interaction. In Norman, D.A. and Rumelhart, D.E. (Eds.), Explorations in cognition. San Francisco: W.H. Freeman, 1975, pp. 279-307.

Peschl, I.A.S.Z. Passage capacity of door openings in panic situations. Bowen (Construction), January 9, 1971, 2, 62-67.

Proshansky, H.M., Ittleson, W.H. and Rivlin, L. (Eds.), Environmental psychology. New York: Holt, Rinehart and Winston, 1970.

Proshansky, H.M., Ittelson, W.H. and Rivlin, L. (Eds.), Environmental psychology, Second Edition. New York: Holt, Rinehart and Winston, 1976.

Raser, J.R. Simulation and society. Boston: Allyn and Bacon, 1969.

Saegert, S. Special issue on environment and crowding. Environment and behavior, 1975, 7.

Saegert, S. Stress inducing and reducing qualities of environments. In Proshansky, et al. (Eds.), Environmental Psychology, 2nd Edition. New York: Holt, Rinehart and Winston, 1976, pp. 218-223.

Shaw, M.E. Some motivational factors in cooperation and competition. Journal of personality, 1958, 26, 155-169.

Shultz, R.L. The use of simulation for decision making. Behavioral science, 1974, 19, 5, 344-350.

Simon, H.AS. Motivational and emotional controls of cognition. Psych. review, 1967, 74, 29-39.

Simon, H.A. The sciences of the artificial. Cambridge, Ma.: M.I.T. Press, 1969.

Sinay, J.P. Unpub. computer program. Annapolis, Md.: Naval Ship R&D Laboratory, 1971.

Stahl, F.I. Simulating human behavior in high-rise building fires: modeling occupant movement through a fire-floor from initial alert to safe egress. Washington, D.C.: U.S. Dept. of Commerce, National Bureau of Standards, NBS GCR 77-92, 1975 (a).

Stahl, F.I. Behavior-based fire safety performance criteria for tall buildings. Unpubl. ms. presented at E.D.R.A.-6, Univ. of Kansas, Lawrence, Ks., April 1975 (b).

Stahl, F.I. Some factors influencing human repsonses in building fires: exploratory and experimental approaches. Unpubl. ms., The City University of New York, Environmental Psychology Program, 1975 (c).

Stahl, F.I. Some prospects for simulating human behavior in high-rise building fires: a pilot demonstration. In Suedfeld, P. and Russell, J. (Eds.), The behavioral basis of design, Book 1. Stroudsburg, Pa.: Dowden, Hutchinson and Ross, 1976, pp. 211-218.

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.

Studer, R.G. and Hobson, R.H. Simulation of human learning in urban movement systems. In Preiser, W.F.E. (Ed.), Environmental design research, Vol. 2. Stroudsburg, Pa.: Dowden, Hutchinson and Ross, 1973.

Thibaut, J.W. and Kelley, H.H. The social psychology of groups. New York: John Wiley and Sons, 1959.

Tversky, A. and Kahneman, D. Judgment under uncertainty: heuristics and biases. Science, 1974, 185, 1124-1131.

Wolpert, J. and Zillmann, D. The sequential expansion of a decision model in a spatial context. Environment and planning, 1969, 1, 91-104.

APPENDIX A: A MARKOVIAN ANALYSIS OF HUMAN BEHAVIOR IN FIRES

A.1 A Markovian Analysis of the Problem

The model suggested here is offered as a hypothetical description of human movement behavior in response to life-threatening stimuli within the boundaries of a single building floor. In simplest terms, the model permits the description of individual and group decision-making and movement behavior in a spatial field defined in terms of various kinds of information. For all practical purposes, we shall take the final "goal" of egress movement behavior as the point of entry into a stair or other perdefined refuge zone.

From here on, we are concerned with the argument that movement behavior of the kind described above is approximated by a form of Markov process. The Markov process (or Markov "chain", or "model") is a probabilistic model, said to be useful in analyzing complex systems (Howard, 1971; Kemeny and Snell, 1972). The principal compenents of Markov models are states (specifications of parameters which describe a system at any point in time and space), and state transitions (incremental movements of the system from its present state to the next future state). The fundamental Markov assumption specifies that only the present state of the process is releveant in determining its future behavior. Accordingly, the probability of making a particular state transition depends only on the specification of parameters defining the most recent position.

As a result, Markov processes have been referred to as "memoryless". However, it can be said that the present state of a system is the cumulative result of the system's "history", and that this state can be thought of as containing this history (e.g., the case of transmitting genetic information between generations).

Between any two contiguous point in time, there may be any number of alternative states to which a system could move. Each of the alternatives possesses a certain probability of selection, and at any point in time, the probabilities of each of the alternative state transitions sum to unity. Accordingly, Markov processes are probabilistic, or stochastic models, and state-transition is a stochastic variable.

Our concern is with the conceptualization of building fire systems as Markov processes. If we consider the fire system to consist of fire, building, and human components, then we can surely think of these components as undergoing various forms of change over time: The fire itself goes through various pyrological stages, and it may expand or contract; portions of the building may undergo structural changes, and various spaces may cease to permit occupancy; people may move about through the spaces of the structure, and their movement patterns may show distinct patterns over time. When we think of the entire fire system as moving from state to state over time, we are actually dealing with the complex interactions between system components, and the complex combinations of alternative states which could conceivably be selected at any given instant.

We shall focus, at present, on the human component of the building fire system - the occupants of a building under fire conditions. Even more specifically, we shall focus upon occupants' egress movement in space, in response to social and environmental stimuli which continuously change over time.

In Markovian terms, we shall consider an occupant's displacement from one point in space to another as part of a state transition. The collection of all occupants' spatial displacements during a given increment of time shall be taken as a complete state transition.

Accordingly, if a person occupies location i at time t, then at time t+1 he shall have moved to location j (unless, of course, he had decided to remain in place). Moreover, he will have had to select his next location from among some range of choices. For each occupant in the fire, spatial displacement ("move") alternatives may be assigned probability values, and these may be unique to, and determined by, the conditions which define the system at time t. That is to say, under certain social and/or environmental conditions, a particular move alternative may appear quite attractive, and hence be highly weighted. Under other conditions, the same move might be perceived as highly threatening, and hence be assigned a very low probability of selection.

At this point, it is necessary to introduce another Markov property into the discussion: stationarity. We distinguish between "stationary" and "non-stationary" Markov processes such that:

For the case of stationary processes, state-transition probabilities are not dependent upon time. Therefore, a single matrix of transition probabilities may be specified a priori, and this matrix entirely defines the Markov process over all time-frames (refer to Figure A.1).

In non-stationary models, transition probabilities are time-dependent, implying the existence of a different transition matrix for each time-frame, and further implying that the process may not necessarily be a priori definable beyond the first time frame (i.e., the outcomes from the first time-frame, t, determine outcome probabilities for frame t+1, etc.). Refer to Figure A.2.

The distinction between stationary and nonstationary processes is extremely relevant to the application of a Markov modeling strategy to the fire problem. Let us contrast the work of Breaux (1977), who offers a stationary explanation, with that of Stahl (1975a; 1976) and Nelson (1976), whose preliminary conceptualizations suggested the need for a time-dependent (non-stationary) approach:

Breaux conducted intensive interviews after a hotel fire in England. Using an open-ended interview format, he elicited information from victims concerning what they did during the fire. In reviewing his data, Breaux found that many actions were reported by more than one victim, and that in many instances, occupants reported having chosen particular actions from among certain alternatives. He referred to these choices as "degrees of freedom", and noticed that in certain cases occupants may have perceived alternatives which were physically unavailable -- and vice versa. He also hypothesized a linkage between egress success, and the availability of action alternatives (degrees of freedom) in the environment: If a person perceives a reduction in degrees of freedom as the severity of the fire increases, then he is less likely to escape than a person for whom at least a minimum number of alternatives had been available.

According to Breaux's analysis, a person's total fire experience may be defined in terms of particular actions taken along a discrete time scale. Accordingly, each action point is analogous to a Markovian 'state', and transitions between such states advance the individual's expeience through time. Where action choices exist, a probability of selection exists for each.

It should be possible then, to define the human behavorial aspects of a fire in a given building type (e.g., Breaux's "hotel") as a stationary Markov process, as follows: Assume that victims from a sufficiently large number of hotel fires were interviewed in detail about their actions, and about their perceptions of choices. Assume further that, except for minor sampling variations, actions and patterns of choice availability were consistent across the population of hotel fires. Then, based on the relative frequency of action choices actually made, the probability that a given choice will be made again under similar circumstances during a future hotel fine could be assigned. By assigning such values to all action alternatives along the time-line, the complete human behavioral system relative to hotel fires would be entirely defined by the single matrix of action-selection probabilities. The Markov process described by such a matrix is considered stationary, since all selection probabilities are predefined, irrespective of the actual time demands of a particular fire. Refer to Figure A.3.

The practical appeal of Breaux's approach lies in its single-statement, a priori description of a behavioral system: the action-selection probability matrix. Given such a matrix for, say, hotel fires, we could predict probabilistically the next action an occupant will take, on the basis of our knowledge of his immediately preceding action. Moreover, we could make such a prediction irrespective of the point in time at which the new action is being selected. Simply put, we need only know a person's action at time t, in order to predict his action at time t+1.

A.2 Factors Which Complicate the Analysis

As mentioned above, Breaux's application of the Markov methodology to the prediction of human behavior in building fires assumes that: (a) a large number of fires in a specific building type were intensively investigated, and (b) the behavioral outcomes and selection patterns were found to be relatively invariate across all the fires studied. The latter assumption must be true if the deduced selection-probability matrix is to be representative of the building type, and therefore potentially useful in the prediction of future fire outcomes relative to that type. If this assumption is false, then discrepancies between individual fire cases would yield probability matrices useful mainly as post-hoc descriptions of individual historical events.

However, available evidence on human behavior in fires makes the question of whether such behavior is describable by a stationary process, extremely difficult to answer. For example, when we consider actual case studies for which post incident data bases exist, the data may shed very little light on decision-making over time. While Wood, Bryan and others reconstructed action sequences from such data, these sequences illustrated only what people say they did; no attempts were made to elicit their perceptions of action alternatives (Breaux's "degrees of freedom") during various stages of the fire experience.

Moreover, various anecdotal accounts of building fires raise the question of whether consistency of outcomes across a large population of fires in a given building type should even be expected, at all. Such accounts often indicated that highly predictable and consistent patterns of occupant behavior may have been the exception, rather than the rule. This may be especially true in those occupancies where training is likely to be minimal, and where occupant vigilance is likely to be at rather low levels.

Finally, even a casual or intuitive consideration of fire development in a building causes us to question models which ignore the ways in which time-based changes in environmental information influence occupants' actions, and processes of action selection. We may well ask how occupants' perceptions of the threat-laden environment influence the likelihood that various actions will be selected, and how this influence changes as the environment is perceived to change over time?

Nelson (1976) attempted to deal with these questions, by means of a simple conceptual statement: both the behavior of the fire and that of building occupants should be thought of as advancing along two parallel, "communicating", time-lines. A "view" of the fire system at any discrete time frame (t), then, would include descriptions of both the human and fire components, as well as interactions between the two. A state transition of the entire system, from frame t to t+1, would be taken to encompass the transitions made by each component.

State transitions of the "fire" component, according to Nelson, could be readily described, a priori, e.g., ignition (at time t), "flash-over" (at time t+i), spread to first adjacent room (at time t+j), etc. However, the time spent by the fire in each state may be subject to wide variation.

Nelson further posited specific links between the two parallel time-lines; that is, the current state of the fire influences occupants' responses, and these actions in turn affect the physical state of the fire and architectural environment. Nelson's proposition is outlined in Figure A.4. Although fire states are seen as definable, a priori, Nelson's view allows the notion that upon perceiveing the fire in its current state, a person's actions derive from some mediated selection process, rather than from a purely deterministic relationship between the fire environment and occupant behavior. His view further permits the notion that occupants' action sequences, and their probabilities of occurrence, cannot be specified a priori; that sequences of actions built-up as a result of probabilistic events may render both actions and sequential patterns unique for particular fire situations. Unfortunately, Nelson never actually specified the nature of the linkage between occupant response and the fire environment.

A.3 An Expanded Markov Conceptualization

In an independent effort, I drew conclusions similar to those of Nelson on the basic interactive structure of building fire systems (Stahl, 1975a; 1975b; 1975c; 1976). That effort, however, was much more specifically directed toward the explication of human decision-making processes in life threatening environments. My review of the relevant literature at that time yielded the notion that a person's egress behavior during a fire emergency depends upon: (a) his perceptions of the location and severity of the threat; (b) his perceptions of available action alternatives; (c) his immediate experience with decision-making in the given situation (i.e., immediate success/failure history); (d) interruptions to goal-directed action he may have encountered (whether of cognitive, social, physiological, or environment origin); and (e) his level of long-term knowledge and experience (e.g., his familiarity with the building's egress routes, his previous participation in drill or training programs, etc.). Each of these factors were seen to undergo change over time, as changes in the environment implied changes in its perception, and as altered perceptions resulted in variations in the probability that an action choice might be selected at a given point in time.

An important outcome of those studies, then, was the idea that the probability values associated with the selection of action alternatives are not invariate (and should not, therefore, be predefined a priori). Rather, such probability values reflect current realities of the unique event under study, and are determined "on the spot" by the interactive network of system components which contribute changing streams of information about their states. This notion was seen as directly analogous to an information-processing approach to cognition in emergencies, in which persons consciously alter the weights they assign to action alternatives, as information regarding the utility of each changes.

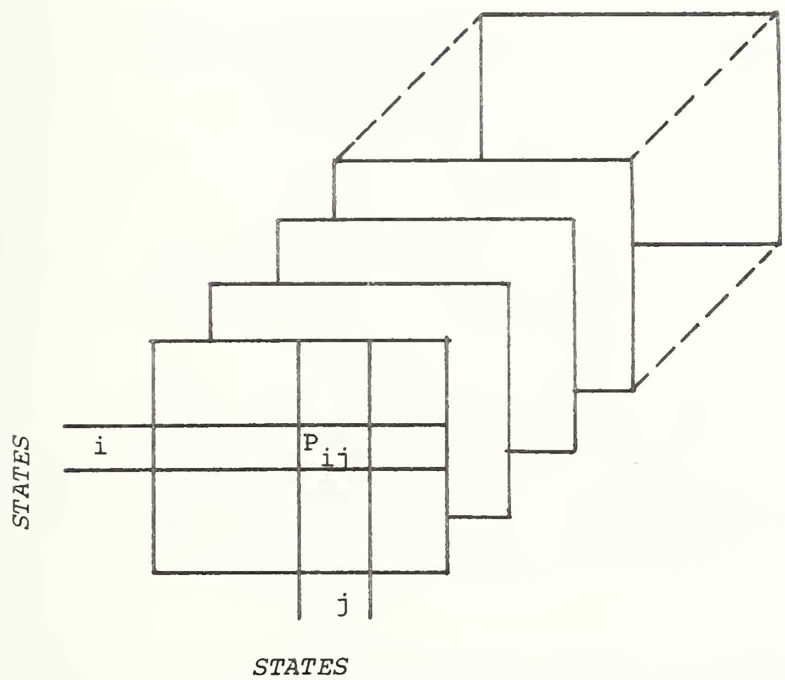
STATES

STATES

	1	2	3	4	....	n
1	P_{11}	P_{12}	P_{13}	P_{14}	....	P_{1n}
2	P_{21}	P_{22}	P_{23}	P_{24}	....	P_{2n}
3						P_{3n}
4				P_{44}		P_{4n}
. . .						
n						P_{nn}

where P_{ij} is the probability that a system in state i will move to state j, irrespective of time

FIGURE A.1 A Single Probability Matrix Describing a Stationary Markov Process



where P_{ij} is determined by parameters describing the state of the system at time t only

FIGURE A.2 A Set of Probability Matrices Describing a Non-Stationary Markov Process

STATES

STATES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. AWAKEN		1.0														
2. HEAR SHOUTING			0.7		0.3											
3. MISINTERPRET NOISE		0.5		0.5												
4. IGNORE NOISE		0.5								0.5						
5. CORRECTLY INTERPRET NOISE						0.8	0.2									
6. DRESS TO LEAVE BLDG.							1.0									
7. LEAVE BLDG. VIA EMERG. EXIT								0.5	0.5							
8. ASSIST IN RESCUE EFFORT									1.0							
9. DIAL 911								1.0								
10. SCAN ROOM											0.8	0.2				
11. DRESS TO INVESTIGATE														1.0		
12. OPEN DOOR													1.0			
13. CLOSE DOOR												0.5		0.5		
14. GO TO WINDOW															1.0	
15. OPEN WINDOW																1.0
16. WAIT TO BE RESCUED																

The matrix is read horizontally. Horizontal P-values sum to 1.0
State-names are from Breaux, 1977, personal communication.
P-values are exemplary, and not based on specific data.

FIGURE A.3 Breaux's Hotel Fire as a Stationary Markov Process

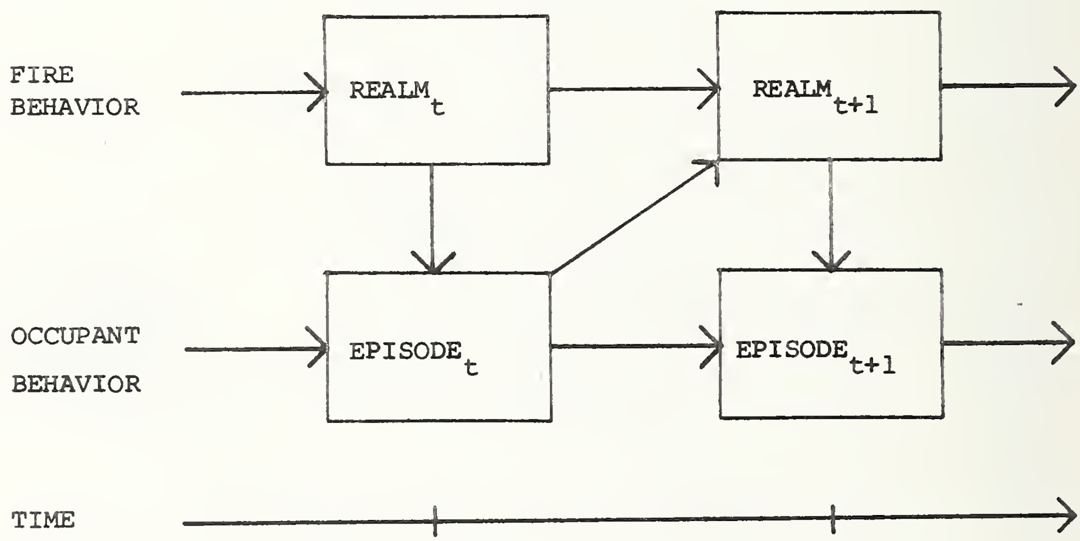
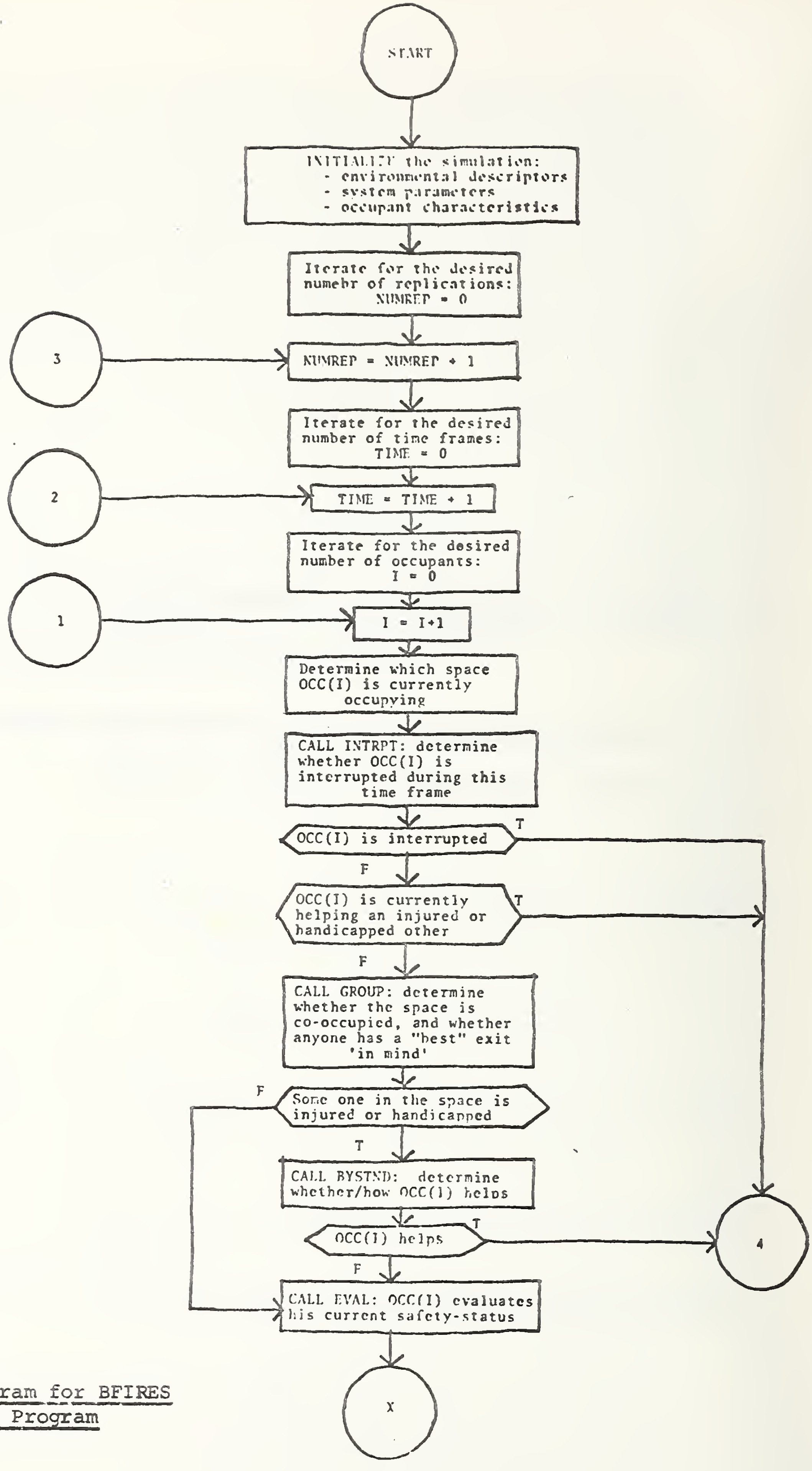
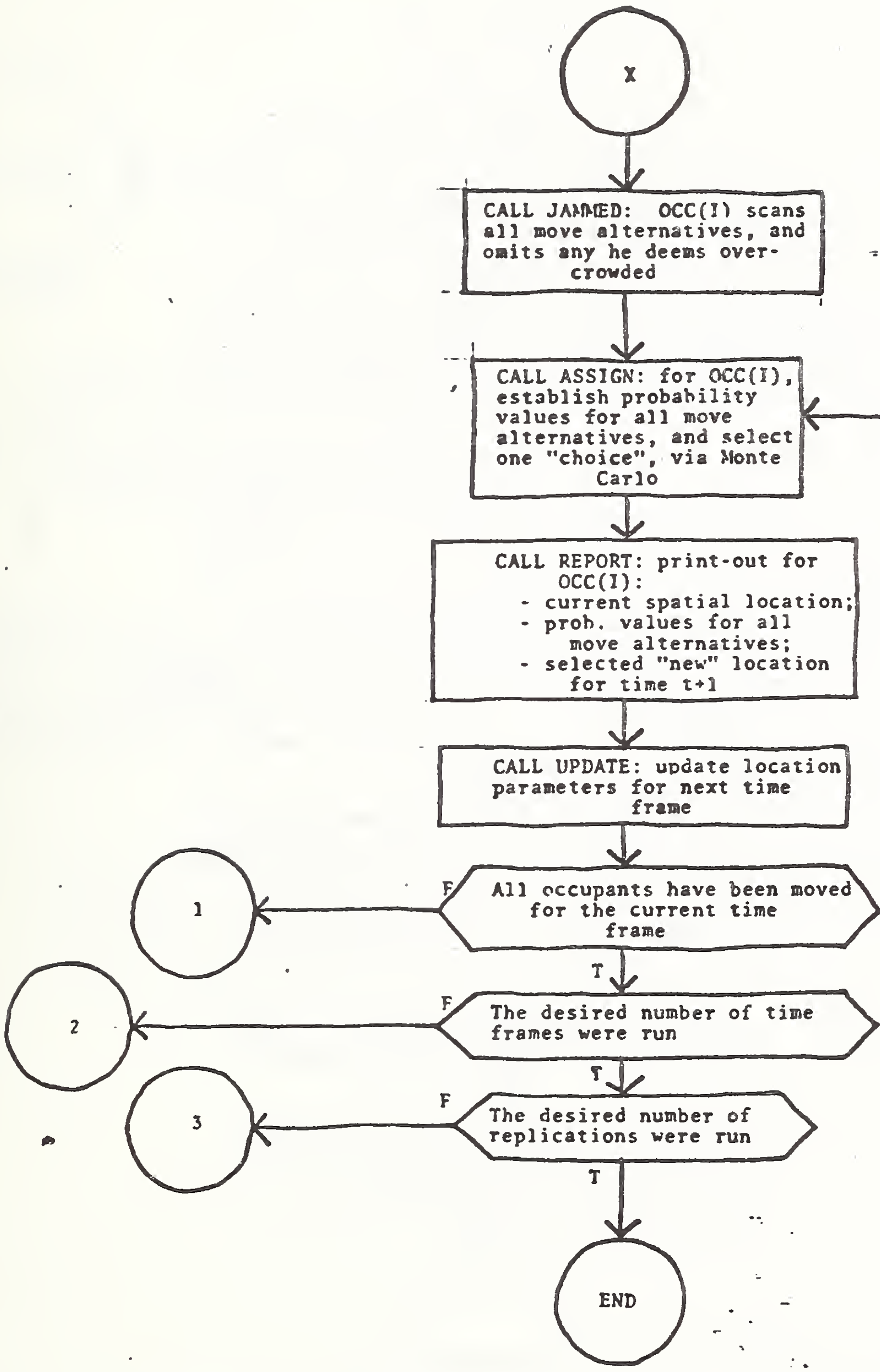


FIGURE A.4 Nelson's "State-Transition" Model of the Building Fire System

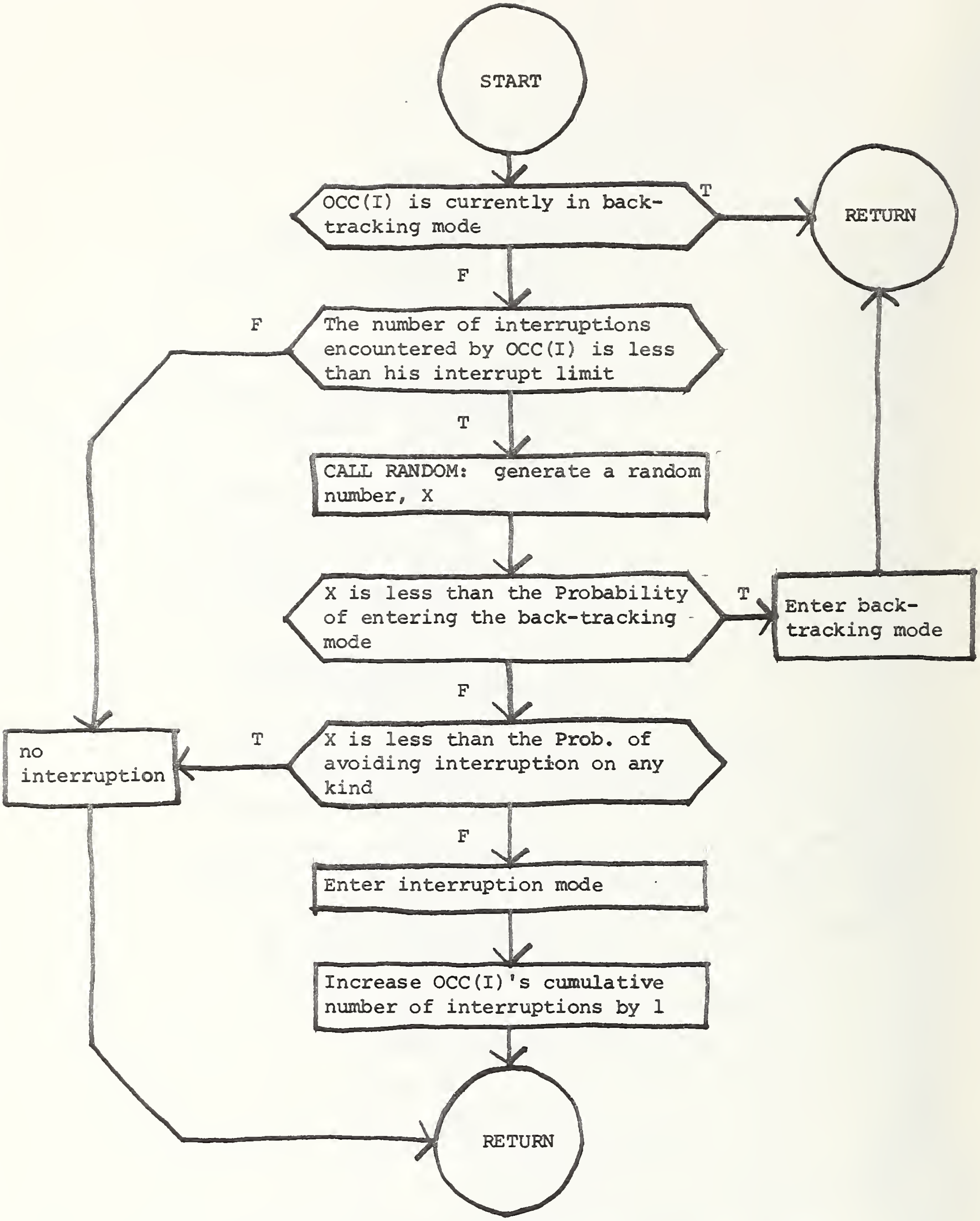
APPENDIX B: A DESCRIPTION OF THE MARKOV-BASED MODEL UNDERLYING BFIRES



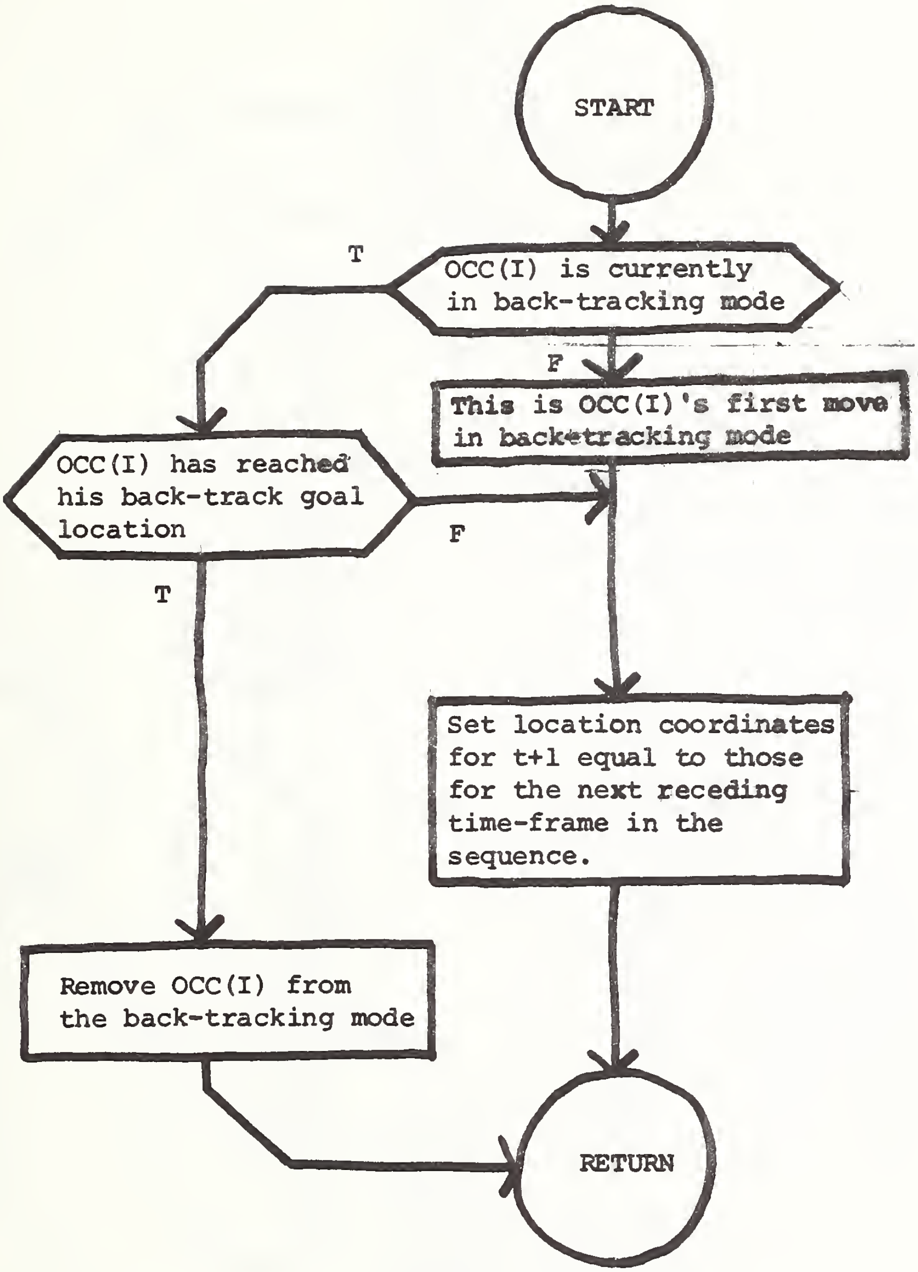
Flow Diagram for BFIRES Executive Program



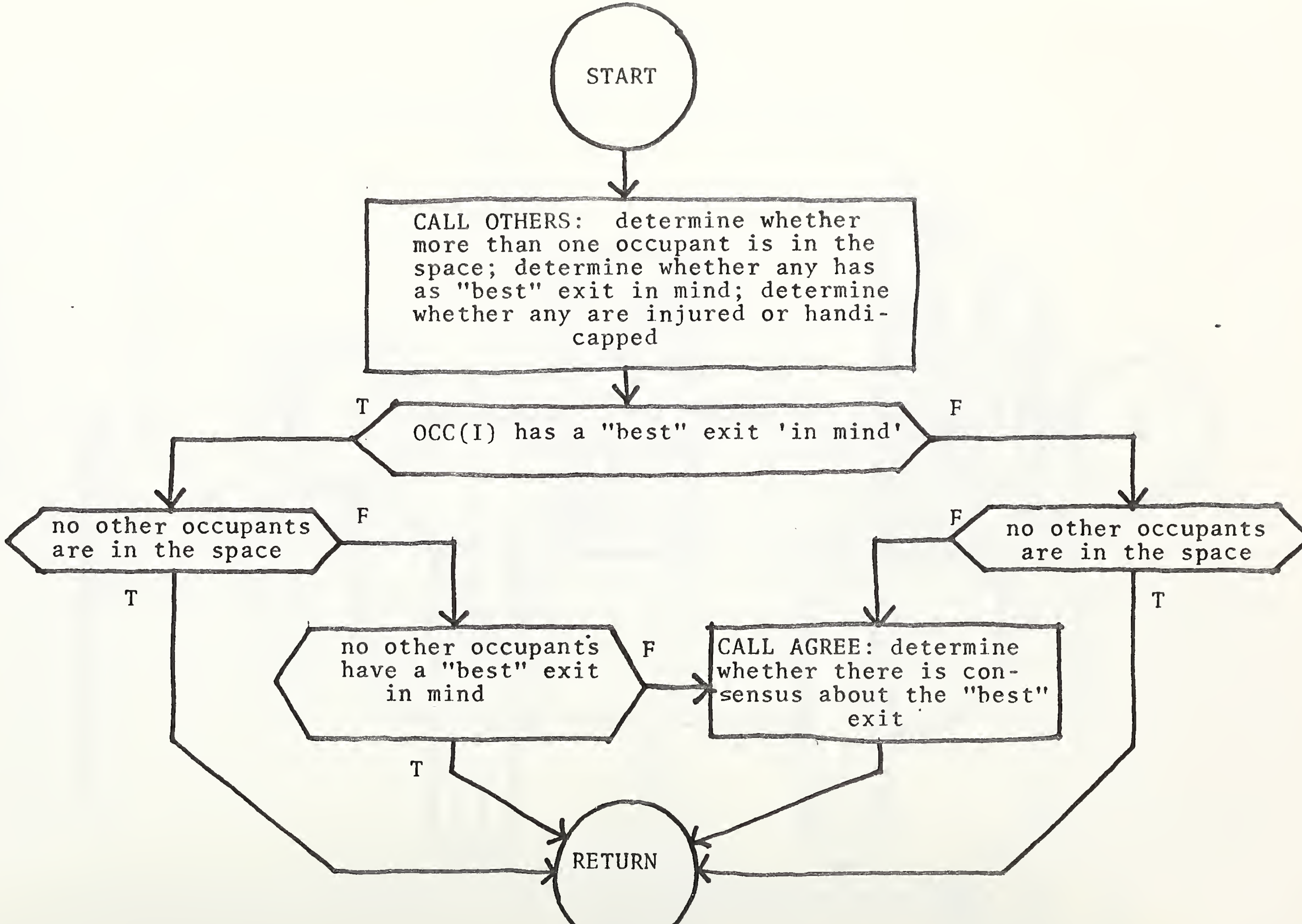
BFIRES Executive, continued



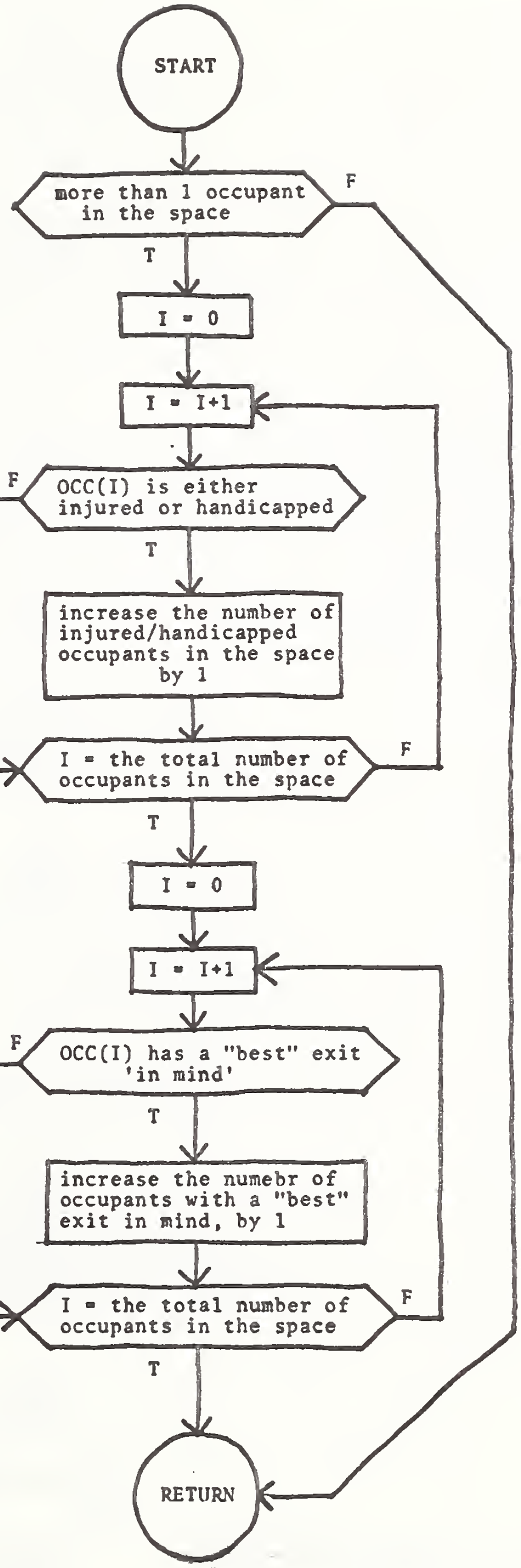
Flow Diagram for Subroutine INTRPT



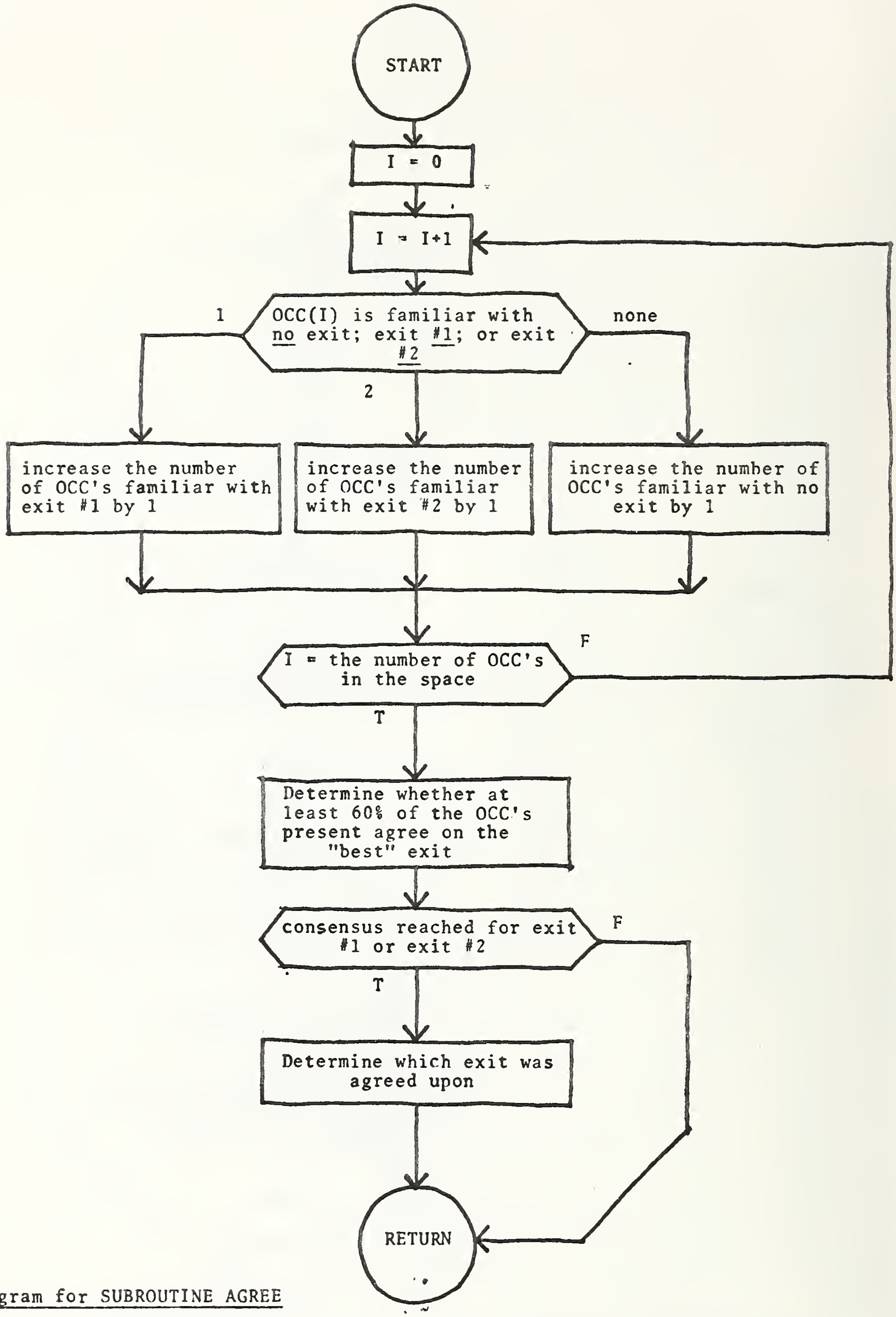
Flow Diagram for Subroutine BACKUP



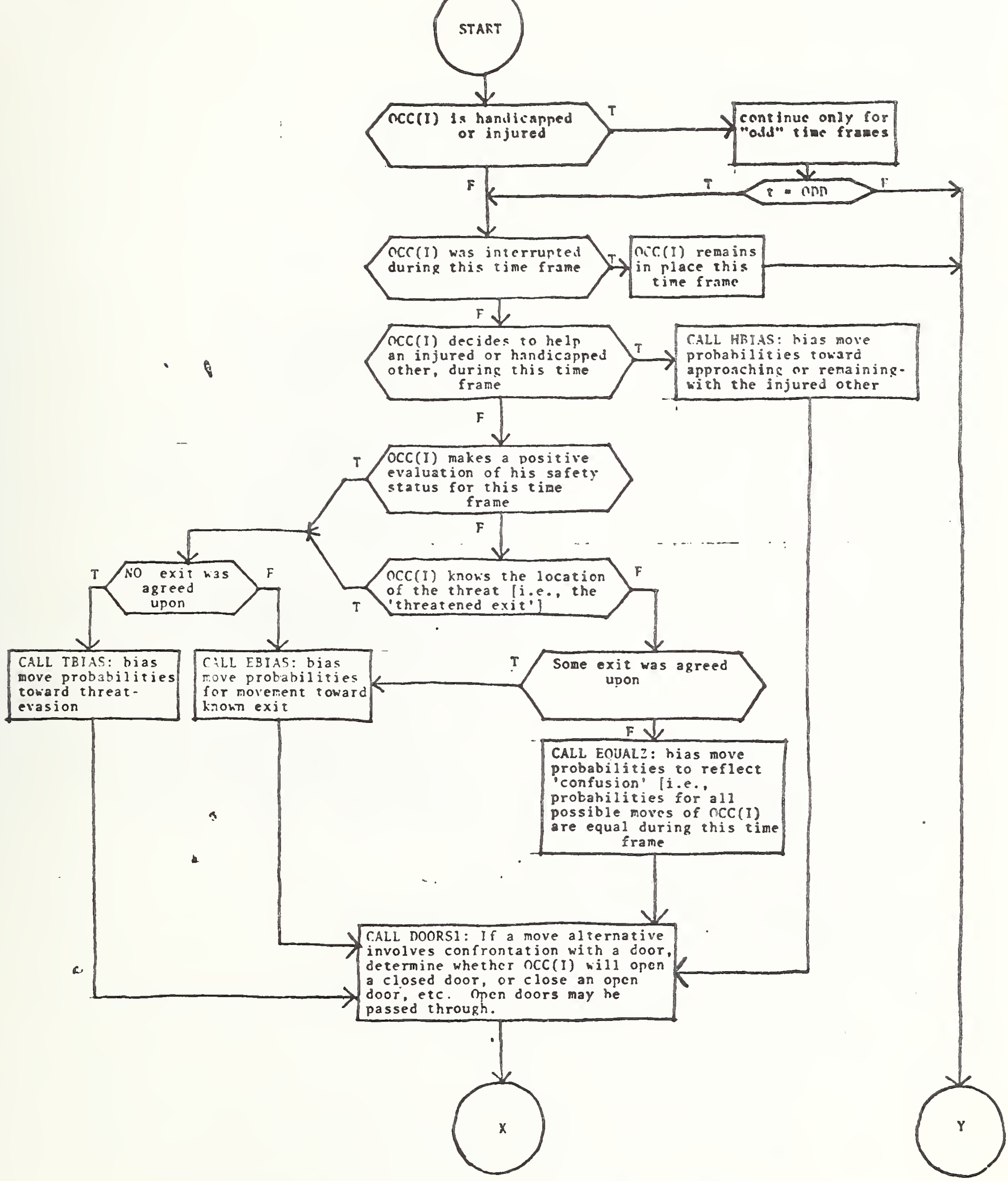
Flow Diagram for SUBROUTINE GROUP



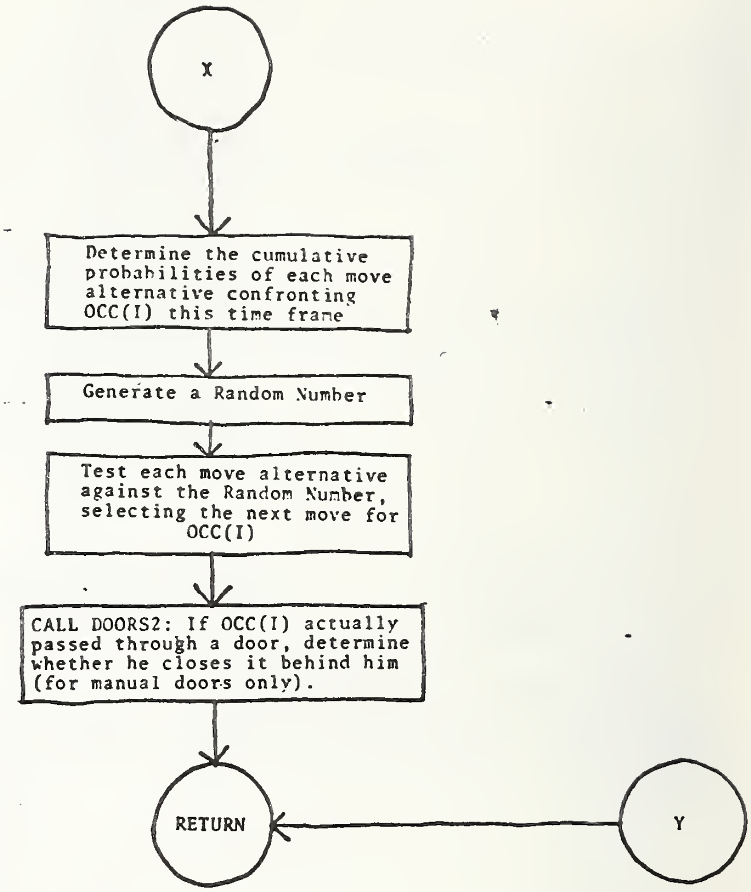
Flow Diagram for SUBROUTINE OTHERS



Flow Diagram for SUBROUTINE AGREE

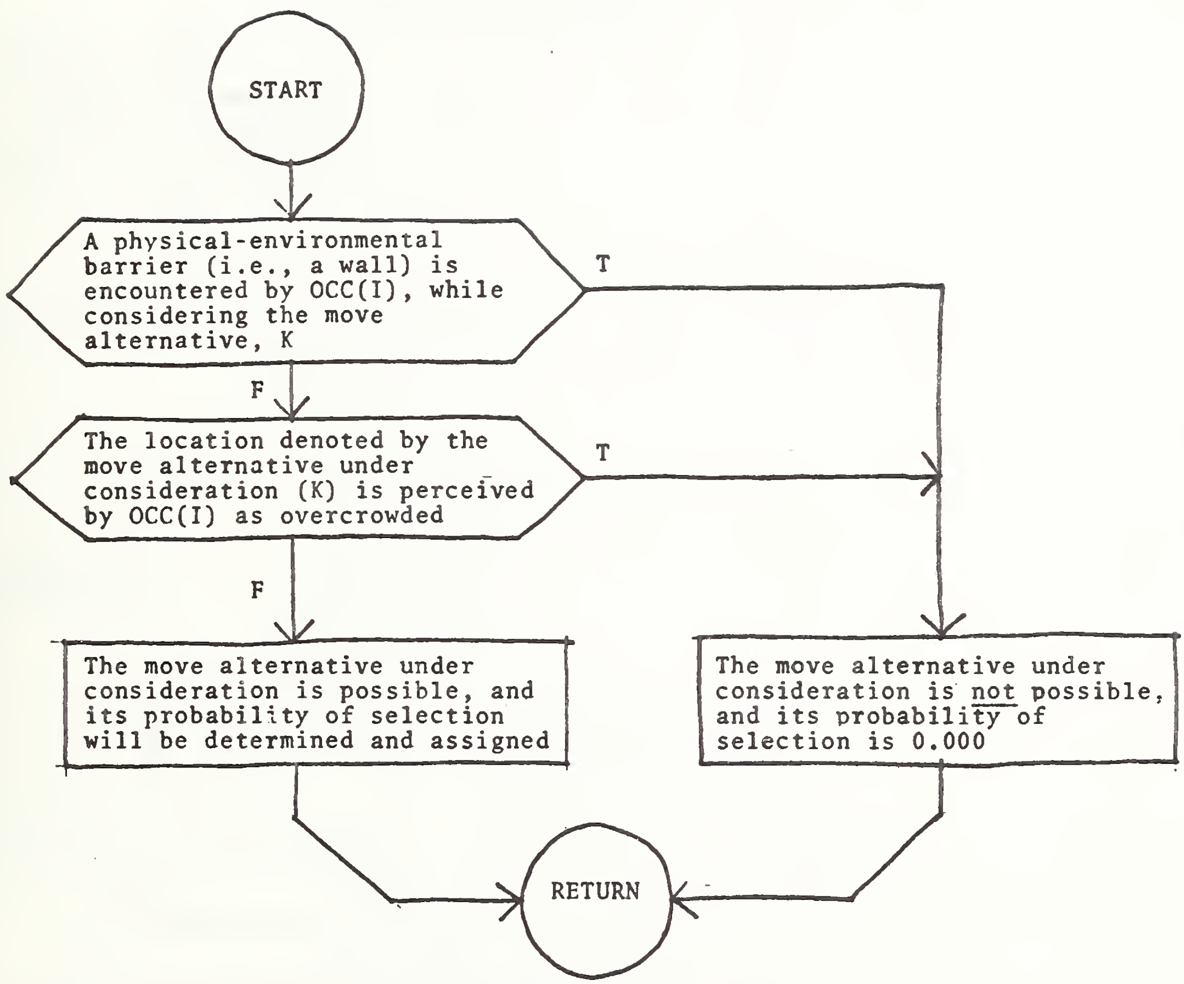


Flow Diagram for SUBROUTINE ASSIGN

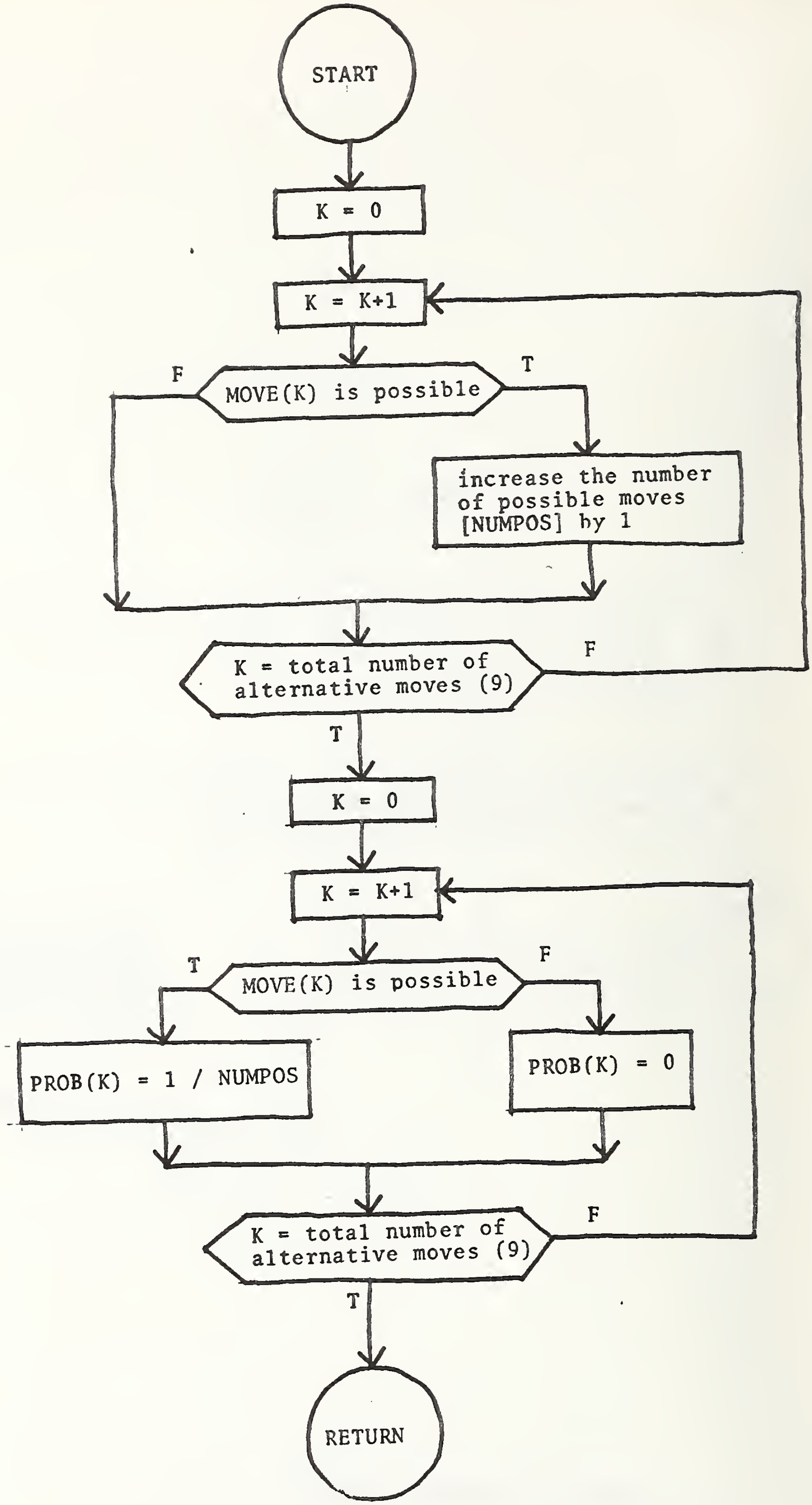


Flow Diagram for SUBROUTINE ASSIGN

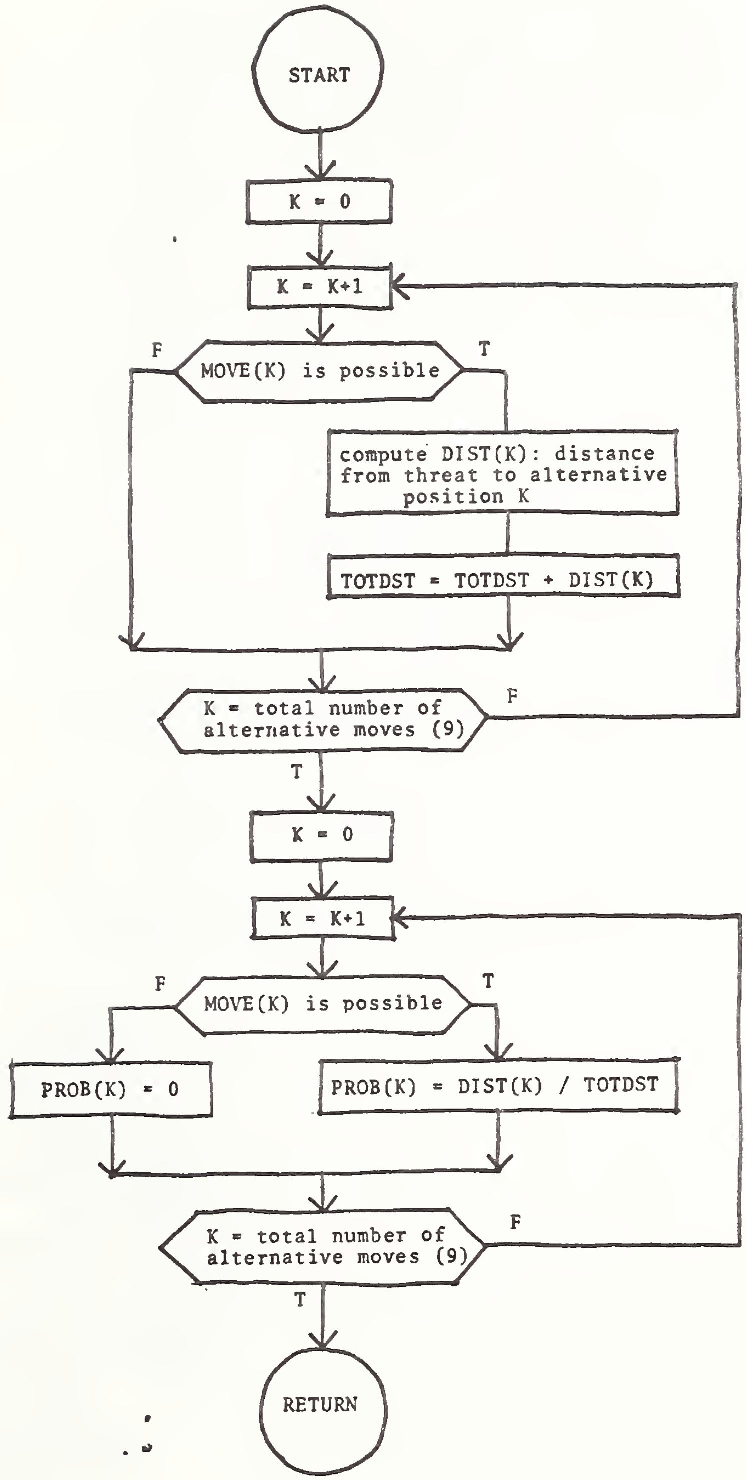
Continued.



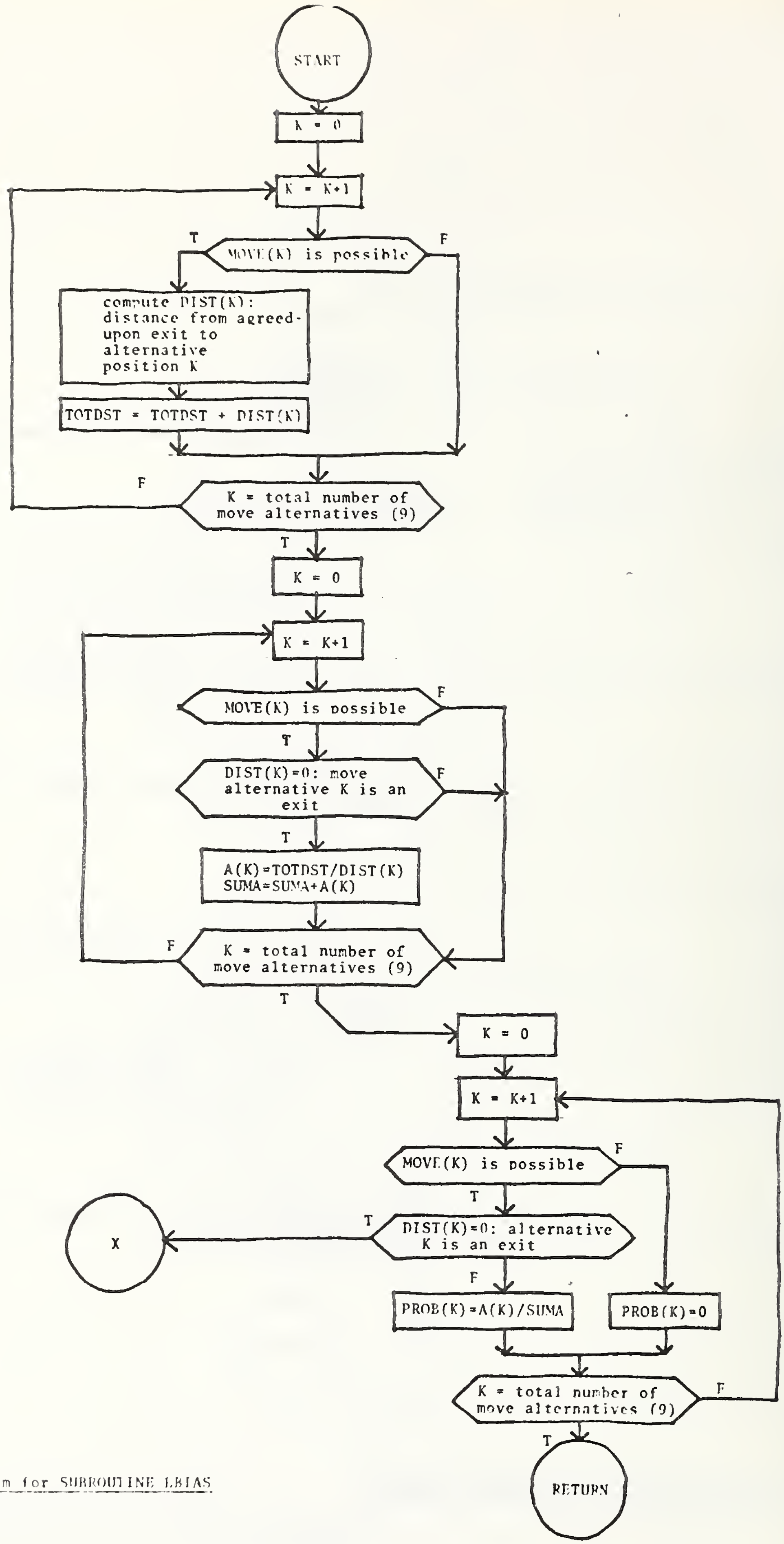
Flow Diagram for SUBROUTINE KPOSS



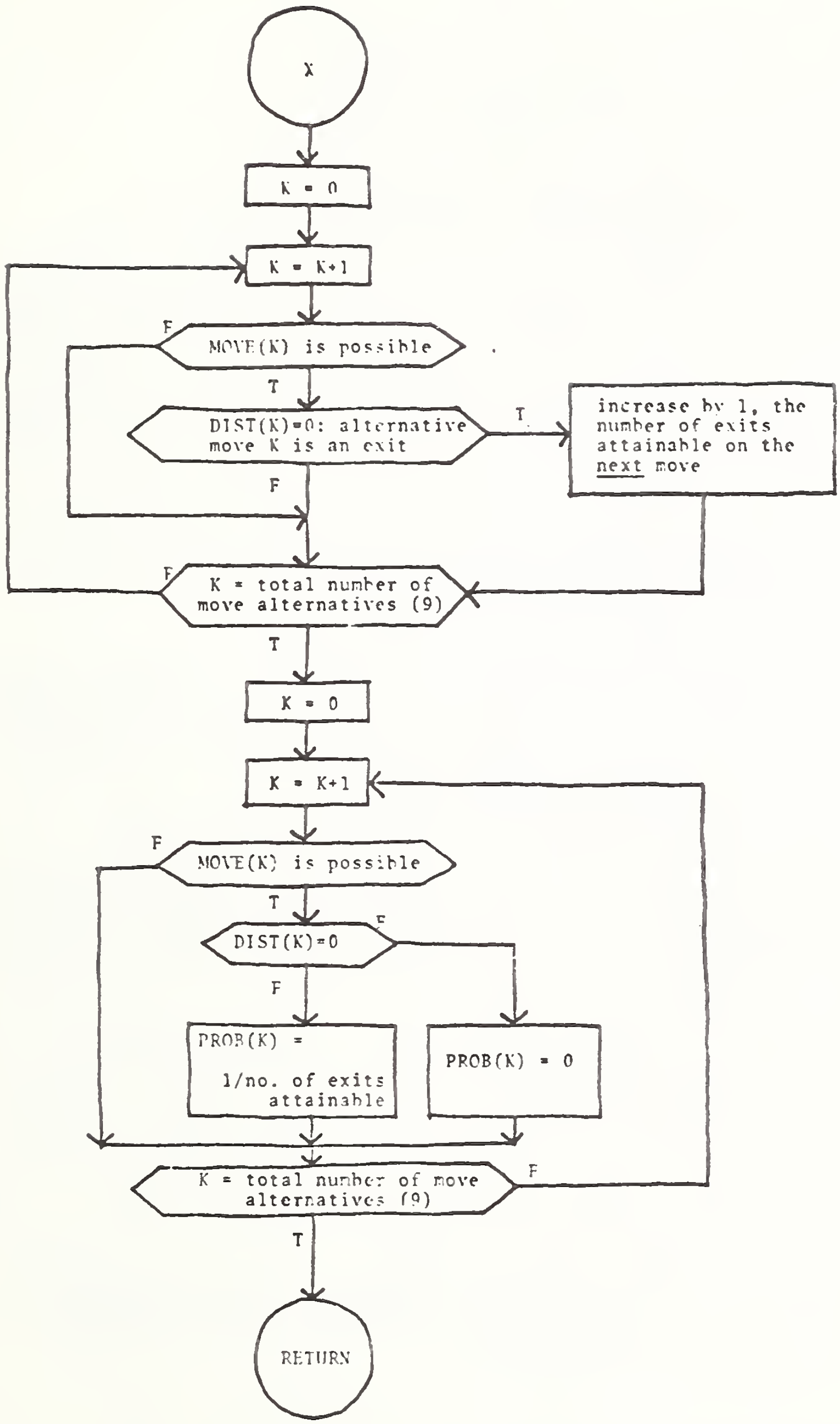
Flow Diagram for SUBROUTINE EQUALZ



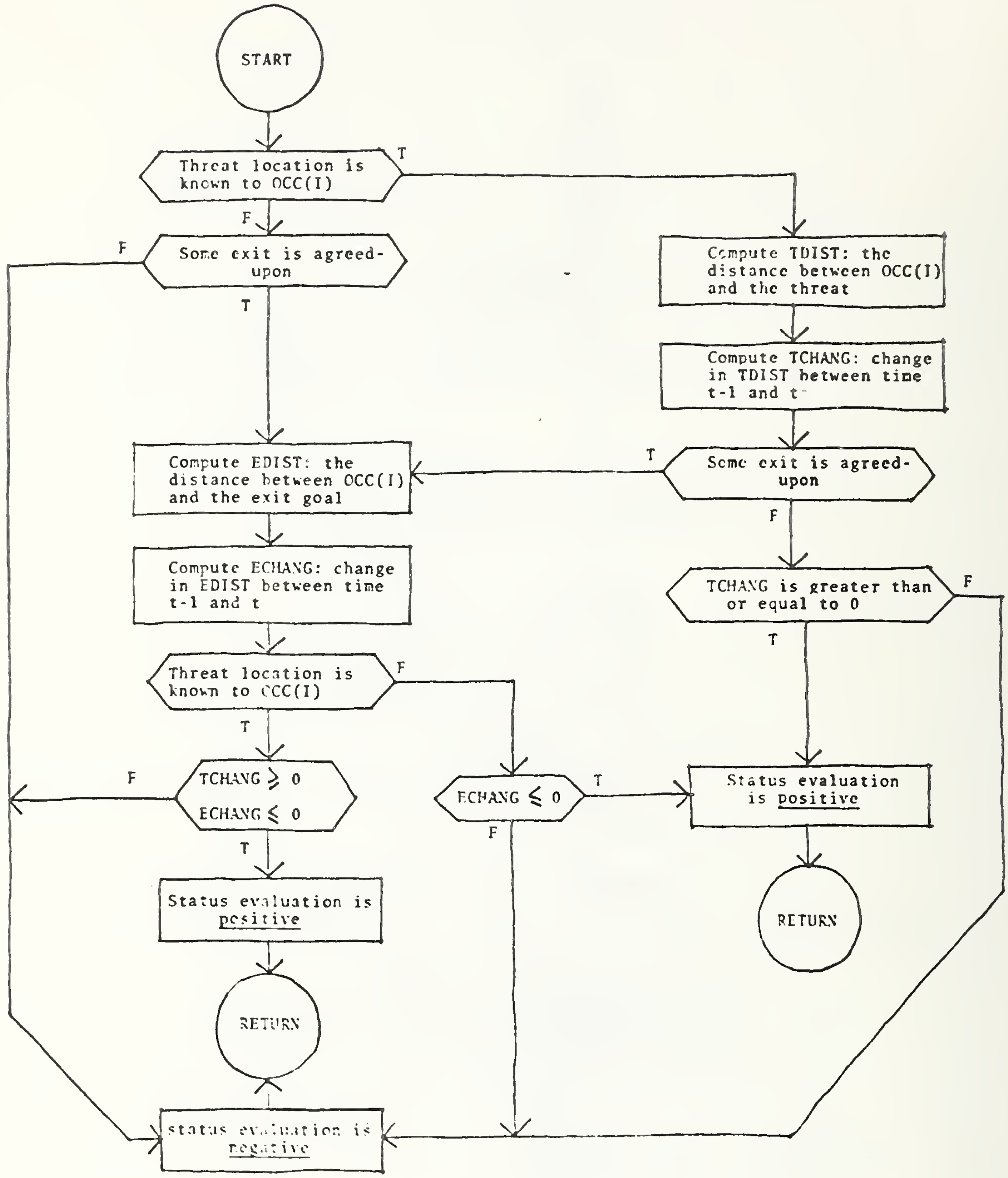
Flow Diagram for SUBROUTINE TBIAS



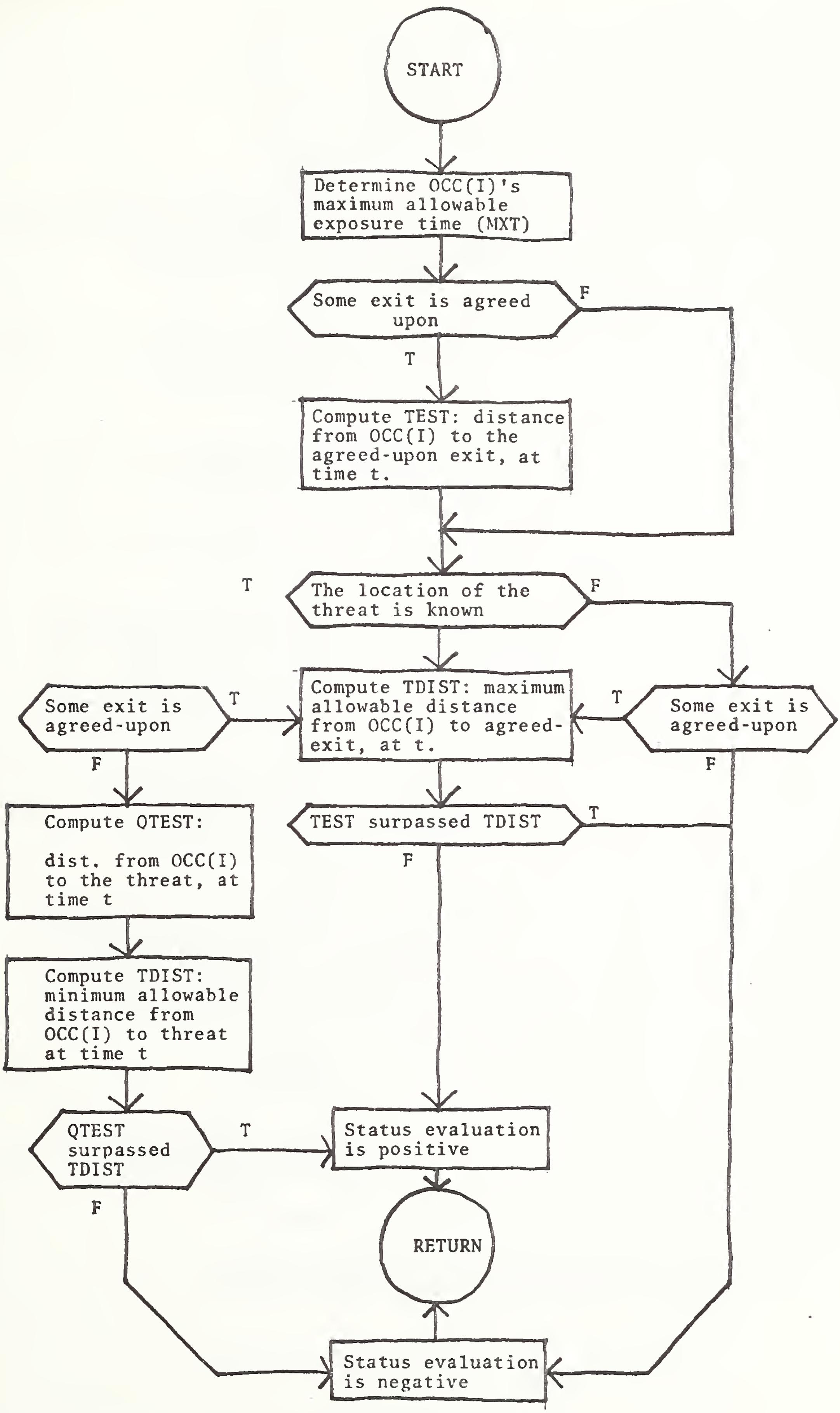
Flow Diagram for SUBROUTINE LBIAS



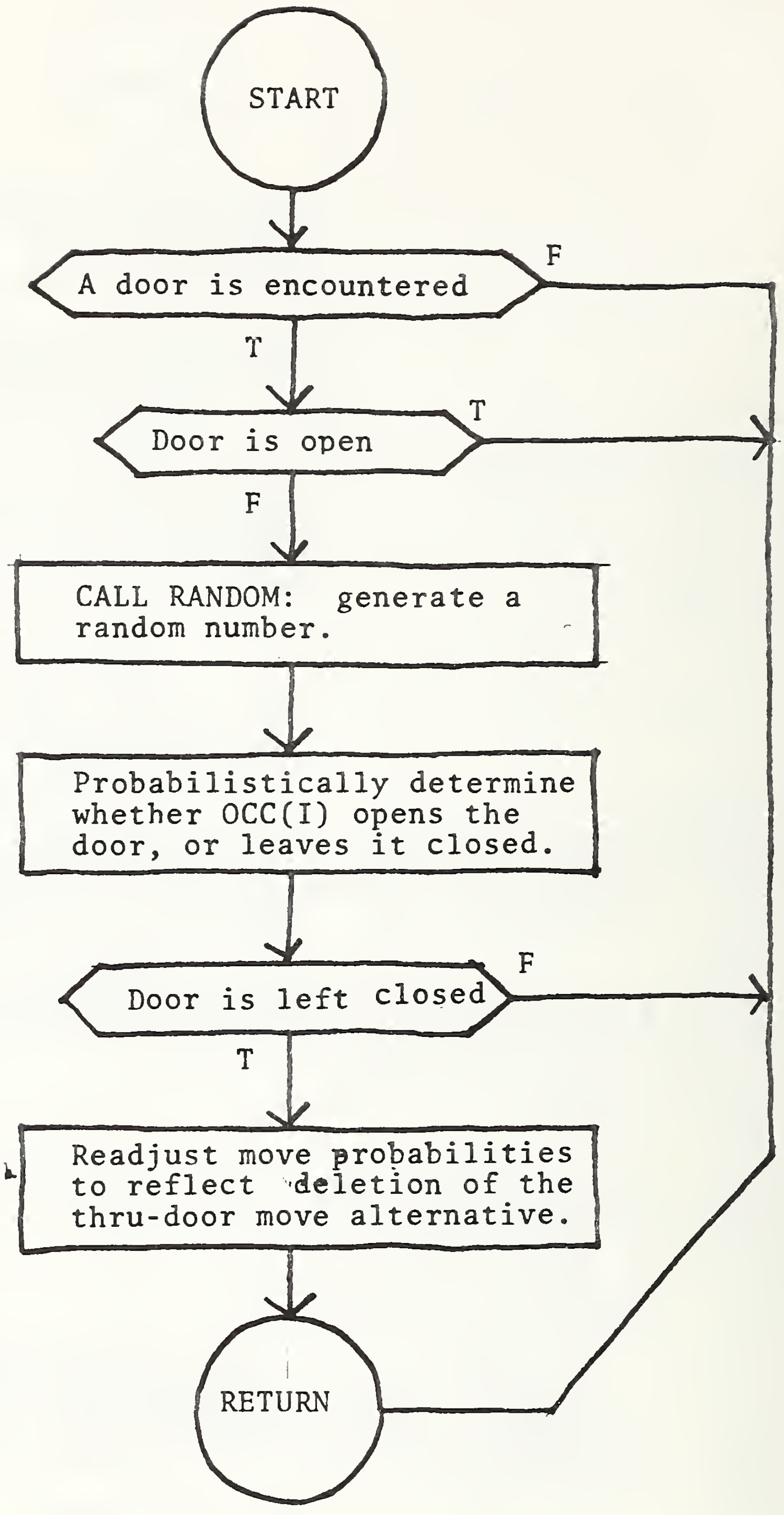
Flow Diagram for SUBROUTINE EBIAS, continued



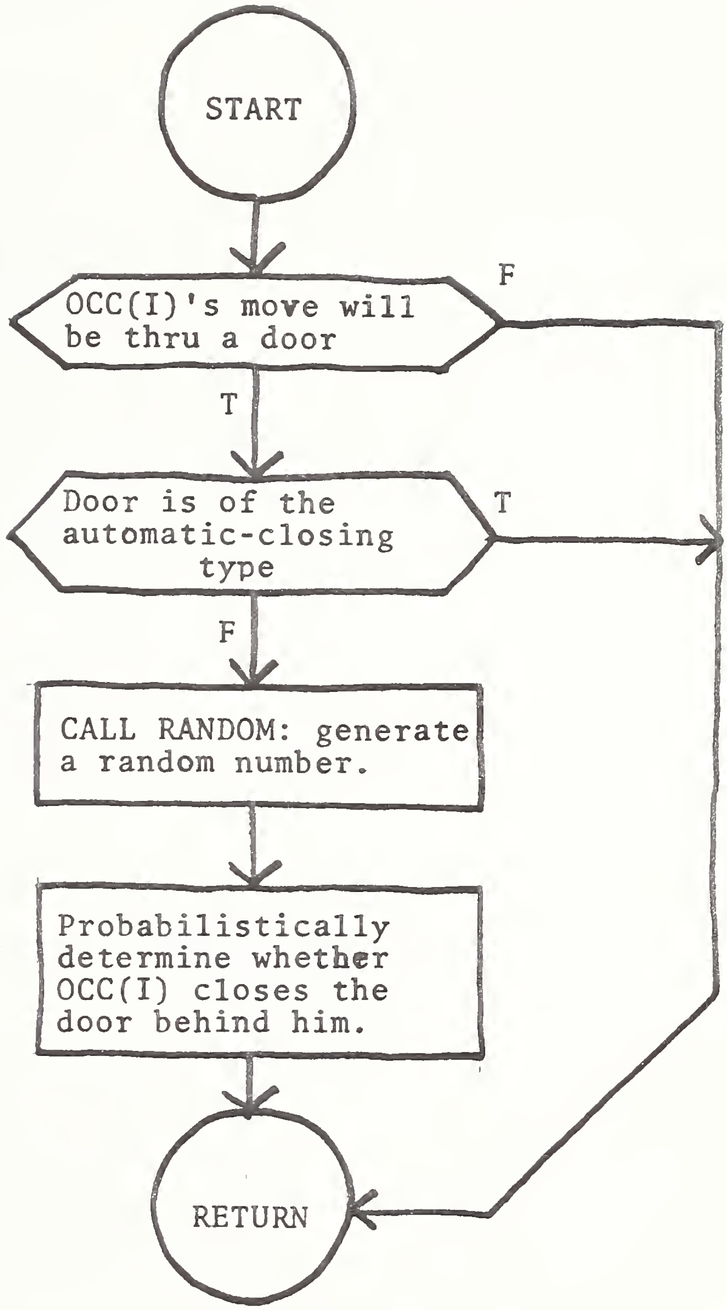
Flow Diagram for SUBROUTINE EVAL8



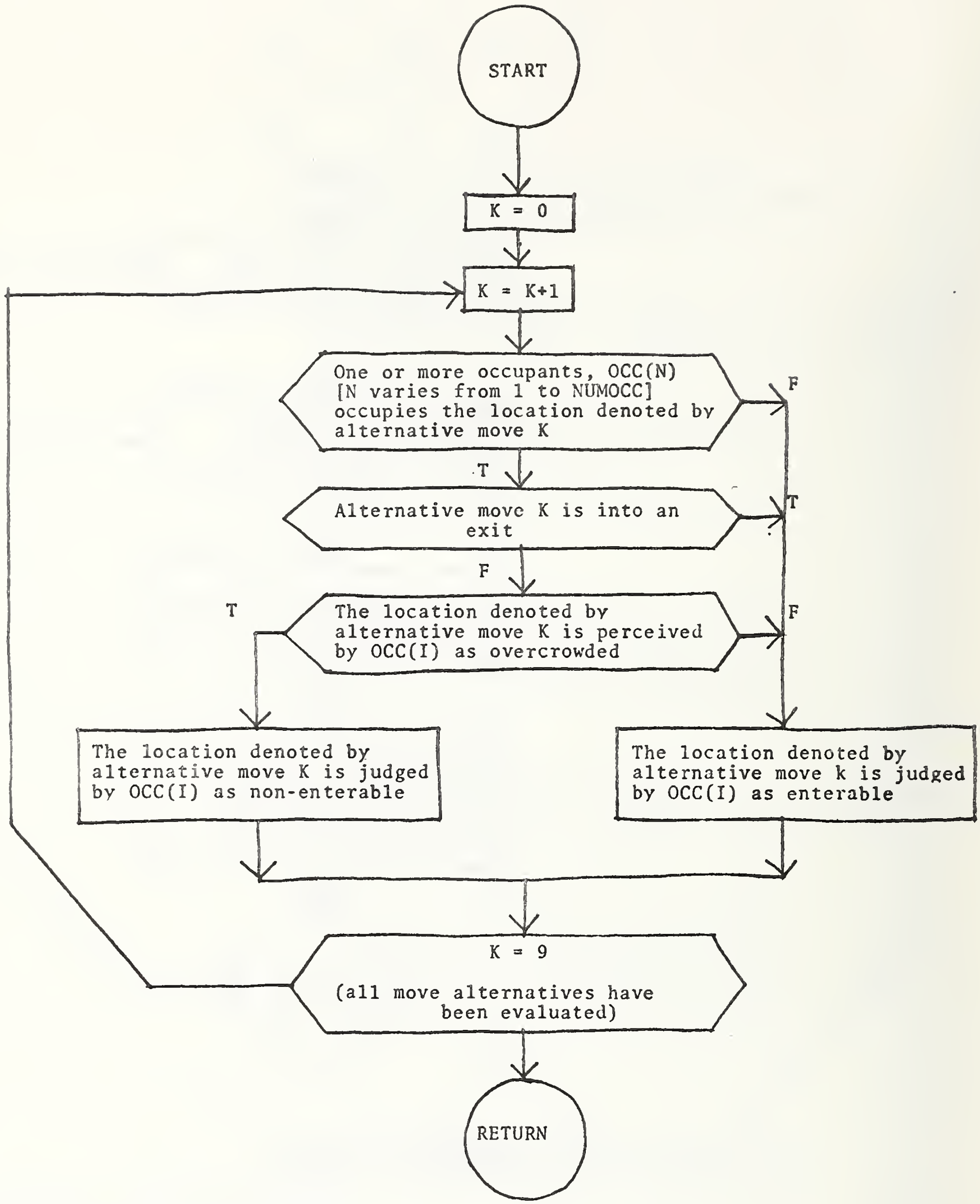
Flow Diagram for SUBROUTINE EVAL2∅



Flow Diagram for SUBROUTINE DOORS1



Flow Diagram for SUBROUTINE DOORS2



Flow Diagram for SUBROUTINE JAMMED

Contingency Trace for BDGFIRE/LEVEL 1 EXECUTIVE PROGRAM

Contingencies:	1	2	3	4	5
OCC(I) is interrupted during the current time frame	T	F	F	F	F
OCC(I) is already in a helping mode		T	F	F	F
OCC(I) confronts an injured or handicapped other during the current time frame			F	T	T
OCC(I) first enters a helping mode, during the current time frame				T	F
Outcomes:	**1**	**2**	**3**	**4**	**5**
Next action is determined by the interruption mode in effect	*				
Next action is determined by the helping mode in effect		*		*	
Next action reflects either goal-seeking or threat-evasion, depending upon OCC(I)'s current status evaluation			*		*

Contingency Trace for SUBROUTINE INTRPT

Contingencies	1	2	3	4	5
OCC(I) is currently in the back-tracking mode	T	F	F	F	F
The number of interruptions encountered by OCC(I) is less than his interruption limit		T	T	T	F
Back-tracking is probabilistically initiated		T	F	F	
Interruption is probabilistically initiated			T	F	
Outcomes:	**1**	**2**	**3**	**4**	**5**
Exit INTRPT	*				
Enter back-tracking mode		*			
Enter interruption mode			*		
No interruption to OCC(I) during this time-frame				*	*

Contingency Trace for SUBROUTINE BACKUP

Contingencies	1	2	3
OCC(I) is currently in the back-tracking mode	F	T	T
OCC(I) has reached his back-track goal		F	T

Outcomes:	1	2	3
This is OCC(I)'s first move in the back-track mode	*		
Set location coordinates for time-frame t+1 equal to those of the next receding time-frame in the sequence	*	*	
Remove OCC(I) from the back-tracking mode			*

Contingency Trace for SUBROUTINE GROUP

Contingencies:	1	2	3	4	5
OCC(I) has a "best" exit 'in mind'	T	T	T	F	F
There are no other occupants in the space	T	F	F	T	F
No other occupants have a "best" exit		T	F		

Outcomes:	1	2	3	4	5
Return	*	*		*	
Determine whether an exit consensus was reached			*		*

Contingency Trace for SUBROUTINE OTHERS

Contingencies:	Possible Situations 1	2	3	4
More than one occupant in the space	F	T	T	T
OCC(I) is either injured or handicapped		T	T	F
OCC(I) has a "best" exit 'in mind'		T	F	T

Outcomes:	1	2	3	4
Return	*			
Increase number of injured/handicapped by 1		*	*	
Increase number of occupants with exit in mind by 1		*		*

Contingency Trace for SUBROUTINE AGREE

Possible Situations

Contingencies:	1	2	3	1	2	3
For Each Occupant:						
OCC(I) is familiar with Exit #1	T	F	F			
OCC(I) is familiar with Exit #2	F	T	F			
OCC(I) is familiar with no exit	F	F	T			
For entire group:						
Consensus reached for Exit #1				T	F	F
Consensus reached for Exit #2				F	T	F
No con ensus reached				F	F	T

Outcomes:	1	2	3	1	2	3
Increase # of occ's familiar with exit #1 by 1	*					
Increase # of occ's familiar with exit #2 by 1		*				
Increase # of occ's familiar with no exit by 1			*			
Record consensus				*	*	*

Contingency Trace for SUBROUTINE ASSIGN

Possible Situations

Contingencies:	1	2	3	4	5	6	7	8
OCC(I) is handicapped/injured	T	T	F	F	F	F	F	F
time = ODD	F	T						
OCC(I) was interrupted during t		↳	T	F	F	F	F	F
OCC(I) helps handicapped other				T	F	F	F	F
OCC(I) makes positive status eval					T	T	F	F
An exit was agreed upon					T	F	T	F

Outcomes:	1	2	3	4	5	6	7	8
Return	*							
OCC(I) remains in place			*					
Bias toward helping other				*				
Bias toward exit-seeking					*		*	
Bias toward threat-evasion						*		
Equalize choice prob's (confuse)								*

Contingency Trace for SUBROUTINE KPOSS

Contingencies:	1	2	3
A physical-environmental barrier (e.g., a wall) has been encountered	F	F	T
The location denoted by the move alternative under consideration is perceived as over-crowded	F	T	T
Outcomes:	**1**	**2**	**3**
The move alternative under consideration is possible, and its probability of selection will be assigned	*		
The move alternative under consideration is not possible, and its probability of selection is 0.000		*	*

Contingency Trace for SUBROUTINE EQUALZ

Contingencies:	1	2
MOVE(K) is possible, for OCC(I), during time frame t	T	F
Outcomes:	**1**	**2**
PROB(K) = 1 / the number of possible move alternatives available to OCC(I)	*	
PROB(K) = 0		*

Contingency Trace for SUBROUTINE TBIAS

Contingency:	1	2
Move K is possible	F	T
Outcomes:	**1**	**2**
The probability of selecting move K is 0.000	*	
The probability of selecting move K is a function of DIST(K): the distance between the threat and location K. That is, as DIST(K) increases, Prob(K) also increases		*

Contingency Trace for SUBROUTINE EBIAS

Contingencies:	1	2	3	4
Move K is possible	F	T	T	T
The distance between a goal and OCC(I) [DIST(K)] = 0; i.e., move alternative K is into an exit		F	T	T
More than one move alternative is into an exit			F	T
Outcomes:	**1**	**2**	**3**	**4**
The probability of selecting move K is 0.000	*			
The probability of selecting move K is a function of DIST(K), such that as DIST(K) decreases, Prob (K) increases		*		
The probability of selecting move K is 1.000			*	
Each of the exit alternatives has an equal chance of selection				*

Contingency Trace for SUBROUTINE EVAL8

Contingencies:	1	2	3	4	5	6	7
The Threat location is known	T	T	T	F	F	F	T
Some exit is agreed-upon	T	T	F	T	T	F	F
The distance between OCC(I) and the threat increased between t-1 and t			F				T
The distance between OCC(I) and the exit goal decreased between t-1 and t				T	F		
The distance between OCC(I) and the exit goal decreased and the distance between OCC(I) and the treat increased between t 1 and t	T	F					
Outcomes:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Status evaluation is positive	*			*			*
Status evaluation is negative		*	*		*	*	

Contingency Trace for SUBROUTINE EVAL20

Contingencies	1	2	3	4	5	6	7
Some exit is agreed-upon	T	T	T	T	F	F	F
The Threat location is known	T	T	F	F	T	T	F
Actual distance from OCC(I) to the exit is greater than his maximum allowable distance	T	F	T	F			
Actual distance from OCC(I) to the threat is greater than his maximum allowable distance					T	F	
Outcomes:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Status evaluation is positive		*		*	*		
Status evaluation is negative	*		*			*	*

Contingency Trace for SUBROUTINE JAMMED

Contingencies:	1	2	3	4
The location denoted by alternative move K is currently occupied by one or more other individuals	F	T	T	T
Alternative move K is into an exit		T	F	F
The location denoted by alternative move K is perceived by OCC(I) as overcrowded			T	F
Outcomes:	**1**	**2**	**3**	**4**
The location denoted by alternative move K is judged by OCC(I) to be enterable	*	*		*
The location denoted by alternative move K is judged by OCC(I) to be non-enterable			*	

Contingency Trace for SUBROUTINE DOORS1

Contingencies:	1	2	3	4
A door is encountered by OCC(I) during t	F	T	T	T
This door is already open		T	F	F
A closed door is left closed			T	F
Outcomes:	**1**	**2**	**3**	**4**
Bypass door routines	*			
Consider movement thru the door as a move alternative for OCC(I), during t		*		*
Delete the thru-door move from the array of move alternatives for OCC(I), during t.			*	

Contingency Trace for SUBROUTINE DOORS2

Contingencies:	1	2	3	4
OCC(I)'s move will be through a door, during t	F	T	T	T
The door is of the automatically-closing type		T	F	T
As OCC(I) passes thru the door, he closes it behind him			T	F
Outcomes:	**1**	**2**	**3**	**4**
Bypass door routines	*			
Update status of DOOR(N), showing that it is now closed		*	*	
Update status of DOOR(N), showing that it is now open				*

APPENDIX C: FORTRAN-V LISTING OF THE BFIRES SIMULATION PROGRAM

```
$BATCH
C
C*****************************************************************************
C*****************************************************************************
C
C               "SIMULATING HUMAN BEHAVIOR IN FIRES"
C
C       COMPUTER SIMULATION PACKAGE WRITTEN BY:
C            FRED I. STAHL, RESEARCH ARCHITECT
C            ARCHITECTURAL RESEARCH SECTION
C            CENTER FOR BUILDING TECHNOLOGY
C            NATIONAL BUREAU OF STANDARDS
C
C       PREPARED FOR:
C            DESIGN CONCEPTS PROGRAM
C            CENTER FOR FIRE RESEARCH
C            NATIONAL BUREAU OF STANDARDS
C
C*****************************************************************************
C
C                    UPDATED: 23 NOVEMBER 1977
C
C                    CHECKED: 23 NOVEMBER 1977
C
C*****************************************************************************
C*****************************************************************************
C
C
C: BUILDING FIRE: LEVEL 2.8 -- BDGFIRE:LEVEL28  -- BFIRES
C
C: SIMULATING HUMAN BEHAVIOR IN BUILDING FIRES
C
C
      DIMENSION ITYPE1(20),ITYPE2(20),IDPASS(20)
      DIMENSION IXTRCE(20,30),IYTRCE(20,30)
      DIMENSION IBACK(20),JTIME(20),INITYO(20),INITXO(20)
      DIMENSION INTR(20),INTNUM(20)
      DIMENSION IFMT(20),JFMT(20),KFMT(20),IENTER(9)
      DIMENSION IBAR(20,20,2),LBYSTD(20),IHANDI(20),KNOWAY(20)
      DIMENSION INTLIM (20),IBYSTD(20),NE(20),NPOINT(20)
      DIMENSION PTDIST(20),PEDIST(20),A(9),M(9),DIST(9),P(9)
      DIMENSION IGOALX(20,10),IGOALY(20,10),KXO(20),KYO(20)
      DIMENSION POPEN(20),PCLOSE(20),IDOOR(30,4),IDOPEN(30,30)
      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(20,30),YOB(20,30),REPORT
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,
```

```
     1   IALLOW,ND,REPORT
      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=1,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 **  BFIRES EXECUTIVE **
C
C: RUN THE DESIRED NUMBER OF REPLICATIONS:
C
      DO 90 III=1,NUMREP
      DO 91 N=1,NUMOCC
      XO(N)=KXO(N)
91    YO(N)=KYO(N)
C
      DO 92 NTHIS=1,NUMOCC
      IBACK(NTHIS)=0
      JTIME(NTHIS)=0
      INTR(NTHIS)=0
      INTNUM(NTHIS)=0
      ITYPE1(NTHIS)=0
      ITYPE2(NTHIS)=0
92    IDPASS(NTHIS)=0
C
C: RUN THE SIMULATION FOR THE DESIRED NUMBER OF TIME UNITS:
C
      DO 50 ITIME=1,TOTIME
C
      DO 501 I=1,ND
501   IDOPEN(I,ITIME)=IDOOR(I,4)
```

```
C
C: FOR EACH ...E INCREMENT, RUN ALL OCCUPANTS IN THE SPACE...
      DO 60 NTHIS=1,NUMOCC
      IXTRCE(NTHIS,ITIME)=XO(NTHIS)
      IYTRCE(NTHIS,ITIME)=YO(NTHIS)
      XOB(NTHIS,ITIME)=XO(NTHIS)
      YOB(NTHIS,ITIME)=YO(NTHIS)
      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)
      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
27    ITYPE1(NTHIS)=ITYPE1(NTHIS)+1
      GO TO 70
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
      CALL GROUP (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,NKNOW,NAGREE,
     1   IAGREE)
      IF (NHANDI.GT.0) GO TO 65
      GO TO 67
65    CALL BYSTND (IBYSTD,NTHIS)
      IF (IBYSTD(NTHIS).EQ.1) GO TO 70
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 (MXTIME,MK,XO,YO,XE,YE,NTHIS,IAGREE,
     1   ITIME,C,IEVAL)
70    CALL 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)
      CALL ASSIGN (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)
```

```
      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)
      CALL PASSG (IDPASS,IDOOR,XO,YO,NTHIS,ND,NEWXO,NEWYO)
71    IF (REPORT.EQ.1) GO TO 72
      GO TO 61
72    CALL 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)
61    CALL UPDATE (XO,YO,NTHIS,NEWXO,NEWYO)
60    CONTINUE
50    CONTINUE
      CALL TRACE (IXTRCE,IYTRCE,NTHIS,ITIME,NUMOCC,TOTIME)
      CALL TOTALS (IDPASS,ITYPE1,!TYPE2,NTHIS,NUMOCC)
90    CONTINUE
C
C: INPUT FORMATING
C
100   FORMAT (5(I2,1X),2(I1,1X),F1.0,1X,I2,1X,I2,1X,I1)
101   FORMAT (20A4)
102   FORMAT (2(I2,1X),I5,1X,I2,2(1X,F4.2))
103   FORMAT (20A4)
104   FORMAT (20A4)
      END
C
C
C /////////////// SUBROUTINES GO HERE ///////////////////////
C
C
      SUBROUTINE BYSTND (IBYSTD,NTHIS)
      IBYSTD(NTHIS) = 0
      RETURN
      END
C
C
C
      SUBROUTINE GROUP (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,
     1   NKNOW,NAGREE,IAGREE)
      DIMENSION KNOWAY(20)
      CALL OTHERS (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,NKNOW)
      IF (KNOWAY(NTHIS).GT.0) GO TO 1
      IF (KOOCC.EQ.0) GO TO 999
      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
C
C
C
```

```
      SUBROU'  'E OTHERS (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,NHANDI,
     1   NKN..)
      DIMENSION IHANDI(20),KNOWAY(20)
      NKNOW=0
      NHANDI=0
      IF (NUMOCC.GT.1) GO TO 1
      KOOCC=0
      GO TO 999
1     KOOCC=1
      DO 50 I=1,NUMOCC
      IF (I.EQ.NTHIS) GO TO 50
      IF (IHANDI(I).EQ.1) GO TO 51
      GO TO 50
51    NHANDI=NHANDI+1
50    CONTINUE
      DO 60 I=1,NUMOCC
      IF (I.EQ.NTHIS) GO TO 60
      IF (KNOWAY(I).GT.0) GO TO 61
      GO TO 60
61    NKNOW=NKNOW+1
60    CONTINUE
999   RETURN
      END
C
C
C
      SUBROUTINE AGREE (NTHIS,NUMOCC,IHANDI,KNOWAY,KOOCC,
     1  NHANDI,NKNOW,NAGREE,IAGREE)
      DIMENSION KNOWAY(20)
      KONE=0
      KTWO=0
      KZERO=0
      DO 50 I=1,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+1
      GO TO 50
52    KTWO=KTWO+1
      GO TO 50
53    KZERO=KZERO+1
50    CONTINUE
      ONE=KONE
      TWO=KTWO
      ZERO=KZERO
      SUM=ONE+TWO+ZERO
      PSUM=.60*SUM
      IF ((ONE.GE.PSUM).OR.(TWO.GE.PSUM)) GO TO 1
      NAGREE=0
      IAGREE=0
      GO TO 2
1     NAGREE=1
      IF (ONE.GE.PSUM) GO TO 3
```

```
      IAGREE=2
      GO TO 2
3     IAGREE=1
2     RETURN
      END
C
C
C
      SUBROUTINE ASSIGN (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)
C
C: THIS SECTION OF "ASSIGN" DETERMINES WHETHER ITIME (THE
C: CURRENT VALUE OF TIME) IS ODD OR EVEN.  INJURED OR
C: HANDICAPPED OTHERS MAY MOVE ONLY ON ODD TIME VALUES:
C
      DIMENSION IHANDI(20),IBYSTD(20),P(9),IMPOSS(9),M(9),
     1   A(9),DIST(9),CUM(9)
      INTEGER XO(20),YO(20),XE(10),YE(10),XT,YT
      TIME=ITIME
      ATIME=TIME/2.
      JTIME=ATIME
      BTIME=JTIME
      TEST=ATIME-BTIME
C
C: NOW, RUN THROUGH THE "ASSIGN" SUBROUTINE, TO SET MOVE
C: PROBABILITY VALUES ACCORDING TO THE APPROPRIATE BIASES.
C: SPECIFIC BIASING ROUTINES ARE INCLUDED AS SEPARATE SUB-
C: ROUTINES.
C
      IF (IHANDI(NTHIS).EQ.1) GO TO 1
      GO TO 11
1     IF (TEST.NE.0.) GO TO 2
11    IF (INT.EQ.1) GO TO 2
      IF (IBYSTD(NTHIS).EQ.1) GO TO 3
      IF (IEVAL.EQ.1) GO TO 4
      IF ((XT.EQ.0).AND.(YT.EQ.0)) GO TO 5
      IF (NAGREE.EQ.0) GO TO 404
      GO TO 504
404   CALL TBIAS (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)
      GO TO 6
4     IF (NAGREE.EQ.0) GO TO 404
504   CALL 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)
      GO TO 6
2     P(5)=1.0
      DO 50 K=1,4
50    P(K)=0.0
      DO 51 K=6,9
51    P(K)=0
```

```
      GO TO    '
3     CALL H..AS (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1  XO,YO,IBAR,TOTBAR,XT,YT,NAGREE,XE,YE,IAGREE,
     2  IRAND,P)
      GO TO 6
5     IF (NAGREE.NE.0) GO TO 504
      CALL EQUALZ (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)
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)
601   CONTINUE
      DO 100 K=1,9
      IF (K.EQ.1) GO TO 200
      CUM(K)=P(K)+CUM(K-1)
      GO TO 100
200   CUM(K)=P(K)
100   CONTINUE
      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
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
C
C
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 (20,20,2),IENTER(9)
      INTEGER XO(20),YO(20),XK,YK,TOTBAR
      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)
      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
      L=0
      GO TO 6
5     L=1
      IF (IENTER(K).EQ.0) GO TO 4
6     RETURN
      END
C
C
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
      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
C
C
C
C: RANDOM NU  ER GENERATOR:
```

```
C
      SUBROU  NE 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)
C
C: IBM UNIFORMLY DISTRIBUTED RANDOM NUMBER GENERATOR:
C: SUBROUTINE "RANDU" (FROM SSP-2 PACKAGE). BASED ON THE
C: POWER-RESIDUE METHOD.
C
      IY=IRAND*65539
      IF (IY) 5,6,6
5     IY=IY*2147483647*1
6     X=IY
      X=X*.4656613E-9
      IRAND=IY
      RETURN
      END
C
C
C
      SUBROUTINE EQUALZ(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
C: "EQUALZ" (EQUALIZE) CAUSES THE PROBABILITY VALUES OF THE
C: VARIOUS POSSIBLE MOVES TO BE SET EQUAL TO EACH OTHER, RESULTING IN
C: NO BIASING EFFECT:
C
      INTEGER XO(20),YO(20),XK,YK
      DIMENSION IMPOSS (9), P (9)
      NUMPOS=0
      DO 1 K=1,9
      CALL KROSS (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
      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
C
C
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)
C
C: "TBIAS" (THREAT-BIAS) CAUSES THE PROBABILITY VALUES OF THE
C: VARIOUS MOVES TO BE ADJUSTED SO AS TO BIAS TOWARD THREAT-
C: REDUCTION (I.E., BIASING TOWARD INCREASING THE
C: DISTANCE BETWEEN OCC(NTHIS) AND THE THREAT POINT):
C
      INTEGER XO(20),YO(20),XT,YT,XK,YK
      DIMENSION M(9),DIST(9),P(9)
      TOTDST=0.
C
C: FOR EACH POSSIBLE MOVE, COMPUTE DISTANCE TO THREAT POINT:
C
      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)
      IF (L.EQ.1) GO TO 1
      M(K)=1
      GO TO 10
1     M(K)=0
      DIST(K)=SQRT(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
      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
C
C
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)
C
C: THE DISTANCE BETWEEN OCC(NTHIS) AND THE AGREED:UPON EXIT:
C
      INTEGER XO(20),YO(20),XE(10),YE(10),XK,YK
      DIMENSION M(9),DIST(9),XE(10),YE(10),A(9),P(9)
      DIMENSION IGOALX(20,10),IGOALY(20,10)
      TOTDST=0.
      SUMA=0.
C
C: FOR EACH POSSIBLE MOVE, COMPUTE THE DISTANCE TO THE
C: AGREED-UPON EXIT:
C
```

```
      DO 10 '   ,9
      CALL KI..S (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 1
      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
C: FOR EACH POSSIBLE MOVE, COMPUTE MOVE-PROB. VALUES, P(K).
C: IF DIST(K)=0.0, MOVE K IS SELECTED.  IF DIST(K)=0.0 FOR
C: MORE THAN ONE MOVE ALTERNATIVE, THEN THE MOVE-PROBS. FOR
C: THESE ARE EQUALIZED:
C
      DO 15 K=1,9
      IF (M(K).EQ.1) 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.1) 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.1) GO TO 20
      IF (DIST (K).EQ.0.) GO TO 6
      GO TO 20
6     ZERO=ZERO+1.
20    CONTINUE
      DO 25 K=1,9
      IF (M(K).EQ.1) 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
C
C
C
      SUBROUTINE EVAL (XO,YO,XT,YT,XE,YE,NTHIS,IAGREE,
```

```
     1   ITIME,IEVAL,PTDIST,TDIST,PEDIST,EDIST,
     2   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)
      IF ((XT.GT.0).AND.(YT.GT.0)) GO TO 1
      GO TO 3
1     TDIST=SQRT(FLOAT((XO(NTHIS)-XT)**2+(YO(NTHIS)-YT)**2))
      IF (ITIME.GT.1) GO TO 5
      PTDIST(NTHIS)=TDIST
5     TCHANG=TDIST-PTDIST(NTHIS)
      IF (IAGREE.EQ.0) GO TO 2
      EDIST=SQRT(FLOAT((XO(NTHIS)-IGOALX(IS,IAGREE))**2 +
     1   (YO(NTHIS)-IGOALY(IS,IAGREE))**2))
      IF (ITIME.GT.1) GO TO 6
      PEDIST(NTHIS)=EDIST
6     ECHANG=EDIST-PEDIST(NTHIS)
      IF ((TCHANG.GE.0.).AND.(ECHANG.LE.0.)) GO TO 2
3     IEVAL=0
      GO TO 4
2     IEVAL=1
4     PTDIST(NTHIS)=TDIST
      PEDIST (NTHIS)=EDIST
      RETURN
      END
C
C
C
      SUBROUTINE UPDATE (XO,YO,NTHIS,NEWXO,NEWYO)
      INTEGER XO(20),YO(20)
      XO(NTHIS)=NEWXO
      YO(NTHIS)=NEWYO
      RETURN
      END
C
C
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 (20,20,2),INTLIM(20),LBYSTD(20),IHANDI
     1  (20),KNOWAY(20),IBYSTD(20),P(9),INTR(20)
      DIMENSION IDOOR(30,4),IDOPEN(30,30)
      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 (^ 100)
```

```
      WRITE    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= ',I2,4X,'Y=',I2)
102   FORMAT (24X,'NUMBER OF EXITS:  = ',I2)
103   FORMAT (24X,'NO. OF BARRIER PTS=',I3,/)
104   FORMAT (24X,'COORDINATES OF EXITS:  1  2  3  4  5  6  7  8  9 10',
     1 /)
105   FORMAT (43X,'X: ',10(I2,1X))
106   FORMAT (43X,'Y: ',10(I2,1X),/)
107   FORMAT (1X,'BARRIER-POINT MATRIX:',/)
108   FORMAT (2X,'X:',38(I2,1X),/,2X,'Y:',38(I2,1X),/)
109   FORMAT (1X,'(2) SYSTEM',/,24X,'NUMBER OF OCCUPANTS IN THE SPACE ='
     1 ,I3)
110   FORMAT (24X,'TOTAL NO. OF TIME INCREMENTS =',I3)
111   FORMAT   (24X,'RANDOM NUMBER STARTER         =',I3,/)
112   FORMAT (1X,'(3) OCCUPANT:',/,12X,'PARAMETER',5X,'OCC NO  1  2  3
     1 4  5  6  7  8  9 10 11 12 13 1 4 15 16 17 18 19 20',/)
113   FORMAT (12X,'INTLIM',15X,20(I2,1X))
114   FORMAT (12X,'LBYSTD',15X,20(I2,1X))
115   FORMAT (12X,'IHANDI',15X,20(I2,1X))
116   FORMAT (12X,'KNOWAY',15X,20(I2,1X),/)
117   FORMAT (2(1X,120('*'),/))
118   FORMAT (1X,120('*'),/)
119   FORMAT (1X,'TIME = ',I3,/)
120   FORMAT (6X,'PRIOR',18X,'EXIT',89X,'NEW',/,1X,'OCC',2X,'LOCAT',17X,
     1'AGREED',87X,'LOCAT',/,1X,'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,I2,1X,I2,4X,I1,6X,I1,6X,I2,3X,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,I2,4X,I1,6X,I1,6X,
     1   I2,33X,9(F5.3,1X),4X,I2,1X,I2)
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,I2,5X,I2,1X,I2,7X,I1,8X,30(I2,1X))
127   FORMAT ''X,I2,3X,I2,1X,I2,4X,I1,106X,I2,1X,I2)
```

```
6     RETURN
      END
C
C
C
      SUBROUTINE HBIAS (P)
      DIMENSION P(9)
      DO 10 K=1,9
      P(K)=0.0
10    CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE EVAL20 (MXTIME,MK,XO,YO,XE,YE,NTHIS,IAGREE,
     1   ITIME,C,IEVAL)
      INTEGER XO(20),YO(20),XE(10),YE(10),XT,YT
      MXT=MXTIME/MK
      IF (IAGREE.EQ.0) GO TO 5
      TEST=SQRT(FLOAT((XO(NTHIS)-XE(IAGREE))**2+
     1   (YO(NTHIS)-YE(IAGREE))**2))
5     CONTINUE
      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: ESCAPE-PENALTY:
20    IF (ITIME.LE.MXT) GO TO 21
      TIME=ITIME
      XTIME=MXTIME
      TDIST=XTIME-TIME/C
      GO TO 22
21    XDIST=XTIME-(FLOAT(MXT))
      TDIST=XDIST
22    IF (TEST.LE.TDIST) GO TO 51
      GO TO 50
C: THREAT-EVASION PENALTY:
30    QTEST=SQRT(FLOAT((XO(NTHIS)-XT)**2+
     1   (YO(NTHIS)-YT)**2))
      IF (ITIME.LE.MXT) GO TO 31
      TIME=ITIME
      TDIST=TIME/C
      GO TO 32
31    TDIST=0.0
32    IF (QTEST.GE.TDIST) GO TO 51
50    IEVAL=0
      RETURN
51    IEVAL=1
      RETURN
      END
C
C
```

```
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)
      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
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)
      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
7     PTDIST(NTHIS)=TDIST
      PEDIST(NTHIS)=EDIST
      RETURN
      END
C
C
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)
      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   CONTIN'
```

```
      IF ((X   Q.XE).AND.(YK.EQ.YE)) GO TO 2
      IF (JA    ).LT.IALLOW) GO TO 2
      GO TO 3
2     IENTER(K)=1
      GO TO 100
3     IENTER(K)=0
100   CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE 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)
      DIMENSION P(9),IDOOR(30,4),POPEN(20)
      INTEGER XO(20),YO(20),XK,YK,TOTBAR
C
C: DETERMINE WHETHER OCC(I) ENCOUNTERS A DOOR:
C
      K=0
5     K=K+1
      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
C: DOOR IS ENCOUNTERED:
C
4     IX=I
      MDOOR=K
C
C: IF DOOR IS ALREADY OPEN, RETURN:
C
      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
C: OCC(I) OPENS CLOSED DOOR:
C
      IDOOR(I,4)=1
      RETURN
      GO TO 999
C
C: OCC(I) LEAVES DOOR CLOSED:
C
6     P(MDOOR)=0.0
C
C: OCC(I) CHOSES TO LEAVE DOOR CLOSED:
C: REDISTRIBUTE MOVE PROBABILITIES:
C
      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   X0,Y0,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   X0,Y0,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
C
C
C
      SUBROUTINE DOORS2 (ITIME,NTHIS,IHANDI,INT,IBYSTD,IEVAL,
     1   X0,Y0,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)
C
C: DETERMINE WHETHER OCC(I) CLOSES (A MANUAL) DOOR BEHIND HIM:
C
      IF (MDOOR.EQ.0) GO TO 999
```

```
      IF (MO'   EQ.MDOOR) GO TO 1
      GO TO ...
1     IF (IDOOR(IX,3).EQ.0) GO TO 2
      GO TO 999
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
C
C
C
      SUBROUTINE 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)
      DIMENSION INTNUM(20),INTLIM(20)
      DIMENSION INTR(20)
      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.PI2) GO TO 3
      IF (X.LT.PI0) 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
C
C
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(20,30),YOB(20,30),XO(20),YO(20)
      IF (IBACK(NTHIS).EQ.0) GO TO 1
      IF ((XO(NTHIS).EQ.INITXO(NTHIS)).AND.
     1   (YO(NTHIS).EQ.INITYO(NTHIS))) GO TO 3
1     IBACK(NTHIS)=IBACK(NTHIS)+1
      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)
      NEWXO=XOB(NTHIS,KTIME)
      NEWYO=YOB(NTHIS,KTIME)
      RETURN
3     INTR(NTHIS)=0
      IBACK(NTHIS)=0
      RETURN
      END
C
C
C
      SUBROUTINE TRACE (IXTRCE,IYTRCE,NTHIS,ITIME,NUMOCC,
     1   TOTIME)
      DIMENSION IXTRCE(20,30),IYTRCE(20,30)
      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,I2,10X,I2,4X,I2)
4     FORMAT (1X,120('*'))
5     FORMAT (1X,120('*'),//,55X,'END OF TRACES',//,
     1   1X,120('*'))
      RETURN
      END
C
C
C
      SUBROUTINE PASSG (IDPASS,IDOOR,XO,YO,NTHIS,
     1   ND,NEWXO,NEWYO)
      DIMENS' ' IDPASS(20),IDOOR(30,4)
```

```
      INTEGE'  'O(20),YO(20)
      IXPASS  .IEWXO+XO(NTHIS))/2
      IYPASS=(NEWYO+YO(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
5     IDPASS(NTHIS)=IDPASS(NTHIS)+1
10    CONTINUE
      RETURN
      END
C
C
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',28X,'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
C
C
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
      K=MOVE
      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
$BEND
```

This Appendix provides the user with basic information needed to run a simulated fire event with BFIRES. As described elsewhere in the report, the user must provide four basic types of input data. These are:

(1) data which define or describe the layout of the building floor under study;

(2) data which define or describe initial environmental conditions;

(3) data which describe individual differences among occupants in the simulated fire event; and

(4) data which initialize system functions.

Two tasks are required in the preparation of a BFIRES input file. These are the determination or selection of actual numerical values which describe the simulated event, and the organization of these data into the appropriate machine-readable format. Value selection is described below. Input format requirements are described in Table D.1, and a sample data file is provided in Table D.2. A glossary if input variable names is given in Table D.3.

D.1 Floor-plan Description

Certain data must be input to describe the desired floor-plan, as a whole (refer to Figure D.1). These are:

(1) the number of exits from the floor (NUMEXT);

(2) the x,y coordinates of each exit (XE[e] and YE[e]);

(3) the total number of rectangular spaces (e.g., rooms) comprising the floor (NSPACE);

(4) the location of doors ($IDOOR_1$ gives x coordinates, $IDOOR_2$ gives y coordinates);

(5) door type, i.e., manually versus automatically closing ($IDOOR_3$); and

(6) the total number of doors on the floorplan (ND).

Other descriptive data will relate specifically to a given space within the floor-plan, and these data must be read-in on a space-by-space basis (refer to Figure D.1):

(1) the total number of exits from the space (NE);

(2) the total number of wall-defining coordinate points required to enclose the space (NPOINT);

(3) x,y coordinates of wall-defining points ($IBAR_1$ gives x coordinates, $IBAR_2$ gives y coordinates);

(4) exit-goal points outside each exit from the space (IGOALX (e) gives x coordinates, IGOALY (e) gives y coordinates);

(5) overall x boundaries of the space (XLO gives lowest x value, XHI gives highest x value);

(6) overall y boundaries of the space (YLO gives lowest y value, YHI gives highest y value).

D.2 Initial Environmental Conditions

Two initial conditions are provided. These are:

(1) the x,y coordinates of the threatened exit (XT and YT); and

(2) the status of each door on the floor-plan, i.e., whether it is initially open or closed ($IDOOR_4$).

D.3 Occupant Description

The specification of seven conditions are required to describe each occupant in the simulation:

(1) interruption limit, i.e., the maximum number of interruptions the occupant will respond to (INTLIM);

(2) bystander intervention limit, i.e., the maximum number of interventions an occupant will engage in (LBYSTD);

(3) the occupant's mobility status (IHANDI);

(4) the occupant's familiarity with an exit from the floor (KNOWAY);

(5) the occupant's location on the floor (XO gives the x-coordinate, YO gives the y-coordinate); refer to Figure D.2;

(6) the probability that the occupant will open a closed door (POPEN); and

(7) the probability that the occupant will close an open door passed through (PCLOSE).

D.4 System Initialization

Before a simulation run may be conducted, several additional parameters must be initialized. These include:

(1) the maximum number of occupants permited in a single spatial location at any given time (IALLOW);

(2) the desired print-out option (REPORT);

(3) the desired status evaluation option (EVLOPT); see default values below;

(4) the total number of occupants in the simulation (NUMOCC);

(5) the total number of time-frames to be run (TOTIME);

(6) the random number seed (IRAND);

(7) the total number of replications of a given simulation desired (NUMREP);

(8) the probability of encountering a backtracking interruption (PI2);

(9) the probability of encountering no interruptions (PI0).

For the current version of BFIRES, the following default values must be used:

(1) EVLOPT = 1

(2) MXTIME = 0

(3) MK = 0

(4) C = 0

TABLE D.1. Input Data Sequence and Format

DATA LINE	FORMAT
IFMT*	(20A4)
JFMT*	(20A4)
KFMT*	(20A4)
XT,YT,NUMEXT,MXTIME,NSPACE,EVLOPT,MK,C,IALLOW,ND,REPORT	(5(I2,1X),2(I1,1X),F1.0,2(1X,I2),1X,I1)
XE(1),XE(2),XE(n),YE(1),YE(2),YE(n)**	(IFMT)
Repeat the following sequence for each space designated on the floorplan:	
NE, NPOINT	(IFMT)
$IBAR_1$ [x coord's of all grid points lying on a wall]	(JFMT)
$IBAR_2$ [y coord's of all grid points lying on a wall]	(JFMT)
IGOALX [as many x coord's as there are exits from the space], IGOALY [as many y coord's as there are exits from the space]	(IFMT)
XLO,XHI,YLO,YHI	(IFMT)
$IDOOR_1$ [x coord's of all door centers on the floorplan]	(JFMT)
$IDOOR_2$ [y coord's of all door centers on the floorplan]	(JFMT)
$IDOOR_3$ [for each door on the floorplan]	(JFMT)
$IDOOR_4$ [for each door on the floorplan]	(JFMT)
NUMOCC,TOTIME,IRAND,NUMREP,PI2,PIØ	(2(I2,1X),I5,1X,I2,2(1X,F4.2))
Repeat the following line for each occupant in the simulation:	
INTLIM,LBYSTD,IHANDI,KNOWAY,XO,YO,POPEN,PCLOSE	(KFMT)

Notes: * user-supplied format statements
** up to NUMEXT, the total number of exits from the floor

TABLE D.2. Sample Input File

TYPE OF INPUT DATA		ACTUAL INPUT FILE
(1) User-supplied format statements		(20(I2,1X)) (20(I2)) (3(I1,1X),3(I2,1X),2(F3.2,1X))
(2) Threat, exit, and system data		02 04 02 05 14 1 3 1 10 15 0 10 02 04 04
(3) Space-defining data:	Space #1	01 07 03 4 5 5 5 3 3 01 1 1 2 3 3 2 04 04 04 04 03 05 01 03
	Space #2	01 07 05 6 7 7 7 5 5 01 1 1 2 3 3 2 06 06 04 04 05 07 01 03
	Space #3	01 07 07 8 9 9 9 7 7 01 1 1 2 3 3 2 08 08 04 04 07 09 01 03
	Space #4	01 07 0910111111 9 9 01 1 1 2 3 3 2 10 10 04 04 09 11 01 03
	Space #5	01 07 11121313131111 01 1 1 2 3 3 2 12 12 04 04 11 13 01 03
	Space #6	01 07 13141515151313 01 1 1 2 3 3 2 14 14 04 04 13 15 01 03
	Space #7	01 07 15161717171515 01 1 1 2 3 3 2 16 16 04 04 15 17 01 03
	Space #8	01 07 03 5 5 5 4 3 3 05 5 6 7 7 7 6 04 04 04 04 03 05 05 07
	Space #9	01 07 05 7 7 7 6 5 5 05 5 6 7 7 7 6 06 06 04 04 05 07 05 07

(3) Space-defining data, continued:

```
Space #10    01 07
             07 9 9 9 8 7 7
             05 5 6 7 7 7 6
             08 08 04 04
             07 09 05 07
Space #11    01 07
             0911111110 9 9
             05 5 6 7 7 7 6
             10 10 04 04
             09 11 05 07
Space #12    01 15
             1112131515151515141312111111111
             05 5 5 5 6 7 8 9 9 9 9 9 8 7 6
             14 14 04 04
             11 15 05 09
Space #13    01 15
             1517181919191919181716151515l5
             05 5 5 5 6 7 8 9 9 9 9 9 8 7 6
             16 16 04 04
             15 19 05 09
Space #14    02 17
             03 5 7 9111315171715131211 9 7 5 3
             03 3 3 3 3 3 3 3 5 5 5 5 5 5 5 5 5
             18 02 04 04
             03 17 03 05
```

(4) Door-defining data

```
03 4 6 810121416171614l0 8 6 4
04 3 3 3 3 3 3 3 4 5 5 5 5 5 5
00 0 0 0 0 0 0 0 0 0 0 0 0 0 0
00 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

(5) System data

```
08 30 08895 05 0.10 0.80
```

(6) Occupant data

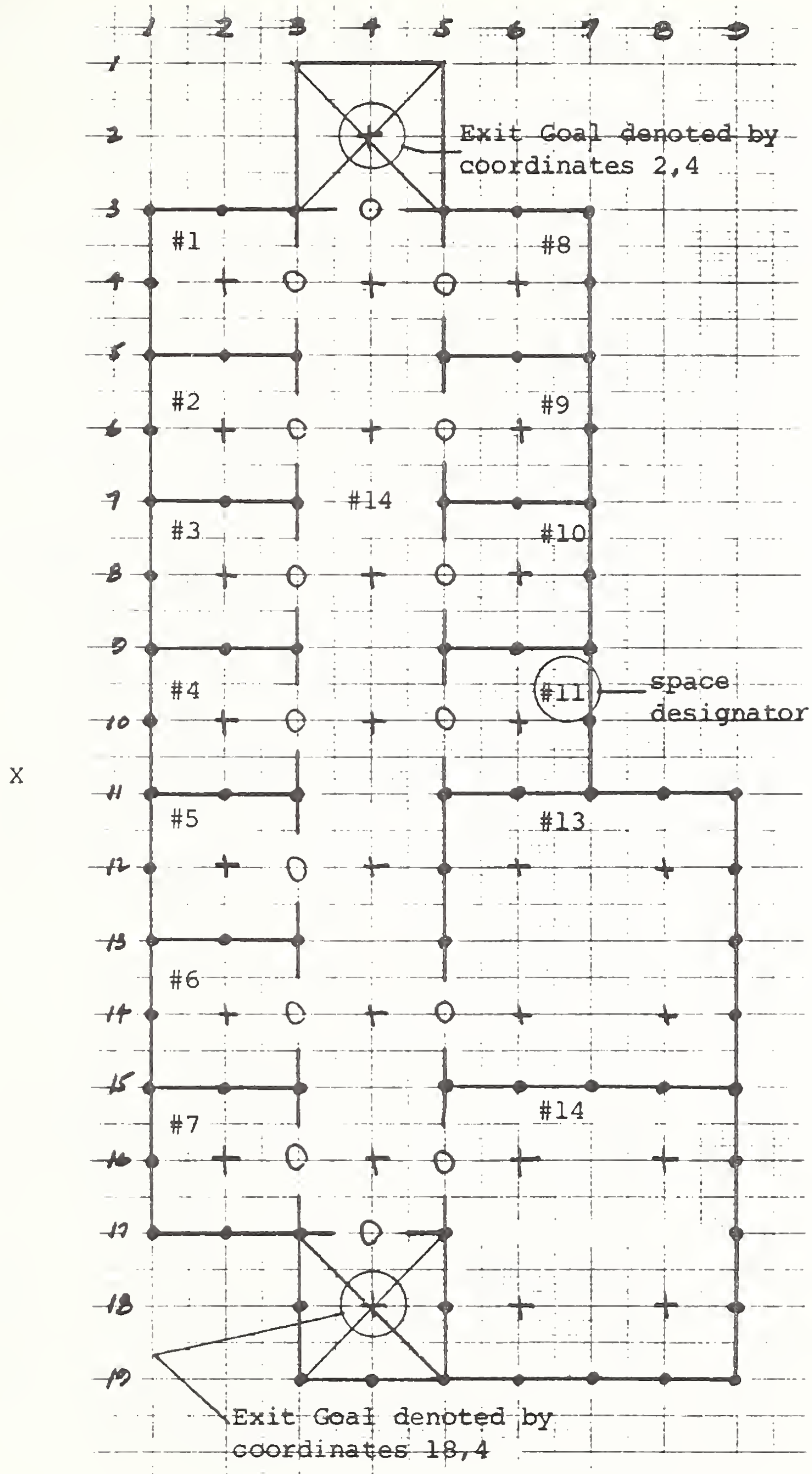
```
3 3 1 01 14 02 .25 .25
3 3 0 01 14 02 .75 .75
3 3 1 01 14 02 .25 .75
3 3 0 01 14 02 .75 .25
5 3 0 01 14 02 .25 .25
5 3 1 01 14 02 .75 .75
5 3 0 01 14 02 .25 .75
5 3 1 01 14 02 .75 .25
```

TABLE D.3. Glossary of Input Variable Names

LABEL	DEFINITION	FORMAT
C	This parameter must be specified whenever EVAL2Ø is called	F
EVLOPT	Evaluation subroutine option selector: 1 = EVAL8 2 = EVAL2Ø	I
IALLOW	Maximum number of occupants allowed in a given space, during a single time-frame	I
$IBAR_1$	X coordinate of a wall point	I
$IBAR_2$	Y coordinate of a wall point	I
$IDOOR_1$	X coordinate of a door center	I
$IDOOR_2$	Y coordinate of a door center	I
$IDOOR_3$	Door-type designator for a given door: 0 = manual 1 = automatically-closing	I
$IDOOR_4$	Initial position of a door: 0 = closed 1 = open	I
IGOALX	X coordinate of an exit goal from a space	I
IGOALY	Y coordinate of an exit goal from a space	I
IHANDI	An occupant's mobility status: 0 = mobile 1 = immobile	I
INTLIM	An occupant's interruption limit	I
IRAND	Random number seed [any 5 digit odd number]	I
KNOWAY	An occupant's knowledge of a "best exit": 0 = no knowledge 1 = exit #1 2 = exit #2	I
LBYSTD	An occupant's bystander intervention limit	I
MK	This parameter must be specified whenever EVAL2Ø is called	I
MXTIME	This parameter must be specified whenever EVAL2Ø is called	I

TABLE D.3, continued:

LABEL	DEFINITION	FORMAT
ND	Number of doors on the floorplan	I
NE	Number of exits from a space [max = 2]	I
NPOINT	Number of wall-defining points for a given space	I
NSPACE	Number of spaces designated on the floorplan	I
NUMEXT	Number of exits from the floor [max = 2]	I
NUMOCC	Number of persons initially on the floor [max = 20]	I
NUMREP	Number of replications of a run desired	I
PCLOSE	Probability that an occupant will close an open door	F
PIØ	Probability of no interruption encountered during t	F
PI2	Probability of encountering/initiating back-tracking during t	F
POPEN	Probability that an occupant will open a closed door	F
REPORT	Print-out option selector: 0 = print-out traces and totals only 1 = print-out time-frame reports and door-status summaries, only	I
TOTIME	Number of time-frames desired in the rum [max = 30]	I
XE	X coordinate of an exit from the floor	I
XHI	High X coordinate of a space	I
XLO	Low X coordinate of a space	I
XO	X coordinate of an occupant's location at time t = 1	I
XT	X coordinate of the threatened exit	I
YE	Y coordinate of an exit from the floor	I
YHI	High Y coordinate of a space	I
YLO	Low Y coordinate of a space	I
YO	Y coordinate of an occupant's location at time t = 1	I
YT	Y coordinate of the threatened exit	I



Legend:

—●— Coordinate points which describe wall locations

— ○ — Coordinate points which locate doors

+ Coordinates of person-occupiable locations

FIGURE D.1 Describing the Floor-plan for the Computer, in X,Y Space

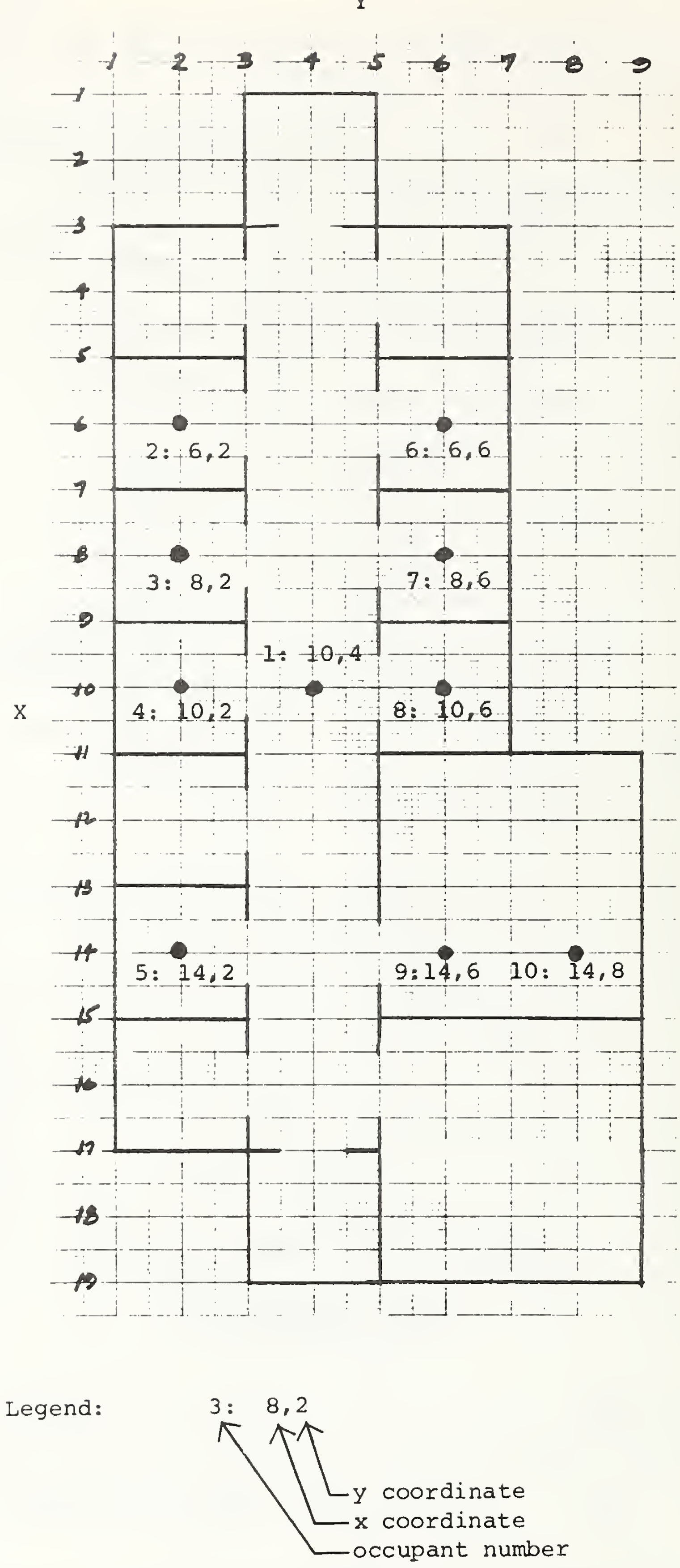


FIGURE D.2 Locating Occupants on the Floor-plan

FEDERAL INFORMATION PROCESSING STANDARD SOFTWARE SUMMARY

01. Summary date (Yr. Mo. Day): 7 8 0 8 1 7

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

03. Summary action: New [X] Replacement [ ] Deletion [ ]

Previous Internal Software ID

04. Software date (Yr. Mo. Day): 7 8 0 7 2 1

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
- [X] Computer Program
- [ ] Subroutine/Module

09. Processing mode

- [ ] Interactive
- [X] Batch
- [ ] Combination

10. Application area

General

- [ ] Computer Systems Support/Utility
- [X] 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	16. Computer operating system	17. Programing language(s)	18. Number of source program statements
UNIVAC 1108	EXEC 8	FORTRAN V	1153

19. Computer memory requirements	20. Tape drives	21. Disk/Drum units	22. Terminals
28.62 K 36-bit words			

23. Other operational requirements

24. Software availability: Available [X] Limited [ ] In-house only [ ]

NBSIR 78-1514, NTIS, Springfield Virginia 22151

25. Documentation availability: Available [ ] Inadequate [X] In-house only [ ]

26. FOR SUBMITTING ORGANIZATION USE

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

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 78-1514	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE	5. Publication Date
A Computer Simulation of Human Behavior in Building Fires: Interim Report	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, D.C. 20234	10. Project/Task/Work Unit No. 7400504 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address (*Street, City, State, ZIP*) Same as item 9	13. Type of Report & Period Covered Interim Report: 2/77 - 2/78 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

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 interim report presents the conceptual development, structure, and function of BFIRES, a computer program designed to simulate human movement behavior during building fires. The basic model underlying BFIRES is derived from a non-stationary, discrete time Markov Process. This model postulates that occupants construct their emergency responses and behavioral decisions dynamically, in response to continually changing social and environmental information fields. The simulation of this process is accomplished through BFIRES, a computer program written in FORTRAN V. Directions for further study are discussed.

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 psychology; architectural research; building fires; computer-aided design; fire computer program; fire research; fire safety; human performance; model documentation; modeling technique; programming; simulation.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[X] Unlimited [ ] For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	131
[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 [X] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $7.25

USCOMM-DC 29042-P74