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...me-Based Capabilities of Occupants to Escape Fires in Public Buildings: A Review of Code Provisions and Technical Literature

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

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Home and Public Building Safety Division
U.S. Fire Administration
Federal Emergency Management Agency
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TIME-BASED CAPABILITIES OF OCCUPANTS TO ESCAPE FIRES IN PUBLIC BUILDINGS: A REVIEW OF CODE PROVISIONS AND TECHNICAL LITERATURE

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ABSTRACT

This document reviews available technical literature pertaining to exit facility design and emergency escape provisions of the National Fire Protection Association's Life Safety Code (1976 Edition) in order to determine the technical support for such provisions. The report focuses on the time-based capabilities of building occupants to effect rapid evacuations, in relation to evacuation time available during fires. A number of functional criteria are examined in relation to Code provisions influencing the design of means of egress and fire protection and protective signalling systems for places of assembly, residential occupancies, mercantile occupancies, and business occupancies. Provisions affecting fire exit drill and building management practices are also considered. The technical literature bearing on applicable Code provisions is reviewed, the validity and generalizability of findings presented in the literature are discussed, and the degree of technical support currently available for egress provisions of the Code are evaluated. In addition, gaps in the technical literature are identified, and recommendations regarding future research are offered. Finally, preliminary conclusions about the supportability of Code provisions are presented.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

1. OVERVIEW

1.1 PROBLEM

This report reviews available technical research pertaining to the exit facility design and emergency escape provisions of the National Fire Protection Association's Life Safety Code (1976 Edition, hereafter referred to as the Code), in order to determine the technical support for such provisions. The central foci of the investigation are the time-based capabilities of building occupants to effect rapid evacuations, in relation to evacuation time available during fires. A number of functional criteria (e.g. maximum travel distance, building configuration, remoteness of exits, and bariers to egress flow) are examined in relation to Code provisions influencing the design of means of egress and fire protection and protective signalling systems for places of assembly, residential occupancies, mercantile occupancies, and business occupancies. Provisions affecting fire exit drill and building management practices are also considered.

1.2 TECHNICAL APPROACH

To effectively treat this broad problem, the current report organizes Code provisions and related technical discussions in relation to areas of potential impact, including provisions affecting: (1) pre-emergency training and preparation (Chapter 2 of the report), (2) the perception of the emergency environment and recognition of egress facilities (Chapter 3), (3) egress strategy formation (Chapter 4), (4) disciplined egress behavior and crowd movement (Chapter 5), (5) occupants' capabilities to safely and rapidly negotiate egress ways (Chapter 6), and (6) the capacity of means of egress (Chapter 7).

Within each chapter of the report, provisions of the Code which have a common area of potential impact, and human behavioral assumptions underlying these provisions, are enumerated. The technical literature bearing on these provisions and assumptions is presented, including references to applicable theories and models, pertinent empirical data from published experiments and field studies, and where appropriate, anecdotal accounts of actual fire events. The validity and generalizability of findings presented in the literature are discussed, and the degree of technical support currently available for egress provisions of the Code is evaluated. In addition, each chapter provides a summary of gaps in the technical literature, recommending specific areas for future research. Finally, preliminary conclusions regarding the supportability of Code provisions in each impact area are offered. A summary of the major conclusions presented in the report follows.

2. SUMMARY OF MAJOR CONCLUSIONS PRESENTED IN THE REPORT

2.1 A CAUTIONARY NOTE

The intention of NBS researchers is not to pass judgment on the validity and usefulness of Code provisions. Indeed, where technical support for individual provisions, or more precisely human behavioral assumptions underlying these provisions, is either weak or unavailable, the authors do not recommend eliminating or otherwise modifying these provisions. In such instances, rather, the authors suggest that code-writers approach the task of revision with caution, and that further technical investigations be conducted.

2.2 PROVISIONS AFFECTING PRE-EMERGENCY TRAINING AND PREPARATION

Behavioral assumptions underlying code provisions affecting pre-emergency training and preparation are evaluated by reference to psychological models of learning, experimental data reported in the psychological literature, and the growing body of evidence from post-incident fire investigations. To date, experimental and post-incident investigations provide mixed conclusions concerning the supportability of these assumptions. Moreover, available evidence does not often permit direct inferences to be drawn between research findings and the specific questions raised by code provisions. Future modifications to provisions affecting pre-emergency training appear to require additional research on the role of training and its relation to emergency behavior.

2.3 PROVISIONS AFFECTING PERCEPTION OF THE EMERGENCY ENVIRONMENT, AND RECOGNITION OF EMERGENCY FACILITIES

A number of human behavioral assumptions about the perception of emergency environments and the recognition of egress facilities underlie various provisions of the Life Safety Code. These assumptions are evaluated by reference to several models of perception, to limited data from experiments on visibility, and to a small body of evidence from post-incident fire investigations. Taken as a whole, available data neither support nor refute behavioral assumptions about occupants' emergency perceptions at a level technically sufficient to permit a thorough evaluation of pertinent Code provisions. Where data are available in sufficient quantity, however, it has been suggested that behavioral assumptions underlying alarm provisions of the Code tend not to be supported. The Code provision specifying a maximum (10 second) switchover delay between standard and emergency lighting, on the other hand, tends to be supported by available technical data. Initial emergency perceptions are important, and their relationship to rapid escape has been shown. Consequently, future research which leads to more effective perceptions of the fire environment by victims is recommended.

2.4 PROVISIONS AFFECTING EGRESS STRATEGY FORMATION

A number of assumptions about human information processing and decisionmaking behavior during fire emergencies underlie several provisions of the Life Safety Code. Such assumptions are evaluated by reference to models of cognitive behavior, as well as to data from recent psychological research on way-finding behavior, environmental cue processing, disaster response, and stress. Few directly relevant technical data were found within the field of fire research itself. Taken as a whole, available technical knowledge is not sufficient to warrant statements specifically supporting or refuting Code provisions which may influence egress strategy formation. However, the literature generally supports the notion that the demands of occupying a burning building require individuals to efficiently extract information from the fire environment, and to formulate effective and timely decisions about what to do. Depending upon the design and layout of a building, and upon the nature of given fire conditions, these processes will consume some proportion of the time within which occupants must escape. Errors in judgment and decisionmaking will frequently consume even more time. However, crucial gaps in current knowledge about the time-based capabilities of building occupants to effect rapid emergency escape continue to center about questions of emergency information processing and strategy formation.

2.5 PROVISIONS AFFECTING DISCIPLINED EGRESS BEHAVIOR AND CROWD MOVEMENT

A number of human behavioral assumptions about crowd movement and disciplined group behavior underlie selected provisions of the Code. These assumptions are evaluated by reference to several models of human collective behavior, data from research in experimental social psychology, field research on natural disasters, and post-incident fire investigations. In general, the technical literature suggest support only for those assumptions pertaining to leadership and direction-taking behavior. Behavioral assumptions pertaining to the effects of occupant loading and physical obstacles upon orderly and rapid crowd movement appear to be neither supported nor refuted by available technical literature. To the extent that impediments to crowd movement result in maladaptive collective behavior and panic, future research on the role of building design in facilitating crowd movement seems an essential percursor to Code revision.

2.6 PROVISIONS ACCOMODATING OCCUPANTS' CAPABILITY TO SAFELY AND RAPIDLY NEGOTIATE EGRESS WAYS

Human behavioral assumptions which underlie Code provisions relating to occupants' capability to safely and rapidly negotiate means of egress are evaluated by reference to biomechanical models of human movement, toxicological research, stair and ramp use field studies, physiological measurements, and anecdotal evidence from actual fire incidents. At present, much of the evidence reported in the experimental and nonexperimental literature on occupants' capabilities presents contradictions and mixed opinions, and does not permit specific conclusions or inferences to be drawn. As a result, there appears to be no analytical basis upon which to unequivocally support or refute applicable Code provisions. It is left for future research to determine the specific domains (i.e., occupancies and fire scenarios) under which particular data are valid and useful in this context.

2.7 PROVISIONS GOVERNING THE CAPACITY OF MEANS OF EGRESS

A number of human behavioral assumptions underlying Code provisions which govern the capacity of means of egress are presented. These assumptions are evaluated by reference to several models of pedestrian movement, data from laboratory and field studies of walking behavior during normal occupancy conditions, and observations of stair use during fire exit drills in high-rise office buildings. With regard to Code provisions affecting the design of doors, available technical literature support only those assumptions concerning the deleterious effects of particularly severe constrictions or obstructions. However, behavioral assumptions underlying provisions governing the design of corridors and stairs find challenge within the technical literature. This is especially true of provisions depending on the validity of assumptions about the linearity of pedestrian movement and the 22 inch (0.56 m) unit width standard. Because there remain differences in reported data describing pedestrian behavior on stair and level surfaces, inconsistent definitions of important variables, and nonstandardized techniques for measuring the performance of means of egress, it is not now possible to either support or refute exisitng provisions and their underlying behavioral assumptions on the basis of the available technical literature. The most important objectives for future research on the subject of the capacity of means of egress are: (1) the development and validation of standardized measures and measurement methods, and (2) the systematic analysis of complete egress systems, emphasizing transitions between means of egress elements.

1. INTRODUCTION

A predominant motivating factor behind America Burning (National Commission on Fire Prevention and Control, 1973) was the potential for multifatality fire tragedies in buildings. Accordingly, a primary goal of the Home and Public Building Safety Program of the United States Fire Administration is to ensure that up-to-date and feasible criteria are implemented to provide for life safety in public occupancy buildings, including multifamily residential occupancies, places of assembly, mercantile occupancies, and business facilities. The three most obvious alternative approaches to providing life safety from fire in buildings involve rapid emergency escape, protection of occupants in place, and rescue. The study reported here focusses only on the problem of rapid emergency escape.

Many building code provisions influencing emergency escape have remained virtually unchanged since important research was reported by the National Bureau of Standards (NBS) in 1935. In general, these provisions govern the design and capacity of means of egress (or, egressways), and are based upon empirically derived relationships between pedestrian flow, egressway capacity, and escape time. Since then, several of these relationships have been called into question. For example, it has become more widely believed that occupants usually do not move through stairways and other egress channels in regemented fashion at constant speeds (although the computation of egress way capacity often requires this assumption), that fire products can move into and thereby contaminate exit stairwells not carefully designed to prevent smoke infiltration, and that many buildings of substantial size or population cannot be completely evacuated rapidly. Moreover, researchers and life safety design professionals have learned that early warning devices, pre-emergency training, and various social, psychological and organizational factors each play an important--although not fully understood--role in rapid emergency egress. Finally, it has also become more widely accepted during recent years that functional variations between occupancy categories, and the differing needs of people with varying escape capabilities, both affect emergency readiness and the ability to evacuate buildings efficiently. Many of these problems were first discussed by Stahl and Archea (1977) of the Center for Building Technology, NBS, in their original assessment of the technical literature on emergency egress from buildings. Since that time, various issues have been expanded and investigated by numerous other investigators at NBS and elsewhere[1].

1.1 PROBLEM

The principal lessons to be learned from research conducted during the last 10 years on human responses to fires are that individual design provisions, which

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[1] A substantial portion of the research on emergency egress and human behavioral aspects of life safety from fire is discussed later in this report. Consequently, individual investigators are not listed here.

usually embody professional engineering judgment and responses to specific disasters, and (1) are not consistently applicable under all conditions or circumstances, or (2) are not consistently supportable by reference to the technical literature. Thus, analyses of means of egress design provisions (e.g. Rivers and Bickman, 1979; Stahl and Archea, 1977) reveal that underlying behavioral assumptions are often expected to hold under a relatively broad range of conditions, and that empirical support for the validity of these assumtions is frequently difficult to identify. The problems of identifying relevant technical literature and of applying it to the verification of current means of egree design provisions are key issues addressed by the present study.

1.2 OBJECTIVES AND SCOPE

The primary objective of the present investigation is to assess available research pertaining to exit facility design and emergency escape criteria of the National Fire Protection Association's (NFPA) Life Safety Code (1976 Edition, hereafter referred to as the Code), in order to determine the technical support for such criteria. A secondary working goal is to identify human behavioral assumptions believed to underlie egress and related provisions of the Code. By gaining an understanding of occupant behavior patterns implicit in compliance with various Code provisions, the project staff felt better able to evaluate individual provisions against state-of-the-art technical data, and thereby better able to verify currently promulgated egress requirements. The purpose of these activities is to provide a technical foundation from which substantive modifications to egress provisions may eventually be made.[2] In preparing this report, the intention of NBS researchers is not to pass judgment on the validity of the Code. Where technical support for given provisions is either weak or unavailable, the authors do not recommend eliminating or otherwise modifying these provisions. In such instances, rather, the authors suggest that code-writers approach their task with caution, and that further technical investigations be conducted.

The central foci of the investigation are the time-based capabilities of building occupants to effect rapid evacuations, in relation to evacuation time available during fires. Numerous functional criteria were studied, including: (a) maximum travel distance; (b) building configuration; (c) remoteness of exits; (d) barriers to egress flow (e.g., railings, security devices, doorways); (e) illumination of means of egress and of directional signs; (f) egress channel carrying capacity; (g) the ability to totally evacuate a building, in terms of competition for available space, and in terms of physiological and psychological fatigue.

Such functional criteria are specifically treated within various chapters of the Code, and provisions from the following Code chapters were selected for evaluation: Chapter 5, Means of Egress; Chapter 6, Features of Fire Protection (specifically, provisions concerning protective signaling systems); Chapter 8, Places of Assembly; Chapter 11, Residential Occupancies; Chapter 12, Mercantile

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[2] Recommendations for modifying provisions of the Code lie outside the scope of the present report.

Occupancies; Chapter 13, Business Occupancies; and Chapter 17, Operating Features (specifically, provisions concerning fire exit drills and building management practices).

1.3 ORGANIZATION OF THE REPORT

During the course of the project an attempt was made to posit a model of emergency escape behavior, and to functionally relate provisions of the Code to such a model. Principal components of this time-based model included: sensation and perception of emergency environmental cues, interpretation of emergency cues, strategy formation and decisionmaking, action initiation, and action completion (generally after models suggested elsewhere by Bickman, Edelman and McDaniel, 1977; Stahl, 1978a, 1979, 1980; and others). However, organizations based upon a time-based model of human response were found incapable of accommodating numerous important code provisions. For example, provisions governing the management of fire exit drills, or the carrying capacity of stairs, could not easily be addressed by reference to a model of human perceptual and cognitive behavior. Moreover, useful models of human response to fires are necessarily dynamic: environmental cues are received and assessed not once at the outset of an event but continuously; action strategies are not rigidly adhered to but change as events unfold and as new information becomes available to occupants. Indeed, the task of relating existing design provisions to emergency egress dynamics is one of enormous complexity (especially since available models are largely hypothetical) and was judged to lie outside the immediate scope of the study.

Egress provisions and their underlying behavioral assumptions were, however, found to cluster with respect to more or less naturally occurring categories within the Code, including provisions: affecting pre-emergency training and preparation (Chapter 2 of the current report); affecting the perception of the emergency environment, and recognition of egress facilities (Chapter 3); affecting egress strategy formation (Chapter 4); affecting disciplined egress behavior and crowd movement (Chapter 5); accommodating occupants' capabilities to safety and rapidly negotiate egress ways (Chapter 6); governing the capacity of means of egress (Chapter 7). In order to simplify the presentation of egress provisions, underlying behavioral issues, and supporting technical material, therefore, the report is organized about these categories.

Each of the six technical Chapters (Chapters 2 through 7) provides a complete analysis of a single class of Code provisions. These Chapters are organized as illustrated below with reference to hypothetical Chapter n:

n.1 APPLICABLE CODE PROVISIONS

This section lists provisions of the Code pertaining to the technical issue treated by the Chapter.

n.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

This section presents a set of human behavioral assumptions hypothesized to underlie Code provisions enumerated in section n.1.

n.3 COMMENTARY

n.3.1 Problem. A succinct description of the problem or class of problems addressed by applicable provisions of the Code.

n.3.2 Underlying behavioral models. Theories and models selected from the behavioral science (and other related) literature to provide a framework for understanding emergency events, and for guiding the development of design solutions.

n.3.3 Assessment of behavioral assumptions based on the technical literature. (1) literature review; (2) discussion of strengths and weaknesses of the technical literature.

n.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

This section reviews areas for future research, and summarizes the usefulness of available studies in analyzing provisions of the Code.

n.5 SUMMARY

This section provides an overall review of the Chapter, and highlights specific conclusions.

1.4 TECHNICAL APPROACH

1.4.1 Study Design and Task Organization

The study was designed to analyze egress related design requirements of the Code, from the standpoint of occupants' abilities to rapidly escape buildings during fires. The goal of the analysis was to determine the extent to which Code provisions influencing the escape potential of buildings can be technically supported on the basis of state-of-the-art knowledge of time-based human capabilities during fire emergencies. It was recognized at the outset that in many cases the needed technical data are either not available, or else inconclusive. Therefore, another important objective of the research design was to identify gaps in the available technical base, and to recommend areas for further empirical investigation. The investigation reported here is a continuation and expansion of preliminary work on human behavioral aspects of the Code funded by the NBS Center for Fire Research and conducted by Loyola University of Chicago (Rivers and Bickman, 1979).

To effect the goals of the study, the following tasks were undertaken: (1) The Code was reviewed and escape related provisions were identified. (2) Human behavioral assumptions seen as potentially underlying egress provisions were hypothesized by the project staff. (3) An initial set of hypothetical behavioral assumptions was distributed among members of a peer review panel for detailed comment, and on the basis of this review, initial hypotheses about behavioral assumptions were modified and refined. (4) A comprehensive review of technical literature pertaining to human behavior during fires and other emergencies, and to other salient problems in the behavioral sciences was conducted.

(5) Egress provisions and related behavioral assumptions were organized into logical categories, and the extent to which provisions and assumptions are supported by evidence in the technical literature was assessed. The literature review and peer review tasks are discussed in more detail below.

1.4.2 Literature Review

Rivers and Bickman (1979), in their assessment of behavioral assumptions underlying Code provisions, relied almost entirely upon technical literature on human behavior during fires. Referring to the newness of this field of study and to various methodological shortcomings, these investigators cautioned that indeed few conclusive inferences could be drawn from available data in this impoverished area. Ongoing objectives of the current investigators in discussing behavioral aspects of egress provisions, therefore, have been to draw upon salient theoretical concepts from various areas of the behavioral sciences, and to cite pertinent empirical data from the nonfire related psychological literature, in order to amke inferences about probable behavior in fires.

1.4.3 Behavioral Assumptions Peer Review Procedure

The project sought to determine the degree to which emergency exiting provisions of the Code may be supported by reference to state-of-the-art knowledge about the time-based escape capabilities of building occupants. Implicit in this goal is the notion that "hidden" expectations, or assumptions, about human behavior during fire emergencies, and about the abilities of occupants to perform as expected, underlie many design provisions. In the current context behavioral assumptions refer to those patterns of occupant response that a building designer or code official might reasonably assume will occur, (implicitly or explicitly) under prescribed design conditions, in the event of a fire. For example, if an "EXIT" sign of particular characteristics is specified, the designer or code official may be thought to assume that, in general: (1) during fires many occupants in fact look for and use "EXIT" signs, and (2) the specified design characteristics influence the utilization of such signs in some positive fashion.

To evalute Code provisions on the basis of human capabilities, therefore, seemed to require a thorough identification and assessment of underlying behavioral assumptions. It became apparent to the project staff, moreover, that evaluating the technical support for behavioral assumptions believed to underpin individual provisions or sets of provisions, yielded the most direct and effective means of evaluating behavioral aspects of Code provisions themselves.

As indicated earlier, the project staff hypothesized a set of assumptions it believed underlie selected provisions of the Code. To avoid the liklihood that these assumptions reflected only the biases and experience of the project staff, to ascertain that the Code itself was not being misunderstood, and to elicit useful ideas from other life safety professionals, a peer review procedure was developed. This procedure involved distributing a specially designed review package among more than 20 professionals in government, industry, and academia. The review package displayed all provisions of the Code included in the study, along with various hypothesized behavioral assumptions pertaining to each[3]. Respondents were instructed to review the sets of provisions and assumptions, noting any changes, corrections, additions, or new ideas. Statements of behavioral assumptions appearing later in this report reflect the recommendations of the peer review panel. Members of the panel are listed in Appendix A; instructions distributed with peer review packages are provided in Appendix B.

1.5 SUMMARY

This report addresses the time-based capabilities of building occupants to effect rapid emergency escape during fire situations, and in particular, documents the availability of technical support for egress related provisions of the NFPA Code (1976 edition). These provisions were noted to cluster with respect to six distinct categories, and each category is treated within a separate chapter of the report.

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[3] In some instances, several assumptions were listed for a single provision. In other cases, a single assumption pertained to a set of provisions.

2. PROVISIONS AFFECTING PRE-EMERGENCY TRAINING AND PREPARATION

2.1 APPLICABLE CODE PROVISIONS

17-1.2.1.1[4] Every required exit access and exit discharge shall be continuously maintained free of all obstructions or impediments to full instant use in the case of fire or other emergency.

17-1.4.1 Fire exit drills conforming to the provisions of this chapter of the Code shall be regularly conducted in occupancies where specified by the provisions of this chapter, or by appropriate action of the enforcing authority having jurisdiction, but with any necessary modifications in detail of procedures to make the drills most effective for their intended purpose in any individual building.

17-1.4.2 Fire exit drills, where required by the authority having jurisdiction shall be held with sufficient frequency to familarize all occupants with the drill procedure and to have the conduct of the drill a matter of established routine.

17-1.4.3 Drills shall include suitable procedures to make sure that all persons in the building, or all persons subject to the drill, actually participate.

17.1.4.4 Drills shall be held at unexpected times and under varying conditions to simulate the unusual conditions obtaining in case of fire.

2.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

2.2.1 Assumptions Relating to the Ability to Predict Occupant Responses During Real Fires

(1) The likelihood that people will panic, behave maladaptively and increase the risk to themselves and others is a clear and constant threat (17-1.4)[5].

(2) During Fire emergencies, people are often confused or lack disipline, and hence may require lengthy time periods for evacuation; properly conducted fire exit drills result in more orderly and disciplined behavior during real emergencies, and thereby help to reduce needed evacuation time (17-1.4).

(3) Disciplined and orderly behavior during fire emergencies are more important than the actual speed with which people evacuate themselves (17-1.4.4).

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[4] Numbers refer to provisions of the NFPA Life Safety Code, 1976 Edition.

[5] Numbers refer to Code provisions enumerated in the previous section of this chapter.

2.2.2 Assumptions Relating to the Transfer of Responses Learned During Drills to Actual Fire Situations

(1) People are more likely to exit rapidly, and are less likely to panic or respond maladaptively during actual fires, when fire exit drills are practiced frequently (17-1.4).

(2) People respond appropriately and effectively during real fires when they have participated in properly conducted fire exit drills (17-1.4).

(3) Effective emergency behavior becomes habituated through frequent participation in properly conducted fire exit drills (17-1.4.2).

(4) Occupant's responses during particular emergencies will be most rapid and effective if drill training accurately simulates a variety of potential fire scenarios (17-1.4.6).

2.2.3 Assumptions Relating to Occupants' Attitudes About Drills

(1) If occupants do not take drill participation seriously, they may not behave effectively during actual fire emergencies (17-1.4.4).

(2) Some individuals may not take drill procedures seriously if other persons are excused from participation (17-1.4.5).

2.2.4 Assumptions Relating to the Accommodation of Training Procedures to the Diversity of Potential Fire Scenarios

(1) Occupants will be better prepared by fire exit drills and similar training in occupancies in which controlled discipline is present (as in schools or hospitals) (17-1.4).

(2) Behaviors learned and practiced during drills designed for one type of occupancy may not be effective in emergencies in other occupancies (17-1.4.1).

2.3 COMMENTARY

2.3.1 Problem

Code provisions affecting pre-emergency training and preparation are intended to prepare people for actual emergencies, reduce the probability of maladaptive behavior during fires, and increase the likelihood of effective egress or movement to refuge areas. The general notion underlying many of these provisions is that behavior patterns learned during training situations transfer to actual fire events. Following from this supposition, behavioral assumptions underlying these provisions address four principal areas of concern: (1) the ability to predict occupant responses during actual fire emergencies; (2) the relevance and transferability of responses learned during fire exit drills to actual fire situations; (3) occupants' attitudes toward the value of fire exit drills and other forms of pre-emergency training and preparation; (4) the ability of fire exit drill procedures and management to predict and accommodate the diversity of potential fire scenarios in various occupancies. Several established models of human learning within the behavioral sciences offer useful perspectives on the role of training in promoting adaptive emergency behavior. Three important models are considered below.

2.3.2 Underlying Behavioral Models

Three approaches to learning which offer useful insights into the problem of pre-emergency training are the instrumental conditioning or reinforcement approach, the social learning approach, and the cognitive approach. The most basic and best known of these is the instrumental conditioning approach. This approach assumes that, with learning, the individual acquires a connection between a specific environmental stimulus and a particular behavioral response. The person has an active role in creating the environmental conditions which strengthen the stimulus-response connection. When an individual provides the proper response under certain stimulus conditions, the result is a "reward" (or reinforcer) of some kind. The reinforcer, which can be either learned or unlearned, strengthens the association between the stimulus and the response. It is this strengthening to which the term "learning" refers in instrumental conditioning.

Numerous experiments on the conditioning of laboratory animals and human subjects have demonstrated that: (1) learning may generalize, i.e., a particular learned connection may transfer to other stimuli or responses; (2) subjects may be taught to discriminate stimuli and thereby limit learned connections to very specific situations; (3) learning may be lost, or extinguished, if the connection between stimulus and response is weakened by discontinuing reinforcement.

The first category of assumptions addresses the ability to predict occupant responses during real fires. One theory of instrumental conditioning that has implications for this category is Clark Hull's systematic behavior theory (Hilgard and Bower, 1966). In Hull's view, learning a response and performing it are distinguished. Moreover, motivational factors, such as physiological needs, anxiety, and fear, play a central role in learning. To illustrate an application of these ideas: If a fire in a building creates high levels of anxiety or fear among occupants, these occupants are likely to have difficulties learning new and appropriate behaviors with which to deal with the emergency. Habitual ways of responding, under the pressure of motivational factors, are likely to be performed and could result in inappropriate activity. However, if occupants were well-drilled in fire emergency procedures, that is, had a well-learned response or habit associated with fire emergency situations, then the motivational factors created by the fire are likely to result in the vigorous performance of the learned emergency procedure (Hilgard and Bower, 1966).

The second category of behavioral assumptions addresses the expectation that fire exit drills prepare occupants to respond effectively during actual fire events. For example, fire exit drills in elementary schools have been based upon an instrumental conditioning approach: students are conditioned to respond to an alarm stimulus (e.g. a bell or buzzer), and when the stimulus is presented the students respond by performing a prescribed sequence of actions designed to result in rapid egress from the school building. Reward for successful performance during drills may take the form of praise from the teacher, early dismissal from class, etc. Generalization also is illustrated in the school exit drill. Should the alarm bell malfunction on one occasion, for example, a teacher's call of "FIRE" is likely to elicit the appropriate sequence because the alarm bell and the teacher's call share the same meaning for students. From an instrumental conditioning viewpoint, the overall objective of exit drill training is to establish behavior sequences which lead to rapid and orderly evacuation. It is generally assumed that if such patterns can be established through a program of exit drills, then the learned behaviors will transfer to actual fire events in schools and other occupancies so long as the different settings share conditions associated with the learned activity.

Another category of behavioral assumptions considers the ability of fire exit drill planners and emergency managers to predict and accommodate the diversity of potential scenarios in various occupancies. The instrumental conditioning approach, for example, suggests that if persons are trained only to behave in a particular manner within a given building, they may respond adaptively during fires in that building (or within very similar buildings) only. On the other hand, this approach suggests that training can also be specially designed to permit the generalization of learning to other building types, or alarm modes, and other fire scenarios.

Social learning approaches to understanding behavior are often built on instrumental conditioning concepts. Social learning approaches emphasize the role that other persons play, as individuals or groups, as sources of reward or of punishment. These approaches are predicated on the assumption that as social animals, humans depend on others for help in achieving rewarding goals and in avoiding punishing ones. Therefore, what others say and do can influence an individual's behavior. That is, people are effective sources of reward and punishment for one another. These concepts are often used by social psychologists to explain the relations among individuals and the operation of groups (see Shaw and Costanzo, 1970, chapters 2-4). Thus, people learn to follow an instruction from a person in authority because of the rewards that compliance may bring and to avoid the punishments or costs of noncompliance. The rewards (and costs) come from both the authority and from the achievement (or nonachievement) of desired goals. With regard to group effects, groups offer interaction with other members and aid in meeting shared goals that can be sources of rewards and costs. The rewarding effects of group membership make one member a source of satisfaction to other members, make the group attractive, and encourage members to remain in the group (Shaw and Costanzo, 1970, chapter 4).

Imitative learning is another important feature of social learning (McLaughlin, 1971). By observing other people, individuals learn both how and when to respond. Imitative behavior may be directly rewarded by other persons, who approve of how a given individual has responded. It may also be rewarded vicariously, as when an individual observes the rewards or costs another person received for a given response. Imitation has also been referred to as observational learning and modeling. It applies to the learning of emotional responses and motor behavior, both of which are important elements in fire emergency situations. Some explanations of observational learning are based on instrumental conditioning principles (e.g. Gewirtz and Stingle, 1968). Others explained observational learning in terms of verbal and visual skills, and the performance of such responses in terms of instrumental conditioning and motivational factors (e.g. Bandura, 1965). Thus, if a person is seen to be rewarded for an action, the observer is more likely to perform this action than if the person was punished for that action. Studies suggest that people tend to imitate others who control resources (i.e. have power), such as people high in status or in positions of authority.

Social learning principles apply to the transfer of responses learned during drills to actual fire situations. If the individual has been rewarded for fire drill performance as part of a group, and if the individual wishes to maintain the rewards (e.g., praise, esteem) that come from group membership, then during other drills or an actual emergency the person is likely to do what has been taught. This behavior is even more likely if others are also doing what they have been taught. This is because doing what others are doing is an activity that could lead to escape (which is rewarding), and which is rewarded for helping the group by not performing disruptive (e.g. maladaptive) actions for others (McLaughlin, 1971).

Social learning principles also apply to the ways in which attitudes toward drills are learned. A learning-theory approach to social behavior developed by Homans (1961) considers the role of distributive justice in this context. Simply stated, people expect a fair exchange in their dealings with other individuals. The more a person puts into a given social interaction (referred to as the costs of interaction), the more the individual expects to get out of the transaction (referred to as the rewards of interaction). Thus, if all the people asked to participate in a fire exit drill are called away from an activity perceived to be more preferable than the drill, the drill is likely to represent a cost. If one person does not attend the drill, those who do attend, by comparison, may have incurred proportionately greater costs. According to Homans (1961), persons who are disadvantaged in an exchange will become angry. This effort can be reflected as disinterest in future drills ("why should _I_ attend if others don't?"). It could also be reflected in anger toward those responsible for enforcing drill attendance or toward those individuals who would not attend.

Pre-emergency training based upon social learning concepts might take advantage of relationships between occupants and leaders or legitimate authority figures, and would emphasize the training of these leaders. Such leaders, once trained, could serve as models for observational learning of emergency egress procedures, among other techniques for instruction. The availability of such individuals, and the likelihood that appropriate relationships will exist within a given building, depends considerably upon the nature of the occupancy. The proper personnel and conditions may exist with an elementary school or nursing home, for example, but not within an apartment building, hotel, or shopping mall.

In contrast with conditioning concepts and social learning approaches (which are also rooted in conditioning principles), the cognitive approaches to learning tend to underplay the role of conditioning, specific stimulus-response connections, and physiologically-based motives. Instead, they emphasize types of learning that result in an individual's understanding of social and environmental events (Shaw and Costanzo, 1970, chapter 7). Tolman, a major learning theorist, conducted research suggesting that people learn about their environment through repeated exposure to (i.e., familiarization with) it, even in the absence of explicit reward systems (Hilgard and Bower, 1966).

Much more recently the cognitive approach has been applied to understanding the ways people learn to understand and negotiate the architectural environment (Ittelson, Proshansky, Rivlin, and Winkel, 1974, chapters 4 and 5; Evans, Fellows, Zorn, and Doty, 1980). In this view, the process of learning is frequently linked with human information processing which involves: (1) perception and information gathering; (2) mediation or "filtering" of environmental stimuli stimuli in accordance with a person's goals and traits; (3) allocation and retention of environmental information in short- and long-term memory; (4) formulation and implementation of specific action strategies as required by current environmental events, (5) evaluation of actions against goals. These cognitive activities form and reform mental images, or "cognitive maps" of environmental situations, within people's minds. As people are required to respond to specific events, they test their cognitive maps against the reality of the event. As more experience with a particular class of events is gained, individuals' cognitive maps more accurately reflect reality and provide better preparation for adaptive behavior. Learning, then, is viewed within cognitive theory as the development of processes by which information is assimilated, processed and utilized, and by which the environment is effectively accommodated. Training programs based on this view frequently stress the need to expose individuals to relevant sets of experiences, and to match these experiences to individuals' level of development. Children, or adults with developmental disabilities, for example, may extract considerably less (or different) information from a given environmental event (whether an actual fire emergency or a drill simulation) than might average adults.

Conditioning principles were applied with reference to assumptions regarding the expectation that fire exit drills prepare occupants for emergency egress during a real fire. However, certain occupancies, such as health care and custodial care facilities, may require a cognitive approach. Such facilities present circumstances marked by mobility or cognitive impairments of occupants, and by the presence of a cadre of supervisory personnel. Under these conditions, emergency training often includes lectures, films and other methods of sensitizing staff personnel in addition to practice performance during fire exit drills (Bickman, Herz, Edelman, and Rivers, 1979). Unlike the situation in schools, pre-emergency training in health care institutions seems to follow the cognitive approach to learning, which emphasizes the development of skills intended to promote effective decisionmaking in response to unique and unpredictable events. For example, the decision as to whether patients should first be evacuated or doors should first be closed requires staff personnel to formulate an action strategy on the basis of their current evaluations of specific conditions. Thus, training for this type of occupancy may stress the accommodation of emergency procedures to the demands of unpredictable fire situations. As with conditioning, it is assumed with the cognitive approaches to training that lessons learned during drills or from films will transfer appropriate response patterns to actual fire crises.

Cognitive learning models are also useful in understanding the role of participants' attitudes toward training. These models stress the importance of individuals' experiences, levels of development, goals, motivations, values, and beliefs. Thus, a cognitive approach to pre-emergency training might attempt to change individuals' own motivations, attitudes, and beliefs about fires and the need for training, in addition to training specific responses.

Pre-emergency training based on a cognitive approach to learning may also lead to both situation-specific and generalized training programs. Programs may be specifically designed to reflect potential scenarios within a given building type, and to take into account the capabilities of a particular class of occupants. Or programs may be designed to equip people with fundamental life safety knowledge useful during almost any fire scenario in almost any building type.

In summary, human behavioral assumptions believed to underlie Code provisions affecting pre-emergency preparation and training are discussed in relation to three general models of human learning. While each model presents a somewhat different explanation of learning processes, each one seems useful in understanding the problems associated with fire emergency training, and in evaluating behavioral assumptions believed to underlie applicable provisions of the Code. The next section of this chapter discusses the behavioral assumptions in relation to data presented in the technical literature.

2.3.3 Assessment of Behavioral Assumptions Based on the Technical Literature

Literature review. Assumptions stated in section 2.2.1 assert that panic is a likely response to a fire emergency and that there is a need to prevent panic behavior during fire emergencies. Before presenting arguments supporting these assumptions based on the technical literature, it is important to discuss panic as a psychological concept.

Although many investigators have addressed the topic of panic, the term "panic" lacks a clear, widely accepted technical definition. There are at least two views about what panic means. The more common view stresses the irrational roots of, and maladaptive responses to panic. This view is endorsed by Melinek and Baldwin (1975), Janis and Mann (1977), Phillips (1978), and Schultz (1967). A second, far less common view, stresses the rational nature of what is called panic. In this view panic is an adaptive but thoroughly self-serving attempt to gain a desired personal outcome (i.e., escape) even at the cost of sacrificing others to the existing, oncoming danger or threat (Burstein, 1969). This view is consistent with research on panic by Brown (1965), Mintz (1951), and Kelley, Contry, Dalhke, and Hill (1965). In either case, these views suggest that if there is panic, it is more likely that there will be unncessary victims than if there is no panic.

Arguments supporting the assumptions about panic are based primarily upon post-incident accounts of actual fires, and find additional basis in the experimental literature on panic behavior. For example, the 1903 Iroquois Theater fire is frequently cited as a case in which irrational panic behavior (including simply remaining in one's seat throughout the fire) is believed to have claimed some 602 lives, although the building itself was not completely destroyed. Galbreath (1969) related the probability of panic (which he did not define in behavioral terms) to available egress capacity in a building. He suggested that panic may occur in buildings where stair enclosures have been designed to accommodate 50 percent of the population of a given floor, as was recommended by NBS (1935).

Relationships between occupants' perceptions of their own safety, the amount of time available for safe escape, and the likelihood of panic behavior have been stressed by several researchers. Melinek and Baldwin (1975) suggested that after a 2.5 minute waiting period, people are likely to panic, and engage in maladaptive, ineffective behavior. Janis and Mann (1977), Kelley et al. (1965), and Phillips (1978) all have emphasized the importance of actual or perceived time on the probability of panic behavior. An examination of Janis and Mann's (1977) argument may suggest why time plays a critical role in creating panic. According to these investigators, panic arises when time is perceived as insufficient for finding or using a means of escape from a serious, oncoming threat. In such instances, people tend to deal ineffectively with available information, and their thoughts frantically focus on too narrow a range of alternatives. Wrapped in thought, these people are likely to further underestimate available time. In this regard, studies have found that there is a decrease in the perceived duration of an event when judgments of time intervals are made while people are performing tasks which draw attention away from the passage of time (Dember and Warm, 1979). This potentially vicious cycle is likely to invoke actions which are counterproductive and maladaptive, unless environmental conditions improve.

The importance of leadership and supervision in producing adaptive responses during fire emergencies was discussed in section 2.3.2. Experiments conducted for the Central Intelligence Agency (Klein, 1976) found that orderly discipline channeled through a hierarchical organizational plan was essential to successful egress. Schultz (1967) concluded from his experiments that dependent persons may tend to respond maladaptively to life threats when leadership or supervision is absent. Reporting on the tragic Andraus Building fire in Sao Pualo, Brazil, Willey (1972) noted that a rescue helicopter was almost destroyed by a panicking crowd on the building's roof. A second helicopter landed successfully when firefighters were first lowered to the rooftop to control the crowd, clear a landing area, and assure those waiting that they would be rescued.

The concepts of leadership and social control can be put into a larger perspective, and one consistent with social learning (particularly modeling) principles. Kelley et al. (1965) who experimentally examined panic behavior, found that if volunteers faced with a serious personal threat learned that some of their peers were willing to wait their turn in a queue in order to escape, and if these peers had experience with escape and were trustworthy sources of guidance, then successful escape was likely and the probability of panic decreased. These results underscore the importance of social control, and of the disciplined response to a threat, on successful emergency escape. These findings also suggest that there is potential uncertainty about how others will react to an oncoming threat: Will they respond in a self-serving way, or take their turn in a queue? If other individuals make clear their intentions to behave in a disciplined fashion, then this may serve to reduce uncertainty and thereby reduce the likelihood of panic.

A number of investigators, however, have argued against panic as a real and likely threat. Pauls (1979), for example, has contended that contrary to popular opinion, panic responses are rare even where people perceived the situation to be potentially or actually dangerous. In a study of fires in health care institutions, Haber (1977) found no incidents of panic-like behavior. Wood (1972), in his investigation of nearly 1,000 fires noted that only about 5 percent of all persons interviewed claimed to have engaged in behavior judged to increase personal risk. In recent studies modeled after Wood's work, Bryan (1977) also found little evidence to support the notion that panic is a frequent occurrence. Best (1978), Canter, Breaux, and Sime (1978), and Swartz (1979) also presented evidence to support the view that panic is infrequent.

Assumptions enumerated in section 2.2.1 not only stress the importance of panic as a problem, but also suggest that the threat of panic may be reduced through fire exit drill training. No direct evidence of this relationship was found in the technical literature. However, Bryan's (1977) post-hoc studies of actual fires suggest that pre-emergency training in the form of exit drills did produce more disciplined egress behavior. Also, Kelley et al. (1965), in their experiments on panic behavior, indicated that conditions such as drills, which lead people to be self-confident in their belief that they will successfully escape, can decrease the extent of panic behavior.

The general question of whether behavior patterns learned during drills and other forms of pre-emergency preparation transfer to actual emergency conditions was addressed by the assumptions enumerated in section 2.2.2. This question has been discussed in detail by a number of investigators, and in addition, researchers also have often stressed the importance of exit drill frequency. For example, reviewing the tragic Beverly Hills Supper Club fire, Best (1978) similarly argued that the lack of fire emergency training was a major cause of death and injury. However, there remains no direct experimental evidence of a transfer of training from drills to performance during actual building fire emergencies.

Rivers and Bickman (1979) analyzed selected provisions of the Life Safety Code (1976 edition), pointing out that once a particular sequence of emergency responses has been learned, it must be practiced. According to Bird and Docking (1949), participation in exit drills, however, is most likely to occur in buildings with a single, consistent occupancy. Moreover, to be predictive of responses during actual fires, fire exit drills must simulate actual emergency conditions as closely as possible (Rivers, 1978). This notion is supported by Garner and Blethrow (1970), who conducted experiments simulating emergency conditions in commercial aircraft. They argued that simulations approximating real emergencies could in fact be conducted, and that such simulations should prepare participants (e.g. aircraft crew personnel) to respond effectively in the event of a crash, fire, or other catastrophe. Observations drawn from Bryan's numerous post-hoc fire investigations suggest a similar conclusion. If actual emergency conditions are likely to be unique, then to avoid the possible confounding (interfering) effects of unique aspects of a fire emergency on performance during fire drills, simulated fire scenarios, time of day, exit route blocking, etc., should be varied during drill exercises. This idea is supported by the experiments of Posner and Keele (1968) on the value of high-variety learning in minimizing the effects of interfering events on task performance.

In such occupancies as nursing homes and hospitals, staff (in contrast to patient) drills are critical. In a review of two Pennsylvania hospital fires, for example, Lathrop (1978) credits frequent staff drills as the most significant reason for successful patient evacuations. Moreover, instances of multiple fatalities due to fires in health care facilities often have been attributed to the fact that these emergencies occurred during night time or early morning hours, when the smallest number of staff personnel were present.

Other arguments appear in the literature, however, which question the relationship between exit drill training and performance during actual fires. In their report on a fire at the National Institute of Health Nursing Home, Bryan and DiNenno (1979) suggested that the frequency of exit drills may have led to the belief by building occupants that the fire alarm signaled another drill, and not a real fire. According to Bryan and DiNenno, some occupants, apparently "tired" of drills, ignored the alarm signal and delayed the initiation of emergency procedures. Rivers and Bickman (1979) raised the point that people vary in their capabilities, and that what may be an effective practice exercise for one person may not be effective for another. Thus, the frequency of practice of a particular type of drill cannot, in and of itself, guarantee that adequate learning has taken place, or that adequate performance will take place during an actual fire emergency.

In summary, researchers' conclusions and opinions on the significance of exit drill frequency and on the design of particular training programs differ. Moreover, there appears to be no universally accepted opinion regarding the degree to which exit drills prepare building occupants to respond effectively during actual fires.

Section 2.2.3 enumerated assumptions relating to occupants' attitudes toward fire exit drills, and the effects of such attitudes upon performance during both drills and actual emergencies. Rivers and Bickman (1979) argued that unless drills are conducted properly and are taken seriously by participants, inappropriate behavior patterns may be rehearsed and learned. Bryan and DiNenno (1979) indicated that maladaptive responses may have resulted from the inconsistent participation of personnel in exit drill procedures.

Section 2.2.4 contains assumptions concerning the accomodation of training procedures to suit diverse occupancy conditions. Experiments discussed earlier by Schultz, Klein, and Kelley et al. all suggest that effective emergency response requires a social organization possessing leadership and discipline. Clearly, however, not all occupancies are characterized by organizational structures which possess these qualities. Moreover, few technical data appear in the literature (e.g. Lathrop, 1978) describing occupant performance during fire drills or actual fires in which disciplined, confident leadership was present.

Conventional wisdom currently holds that programs for pre-emergency training and preparation should be designed to meet the special requirements of various occupancies, and this is reflected in the Code. Evidence supports this assumption. For example, problems associated with evacuating handicapped persons in an acceptable period of time have been reported (Baldwin, Melinek, and Appleton, 1976). Additional evidence has been reported by the Federal Aviation Administration in connection with the evacuation of handicapped persons from commercial aircraft (Blethrow, Garner, Lowrey, Busby, and Chandler, 1977). Nevertheless, no evidence was found which documents the extent to which handicapped, incapacitated, or elderly persons avoid participation in drills, or which indicates specific consequences of their failure to participate. Thus, not only is there no technical data available addressing the conventional wisdom on drills with special user groups but no tests of emergency training programs have been conducted across various building occupancies.

In summary, researchers hold a variety of positions on the relationship between drill behavior and responses to real fires, on the significance of drill frequency, and on the design of individual training programs. Moreover, there appear to be no universally accepted conclusions regarding the degree to which exit drills actually prepare building occupants for potential life threats.

Strengths and weaknesses of the techical literature. Many of the behavioral assumptions underlying Code provisions affecting pre-emergency preparation and training deal with the notion of panic. The term "panic" lacks a widely accepted technical definition. For example, returning to a burning building to retrieve valuable possessions might be called panic by an observer, while thought to be an acceptable risk based on well-planned behavior by the individual performing these action. If panic is defined to result in mass flight or behavior which increases risk, then it is not surprising that Pauls, Bryan, and others noted so few examples. In the absence of a common technical definition of the panic response, reliable conclusions regarding either the predictability on occurrence of this response will be extremely difficult to obtain.

Experiments on behavior during stressful events conducted by Schultz (1967), Kelley et al. (1965) and Klein (1976) were all conducted under controlled laboratory conditions. These investigators obtained similar results under varying experimental conditions, and this supports their conclusions regarding conditions under which panic is likely and regarding the need for supervision and discipline. However, since important characteristics of actual life threats, such as fire emergencies, cannot be simulated in the laboratory, it is difficult to infer real-world emergency behavior from these studies.

The assertion that panic behavior is infrequent is supported by experimental findings, anecdotal accounts, and by observations reported during post-hoc interviews with fire victims and eyewitnesses. As the body of data from such post-hoc case studies grows, reliable statements regarding the nature and frequency of the so-called panic response may be possible. This process should be further aided by improvements in post-incident surveying and eyewitness interviewing technique (Loftus, 1980).

The literature addressing relationships between fire drill performance and behavior during actual emergencies is primarily nonexperimental. This literature presents two important difficulties for the analyst. First, although the frequency of exit drills is often discussed, drill frequency has not been treated as an independent variable in research design and data analysis. Second, no investigator has specifically measured the potential long-term effects of drill participation as a dependent variable. Hence, while it is possible (and potentially useful) to continue speculating about the magnitude and direction of relationships between drill performance, drill frequency, and emergency behavior, conclusions cannot now be substantiated.

Concerning the question of whether fire exit drills can adequately simulate real emergency conditions, Pauls' (1974) data from drills in high rise buildings and Garner and Blethrow's (1970) evacuations from simulated plane wrecks provide noteworthy data. These investigators learned, by analyzing questionnaires returned after the events, that a number of participants appeared to believe the drills to be "the real thing." For these persons, at least, creating the impression of an actual life threat may have provided opportunities to observe their own performance under actual conditions. It may be useful to test whether these individuals are better prepared during some future emergency than are those who believed the drill to be an artificial exercise.

The paucity of research on participants' attitudes toward fire exit drills, and on the need to accomodate training to specific occupancies makes it difficult to evaluate the strengths and weaknesses of individual studies at present. Several investigators have suggested hypotheses regarding these issues, but these remain to be evaluated. Specific directions for further research on pre-emergency training and preparation are discussed in Section 2.4.

2.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

2.4.1 Research on the Prediction of Occupants' Responses During Real Fires

Contrasting opinions appear to have emerged concerning the assumptions that so-called panic behavior is a clear and constant threat, and that the danger of panic can be minimized through effective pre-emergency training. Although experimental data exist which support these assumptions, a growing body of evidence from post-incident fire investigations suggests they are not well founded. Several important issues, however, have not been adequately treated in either the experimental or survey literature: (1) adoption of a standard definition of panic; (2) identification of environmental and situational cues and stimuli which affect the likelihood of panic (3) identification of perceptual and cognitive processes which lead to panic (e.g. time and distance-to-threat perception); (4) understanding the processes by which leadership and the channeling of tasks and responsibilities reduces the likelihood of panic; (5) specification of the relationship between pre-emergency training and the occurrence of panic; (6) specification of the relationship between the likelihood of panic and the nature of the occupancy.

2.4.2 Research on the Transfer of Training

Assumptions that behavior learned during drills transfers to actual fire situations remain to be empirically tested. While this problem presents complex methodological difficulties (e.g., neither trained nor untrained subjects can be randomly assigned to buildings which are later purposefully burned), the use of rigorous drill evaluation methods and the standardization of training procedures (as noted by Rivers and Bickman, 1979) may provide elementary controls which improve the reliability and validity of data from post-incident investigations. Carefully designed field experiments, involving appropriate safeguards for human participants, may ultimately be required to determine the extent to which transfer of emergency training occurs. Pauls' (1974) observations of evacuation drills in high-rise buildings, in which a number of participants believed actual emergencies were in progress, provide a useful model for the design of such experiments.

2.4.3 Research on Occupants' Attitudes Toward Exit Drills

The objectives of future research on the role of occupants' attitudes will be to: (1) determine correlations between attitudes toward drill participation, performance during drills, and in rare cases, performance during actual (or least perceived) emergencies; (2) determine ways by which adaptive behavior patterns can be effected through attitude change. Attitudes toward the value of pre-emergency training are complex phenomena, partly because they result from interactions between a person's history of experiences, physical capabilities, emotional and motivational predispositions, and personality makeup. For example, while a healthy adult who has never experienced a building fire may consider exit drills to be necessary and important, this person may be distressed to find other people joking and taking drills less seriously. A handicapped person working in a high-rise office building however, may view serious participation by all during an exit drill as the difference between life and death in the event of a real fire. Unfortunately, the psychological literature on the relationship between attitudes and behavior, and on the potential for effecting behavior change through attitude change, provides no sound basis for specific conclusions in the area of life safety.

2.4.4 Research on the Accommodation of Training Programs to Specific Occupancy Requirements

Assumptions suggesting that exit drills and training programs be designed to recognize differences between various occupancies may be relatively easy to test empirically. For example, studies modeled after Pauls' drill observations and Hertz et al's. analysis of training methods could be extended to permit analytical comparisons between building types, modes of occupancy and types of organizational structure, after various training procedures have been introduced.

2.5 SUMMARY

Behavioral assumptions underlying Code provisions affecting pre-emergency training and preparation may be evaluated by reference to psychological models of learning, experimental data reported in the psychological literature, and the growing body of evidence from post-incident fire investigations. To date, experimental and post-incident investigations provide mixed conclusions concerning the supportability of these assumptions. Moreover, available evidence does not often permit direct inferences to be drawn between research findings and the specific issues implied by code provisions. Future modifications to provisions affecting pre-emergency training appear to require additional research on the role of training and its relation to emergency behavior.

3. PROVISIONS AFFECTING THE PERCEPTION OF THE EMERGENCY ENVIRONMENT AND THE RECOGNITION OF EGRESS FACILITIES

3.1 APPLICABLE CODE PROVISIONS

5-2.1.1.1.2 Every door and every principal entrance which is required to serve as an exit shall be so designed and constructed that the way of exit travel is obvious and direct. Windows which because of their physical configuration or design and the materials used in their construction could be mistaken for doors shall be made inaccessible to the occupants by barriers or railings conforming to the requirements of 5-2.2.3.

5-5.2.2 Ways of exit access and the doors to exits to which they lead shall be so designed and arranged as to be clearly recognizable. Hangings or draperies shall not be placed over exit doors or otherwise so located as to conceal or obscure any exit. Mirrors shall not be placed on exit doors. Mirrors shall not be placed in or adjacent to any exit in such a manner as to confuse the direction of exit.

5-8.1.3 The floor of means of egress shall be illuminated at all points including angles and intersections of corridors and passageways, stairways, landings of stairs, and exit doors to values of not less than 1.0 foot-candle measured at the floor.

5-9.1.2 Where maintenance of illumination depends upon changing from one energy source to another, there shall be no appreciable interruption of illumination during the changeover. Where emergency lighting is provided by a prime mover-operated electric generator, a delay of not more than 10 seconds shall be permitted.

5-10.1.2 Access to exits shall be marked by readily visible signs in all cases where the exit or way to reach it is not immediately visible to the occupants, and in any case where required by the applicable provisions of Chapters 8 through 16 for individual occupancies.

5-10.1.3 Every required sign designating an exit or way of exit access shall be so located and of such size, distinctive color, and design as to be readily visible and shall provide contrast with decorations, interior finish, or other signs. No decorations, furnishings, or equipment which impair visibility of an exit sign shall be permitted, nor shall there be any brightly illuminated sign (for other than exit purposes), display, or object in or near the line of vision to the required exit sign of such a character as to so detract attention from the exit sign.

5-10.3 Illumination of Signs. Every sign shall be suitably illuminated by a reliable light source giving a value of not less than 5 foot-candles on the illuminated surface. Such illumination shall be continuous as required under the provisions of Section 5-8, Illumination of Means of Egress, and where emergency lighting facilities are required, exit signs shall be illuminated from the same source.

5-10.4.1.1 A sign reading "EXIT," or similar designation, with an arrow indicating the direction, shall be placed in every location where the direction of travel to reach the nearest exit is not immediately apparent.

5-10.4.1.2 Escalators, Moving Walks. A sign complying with 5-10.2 indicating the direction of the nearest approved exit shall be placed at the point of entrance to any escalator or moving walk that is not in a means of egress.

5-10.4.2.1 Any door, passage, or stairway which is neither an exit nor a way of exit access, and which is so located or arranged as to be likely to be mistaken for an exit shall be identified by a sign reading "NOT AN EXIT" or simi-designation or shall be identified by a sign indicating its actual character, such as "TO BASEMENT," "STOREROOM," "LINEN CLOSET" or the like.

6-3.4.1 Audible alarm indicating devices shall be of such character and so distributed to be effectively heard above the maximum noise level obtained under normal conditions of occupancy.

6-3.4.2 Audible alarm indication shall produce signals which are distinctive from audible signaling indicating devices used for other purposes in the same area.

6-3.4.3 Audible fire alarm devices as required by Chapters 8 through 16 other than voice communication shall be used only for fire alarm system purposes.

6-3.4.4 Visual alarm indicating devices may be used in lieu of audible devices, where permitted by Chapters 8 through 16.

6-3.4.5 Where a protective signaling system is required for purpose of evacuation, it shall be so installed as to provide effective warning of fire in any part of the building.

Exception: Where a building is divided by (1) fire walls into separate fire sections or (2) by other means with adequate safeguards against the spread of fire or smoke from one section to another, each section may be considered a separate building.

11-3.2.10.1 Any apartment building with 26 or more living units shall have emergency lighting in accordance with 5-9.

3.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

3.2.1 Assumptions Relating to the Effect of Door and Window Design Upon Egress Route Perception

(1) Occupants' perceptions of the obviousness and directness of the way of exit travel may be influenced by the design of doors and entrances; the design of these elements may affect egress time (5-2.1.1.1.2).

(2) While seeking, identifying, or using an egress way, occupants may mistake some improperly designed windows for doors, and thereby delay egress (5-2.1.1.1.2).

(3) Occupants' perception of proper egress route elements can be enhanced by providing physical barriers to windows when these are not elements of exit ways. Preventing the use of incorrect building elements during fires increases the likelihood that egress ways will be quickly recognized and effectively used (5-2.1.1.1.2).

(4) To facilitate rapid perception and recognition of egress facilities, occupants require unobscured visual access to ways of exit access. Mirrors or wall hangings on, over, or adjacent to doors leading to means of egress may obscure the means of egress and/or otherwise confuse occupants, and thereby lead to excessive evacuation time (5-5.2.2).

3.2.2 Assumptions Relating to the Affect of Illumination Level Upon Egress Route Identification

(1) Escaping occupants require the uniform illumination of egress way floor surfaces. One foot-candle, measured at the floor, is sufficient for emergency egress (5-8.1.3).

(2) Occupants' recognition of egress facilities requires the continuous illumination of various architectural and safety elements. Delays in the actuation of emergency lighting facilities greater than 10 seconds may reduce egress flow and jeopardize safe pedestrian movement (5-9.1.2).

(3) In multifamily residential buildings which require occupants to negotiate corridors en route to exits (as distinct from buildings which permit all occupants to exit directly to the outside), emergency lighting will facilitate evacuation and reduce egress time (11-3.2.10.1).

3.2.3 Assumptions Relating to the Role of Visual Signage and Directional Information in Egress Route Recognition and the Formation of Emergency Egress Strategies

(1) During fire emergencies occupants require visual access to exits or egress ways in order to achieve timely emergency egress. Where direct visual access is not possible, directional signs will achieve the same result (5-10.1.2; 5-10.4.1.1; 5-10.4.1.2).

(2) Occupants will be able to see directional signs in spaces infiltrated by smoke (5-10.1.2; 5-10.1.3).

(3) Occupants are more likely to see and use directional and exit marking signs when such signs are properly illuminated (5-10.3).

(4) Signs denoting that a door or pathway does <u>not</u> lead to an exit are sufficient to keep occupants along intended egress ways, and are effective in reducing overall egress time (5-10.4.2.1).

3.2.4 Assumptions Relating to the Ability of Audible and Visual Alarm Signals to Effectively Alert Building Occupants to a Fire Threat

(1) Occupants will receive an unambiguous alert of an actual fire danger from audible and visual alarm devices, and will take immediate and effective action upon hearing or seeing an alert signal (6-3.4.1 through 6-3.4.5).

(2) Occupants receive sufficient information from alarm devices to enable them to formulate effective response strategies in a timely manner (6-3.4.1 through 6-3.4.5).

3.3 COMMENTARY

3.3.1 Problem

In some instances, the design and implementation of emergency egress facilities for buildings may directly affect occupants' perceptions of the emergency environment and their recognition and consequent use of egress facilities. In general, provisions of the Code are intended to provide occupants with readily identifiable egress channels, facilitate rapid and accurate escape route determination, and confirm occupants' overall awareness and understanding of a fire emergency situation. These goals are based on the notion that the physical features of buildings and of certain fire safety system components can be designed to influence stimulus and cue detection, situation definition, and egress strategy formation in some positive manner, by building occupants.

Behavioral assumptions underlying Code provisions affecting occupants' perception of the emergency environment and their recognition of egress facilities focus on four principal issues: (1) the impact of door and window design on the perception of egress routes; (2) the effects of lighting level on the recognition and perception of escape routes; (3) the degree to which occupants depend upon visual signage and directional information while formating and executing egress strategies; (4) the ability of visual and audible alert signals to stimulate rapid situation definition and effective response strategy formation.

Models of perception which provide useful insight to the role of fire safety systems and building components in the emergency perception process are discussed below. Later in this chapter the models and supporting research findings are considered in relation to behavioral assumptions believed to underlie Code provisions affecting occupants' perception of the emergency environment and recognition of egress facilities.

3.3.2 Underlying Behavioral Models

Three models of perception offer perspectives on the process of egress facility identification. These are perceptual field theory (also called Gestalt Psychology), environmental information processing theory, and signal detection theory. Following a description of each model, its implication for one or more of the categories of assumptions enumerated in section 3.2 will be presented.

Perhaps the most widely known of these is perceptual field theory, which focuses upon the configuration or organization of sensory events (Dember and Warm, 1979). According to perceptual field theory, individuals perceive real world stimuli as patterns set within "fields," or backgrounds. Accordingly, objects are always viewed against a background which may provide varying degrees of contour, contrast and boundary to the figure. The nature of the background is thought to determine the clarity and distinctiveness with which a figure or object can be perceived. Figure-ground segregation, considered to be one of the most primitive aspects of perceptual organization, is not limited to visual phenomena but is applicable to other sensory modalities as well. In audition, for example, a melody may be perceived as a "figure" against a "ground" of harmony.

Empirical research based upon perceptual field theory generally suggests that physical objects, and the environment itself, can only be understood in terms of how they "appear" to the observer, rather than in terms of their actual (or objective) physical composition. Recent research in retinal organization, for example suggests that after stimulation, sensory receptors in the eye initiate an encoding process which requires some mediating mechanism to decode the information before a response can be offered (Ratliff, 1972). What is "perceived" is thus thought to be a synthesis of sensory data as mediated by past experience, cognitive style, expectation and other factors.

The perceived image may not correspond precisely to the pattern of environmental data encoded by retinal stimulation. For example, color is frequently used for contrast in exit signage because of its attention-getting capabilities (Dember and Warm, 1979). However, the traditional choice of red or green as opposed to other colors may lie less in the physical intensity of these colors than in their apparent brightness. A green exit light fixture is known to appear brighter than a blue one of equal physical intensity.

Perceptual field theory has implications for the first and third categories of assumptions in section 3.2. The first category of human behavioral assumptions concerns Code provisions for the design of doors and windows along egress routes, and generally presupposes some relationship between door and window design and egress route perception. Field theory suggests that color and form are critical factors affecting figure-ground discrimination. In an office setting, for example, in which corridors are bounded by glazed panels of equal size, shape and color, valuable escape time may be lost if doorways (which may or may not lead to a means of egress) consist of panels equivalent to fixed wall panels. Similarly, doors which reflect the color, texture or design of surrounding wall surfaces may also be difficult to discern quickly. These instances point to the need to make elements of egress routes visually distinct from nonegress elements.

The third category of assumptions concerns Code provisions for signage and directional information. In general, behavioral assumptions underlying these provisions hold that safe and rapid evacuation from public occupancy buildings depends in some way upon the proper use of directional information displayed on signs. The importance of contrast and contour to easy and rapid information perception is considered by field theory. To maximize the effectiveness of egress directional signs, accordingly, these signs must be designed and located so that information lettered on them is clearly distinguishable from background surfaces under various lighting conditions, and so that entire signs are clearly distinguishable from walls or other surfaces to which they are applied. Contrast and contour in visual imagery is perhaps even more critical in connection with pictographic, or symbolic directional signs now under consideration by the NFPA and other standards writing bodies (see Collins and Lerner, 1980).

Having its basis in perceptual field theory, the environmental information processing theory of perception suggests a mechanism which processes stimulus input by means of sequences of operations occurring in stages. These stages involve the encoding, storage, decoding and translation of information from the environment. But while field theory focuses upon the perception of the environment by passive individuals, environmental information processing theory suggests that observers be viewed as active participants in settings (Ittelson, et al., 1974). The perceptual exploration of a setting by any person uses all of the sensory systems through which the environment and the individual transact.

Frequently, environmental settings provide far more information than can possibly be processed by a given individual on a particular occasion. Such conditions of "information overload" have been shown to produce increased levels of stress and of maladaptive behavior. To deal with information overload, the individual uses criteria in order to select from available information. These selection criteria are determined by the person's own goals, expectations, and needs may be affected by the individual's beliefs about the probabilities of various events and of their outcomes.

When cues from the environment contradict a person's expectations and beliefs, the individual often must formulate some "best bet" response (Brunswik, 1956). For example, a brief fire in the World Trade Center in New York City produced smoke which was carried through the building's air-handling system. Although the fire was extinguished almost immediately and the public address system properly directed occupants to remain in place, the sight of smoke appears to have caused many occupants to ignore the verbal announcement. As a result, floors 9 through 22 were evacuated (Glass and Rubin, 1979). In this case, one stimulus (the verbal message) contradicted another, perceptually clearer source of information (seeing actual smoke). In the absence of less ambiguous instructions, and in view of the information actually available (the smoke itself), the "best bet" response appears to have been to evacuate the affected floors. Thus, perception seems to function as an integral element of the decisionmaking process by regulating the selection of information from the environment thereby reducing the degree of uncertainty with which an individual negotiates a given setting.

Environmental information processing theory has implications for the second, third, and fourth categories of assumptions in section 3.2.

The second category of assumptions concerns Code provisions addressing the level of egress route illumination. According to environmental information processing theory, the selection of environmental data for subsequent decisionmaking is a conscious task which not only depends upon the nature of the cues themselves, but also depends on the needs, goals, expectations and previous experiences of the participant. For example, it is quite common for an individual to feel uneasy upon entering a darkened stairway or corridor. It is not necessary for the person to have actually had the experience of tripping in the dark, or of being "mugged" in the past; most people have become well aware of such potential hazards through learning of other individuals' experiences. Accordingly, people sufficiently uneasy about entering dark passageways may simply not use them, until or unless the prevailing life threat is judged to be the more serious risk.

The third category of assumptions concerns Code provisions for signage and directional information. Environmental information processing theory suggests that individuals consciously select information from the environment in accordance with their unique goals and expectations. Thus, to the extent that directional signs are identifiable, legible, unambiguous, and consistent with occupants' expectations, information contained on them will be effectively incorporated within individuals' egress strategies. Ambiguous or inconsistent information may, however, also be assimilated, and it may result in inappropriate or ineffective egress movement. In addition to occupants' goals, expectations and previous experiences, stress has also been found to affect the rate of response to information provided by signs. Smillie (1978), for example, found that response times were faster for pictographic signs (e.g., shapes and figures) than for verbal signals when stress was introduced as a variable. This finding is clearly relevant to the fire emergency problem.

The fourth category of behavioral assumptions deals with Code provisions for alarm signals. One problem is the potential for "competition" between alarm signals and other features of the physical and social environments among which an individual's attention may be divided. Environmental information processing theory provides some basis for understanding this phenomenon. This model posits mechanisms which permit people to deal with a continual melange of potentially redundant, ambiguous, conflicting or contradictory information. These mechanisms provide data necessary for the interpretation of settings and events, and to the formulation of action strategies. According to the environmental information processing model, individuals cope with information overload by purposefully selecting those aspects of the environment which are judged to be relevant to their immediate goals, needs or expectations. Where environmental information is unambiguous and judged to be consistent with one's expectations, competition among various pieces of information will be relatively low and the individual is likely to attend to those environmental data most useful in attaining immediate objectives. Where environmental information is ambiguous or contradictory, however, it will be difficult for the individual to determine which data are most relevant. Consequently, the person's attention will be distributed among the various data sources. In especially complex or ambiguous settings, this division of attention is likely to result in reduced attention to each information source.

While rapid egress is certainly an essential goal for building occupants during a fire emergency, for example, it may well not be their only objective. Where occupants must divide their attention among alarm signals or specific vocal egress instructions and, say, other persons they perceive to be endangered, perception of alarm signal or instruction content may be significantly diminished. Similarly, the competition between vocal instructions and the contradictory sight of actual smoke could result in these instructions being virtually ignored by many building occupants (as occurred in New York's World Trade Center).

The theory of signal detection is a major recent innovation in thinking about the way in which information is processed in psychophysical studies. These studies have focused on the quantitative relations between changes in physical stimulation and concomitant changes in reported aspects of sensory experience (Dember and Warm, 1979). Early psychophysical research posited the concept of "threshold", which requires that before a given stimulus can be perceived by an organism that stimulus must have attained a certain physical intensity. The threshold notion implies two possible states: a detection state in which the stimulus or signal is present and above the threshold intensity, and a nondetection state in which the stimulus is either absent or below the threshold intensity. Signal detection theory diverges from this two-state notion. By postulating a multistate approach, it entirely avoids the threshold concept. According to the theory of signal detection, every perceptual event contains some degree of interference or "noise". This noise may eminate from a number of possible sources including personal and environmental sources. The concept of noise implies that the starting point for perception is a greater-than-zero level of sensation, and that the signal to be detected must always be distinguished from the background noise. Signal detection, then, is a process through which the stimulus of interest can be reliably and repeatedly distinguished from the background stimuli, so long as the perceiver has the needed sensory capacity. For signal detection to occur, it is believed that a criterion value for sensitivity to the signal of interest is set by the person. This criterion value may vary depending upon how often the signal is expected to occur, and on which behavior yields the greater "payoff": responding when in fact only noise (in the form of irrelevant signals) is present or not responding when in fact a true signal is presented against a background of irrelevant noise. Thus, "payoff" is based upon the tradeoff of values: response to a false alarm versus failure to respond to a true alarm.

An example of this phenomenon involves coded emergency communications recommended for use in health care facilities. Over a long period of time, and in an environment where vocal messages specifying individuals' names are common and frequent, staff members may find themselves primarily responsive to the call of their own names. Hence, an individual staff member may anticipate calls paging that person by name, while treating other messages as background noise. Yet the "payoff" in missing an encoded emergency alarm message such as "Nurse Blaze" or "Code Blue" represents a far more serious threat to life safety than the misinterpretation of a non-emergency message and the inappropriate initiation of emergency procedures when there is in fact no fire emergency (see Keating and Loftus, 1977). In this example, anticipation of a criterion signal (e.g., one's own name versus an encoded emergency signal) may vary as a function of other factors. For instance, physicians who spend only a few hours per day at a hospital may be considerably less likely to notice encoded emergency messages than may full time nurses who have been specifically trained in emergency procedures. Time of day, ambient temperature, fatigue and personality have also been found to affect arousal in similar instances (Craig and Colquhoun, 1975).

A somewhat related determinant of signal detection and the perception of emergency conditions is the so-called "orienting response," a pattern of skeletal and biological changes which occurs upon the presentation of novel and unexpected stimuli (e.g., "FIRE!"). Such stimuli disrupt ongoing activity and prepare the individual to receive future related stimuli and to respond effectively (Sokolov, 1963). Recommendations concerning the use of a male voice for certain portions of vocal emergency messages while using a female voice for other portions (Loftus and Keating, 1974) is an apparent attempt to optimize the likelihood of getting and maintaining occupants' attention and producing adaptive response patterns during various stages of fire emergencies.

Signal detection theory has implications for all four categories of assumptions in section 3.2. Thus, with regard to the first category, which deals with the effects of door and window design or egress route perception, signal detection theory suggests that this need is most critical in situations where building occupants are likely to be transient (and hence not familiar with the true location of egress elements), or where low levels of alertness may impair occupants' utilization of directional signs.

Another perspective on the illumination of egressways, the topic for the second category of assumptions, is provided by signal detection theory. During fire emergencies, most occupants of public occupancy buildings are likely to be more vigilant, and function at increased levels of physiological arousal, than they would during nonemergency periods. As a result, individuals may adopt lower visual thresholds to provide cues and stimuli necessary in the identification or recognition of egress route elements. Hence, lower levels of illumination may be sufficient to permit the rapid recognition or negotiation of environmental elements during a fire emergency than during periods of normal building use, particularly in a public occupancy building where many individuals are only marginally familiar with the building's layout and exit facilities. Thus, whereas environmental information processing theory stresses the possibility that the effect of variation in illumination level depends on individuals' motivations, previous experience, and training, signal detection theory emphasizes maintaining illumination levels above some sensory threshold.

Factors relating to the effective use of signage, an aspect of the third category of assumptions, also may be explained by reference to signal detection theory. According to this model, variability in cue detection results from variation in both environmental and psychological parameters. The word "EXIT" and an arrow presented on a directional sign may be thought of as visual signals which occur within visual "noise" produced by complex interior design, the moving about of other occupants, or by such fire products as smoke. If the information on signs can be made distinguishable from cues produced by competing environmental elements, there is a greater likelihood that signs will be used effectively. Similarly, the manner in which building occupants anticipate the availability of directional signage may affect the extent to which this information is sought out from a visually complex (or "noisy") environment, the threshold at which information displayed on signs will be discerned, and the nature of resulting egress behavior patterns.

For example, an occupant who is unfamiliar with the arrangement of exits and egress routes within a building may believe that in case of fire, "EXIT" signs and directional arrows can be counted upon to ensure rapid egress. Whether by previous experience, training or cultural norm, the individual may specifically anticipate that signs designating exits will display the term "EXIT," and hence the person's threshold for perceiving this word will adjust to ensure the rapid detection of such signs even in visually complex settings. While negotiating an egress path, however, other signs marked "NO EXIT" or "NOT AN EXIT" may be misinterpreted because of the individual's greatly reduced threshold for the term "EXIT" only. Under conditions of stress during which a person believes there is extremely little time, such mistakes may occur because the individual <u>fails</u> to take sufficient time to <u>fully read</u> and interpret verbal signs, even though the additional time required may be considerably less than needed to negotiate an incorrect path (i.e., a path produced by misinterpreting a sign). As mentioned earlier, the use of graphic or symbolic exit and directional signage may be advantageous in such situations as fire emergencies, where above-normal levels of stress can be anticipated (Smillie, 1978).

The final category of behavioral assumptions deals with <u>Code</u> provisions for alarm signals. These assumptions concern the effectiveness of audible and visual alarm signals in alerting building occupants to a fire threat, in enabling occupants to correctly define the emergency situation, and in helping occupants to rapidly formulate adaptive response strategies. The specific usefulness of alarm stimuli are perhaps most simply explained by reference to signal detection theory. If a visual or audible alarm is to effectively bring forth a response, then this signal must be consistently and reliably differentiated with respect to other signals in the environment (i.e., noise) which may vary considerably in substance and intensity over time. Because the purpose of the alerting signal is to evoke within building occupants an orienting response by communicating the occurrence of some adverse change in the environment, the alarm signal must be discriminable as well as detectable. A very loud, clanging, audible alarm in a building where false alarms are frequent, for example, may fail to communicate the fact that an actual emergency is in progress.

In summary, perceptual field theory, environmental information processing theory, and signal detection theory present different but related views of human perception. Each theory emphasizes the significance of the overall context in which the perception of information occurs. This context has been called a field, an environmental setting, and background noise. Moreover, each of these theories stresses the importance of individual differences in perceptual organization, and the role of personality variables upon perceptual judgment. Human behavioral assumptions which underlie <u>Code</u> provisions affecting occupants' perception of the emergency environment and their recognition of egress facilities were discussed in relation to these general models of perception. One or more theoretical explanations for each of four categories of assumptions were presented, and it was shown that while each model is useful, no single model is capable of explaining all aspects of environmental perception during fire emergencies. The next section treats code provisions and their underlying behavioral assumptions in view of data presented in the technical literature on human behavior during fires and other stressful events.

3.3.3 Assessment of Behavioral Assumptions Based on the Technical Literature

Literature review. Assumptions enumerated in section 3.2.1 focus on the effect of door and window design upon rapid recognition of egress routes and facilities. At the time of this writing, no technical data either supporting or refuting these assumptions were found. In general, however, the position held by writers of the Code that doors should not be designed so as to "blend in" with walls, and that windows should not be designed so as to be mistaken for exit doors (note provision 5-5.2.2), agrees with psychological models and data from other contexts. Melinek (1975) recommend that designers avoid placing mirrors or other reflective surfaces where they could mislead occupants regarding the direction of corridors and the location of exit doors. However, he provided no data from cases alleging such confusion to have actually occurred. In their analysis of selected provisions of the Code, Rivers and Bickman (1979) call for future research on this topic. They emphasize the special problem of egress route perception in the presence of smoke, and also argue that what is obvious to alert and able-bodied individuals may appear quite differently to fatigued or otherwise handicapped persons.

The influence of illumination level upon the perception of egress ways is addressed by assumptions enumerated in Section 3.2.2. In general, there is currently a dearth of empirical knowledge about the quality of illumination measured at floor level (provision 5-8.1.3), and no data are now available to confirm or refute the applicable Code provision. Rasbash (1975), in an experiment designed to evaluate visibility under various conditions, found that where visibility was 10 meters (32.81 feet), 10 percent of all subjects could not complete a way-finding task and instead returned to the starting location. Where visibility was reduced to five meters (16.40 feet) 20 percent of all subjects returned. On the basis of these data, Rasbash suggested a requirement that the minimum visibility during emergency evacuation be 10 meters. But he did not convert this value to illumination level measured at the floor. In a study connducted by Horiuchi (1974), emergency floor illumination of one lux (0.1076 foot-candles) was compared with that under normal lighting conditions. Only a small difference in occupants' walking velocity was found. Edmondo and Macey (1968), on the basis of their studies of emergency lighting on board U.S. Naval vessels, concluded that standard Navy handlanterns (providing an unspecified quantity of illumination) positioned two feet above the floor and spaced six feet apart facilitated egress route detection by ship occupants.

Perhaps Jin, who studied illumination and visibility through smoke, expressed the state-of-the-art most succinctly noting, "It has not been made clear yet how much visibility is needed to escape from fire (in this case, through smoke). But it is generally believed that visibility of 15 or 25 meters (49.20 to 122.00 feet) is necessary to escape from fires in such places as department stores, underground shopping plazas, etc., crowded with people who are unfamiliar with the interior of the building, while three to five meters (9.84 to 16.40 feet) is enough if escape routes are well known" (Jin, 1972a, p. 138). Jin also provided tables showing comparative smoke densities for the visibility distances expressed above. In addition to the problem of illumination level, the question of whether delays in activating emergency lighting facilities affect egress flow (e.g., the 10 second maximum delay permitted under provision 5-9.1.2) finds no answer--definitive or suggestive--in the technical literature currently available.

Jin (1972) considered illumination level in corridors as an independent variable in his study of response time in a smoke-filled environment. In a later experiment, Jin (1976) found walking speed to be only slightly affected by variations in corridor illumination. Psychophysical experiments designed to study light-dark adaptation have indicated that visual response is delayed when a person moves from a lighted to a totally darkened setting (Brindley, 1970). But while perception is slowed under such conditions in the laboratory, no documented evidence was found by the present investigators relating perceptual decrement to impaired movement by building occupants negotiating actual settings.

In Section 3.2.3 behavioral assumptions concerning the degree to which building occupants depend upon visual signage and directional markers were presented. Extremely few technical data are currently available indicating that directional signs are actually considered whether in formulating initial egress strategies or used during an emergency evacuation. Although conclusions drawn from experiments conducted by Horiuchi (1974), Jin (1971, 1972a, 1975) Garner and Lowery (1976) all appear to imply that signage is used by evacuees, sign use has never itself been treated as an experimental variable by these investigators. In another experiment, however, Horicuchi (1978) found that the visibility of stairs was the most important factor in directing occupants to stairs. Moreover, studies by Jin (1972b, 1976) and Tadahisa (1975) on visibility through smoke, though not definitive regarding sign use, suggest that persons who are familiar with a building and with routes to exits are less likely to use directional signage.

A number of researchers have discussed the visibility of overhead directional signs under smoke conditions. In research conducted by the Federal Aviation Administration (Garner and Lowrey et al., 1976) several types of aircraft cabin exit signs were evaluated under smoke conditions. These investigators concluded that increasing the luminosity of an overhead exit sign to compensate for smoke conditions produces, at certain levels of smoke density, a diminishing return in brightness and only marginally increases visibility. Jin (1972b) found that the visibility of exit signs varies with the density and composition of the smoke. Bryan (1976) cited data from an earlier study conducted by Underwriters Laboratory (1972), noting that signs placed at a distance of 7.5 feet (2.59 m) above the floor become obscured more quickly in smoke than do those placed at distances of 5.0 feet (1.73 m) and 2.5 feet (0.86 m) above floor level. Rivers and Bickman (1979) concur, noting that the placement of exit signs near ceilings may be inappropriate under smoke conditions. This notion is further supported by Edmondo and Macey (1968), who presented U.S. Navy data suggesting that the optimal location for illuminated directional markers is not more than 2.0 feet (0.61 m) above floor level.

The basic theme underlying behavioral assumptions discussed in this section is that clearly visible instructional and directional signs tend to reduce the overall time required by occupants to evacuate a building during a fire emergency. However, few empirical data are available to support this notion. For example, Edmondo and Macey (1968) reported no significant difference in transit time between experienced and inexperienced Naval personnel when both were provided directional markers. From a somewhat different perspective, toxicological studies appear informative. Several studies have addressed the affects of carbon monoxide (CO), usually produced in measurable quantities during fires, upon sensory reaction time and behavior (Laties and Merigan, 1979). Although results of research on the visual effects of low levels of CO remain controversial, blood saturation levels as low as 5-9 percent of carboxyhemoglobin (COHb) have been shown to significantly elevate the visual light threshold (Stewart, 1976). Moreover, even a brief exposure to high levels of CO may result in substantially elevated COHb saturation, producing a significant decrement in the psychomotor reaction to visual stimuli (Ramsey, 1973). Hence, smoke conditions may not only have adverse affects on sign detection, but they may increase reaction time (and overall egress time) as well. These findings underscore the need to further understand the role of smoke.

The source of illumination for egress directional signs has also been the subject of research. Edmondo and Macey (1968), for example, found the standard battery powered sealed-beam Naval handlantern to be an effective directional marker, while Jin (1975) concluded that the xenon lamp best illuminated signs in smoke. The detection of exit signs under both smoke and clean-air conditions and under different lighting conditions was studied experimentally by Underwriters' Laboratory (1973). Data from this research indicated that signs illuminated by an electric lamp were detected and interpreted more rapidly than were "self-luminous" signs.

No data are currently available specifically indicating whether or not fixed directional arrows produce desired pedestrian movement patterns and reduce egress time during building evacuations. Although directional arrows were not treated as an experimental variable per se, findings by Edmondo and Macey do suggest that directional markers have a positive effect on egress. Janda and Volk (1934), in experiments designed to study the effectiveness of symbols on highway directional signs, found that symbols yielded shorter driver reaction times than did verbal directional signs. Later research by Walker, Nicolay and Stearns (1965) corroborate this finding. Moreover, Smith and Weir (1978) and Lerner (1981) found that arrows of unconventional design tended to be more highly visible than were conventional arrow types.

No reference to the effectiveness of verbal "NO EXIT" signs in reducing egress time was found in the technical literature. Recent studies conducted at the National Bureau of Standards have, however, addressed the comprehensive of pictographic no-exit signs. For example, Collins and Pierman (1979) and Collins and Lerner (1980) found that the no-exit pictograph proposed by the International Standards Organization Technical Committee 21 was judged incorrectly as meaning "EXIT" by some 70 percent of all subjects participating in an experiment.

The effectiveness of visual and audible alarm devices to provide occupants clear alert signals and sufficient information for egress strategy formation is the subject of assumptions presented in Section 3.2.4. Although the Code gives designers little guidance regarding the quality of alarm signals, application of the Code's alarm provisions generally assumes fire alarm systems will enable building occupants to initiate effective emergency egress behavior with minimal delay. Almost without exception, however, the technical literature contradicts this notion. Pauls studied egress behavior during exit drills in high-rise office buildings in Canada (Pauls, 1971, 1974, 1979). He noted that in several instances public address systems were used by an excited announcer providing occupants with ambiguous information. On the basis of his observations, Pauls argued that a simple alarm device can confuse occupants as often as it effectively informs them, and that even automated public address systems utilizing prerecorded announcements may annoy and confuse occupants. Moreover, Pauls suggested that the long-term performance capabilities of prerecorded vocal alerting systems has not been adequately addressed, even during the pioneering research on these systems conducted by Loftus and Keating (1974) and Groner, Keating and Loftus (1978).

A number of investigators have reported on the problem of alarm credibility. Breaux, Canter and Sime (1976), for example, concurs with Pauls (see above); he suggests that alarm signals often have low credibility for building occupants (i.e., are not regarded as signalling a real fire emergency, in contrast to a drill). Likewise, Baker and Mack (1960), who studied responses to unanticipated air raid signals, concluded that merely hearing a warning signal is insufficient, in and of itself, to stimulate people to take immediate protective action. Haber (1977), in post-incident studies of fires in health care facilities, noted that alarm signals were sometimes disregarded as an indication that a fire is actually in progress. She described one case in which nursing home residents and staff attributed an alarm signal to factors other than fire, and another case in which the alarm was specifically interpreted as signalling the onset of an exit drill. Confusion regarding the meaning of an alarm signal was also noted in a fire at a nursing facility at the National Institutes of Health (Bryan and DiNenno, 1979b). Reporting findings from a similar incident, Bickman, Hertz, Edelman, and Rivers (1979) noted that some patients did not define the situation as an actual fire emergency until they heard shouts of "FIRE." In view of such evidence, Rivers and Bickman (1979) have suggested that the assumption that occupants will be effectively alerted by means of standard audible alarm devices may not be true in all cases.

Visual alarm devices also are permitted by the Code (note provision 6-3.4.4). According to Kravontka (1975), visual alarm systems usually consist of flashing red lights working in unison with audible alarm "gongs." However, where certain physiological factors are not taken into account, the health and safety of occupants may be compromised by such systems. For example, Kravontka has suggested that in deaf persons with epilepsy, seizures may be triggered by certain flashing rates (6-8 Hz). However, other studies question this effect (Engle, 1974).

Regarding the sufficiency of information provided by audible and visual alarms, Baird (1963) reported that responses elicited by manual alarm bells tended to be ambiguous. Baker and Mack (1960) found in their research that most people sought some sort of additional information to validate the meaning of alarm signals. Results from these studies suggest that when hearing an alarm signal, building occupants construct their egress behavioral strategies on the basis of available information, and, in order to reduce the degree of uncertainty under which decisions are made, they actively seek out additional information (which may come from simply observing the behavior of other occupants, from seeing smoke, from persons in authority, etc.).

Several models of human behavior during fires (e.g., Bickman, Edelman, and McDaniel, 1977) treat the sufficiency of information provided by audible and visual alarms as the "situation definition" stage of a fire event. Sufficient information, in this view, will unequivocally and unambiguously inform the occupant that a situation is, or is not, a fire emergency. To illustrate insufficient information, during the fire at New York's World Trade Center, the emergency communications system failed to provide information sufficiently effective to prevent occupant movement (the desirable objective in that case), especially since smoke--an extremely powerful stimulus--was present (Glass and Rubin, 1979). A somewhat related problem pointed out by Rivers and Bickman (1979) is that audible alarm signals (e.g., gongs) may actually be too loud, and thereby interfere with necessary verbal communications among occupants during emergencies. These investigators found in several nursing homes they studied, that staff experienced considerable difficulty giving and receiving verbal instructions due to the loud sound produced by alarm devices.

In support of the general assumption that alarm devices provide sufficient information to effect rapid emergency egress, are occasional news media accounts in which occupants specifically reported having seen or heard an alarm signal, formulated an egress strategy, and successfully escaped. However, no research has been reported evaluating the generalizability of these anecdotes in view of such potentially confounding factors as occupants' familiarity with the buildings, previous training and experiences, and whether or not ambient social and organizational environments supported the egress activity.

Overall, there is little technical evidence presently available which directly supports or refutes behavioral assumptions believed to underlie Code provisions governing the design of doors and windows, emergency illumination, and signage. However, a growing body of evidence has begun to challenge assumptions that alarm signals of the type currently specified by the Code are effective in arousing egress behavior and that they provide sufficiently unambiguous emergency information.

Strengths and weaknesses of the technical literature. Behavioral assumptions underlying Code provisions which affect door and window design emphasize the importance of these architectural elements in egress route perception by building occupants during fire emergencies. These assumptions are based primarily on a consensus of professional opinion. The assumptions' credibility is reinforced by reference to various behavioral models and experimental data from other contexts. However, no direct tests of the role of door and window design have been conducted in connection with building evacuation behavior. Consequently, it is not currently possible to make definitive technical statements regarding the validity of these design provisions on the basis of available literature.

Although the literature on illumination level and its effect on egress route perception reports experimental data, shortcomings in the design of various experiments render many of these results difficult to interpret and apply in relation to the Code. For example, Rasbash (1975) found that within a certain visibility range subjects returned to their starting locations rather than complete a way-finding task. He concluded that the ability of individuals to complete the task depended upon the light-filtering qualities of smoke. He did not discuss visibility impairment due to lacrimation or motor impairment resulting from smoke inhalation as possible alternative explanations of such results. In Horiuchi's (1974) experiment, groups of subjects followed leaders, and all subjects were familiar with the spatial layout under study. A reasonable hypothesis is that Horiuchi's finding (that evacuation speed under conditions of low-level emergency illumination differed insignificantly from that under normal lighting conditions) may not generalize to situations in which leaders are not present or where transient occupants lack familiarity with egress ways. Similarly, while Edmondo and Macey (1968) evaluated the effectiveness of various lighting sources and lighting fixture locations, they did not specifically compare lighting configurations on the basis of illumination quantity. Hence, their results are not directly applicable to validating present Code provisions regarding egress way illumination. Jin (1972a) and Tadahisa (1975) have themselves indicated that data from their studies are not as yet conclusive concerning minimum required emergency lighting levels.

The Code provision permitting a 10 second maximum delay in the activation of emergency lighting is partially supported by the literature. Light-dark adaptation experiments suggest that the need for people to adapt from light to dark (and then again to light) be minimized. However, because these data were collected under ideal laboratory conditions, they may not be directly applicable to actual emergency settings in which the visual and other sense modalities are simultaneously stimulated, and in which visual perception is continually influenced by the individual's motivations, experience, and by physiological stressors.

Current knowledge regarding the effectiveness of signs and visual directional information also is based on limited experimental data. Perhaps the most applicable data were collected by Edmondo and Macey (1968), who found that directional markers assisted Naval personnel in way-finding, and that the presence of these markers produced no significant difference in transit time between experienced and less experienced sailors. A critical unanswered question, however, is whether the transit times were influenced at all by the presence of the markers. That is, the research design failed to include a comparison of two important groups of inexperienced personnel: those performing an escape task with directional markers, and those performing the task without markers. Moreover, since Naval personnel are likely to have undergone more extensive safety training than have most civilian building users, inferences from this study should be limited to those civilian situations in which occupants can be expected to be well trained and disciplined. In addition, toxicological experiments suggesting perceptual and cognitive decrement resulting from carbon monoxide exposure are not yet sufficiently advanced to permit inferences concerning the physiological effects of smoke upon sign effectiveness. Moreover, data from highway safety symbol studies are applicable only to the degree that driving behavior transfers to pedestrian behavior (especially during emergencies), itself an unanswered empirical question at this time.

A brief digression into the nature of experimental design in fire research seems useful at this point. Laboratory experimentation has traditionally afforded researchers the greatest opportunities to obtain highly reliable data. Many problems, however, are extremely complex, making laboratory experiments difficult to design and experimental data difficult to apply. Where experiments cannot be designed to accommodate (and control) the full range and complexity of environmental factors, the data obtained will often lack external validity (that is, data may not be generalizable across time frames, settings, or groups of persons). When studies do not cover the range of factors accounting for a phenomenon, then external validity is threatened (Cook and Campbell 1976).

The study of human behavior in fire situations is an obvious case in point. For example, experimental data on directional sign perception in a smoke simulation study may yield important psychophysical information about the effects of variation in smoke density on visual perception. But where experimental subjects performed a visual task in relative safety, neither actually being exposed to a life threat, nor believing their lives were otherwise endangered, the potential effects of fear, stress, and other pertinent factors remain indeterminate. How then is the analyst to draw conclusions about sign perception and its effect on behavior during actual fires? Clearly, researchers must not expose human subjects to real or imagined life threats for experimental purposes. Consequently, researchers may never advance beyond the limits of validity attainable through simulations such as those reviewed above. Considerable additional work may well be needed, however, merely to approach these limits.

In contrast to the quasi-experimental nature of the technical literature on illumination and sign perception, the literature on alarm effectiveness reports primarily nonexperimental post-incident case study data. Post-incident surveys conducted after air raid drills, natural disasters, and fires in commercial, educational, health care, and residential buildings provide a growing body of evidence contradicting the general notion that alarm devices, once activated, will yield unambiguous emergency information. However, conclusions based on available post-incident investigations are by no means unequivocal. Consequently, specific recommendations concerning the value of present Code provisions for alarms are open to varying opinions. Nonetheless, the post-incident case study is expected to remain a valuable source of field data necessary in validating findings from laboratory simulations.

3.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

3.4.1 Research on the Effects of Door and Window Design

No data currently exist either supporting or refuting Code provisions governing the design of doors and windows within egress ways, or dealing with assumptions about occupants' behaviors with respect to these building elements. Questions raised by these provisions and assumptions are nevertheless important ones requiring empirical investigation. For example, Code provision 5-5.2.2 requires that doors along egress paths not be designed so as to "blend in" with surrounding walls or decor, on the assumption that doors which visually contrast with surrounding surfaces are more likely to be quickly detected. However, the designer is provided no guidelines by which to determine the adequacy of any given door/wall combination, nor any range or region of acceptability for various design solutions. Similarly, while such additional factors as illumination and occupants' visual capabilities are believed to influence individuals' perception of egress route elements, the effects of variation in these parameters upon door/wall contrast and door detection is not now known. Most important, no data currently exist describing the impact of door/wall contrast variation and other design features upon egress time.

As a point of departure, laboratory experiments should be designed to evaluate way-finding and exiting time performance for individuals of varying visual ability under different conditions of door design and door/wall contrast. Similar experiments may also be designed to assess the extent to which doors are distinguishable from windows under various environmental conditions. Where proper controls and safeguards are feasible, moreover, future experiments on door and window perception should be designed to evaluate the effects of smoke (a laboratory procedure for optically simulating characteristics of smoke and its effects on visibility is currently under development by Drs. Lerner and Collins of the Center for Building Technology, NBS).

3.4.2 Research on Illumination Required for Egress Route Identification

Findings from recent research on the role of illumination in emergency egress are ambiguous and difficult to apply when evaluating Code provisions. Although such factors as the presence of smoke and the degree of familiarity with egress ways have been treated to a limited extent as variables by previous investigators, other important factors including stress, motivation, and visual acuity have not. Although studies such as those conducted in Japan by Jin and Tashida have been somewhat successful in simulating smoke conditions safely, the introduction of other stressful and more dangerous aspects of fires into experimental settings may be too costly--especially in human terms--to be feasible. Future research directed toward building a more reliable data base under "safe" laboratory conditions, and then validating these data against victims' experiences reported during post-incident case studies, appears the best approach to obtaining a quantitative basis for emergency illumination standards.

3.4.3 Research on Directional Signage

Previous research on directional signage has focused primarily on the visibility of signs under varying conditions of illumination for people varying in their familiarity with egress ways. In some instances, particularly in the Japanese studies, effects of smoke were considered. Work in progress at the National Bureau of Standards (Collins and Pierman, 1979; Collins and Lerner, 1980; Lerner, 1981) is evaluating the extent to which various pictographic symbols are interpreted correctly under experimental conditions. In these studies, subjects were specifically instructed to look at signs. Consequently, one cannot infer from the data that the mere presence of directional signs assures their detection and proper use in real buildings under emergency conditions.

The degree to which signs are in fact used by building occupants as an aid to egress route perception, and the manner in which information derived from signs is integrated with occupants' goals, experiences, and other environmental information, have not been addressed to date. Future research on directional signage (verbal, pictographic, or their combination) must be specifically designed to assess the contribution of signs to way-finding performance and escape time. Moreover, researchers must examine the influences of sign location, lettering and graphic design, and of variations in human visual acuity, building familiarity, smoke density, and illumination, all of which may interact to reduce the positive and useful aspects of directional signs.

3.4.4 Research on Alarm Signals

The ability of alarm signals to alert building occupants to act effectively during fire emergencies cannot readily be determined from the technical literature currently available. This is primarily due to the lack of data useful in understanding the role of several key parameters, especially for noninstitutional public occupancies. Among the critical parameters are (1) mode of signal or message delivery, (2) clarity of the alerting message and the extent to which message content is consistent with occupants' perceptions, (3) emergency training, and the degree of consistency between previous training and messages provided in any given building, (4) occupants' familiarity with building layouts, and (5) occupants' physical and psychological characteristics. Controlled field experiments in actual buildings during simulated exit drills, such as those recommended by Stahl (1978b), may provide data useful in assessing the role of such parameters in alarm effectiveness, and contribute to the improvement of alarm system design. Similar experiments evaluating deaf individuals' responses to various types of visual alerting devices, and blind persons' responses to audible alarms (especially in relation to other parameters noted above) are also required.

3.5 SUMMARY

A number of human behavioral assumptions about the perception of emergency environments and the recognition of egress facilities underlie various provisions of the Code. These assumptions were evaluated by reference to several models of perception, to limited data from experiments on visibility, and to a small body of evidence from post-incident fire investigations. Taken as a whole, available data neither support nor refute behavioral assumptions about occupants' emergency perceptions at a level technically sufficient to permit a thorough evaluation of related Code provisions. To the extent that initial emergency perceptions (as developed by alarm systems, for example) can be linked to confusion resulting in increased evacuation time, however, research on the role of emergency perception and its relation to egress behavior will remain a necessary precursor to effective codes and standards.

4. PROVISIONS AFFECTING EGRESS STRATEGY FORMATION

4.1 APPLICABLE CODE PROVISIONS

5-2.2.2.12 Stairs and other exits shall be so arranged as to make clear the direction of egress to the street. Exit stairs that continue beyond the floor of discharge shall be interrupted at the floor of discharge by partitions, doors, or other effective means.

5-2.4.1.2.1 Every fire section for which credit is allowed in connection with a horizontal exit shall have in addition to the horizontal exit or exits at least one stairway, doorway leading outside, or other standard exit. Any fire section not having a stairway or doorway leading outside shall be considered as part of an adjoining section with stairway.

5-4.1.2 Exits shall be so located and exit access shall be so arranged that exits are readily accessible at all times *(see 5-5.1.1)*. Where exits are not immediately accessible from an open floor area, safe and continuous passageways, aisles, or corridors shall be maintained leading directly to every exit, and shall be so arranged as to provide convenient access for each occupant to at least 2 exits by separate ways of travel.

Exception: Where a single exit or limited dead ends are permitted by other provisions of this Code.

5-5.1.2 When more than one exit is required from a story, at least two of the exits shall be remote from each other and so arranged and constructed as to minimize any possibility that both may be blocked by any one fire or other emergency condition.

4.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

4.2.1 Assumptions Relating to Occupants' Capacity to Process Information About the Location and Function of Egressways.

(1) Occupants generally expect stairs to discharge to the street, and lacking information to the contrary, they might assume that exit discharge occurs at the lowest level of the building (5-2.2.2.12).

(2) Building occupants understand the purpose of horizontal exits (5-2.4.1.2.1).

(3) Routes leading from horizontal exits to stairways or other means of reaching the outside are known to building occupants (5-2.4.1.2.1).

4.2.2 Assumptions Relating to Occupants' Abilities to Determine the Safest and Most Accessible Escape Route Under Potentially Stressful Conditions

(1) Where exits are not immediately accessible from an open floor area, alternate routes to exits will be perceived and understood by occupants (including occupants not otherwise familiar with the building), even under conditions of stress posed by a fire emergency. The formation of egress

strategies in situations where exits are not immediately accessible will not require so much time as to significantly increase occupants' exposure to fire products or to other dangerous conditions (5-4.1.2).

(2) When access to one exit is blocked by fire products, occupants will adjust their egress strategies to seek an alternative egress route. Any additional time required for these adjustments (and to traverse the newly selected route) will not pose additional dangers to occupants (5-5.1.2).

4.3 COMMENTARY

4.3.1 Problem

Several provisions of the Code are intended to ensure to a reasonable degree that occupants will not be trapped because any single egress way is blocked, that the occupants will not become unnecessarily confused if exits are not immediately accessible, and that they will not "overshoot" the discharge point when moving through stairways and other exits during fire emergencies. Each of these conditions requires that occupants make decisions about egress routes during various stages of the exiting event. Accordingly, Code provisions affecting the availability of choices (e.g., at a corridor intersection or stair landing) influence occupants' emergency egress strategy formation.

A broad-based assumption underlying these provisions appears to be that the physical and social environments provide building occupants with information necessary for situation definition and strategy formation during a fire event. More specifically, human behavioral assumptions underpinning choice related design provisions seem to address two important concerns: (1) occupants' capacity to process information about the location and function of egressways; and (2) occupants' ability to determine the safest and most accessible escape route under potentially stressful conditions.

Strategy formation leading to effective emergency egress behavior may be best understood in terms of the cognitive processes--most specifically information processing--which govern this activity. Models of information selection and decisionmaking processes are considered below in relation to behavioral assumptions believed to underlie Code provisions affecting egress strategy formation.

4.3.2 Underlying Behavioral Models

In general, the environmental information processing model (Ittelson et al., 1974) holds that sociophysical settings usually supply participants with more information about current and ongoing events than can be processed by any individual. People obtain information about the current state of a setting directly through personal experience with an actual event, and indirectly through media accounts of the event and from conversations with other individuals who may or may not have had direct experience with the event. This information is transferred to so-called "short term memory," where it is available for immediate use, and may be transferred to "long term memory," to be made available for future use. Long term memory refers to what an individual "knows" but is not currently attend to (i.e., thinking about) at the moment. A person can know and be capable of retrieving information about an enormous number of things (i.e., can have stored billions of items of information in long term memory), but can retrieve, decode, and use only an extremely small number of items at any one time.

People formulate decisions by comparing present information about an event against information previously stored and available. This stored information is continually affected by information gained from more recent experiences. For example, a person who never experienced a building fire but who has participated in numerous exit drills will have stored a "mental picture" (structure of information) about fire events and effective behavior during such events. This mental picture comprises the individual's expectations about fire events. Should this person become involved in an actual fire which matches these expectations, the individual's mental picture of fires and of appropriate responses to fires may not substantially change. Moreover, new information that conforms to current expectations is assimilated so as to enrich the individual's knowledge of fires and of effective means of responding to them. If, however, the person becomes involved in an actual fire which creates conditions differing substantially from expectations based upon fire drills, the individual is likely to alter or adjust the mental picture of fire events and his or her opinions about the value of fire drills as well. The alteration may result in a new conception of fire events and of proper responses to the events, which might be an adapative solution to the extent that it matches future fire events, or it may result in confusion about the nature of fire events and of the proper response to fire emergencies, which could prove to be disfunctional during an actual fire emergency.

When negotiating an egress route, frequent decisions may be required which necessitate the evaluation of current environmental information. For example, when receiving an alarm signal, hearing shouts of "fire", or seeing other occupants engage in behavior suggesting a fire drill or fire emergency, an individual will decide on an initial course of action. Proceeding along an egress route, the individual can reach corridor intersections, doorways, stair landings, or other choice points, each requiring additional decisions to be made. On what basis is an initial egress strategy formulated? How does this strategy enable subsequent decisions to be made? What is the effect of subsequent strategy change upon egress time and success? What is the role of architectural design and building configuration in egress strategy formation?

According to the environmental information processing model, initial emergency strategies result from "first cut" comparisons between incoming information and information retrieved from memory. Upon receiving an emergency alert, the person's initial strategy may simply be to "get out of the building." If the individual is familiar with the building's layout and safety features (i.e., this information is stored in long term memory), enacting the initial strategy should not require much additional information. If the occupant lacks such familiarity, or if the initial strategy is rendered ineffective because of unexpected events (e.g., a blocked exit or the presence of another person needing immediate assistance), considerably more information may be required: Where is the fire?

Where are exits? Is enough time available to assist another person and still assure one's own safety? Acting on the initial strategy, then, creates conditions that favor seeking specific information about the environment. Many subsequent decisions may derive from the need to obtain necessary information, and may not appear to lead directly to escape. For example, upon receiving an ambiguous alert from an audible gong, occupants might either continue their routine activities or attempt to verify the existence or emergency conditions.

As a person proceeds through the fire event, more information about its nature is obtained and stored in memory. This information stems from direct experience and indirectly from rumors, persons in authority, and (where available) from public address messages. When a choice point concerning the egress route is reached, information pertaining to the needed decision is compared with information obtained and stored during the fire event. If the current situation could not have been predicted from earlier experiences (i.e., if the initial egress strategy cannot handle a new problem such as a blocked exit), the individual might react adaptively by formulating a new strategy which accommodates the current understanding of the situation. Alternatively, the individual may react maladaptively by continuing to pursue the original strategy, ignoring new information, and otherwise failing to deal rationally with unanticipated changes in events.

As indicated earlier, the environmental information processing model generally holds that physical settings provide more information than possibly can be processed by individuals at any given time. Hence, the likelihood that a person will respond adaptively to events requiring shifts in egress strategy may depend upon whether the most important, or attention-getting, information is easily detectable in an otherwise overloaded or "crowded" information field. An important implication of this idea is that the architectural design and layout of the building environment may themselves facilitate--or inhibit--information processing, decisionmaking, and strategy formation.

Clearly, then, successful egress strategy formation demands the ability to select important information from an environment and to use this information in effective decisionmaking. Several models offer useful perspectives on these issues. These include Broadbent's "filter" model and Brunswik's multiple cue probability model.

The selection of information from the environment is addressed by Broadbent's (1971) "filter model," which compares the initial stages of information processing (sensation and encoding) to an automatic railway switching system. According to the filter model, various data are introduced via individual neural channels which meet just prior to the encoding point in the brain. Here, one channel is permitted to continue emitting signals, while others are placed in a standby mode. In other words, a stop-gate or filter is posited, that protects the encoding and processing mechanisms against information overload. Criteria for filtering information (i.e., opening and closing various input channels) depend on the attention-getting properties of the information itself. These properties include the intensity, biological importance, and novelty of the information (Miller and Mackie, 1980).

Another explanation of the function of this stop-gate involves the use of short term memory. While important information is being encoded and processed, other incoming data may be temporarily stored in a short term memory buffer (holding area). The gate thus controls the flow of data from receptors to short term memory and higher-order information processing centers in the brain. If the information in the buffer goes unused for a period of time, it may decay (be forgotten), or alternatively, it may be transferred to long term memory. An example illustrating both the stop-gate and buffer concepts can be drawn from the Arundel Park Hall fire. Post-incident interviews revealed that a great many participants could not recall whether exit signs were illuminated or whether they were even present (Bryan, 1957). These signs were in fact both present and illuminated, and clearly some occupants did use the signs during egress. The filter model suggests, however, that sensory information concerning the presence and characteristics of exit signs was overriden by more obvious information (e.g., visual data from the fire itself) requiring rapid processing. Information about the exit signs was either filtered out and never processed at all, or it was encoded into a short-term memory buffer and eventually decayed. In either case, this information was lost during the relatively short period between the fire event and the post-incident interviews.

Brunswik's (1956) multiple cue probability model offers a somewhat different perspective on information selection. Brunswik held that information transmitted by the environment is always less than consistent and complete, that there is usually more information available than can be processed, and that at any time a person must make decisions on the basis of partial and sometimes conflicting information. As a result, the individual selects information by perceptually "sampling" the environment. The sampled data are encoded and compared against previous knowledge, expectations, and needs, and although no single piece of information perfectly satisfies all requirements, some are judged to have a better probability of satisfying requirements. A decision based on probabilistically weighted environmental information is called a "best bet" by Brunswik. A simple example concerns the fire victim who finds all stairways to be blocked by fire products. Several options are available to this person, including: jumping from a window, riding-out the fire in place, risking injury in attempting to use a stairway. The environment itself provides little information about the likelihood of success or failure associated with any one alternative, but the victim must weigh the subjective probability of death or injury resulting from jumping against those associated with smoke inhalation and/or burning resulting from using a stair or remaining in the building. Which strategy appears to the individual as offering the greatest likelihood of success may well depend upon the person's prior emergency training (e.g., "close the door to your apartment and ride-out the fire"), exposure to media headlines (e.g., "man dies attempting to jump to safety"), and the like.

Strategy formation, then, involves decisionmaking as well as information selection. The conflict-vigilance model and various heuristics are useful in explaining cognitive behavior under stressful conditions which may exist during fire emergencies, and shall be discussed here briefly. The conflict-vigilance model (Janis and Mann, 1977) offers a step-by-step explanation of decisionmaking during a stressful event in terms of how people cope with stress. One coping pattern, vigilance, results in thorough information search and an unprejudiced assimilation of new information. Vigilance alone among the various coping patterns discussed by Janis and Mann is held to result in effective decisionmaking.

The conflict-vigilance model views behavior as responses to a series of questions which are posed during a decisionmaking task. Depending on how a person answers these questions, the coping behavior will be either adaptive or maladaptive.

The first question concerns risk evaluation. When a person determines that risks will be high if no protective or defensive actions are taken, then arousal to the danger will occur and the individual will, for example, vigilantly seek escape routes and other options. If failure to initiate protective actions is not expected to increase personal risk, then the likelihood of arousal and of altering preceding behavior patterns will be quite low.

The second question concerns the effect of taking the most readily available protective action in response to exposure to a risk. If the individual believes that taking the most readily available protective action will result in a reduction in risk, then the psychological state of arousal is likely to subside and the individual is expected to initiate protective actions in a routine fashion. However, the actual risk may well exceed the person's expectations, and the most readily available protective actions may not be the most effective. Under such conditions, arousal will not diminish, and the individual may become preoccupied with finding a more effective escape route. For example, a building occupant who is most familiar with travel routes used daily in nonemergency ingress and egress is likely, in the event of a fire, to regard egress on these routes as an effective protective action. On evacuating the building, the person could find that a portion of this route has been rendered impassible. The occupant's level of arousal should increase substantially, and alternative actions will be sought.

The third question in the series concerns whether it is realistic for a person to expect to find a better alternative action. Information necessary to answer this question can come from knowledge already acquired by an individual, or from contact with other persons' experiences, from rumors, etc. Defensive avoidance and the avoidance of environmental events which increase anxiety are most likely to occur when the individual has little hope of finding a more effective alternative action. The occupant may purposefully "tune-out" life-threatening events, may attempt to pass on decisionmaking obligations to other individuals in the immediate environment ("you decide, I just can't cope"), and may attempt to perform less stressful actions despite knowledge that such actions are likely to increase risk. When an occupant believes it is realistic to expect to find more effective alternatives, the individual is likely to initiate a vigilant search for these options.

The fourth and final question is the most crucial. It concerns the availability of sufficient time for conducting searches and evaluating new information. If a fire victim believes available time is insufficient, "panic" (e.g., snap judgments; herd behavior) is more likely to occur. That is, levels of stress can become high enough to interfere with the perception, mediation, and processing of information. As a consequence, effective decisionmaking seldom results.

However, when an occupant does perceive that sufficient time exists in which to carry out the escape task, normal vigilant behavior is likely to continue and yield effective coping patterns which result in successful escape.

A somewhat different decisionmaking strategy is posited based on optimization models. These models emphasize the values that individuals place on alternative course of actions and the subjective probabilities of success or failure of these alternatives. Such models suggest that during fires occupants will tend to choose those egress strategies that yield the highest payoff (that are optimal) for the individual. Payoffs are a joint function of the values and probabilities for each alternative. Thus, a person is likely to choose the alternative that offers the best balance between success likelihood and risk of failure.

A special case of the optimization model is a decisionmaking strategy called "satisficing" (Janis and Mann, 1977). Satisficing implies that people do not necessarily choose the highest or best payoff. In some situations, because of the complexity of the alternatives or the stresses on the individual, people will not consider all the alternatives but only a subset they are able to handle. Under such circumstances, they are most likely to choose alternatives they regard as workable or satisfying. Thus, if a person in a fire emergency has as an ultimate objective staying alive, any course of action the person believes will meet that objective will be adjudged as satisfactory. Time will not be needed or spent seriously evaluating alternatives to determine the best option, as is implied by optimization models of decisionmaking.

Another special case involves elimination by aspects. This strategy treats selection and decisionmaking as processes of elimination. For example, a building occupant may choose to eliminate one egress route because it has been blocked by fire products, another because it has become blocked by other escaping occupants, still another because of unfamiliarity, and so on. The remaining alternative is chosen.

In summary, using current psychological models of human information processing to analyze pertinent behavioral assumptions provides a useful, although somewhat complex, framework for evaluating Code provisions affecting egress strategy formation. In the next sections of this chapter provisions and their associated behavioral assumptions are evaluated in relation to specific findings reported in the technical literature.

4.3.3 Assessment of Behavioral Assumptions Based on the Technical Literature

Literature review. The assumptions presented in section 4.2.1 address the capacity of occupants to rapidly and effectively process and use information about the location and function of egressways. The literature review revealed little substantive technical data directly relevant to this issue. Moreover, although a number of time-based models of emergency behavior have appeared in the literature (Bickman et al., 1977; Stahl, 1978a, 1979, 1980), only Stahl's computer simulation model postulates specific mechanisms by which information about exits and egress paths is applied to strategy formation and evaluation. The review of pertinent technical literature which follows here covers the state-of-the-art. Wood (1972), in a post-incident survey of more than 1,000 fires, found a significant positive relationship between familiarity with particular means of escape and the actual use of these elements. Specifically, Wood found that about 95 percent of those respondents who left buildings during fires used the route by which they entered. However, Wood's research design and findings permit no inferences about how occupants' sought alternative exits or formulated egress strategies.

Unlike Wood (1972), Weisman's (1980) study of way-finding in buildings under nonemergency conditions concluded that occupants' prior familiarity with a building probably accounts for only a small portion of the variance in successful completion of a way-finding task. Rather, the simplicity or complexity of the building's layout appeared to be the most important variable in predicting way-finding success. Weisman's findings suggest two interesting hypotheses: (1) during fire emergencies, time spent formulating egress strategies is influenced by the complexity of a building's layout, and (2) a person's general knowledge of a building, which may have accumulated over a long period of nonemergency building usage, may include little information about emergency exit location. Similarly, in Huriuchi's (1978) experimental investigation of exit choice in a Japanese department store, exit visibility was an important variable in egress route choice. Huriuchi reported that the most immediately visible egressways (in this case stairwells) were the most commonly used by experimental subjects.

Based on Weisman's and Huriuchi's studies, building layout complexity and egressway visibility appear to be the most salient environmental cues affecting escape strategy formulation. However, the available technical literature does not address occupants' knowledge about emergency exit location and use, except for institutional and other occupancies in which egress training programs have been effected. In addition, any assumption that occupants understand the purpose of horizontal emergency exits has not as yet been empricially verified.

Assumptions in section 4.2.2 focus on occupants' ability to determine the safest and most accessible escape routes during potentially stressful fire conditions. Again, fire research directly applicable to this issue is scarce. Wood's (1972) finding that occupants were more likely to initiate immediate egress action even when escape routes were not clearly recognizable, for example, seems to illustrate one manifestation of psychological stress during fires. Findings from research on environmental stressors other than fire and from studies of natural disasters provide additional bases for evaluating pertinent <u>Code</u> provisions and behavioral assumptions. Examples of this research are reviewed below.

Cohen (1978) postulated that in a stress-provoking environment, unique demands are exerted on individuals' capacities to attend to environmental and social stimuli. According to Cohen, the nature of the effect of these demands varies with the intensity, predictability, and controllability of the stress-producing agent. Recalling that human information processing is analogous to a limited channel information network, a person exposed to a stressor may be less able to process task-relevant information because attention has shifted to the stressor or its source. Thus, features of the physical and social environments which are largely irrelevant to the task at hand compete with important and necessary information for the individual's attention. Since considerable effort may be expended monitoring task-irrelevant input, the individual will process fewer relevant stimuli, and this activity could result in overall performance degradation.

For example, an occupant might attempt to return to a dangerous area in a burning building in order to retrieve a valued personal possession. The attempt may be motivated by the anguish created by the anticipated loss of the item or by the sense of embarrassment or guilt associated with having left the object behind. These feelings may so dominate the individual that there is insufficient consideration of the risks to be faced or the alternate strategies which could be employed.

Saegert (1973, 1976) studied cognitive fatigue resulting from information overload. Cognitive fatigue often characterizes stress-producing situations. Under these conditions, the amount of information that can be effectively processed by the brain can be considerably reduced, and decreased perceptual and cognitive efficiency have been noted. According to Saegert, overload may result from an overabundance of stimulation, information, and decision. Stimulus overload implies the excessive stimulation of the human neural system. Information overload results when the processing of environmental information produces excessive emotional arousal. An example is the high anxiety of an acrophobic individual confronting the use of an outside stair. Decision overload results from increases in the number of required decisions and responses in a given situation, and is particularly applicable to the present investigation. Saegert (1976) suggests that as the response requirements increase for an individual, the amount of useful feedback from each response tends to decrease. Under such conditions, responses result from decisions made on the basis of incomplete or erroneous evaluations. When this leads to maladaptive responses, elevated levels of psychological stress for the individual are likely.

Saegert's findings are applicable to the situation in which an escaping occupant must formulate a complex egress strategy in a relatively short time. The number of decisions or choices which this individual must make is directly related to the complexity of spatial network to be traversed and to the person's perception of the fire threat. In a complex spatial setting the number of decisions likely to be required may be quite high, and the likelihood of making incorrect decisions may be high as well. As more errors are made, psychological stress increases, and the sources of this stress compete for the individual's attention. Degraded task performance in the form of excessively time-consuming evacuation or failure to evacuate is a likely outcome of this scenario.

Best (1970) conducted way-finding experiments in public buildings and found that the uncertainty with which occupants perceived a route correlated positively with the quantity of information individuals must process in order to successfully negotiate that route to reach a predetermined location within a building. If complex routes require the person to process a greater quantity of information than do simple routes, complex routes could induce stimulus overload with the result that information processing and way-finding are degraded. With maladaptive responses more likely, stress could increase and this in turn could result in a further degradation of information processing and way-finding processes (Janis and Mann, 1977). Would familiarity with a building's layout facilitate successful way-finding? Weisman's (1980) way-finding research indicates that even when a person intentionally searches for a route, familiarity with the building layout does not predict successful way-finding. As discussed in chapter 2.0 of the present report, in an emergency situation, high arousal favors the performance of well-learned responses, such as taking a familiar route. But it also interferes with new learning. The complex layout of a building should not only be difficult to learn under high arousal conditions, but it should further increase arousal. This analysis suggests that in buildings with complex layouts, unless occupants are familiar with fire emergency escape routes, the likelihood of maladaptive behavior or unsuccesful way-finding during a stress-producing fire emergency may be high.

Simon (1967) and Weick (1970) view stress as an interruptor of ongoing behavior. Easterbrook (1959) argues that high levels of emotional arousal are most disruptive of those cognitive tasks requiring attention to large numbers of cues or stimuli. Kelley et al. (1965) presented experimental data describing the effects of potential entrapment. Holsti (1970) reported experimental data which suggest that decreasing the time available for decisionmaking results in increased error rates. When stress levels were high, relatively few individuals appear to make full use of available information necessary in formulating an effective course of action.

Field data from natural disasters are reviewed by Janis (1977), who concludes that perceptions of time-to-escape comprise the essential inducer of stress (possible mechanisms underlying this phenomenon were considered in section 2.3.3 of the current report). Dynes and Quarantelli (1967), who studied natural disasters, reported that people devote considerable effort and attention to information gathering. However, a study of combat experience by Glass (1968) reveals that under life-threatening conditions persons capable of initiating prompt action on their own, are clearly in the minority.

This section has illustrated ways in which emotional characteristics of fire situations may influence important cognitive processes such as decisionmaking. Consideration also must be given to the role of physiological stressors commonly found in the fire environment. Chief among these is carbon monoxide (CO). Chapter 3.0 of the present investigation notes that at certain levels of concentration within the blood CO has been found to have a detrimental effect upon sensory threshold and reaction time, especially after initial low-level exposure. Research on CO toxicity in rats by Petajan (1976) found that after 15 minutes of increasing exposure to CO (up to 45.9 percent COHb), the animals failed to perform appropriately in a simple shock-avoidance test. Petajan argued that the failure of the rats to perform adaptively could not be attributed to any physical breakdown in sensory or motor systems, but rather was based upon the animals' inability to process and integrate new information. Petajan made no attempt to draw inferences from his findings to the behavior of human beings. In another animal experiment, Carter, Schultz, Lizotte, Harris, and Federsen (1973) also noted that CO affected performance on discrimination tasks.

Studies on the effect of CO on human cognitive function report conflicting findings. Much of this research has addressed performance on time perception tasks (e.g., Beard and Wertheim, 1967, 1969; Otto, Benigus, and Prak, 1979; Stewart, Newton, Hasko, and Peterson, 1973), arithmetic problem solving (e.g., Schulte, 1963), vigilance (e.g., Groll-Knapp, Wagner, Hauck, and Haider, 1972; Fodor and Winneke, 1972; Horvath, Dahms and O'Hanlon, 1971), and driving performance (e.g., Forbes, Dill, DeSilva, and Van Deventer, 1973; Ray and Rockwell, 1970; Wright, Randell and Shepard, 1973; McFarland, 1973). Although a number of investigators report decrements in cognitive behavior at low COHb saturation levels, others find no such effect. Stewart (1976) concluded that COHb saturations must be above 5 percent to function as a stressor or as an inhibitor of cognitive processes. He also noted that partial loss of memory may be the most obvious effect of CO exposure.

Thus there is little technical evidence available which directly supports or refutes behavorial assumptions underlying Code provisions on (1) the ability of occupants to process, store, and retrieve information about the location and function of exits during fires, and on (2) the capacity of occupants to choose the safest and most accessible escape route under stressful conditions. However, studies in the areas of information processing, environment psychology, natural disasters, and toxicology offer substantial but indirect support for these assumptions and provisions. The remainder of section 4.3.3 reviews the strengths and weaknesses of the available technical literature, and comments upon the extent to which cited studies are useful for evaluating provisions of the Code.

Strengths and weaknesses of the technical literature. Behavioral assumptions concerning the capacity of building occupants to select, store, and retrieve information about the location and function of exit facilities involve the notion that occupants consciously familiarize themselves with a building's egress routes and exits prior to the onset of an actual emergency event. None of the models of fire event dynamics nor the field studies discussed above specifically address the validity of this notion. As noted earlier, Wood (1972) found that most occupants left buildings via the same means by which they entered. This suggests that people do not generally search for new routes or egress strategies. However, certain aspects of Wood's research design make his finding difficult to interpret in the present context. For example, Wood emphasized single family and other relatively small residential structures. It is likely that occupants were inordinately familiar with these buildings, and with alternate movement routes within them. Wood's research design does not allow an analyst to determine whether the use of a single route for entry and emergency egress resulted (1) from the habitual use of this route during years of occupancy, (2) from conscious decisionmaking by occupants during actual fire events, or (3) because small buildings (e.g., single family residences) offer relatively few entry and exit options.

Horiuchi (1978) suggested on the basis of his experimental data that when subjects were completely unfamiliar with the experimental setting (ensured during his study by conducting subjects blindfolded to the starting position in a building), the visibility of egress routes was an essential factor in egress strategy formation. However, Horiuchi's subjects were firefighters; they are expected to be more sensitive to problems of emergency escape, and to the location of means of egress. Hence, it seems inappropriate to generalize these findings to lay populations. The usefulness of Horiuchi's data are further clouded because his subjects took part in several experimental tasks in the same building. Their possibly increasing familiarity with the building's layout over time could have affected their performance on later tasks. The effects of familiarity were not controlled in the research design.

The psychological literature on decisionmaking under stress deals only indirectly with behavioral assumptions concerning safe and successful egress route selection during fire emergencies. Moreover, treatments of this problem by environmental psychologists tend to be theoretical rather than empirical. To date, there have been no field studies in natural settings as stressful and as complex as the fire environment. As a result, inferences from environmental research on way-finding (Bronzaft, Dobrow, and O'Hanlon, 1976; Sadalla and Magel, 1980; Weisman, 1980) about human behavior under actual fire conditions should be made with caution. On the basis of Best's (1970) argument, that the degree of ambiguity and uncertainty of (and therefore the amount of information obtained from) building circulation routes affects the likelihood of decisionmaking errors, it seems reasonable that the fewer decisions that must be made about direction and route, the higher the probability that occupants will make effective way-finding judgments.

The studies by Kelley et al. (1965), Janis (1977), Easterbrook (1959), and Simon (1967) reinforce the notion that stressors originating in the physical environment impact can negatively (e.g., interrupt) decisionmaking and other pertinent cognitive processes. At present, however, it is not clear how such stressors prevent or inhibit the selection of effective egress routes during fire emergencies. It is clear, by comparison, that they cause decisionmaking to consume more time. The emphasis of Janis (1977), Hosti (1970), and Glass (1968) on decisionmaking under stress created by time constraints reinforces the importance of time, (more specifically the situational deterioration which may occur over time), as a stress-producing agent. Although this experimental work offers important hypotheses about behavior during fires, inferences from currently available data to further building code development do not now seem warranted.

Definitive inferences to humans from toxicological studies involving laboratory animals are not currently recommended. Petajan (1976) has cautioned against applying results from these animal experiments to human behavior under naturalistic conditions. Moreover, the overall lack of consistency in currently available human CO studies weakens inferences and conclusions which might otherwise be generalized from this line of research.

Neither standard cognitive tasks nor well-controlled experimental procedures available which reflect the complexities of actual building fire events are currently. Until these have been carefully designed and validated there shall remain a lack of data illuminating processes by which building occupants develop egress strategies and select egress routes, especially under conditions typified by higher than normal levels of physiological and psychological stress.

4.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

At present few data clearly and directly support or refute Code provisions reflecting assumptions about occupants' information processing capabilities in connection with emergency escape. The complexity of human cognitive functions, particularly during stressful and potentially life-threatening events, has understandably discouraged fire researchers from studing cognitive behavior. Moreover, many investigators seem reluctant to consider the cognitive and motor behavior of individuals during fire emergencies, believing that studies of non-emergency group behavior, crowd flow, and gross patterns of pedestrian movement have the greatest payoff as far as building design regulations are concerned (Pauls, 1974; Seeger and John, 1980; Francis and Saunders, 1979). However, research in cognitive psychology and other areas discussed earlier in this chapter suggest a role for information selection and decisionmaking processes within any time-based model of emergency escape. Hence, further study of cognitive processes in the emergency context is indicated.

For example, it may be possible and relatively easy to measure the speed with which certain stimuli can be sensed and perceived. Similarly, motor response time can also be measured. However, the intervening processes by which perceived environmental information is incorporated into decisions and action strategies is currently difficult to quantify and measure. This is especially true in complex and relatively ambiguous and stressful emergency environments in which an individual switches between numerous decisions and strategies--both consciously and subconsciously--at various points during the escape task. Thus, Caravaty and Haviland's (1967) equation for estimating life safety during fires,

$$\frac{t_e}{t_c} < 1 \qquad (1)$$

suggests that an individual will reach a safe refuge if and only if the time required for escape, t_e, is equal to or less than the time required for the toxic environment to reach a critical or untenable state, t_c. In many cases this equation may be difficult to apply accurately. The problem becomes more obvious when equation (1) is expanded to the form,

$$\frac{t_a + t_s + t_t + t_e + t_i + t_x}{t_c} < 1^* \qquad (2)$$

where t_a = time required for sensation of a stimulus from the fire environment,

t_s = time required to become aware of this sensation,

t_t = time required to become aware of the sensation as a potential life threat,

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* Based on personal communications with Harold E. Nelson and Bernard M. Levin of the Center for Fire Research, National Bureau of Standards, between 1977 and 1980.

t_e = time required to evaluate the quality and extent of the life threat,

t_i = time required to initiate effective actions,

t_x = time required to follow-through and complete actions leading to safety.

Research reported in this chapter suggests that the factors t_t and t_e are not now capable of being estimated with any degree of accuracy. This chapter has also suggested, moreover, that the processes of egress strategy formation and resulting escape behaviors may not follow the linear-additive model implied by equation (2). Rather, some factors may be more heavily weighted than others, and some elements of the processes may require repetition more frequently than others during a single fire event. Further research must focus upon the characterization and measurement of these processes before escape time equations such as (1) and (2) can be routinely applied to building design.

Presently there is also a lack of useful technical information directly applicable to evaluating Code provisions and related behavioral assumptions reflecting escape route choice behavior. However, investigations of way-finding, environmental cue processing, response to natural disasters, and the effects of stress and elevated levels of environmental toxicants discussed earlier in this chapter suggest a number of directions for further research. For example, the capacities of individuals to make decisions under highly stressful conditions, and in environments characterized by elevated levels of CO, remain to be examined in detail. The reader will recall that Glass (1968) could not explain why approximately 50 percent of those disaster victims he studied were incapable of making decisions, although they appeared sufficiently able to perceive and process environmental information.

Future research should employ a sophisticated post-incident interview technique (see Loftus, 1980) capable of revealing complex route choice behavior, and of identifying organizational, social, and psychological attributes of the route selection process. In addition, field and laboratory experiments should be conducted to determine the influence of architectural design and building configuration upon route selection and way-finding performance. Finally, future research should, wherever feasible, strive to study the effects of physiological and emotional stress on route choice behavior. When practical and ethical considerations render the introduction of stressproducing stimuli undesirable, however, researchers may--within the limits of inference--make prudent use of currently available research on CO-induced physiological stress (Laties and Merigan 1979) and on emotionally-induced psychological stress (Koriat, Melkman, Averill and Lazarus, 1972).

Because the stress-producing qualities of emergency environments may influence the amount of time required by individuals to formulate egress strategies and select egress routes, the significance of stress as an experimental variable should not be underestimated by future investigators. Janis (1977) has pointed out that to a certain degree stress arouses a person and increases vigilance to danger; higher levels of stress tend to interfere with effective decisionmaking. Properly conducted post-incident interviews with fire victims, possibly in a clinical setting, may provide clues about the onset of stress-induced response patterns and their relation to decisionmaking and choice behavior during emergency periods.

4.5 SUMMARY

In summary, a number of assumptions about human information processing and decisionmaking behavior during fire emergencies underlie several provisions of the Code. In this chapter, such assumptions were evaluated by reference to models of cognitive behavior, as well as to data from recent psychological research on way-finding behavior, environmental cue processing, disaster response, and stress. Few directly relevant technical data were found within the field of fire research itself. Taken as a whole, available technical knowledge is not sufficient to warrant statements specifically supporting or refuting Code provisions which may influence egress strategy formation. However, the literature generally supports the notion that the demands of occupying a burning building require individuals to efficiently sample information from the fire environment, and to formulate effective and timely decisions about what to do. Depending upon the design and layout of a building, and upon the nature of given fire conditions, these processes will consume some proportion of the time within which occupants must escape. Errors in judgment and decisionmaking will frequently consume even more time. However, a crucial gap in current knowledge about the time-based capabilities of building occupants to effect rapid emergency escape continues to centers questions of emergency information processing and strategy formation.

5. PROVISIONS AFFECTING DISCIPLINED EGRESS BEHAVIOR AND CROWD MOVEMENT

5.1 APPLICABLE CODE PROVISIONS

5-2.1.2.1.3 No lock, padlock, hasp, bar, chain, or other device, or combination thereof shall be installed or maintained at any time or in connection with any door on which panic hardware is required by this Code if such device prevents, or is intended to prevent, the free use of the door for purposes of egress.
5-3.1.1 The capacity of means of egress for any floor, balcony, tier, or other occupied space shall be sufficient for the occupant load thereof.

5-3.1.2 The occupant load shall be the maximum number of persons that may be in the space at any time, as determined by the authority having jurisdiction, but shall not be less than the number computed in accordance with the requirements of Chapters 8 through 16 for individual occupancies. (Where both gross and net area figures are given for the same occupancy class, the gross area figure shall be applied to the building or structure as a whole. A separate calculation shall then be made for those spaces where occupant load is determined on the basis of net area and if the total occupant load determined on the net area basis exceeds that on the gross area basis, the means of egress shall be based on the large occupant load figure.)

5-3.1.3 Where exits serve more than one floor, only the occupant load of each floor considered individually need to be used in computing the capacity of the exits at that floor, provided that exit capacity shall not be decreased in the direction of exit travel.

5-3.1.4 When means of egress from floors above and below converge at an intermediate floor, the capacity of the means of egress from the point of convergence shall be not less than the sum of the two.

5-6.2 The travel distance to an exit shall be measured on the floor or other walking surface along the center line of the natural path of travel, starting one foot from the most remote point, curving around any corners or obstructions with a one foot clearance therefrom, and ending at the center of the doorway or other point at which the exit begins. Where measurement includes stairs, it shall be taken in the plane of the tread nosing.

5-7.1 All exits shall terminate directly at a public way or at an exit discharge. Yards, courts, open spaces, or other portions of the exit discharge shall be of required width and size to provide all occupants with a safe access to a public way.

17-1.4.3 Responsibility for the planning and conduct of drills shall be assigned only to competent persons qualified to exercise leadership.

17-1.4.4 In the conduct of drills emphasis shall be placed upon orderly evacuation under proper discipline rather than upon speed as such; no running or horseplay shall be permitted.

17-1.2.1.1 Every required exit, exit access and exit discharge shall be continuously maintained free of all obstructions or impediments to full instant use in the case of fire or other emergency.

5.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

5.2.1 Assumptions Concerning the Influence of Designated Leaders Upon Egress Time During Fire Emergencies

(1) Specially trained occupants (e.g., "floor wardens") assure that building evacuations are effected within acceptable time limits and minimize the likelihood of panic during fire emergencies (17-1.4.3; 17-1.4.4).

(2) During actual fire emergencies where specially designated leaders are present, occupants usually take directions from these authority figures; this minimizes escape time (17-1.4.3; 17-1.4.4).

5.2.2 Assumptions Concerning Pedestrian Movement Under High Density Occupancy Conditions

(1) In the event of a fire on a floor, balcony, tier or other occupied space which offers a potential for high density use, the entire population of the space will in fact be evacuated to the outside or to a place of refuge before the level of toxicants in the space becomes untenable (5-3.1.1 through 5-3.1.4).

(2) Once occupants discharge from a building, they will clear the area and not congest the discharge area; discharging occupants will proceed directly to public ways outside the building (5-7.1).

5.2.3 Assumptions Concerning the Effects of Building Configuration and Architectural Obstructions on Efficient Crowd Movement

(1) Although the natural path of egress travel may be influenced by furnishings and other fixtures, occupants can generally be expected not to deviate from straight-line paths (5-6.2).

(2) The improper utilization of security measures or devices increases the overall time required for emergency escape (5-2.1.2.1.3).

(3) The full carrying capacity of means of egress may be expected to be available at any time a fire occurs (17-1.2.1.1).

5.3 COMMENTARY

5.3.1 Problem

A number of *Code* provisions are intended to increase the likelihood that emergency egress from public buildings will be orderly and well organized, and that maladaptive crowd behavior during fires will be minimized. Human behavioral assumptions hypothesized to underlie these provisions address: (1) the degree to which occupants will follow the instructions of a leader or person in authority, (2) the ability of occupants to tolerate undesirable conditions (e.g. crowding) which may be present within egress ways during fire emergencies, and (3) the influence of obstructions to effective crowd flow upon efficient emergency escape.

Many issues pertaining to crowd flow in relation to social and environmental factors can be understood in terms of social psychological models of group behavior. Several models are available which elucidate the influence of group or crowd phenomena upon the behavior of individuals. The relevance of such models to Code provisions and underlying behavioral assumptions enumerated in sections 5.1 and 5.2 is considered below.

5.3.2 Underlying Behavioral Models

Four social psychological models applicable to group behavior offer perspectives on disciplined egress behavior and crowd movement which can be useful in understanding large-scale emergency response phenomena in public buildings. These are (1) the outcome dependence model (Thibaut and Kelley, 1959), (2) the imitation model (Bandura, 1965), (3) the reward-exchange model (Homans, 1961), and (4) the environmental space model (following Hall, 1966).

The outcome dependence model proposed by Thibaut and Kelley (1959) is based on the notion that persons experience varying degrees of confidence in the validity of their perceptions at given times. Thus, an individual or group can become dependent for information upon another individual or group, if the latter can improve the validity of the former's perception of some event beyond the level attainable through other sources. According to Thibaut and Kelley, information dependence may be defined in terms of either actual experience or anticipated (future) effects. In the case of anticipated effects, a person or group seeking to validate environmental information tends to increase social interaction with others upon whom the person or group is dependent for information.

Before considering an example which illustrates this phenomenon in the context of fire emergencies, several social psychological premises of the fire emergency event will first be identified. So-called panic behavior is more likely when the time available for safe escape from a life-threatening situation is judged by an individual to be insufficient (Janis, 1970; Janis and Mann, 1977; the reader should also refer to discussions presented in chapter 2.0 and 3.0 of the current report). The onset of panic behavior also has been related to occupants' expectations regarding the nature of social and physical interactions in anticipation of and during the use of available egress channels. Such interactions can be cooperative or competitive in nature. When occupants view one another as potential obstacles to safe egress, for example, the likelihood of a so-called panic response increases. Similarly, to the extent that occupants do not compete with each other for access to available egress pathways, the entire group could more rapidly and effectively exit the building. Thus, in situations where occupants view themselves as individuals unaffiliated with any larger group within the building, which can occur in multifamily apartment buildings or in mercantile and other public facilities, then the onset of fire might bring individuals together in cooperative or competitive relationships in regard to the use of available exit facilities. The importance of facilitating the movement of a crowd, particularly in public buildings, is underscored by the possibility that large numbers of individual occupants can collect and either will compete for, or cooperate in, the use of scarce means of egress.

Previous research on fire hazards in health care facilities provides an example of crowd movement which can be explained, in part, by the outcome dependence model. Investigations of fires in health care facilities have often noted that during fire emergencies, hospital staff are perceived to be the legitimate authority figures by patients, visitors, and other transient occupants (Bickman, et al. 1979; Appleton and Quiggen, 1976; Archea, 1979). Even physicians who are not regular hospital personnel follow the authority of trained nursing staff during hospital evacuations.

Another approach introduced in chapter 2.0, is the imitation or observational learning model. As developed by Bandura (1965), this model suggests that individuals copy the behavioral responses of others, particularly if the other people control resources on which the individuals depend during everyday (nonemergency) events and activities. The individual might observe that the other person behaves in a particular manner, and that he or she is positively reinforced for that behavior. The observed person becomes a model for the observer, and the environmental cues which set the stage for a particular behavior from the model become associated in the observer's mind with the model's behavior. Through a process of vicarious reinforcement (i.e., the observer experiences the reward or punishment that happens to the model), the observe imitates the rewarded response patterns of the model whenever a similar set of environmental cues is introduced. Observation of a model can inhibit an observer's performance of a model's response if the observer perceived that the model's enactment of the response led to negative consequences. Conversely, an observer's inhibitions about performing a response can be reduced if the model is observed being positively reinforced (rewarded) for the behavior.

During fire emergencies in public buildings, it might not be easy to determine who to observe. For example, while people dressed in uniforms or hospital "whites" can clearly emerge as models in certain types of buildings, in public occupancies such as office buildings or shopping malls identifying those who control resources can be far more difficult. Here, well-dressed business executives, desk clerks, or janitors may be identified as appropriate models depending upon a wide variety of circumstances (e.g., the degree to which each is known by, and is perceived as credible to, other building occupants).

Although the model is usually conceived of as a person, it also can be a group. Here, the group is perceived as a source of direction and information about safe egress during a fire emergency. The case of a transient visitor to an office building is illustrative. The visitor, upon hearing a fire alarm signal and observing the movement of office workers, joins the group on the assumption that there will be "safety in numbers." However, this process could also inhibit the visitor from entering a usable egressway when other occupants are observed ignoring it. Data from post-incident questionnaires administered to victims of the Thurston Hall fire (Bryan, Milke and DiNenno, 1979) indicate that only a few occupants, having failed to successfully evacuate the building, refused to await rescue in interior refuge areas. This suggests that a sequence of responses performed by some occupants (i.e. movement toward interior refuge zones) may have reassured other individuals about the value of waiting in an interior location until rescued.

The reward-exchange model (Homans, 1961), also introduced in chapter 2.0, uses the basic concepts of economics and of instrumental conditioning to explain face-to-face interactions among individuals. According to Homans, interaction among individuals will continue and be positively valued so long as the participants receive more rewards (benefits) than punishments from the interaction. Put differently, interactions that participants find profitable will continue. Punishments can be direct (e.g., being cheated out of money, being injured) or indirect (i.e., unavoidable). Unavoidable punishments, which Homans calls costs, refer to the forgone value of an activity. Whenever the psychological cost-benefit equation shifts toward unprofitable interactions for a participant, that person is more likely to choose a different course of action, one that is perceived as more profitable. Thus, competition can arise among individuals if one person's activities results in his or her receiving more than their fair share of rewards or if their activities result in reductions of rewards to others to unprofitable or unfair levels.

The relevance of the reward-exchange model to behavioral assumptions underlying <u>Code</u> provisions affecting disciplined egress behavior and crowd movement is illustrated by anecdotes. Accounts of the 1903 Iroquois Theater fire indicated that some exit doors were either locked or were otherwise inoperable (Foy and Harlow, 1928). Obstacles resulting from turns in stairways were also reported to have caused the trampling of many victims. During this fire event, normal queuing behavior by theater occupants apparently gave way to "survival at all costs" behavior. In other words, physical impediments to orderly evacuation (resulting from locked doors, turns which narrowed the exit channel, or from fallen persons) may have led to the belief that queuing would not produce the desired reward (safe escape) and could result in the ultimate cost (death). Lacking perceptions that would support coordinated action, members of the audience acted independently, each trying to minimize the risk to his or her life (i.e., trying to reduce their possible loses), resulting in a desperate competition for access to egressways under severe time constraints.

The reward-exchange model is also useful in understanding altruistic and heroic behavior reported in the fire literature. For example, see Bryan, DiNenno's (1979), discussion of the Georgia Towers fire. It may be argued that those who engage in altruistic or heroic acts during fires are invoking what Homan's calls rare costs, costs which increase a person's worth because so few people can experience these rare costs. In this sense, having experienced the rare cost of risking one's life for another, one earns the commensurate rewards of being identified as a hero and receiving adulation from others. However, the reward-exchange model also suggests that a would-be rescuer may not believe a situation is a serious risk to life, or may find risk-taking itself rewarding. Otherwise the risk could upset the cost-benefit equation in favor of not helping an endangered victim.

The environmental space model (based on Hall, 1966) developed from studies of animal and human territorial behavior. This model focuses on the apparent need of individuals to lay claim to certain areas. This need has been expressed in two forms: the need for personal space and the territorial need. Personal space is usually defined as an area with invisible boundaries surrounding a person's body into which no one may intrude. The size of this surrouding "bubble" varies between cultural groups and for different persons and situations in the same culture. By contrast, terrioriality refers to the need of individuals and groups to lay claim to some geographical areas as their own. Territories are fixed, circumscribed areas access to and the use of which individuals and groups have the capacity to control. Personal space, which is something the person "carries around," is sometimes called a portable territory (Gutman, 1972). When applied to the study of human spatial behavior, the concepts of personal space and terrioriality aid in our understanding the environmental forms by which individuals protect their idiosyncracies and resources and project their identities.

Indeed, distancing behavior serves important physical and psychological purposes. The distance between persons, or between a person and a physical object, is an important factor in the ability of the individual to properly perceive objects in the environment. Such environmental data is crucial to effective negotiation of the environment. But important psychological processes are believed to govern distancing behavior as well. For example, distancing appears to vary as a function of an individual's role in a given setting. The size of a person's personal space "bubble" is determined in part on the basis of behavior patterns normally associated with carrying out a role. For example, the spacing between a lecturer and a large audience differs dramatically from the distance between discussants participating in an informal seminar. Similarly, subway passengers typically seek to avoid physical contact with fellow riders until the train becomes quite crowded (Ittelson et al., 1974). It also has been found that in addition to protecting their own personal spaces, individuals are frequently reluctant to invade the personal domains of others (Horowitz, Duff and Stratton, 1964). Moreover, as already noted, there are cultural differences in the size and role of personal space envelopes.

The computation of permissible occupant loads in buildings is based, in part, upon the anticipated capacity of means of egress. Code provisions which specify rates of flow for various egressway elements are typically based on assumptions about the average area occupied by pedestrians, and about the uniformity of pedestrian movement over some time period. Unless a building is relatively sparsely occupied at the time of a fire outbreak, however, emergency egress by individuals is likely to involve some degree of social and physical interaction with other persons. As the population of a building increases, moreover, the potential for infringments upon each individual's personal space envelope during emergency egress also increases. Two questions are relevant here: (1) What amount of personal space reduction will individuals accept during fire emergency conditions? (2) What are the effects of personal space infringment upon rapid and orderly emergency escape? Saegert (1973) reported that as the number of persons required to occupy a given space increases, the complexity and uncertainty associated with the event at hand increases, while the ability of individuals to organize their behavior decreases. Saegert also noted that personal space infringments reduce behavioral alternatives available to individuals. Furthermore, reduced freedom of choice, combined with unavoidable social and physical interaction among persons, results in decreased cognitive control over the situation by an individual, and in a general increase in psychological arousal. Thus individuals who cannot accept prolonged infringements of personal space may revert to simpler, more regimented behavior patterns and may find individually determined and flexible behavior patterns to be somewhat problematic.

5.3.3 Assessment of Behavioral Assumptions Based on the Technical Literature

Literature review. Assumptions in section 5.2.1 address the degree to which occupants will follow a perceived "leader" or person in authority during a fire emergency. Available technical literature provides considerable support for the notion that individuals and groups will tend to follow the lead of a perceived authority figure. Klein (1976), in a laboratory experiment designed to simulate egress from a theater from which only one narrow exit was available, found empirical support for the hypotheses that groups lose coordination under conditions which personally threaten the members, and that a group under stress wil perform best in the presence of a strong leader (initially advanced by Kelley, et al., 1965). Similarly, Glass (1968), in his studies of mass psychology, noted that as many as 50 percent of participants in large-scale disasters are willing to follow the lead of others and to respond to the directions of some authority figure. Moreover, McLuckie (1970) reported that upon being warned of an impending crisis, individuals tended to telephone "significant" persons to seek recommended action strategies.

Under conditions of stress and impending life threat, individuals who are regarded as "knowing more" may, by consensus of other persons present, be given decisionmaking authority over the group (Quarantelli and Dynes, 1967). In support of this finding, Best (1978), in his review of the Beverly Hills Supper Club fire, concluded that the majority of patrons responded to and followed the directions of waitresses and bartenders. Yamada (1975) suggested that when bewilderment among victims becomes extreme, individuals become docile and take directions more easily. Although Klein (1976) noted the key role played by leaders in achieving safe egress from a simulated theater fire, Quarantelli and Dynes (1972), Form and Nostow (1958), Fritz and Williams (1957) and Drabek (1968) all found that during large-scale natural disasters victims typically do not wait for an authority figure to provide direction; they tend to react immediately, attending to their own well being and helping others nearby.

A significant and frequent phenomenon is the emergence of a leader who "gets people organized" during the early stages of a disaster (Killian, 1954). Numerous post-incident studies by Bryan (1977) of fire episodes in nursing homes also provide evidence suggesting that patients and physicians alike are willing to take directions from more knowledgeable staff (e.g., nurses or orderlies). Evidence from post-incident studies of hospital fires reported by Lathrop (1978) corroborates these findings. But when no leader is perceived to be present, individuals tend to seek information from other nearby people. For example, Breaux, Canter, and Sime (1976) reported that during fires people look to other individuals around them for information which will help define the situation.

The influence of crowd behavior on individuals is summarized in a report by Johnson, Stemler and Hunter (1977). Results of research in this area suggest that groups are more willing to tolerate higher levels of risk than are individual decisionmakers. Studies on altruistic behavior (Latane and Darley, 1968; Pilavin, Radin and Pilavin, 1969) demonstrate rather clearly the potential influence even small groups can have over an individual's behavior.

Behavioral assumptions in section 5.2.2 underlying Code provisions on occupant loading can be evaluated using environmental and social psychological research on density. For example, Saegert (1978) investigated "cognitive overload", an hypothesized result of forcing an individual to process more environmental information than is psychologically possible. Saegert noted that in crowded situations with little or no social structure, the likelihood that an individual's goal-directed behavior will be interrupted may be quite high. Saegert further noted that interruptions to goal-directed behavior frequently leads to either frustration and aggression, or to withdrawal. Examples of environmental settings with relatively weak social structures include shopping malls and theaters.

In another study, Saegert (1974) found that inescapable interaction with large numbers of people increased arousal within individuals. D'atri (1975) reported a concommitent elevation in blood pressure under such conditions. Other investigators have suggested that the magnitude of physiological consequences of inescapable crowd involvement depends upon the period of exposure and the perception of escape or control alternatives (Averill, 1973; Kahn and French, 1970; Saegert, 1976). Nevertheless, elevated arousal has been shown to interfere with complex information processing required to discern changes in the environment (Broadbent, 1971; Cohen, 1978).

While the literature suggests that, under certain conditions, effective leaders can facilitate orderly emergency egress, there is almost no technical documentation of emergency experiences during which specially trained leaders (e.g., "floor wardens") were available within various public occupancies. Available research on this topic, moreover, has cast doubts about the effectiveness of specially trained occupants during crisis situations. For example, although studies of simulated aircraft evacuations demonstrated the need for specialized crew training, they also showed the inadequacies of much of the training provided aircraft emergency "leaders" (Mason, 1974; Becker, 1973; Garner and Blethrow, 1966, 1970). With regard to buildings, Roytman (1969) suggests that special emergency-related responsibilities be allocated to buildings occupants. Pauls (1977, 1979), on the other hand, criticizes the usefulness of trained supervisors in office buildings, noting that assigned floor wardens tended to be poorly trained and to perform incompetently during fire drill situations. Hertz, Edelman and Bickman (1978), examining differences between various methods of training nursing home staff personnel, concluded that in many cases such staff were unfamiliar with existing fire emergency plans. However, these investigators also found that training did improve the performance of nursing home staff during evacuation drills, although this effect was not as strong as anticipated, (this may be due to the extremely high staff turnover at such institutions).

Such factors as environmental conditions, type of clothing worn, cultural norms, the sex of occupants, and the degree of familiarity with other people seem to influence the spacing requirements of an individual (Horowitz, Duff and Stratton, 1970; Evans, 1973). Ciolek (1978) attempted to suggest specific requirements and dimensions for interpersonal spacing, concluding that personal space needs increase in settings which are unfamiliar to the individual as well as in poorly lighted areas. Similarly, Shiffenbauer (1977) noted that increased illumination appears to decrease feelings of being crowded in a room. Evans (1973) and Pauls (1974) have suggested that individuals might require more personal space under emergency conditions. Others have argued, however, that observed increases in the personal space required during evacuations may be due more to faster walking speeds than to underlying psychological needs (Canter and Matthews, 1976).

Suggestions also appear in the literature that personal space needs during emergencies vary as a function of the homogeneity of an occupancy (Canter and Matthews, 1976) and emergency preparedness (Rivers and Bickman, 1979). Moreover, research on pedestrian movement by Fruin (1971) has shown that as occupant density increases in a given pedestrian way, people are more likely to reduce their longitudinal (front-to-back) spacing than their transverse (side-by-side) spacing. Unfortunately, there are no available data describing the effects of personal space variations on the time required for evacuation.

Other assumptions in section 5.2.2 involve the notion that upon reaching a safe area, usually outside the building, escaping occupants will clear the area and thereby not hinder the subsequent evacuation of other occupants. No studies treat this issue directly. Of some relevance, however, are data describing re-entry into burning buildings by evacuees. For example, Wood (1972) found during his post-incident survey that about 44 percent of the fire victims he interviewed re-entered the building after having evacuated. Similarly, Bryan (1977) found that approximately 28 percent of those victims he surveyed also re-entered. Moreover, Bryan (1977) reported that re-entry was more typical of male than of female fire victims. There is presently no evidence, however, to suggest that re-entry into burning buildings by victims interrupts or otherwise blocks other individuals who are attempting to escape.

Behavioral assumptions in section 5.2.3 address the potentially inhibitory effects of building configuration and environmental obstructions on safe and efficient crowd movement. Melinek and Booth (1975) found that bends and corners did not appear to reduce flow rates on stairs. Moreover, the London Transport Board (1958) found no evidence to suggest that queues of pedestrians formed at bends or at other changes in pedestrian movement paths. However, the London Transport Board did find that minor constrictions in passageways tended to increase overall travel time. This finding was not corroborated by Melinek and Booth (1975), who argued that slight projections into pedestrian ways, such as those produced by boxes being stored in a hallway, tend to have little effect upon pedestrian flow rate. In smoke-filled environments, walking speeds were recorded to be lower at corners than they were along linear portions of an experimental pedestrian way (Watanabe, Nayuki and Torizaki, 1973). Similarly, Weisman (1980) suggests that even when occupants are familiar with a building, some architectural configurations may be so complex as to induce confusion and a concommitent reduction in walking speed at such decision points as corridor junctions. Finally, Sadalla and Magel (1980) demonstrated experimentally that as the number of turns or bends in a pedestrian path was increased, subjects' perceptions of the time required to negotiate the paths increased as well. The importance of this finding could be substantial, particularly when one recalls that perceptions of time have been found to be linked with the onset of so-called panic behavior (Janis, 1977).

The available technical literature contains no documentation of inhibitions to crowd flow caused by security procedures or by the improper use of security hardware in buildings. However, anecdotal accounts of the Iroquois Theater fire, the Triangle Shirtwaste factory fire, and other more recent tragedies provide ample evidence of the potential for panic, and for the crushing of occupants attempting to escape, which may result from locking means of egress.

Thus, although considerable technical evidence can be cited in support of the assumption that building occupants will follow the directions of a leader or authority figure during a fire emergency, there is very little evidence that leaders will have been amply trained in emergency escape procedures. Moreover, while there is a growing body of evidence concerning the role of personal space in group behavior and pedestrian movement, the relationship between personal space variation and building evacuation time is presently little understood. Technical evidence concerning the behavior of occupants upon their evacuation from burning buildings and regarding the effects of physical obstacles on crowd flow is not now sufficient to permit an analysis of applicable behavioral assumptions or their antecedent Code provisions. The weight of anecdotal evidence concerning the impact of security procedures and the improper use of security hardware in buildings upon crowd flow and panic behavior, however, does appear sufficient to support related behavioral assumptions and provisions of the Code.

Strengths and weaknesses of the technical literature. In general, current knowledge about whether or not occupants follow the lead of individuals perceived to be in authority during fire emergencies comes from post-incident fire investigations. Results of numerous social psychological experiments are consistent with this finding, as are several theoretical positions. Examples of this research were presented above. The literature on natural disasters tends to stress the emergence of ad-hoc leaders, and this concept may only be useful in relatively large-scale building fires of long duration.

Currently available evidence on the dependability and usefulness of specially trained emergency managers (e.g., floor wardens) does not generally support the assumption, presented in section 5.2, that the presence of such individuals will facilitate prompt and orderly evacuation. Pauls' (1977, 1979) finding that many occupants were unable to obtain needed information from floor wardens during evacuation drills is relevant to this argument, particularly in view of his additional finding that many occupants believed the drill situations to be actual fire events. Substantial differences between building and aircraft evacuations, however, tend to make the aircraft studies less useful to the evaluation of building regulations. The anecdotal nature of reports about leadership qualities displayed by waiters and bartenders during the Beverly

Hills Supper Club Fire (Best, 1978) render generalizations other than informal ones untenable.

Psychological studies of density and crowding were discussed in connection with provisions of the Code which bear on occupant loading in public buildings. Although increased emotional and physiological arousal have been reported to accompany high density occupancy conditions, it is not known whether such increases in arousal will inhibit or stimulate vigilance during actual fire emergencies. In addition, the importance of personal space, and its precise role in emergency egress performance, remain little understood despite statements by some researchers (Evans, 1973; Pauls, 1974). For example, experience in a large metropolitan subway system seems to suggest that most individuals will tolerate an extreme loss of personal space provided this condition is perceived to be of short temporal duration and provided movement toward some goal is apparent.

Almost no technical data are currently available to evaluate the assumption that upon evacuating a building occupants leave the discharge area. The most tangible evidence was presented by Bryan (1977) and Wood (1972), who commented upon re-entry behavior by evacuees. However, extremely few of the cases investigated by these researchers involved public occupancy buildings. Morever, neither investigator documented the influence of re-entrants upon the egress performance of other evacuees.

Crowding, occupant density, and the potential for panic are also relevant to behavioral assumptions underlying Code provisions intended to limit projections and other physical obstacles in egress ways. Here too there are not enough data to permit an evaluation of these assumptions. However, research on individuals' perceptions of traversed distances (Sadalla and St. Magel, 1980) may assist in evaluating the assumption that during fire emergencies, escaping occupants tend to traverse linear routes. For example, Sadalla and Magel found that individuals perceive paths with bends and turns to be longer than linear paths of equivalent length. If one wishes to assume that, under emergency conditions, people consciously seek the shortest known paths, then Sadalla and St. Magel's finding would appear to support both the assumption and its antecedent Code provision. It should be kept in mind, however, that no research on either distance perception or linearity of pedestrian movement routes has been conducted under conditions designed to simulate building fires.

The assumption that egress ways in buildings will be maintained fully available for instant use in case of fire emergencies can not be evaluated because there are no technical data on this topic. Although some anecdotal accounts have suggested that the storage of boxes, etc., within corridors or stairwells might have little effect on egress flow or escape time, there are currently no empirical data to either support or refute this notion.

The available literature on potential conflicts between emergency escape and building security objectives consists almost entirely of anecdotes and reports by fire victims. Indeed, security procedures could have made emergency escape very time consuming, even impossible, during numerous fires reported in the press. It is precisely such events which have given rise, over the years, to public concern about potential conflicts between emergency escape and security goals. However, no systematic investigations of the mutual effects of emergency escape requirements and building security procedures under real or simulated emergency conditions have been conducted to date. In view of the likelihood that there are numerous impediments to speedy egress movement, as well as numerous sources of maladaptive behavior during building fires, it is important to determine what aspects of the problem are actually attributable to the improper implementation of security procedures. At present, however, the lack of technical data on this topic makes such a determination impossible.

5.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

5.4.1 Research on the Effectiveness of Trained Leaders in Facilitating Rapid Emergency Escape and in Avoiding "Panic"

The notion that, during simulated emergencies and large-scale natural disasters, individuals tend to take directions from a perceived leader was amply illustrated by laboratory experiments and case studies described in section 5.3.3. However, the degree to which this phenomenon occurs during building fires cannot be accurately stated on the basis of currently available technical results. This is also true of the actual effectiveness of trained leaders during real fire situations. The principal reason for these gaps is that, to date, no post-incident studies specifically designed to assess the leadership function have been reported.

Human responses during fire emergencies comprise a highly complex area for post-hoc research. A substantial proportion of this complexity owes to the need for investigators to successfully distinguish truthful and accurate answers to their inquiries from answers respondents may fabricate for fear of "looking bad" or becoming involved in legal actions. To a certain degree, such difficulties can be overcome by comparing and cross-checking the responses of numerous victims, or witnesses to the same event. In this way, it may be possible to converge upon a reasonably accurate description of the actual event. Special techniques for obtaining and using information from eyewitnesses have recently been developed for use in police and courtroom investigations (Loftus, 1980), and these approaches may be useful in the present context.

It also should be noted that although behavioral assumptions concerning leadership and direction-taking appear to be generally supported by available technical literature, situational variables affecting these phenomena have not been widely investigated. For example, Keating and Loftus (1974) recommended, on the basis of their research, that female voices be used for certain portions of messages delivered by vocal alarm systems, while male voices be used for other segments. These investigators noted that the female voice is less likely to agitate occupants and cause panic during and is most appropriate for an initial alert, while the male voice is more likely to be associated with an authority figure and therefore should be used to impart specific instructions. However, the extent to which direction-taking is influenced by additional factors such as victim's previous emergency experiences, their emotional and physical capabilities, and the degree of social and functional variation characterizing the affected occupancy, have not been systematically studied.

Finally, behavioral assumptions regarding the availability and function of trained leaders presuppose leaders' knowledge about effective emergency escape procedures. The few available studies do not support this notion (recall Pauls' finding that even where designated floor wardens were specially trained, they did not function as expected during fire escape drills). Accordingly, questions about the social dynamics which arise during building emergencies, and about the nature and quality of training programs, must be considered. Particularly vulnerable are visitors to public (noninstitutional) building because they will have few, if any, preconceptions about the availability or role of emergency supervisors.

5.4.2 Research on the Effects of Occupant Loading and Discharge Behavior on Successful Crowd Movement

Presently available data are insufficient to either support or refute human behavioral assumptions underlying Code provisions affecting building occupant loading and exit discharge facility design. Although several investigators have suggested the need to incorporate personal space requirements and side-to side body sway into the design of means of egress (e.g. Pauls, 1974; Fruin, 1971), the effects of such factors on escape time, particularly under actual emergency conditions, remains little understood. For example, the manner by which occupants physically utilize egress ways (viz. their interpersonal spacing behavior and the biomechanics of walking, stair use, etc.) may well influence the time required to negotiate an entire egress route. But it is not now known at what point and by what mechanisms occupants will relax their own personal space requirements and accept more physically crowded conditions during egress. The ability to identify this threshold and, more fundamentally, to determine a logical connection between constriction in egress ways, increased physiological and emotional arousal, and the onset of maladaptive (panic) behavior, may eventually lead to modifications in the design of exit components and systems.

5.4.3 Research on the Effects of Architectural Impediments and Physical Obstacles Upon Crowd Behavior and Disciplined Movement

Extremely little technical literature was found applicable to evaluating Code provisions intended to minimize physical impediments and obstacles to rapid escape. The specific effects of physical obstacles (e.g. corridors or stairwells being used as storage facilities) on escape time has not been systematically investigated. Future "time-motion" experiments under a wide variety of simulated egress conditions should provide data useful for comparative purposes. Moreover, future post-incident investigations using sophisticated interviewing techniques can query victims about problems they may have encountered with architectural impediments or other physical obstacles.

Similarly, experiments on the effects of locking exit doors or of other security procedure infractions could be conducted under carefully controlled simulated emergency conditions. The appropriate dependent variable in such studies is a measure of elapsed perceived time-to-escape, and this measure should be compared under various conditions of occupancy, density and occupant loading, actual as well as perceived alternative escape routes, and emergency training. Although data obtained from such experiments may be useful for comparative purposes, extrapolations from simulations to behavior during real emergencies should be made with caution. For example, while maladaptive behavior may take the form of an incorrect response leading to excessive escape time in a laboratory simulation, it may take the form of "panic", injury, or even death during a real fire.

Code provisions specifying the measurement of distances to means of egress along along linear path segments seem to suggest that during fire emergencies occupants will traverse linear-segmented routes. If individuals traverse nonlinear paths or if on occasion they meander during an evacuation, then their egress times will be longer than those produced by purely linear travel. Longer egress times would imply a reduction in the maximum allowable distance between the furthest location on a floor and an exit (see provision 5-6.2). Available data do not make such a recommendation possible now. Future research is required to document actual path lengths and patterns traversed by escaping occupants. This research may be accomplished during evacuations of large rooms or entire building floors under simulated emergency conditions, using specially placed motion picture or videotape recording equipment.

5.5 SUMMARY

A number of human behavioral assumptions about crowd movement and disciplined group behavior underlie selected provisions of the Code. These assumptions were evaluated by reference to several models of human collective behavior, data from research in experimental social psychology, field research on natural disasters, and post-incident fire investigations. In general, the technical literature suggest support only for those assumptions pertaining to leadership and direction-taking behavior. Behavioral assumptions pertaining to the effects of occupant loading and physical obstacles upon orderly and rapid crowd movement appear to be neither supported nor refuted by available technical literature. To the extent that impediments to crowd movement result in maladaptive collective behavior and panic, future research on the role of building design in facilitating crowd movement seems an essential precursor to Code development.

6. PROVISIONS ACCOMMODATING OCCUPANTS' CAPABILITIES TO SAFELY AND RAPIDLY NEGOTIATE EGRESS WAYS

6.1 APPLICABLE CODE PROVISIONS

5-2.1.1.3.3 The floor on both sides of a door shall be substantially level and shall have the same elevation on both sides of the door, for a distance on each side at least equal to the width of the widest single door. When the door discharge to the outisde or to an exterior balcony, exterior exit, or exterior exit access, the floor level outside the door may be one step lower than the inside but not more than 8 inches lower.

5-2.1.1.4.5 The force required to fully open doors shall not exceed 50 pounds applied to the latch stile.

5-2.1.2.1.2 A latch or other fastening device on a door shall be provided with a knob, handle, panic bar, or other simple type of releasing device, the method of operation of which is obvious, even in darkness.

5-2.1.2.2.1 When a door is required to be equipped with panic hardware by some other provision of this Code, then panic hardware shall cause the door latch to release when a force of not to exceed 15 pounds is applied to the releasing devices in the direction of exit travel.

5-2.1.2.3 Self-Closing Devices. A door designed to be kept normally closed in a means of egress, such as a door to a stair enclosure or horizontal exit, shall be a self-closing door and shall not at any time be secured in the open position.

5-2.1.3.1.1 Where required doors are operated by power, such as doors with photo-electric actuated mechanism to open the door upon the approach of a person or doors with power-assisted manual operation, the design shall be such that in event of power failure the door may be opened manually to permit exit travel or closed where necessary to safeguard means of egress.

5-2.2.2.1 Each new stair and platform, landing, etc., used in conjunction there with in buildings more than 3 stories in height and in new buildings required by this Code to be of fire-resistive construction, shall be of noncombustible material throughout.

Exception: Handrails are exempted from this requirement.

5-2.2.2.2 There shall be no enclosed usable space under stairs in an exit enclosure nor shall the open space under such stairs be used for any purpose.

5-2.2.2.4 No arrangement of treads known as winders shall be permitted in new stairways.

5-2.2.2.6 Where material of stair treads and landings is such as to involve danger of slipping, nonslip material shall be provided on tread surface.

5-2.2.2.7 The height of every riser and the width of every tread shall be so proportioned that the sum of 2 risers and a tread, exclusive of its nosing or projection, is not less than 24 nor more than 25 inches.

5-2.2.2.8 The minimum number of risers in any one flight of stairs shall be 3.

5-2.2.2.10 There shall be no variation exceeding 3/16 inch in the depth of treads or in the height of risers in any flight.

Exception: As permitted by 5-2.2.1.4 for monumental stairs.

5-2.2.3.1 Means of egress such as stairs, stair landings, balconies, ramps and aisles, located along the edge of open-sided floors and mezzanines, shall have guards to prevent falls over the open side. Each new stair and Class B ramp shall have handrails on both sides (see also 5-2.2.3.4).

5-2.2.3.2 Required guards and handrails shall continue for the full length of each flight of stairs.

5-2.2.3.4(e) Every stairway required to be more than 88 inches in width shall have not less than 1 intermediate handrail for each 88 inches in required width (see also 5-2.2.3.1).

Exception: On monumental outside stairs 2 handrails may be permitted.

5-2.3.7 Access from a building to vestibules or balconies shall be through doorways not less than 40 inches wide for new and 36 inches wide for existing towers. These openings and the entrances to the towers shall be provided with approved, self-closing fire doors swinging with the exit travel. Clear wired glass not exceeding 720 square inches shall be provided in all doors giving access to the enclosure.

5-2.5.1.3.3 Visual Enclosure. Outside stairs shall be so arranged as to avoid any handicap to the use of the stairs by persons having a fear of high places. For stairs more than 3 stories in height any arrangements intended to meet this requirement shall be at least 4 feet in height.

5-2.5.1.3.4 Weather Protection. Outside stairs in climates subject to snow and ice shall be protected to prevent accumulation of snow or ice.

5-2.5.3.3 Risers shall be solid.

Exception: The skirt-type, having 1 inch space for drainage, shall be permitted.

5.2.6.1.4.2 The slope of a ramp shall not vary between landings. Landings shall be level and changes in direction of travel, if any, shall be made at landings.

5-2.6.2.2.4 Weather Protection. Outside ramps in climates subject to snow and ice shall be protected to prevent accumulation of snow or ice.

5-5.1.1 Exits shall be so located and exit access shall be so arranged that exits are readily accessible at all times.

5-5.1.2 When more than one exit is required from a story, at least two of the exits shall be remote from each other and so arranged and constructed as to minimize any possibility that both may be blocked by any one fire or other emergency condition.

5-5.1.3 Means of egress shall be so arranged that there are no dead end pockets, hallways, corridors, passageways or courts whose depth exceeds the limits specified for individual occupancies by chapter 8 through 16.

5-6.5 Where open stairways or ramps are permitted as a path of travel to required exits, such as between mezzanines or balconies and the floor below, the distance shall include the travel on the stairway or ramp, and the travel from the end of the stairway or ramp to reach an outside door or other exit, in addition to the distance to reach the stairways or ramp.

5-6.6 Where any part of an exterior way of exit access is within 15 feet horizontal distance of any unprotected building opening, as permitted by 5-2.5.1.3.1 for outside stairs, the distance to the exit shall include the length of travel to ground level.

6.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

6.2.1 Assumptions Relating to the Effects of Stair and Ramp Design on Occupants' Capabilities to Safely and Rapidly Negotiate Egress Ways

(1) Non-level floors or steps immediately on either side of a doorway may reduce the discharge rate of the doorway (5-2.1.1.3.3).

(2) Certain materials used on the surface of stair treads may cause slipping, whereas others may prevent slipping. Slipping by occupants attempting to escape via an exit stair contributes to reduced egress flow (5-2.2.2.6).

(3) The ratio of riser-to-tread dimensions influences flow rate along stairs (5-2.2.2.7).

(4) Stair flights with fewer than 3 risers may cause falls or accidents, or otherwise impede egress flow (5-2.2.2.8).

(5) Irregular riser or tread dimensions along any stair may contribute to missteps or falls, and thereby reduce egress flow (5-2.2.2.10).

(6) Handrails prevent falls, slips, or missteps on stairs, and thereby prevent reductions to egress flow (5-2.2.3.1; 5-2.2.3.2).

(7) On stairways greater than 88 inches in widths, an intermediate handrail will reduce the likelihood of falls, slips, or missteps, and thereby prevent reductions to egress flow (5-2.2.3.4).

(8) Egress flow on outside stairs may be impeded by weather conditions which increase the slipperiness of stairs (5-2.5.1.3.4; 5-2.5.3.3).

(9) Variations in the slope of a ramp between landings may reduce the flow rate on the ramp (5-2.6.1.4.2).

(10) Ramp surfaces not specifically treated to increase slip resistance may cause slips, trips, missteps, or falls, which reduce egress flow (5-2.6.1.4.4).

(11) Slips, trips, missteps, or falls which reduce egress flow occur more frequently on outside ramps not adequately protected from the weather, than on ramps which are adequately protected (5-2.6.2.2.4).

6.2.2 Assumptions Relating to the Effects of Physiological and Psychological Stress Upon Occupants' Capabilities to Safely and Rapidly Negotiate Egress Ways

(1) Infiltration by fire products into egress ways may impede egress flow (5-2.1.2.3; 5-2.2.2.1; 5-2.2.2.2).

(2) Occupants' entry into enclosed stairways may be influenced by these individuals' ability to see into the stair enclosure (5-2.3.7).

(3) Persons having a fear of high places may impede egress flow on certain outside stairs (5-2.5.1.3.3).

(4) Dead end pockets, hallways, corridors, passageways and courts which exceed certain limits reduce egress efficiency and increase egress time; these limits vary according to occupancy (5-5.1.1; 5-5.1.2; 5-5.1.3).

(5) Travel to a means of egress which requires passing through an uprotected zone or area may result in slower overall evacuation (5-6.5; 5-6.6).

6.2.3 Assumptions Relating to the Biomechanics of Exit Door Operation.

(1) In general, building occupants can apply as much as 50 pounds of force to a door stile, and 15 pounds of force to a panic bar, and in so doing will not impede flow through a doorway or means of egress (5-2.1.1.4.5; 5-2.1.2.2.1).

(2) The design of door hardware influences flow through the door, under both conditions of light and darkness (5-2.1.2.1.2).

(3) The means of manually operating automatic or power assisted doors (as may be required during a power failure) are familiar to, or known by, escaping occupants; hence any need to manually operate such doors will not increase evacuation time (5-2.1.3.1.1).

6.3 COMMENTARY

6.3.1 Problem

The ability of building occupants to safety and rapidly negotiate egressways may be affected by the sensory-motor capacities of these individuals. Writers of the Code have recognized, at least in principle, the need to consider human performance criteria in the design and organization of building egress facilities. This concern is reflected in several provisions of the Code. Human behavioral assumptions believed to underlie Code provisions intended to accommodate occupants' abilities to safely and rapidly negotiate egressways primarily address three issues: (1) the extent to which accidents such as, slips, missteps, or falls, which may occur while people negotiate pedestrian ways, impede flow along corridors, stairs, and ramps, and through doorways; (2) the degree to which stress and fatigue impair walking behavior and increase the time required for egress; and (3) the influence of door and other hardware design upon occupants' abilities to rapidly and effectively operate elements comprising means of egress. Several models which provide useful insights about human performance capabilities pertinent to emergency escape during building fire situations are discussed below.

6.3.2 Underlying Behavioral Models

Research in the fields of human factors psychology and biomechanics has given rise to a number of models explaining human performance capabilities under various circumstances. Most of the Code provisions and behavioral assumptions in sections 6.1 and 6.2, respectively, address occupants' negotiation of stairs and ramps in buildings. Thus a model of stair and ramp use is presented first.

A general assumption which appears to underlying Code provisions concerning the design of stairs and ramps is that conditions which increase the likelihood of trips, slips, missteps, or falls may increase overall egress time. So-called "human error" is the most commonly cited cause of accidents involving people's negotiation of the environment (Zeller, 1970). By analogy, man-machine and feedback-loop models have been used to describe behavioral sequences which lead to accidents (Zeller, 1959). For example, the user of a stair approaches this portion of an egress way and perceives its configuration. The individual interprets information perceived about the stair, and compares knowledge of this egress way with prior experiences with other stairs. This process results in decisions about required gait, interpersonal spacing, level of vigilance, etc., after which actual negotiation of the stair begins.

The stair user continually obtains feedback concerning stair use. As the occupant ascends or descends the stairway, successful biomechanical behaviors (i.e., those which result in an unencumbered negotiation of the stair, and which result in no missteps or falls) are reinforced. The more succesful steps that are taken on this stair, the more likely is the user to continue exercising the particular set of biomechanical patterns, and the less vigilant is the user likely to become (Archea, Collins and Stahl, 1979). Negative feedback (unsuccessful steps) most frequently take the form of missteps, which tend to alert the stair user to exercise greater caution in negotiating the remainder of the stair, and which may also cause the user to be vigilant with regard to potential stair hazards (Archea et al. 1979).

Thus, stair users continually test their preconceptions about what they expect to encounter during stair use against the physical properties of the stair actually negotiated. According to Archea et al. (1979), the user initiates this test cycle immediately upon approaching a given stairway. Even before taking the first step, the user compares perceptions of the present stair environment with an internalized image of stairs in general (i.e., what stairs ought to be) which have been built up over years of experience using stairs. If the user finds a close match to exist between the current stair and the internalized image, then the individual enters the stairway with confidence that it can be successfully negotiated. Each subsequent movement on the stair then engages tactile and kinesthetic feedback mechanisms which provide environmental data necessary to test the "fit" between physical properties of the stair and the user's internalized image. As noted earlier, the individual may become less vigilant (i.e., less aware of tactile and kinesthetic information obtained during stair negotiation) as the internalized image of the stair is confirmed through actual stair use. According to Archea et al. (1979), experience in negotiating the first few treads may be the most critical in establishing a "working" level of vigilance.

While negotiating a stair, deviations from anticipated physical properties may require the user to adjust biomechanical behavior patterns. According to Archea et al. (1979), minor deviations which fall within some acceptable range (e.g., occasional irregularities in riser or tread dimensions) are likely to require only very small biomechanical adjustments. Inconsistencies which fall outside this range (e.g., a broken tread or handrail), however, if detected, will arouse the user's vigilance to the stair environment and cause the individual to re-evalute the correctness of the originally-chosen behavior pattern, making any adjustments required. Whether or not the stair user successfully adjusts to gross deviations in the stair environment may depend, to a large extent, upon how far the individual has proceeded in negotiating the present stair. For example, an individual who has only taken a few steps onto the stair, and who is still in the process of confirming mental hypotheses concerning this stair, may consciously anticipate errors and therefore be likely to make behavioral adjustments relatively easily. In this instance, stair negotiation is not likely to suffer. However, a user who has negotiated almost the entire stair before obtaining negative feedback may have already obtained sufficiently strong confirmation of mental hypotheses concerning the stair to cause overall vigilance reduction. In this case, the user may be ill-prepared to respond to unexpected variations in the physical properties of the stair, and may misstep, slip, or fall.

Thus, Archea et al. (1979) suggest that stair accidents result when stair users (1) base their stair use behavior patterns upon erroneous expectations, (2) select inappropriate biomechanical response patterns, or (3) under- or over-estimate required biomechanical modifications when responding to the physical properties of a stair.

Research on stair use reported by Archea et al. (1979), Carson, Archea, Margulis, and Carson (1978), and Templer, Mullet, Archea, and Margulis (1978) also has pointed to the importance of the so-called orientation edge. This concept may be defined as any abrupt change from the typically visually-enclosed stair to an open view of another larger space at the top or bottom of the stair. When descending a moving stair in a department store, for example, the pedestrian often moves from a visually-confined enclosure to a wide-open and visually complex space. This sudden change can distract the user from the fixed stair or moving stair and cause the user to orient toward the activities, people, or milieu within the larger open space. If this results in a substantial reduction in attention to stair negotiation while the individual must respond to some deviation in the stair itself, the likelihood of a stair accident is presumed to increase.

Presently there are no behavioral models describing ramp use per se. It has been suggested that general models of pedestrian movement in bounded environments, based primarily upon the negotiation of level planar surfaces, can account for ramp usage (Fruin, 1971). However, models of pedestrian movement in bounded environments typically are based on physical analogs rather than on theories of human behavior. These models are discussed in chapter 7.0 of the present report. For the purpose of describing occupants' capabilities to safety and rapidly negotiate ramps, the stair use model described above appears plausible.

The influences of stress and fatigue on occupant capabilities, particularly under emergency conditions, involves numerous and diverse perceptual, cognitive and physiological reactions. These phenomena have not been organized into a single model of emergency behavior under stress. However, concepts from both environmental psychology and neurophysiology may contribute to a greater accommodation of occupants' capabilities to safely and rapidly negotiate egress ways.

For example, stress can be operationally defined as the effect of stimuli sufficient in intensity to adversely influence response behavior. Stressors so defined may be viewed as behavior-interrupting mechanisms of environmental, emotional, or physiological origin (Simon, 1967). Examples of stressors which interrupt ongoing behavior patterns include input (sensory) and motor (neuromuscular) overload, conflicting or contradictory information from the environment, and sensory-motor system failures (physical disease). Stressors such as these influence behavior either indirectly by affecting the sensory organs, or directly by affecting human central and autonomic nervous systems. Alarm reactions resulting from stress can generate a local adaptation syndrome (Selye, 1956). The reactions and the syndrome are directed toward the immediate stressor and have survival as their immediate objective.

The local adaptation syndrome consists of short-term physio-regulatory processes which the human body automatically and immediately evokes in response to some physical change. These processes avoid, repel, or utilize stressors which have interrupted ongoing and adaptive behavior in order to compensate for the stressors' presence and restore ongoing activity patterns. When the local adaptation syndrome is triggered, an individual can expend considerable energy, attention, and time on stress reduction. Moreover, extremely intense stressors, or those of relatively long temporal duration, may bring about the general activity syndrome characterized by endocrinal activity resulting in physiological changes throughout the body. Under the most extreme circumstances, adrenal exhaustion may result, wherein an individual's neuroendocrine system becomes completely overloaded and is rendered incapable of responding to any environmental stimuli at all.

The onset of fire conditions in a building illustrates the processes described above. On being alerted to a life threat in the building, an occupant's current pattern of behavior is suddenly interrupted by stimuli (i.e., information contained in the alert message) which may be perceived by the occupant as both unanticipated and ambiguous. Such an alert engages the individual's neurological orienting response mechanism (Sokolov, 1963), which focuses the occupant's attention on the newly-discovered environmental conditions. This process involves activation of the sympathetic nervous system, as well as secretion of hormones by the adrenal medulla. The result of these physiological processes is a mobilization of the body's resources in preparation for swift action (primarily "fight" or "flight"). A marked increase in heartbeat rate and strength, necessary to satisfy the body's increased demands for oxygen, also results.

These demands require the spleen to contract (and thereby release stored red blood cells which are needed to carry the increased oxygen supply), respiration to deepen, and the bronchi to dilate. These are the principal physiological steps taken automatically by the human body to meet the perceived challenges of an external threat. Once oriented to the threat, interruptive stressors may distract the individual from the demands of the impending crisis, may redirect the focus of concern, or may overload the person's physiological capability to cope.

This cybernetic model of neurophysiological coping bears relevance to human behavioral assumptions believed to underlie provisions of the Code intended to accommodate occupants' capabilities to safely and rapidly negotiate egress ways. For example, the Code addresses itself to the infiltration of fire products into means of egress. Where such infiltration occurs, CO often acts to interrupt the body's normal oxygen intake mecahnisms. As a result, the body's pulmonary system is adversely stressed in its attempt to reject the poisonous substance (as evidenced by coughing, choking, gagging, etc.). The initial inhalation of smoke evokes an alarm reaction, which may lead the individual to seek a less toxic environment. Indeed, the individual is physiologically prepared to consume larger amounts of oxygen; however, oxygen cannot be biochemically processed in the presence of CO contamination. If the individual cannot move to a less toxic environment, therefore, the body's vital homeostasis will be lost.

Stress can also affect cognitive-perceptual processes. Infiltration of fire products into an egressway can provide escaping occupants their first actual glimpse of fire products. In this instance, a perceptual-cognitive alarm reaction is triggered when the individual realizes that the life threat is considerably nearer than previously expected. The orienting response evoked by the presence of fire products results in a temporary, although possibly distracting, adjustment in the focus of the person's attention away from the escape task and toward nearby fire products. Here, the sudden recognition of the fire's reality serves to interrupt adaptive behavior (movement through the egress way).

Once an occupant's attention has been redirected away from those components of egress ways crucial to their successful egress, the likelihood of a potentially time-consuming misstep or fall is increased. If a stair is being entered, for example, the redirection of visual attention to fire products above or to one side may result in only kinesthetic testing of just the first few treads. This redirection of stair users' attention may result in a stair accident which temporarily impairs the use of the stair by other evacuees (Archea et al. 1978). Alternatively, environmental stressors may interrupt ongoing adaptive behavior patterns by causing an individual to avoid a particular action and to reformulate the egress strategy.

Upon opening the door to a stairwell, for example, an occupant may see fire products, conclude that this means of egress is unsafe, and seek another stair, means of egress, or refuge.

Impairments to visibility also can limit a person's capacity to rapidly negotiate means of egress, and can interrupt egress-related behavior patterns. The light diffusing and obscuring qualities for fire products (smoke), as well as irritation to the eye's membranes produced by these products, combine to encourage cautious and hesitant behavior by occupants. Such behavior may result in reduced walking speed, using a nonlinear walking path, and in some instances, total avoidance of the smoke-filled area. Similarly, occupants tend to approach and utilize darkened pedestrian ways with extreme caution, and may, in some cases, prefer to avoid darkened routes entirely.

Finally, acrophobia--abnormal fear of high places--can be triggered by visual information, which is particularly relevant to the forced use of outside stairs during fire emergencies. During an evacuation utilizing such a stair, an acrophobic occupant may hesitate, "freeze", or "panic."

Fatigue may also impair occupants' capabilities to safely and rapidly evacuate buildings during fires. An illustrative case involves occupants' negotiation of dead end corridors. Where an occupant has unknowingly been brought to a dead end, a rapid shift in egress strategy may be required. This shift can increase stress for the individual in two important ways: (1) nonproductive negotiation of an incorrect path uses valuable time, during which effective egress routes could become blocked; and (2) the sudden realization that a particular strategy was nonproductive may create within the individual perception that the time remaining for safe escape has dramatically decreased. Under these circumstances the individual, having made an erroneous response, must adjust quite rapidly to a new set of environmental conditions. Where the occupant perceives extremely little time available for safe escape, the person's information processing capacities become highly stressed. Such stress may result in psycho-motor fatigue. Hence, not only is motor behavior slowed, but the occupant is less able to process critical environmental information as well.

Behavioral assumptions believed to underlie Code provisions in section 6.2.3 address the operability of exit door hardware during fire emergencies. A biomechanical model of the human body provides some insight into questions posed by these provisions. In brief, the human body may be conceptualized from a mechanically dynamic viewpoint as a highly complex mechanical structure consisting of numerous mass-spring-damper elements. In addition to their inertial characteristics, the skeleton, organs, ligaments, and muscles have elastic properties as well. Within this model, the torso may be considered a pure mass which is supported by the spinal column resting on the pelvis. Arm--shoulder configurations (which are most relevant to the present discussion) comprise subsystems (see Coermann, 1970). Subsystem components and entire subsystems are interconnected by a limited set of rigid links. The links articulate at pivot points which may be characterized in terms of their limitations to free movement. Under the biomechanical model, the body's density is assumed to be homogenous. The biomechanical manipulation of architectural hardware may be modeled as the vector motion of spring-like links with intervening pivots.

The relevance of the biomechanical model to emergency escape may now be considered more specifically. The model suggests that when calculating the force required to actuate panic hardware, a thorough analysis of static and dynamic forces applied by the human body through both rigid elements and pivots is necessary. Such analyses may yield, for example, that different door/landing configurations provide varying opportunities for individuals to apply forces to hardware efficiently and rapidly. They would also illustrate the differences in panic hardware operation between, say, able-bodied occupants approaching the door via rapid movement along a level surface, able-bodied persons approaching the door immediately upon stepping off a stair, and wheelchair-bound individuals likely to exert smaller forces through non-normative vector paths.

Another concern of this set of assumptions focuses upon the design of door hardware. Here too, a biomechanical understanding of arm-shoulder and hand manipulation is useful. For example, most doors may be quickly and easily opened by placing one hand on a circular knob, and then by turning this knob while simultaneously pushing (or pulling) the knob and door. However, the design and placement of such hardware has typically been intended for persons of average height, stature, and motor capabilities (Margulis 1981). A child who must reach upward before pushing upon or pulling a door knob, an arthritic person who might be unable to rotate the knob sufficiently, or an elderly individual who may be incapable of applying sufficient force to open a door into a stairway, may be biomechanically disadvantaged in manipulating exit doors which are not required to contain panic hardware.

6.3.3 Assessment of the Behavioral Assumptions Based Upon the Technical Literature

Literature review. Assumptions enumerated in section 6.2.1 concern the use of stairs and ramps as means of egress. A number of studies reporting data on stair and ramp utilization became available immediately prior to and since the publicaton of the 1976 edition of the Code. In several instances these data appear to support applicable Code provisions. For example, the Code prohibits the placement of non-level floor surfaces or steps immediately on either side of most doorways (provision 5-2.1.1.3.3). Designers and building officials apply this prohibition under the assumption that floor plane irregularities in the immediate vicinity of doorways may slow egress flow either directly, or indirectly by causing missteps or falls. This notion is supported by Archea et al. (1979), who suggest that the sudden shift in people's attention from door negotiation to the floor surface irregularity may indeed decrease the efficiency of the doorway as a means of egress. Additional support is provided by Peschl (1971), who found that occupants passing through doorways which immediately preceded steps frequently fell or stumbled.

Other behavioral assumptions deal with the matter of traction on walking surfaces. Archea et al. (1979) suggest that most so-called "slip" accidents may in fact result from incorrect placement of the foot when negotiating stairs, and may not result from insufficient traction. Moreover, they point out that when stair tread surfaces are maintained clear and dry, severe slips in either ascent or descent, due to reduced traction, may be virtually impossible. Further, these investigators point out that a certain amount of "slip" is required for safe and efficient stair negotiation, and that excessive friction between footwear and tread surfaces may also contribute to missteps and other factors which reduce rapid egress through stairways. This notion is supported by Carson, et al., (1978) who, finding no statistical relationship between stair accident rates and stair tread materials, report a positive correlation between stair accident rates and coefficients of friction. However, Carson et al. (1978) note that coefficients of friction of materials ordinarily found on stair treads (particularly in residential construction) fall in a range which cannot be statistically linked with stair accident rates. With reference to inclement weather conditions, such as those which may influence the efficient use of outside egress stairs, Sigler (1973) found wet stairs to be substantially more slippery than dry stairs. However, Sigler found no statistical correlation between surface wetness and stair accident rates. Measures taken to correct slippery conditions on stairs may also lead to anomolous stair use behavior. For example, Miller and Esmay (1961) found that rubber mats and varnish coatings were each twice as hazardous as paint coatings or bare wood surfaces of residential stairs. Where tread coverings (e.g., carpets or plastic runners) are applied to stair surfaces in residential structures, it is estimated that the improper fastening of such coverings may account for as many as 10 percent of all stair accidents (Velz and Hemphill, 1953).

A number of other assumptions concerning effective emergency stair use involve dimensional relationships between risers and treads, as well as the number of risers present in stairs. McGuire (1971) suggests that steep and nonuniform stairs be avoided, citing a study in which 22 percent of all stair-related accidents were attributable to excessively steep stair design. Based on gait rhythm data collected during laboratory experiments utilizing a mechanical stair treadmill apparatus, Templer (1974) found that individuals are least likely to experience missteps in ascent when risers were between 6.3 inches (0.16 m) and 8.9 inches (0.23 m), and when treads were between 7.7 inches (0.20 m) and 14.2 inches (0.36 m). With steeper stairs, Templer found an increased number of missteps in descent.

In contrast, Neutra (1972) and Carson et al. (1978) found no significant correlation between stairway slope and accident rates. These investigators note that particular combinations of riser and tread dimensions may contribute to a greater likelihood of missteps, suggesting that more attention be paid to these combinations than to gross measures of stair slope.

Concerning the potential effects of stair design upon the speed and efficiency with which stairs can be negotiated, Fruin (1971) reports a negative correlation between pedestrian movement speed and stair slope. Pauls (1980) concurs with Fruin, suggesting on the basis of his observations of stair use behavior in public buildings, that within a certain range, larger treads promote more efficient utilization of stairs.

The Code is also concerned with the provision of handrails in egress stairways. In general, when providing handrails, the designer and building official assume that the proper location (and subsequent use) of these elements promotes rapid and efficient use of stairs, particularly during emergencies. Similarly, the ommission of handrails, or their improper design or location, may be assumed to increase the likelihood of stair accidents and of other impediments to safe and rapid movement. The literature on stair use behavior and stair accidents remains equivocal on these points. For example, while McGuire (1971) and Templer (1974) attribute a substantial proportion of stair accidents studied to a lack of available handrails, Carson et al. (1978) could establish no significant relationship between the presence or absence of handrails and accident rates. Interestingly, Carson et al. (1978) note a positive relationship between handrail availability and such less serious stair incidents as missteps. This relationship, however, is counterintuitive, since missteps were found by these investigators to be more frequent in cases where handrails were in fact available.

However, these investigators did find that the severity of stair accidents tends to increase when handrails are absent, and that in general, accidents on stairs without handrails tend to result in more serious bodily injuries. In this regard, Pauls (1980) has pointed to the varying needs of individual occupants for handrail support. Archea et al. (1979) also found differenes in the need for handrail support between elderly persons, children, able-bodied adults, and other individuals.

Benefits derived from providing center handrails in wide stairs have not been analyzed in detail by researchers. Galbreath (1969) suggests that while the provision of center handrails may decrease the likelihood of accidents, it also reduces the overall width of the egressway. Archea et al. (1979) report that no causal link between the provision of center handrails and accident rates on heavily-traveled stairs has as yet been empirically established. However, these investigators also recommend the use of intermediate handrails on wide stairs.

Regarding the efficient use of ramps under egress conditions, Fruin (1971) found that grades up to 6 percent appeared to have little effect on pedestrian movement speed. This finding is corroborated by Tregenza (1976), who also notes that a 10 percent ramp gradient could reduce upward walking speed by as much as 40 percent. Most recently, the importance of ramps as means of ingress, egress and interior circulation has been heightened by concerns for handicapped occupants of public buildings. Tregenza (1976) reports that ramps steeper than 8 percent can be dangerous for wheelchair users and other persons with motor disabilities. Steinfeld (1975) recommends that ramps designed for disabled occupants vary between 4 and 8 percent, with 5 percent as the preferred design value. Walter (1971) suggests that a 7 percent gradient was optimal for handicapped users. To date, no evidence was found to support or refute the slip-resistance features of ramp provisions of the Code.

Assumptions considered in section 6.2.2 consider the influence of stress and fatigue on occupants' capabilities to safely and effectively negotiate egressways. A number of these assumptions assert that the infiltration of smoke into egressways such as stairs, because of its potential effects on human respiratory, visual, and nervous systems, may exert physiological stresses on escaping occupants, reducing their egress capabilities. Perhaps the most prevalent fire product is toxic smoke, a critical constituent of which is carbon monoxide (CO). A number of experiments have been conducted to study the effects of high doses of CO on both conditioned and unconditioned responses of laboratory animals (Laties and Merigan, 1979). In most of these studies, the onset of abnormal behavior occurs at CO concentrations of between 200 and 400 parts per million for a minimum exposure of one hour. These concentrations are generally associated with carboxyhemoglobin (COHb) levels of between 13 and 25 percent.

Petajan (1976) has pointed out on the basis of his experiments with laboratory animals that nonadaptive behavior may result from impairments of animals' abilities to process and utilize new environmental information, rather than from purely physiological impairments of sensory and motor systems. Obviously, the examination of human cognitive, sensory, and motor behavior under exposure to high concentrations of CO for prolonged periods is life-threatening and is not advocated here. A number of experiments utilizing human subjects have been carried out, however, to study potential effects of relatively low CO concentrations over time periods somewhat characteristic of those encountered during fire emergencies. Under such conditions, most investigators found that COHb level of up to 30 percent had little effect of human psychomotor response patterns, even when subjects were exposed to low concentration CO for five hours (Milkulka, O'Donnell, Heinig and Theodore, 1970; Stewart, Peterson and Buretta, 1970; O'Donnell, Milkulka, Heinig and Theodore, 1971). Results of these studies suggest that moderate doses of CO, as might be experienced under certain conditions during building fires, would not adversely affect occupants' escape performance to any significant degree. In support of these empirical findings, post-incident fire investigations by Wood (1972) and Byran (1977) revealed that a substantial proportion of individuals interviewed moved through smoke while evacuating, and that some of these occupants may have traversed up to 400 feet (122 m) in a smoke-filled environment. Wood called this finding "surprising."

These findings indicate that CO contributes to performance decrement during fires in only minimal ways. However, anecdotal evidence from actual fires provides a contradictory viewpoint. The December 4, 1980 Stouffer Inn fire in Westchester County, New York, (The Herald Statesman, December 14, 1980) provides a case in point. The fire department was on the scene within 12 minutes of the fire's initial detection, and found that a number of victims had already died from what is believed to have been CO poisoning. County medical examiners have speculated that in this case the presence of automatic sprinklers might not have prevented the rapid spread of toxic gases which are believed to have been the cause of death for numerous victims. In one instance, the last person leaving a room inadvertently made a wrong turn and was soon overcome by smoke. This individual died as a result of toxic gas inhalation. Such events as the Stouffer Inn fire and the recent hotel fires in Las Vegas, Nevada, point to the rapid incapacitation of occupants as a result of smoke products.

One explanation for the apparent disparity between research findings and anecdotal accounts concerns the nature of building materials which, during fire conditions, release toxic products. For example, an experiment by Mitchell (1978) demonstrated that the time required to incapacitate laboratory rats was less in the presence of burning synthetic polymeric furnishings than in the presence of burning natural fibrous materials. Extremely few data are currently available regarding human tolerance to short term exposures (i.e. less than five minutes) to high concentrations of multiple contaminants. However, the inhalation of hydrogen chloride simultaneously with carbon monoxide is now known to be corrosive to human respiratory organs (Phillips, 1978). A single material comprising a room furnishing may release a relatively harmless toxicant when ignited. But when such toxicants combine with other substances in the fire environment, the result may be debilitating and even lethal (Phillips, 1978).

Another problem associated with the infiltration of fire products into egressways, is visibility. Phillips (1978) noted that when hydrogen chloride gas comes in contact with the human eye hydrochloric acid is formed, causing intense pain and tearing, and interfering with normal vision. Ammonia and fluoride gases have similar effects. Such toxicants are capable of impairing human vision even before smoke density is sufficient to obscure visibility through diffusion. Experimental data reported by Rasbash (1975), and Jin (1976), indicate that when visibility is reduced to approximately five meters, the ability of subjects to negotiate egressways is impaired. However, these findings are not corroborated by data from post-incident surveys collected by Bryan (1977) and Wood (1972).

Research on the effects of CO also has indicated that this toxicant may influence tje visibility threshold (McFarland, Roughton, Halperin and Niven, 1944; Halperin, McFarland, Niven and Roughton, 1959). Recent studies have suggested that visual function is relatively insensitive to CO (Salvatore, 1974). However, Laties and Merigan (1979) note that the brief exposure to particularly high concentrations of CO may impair vision. An anecdotal account of one victim's experience during the recent Stouffer Inn fire illustrates this phenomenon. This individual reported escaping only after having seen a "flash of light" (as an exit door was momentairly opened). Although the individual quickly lost sight of the light source itself, he did remember the general direction from which the light had come. Thus, it would appear that while occupants are often willing to walk through a smoke-filled egressway, the infiltration of smoke and toxic gases into such channels may create physiological stresses which inhibit effective egress behavior.

In addition, the infiltration of fire products into egressways may substantially increase ambient temperatures in these spaces. Mura (1975) reported that the highest ambient temperatures which humans can tolerate without undue physiological stress is 42°C (110°F). Most of the literature on human physiology under high temperatures has been concerned with relatively long-term endurance, and stress due to heat has been examined primary in relation to performance decrement and fatigue by humans performing experimental tasks in laboratories (McCormick, 1976).

The present review of the literature yielded little information concerning potential effects of dead end corridors upon egress time. The perception that dead end corridors contribute to fire deaths and injuries continues to be held, however. For example, Westchester County (New York) Executive Alfred Del Bello called for a County-wide fire code provision prohibiting dead-end corridors, in the immediate aftermath of the Stouffer Inn fire (The Herald Statesman, December 6, 1980). The current investigators' examination of the Stouffer Inn floor plan, indicating locations where fire victims found (as published in The Herald Statesman), however, yielded no direct evidence that the presence of dead end corridors in that building was a direct cause of death. It should also be recalled that Best (1970) found, on the basis of his field experiments under nonemergency conditions, no statistically significant relationship between the presence of dead-ends and subjects' reports of being lost.

One somewhat obvious argument for the limitation or prohibition of dead end pockets or corridors concerns the notion that a person may suddenly become intensely stressed psychologically upon realizing that an erroneous -- and potentially very costly--egress decision was made. Although the literature on human behavior during fire situations sheds little light on this notion, the psychological experiments indicate that when turns or other adjustments are present in pedestrian routes, experimental subjects perceive these routes to be longer than linear paths of equal length (Sadalla and Magel, 1980). This phenomenon may contribute to occupants' perceptions of increased distance (and time)-to-safety when dead ends are encountered. Indeed, the perception of increased time-to-safety has been linked "panic" (Janis and Mann, 1977).

The hypothesis that persons with fear of high places (acrophobia) could panic or otherwise slow movement on unenclosed outside stairs is reasonable but must be qualified. According to knowledgeable experts who treat acrophobia clinically, the following scenarios are reasonable: Faced with a clear life-or-death situation posed by a fire emergency, many arophobics will successfully use an unenclosed outside stair if there is no other alternative. If it is clear to the acrophobic that others who are facing the fire emergency are fearful, many phobics are less likely to have the phobia interfere with using an outside unenclosed stair. If the acrophobic is with someone who can guide this individual and offer him or her physical and psychological support during egress, the acrophobic is increasingly likely to use an outside unenclosed egress stair. Of course, if the outside stair is sufficiently enclosed to prevent the phobic from seeing over the side or down, this will make the outside route acceptable to the acrophobic since the cues that would arouse the phobia are avoided. There is consensus among expert clinicians interviewed by the current investigators that a properly enclosed outside stair should increase the likelihood that acrophobics will use the stair during a fire emergency as an egress route. These experts do, however, question the adequacy of the current Code provision for meeting the needs of acrophobics.

Thus, the available literature supports behavioral assumptions on the effects of fire products on occupant's capabilities to escape rapidly. Support for assumptions concerning the effects of dead end corridors, however, remains weak and equivocal. Clinical evidence appears to support the assumption concerning occupants with fear of high places.

Behavioral assumptions enumerated in section 6.2.3 address the influence of doorway and door hardware design upon occupants' capabilities to negotiate means of egress. Very few data are available describing door operation by building occupants. Code provisions specifying a maximum door opening force of 50 pounds applied at the latch style and 15 pounds applied to a panic bar may be applied under the assumption that these represent normative maximum forces applicable by most building users. Experimental research by Van Cott and Kinkaid (1972) suggests that when standing individuals apply right-handed static forces to vertical handgrips, somewhat less than 50 pounds of force may in fact be available. However, evacuees can often generate additional dynamic forces associated with potentially rapid movement up to a door. In addition, occupants can be expected to apply extra forces available from the shoulder and other portions of the body, if necessary.

Steinfeld, Schroeder and Bishop (1979), studying problems associated with making buildings more accessible to disabled persons, investigated the ability of individuals with various disabilities to exert forces on doors and other architectural hardware. These researchers note that more than 23 percent of the wheelchair users they observed could exert forces greater than 15 pounds in any required direction. In addition, between 33 and 44 percent of all other disabled subjects tested could exert forces greater than 15 pounds in any required direction. However, available evidence also suggests that disabled polulations, even those with comparatively "nonserious" disabilities, are not able to exert 50 lb (222 N), which is the maximum force permitted to open a nonfunctional power-operated door (see Margulis, 1981).

Based on data from a survey designed to study walking and panic behavior during fires, Yamada (1975) found that the design and configuration of doors influence the flow rate through doorways. For example, substantial decreases in flow were noted for sliding doors and doors opening against the flow of pedestrian traffic. The study also noted that people often tended to pull at doors designed to be pushed. These data suggest that occupants' lack of familiarity with the opearting characteristics of various types of doors may lead to increased evacuation time.

Thus, with the exception of data describing panic bar operation (primarily by disabled occupants), there are presently too few data on door manipulation to support or refute behavioral assumptions believed to underlie provisons of the Code enumerated in section 6.2.3.

Technical strengths and weaknesses of the literature. Many of the behavioral assumptions relating to Code provisions intended to maximize the safe and efficient negotiation of egressway by occupants focus on vertical components of building circulation systems (i.e., stairs and ramps). Although several studies provided data concerning stair use, the application of much of this data to the specific issue of emergency egress remains problematic for a number of important reasons. First, all stair use data available in the literature are derived either from field studies conducted in everyday, nonemergency building environments (e.g., Carson et al., 1978; Fruin, 1971), or from experiments utilizing relatively unrealistic laboratory apparatus (e.g., Templer, 1974). Thus, environmental cues and stimuli, sources of psychological and physiological stress, levels of occupant density, and determinants of arousal and vigilance may differ widely between settings from which available data have been gathered, and those found during actual fires requiring rapid emergency egress.

Second, the nature of the available data on stair use behavior presents certain difficulties for the building design and regulatory analyst. There have been no attempts to systematically compare stair use behavior under different design, structural, and environmental (e.g., smoke) conditions. Hence, there is no real basis for determining the relative advantages or disadvantages of particular conditions. Worse, with the exception of Templer's (1974) research on the biomechanics of stair negotiations, all relevant studies involve nonexperimental research designs. Thus, even given a comparison of design, structural, or environmental conditions, these research designs do not allow researchers to draw plausible inferences about the casual relationship between these antecedents and stair use behavior. Similarly, the failure of investigators to make systematic comparisons between occupancies, classes of events, and occupants of varying capability render many of the available conclusions difficult to generalize with any degree of precision. In all, there is little basis for supporting or refuting the acceptance of particular design or structural solutions or of environmental conditions.

The reader also should be cautious when making generalizations about the use of ramps as means of egress during actual fire situations on the basis of available data. Nevertheless, data reported by Fruin (1971) and Tregenza (1976) which suggest that ramp slopes greater than 6 percent substantially reduce upward walking speed do seem useful in establishing performance objectives for ramp design. By contrast, the lack of data currently available to either support or refute assumptions about the role of weather protection and slip resistance in ramp design make analyses of certain Code provisions at this time impossible.

The literature on respiratory and visual stress and fatigue reports data which are often only indirectly relevant to anaylses of egress time. Moreover, findings noted in this literature, when relevant, are sometimes contradictory. In most cases, studies of CO exposure employed wellcontrolled laboratory procedures. While laboratory experimentation is intended to assure internal validity, its very strengths may severly limit the extent to which inferences from experimental data can be generalized to complex settings encountered during real fires. For example, experimental data describing the effects of long-term exposure to low level concentrations of CO on behavior should not be assumed to describe behavior under short-term exposure to relatively high level CO concentrations, or under conditions when CO combines with other toxicants.

Findings reported by Bryan (1977) and Wood (1972) are relevant to the role of smoke in analyzing emergency escape behavior. However, neither investigator actually measured smoke density and levels of CO and other toxicants, nor systematically correlated characteristics of smoke-filled environments (beyond the mere presence of absence of "smoke") with such observed behavior patterns as re-entry.

Dramatic decreases in occupants' egress capabilities arising from the exposure of human eyes to fire products have been well documented (Phillips, 1978). Such performance decrement is almost entirely physiological in nature. In addition, reductions in visibility, while they do not physiologically affect the eyes, may psychologically stress the evacuee. Research by Jin (1976), Rashbash (1975), and Watanabe et al. (1973) has begun to yield physical measures of visibility distance under varying levels of smoke density. However, no investigators have empirically studied the influence of visibility decrement on egress decisionmaking, strategy formation, and on other cognitive factors which influence overall egress time. For example, smoke may be presumed to slow walking speed under certain conditions, and this increases egress time. But perhaps smoke also prompts occupants to seek alternative (potentially smokefree) paths to safety. How does this behavior influence egress time? Does the need to rethink the egress strategy create additional stresses for humans which exaggerate any time lost negotiating longer paths?

Similarly, it is not now possible on the basis of available literature to evaluate either Code provisions intended to limit dead end corridors and to regulate the design of outside stairs, or behavioral assumptions concerning occupants' use of these design features. Relevant research has suggested a number of useful hypotheses. However, these need to be empirically tested. Current clinical assumptions regarding the behavior of acrophobics do appear useful in understanding certain problems in the use of unenclosed outside egress stairs, although the effects of acrophobia on egress behavior in the presence of life-threatening environmental stimuli are, at present, little understood.

Current data are not useful for describing the effects of door and hardware design upon evacuation time. Much of what is available provides a basis for the design of doors to be operated by handicapped persons. Today, the building design community generally holds that design solutions intended for handicapped persons should pose no obstacles for able-bodied persons. However, there remains no generally held analytical base which either supports or refutes behavioral assumptions about door use, and related provisions of the Code.

6.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

6.4.1 Research on the Affect of Stair and Ramp Design on Occupants' Capabilities to Safely and Rapidly Negotiate Egressways

The stair use model proposed by Archea et al. (1979) has found some support in the accident and human factors literatures. However, connections between specific perceptual failures and accident modalities, as predicted by this model, have never been empirically established. Even minor stair mishaps can be significant during emergency evacuations, insofar as they block egress pathways and slow pedestrian flow, and increase overall exit time. To the degree that perceptual failures indeed increase the likelihood of such events, their specific role must be more fully understood. This understandably will make designers better informed as to opportunities for mitigating potential sources of increased evacuation time. For example, it is important for designers to comprehend the role of color, lighting, and surface texture in occupants' use of stairways, precisely because these factors may either clarify or obscure visual and tactile stimuli necessary for efficient stair negotiation. Changes in occupants' attention to stair-specific environmental cues, particularly those which may be brought about in a rapidly changing fire emergency scenario, have not been investigated and therefore require study.

Available research on riser-tread dimensions is not sufficient to permit conclusions regarding stair design practice for emergency escape. Future research on this topic should strive to ascertain the degree to which particular riser-tread ratios influence egress flow rates on stairs. Similarly, future research on stair tread and ramp surface treatment should be directed toward developing standard friction-versus-flow functions useable by designers.

Ramps are frequently provided to facilitate building access and egress by handicapped persons, particularly those in wheelchairs. In an increasing number of instances, designers are providing ramps exclusively for changes in level of less than one story. In such cases ramps are clearly useful by both wheelchair-bound and ambulatory persons. But can this be said for many elderly individuals, or for people suffering degenerative decreases of the foot, knee, and hip joints? For such individuals, the presence of a ramp may have an appreciable effect upon the selection of an egress route, and hence, impact these people's egress times. Differences in ramp effectiveness must be studied across groups of people who differ in mobility characteristics before designers can provide facilities for vertical movement on a well-informed basis. Similarly, designers require information describing the relative effectiveness of stairs versus ramps during egress, for nonwheelchair-bound occupants.

6.4.2 Research on the Affect of Stress and Fatigue on Occupants' Capbilities to Safely and Rapidly Negotiate Egressways

Behavioral assumptions suggesting that the infiltration of fire products into egress ways adversely influences egress flow require further empirical verification. Available research and anecdotal accounts discussing the effects of CO exposure are contradictory and of limited utility. While certain effects of short duration exposure to low doses of CO have been noted in the literature, inferences from these findings to behavior during actual building fires are difficult to justify. This report's authors do not advocate the use of human subjects in experiments which accurately reproduce the toxic and other life-threatening qualities of fire environments. They do, however, suggest that animal time-to-safety experiments within toxic environments, as well as simulation excercises using human subjects, be redesigned to account for greater percentages of extraneous variation due to likely environmental effects than has been accommplished to date.

Studies of respiratory, visual, and temperature adaptability of various occupants under a number of fire scenarios are warranted by available evidence. For example, contact with toxic fire products may lead to occupants' incapacitation more quickly in a senior citizen's center than in an office building. Available knowledge on the effects of visibility decrement upon egress speed also requires expansion and verification.

Clinical experience suggests the need to obtain evidence to specifically determine the adequacy of the Code provision addressing the needs of acrophobics. This provision requires stairs three or more stories in height to have partitions at least 48 inch high. However, clinical experience suggests that partitions are required on outside stairs at least two stories in height, since the acrophobic response may be likely on an unenclosed stair two stories high. Clinical experience and anthropometric data also suggest that a 48 inch minimum may be too low. While it is critical to have a stair properly enclosed at its entrance, there is debate among clinical experts about whether enclosure should continue to the bottom of the run, a point that is unclear in the provision. As for the nature of the enclosure, if the walking surface of the landing or treads of an outside stair permits the phobic to see down through the metal elements, a phobic response is likely. So, too, is phobic response likely with an enclosure that is only 48 inch high. A significant portion of the population (assuming that acrophobics are representative of the larger population of their sex in height) will be able to see over a 48 inch partition and down.

6.4.3 Research on the Effects of Doorway and Door Hardware Design on Occupants' Capabilities to Safely and Rapidly Negotiate Egressways

Current research on the door-manipulating capabilities of handicapped persons should be expanded to include all categories of building occupants, as well as the wide variety of door and landing configurations. While the design of physical elements (doors, hardware and spatial configuration) comprise one class of independent variables, ambient environmental conditions provide another class. As a point of departure, future investigators should be concerned with identifying variations in door manipulation performance which may be attributable to changes in lighting and visibility.

Another important gap in the technical literature concerns knowledge of the relationship among stress, fatigue, and evacuees' capabilities to manipulate doors and door hardware. Phillips' (1978) comments illustrate this critical, although little understood, issue: She notes anecdotes describing evacuees clawing at doorknobs under smoke and fire conditions; apparently these individuals actually thought they were properly turning the knobs.

6.5 SUMMARY

In summary, human behavioral assumptions believed to underlie Code provisions relating to occupants' capabilities to safely and rapidly negotiate means of egress may be evaluated by reference to biomechanical models of human movement, toxicological research, stair and ramp use field studies, physiological measurements, and anecdotal evidence from actual fire incidents. At present, much of the evidence reported in the experimental and nonexperimental literatures on occupants' capabilities is contradictory, results in mixed opinions, and does not permit specific conclusions or inferences to be drawn. As a result, there appears to be no analytical basis upon which to unequivocally support or refute applicable Code provisions. It is left for future research to determine the specific domains (i.e., occupancies of fire scenarios) under which particular data are valid and useful in this context.

7. PROVISIONS GOVERNING THE CAPACITY OF MEANS OF EGRESS

7.1 APPLICABLE CODE PROVISIONS

5-2.1.1.2.2 Where a doorway is divided by mullions, the allowable units of exit width for the entire doorway shall be the sum of the units of exit width calculated separately for each individual door in the opening.

5-2.1.1.3.1 No single door in a doorway shall be less than 28 inches wide.

5-2.1.1.3.2 No single door in a doorway shall exeed 48 inches in width.

5-2.1.1.4.1 Any door in an exit and not exempted by 5-2.1.1.4.4 or other provisions of this Code shall be so designed and installed that when a force is applied to the door on the side from which egress is to be made, it shall swing in the direction of exit travel from any position to the full instant use of the opening in which it is installed. During its opening process or when fully opened, a door shall not obstruct the exit width as determined by 5-2.1.1.2.1.

5-2.1.1.4.2 A door giving access to a stairway shall swing in the direction of exit travel. A door during its swing shall not block stairs or landings. In new buildings any door, at any point in its swing, shall neither reduce the effective width of stair or landing to less than one unit of exit width nor when open interfere with the full use of the stairs.

5-2.1.1.4.3 An exit door or exit access door swinging into an aisle or passageway shall not restrict the effective width thereof at any point during its swing to less than 1/2 the required widths hereafter specified.

5-2.1.1.4.4 Any door in a means of egress shall be of the side-hinged, swinging type and shall swing in the direction of exit travel when serving a high hazard area or an occupant load of more than 50. Such doors shall conform to the appropriate requirements of 5-2.1.

5-2.1.3.2.1 A revolving door shall not be used in a means of egress.

Exception: Where specifically permitted by some individual occupancy chapter of this Code for an exit from the level of exit discharge directly to the outside, in which case:

(a) Such door(s) shall not be used at the foot or at the top of stairs at the level of exit discharge.

(b) Such door(s) shall not be given credit for more than 50 percent of the required units of exit width.

(c) Such revolving door(s) shall be of approved type(s).

5-2.1.3.2.2 Each allowed revolving door may receive credit as constituting 1/2 unit of exit width.

5-2.1.3.2.3 The number of revolving doors used as exit doors shall not exceed the number of swinging doors used as exit doors within 20 feet thereof.

Exception: Revolving doors may serve as exits without adjacent swinging doors for the street floor elevator lobbies, if no stairways or doors from other parts of the building discharge through the lobby, and the lobby has no occupancy other than as a means of travel between elevators and street.

5-2.1.3.2.4 Revolving doors shall be equipped with means to prevent their rotation at too rapid a rate to permit orderly egress.

5-2.1.3.3.1 No turnstile or simular device to restrict travel to one direction or to collect fares or admission charges shall be so placed as to obstruct any required means of egress.

Exception: Approved turnstiles not over 3 feet high, which turn freely in the direction of exit travel, shall be permitted in any occupancy where revolving doors are permitted.

5-2.1.3.3.2 Turnstiles over 3 feet high shall be subject to the requirements of revolving doors.

5-2.1.3.3.3 Turnstiles in or furnishing access to required exits shall be of such design as to provide 22 inches clear width as the turnstile rotates.

5-2.1.3.3.4 No turnstile shall be placed in any required means of egress.

5-2.1.3.3.5 Turnstiles shall be rated the same as revolving doors as regards units of exit width and rates of travel.

5-2.2.2.5 Stairways and intermediate landings shall continue with no decrease in width along the direction of exit travel.

5-2.8.2.4 A single escalator 32 inches wide shall be given credit for 1 unit of exit width. An escalator 48 inches wide shall be given credit for 2 units of exit width.

5-3.2.1 Means of egress shall be measured in units of exit width of 22 inches. Fractions of a unit less than 12 inches shall not be counted. Fractions of a unit comprising 12 or more inches, added to one or more full units, shall be counted as 1/2 unit of exit width.

5-3.2.2 Width of means of egress shall be measured in the clear at the narrowest point of the exit component under consideration.

Exception No. 1: A handrail may project inside the measured width on each side not more than 3 1/2-inches.

5-3.3 Capacity of Units of Width. The capacity in number of persons per unit of width for approved components of means of egress shall be as follows:

(a) Level of egress components, a Class A ramps--100 for travel in either direction.

(b) Class B ramps--60 for travel in the up direction, 100 for travel in the down direction.

(c) Stairways--60 for travel in either direction.

5-3.4.1 The minimum width of any way of exit access shall be as specified for individual occupancies by Chapters 8 through 16; but in no case shall such width be less than 28 inches.

17-1.2.1.1 Every required exit, exit access and exit discharge shall be continuously maintained free of all obstructions or impediments to full instant use in the case of fire or other emergency.

7.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

7.2.1 Assumptions Pertaining to the Influence of Architectural Barriers and Other Obstructions to Egress Flow

(1) Intended maximal use of means of egress can only be achieved when egress ways are maintained free of obstructions (17-1.2.1.1).

(2) Egress is slower through doorways with mullions than through those without mullions (5-2.1.1.2.2).

(3) Doorway width influences egress time; the optimal width is 28 through 48 inches (5-2.1.1.3.1; 5-2.1.1.3.2).

(4) Architectural obstructions within egressways (e.g. door hinges, railings, etc.) may reduce discharge rate (5-2.1.1.4.1; 5-2.1.1.4.2; 5-2.1.1.4.3).

(5) The degree of reduction of egress time due to obstructions in egress ways is a function of occupant load (5-2.1.1.4.4).

(6) Revolving doors may increase evacuation time by as much as 100 percent; revolving doors cause congestion and a "bottlenecking" effect which reduces flow through the egressway; the speed of rotation influences the flow rate through a revolving door, and within a certain range, an increase in speed of rotation results in reduced flow through the door (5-2.1.3.2.1 through 5-2.1.3.2.4).

(7) Turnstiles have substantially the same effect on the efficiency of pedestrian ways as do revolving doors (5-2.1.3.3.1 through 5-2.1.3.3.5).

(8) Variation in stairway width along the direction of egress travel may result in reduced egress flow (5-2.2.2.5).

(9) To maintain adequate egress flow on an escalator, it must be wider than a conventional stair (5-2.8.2.4).

(10) When an egress channel element varies in width (along its length), its overall flow capacity is approximately equivalent to the capacity at its narrowest point (5-3.2.2).

7.2.2 Assumptions Pertaining to the Flow Capacity of Egress Channels

(1) Flow rates average 100 persons per 22 inch exit unit per minute (pers/unit/min) in level egress ways, and 60 pers/unit/min on stairs (in either direction) (5-3.3).

(2) In general, the capacity of ramps is substantially more than that of a straight flight of stairs, particularly in the downward direction (5-3.3).

(3) The minimum channel width capable of providing appropriate egress flow rates is 28 inches, although this width is expected to yield the same flow characteristics as an egress element 22 inches wide (according to provision 5-3.2.1 and its underlying assumption) (5-3.4.1).

(4) Pedestrians travel in linear files approximately 22 inches in width; an exit between 22 and 34 inches in width provides the same flow capacity as a 22 inch exit; an exit between 34 and 43 inches wide provides 50 percent more flow capacity than a 22 inch exit; a 44 inch exit provides 100 percent more flow capacity than a 22-34 inch exit (5-3.2.1).

7.3 <u>COMMENTARY</u>

7.3.1 Problem

<u>Code</u> provisions governing the capacity of means of egress are intended to assure that exit ways permit escaping occupants to evacuate a burning building as rapidly as possible. This assurance requires not only that exit ways are of sufficient dimension, but that they minimize opportunities for blockages or other impediments to egress flow, as well. Human behavioral assumptions which underlie <u>Code</u> provisions enumerated in Section 7.1 address (1) the influence of architectural barriers and other potential obstructions on egress flow, and (2) the flow capacity of egress channels.

Conceptual views of pedestrian movement drawn from field investigations of such behavior are useful in understanding the flow of occupants through exit ways in buildings. Three models are based on physical analogs (e.g. equating the flow of gas molecules with pedestrian movement), while one concept is derived from human behavioral theory. Their relevance to <u>Code</u> provisions and underlying behavioral assumptions concerned with the capacity of means of egress is considered below.

7.3.2 Underlying Behavioral Models

Prevailing models of pedestrian movement have been derived primarily from physical science concepts. In general, investigators have distinguished high density from low density flow (Henderson, 1971). A number of researchers have shown that, under certain conditions, high density human movement may be adequately modeled as an example of particle movement (Peschl, 1971) or fluid dynamics (Archea, 1979, Henderson, 1971), while others have suggested that low density pedestrian movement is best modeled as an example of gas flow (Henderson, 1971). In addition to the physical analogs, the concept of personal space identified by environmental psychologists (Sommer, 1969) has been usefully applied in explaining human movement in pedestrian ways (Fruin, 1971).

The particle model, useful in explaining high density pedestrian flow, has been most succinctly presented by Peschl (1971). According to Peschl, crowd movement is analogous to the flow of granular particles from bins. The model recognizes that human beings are not merely granules, that spaces within buildings are not simply bins, and that pedestrian movement is not governed by the force of gravity.

However, the particle model posits that under conditions of high density (crowdlike) occupancy, individuals have virtually no freedom of movement and are little more than elements comprising a flowing granular mass. The model further suggests that the behavior of this mass may be described mathematically.

The granular analog suggested by Peschl may best describe high density occupancy conditions within a tightly bounded environment, under a state of panic. Under such conditions, individuals may attempt to escape as quickly as possible. If there is a single exit (in the direction of flow), then there is likely to be a "pile up" of people pressing against the exit and its surrounds. Here individuals will occasionally be able to pass through the exit, but most people will pack against each other attempting to gain access to it. The particle analog suggests a vessel open at the top and with a small hole in the bottom. Ball bearings are poured into the vessel, and these, by force of gravity, fall to the bottom of the vessel. Some ball bearings fall through the hole at the bottom, which is just large enough to admit one ball bearing at a time. But if the ball bearings are poured into the vessel at a rate faster than that at which they leave through the hole, ball bearings soon begin filling the vessel, packing against one another. Soon, very few if any ball bearings are admitted through the hole. A piston pushing down upon the ball bearings from above will make it impossible to empty the vessel.

The particle model is useful in describing the so-called "arch effect", first observed in the field by Togawa (1955). An arch is a small semicircular web of people held firmly in place at a doorway by the force applied by people behind the arch attempting to move toward the doorway. Peschl noted that the formation of such arches, which can prevent individuals from passing through the doorway, is difficult to predict. He conducted experiments with both human subjects and steel balls used to simulate a human mass in order to test the arch concept. On the basis of these experiments, Peschl concluded that (1) the wider the exit way, the smaller the probability of arch formation and the greater the variability in flow rate; (2) the probability of arch formation decreases as density decreases; (3) flow rate through doorways decreases as density increases; (4) exit rate is a positive linear function of doorway width; and (5) pulsating flow through exit ways often results with the natural formation and dissolution of arches.

A clear illustration of the relevance of the particle model to behavioral assumptions concerning the capacity of means of egress, particularly under high density conditions, is found in the eyewitness report of a victim of the Beverly Hills Supper Club fire (The Cincinnati Post, Thursday, June 2, 1977). The individual recalled having first wondered why the egress line had come to a halt. This was prior to the intrusion of fire products into the room in question. The victim next reported pushing against the crowded line ahead. As fire products entered the room, frustration appeared to build. At the open exit way, the victim reported, people had "bottlenecked," forming an arch which enabled very few people to actually pass through the exit. This individual was saved by having grasped hold of the mullion dividing the double door of the exit once reaching the arch, and then by finally exerting considerable force and "popping" out of the arch and through the door (a phenomenon observed previously by both Togawa, 1955, and Peschl, 1971).

A somewhat different analog useful in describing high density pedestrian movement is suggested by the hydraulic model (Archea, 1979). The hydraulic model posits that above some level of occupant density, the movement of people through a network consisting of corridors, doors, stairs, and similar architectural elements is analogous to the downward flow the water through pipes, valves, and other elements of a gravity-fed fluid distribution system. Accordingly, the hydraulic model presents building evacuation as a two-phase process. The initial, or "start up," phase concerns the simultaneous initiation of movement directly toward exits by numerous individuals upon receiving an emergency alert. This is presumed to be analogous to opening valves and filling basins at the periphery of a gravity-fed water distribution system (e.g. household plumbing). The actual egress phase concerns the deliberate and systematic progression of indiviuals through various architectural elements until they have finally exited the building. This is viewed as analogous to the path followed by water as it works its way though a gravity-fed plumbing system, as the peripheral bains are emptied.

In employing the hydraulic model, one assumes that occupants being modeled are alert and able bodied, and that all occupants of a building or section of a building are not only simultaneously alerted to the fire danger, but that all occupants simultaneously initiate purposeful egress behavior as well. Moreover, all occupants are assumed to travel at a uniform rate of flow, and to be sufficiently close to one another so as to severely constrain each other's freedom of movement. Finally, the model assumes the undirectional flow of occupants from occupied spaces along specified paths to predefined exits. In the hydraulic model, valves and pipes are analogous to egress way elements, while sinks, tubs, and similar fluid-holding fixtures are analogous to rooms and other occupied spaces within buildings. Pulling the stopper in a sink is analogous to sounding a fire alarm and thereby initiating uniform mass evacuation. The focus of the model is on maximizing the flow capacity of the egress ways. Here, flow rate is the key measure of system performance. The processes by which building occupants respond to alerts and initiate movement toward (as distinct from through) means of egress are not addressed by the hydraulic model.

In discussing the relevance of the hydraulic model to behavioral assumptions considered in Section 7.2, comparisons with the particle model described earlier are useful. Human behavioral assumptions outlined in Section 7.2.1 of the current report address effects of architectural impediments and other obstructions to the efficient flow of occupants in egress ways. The hydraulic model provides analogs to such barriers as decreases in channel width along a given distance, and such physical obstructions or blockages as doors with insufficient flow capacity. These hydraulic analogs primarily include decreases in the diameter of fluid-carrying pipes, and the partial or full closure of valves, respectively. Such analogs permit the hydraulic model to describe flow characteristics in egress channels which in fact vary in width, and which contain turnstiles or other opportunities for bottlenecks to occur.

However, whereas the particle model provides a physical analog for arching at doorways, blockage or entrapment at tight corners, and the prohibition of pedestrian movement resulting from individuals being pressed against channel walls, these phenomena--observed in the field--cannot be properly modeled using hydraulic analogs. While ball bearings may become jammed and arch against a very small opening (analogous to human arching at a relatively narrow exit), liquid will always flow freely (albeit at a reduced rate) through openings, however small. Thus, the hydraulic model best simulates flow reductions caused by the closure of exits; flow ceases entirely when a channel is completely sealed. In contrast, data indicate that pedestrian flow can become virtually halted even though exits are open, as in the case of jamming and arching. This latter phenomenon is better simulated by the particle model.

Whereas the Beverly Hills Supper Club fire provided an example of arching in support of the particle model, the tragedy which claimed the lives of 11 individuals, and injured approximately 10 others, seeking entrance to the Riverfront Coliseum in Cincinnati, Ohio, in December of 1979 suggests support for the hydraulic model. In repeated testimony before an investigatory body covened during the aftermath of this event, victims reported "waves" of pressure literally lifting them off their feet. Such pressure was reportedly exerted from the rear of the crowd, which as a mass, was pushing against the entrance doors (not all of which were unlocked and available for use). The closer an individual was to the doors, the greater was the force experienced. Once the doors were actually opened, several eyewitnesses reported having been "swept" into the Coliseum. Other victims suggested, when interviewed, that if more doors had been open, fewer people might have been killed or hurt. No evidence of arch formation was reported by victims of this incident. Anecdotal evidence from this incident does suggest, however, that the ease and rate of crowd flow are directly related to available doorway width.

A rigorous analysis of low density pedestrian movement, based on the 19th century Maxwell-Boltzman gas model, was conducted by Henderson (1971).

Henderson argued that while medium and high density crowd behavior could effectively be modeled as a problem in fluid dynamics, under low density conditions pedestrians behaved in a manner more consistent with the kinetic-molecular theory of gases. In particular, pedestrians, irrespective of whether they move as individuals or as members of small social groups, may be viewed as (1) being statistically independent of each other in position and velocity, and (2) moving with a velocity which is uncorrelated with spatial position.

In Henderson's analogy, occupant density (the number of persons per unit area) is equivalent to particle density in a gas. Differences between pedestrian movement modes, i.e. standing still, walking, or running, are compared with differences between gaseous energy modes. Pedestrian movement is assumed to take place on a continuous planar surface, and if the low density crowd is homogeneous, then each individual should exhibit both the same mass and the same probability of attaining expected velocity values in a given mode. According to Henderson, these assumptions would not be expected to hold for relatively high density situations. For example, pedestrian movement from a very large open space through a narrow channel may, on occasion, result in increased population density. Where this density is sufficiently high, the behavior of pedestrians approaching and moving through the narrow channel might be better described by a fluid, rather than a gaseous, model. Hence, Henderson's gas analogy seems relevant: (1) to those situations where low density crowds move within extremely large, effectively unbounded, spatial settings (e.g. outdoor malls), and (2) to those spatial transitions in which density values, although increased, still exhibit the kinetic-molecular properties of gases.

The relevance of the gas model to understanding the capacity of means of egress may now be considered. A frequent barrier to free-flow pedestrian movement along an egress path way is a wall containing a door ensemble. Under high density conditions, Peschl's particle model suggests that such a barrier would entrap pedestrians, jamming individuals against the wall and door opening (where the door is only slightly wider than any individual seeking to pass through). Under similar conditions, Archea's hydraulic model suggests that individuals would flow slowly through the opening, and that eventually all individuals would pass through the door. Both models hold that occupant density in and of itself produces forces which move pedestrians in a given direction, and that such movement is influenced by prevailing spatial boundary conditions. Under low density conditions, however, such forces are presumed not to be present. Here, individuals approaching a potential barrier (such as a transition from a relatively open space to a narrow channel) are not likely to be either pressed against a wall, or else pushed under force toward and through a narrow door way or channel. Rather, any individual directed toward an opening in a physical barrier will pass through. Moreover, seemingly random search behavior and meandering, as has been known to occur when smoke severely limits visibility by transient occupants under low density conditions, may, perhaps, be effectively modeled by the Brownian motion of gas particles.

Although not itself a descriptive model, the psychological concept of personal space (Sommer, 1969) is useful in gaining a deeper and more realistic understanding of the actual capacity of means of egress. Discussed earlier in the current report, personal space refers to the small protective zone, or "bubble," which individuals create around themselves. Perceptions and behaviors associated with the establishment, maintenance, and adjustment of personal space comprise mechanisms by which individuals cope with socio-environmental stressors of the type usually associated with medium and high density occupancy and pedestrian movement. For example, Fruin (1971) and Pauls (1974) have shown that pedestrians appear to purposefully establish minimum distances between themselves and others. Where occupant density becomes quite high, as in a crowded subway train, or behind a blocked exit way, the psychological need for personal space apparently remains: individuals' inability to relieve themselves of crowded conditions for lengthy periods have been known to elevate stress and anxiety.

Fruin (1971) found that under high density conditions in public transit facilities pedestrians are more likely to close their ranks by reducing their longitudinal (front-to-back) spacing rather than their lateral (side-to-side) spacing. Although longitudinal spacing is governed to a great extent by the maximum distance required to avoid tripping over another individual's feet, the need for lateral spacing suggests that whereever possible, pedestrians seek to avoid brushing against or otherwise contacting other individuals. Current provisions concerning the width of stairs and other egress channels, however, are not based upon analyses which specifically consider the role of pedestrians' personal space needs. For these reasons, Pauls (1974, 1980) has drawn attention to the problem of effective channel width computation, suggesting that the traditional 22 inch unit of exit of width, referenced by numerous Code provisions, may be unrealistic and inadequate.

In summary, human behavioral assumptions which underlie Code provisions affecting the carrying capacity of means of egress are considered in relation to three physical models of pedestrian movement and to the psychological concept of personal space. It was shown that while these models and the personal space concept are each useful in understanding a different aspect of egress way flow capacity, no single analog or concept is sufficient to completely describe occupant flow dynamics within buildings. The next Section of the report treats Code provisions and their underlying behavioral assumptions in view of data presented in the technical literature.

7.3.3 Assessment of Behavioral Assumptions Based on the Technical Literature

Literature review. Behavioral assumptions presented in Section 7.2.1 consider the potential effects of architectural barriers and other impediments to rapid and safe occupant movement through means of egress. Generally, such barriers and impediments include doors and doorways, revolving control barriers (i.e. turnstiles and revolving doors), reductions in egress channel width, and obstructions caused, for example, by the use of egress ways for storage. Exit width has long been the key concept used to characterize and measure means of egress, and for analyzing occupant loading and the adequacy of available means of egress (Sharry, 1978).

A number of behavioral assumptions are concerned with occupants' use of doors during egress. The National Bureau of Standards (NBS) reviewed field investigations of pedestrian movement during periods of normal building occupancy at a number of government office buildings and at a major rail terminal (NBS, 1935). On the basis of data obtained during these investigations, NBS concluded that the effective rate of pedestrian flow through doors is approximately 60 persons per minute per 22 inch unit of exit width (p/m/unit), or 1.75 p/sec/m. The same report recommends, for the building types studied, that up to 100 persons per available unit of exit width be permitted to occupy interior spaces. This design capacity would, theoretically, require approximately 1.67 minutes to move all occupants of an interior space through available exits (exclusive of the time it might be required to bring occupants to the exits from various parts of the space). Conclusions reported by NBS in 1935 remain central to Code provisions governing the computation of means of egress today (Sharry, 1978).

More recently, Togawa (1955) surveyed pedestrian walking speeds and flow rates through doors in department stores, apartment buildings, places of assembly, and transportation terminals in Japan. His data, among the most comprehensive available, indicated that flow rates through doors tend to average approximately 50 pers/min/unit (1.50 pers/sec/m). A survey conducted by the Institute of Traffic Engineers (1964) revealed professional opinions suggesting that pedestrian flow through doorways averages 30 pers/min/unit (0.9 pers/sec/m. On the basis of these data, the Institute of Traffic Engineers recommended a design value of only 20 pers/min/unit (0.5 pers/sec/m).

Some of the most recent data were collected by Fruin (1971), who studied pedestrian movement through doors and other facilities at large transportation terminals. Fruin found that queues developed when the flow rate through a door was less than that of the feeding passageway, and that for doors swinging freely in the direction of pedestrian travel, 40 through 60 persons typically passed through per minute (0.67 through 1.00 p/sec.). Fruin also noticed that if a door must be operated manually, and if the following pedestrian arrives before the current individual has completed operating the door, a queue will develop behind the door. Moreover, Fruin reported that elderly and physically handicapped pedestrians, or persons encumbered with baggage or packages, typically require longer periods for door operation. Thus, pedestrian ways (involving doors) which are designed at or near capacity pedestrian loads are likely to generate frequent queues and similar impediments to rapid, free human movement.

Peschl (1971) conducted experiments to assess the capacity of door openings during simulated panic situations. Under a variety of doorway conditions simulated in the laboratory, groups of people were asked to press against door ways until all individuals had moved through. Peschl noted that stable arches formed openings of 47 inches (1.20 m), and that the frequency of arch formation increased as door widths became narrower. Openings of 34 inches (0.86 m) resulted in extremely stable arches, and made passage through the door almost impossible. At openings of 24 inches 0.60 m, Peschl found that flow rate was effectively zero. Under one experimental condition, an "exponentially curved" funnel leading to a door way was used. According to Peschl, this type of design increased pedestrian movement velocities through door ways by a factor of three, when compared with movement velocities through doors set flush with surrounding wall surfaces. Similarly, when an exponentially curved wall was compared with circularly curved walls (also providing a funnel toward a door way), Peschel found pedestrian movement through the exponentially curved condition to be 2.5 times as fast. Peschal also noted, in general, that as crowd density increased, movement speed through door ways decreased, and that the rate of flow through doors was a linear function of door way width. Finally, Peschl suggested, on the basis of his experiments, that floor surfaces in the immediate vicinity of, and leading directly toward, exit doors be sloped downward toward these doors, and that the minimum door width for effective safe egress is 47 inches (1.20 m).

Melinek and Booth (1975) also observed arch formation at door ways under high density exiting conditions. These researchers found that arch formation became conspicuous when the flow rate of an exit reaches 60 pers/min/unit (1.80 pers/sec/m). They also noted that the frequency of arch formation is inversely proportional to the square of exit width. The former finding appears substantially higher than Peschl's (1971) findings that stable arches tended to form when the flow through doors averaged 40 pers/min/unit (1.20 p/sec/m). The later finding is, however, consistent with Peschl's data.

No data are presently available to illuminate the effects of intermediate mullions on egress flow through door ways. Data are available on the effects of introducting handrails on wide stairs, an indirectly related problem (London Transport Board, 1958). Studying the movement of passengers in mass transit stations, the London Transport Board found that pedestrian movement speed down a stair 72 inches (1.83 m) wide was reduced from 130 to 105 pers/min (2.17 to 1.75 pers/sec),a reduction of some 19 percent, after the addition of a center handrail. This finding contrasts with the fact that the actual number of pedestrian lanes on the stair was effectively reduced from three to two, a difference of 33 percent.

Direction of door swing in relation to flow has also been studied. Peschl (1971) and NBS (1935) each recommend that exit doors be designed to open in the direction of egress travel, but neither provided supporting technical evidence to indicate the magnitude of this problem. Yamada (1975) found that egress time increased by 12 percent when pedestrians were required to pass through doors which opened against the traffic flow, provided pedestrian density was sufficiently low to permit the doors to be operated at all.

Other comments regarding obstructions to egress flow suggest mixed conclusions. For example, Stevens (1969) notes that obstructions generally tend to reduce walking speed along pedestrian ways in buildings. Similarly, Galbreath (1969) indicates that side railings along stairways tend to have a negative effect on pedestrian flow. Moreover, Landon-Thomas (1972) has argued that even the slightest obstruction in an egress way could be fatal. In contrast, Melinek and Booth (1975) holds that minor restrictions such as wall projections have little effect on flow rate in corridors. The London Transport Board (1958) report that obstructions up to 1 foot (0.31 m) had no effect on flow, even under relatively high density conditions. As noted above, however, this organization also reported that the introduction of center handrails could reduce flow by as much as 19 percent (while effective walking width is reduced by some 33 percent). Provisions of the <u>Code</u> specify allowable occupant loads for interior spaces on the basis of available exit width leading from such spaces (particularly provisions 5-3.3 and applicable appendix notes; see also Sharry, 1978). Accordingly, to the extent that obstructions to means of egress indeed restrict exit flow and egress time, building designers and managers should realize that obstructions may ultimately influence permissible occupant loading on building floors.

Bends or corners along corridors and similar egress path ways frequently result in variations in the effective width of egress ways. The London Transport Board (1958) reports no queue formation at bends and corners. Similarly, Melinek and Booth (1975) found that bends and corners along any given stair way did not appear to reduce pedestrian flow on stairs. In contrast, Watanabe, Nayuki, and Torizaki (1973) report that walking speeds decreased when subjects passed through corners along an experimental walking course.

When linear paths become narrower as one traverses their length, movement speed may decrease. For example, the London Transport Board (1958) found that while small reductions in corridor width had virtually no effect on the capacity of egress ways, such architectural features did tend to increase the overall travel time for individuals. This organization noted that flow (i.e. capacity) reductions as high as 10 percent requir channel width reductions on the order of 33 percent.

A number of additional Code provisions and behavioral assumptions deal with potential impediments to pedestrian movement which may be caused by revolving doors and turnstiles. Research reported by NBS (1935) examined the viability of revolving doors as components of building egress systems. Pedestrian movement through revolving doors in a department store and in a Federal office building was evaluated. The investigators found that for a revolving door with leafs 42 inches (1.07 m) wide, an average of 11 to 12 persons discharged per minute per foot of width (approximately 0.63 pers/sec/m). Evaluating another doorway in which the revolving leafs were collapsed to form two separate and adjacent openings each 25 inches (0.63 m) wide, an average of 22 persons discharged per minute per foor of width (1.20 pers/sec/m). These flow rates are considerably lower than those for swinging doors. In addition, the mechanical operation of revolving doors may not be "sure" (see NBS, 1935, Appendix A, note 60) and problems associated with their use may be exacerbated under very high density conditions. On the basis of these findings, NBS (1935) recommends that revolving doors not be used as means of egress in places of assembly and certain other occupancies. For most other occupancies, NBS (1935) recommends that revolving doors receive 50 percent of computed exit credit. All editions of the Code published since 1935 have based provisions for revolving doors on NBS' recommendations.

Pedestrian flow through turnstiles was examined by Fruin (1971). Fruin noted that free-swinging turnstiles require a headway of between 1.0 and 1.5 seconds, and accommodate from 40 to 60 persons per minute (0.67 to 1.0 pers/sec). Where ticket collectors were posted, turnstiles were found to require a headway of from 1.7 to 2.4 seconds, and to permit between 25 and 35 persons to pass per minute (0.42 and 0.58 pers/sec). Turnstiles requiring pedestrians to deposit coins in a single slot device were found to require from 1.2 to 2.4 seconds of headway, and to accommodate from 25 to 50 persons per minute (0.42 to 0.83 pers/sec). Finally, where pedestrians had to deposit coins in a dual slot device, a headway of from 2.5 to 4.0 seconds was noted, and these turnstiles were found to permit only between 15 and 25 persons per minute (0.25 and 0.42 pers/sec) to pass through. These statistics appear to be consistent with (although slightly higher than) those reported by NBS for flow through revolving doors, and to justify the similar treatment of revolving doors and turnstiles by provisions of the Code.

Behavioral assumptions presented in Section 7.2.2 underlie Code provisions concerning the flow capacity of means of egress. These assumptions address: (1) pedestrian flow rates per unit width on level surfaces, stairs, and ramps, (2) the value of fractions of standard width units, and (3) the linearity of pedestrian movement within means of egress. Several studies report flow rate statistics, the most pertinent of which are reviewed below. The reader should note, however, that various investigators often differ in their definition of critical terms (e.g. "flow" has been defined in terms of "persons per unit time" as well as "persons per unit time per unit width"). Consequently, it is not always possible to draw direct comparisons between data reported by different researchers. In addition, comparisons among investigations have been complicated by the fact that extremely few researchers sought to verify a standard set of descriptive functional relationships. For example, while the London Transport Board reported a relationship between walking speed and pedestrian density, Fruin considered the relationship between walking speed and area (defined as the reciprocal of density). Similarly, while these investigators were concerned with the influence of pedestrian density (however defined) on walking speed, others sought to describe the relationship between density and flow rate. As a result, analysts should exercise caution when drawing inferences from research reviewed here to questions concerning the validity of either behavioral assumptions about the capacity of means of egress, or their antecedent Code provisions.

Data describing the movement of pedestrians through linear corridors were reported by NBS researchers (1935), who measured flow rates at arbitrarily selected locations during periods of normal building occupancy. These investigators noted that under such conditions, flow rate varied across occupancies, and in general, found a negative relationship between flow rate and channel width. Togawa (1955) also observed variations in flow rate as a function of occupancy, corroborating data reported by NBS, and also reported sex differences.

Togawa further noted that men traversed level surfaces at an average velocity of 4.60 ft/sec (1.40 m/sec) while women typically walked at an average velocity of 3.90 ft/sec (1.19 m/sec), assuming a mean density of approximately 0.90 pers/ft^2 (10 pers/m^2).

The London Transport Board (1958) found that flow rates in linear corridors approximated 27.7 pers/min/ft (1.48 pers/sec/m). This finding is slightly higher than that reported by Galbreath (1968), who noted linear movement in corridors to average 21.86 pers/min/ft (1.19 pers/sec/m). The London Transport Board also reported that flow was often as much as 50 percent higher for short (i.e. less than 10 ft, or 3.05 m) passages when compared with longer segments of equal width. In order to achieve mean free-flow walking speeds of approximately 3.37 ft/sec (1.03 m/sec) in the forward direction, these investigators found optimum pedestrian densities to average 7.7 ft^2/pers (0.69 m^2/pers)[6]. When available area dropped to 5.0 ft^2/pers (0.45 m^2/pers)[7] in corridors, forward walking speed was found to approximate 2.20 ft/sec (0.67 m/sec). Forward movement was noted to stop when occupant density averaged 2.0 ft^2/per (0.18 m^2/pers)[8].

Free-flow walking speeds reported by London Transport Board averaged some 21 percent lower than those reported by Togawa (1955). Fruin (1971) observed variation in free-flow walking speed between male and female pedestrians. Fruin's data agree extremely closely with those reported by Togawa. In addition to sex differences, variation in pedestrian walking speed may also be due to such factors as time of day, trip purpose, and the composition of pedestrian groups. In general, walking speed decreases as pedestrian density increases. According to Fruin, this is mainly due to reductions in available clear area for locomotion. However, pedestrian density appears to have relatively little impact on individual walking speed until average pedestrian area drops to approximately 40 ft^2/pers (3.60 m^2/pers)[9]. Fruin has also found that walking speed approaches zero when area reaches the vicinity of 3.0 ft^2/pers (0.27 m^2/pers)[10], as compared with 2.0 ft^2/pers (0.18 m^2/pers)[8] noted by Galbreath (1968). In addition, Fruin noted that peak flow volumes in corridors averaged approximately 25 pers/min/ft (1.37 pers/sec/m), and that maximum flow capacities were attained when pedestrian volume was about 5.0 ft^2/pers (0.45 m^2/pers)[7].

Melinek and Booth (1975) reported that the flow capacity of corridors between 3.2 and 9.6 feet (1.0 and 3.0 m) wide averaged 28 pers/min/ft (1.5 pers/sec/m). These investigators suggested that a free-flow walking speed of 4.16 ft/sec (1.3 m/sec) be assumed, and that free-flow walking speed could be attained at densities up to 11.1 ft^2/pers (1 m^2/pers).[11] At higher densities, flow rates were found to decrease.

Stairs are vital elements of emergency egress systems. Accordingly, a number of investigations of pedestrian movement on stairs have been conducted. For example, NBS (1935) reported flow rates from 165 separate observations of stairs. The discharge rate of stairways was found to vary somewhat across

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[6] Equivalent to 0.13 pers/ft^2 (1.45 pers/m^2).

[7] Equivalent to 0.20 pers/ft^2 (2.22 pers/m^2).

[8] Equivalent to 0.50 pers ft^2 (5.55 pers/m^2).

[9] Equivalent to 0.03 pers/ft^2 (0.28 pers/m^2).

[10] Equivalent to 0.33 pers/ft^2 (3.70 pers/m^2).

[11] Equivalent to 0.09 pers/ft^2 (1 pers/m^2).

occupancies, as well as on the basis of story height and riser-tread ratio. Under conditions of normal occupancy, NBS reported that flow down stairs averaged approximately 57 pers/min/22 inch width unit (1.70 pers/sec/m). An inverse relationship between stair width and discharge rate was also found. Moreover, NBS investigators noted that people moved more slowly, and at higher densities, on the first half of stair flights. After intermediate landings were passed, however, a decrease in density and a concommitant increase in walking speed were observed. Finally, data recorded by NBS suggest that occupant density on stairs varies with the speed of movement. For example, under rapid discharge conditions, density averaged 0.25 pers/ft^2 (2.78 pers/m^2); at more liesurely discharge rates half this density was observed. On the basis of these findings, NBS recommended that analysts assume a discharge rate of 45 persons per minute per 22 inch exit unit (1.35 pers/sec/m) down stairs, under conditions where occupants are not likely to interfere with one another on stair ways. This is substantially lower than 57 pers/min/unit (1.70 pers/sec/m) NBS found empirically, although is consistent with stair discharge recommendations promulgated earlier by the National Fire Protection Association (1917).

Togawa (1955) concluded on the basis of his field observations that stair width alone was not an effective predictor of flow rate on stairs. Instead, Togawa believes that the most useful predictor of flow rate is individual walking pace, and that for stairs, the critical dimension is tread depth. Moreover, Togawa observed that travel time on stairs is inversely proportional to staircase angle and story height, and that downward walking speed averages 1.64 ft/sec (0.5 m/sec). Finally, Togawa suggested that travel time, either up or down stairs, could be estimated by applying the formula

$$t = 4H \tag{3}$$

where t = travel time in seconds
H = story height in meters.

Flow rates on stairs reported by Togawa are substantially equivalent to those described by NBS (1935).

Findings presented by the London Transport Board (1958) concerning the capacity of stairs differ from those reported by both NBS and Togawa. London Transport Board researchers found flow rates on stairs to average 35.2 pers/min/unit width (1.04 pers/sec/m) in ascent, and 37.4 pers/min/unit width (1.15 pers/sec/m) in descent. These are substantially lower than flow rates reported by either NBS or Togawa, as well as those assumed within the <u>Code</u>.

Fruin (1971) also found movement speed on stairs to be higher in descent than in ascent. He noted that males traverse stair flights more rapidly than do females, and that in general movement speed decreases as the angle of staircase incline increases for both upward and downward travel (contradicting Togawa's finding that movement speed <u>increases</u>, or travel time, in Togawa's own terms, decreases, as the angle of incline increases). Moreover, Fruin found that within low and moderate ranges pedestrian density appears to have relatively little effect on stair traffic flow. According to Fruin, flow rates in the vicinity of 18.9 pers/min/ft (1.03 pers/sec/m) are representative of crowded conditions under which queuing occurs at stair entrances.

Similarly, Melinek and Booth (1975) suggest that flow rates averaging 37.4 pers/min/width unit (1.1 pers/sec/m) represent the normal capacity of stairs. In addition, these investigators note that as crowd density increases, flow rate on stairs also increases until it reaches a certain level. At that point, flow decreases again. Melinek and Booth also found that bends and corners along stair ways did not measurably reduce flow rate.

According to Yamada (1975), people travel up stairs more rapidly than they travel down, where stairs are not more than three stories high. Yamada also notes that people aged 50 and over often require as much as 40 percent more time than do younger pedestrians to descend 14 flights.

Pauls (1974, 1977, 1979, 1980) challenges the assumption promulgated by NBS (1935) and the Code regarding the design flow rate of 45 pers/min/unit width (1.34 pers/sec/m). On the basis of his observations of forty evacuation drills in high rise office buildings, Pauls argues that this assumption may overestimate actual flow rates by more than 50 percent, particularly during winter months in cold climates where escaping occupants are likely to wear bulky clothing. Under many conditions, Pauls found that speed of descent on stairs tends to be considerably more variable than is assumed (indirectly) by users of traditionally-promulgated design flow values. Pauls suggests that a "comfortable" range for evacuation movement of between four and six stories per minute requires densities within the range of 0.1 and 0.2 pers/ft^2 (1.11 and 2.22 pers/m^2). He also found that such movement becomes virtually impossible when density reaches 0.45 pers/ft^2 (5.00 pers/m^2). Pauls has stated that flow rates greater than 30 pers/min/width unit (0.9 pers/sec/m) are usually only achieved under ideal conditions, where building occupants have been specifically instructed about evacuation procedures, where they are motivated to act effectively, and where they are familiar with regimented movement.

Pauls found evacuation time in "total evacuation drills" (those in which all occupants are alerted at once are presumed in initiate evacuation simultaneously) to depend upon total building population and available stair width. For example, a ten story building with 100 occupants per width unit could typically be evacuated in less than five minutes (plus or minus 20 percent). In contrast, a 30 story building with 1,000 occupants per width unit has been shown to require more than 30 minutes to evacuate. Pauls notes that although most evacuees participating in the observed drills had obtained prior drill training, they were typically unaware that the evacuation was in fact only a drill.

On the basis of his most recent analyses of crowd movement on stairs, Pauls (1980) has presented the concept of "effective stair width," suggesting that pedestrians typically maintain themselves at a distance of approximately six inches (150 mm) from the sides of stair wells. Apparently, this spacing results from individuals' body sway, fear of bumping into side walls, and utilization of handrails. Consequently, Pauls suggests, a typical two-unit stair 44 inches (1.10 m) wide may only have an effective width of 32 inches

(0.81 m). According to the Code, such a stair would permit a load of 120 (60 x 2) pers/min; according to Pauls' calculation, however, the same stair might, under certain conditions carry only 38 pers/min.

Regarding flow rates on ramps, NBS (1935) summarized findings reported earlier by the Illinois Central Railway System demonstrating that flow on ramps is essentially equivalent to that on level surfaces. NBS researchers also noted that, according to their own observations of ramps in New York City's Grand Central Station, pedestrian density on ramps averaged approximately 8 ft^2/pers (0.72 m^2/pers)[12], and peaked at approximately 6.2 ft^2/pers (0.56 m^2/pers)[13]. Under similar conditions, NBS concluded that the discharge rate of ramps is faster than that of stair ways.

Evans (1950) estimated flow down ramps to be 37 pers/min/unit (1.10 pers/sec/m) width when slopes were within the range of 6 to 12 percent. Also within this range, walking speed was not found to vary significantly with slope. Moreover, walking speeds on ramps were found to be slightly higher than those on level passages: 4.2 ft/sec (1.28 m/sec) for ascent on a 12 percent ramp, to 4.8 ft/sec (1.46 m/sec) for descent on a 2 percent ramp, as compared with 3.5 through 4.5 ft/sec (1.07 through 1.37 m/sec) on level surfaces.

Fruin (1971) also found that for grades up to 6 percent, ramp grade has little effect on walking speed. Other researchers have suggested that grades as small as 5 percent effect walking speed. A controlled experiment in which military personnel walked on a variable-grade treadmill, reviewed by Turner and Collins (1979), indicated that an increase of grade from 5 to 10 percent decreased average walking speeds by approximately 11.5 percent. Increasing ramp grade to 20 percent decreased walking speed by a total of 25 percent. Melinek and Booth (1975) reported that for upward-sloping ramps, walking speed decreases by 2 percent per degree of grade. They also noted that for downward-sloping ramps, walking speed increases for small grades, but decreases for larger slopes. In general, maximum downward walking speed is associated with gradients of approximately 7 percent.

Tregenza (1976) agrees with other researchers noting that at slopes of 5 percent or less, gradient has virtually no effect on walking speed. Citing data collected by the Road Research Laboratory in the United Kingdom, however, Tregenza indicated that a 10 percent ramp gradient could reduce upward walking speed by as much as 40 percent. Under certain conditions, especially where elderly or partially mobile persons are concerned, a similar effect can occur with downward travel.

In summary, considerable data describing pedestrian flow on level surfaces, stairs, and ramps has been reported in the technical literature. Although it often is not reasonable to compare data collected under different conditions (e.g. evacuation drills in office buildings versus normal movement in transit

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[12] Equivalent to 0.13 pers/ft^2 (1.39 pers/m^2).

[13] Equivalent to 0.16 pers/ft^2 (1.78 pers/m^2).

facilities), observations under a wide variety of circumstances do permit certain conclusions. In particular, data currently available in the technical literature support the assumption that ramps, within certain limits, permit flow rates substantially similar to those found on level surfaces. In addition, available data support the assumption that walking speed on ramps is faster than that on stairs. However, available data do not support the assumption that downward walking speed on ramps is always faster than upward walking speed.

Elaborating on the general issue of egress way capacity, the Code specifies that although the fundamental unit of exit width is 22 inches (0.56 m) for the purpose of establishing occupant load limits, the minimum width required for any egress way element is 28 inches (0.71 m). Several references to the available technical literature support this feature of the Code. For example, Langdon-Thomas (1972) has expressed considerable concern over the possibility that even the slightest obstruction to movement in means of egress may have the most serious consequences. As a results, he has recommended a minimum width of 30 inches (0.76 m) for individual egress channels and elements. Similarly, the Fire Protection Handbook (NFPA, 1976) cites Fruin's (1971) findings that while adult men typically measure less than 20.7 inches (0.53 m) across the shoulders, additional allowances must be made for clothing (especially heavy winter clothing) and for body sway. Fruin has suggested that the average adult "body ellipse" be taken as 24 inches, or 0.61 m. The Fire Protection Handbook further considers the question of side-to-side body sway, estimating sway on each side to be approximately 1.5 inches (0.04 m) under free flow conditions, and as much as 4 inches (0.10 m) on each side under more crowded conditions, particularly on stairs. On the basis of such estimates, the Handbook recommends that egress channel width be no less than 30 inches (0.76 m).

Finally, Code provisions governing the capacity of means of egress appear to be founded on certain assumptions concerning the linearity of pedestrian movement. In general, a majority of investigations of pedestrian movement reviewed by NBS (1935) led the organization to conclude that, on the average, people moving through corridors or stair ways can be assumed to travel in linear files 22 inches (0.56 m) wide. According to NBS, the origin of this assumption lies in military experience. By extention, this line of reasoning leads to the notion that a 44 inch (1.12 m) wide channel adequately supports movement by two linear files of pedestrians. The Fire Protection Handbook (NFPA, 1976), citing more recent research by Fruin (1971), accepts the assumption that people tend to travel through egress ways in linear files. This notion is further supported by Soviet research on emergency egress summarized by Roytmann (1969).

London Transport Board (1958) researchers report that they could not detect this "lane" effect for footways more than 48 inches (1.22 m) wide. However, these investigators noted that for narrower stair ways and corridors flow rate was dependent on the number of available lanes of unit width. The London Transport Board also suggests that widths falling between unit multiples have capacities that are not simply predicted by computing fractions under the "lane" model. For example, when a center handrail was introduced in a stairway previously capable of permitting three files abreast, the lane model suggests a reduction in the stair's capacity by one third (since, presumably, the rail eliminates one aisle). However, actual flow on the stair was reduced by a small amount, suggesting pedestrians walked in staggered, rather than purely linear, files. In discussing the rationale for permitting credit only for additional exit width increments of 12 inches (0.31 m), Appendix notes to the Code also support the notion that flow may be meaningfully increased by providing sufficient space for staggered files. Galbreath (1968) interpreted the London Transport Board's data, discussed above, to suggest that staggered (rather than purely file-like) movement is most common, particularly when tall buildings are being evacuated. The Institute of Traffic Engineers (1964) report finding no studies which actually verify the 22 inch (0.56 m) lane effect, noting further that lanes of this dimension may be too narrow to permit free flow pedestrian movement on stairs.

By far the most noteable challenge to the unit width concept, particularly as this concerns the granting of credit for fractions of units, derives from the work of Pauls (1974, 1977, 1980). In his study of some 40 evacuation drills in high-rise office buildings, Pauls notes that occupants did not move down stairs in a highly regimented fashion, either shoulder-to-shoulder or even in staggered files. Rather, pedestrians observed by Pauls appeared to make every effort to maintain a body buffer zone (similar to the body ellipse concept discussed by Fruin), even in cases where density was fairly high. Pauls suggests that this spacing behavior is influenced by such factors as type and weight of clothing worn, occupants' cultural backgrounds, pedestrians' sex, and their social relationship with nearby persons. Further, Pauls argues that shoulder-to-shoulder movement is rare on stairways narrower than 4.0 feet (1.22 m). Where it does occur, according to Pauls, it primarily involves pedestrians trying to talk to one another.

Pauls also found that side-to-side body sway, and pedestrians' varying need for handrail support, influences movement behavior on stairs. On the basis of his research, Pauls (1980) recommends a minimum width of 55 inches (1.40 m) for stairs normally subject to heavy use. This dimension takes body sway into account, permits movement two-abreast, and allows convenient passing on the stair.

As indicated above, Pauls (1980) has paid particular attention to the problem of granting credit for fractions of egress width units. He has argued that flows down exit stairs tend to be proportional to stair width, and that the relation between width and flow is essentially linear. Thus, since each additional inch of exit width has the potential of increasing flow rate, each such inch should be considered for credit under provisions of the Code. At present, the reader will recall, one-half credit is given for extra width from 12 to 21 inches (0.31 to 0.53 m); no credit is given for extra width from 1 to 11 inches (0.03 to 0.28 m). According to Pauls (1980), this step-like function has no basis in available empirical data, while the linear "effective width" model, on the other hand, can be justified both by Pauls' own data and by those reported much earlier by NBS (1935).

Strengths and weaknesses of the technical literature. A number of behavioral assumptions underlying Code provisions which concern the potential effect of architectural barriers consider the influence of doorways and intermediate mullions on egress flow rate. Most of the available data on flow through door ways (NBS, 1935; Togawa, 1955; Fruin, 1971; Melinek and Booth, 1975) are based on field observations made under conditions of normal building occupancy. A number of difficulties arise, however, when these data are applied in analyses of emergency egress situations. First the process by which occupants form queues at doorways may itself be substantially influenced by circumstances brought about by actual fire conditions. While queuing regularly takes place under normal occupancy conditions, it has been found to become somewhat disorderly during some fires (as reported after the Berverly Hills Supper Club fire), yet remain orderly during others (as reported after the Stouffer Inn fire). Clearly, however, the assumption that door width and design alone influence door flow characteristics seems misguided, and while door ways may be examined under nonemergency conditions, results of such tests may not be predictive of emergency performance.

Second, while the code-writer may be tempted to draw causal inferences about the role of exit design in achieving desired flow rates, available data derive from studies lacking experimental controls which permit such inferences; at best, these data report trends and correlations. Moreover, the available data do not now permit the code-writer or analyst to estimate the probability with which a given exit width or door design will be adequate under hypothetical emergency conditions. Thus, although a considerable amount of data are available describing the flow capacity of door ways, the technical basis for designing door ways to accommodate overall emergency requirements remains weak. On the other hand, a good deal of research is now available describing such specific phenomena as arching at doorways (Togawa, 1955; Peschl, 1971; and others).

Although the effects of arching on egress time remain to be quantified, investigators' beliefs that door ways within a certain width range often result in time-consuming queues and arches do appear to be supported.

Available literature concerning the potential effects of intermediate mullions, door hinges, and other similar projections into door ways on door flow rates is insufficient to support or refute Code provisions and their underlying behavioral assumptions. This is also true for doors which open against traffic, and for mid-stream exit channel width reductions. Research by Melinek and Booth (1975) and the London Transport Board (1958) provide the strongest indications that minor architectural obstructions have little or no effect on egress flow. However, data reported by these investigators were not collected under either real or simulated emergency conditions. Here again, it is not possible to assess whether emergency conditions exert additional forces on escaping occupants, sufficient to alter the effects of otherwise minor obstructions to flow.

Code provisions pertaining to revolving doors and turnstiles are based largely on recommendations by NBS (1935). Fruin is the only other investigator to have empirically addressed these elements. There presently exist no empirical grounds upon which to challenge the pertinent Code provisions.

Available literature describing the capacities of stairs, ramps and level surfaces, while somewhat voluminous, has not developed in a cumulative manner. To data, investigators have rarely attempted analytical comparisons among their findings, data collection strategies and objectives frequently differ in subtle ways, and variables frequently have been defined inconsistently across investigations. For example, Togawa and other investigators studied pedestrian walking speed in relation to density, defined as the number of persons per unit area. Fruin, on the other hand, studied speed and flow in relation to area, which he defines as available area per person, the reciprocal of density. Another shortcoming of this literature concerns ambiguities imposed by data collection techniques. For example, studies of pedestrian walking speed usually involve timing pedestrians as they pass between two fixed points along a measured linear path (e.g. a corridor). Although the length of the measured path remains constant for all pedestrians, the actual lengths of pedestrians' movement paths do not, since some pedestrians are more prone than others to deviate from "purely" linear walking patterns. Thus, if two pedestrians walk the measured path in the identical period of time, the recorded speed of one will be equal to that of the other, even though their actual walking paths--and thereby their actual walking speeds--differ. Such ambiguities make it difficult for the code-writer or analyst to infer trends or draw definitive conclusions from published studies.

The work of Pauls (1974, 1977) departs somewhat from that of other researchers, particularly in that he specifically investigated fire exit drills in public occupancy buildings. According to Pauls, moreover, many occupants participating in these drills actually believed real emergencies to be in progress. In addition to data concerning the time required to evacuate buildings differing in height and under a variety of egress scenarios (e.g. evacuation en-masse, versus "staged" evacuation), Pauls also collected numerous data on film, video tape, and sound tape which describe a large number of behavior patterns occuring along egress routes. Flows reported by Pauls are in most cases lower than those published by other investigators. According to Pauls, flow rates reported elsewhere are artificially high, perhaps due to the artificiality of the situations studied. These differences between Pauls' data and those reported by other researchers remain to be verified and explained empirically.

Pauls' findings are often difficult to compare directly with those reported by other investigators, primarily because Pauls usually reports walking speeds and flows down stair ways in terms of stories per unit time. This difference poses serious problems to the analyst wishing to employ Pauls' data, particularly since story height may vary considerably between building types. Pauls' data, accordingly, appear most directly useable when applied to high-rise office buildings. More generally, however, the fact that Pauls' flow data under drill conditions (which in some ways simulate emergency events) appear substantially lower than those collected in transportation facilities and elsewhere (under decidedly nonemergency conditions) gives cause to reevaluate the present basis for computing building occupant loading for the sizing means of egress. Given the significance of Pauls' findings to goals of the Code, a number of his studies warrant replication, particularly true where the code-writer is interested in making generalizations from Pauls' data describing office buildings to other occupancy categories.

Research on pedestrian movement down ramps involves methods and techniques substantially similar to those employed in stair use research. Although conclusions regarding pedestrian flow on ramps are analogous to those reported in connection with stairs, numerous studies, including those reported by NBS (1935) suggest that pedestrian behavior patterns have more in common with movement on level surfaces than with movement on stairs. At present, most investigators of ramp use report similar findings concerning differences between pedestrian performance in ascent versus descent, although the precise relationship between ramp slope and walking speed remains clouded by equivocal findings.

Available data pertaining to assumptions about the linearity of pedestrian movement and the long-accepted "standard" 22 inch (0.56 m) exit width unit are problematic. As pointed out by NBS (1935), the idea of studying pedestrian movement in terms of linear files of standard width stems from military experience. But to what extent is regimented military walking behavior generalizeable to the movement of building occupants, either under normal or emergency conditions? Despite methodological shortcomings which at times render Pauls' and Fruin's data difficult to interpret and apply, their identification of such clearly observable pedestrian behavior patterns as side-to-side body sway and personal space maintenance raise important questions about the validity of the current standard. On the other hand, available data also suggest that under relatively high density conditions, escaping occupants may be willing to forfeit comforts associated with personal space maintenance, and given little freedom of choice within an egress channel, may effectively follow linear paths and move in files of unit width. Thus, with no replacement for the 22" unit clearly in view, the current standard should not be abandoned.

Pauls has attributed the validity of his findings concerning egress behavior down stairs, to a great extent, to the fact that many occupants of the buildings he studied believed that the drills were actual emergencies. However, Pauls has made this supposition on the basis of a relatively small sample of drill participants, perhaps on the order of 10 percent. Moreover, these individuals were not forced to escape in the presence of fire products, nor did they receive such ambiguous signals as distant shouts, etc., which might have affected escape behavior (refer to Chapter 3 of the present report). Indeed, the problem of predicting behavior during drills remains unresolved, as noted in Chapter 2. From a scientific perspective, consequently, Pauls' recommendations concerning the design of exits to facilitate emergency escape should, perhaps, be viewed more as hypotheses than as statements of fact. Replications of Pauls' work, both under more controlled conditions and under a wider range of occupancies and emergency scenarios, are indicated.

7.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

7.4.1 Research on the Influence of Architectural Barriers and Other Potential Obstructions to Egress Flow

The majority of studies available describe the influence of architectural barriers and other obstructions to egress flow focus on pedestrian movement through door ways. Provisions of the Code specify the design of door ways on the basis of occupant loading criteria and available door width. One point on which there is little equivocation in the literature is the finding that, under conditions of relatively high occupant density, queues form as individuals wait to pass through door ways. However, researchers have yet to study the questions of how queue formation and processing influence egress time, and how door width specifications may be adjusted to compensate for time potentially lost in queues.

A closely related gap in the technical literature concerns the predilection of most researchers to study pedestrian behavior in relation to some one egress way element (e.g. doors) in isolation. Indeed, the task of exiting a building usually involves passing through numerous door ways, as well as corridors, stairs, and lobbies, all of which are more or less interrelated. When a queue forms at a door way, for example, it is not merely flow through this door that is affected: the capacity of the preceding stair or corridor is being taxed as well. Future research must address the interdependencies between adjacent egress way elements, and provide guidelines for the design of effective transitions between elements.

7.4.2 Research on the Flow Capacity of Egress Channels

Flow rate has been the most universally accepted measure of the performance of means of egress. Considerable work remains, however, to develop a standard measurement method. In the absence of such a standard, it will continue to be difficult to determine precisely why data from various investigations often disagree. For example, Pauls and Fruin each found different variables to interact with flow rate and walking speed; Togawa found no such interaction effects. Similarly, although Pauls and Fruin have both advocated an incorporation of body sway and personal space maintenance behavior into computations of flow capacity, there remain neither standard measures nor verified models of these phenomena.

7.5 SUMMARY

A number of human behavioral assumptions underlying Code provisions which govern the capacity of means of egress were presented. These assumptions were evaluated by reference to several models of pedestrian movement, data from laboratory and field studies of walking behavior during normal occupancy conditions, and observations of stair use during fire exit drills in high-rise office buildings. With regard to Code provisions affecting the design of doors, available technical literature support only those assumptions concerning the deleterious effects of particularly severe constrictions or obstructions. However, behavioral assumptions underlying provisions governing the design of corridors and stairs find challenge within the technical literature. This is especially true of provisions depending on the validity of assumptions about the linearity of pedestrian movement and the 22 inch (0.56 m) unit width standard. Because there remain differences in reported data describing pedestrian behavior on stairs and level surfaces, inconsistent definitions of important variables, and nonstandardized techniques for measuring the performance of means of egress, it is not now possible to either support or refute existing provisions and their underlying behavioral assumptions on the basis of the available technical literature. The most important objectives for future research on the subject of the capacity of means of egress are: (1) the development and validation of standardized measures and measurement methods, and (2) the systematic analysis of complete egress systems emphasizing transitions between means of egress elements.

8. SUMMARY AND CONCLUSIONS

The primary objective of the investigation has been to assess available research pertaining to the exit facility design and emergency escape provisions of the NFPA Life Safety Code (1976 Edition), in order to determine the technical support for such provisions. The central foci of the investigation are the time-based capabilities of building occupants to effect rapid evacuations, in relation to evacuation time available during fires. A number of functional criteria (e.g. maximum travel distance, building configuration, remoteness of exits, and barriers to egress flow) are examined in relation to Code provisions influencing the design of means of egress, and fire protection and protective signaling systems for places of assembly, residential occupancies, mercantile occupancies, and business occupancies. Provisions affecting fire exit drill and building management practices are also considered.

To effectively treat this broad problem, the current report organizes Code provisions and related technical discussions in relation to areas of potential impact: provisions affecting pre-emergency training and preparation (Chapter 2), occupants' perception of the emergency environment and recognition of egress facilities (Chapter 3), egress strategy formation (Chapter 4), disciplined egress behavior and crowd movement (Chapter 5), occupants' capabilities to safely and rapidly negotiate egress ways (Chapter 6), and the capacity of means of egress (Chapter 7).

Within each chapter, provisions of the Code which have a common area of potential impact, and human behavioral assumptions underlying these provisions, are presented. The technical literature bearing on these provisions and assumptions is reviewed, including references to applicable theories and models, pertinent empirical data from published experiments and field studies, and where appropriate, journalistic or anecdotal accounts of actual fire events. The validity and generalizability of findings presented in the literature are discussed, and the degree of technical support currently available for egress provisions of the Code is evaluated. Finally, each chapter provides a summary of gaps in the technical literature, recommending specific areas requiring additional reseach. The remainder of Chapter 8 summarizes Code provisions, behavioral assumptions, technical literature, and recommendations presented in each of the substantive chapters of the report.

8.1 SELECTION OF CODE PROVISIONS

Code provisions addressing occupants' "readiness" for fire emergency situations were selected for analysis, emphasizing provisions for the conduct of fire exit drills which appear in Chapter 17 (Operating Features) of the Life Safety Code. Provisions selected for study are presented in Section 2.1 of the report. A number of provisions are noted which potentially influence occupants' perceptions of the emergency environment and their recognition of egress facilities. The principal sources of these provisions were Chapters 5 (Means of Egress) and 6 (Features and Fire Protection) of the Code. Provisions selected for analysis are enumerated in Section 3.1 of the present study. Once occupants have determined that a fire emergency is in progress, they must decide on a specific course of action. When a decision in made to evacuate, an egress strategy must be formulated and acted upon. A number of Code provisions were found which potentially affect occupants' cognitive behavior and their ability to make effective decisions leading to successful emergency escape. These provisions are drawn primarily from Chapter 5 (Means of Egress) of the Code, and are presented in Section 4.1 of the current report. Problems associated with emergency escape during fires in public occupancy buildings are often complicated by the fact that occupants are members of social groupings which may vary quite widely with regard to a number of characteristics. Hence, the control of social interactions during fires may be a desired outcome of building management, and to some extent planning and design as well. A number of provisions, drawn primarily from Chapters 5 (Means of Egress) and 17 (Operating Features) are noted which potentially influence social behavior in the emergency environment, and are shown in Section 5.1 of the report. Provisions intended to minimize human physiological impediments to the safe and rapid use of egress ways were selected principally from Chapter 5 (Means of Egress) of the Code. These are presented in Section 6.1 of the report. Finally, those provisions of Chapter 5 of the Code which focus on the carrying capacity of egress way elements, and which may substantially influence the efficiency with which buildings are evacuated, are presented for analysis in Section 7.1 of the present study.

8.2 UNDERLYING BEHAVIORAL ASSUMPTIONS

Provisions of the Code were selected for analysis because of certain assumptions concerning the potential affect of code compliance on escape performance during fire emergencies. That is, when designers or building officials make design or compliance decisions with respect to many Code provisions, they do so in the underlying belief that, on the average, occupants will respond properly, and that compliance with such provisions thereby increases the likelihood that occupants will survive fires. Initially, the project staff hypothesized a set of human behavioral assumptions pertaining to Code provisions within each impact area. Then, a procedure was established for submitting this set for expert peer review (note Appendices A and B of the current report. The project staff accepted behavioral assumptions as modified during the peer review process as the best currently available description of human behavioral patterns assumed to underlie selected provisions of the Code.

Chapter 2 of the report addresses pre-emergency training and preparation. Human behavioral assumptions found to underlie pertinent Code provisions clustered into four subsets, including: (1) the ability to predict occupant responses during actual fires, (2) the transfer of responses learned during fire exit drills to actual fire situations, (3) occupants' attitudes toward fire exit drills, and (4) the accomodation of training procedures to diverse fire scenarios. Specific assumptions are given in Section 2.2.

Chapter 3 of the report treats provisions affecting occupants' perception of the emergency environment and their recognition of egress facilities. Human behavioral assumptions underlying related Code provisions clustered into the following subsets: (1) the effect of door and window design on egress route identification, (2) the effect of illumination level on egress route identification, (3) the role of signage and directional information in egress route recognition, and (4) the ability of audible and visual alarm signals to effectively alert building occupants to a fire threat. Refer to Section 3.2.

Chapter 4 considers Code provisions which may influence the ways building occupants formulate emergency escape strategies during fires. Underlying behavioral assumptions concern: (1) occupants' capacities to process information about the location and function of means of egress, and (2) occupant's abilities to determine the safest and most accessible escape route under stressful and life-threatening conditions. See Section 4.2.

Code provisions considered in Chapter 5 of the current report potentially affect disciplined emergency escape and crowd movement. Three categories of human behavioral assumptions were found to underlie such provisions: (1) the influence of designated leaders on escape time during fire emergencies, (2) pedestrian movement under high density occupancy conditions, and (3) the effects of building configuration and architectural barriers on efficient crowd movement. These assumptions are presented in Section 5.2.

Chapter 6 deals with the physical capabilities of occupants to safely and rapidly negotiate egress ways. Human behavioral assumptions underlying Code provisions which potentially influence such capabilities cluster in three categories: (1) the extent to which accidents such as slips, missteps, or falls, which may occur while people negotiate pedestrian ways, impede flow along corridors, stairs, and ramps and through door ways, (2) the degree to which stress and fatigue impair walking behavior and increase the time required for safe escape, and (3) the influence of door and other hardware design upon occupants' abilities to rapidly operate elements comprising means of egress. Note assumptions in Section 6.2.

Finally, Code provisions treated within Chapter 7 concern the capacity of means of egress. Two categories of behavioral assumptions appear to underlie these provisions. These are: (1) the influence of architechtural barriers and other potential obstructions on egress flow, and (2) the flow capacity of egress ways. Refer to Section 7.2.

8.3 TECHNICAL COMMENTARIES

Thorough reviews of the theoretical, empirical, and journalistic literature applicable to Code provisions and their underlying human behavioral assumptions were conducted. These reviews made it possible to state, in technical terms, the fundamental nature of various facets of the emergency escape problem, to explain behavioral phenomena known to occur during fire emergencies, and to assess the state-of-the-art of technical data which either support or refute the Code provisions under study.

8.3.1 Problem Statements

Code provisions affecting pre-emergency training and preparation are intended to maintain occupancies at a sufficient state of emergency readiness, to reduce the likelihood of maladaptive responses during actual fires, and to minimize the time required by occupants to either escape buildings or move to refuge areas.

In general, these provisions are based on the assumption that behavior patterns learned during training situations transfer to actual emergencies, and thereby result in effective behavior during real fire events. Problems addressed within Section 2.3.1 of the current report concern the validity of this supposition, as well as other questions about the value of pre-emergency preparation and training.

Under certain conditions, the design and provision of emergency exiting facilities may directly affect occupants' perceptions of the emergency environment, as well as their recognition and subsequent use of these facilities. Chapter 3 treats Code provisions intended to achieve easily identifiable egress ways, facilitate rapid and accurate escape route determination, and to confirm occupants' awareness of immediate fire conditions. These provisions presuppose causal relationships between the design of architectural features, and such attributes of emergency escape performance as stimulus detection, situation definition, and egress strategy formulation. The verifiability of this supposition, the validity of causal relationships between physical design and escape performance, and the availability of empirical support for applicable Code provisions are the chief problems outlined with Section 3.3.1.

Additional Code provisions are intended to assure that occupants are not entrapped in the event that any single exit route becomes blocked by fire products, that occupants will not become unnecessarily confused if exits are not immediate accessible, and that escapees do not overshoot discharge points along any escape route. Decisions which occupants must make concerning the formulation and revision of escape strategies are often required on a number of occasions during the emergency event. Design provisions which potentially affect the quality of occupants' egress strategies presuppose that escaping occupants obtain information vital to decisionmaking from the social and physical environments during the course of the fire event. Technical problems associated with these issues are presented in Section 4.3.1 of the report.

A number of Code provisions are intended to assure that emergency egress from public buildings will be orderly and well organized, and that maladaptive crowd behavior which could lead to panic or abnormally lengthy escape time will be unlikely. The special problems associated with crowd behavior and the implications of building design for crowd management are introduced in Section 5.3.1.

Whether or not building occupants can safely and rapidly negotiate egress ways may be substantially affected by the sensorimotor capabilities of these individuals. This effect is potentially influenced by a number of building design provisions treated in Chapter 6 of the current report. Section 6.3.1 introduces the problem of accomodating human performance capabilities in egress design provisions of the Code.

Code provisions governing the capacity of means of egress are intended to assure that exit ways can adequately carry anticipated occupant loads during fire emergencies. To accomplish this purpose requires not only that exit ways are of sufficient dimension, but that their design and arrangement minimizes opportunities for blockages and other impediments to rapid egress flow. Section 7.3.1 of the report presents the problem of evaluating exit way capacity, in view of occupants' sensorimotor capabilities and the dynamics of fire situations.

8.3.2 Behavioral Models

Theories, models, and concepts from the behavioral sciences and other pertinent disciplines provide an important framework for understanding fire emergency events and for guiding the development of more effective design solutions. Consequently, they provide a useful basis for evaluating Code provisions which potentially impact occupant performance during fires.

In evaluating the effectiveness of pre-emergency training and preparation, three models drawn from the psychology of learning appear to offer insights useful in understanding relationships between training and behavior during actual emergencies. These models are the instrumental conditioning, social learning, and cognitive models. Instrumental conditioning is based on the assumption that an individual, through reinforcement in the form of reward or punishment, acquires connections between specific environmental events or stimuli and particular behavioral responses. Stemming from instrumental concepts, social learning emphasizes the importance of social environmental stimuli to the behavior of any individual. According to the social learning model, the behavior of others may have considerable influence over the behavior of an observing individual, who may find imitative and vicarious behavior to be positively reinforcing. Social learning also suggests that individuals often depend upon others in the immediate environment for help in achieving goals. In contrast, the cognitive model treats learning as a developmental process by which information from the environment is assimilated, interpreted, and applied by individuals as they continuously make decisions essential to effective environmental accomodation. According to one popular approach to cognitive learning, individuals are thought to test their own mental image, or "cognitive map" of an event (which may or may not be accurate or correct) against the reality of the event being confronted. Here an individual's success in negotiating the event may well depend upon the "fit" between the cognitive map (the mental guide for behavior) and the actual event, as well as on the individual's ability to make rapid mid-stream corrections in the cognitive map. These models are considered in detail in Section 2.3.2.

Three theoretical explanations of human perception provide insights to occupants' perceptions of emergency environments and their recognition of egress facilities. These are psychological field theory, environmental information processing theory, and signal detection theory. Psychological field theory (or "Gestalt" psychology) posits that physical objects are always viewed against a background which provides varying degrees of contour, contrast, and boundary to the object. Characteristics of the background field may substantially influence the clarity with which an object is perceived. With its origins in Gestalt psychology, environmental information processing theory suggests a mechanism by which individuals interact with their physical surroundings, simultaneously extracting information from them and contributing to their change. Based on psychophysical research, signal detection theory posits that environmental stimuli must continually compete with other, less relevant, stimuli. Further discussion of these approaches is provided in Section 3.2.2.

Environmental information processing appears to provide the most useful conceptual framework for understanding emergency egress strategy formation. This model holds that sociophysical settings supply individuals with at least as much information as any person can effectively process and use, irrespective of whether the available information is of sufficient quality or quantity to permit successful event negotiation. Accordingly, fire situations can be conceptualized as situations in which escaping occupants continuously seek out information they need to make effective behavioral decisions. In addition to the general framework posited by the environmental information processing model, a number of other models which describe processes by which information is stored, retrieved and utilized, and which illuminate potential impediments to information processing, were also considered within Section 4.3.2.

Models of group behavior, drawn from the field of social psychology, provide a framework for understanding problems which may arise when large groups of people attempt to escape public buildings during fires. The outcome-dependence model, for example, suggests that individuals and groups for which some information dependency exists rely upon other people perceived to be better informed (e.g. visitors to office buildings may, during a fire, depend upon workers in the building whom they expect to be much more familiar with exit locations). The imitation model suggests that under certain circumstances individuals will copy behaviors exhibited by other persons they perceive to be role models. The reward-exchange model posits that an individual will interact with others only to the extent that the products of such interaction are perceived to be congruent with the individual's own objectives. The environmental space model is based on anthropological research and focuses on individuals' apparent need to circumscribe territories for themselves. These territories may be useful as protective boundaries between an individual and other persons in the immediate environment. Consequently, according to the model, individuals strive to maintain personal space buffer zones. Relationships between such models and problems associated with disciplined egress behavior and crowd movement during fire emergencies are treated more fully in Section 5.3.2.

Models stemming from research in human factors psychology and biomechanics are useful in explaining occupants' performance capabilities under various circumstances which may arise during buildings fires. The man-machine and feedback-loop models suggest, for example, that in the process of negotiating an egress way, an individual conducts perceptual, tactile, and kinesthetic tests of environmental conditions, while receiving feedback from the environment concerning its state. The cybernetic model of neurophysiological coding suggests that stressors from the environment interact with human neurological processes, and may interrupt or overload individuals' abilities to cope with environmental stress. The biomechanical model describes the human body as a highly complex structure consisting of numerous mass-spring-damper elements. Such a conceptualization of the body appears useful in describing the way a person negotiates elements of egress ways (e.g. stairs) or operates pertinent architectural hardware (e.g. doors). These models are the subject of Section 6.3.2.

Models adopted from both the physical and behavioral sciences are useful in conceptualizing the performance of means of egress and for predicting their capacities. The particle model treats emergency egress as being directly analogous to evacuating ball bearings from a funnel-shaped bin. In the hydraulic model, the movement of masses of people through complex building configurations is viewed as analogous to the gravity-induced movement of a fluid through a system of pipes, valves, and catch basins. The gaseous model has been suggested to describe low density pedestrian movement, under conditions where individuals exercise considerable freedom of choice. Although not itself a descriptive model, the psychological concept of personal space, which posits individuals' needs to maintain protective buffer zones around themselves, is useful in understanding limitations to the capacity of egress ways. These models and concepts are discussed in relation to Code provisions affecting the capacity of means of egress in more detail in Section 7.3.2.

8.3.3 Assessment of Behavioral Assumptions Based on the Technical Literature

Pre-emergency training and preparation. A review of the literature pertaining to provisions and assumptions concerning pre-emergency training and preparation yielded mixed conclusions. In many instances, assumptions in this area imply that panic is a likely outcome of fire emergencies. However, the term "panic" lacks a widely accepted technical definition. Controlled social psychological laboratory experiments have shown panic-like responses to result when time-to-escape is perceived to be insufficient, and when leadership is unavailable. Journalistic accounts of actual fires have also recorded panic-like behavior under similar conditions. On the other hand, post-incident technical studies of fires have shown that such panic is a rather infrequent occurrence. Behavioral assumptions underlying pre-emergency training and preparation provisions of the Code also imply that the threat of panic may be reduced through fire exit drill training. A number of post-incident studies support this notion, although no direct evidence of a relationship between drill training and panic reduction is currently available in the technical literature.

The question of whether behavior patterns learned during exit drills and other forms of pre-emergency preparation transfer to actual emergency conditions has been considered by a number of investigators. However, there remains no empirical evidence of a transfer of training from exit drill performance to emergency egress behavior. Some fire researchers have also noted the importance of exit drill frequency, although no empirical evidence currently exists demonstrating the effect of drill frequency on performance during actual emergencies. Two incidents recorded in the literature actually question the benefit of frequently-conducted exit drills.

Virtually no technical data are presently available describing occupants' attitudes to drills and drill participation, or illuminating the relationship between occupants' attitudes and their performance either in drills or actual emergencies. The problem of accommodating training procedures to the peculiarities of individual occupancies also has been noted in both the Code and the literature. To date, most research on drill effectiveness has been conducted in occupancies with distinct leadership hierarchies (e.g. nursing homes), and results of studies in these occupancies may not generalize to other building types (e.g. shopping malls). In summary, the technical literature neither universally supports the behavioral assumptions underlying Code provisions affecting pre-emergency training and preparation, nor supports specific alternatives.

Perceptions of the emergency environment. Available technical data are insufficient to either support or refute most assumptionns underlying Code provisions pertaining to occupants' perceptions of emergency environment and their recognition of egress facilities. Various studies appear to refute assumptions concerning emergency alerting signals. Extremely few technical data pertaining to the effect of door and window design on route perception were found. Virtually none of these data specifically addressed problems associated with emergency egress. Similarly, very little research concerning the effect of illumination level on egress route perception has been conducted, and it is not now possible to either confirm or refute the minimum illumination level currently specified in the Code.

A number of experiments have been conducted to examine visibility under smoke conditions. However various methodological difficulties make it difficult to interpret findings from these studies. Moreover, conclusions about optimal visibility distance, particularly under smoke conditions, remain somewhat equivocal. The Code provision specifying a maximum switchover delay between standard and emergency lighting, and its antecedent human behavioral assumption, are supported by available psychophysical literature on light-dark adaptation. It should be noted, however, that the literature reports data from laboratory experiments lacking many of the ambiguities and stimuli which may be present during actual fire emergencies.

Current knowledge about the effectiveness of signs and visual information is based upon laboratory experiments designed to test the visibility and understandability of such signage. However, little is known about how, and whether, directional signage is actually used by escaping occupants during fire situations. The question of whether the visibility of directional signs is impaired by smoke has been specifically considered in the literature. Although the available data are not extensive, they do suggest that such signs, while commonly positioned overhead, would be more easily seen under smoke conditions if positioned within two to three feet (0.61 to 0.92 m) from the floor.

A number of toxicological investigations have considered potential effects of carbon monoxide (CO) on information perception and reaction time. However, research with human subjects is not sufficient to warrant useful conclusions at this time.

A small number of studies are available describing the effectiveness of arrows in way-finding, although no data have been found which show the effects of fixed directional arrows on emergency egress behavior and time. Data from highway research suggests that human subjects respond more quickly to graphic symbols than to information presented on verbal signs. No data were found indicating whether or not this is also true for pedestrians. Similarly, no data are currently available to suggest that verbal "NO EXIT" signs deter occupants from making incorrect egress route decisions, or that the presence of such signs reduces overall building evacuation time.

Much of the literature reporting data on the effectiveness of audible and visual fire alarm signals stems from nonexperimental post-incident investigations of actual fire events. These studies indicate that alarm signals are frequently not perceived by occupants as signaling an actual emergency. A number of sociological investigations of large-scale natural disasters, as well as journalistic accounts of fires, support this notion. These findings tend to refute the behavioral assumption that alarm signals will effectively initiate prompt and purposeful emergency egress action, which tends to underlie a number of Code provisions. The effectiveness of visual alarm devices, important to hearing-impaired building occupants, has not been examined in the literature.

Regarding the quality of alarm signals, a number of investigators have suggested that responses elicited by manual alarm bells tend to be ambiguous and confused. These researchers note that upon receipt of such alarms, occupants are often observed attempting to seek additional information, rather than taking prompt action to evacuate. On the other hand, a small number of anecdotal accounts of actual fires point to victims who, having seen or heard an alarm signal, formulated an effective egress strategy, and subsequently escaped unharmed. Generally, however, available technical evidence suggests little support for the assumptions that alarm devices, once activated, will provide unambigous emergency information, or that they will reduce overall escape time.

Egress strategy formation. Taken as a whole, available technical data are not sufficient to either support or refute behavioral assumptions underlying Code provisions which may influence the ways occupants formulate emergency escape strategies. However, the psychological literature does clearly indicate that occupying a burning building can be a highly stressful, if not life-threatening event, requiring individuals to make complex and potentially very costly decisions under severe temporal and environmental constraints, and under pressing physiological demands.

As of the current investigation, there are few technical data available directly relevant to assumptions about occupants' capacities to rapidly and effectively process and utilize information concerning the location and function of means of egress. In general, questions about how escaping occupants make specific route choices, or about the kinds of information they sought from the environment have not been raised by fire experts. Findings from empirical investigations of way-finding in buildings indicate that floor plan complexity and the visibility of route elements, are key predictors of wayfinding success. These findings, however, contrast with data from post-incident fire studies which suggest occupants' familiarity with building layout and exit locations to be the chief predictor of effective emergency escape.

Few data are available from the field of fire research that are useful in evaluating the assumption that occupants are capable of effectively determining the safest and most accessible escape routes while exposed to the psychological stresses produced during fire emergencies. Findings from seemingly pertinent psychological and toxicological experiments conducted under narrowly defined laboratory simulations, moreover, may be difficult to generalize to actual fire situations, partly because of the impracticality and immorality of conducting research in which human subjects are exposed to actual or potential life threats. Furthermore, psychological investigators have not systematically studied building fires as a special class of events, and hence, generalizations from psychological investigations of decisionmaking and behavior under stress or life threats are little more than untested hypotheses about responses during fires. Research on natural disasters has also addressed the effects of stress on decisionmaking and escape route choice. Although this work has not specifically attempted to clarify mechanisms by which environmental stressors prevent or inhibit effective decisionmaking during emergency situations, it has generally found that under such conditions decisionmaking is more time consuming.

Disciplined egress and crowd movement. Behavioral assumptions regarding leadership and direction-taking behavior, two important aspects of disciplined egress and crowd movement during emergencies, appear to be at least partially supported by available technical literature. In particular, most researchers concur in the belief that under many circumstances, individuals and groups tend to follow directions from strong and clearly perceived leaders or authority figures. However, some criticism of the preparedness of assigned leaders, or "fire wardens," has appeared in the fire literature. Moreover, there exist virtually no data either supporting or refuting the assumption that the presence and actions of specially trained emergency managers facilitates orderly building evacuation and shortens overall egress time. What little is currently known about the use of such personnel stems from aviation research on the evacuation of commercial aircraft cabins. Grounds for generalizing from such experiments to much larger scale building evacuations have not been established.

The literatures of social and environmental psychology provide important sources of data for evaluating assumptions about pedestrian movement under high density occupancy conditions. Investigators from these disciplines have suggested that cognitive overload, frustration, and increased arousal tend to characterize the high density occupancy experience for many individuals. However, it is not now known how these factors influence emergency egress behavior patterns. Some investigators have suggested that increased psychological arousal, and related maladaptive behavior, may result from encroachments upon an individual's personal space envelope. Yet, at least one researcher notes that during life threating emergencies, people may be quite willing to forego all but the most essential personal space.

The orderly evacuation of large numbers of occupants from public buildings implies that once individuals have actually exited to the outdoors, they will remove themselves a sufficient distance from the structure to permit persons behind them to exit as well. Indeed, the Code provides that public occupancy buildings be designed so that exits discharge either to a street or to an area with sufficient holding capacity. In conforming to such provisions, building designers may have to assume that once occupants exit a structure, they will in fact remove themselves from the immediate vicinity of the point of discharge. Specific investigations of exit discharge under naturalistic conditions do not appear in the literature. However, a number of post-incident fire investigations (very few of which dealt with public occupancy buildings) had indicated that re-entry by some evacuees is not uncommon. No research has been conducted to assess the influence of re-entrants upon the egress performance of other occupants. Re-entry is a key issue because it introduces the potential problem of two-way traffic in egress ways, a subject largely ignored by the Code.

Behavioral assumptions concerning potential effects of architectural barriers on crowd movement were evaluated with reference to findings from studies of pedestrian movement and crowd flow phenomena. In general, available data indicate that such minor egress way constrictions as might result from stair railings, door hardware, etc., do not measurably impair the performance of occupants using means of egress. The perceived complexity of a building's floor plan may, however, influence escape time. This conclusion is evidenced, in part, by research suggesting that paths which contain bends and turns are frequently perceived by experimental subjects to be longer than linear paths of equal length. On the other hand, available data do appear to support behavioral assumptions underlying Code provisions specifying maximum forces required to open doors and to manipulate panic hardware. To date, however, researchers conducting post-incident investigations of fire events have not addressed the question of whether either escape route complexity or architectural obstructions influence actual emergency egress performance.

The assumption that means of egress will in fact be maintained clear and fully available for immediate emergency use cannot now be evaluated by reference to technical data. Similarly, while anecdotal accounts have occasionally cited potential conflicts between building security and emergency egress objectives (e.g. journalistic reports of escaping occupants who have encountered locked exit doors), such conflicts have not as yet been systematically investigated by researchers.

Occupants' capabilities to safely and rapidly negotiate egress ways. The current investigators found considerable contradiction in available data describing occupants' capabilities to negotiate egress ways. Consequently, specific conclusions about either the validity of behavioral assumptions or the efficacy of Code provisions which affect such capabilities cannot be drawn. For example, a number of behavioral assumptions concern the notion that accidents (e.g. slips, falls) along means of egress may impede flow along such elements as corridors, stairs, ramps, and through door ways. Investigators have studied stair riser-to-tread ratios, surface friction, and other physical characteristics of egress ways to determine potential causes of accidents. However, the accident literature has failed to reach consensus on the causes of slips, missteps, and falls, has presented no statistically significant correlation between accident rates and surface friction, and presents contractory conclusions regarding the role of stair riser-to-tread ratios in stair accidents. Moreover, specific effects of occupant accidents during emergency evacuations has never been systematically investigated. As a result, it is not possible to determine whether mishaps--which may impede overall egress flow in means of egress--occur with greater frequency during stressful emergency situations, or to what degree they adversely affect overall escape time.

The Code requires that handrails be provided on stairs under the assumption that handrails will facilitate the safe and rapid negotiation of egress ways by, at least in part, reducing the likelihood of missteps, slips, and falls. However, the available literature does not permit specific conclusions concerning the provision of handrails, particularly intermediate handrails which may be required for stairs wider than 88 inches (2.24 m).

Research on ramp negotiation indicates that ramp slope may affect the ease, speed, and safety with which pedestrians use such facilities. The literature on ramp use has not, however, specifically considered surface friction in sufficient technical detail to permit useful conclusions to be drawn at this time.

Physiological stress and fatigue may also affect occupants' capabilities to safely and rapidly negotiate egress ways, and assumptions concerning these phenomena often underlie design provisions of the Code. Technical data relevant to fire egress situations stem primarily from animal and human toxicological research, and from laboratory experiments in human perception. Anecdotal accounts reported by fire victims provide additional insight. Several well-controlled studies have demonstrated the deleterious effects of prolonged CO exposure on both visual and psychomotor performance. However, the low level dosages required in the conduct of experiments using human subjects, and the unrealistic design of many toxicological experiments, has led to findings which are often contradicted by the reported experiences of fire victims. Moreover, limited data from laboratory experiments and field studies on human behavior in smoke-filled environments are contradicted by a number of journalistic accounts of fire victims' experiences.

Potential effects of multiple toxicants (which may combine chemically to produce additional physiological stressors) on emergency egress performance have not been systematically studied by researchers. Heat stress, another important consideration, also has been the subject of physiological investigation. However, the focus of this work has been on long-term endurance under nonemergency conditions, and hence it is difficult to draw specific conclusions from these studies which would be pertinent to the problems of building fires.

Smoke conditions potentially influence visibility. While a number of studies have described the effect of variation in smoke density upon visibility distance, no data are available establishing a direct relationship between smoke density and various factors contributing to escape performance. Several researchers have suggested, however, that impaired visibility can trigger other forms of physiological and psychological stress, which may in turn adversely affect egress performance.

The present review of the technical literature yielded limited useful information concerning potential effects of dead-end corridors on egress time. The assumptions that acrophobics may impede flow on outside egress stairs is based on current clinical judgment, although the effects of acrophobia under life threatening conditions remain little understood and are presently the subject of controversy among clinicians.

In conclusion, the literature on respiratory, visual, and thermal stress and fatigue report data which are often only indirectly relevant to analyses of emergency egress performance. In virtually no cases do research findings point unequivocally to any single explanation or solution. However, findings reported in the literature appear to contradict behavioral assumptions underlying relevant Code provisions.

The capacity of means of egress. Data reported in the technical literature permit few clear conclusions regarding the effects of architectural impediments and other obstructions on egress flow. For example, doors are potential impediments to pedestrian movement along corridors and between elements of egress routes. Estimates of mean pedestrian flow through doors ranging from 30.2 pers/min/22 inch unit (0.90 pers/sec/m) to 58.8 pers/min/unit (1.75 pers/sec/m) have appeared in the literature, (the Code suggests that 60 pers/min/unit, or 1.78 pers/sec/m, can pass through exits along horizontal surfaces). Similarly wide variations in estimates of the effects of egress way width reduction (which often occurs at door installations) upon flow efficiency have also been reported. The question of whether, and how, door swing direction influences flow through door ways, perhaps one of the most critical issues in the provision of doors, has received only minimal attention. Japanese research has shown that egress time may decrease by as much as 12 percent when exit doors swing against traffic flow, provided that pedestrian densities are not so high as to prevent the doors from being opened.

In addition to flow reductions which may accrue from door design and installation, various investigations have indicated that such other architectural obstructions as railings may also impede pedestrian movement. For example, the addition of center handrails on wide stairs has been shown to reduce downward flow by as much as 20 percent. Insofar as other forms of obstructions are concerned, available data suggest that obstructions up to one foot (0.31 m) in width tend to have little or no impact on pedestrian flow, even in relatively high density situations.

Other potential sources of reduced pedestrian flow implied by Code provisions include bends and corners, often found along corridors and stair ways. Data reported in the literature generally indicate that flow rates are maintained at bends on stairs, and that queue formation at corners in corridors are atypical. One experimental investigation of corridor use, in which corridor layouts were artificially configured in a laboratory, reported reductions in walking speed at corners.

In actual buildings, it is not uncommon to find width reductions over the length of a linear corridor segment. Available research suggests that relatively small width reductions have no measureble effect on pedestrian flow. In fact, corridor width reductions of 33 percent have been shown to produce flow reductions of 10 percent.

The Code severely restricts the use of revolving doors as means of egress, as well as the placement of turnstiles in pedestrian ways expected to be used as means of egress. In those cases where such devices are permitted, the exits may not account for more than 50 percent of required exit units. These restrictions are predicated on the notion that revolving doors and turnstiles substantially reduce pedestrian flow, thereby increasing required egress time. Available data on revolving door performance indicates flow through these devices to be between one third and one half that of ordinary doors. Other research has examined pedestrian flow through turnstiles under a variety of conditions (e.g. involving the depositing of coins or taking of tickets). Depending on the specific circumstances, flow through these devices appears to vary from 8.4 to 33.6 pers/min/unit (0.25 to 1.00 pers/sec/m), substantially below the average flow rate of 50.4 pers/min/unit (1.50 pers/sec/m) reported for ordinary doors. Thus, although available data do not permit an evaluation of the degree of restriction in the use of revolving doors and turnstiles permitted by the Code, they do support the need for such restrictions.

As with analyses of egress way obstructions, available data point to relatively few specific conclusions regarding the capacities of individual means of egress. For example, researchers have generally found pedestrian flow in level corridors to vary from 43.7 to 53.8 pers/min/unit (1.30 to 1.60 pers/sec/m), substantially lower than the flow rate of 100 pers/min/unit (2.98 pers/sec/m) recommended by the Code. Thus, flows assumed by the Code appear, in comparison with empirical findings, unrealistically high. The literature has also suggested that the variance in reported flow rates may be attributed to peculiarities associated with various occupancies, and to variation in the widths and lengths of corridors studied (the Code reflects virtually none of these occupancy-related differences in corridor performance). Thus, the age, sex, and other physical characteristics of occupants, architectural and organizational features of buildings, and the physical characteristics of corridors, appear to influence pedestrian performance in corridors in some way. Unfortunately, however, neither specific contributions of each factor nor interactions among factors have been empirically investigated.

It is even more difficult to draw specific conclusions about the capacity of stairs. Although the Code recommends a design rate of 45 pers/min/unit (1.34 pers/sec/m) in descent, empirical studies have shown that measured flow rates may vary between 30.2 and 57.1 pers/min/unit (0.90 and 1.70 pers/sec/m) in descent. The National Bureau of Standards (NBS, 1935) reports the highest rate shown above, indicating that this was measured under somewhat ideal conditions. NBS (1935) recommends that a design rate of 45 pers/min/unit (1.34 pers/sec/m) would more adequately accommodate normal variations in density. Code recommendations concerning the capacity of stairs are based on this recommendation. However, Pauls, who has conducted the most extensive investigations of crowd movement and building evacuation, has pointed to both his own data and those of other researchers, which consistently indicate that design rates recommended by the Code are too high. Pauls recommends that flow down stairs is ordinarily on the order of 30 pers/min/unit (0.90 pers/sec/m) under conditions of normal building occupancy. Pauls has also found that, irrespective of stair design, overall evacuation time for high-rise buildings may vary quite widely depending on the method of evacuation employed (i.e. total versus staged), as well as building height.

Walking speed on stairs also has been investigated in relation to stair slope and direction of travel. Here too, it is difficult to draw specific conclusions on the basis of data reported in the technical literature. For example, stair slope has been found to be both positively and negatively correlated with walking speed. Moreover, while two investigators found that pedestrians move faster down than up stairs, another researcher reported the opposite finding.

The Code treats all ramps[14] as substantially equivalent to level corridors for purposes of computing downward capacity. That is, ramps are expected to carry 100 pers/min/unit (2.98 pers/sec/m). In the upward direction, the Code suggests that while Class A ramps will carry pedestrians at the downward flow rate, Class B ramps will only carry 60 pers/min/unit (1.78 pers/sec/m). In general, data reported in the technical literature indicate that for most ramps with slopes between 1 in 50 and 1 in 8 (i.e. 2 and 12 percent), flow characteristics are substantially similar to those associated with level corridors. However, some investigators have noted lower flows on ramps with slopes greater than 5 to 7 percent, for both upward and downward travel. Hence, available data appear to support some of the assumptions underlying Code provisons concerning the capacity of ramps. In particular, flow on most ramps is similar to that in level corridors, and pedestrian movement speed is higher on ramps than on stairs. Available data do not permit the general conclusion that downward travel on ramps is typically equal to, or greater than, upward travel.

Code provisions governing the capacity of means of egress are partially based on certain expectations about the linearity of pedestrian movement. Data on the capacity of egress ways reported by NBS (1935) led investigators at this organization to recommend that people may safely be assumed to travel in linear files 22 inches (0.56 m) wide. This assumption (which serves as the basis for present Code recommendations) has more recently been supported by Soviet data on occupant circulation within buildings, and to a lesser extent has also been supported by data collected by Fruin in the United States. Other investigators have shown, however, that although such linear movement might occur within particularly narrow egress channels, the "lane" effect is generally not apparent when channels surpass approximately 4.0 feet (1.22 m) in width. For such wide channels, a number of researchers noted "staggered" files to be most common.

Pauls, however, found even staggered files to be atypical, since occupants (particularly stair users) seek to maintain body buffer zones, and since there may be some variation in the size of buffers required by each individual in an egress way. Pauls also reported wide variations in side-to-side body sway and need for handrail support during stair use to be quite common. On the basis of these findings, Pauls recommends that the minimum width for heavily used stairs in public occupancies be 55 inches (1.40 m). According to Pauls, this design value would permit shoulder-to-shoulder walking, as well as easy passing on stairs, in view of the relatively nonlinear movement paths typically found on these elements. This recommendation contrasts sharply with design values provided by the Code: (1) minimum width of 44 inches (1.12 m) for Class A stairs; (2) minimum width of 36 inches (0.92 m) for Class B stairs[15]; (3) absolute minimum of 28 inches (0.71 m).

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[14] Class A ramps are defined to have a minimum width of 44 inches (1.12 m), a maximum slope of 1 in 10, and no limit to the maximum height between landings. Class B ramps are defined to have a minimum width of 30 inches (0.76 m), a maximum slope of 1 in 8, and a maximum height of 12 feet (3.66 m) between landings.

[15] Class B stairs are usually the minimum required by the Code for public occupancies.

Pauls has further argued that the relationship between stair width and downward flow is both linear and continuous, and that each extra inch of stair width can potentially increase flow rate. The Code permits half credit for all extra inches between 12 and 21 (0.31 and 0.53 m), and gives no credit whatever for extra width between 1 and 11 inches (0.03 and 0.28 m). This recommendation conforms to a step-like relationship between stair width and downward flow. Referring to both his own data and those of other researchers, Pauls argues that there is no empirical basis for Code's step-like approach to allowing credit for extra stair width, and that available evidence suggests instead the efficacy of his continuous "effective width" concept.

The reader should note that although numerous studies of egress way capacities have been conducted since the first comprehensive report on this topic was published by NBS in 1935, the majority of this research has been neither cumulative nor replicative. That is, there is no evidence that investigators specifically sought to build upon earlier findings or test hypotheses advanced by other investigators, or that they repeated studies to assess the consistency and validity of previously measured behavior. Moreover, while it is tempting to compare findings reported by various investigators (as was indeed done above), the reader should bear in mind that researchers have tended to work on the basis of widely varying research questions, study designs, operational definitions, and behavioral measurement methods. Finally, it is important to remember that all empirical investigations of egress carrying capacities reported in the literature were conducted either under contrived laboratory conditions, or under nonemergency conditions associated with every-day use of pedestrian ways in buildings. The only exception is, of course, Pauls' investigation of building evaluation during fire exit drills.

8.4 SUMMARY OF GAPS IN THE TECHNICAL LITERATURE

8.4.1 Overview

Clearly, provisions regarding crowd movement and the capacities of means of egress are, at present, the most easily discussed topics with reference available to empirical research. Yet even here current knowledge in these areas remains equivocal on numerous critical issues. Analyses of other attributes of safe and rapid building evacuation require considerable reliance on technical literature outside the field of fire research. On the basis of such literature, it has been possible only to suggest hitherto untested relationships between human behavior in psychological laboratories, large-scale natural disasters, or nonemergency socio-environmental settings, and that believed to occur during building fires. In response to these realities, an important objective of the current report is to identify specific gaps in the technical literature, pointing to areas for future study.

8.4.2 Pre-emergency Training and Preparation

The questions of whether panic is a clear and constant threat and whether potential dangers inherent in panic are reduced through pre-emergency preparation and training, and implied by provisions of the Code which are covered in Chapter 2 of this report, are not now answerable on the basis of current knowledge. This is true, at least in part, because researchers have yet to: (1) adopt a standard operational definition of panic and a standard method for measuring panic behavior, (2) identify and measure environmental and situational stimuli which trigger panic or increase its likelihood, (3) describe perceptual and cognitive processes which lead to panic, (4) understand the processes by which leadership and the subsequent division of tasks and responsibilities reduce the likelihood of panic, (5) specify the relationship between preemergency training and the occurrence of panic, and (6) specify the relationship between occupancy characteristics and the likelihood of panic.

The general assumption that behavior learned during fire exit drills transfers to actual fire situations remains to be empirically demonstrated. In the future, such demonstrations will require researchers to design and conduct longitudinal field experiments which permit assessments of various training protocols in a number of occupancies, and which would allow investigators to evaluate the effects of time on learning. Stahl (1978b) provides a basis for such research designs. Where future research in this area attempts to introduce simulated life threats as independent variables, safeguarding human participants will be of paramount importance.

Additional research should address the role of occupants' attitudes toward drills and drill participation. Required data include: (1) correlations between occupants' attitudes toward drill participation, their performance during drills, and where possible, individuals' performance during actual (or perceived) emergencies, and (2) correlations between attitude change and behavior change.

8.4.3 Perception of the Emergency Environment, and Recognition of Egress Facilities

Few data presently exist to permit an evaluation of assumptions about potential effects of door and window design on egress route perception. However, anecdotal accounts of fire victims' experiences indicate the importance of interior design to evacuation, particular for transient occupants of public buildings. The degree to which various door and window placements can be discerned from surrounding decor can be studied using laboratory experimental designs.

Similarly, the influence of interior design on exiting time can be evaluated by means of field experiments conducted in real buildings. This research can become considerably more complicated, however, if it is desired that life-threatening stimuli be introduced or at least simulated. Here, the safety and well-being of human subjects must be of primary concern.

Available data describing the adequacy of illumination for egress are ambiguous and difficult to apply to evaluations of Code provisions and their underlying behavioral assumptions, especially where conclusions about illumination and visibility in smoke are sought. Here, it will be necessary to study the effects of smoke on visibility under various lighting and environmental conditions within the safe confines of the laboratory. Experimental data may later be evaluated in relation to victims' reports documented during post-incident analyses of actual fires.

Previous research on directional signage has emphasized the visibility of signs under varying conditions of illumination, by individuals varying in their familiarity with a building's circulation system. The questions of whether, and how, directional signs are used during emergency situations have not as yet been addressed. Factors which should be considered in future investigations of directional signage should include sign location, mode of display, lettering and/or graphic design, as well as variations in occupants' visual acuity and familiarity with the research setting (where this is an actual building), smoke density (where feasible), and illumination.

Assumptions about the ability of alarm devices to alert building occupants to take effective action during fire emergencies require further verification. Among the factors which have not been adequately investigated to date include (1) mode of signal delivery, (2) clarity of alert messages and their consistency with occupants' perceptions, (3) relationship between alarm signals and pre-emergency training, (4) occupants' familiarity with available egress routes, and (5) physiological and psychological impediments to effective alarm signals perception.

8.4.4 Egress Strategy Formation

Although a considerable knowledge base now exists describing human information processing and decisionmaking behavior, relatively little is known about the ways building occupants select information from emergency environments, plan escape strategies, modify or switch strategies to accomodate sudden environmental changes, and make decisions which lead to safe escape or failure during building fires.

To expand knowledge about these facets of effective emergency escape, it is necessary to more rigorously debrief victims after fire events, using rather sophisticated clinical techniques for externalizing individuals' behavior. In conjuction with such debriefing, it will also be necessary to more thoroughly cross-validate individuals' self-reports against those contributed by other victims. In this way, it may not only be possible to obtain a clearer understanding of an occupants' decisionsmaking behavior and of the specific environmental factors leading to decisions, but to determine the confidence with which inferences may be drawn from individuals' reports, as well. Future debriefing protocals should be designed to permit the analyst to determine how interior design, building configuration and layout, and physiological and emotional stress influence egress strategy formation and route choice.

8.4.5 Disciplined Egress Behavior and Crowd Movement

The technical literature on group psychology and crowd behavior appear to support behavioral assumptions about leadership and direction taking only indirectly. Laboratory experiments and post-incident studies of large-scale natural disasters illustrate the tendency of many individuals and groups to take directions from perceived leaders or authority figures. Unfortunately, however, too few data describing direction taking during building fires are presently available to permit definitive conclusions. Similarly, the effectiveness of trained leaders (e.g. "fire wardens") during real fire emergencies has not been examined empirically. These gaps in the literature exist primarily because to date, post-incident data collection protocols have not been designed to specifically assess the leadership function. In the future, specially designed debriefing protocols, of the type described above, should assist analysts to evaluate the effectiveness of various leadership scenarios.

Presently available data are not sufficient to either support or refute behavioral assumptions which underlie Code provisions affecting building occupant loading and exit discharge facility design. In addition, extremely little material applicable to evaluating Code provisions intended to minimize physical impediments and obstacles to rapid escape was found in the literature. In the future, knowledge of crowd movement may be advanced through the conduct of time-motion studies under a variety of simulated emergency and exit configuration conditions.

8.4.6 Occupants' Capabilities to Safely and Rapidly Negotiate Egress Ways

In large part, assumptions underlying Code provisions accommodating occupants' capabilities to safely and rapidly negotiate egress ways concern the need to prevent slips and falls along elements of egress ways, and to accommodate occupants' varying physiological abilities. The literature on walking accidents, particularly with respect to stairs, offers tentative support for the assumptions that under certain conditions slips and falls are more likely, and that falls on stairs can impede pedestrian flow and thereby reduce the efficiency of egress ways. However, the literature is rather equivocal on the subject of stair accident causation. Consequently, it is not now possible to offer specific design recommendations for reducing the likelihood of these potential impediments to flow. Clearly, future research should focus on this gap.

The assumption that fire products which have infiltrated means of egress will adversely affect egress flow also requires additional empirical verification. Available experimental evidence does not point to any one conclusion regarding potential effects of CO exposure, and such evidence has been contradicted by anecdotal and journalistic accounts of experiences reported by fire victims. Additional data describing human respiratory, visual and thermal adaptability under a wide range of fire scenarios are required before the effects of fire product infitration on the efficient use of egress ways are fully understood. Other areas requiring further investigation include the role of smoke-induced visibility decrement in egress way negotiatation, the ability of handicapped and other public building occupants to manipulate doors and door hardware, and the role of stress and fatigue in emergency escape.

8.4.7 The Capacity of Means of Egress

Provisions of the Code specify the design of door ways on the basis of occupant loading criteria and available door width. One point on which there is little equivocation in the literature is the finding that, under conditions of relatively high occupant density, queues form as individuals wait to pass through door ways. However, researchers have yet to study the questions of how queue formation and processing influence egress time, and how door width specifications may be adjusted to compensate for time potentially lost in queues.

A closely related gap in the technical literature concerns the predilection of most researchers to study pedestrian behavior in relation to some one isolated egress route element (e.g. doors). Indeed, the task of exiting a building may involve passing through numerous door ways, as well as corridors, stairs, and lobbies, all of which are interrelated. When a queue forms at a door way, for example, it is not merely flow through this door that is affected: capacity of the preceding stair or corridor is being taxed as well. Future research must address the interdependencies between adjacent egress way elements, and provide guidelines for the design of effective transitions between elements.

Flow rate has been the most universally accepted measure of the performance of means of egress. Considerable work remains, however, to develop a standard measurement method. In the absence of such a standard, it will continue to be difficult to determine precisely why data from seemingly similar investigations often disagree. For example, Pauls and Fruin each found different variables to interact with flow rate and walking speed; Togawa found no such interaction effects. Similarly, although Pauls and Fruin have both advocated an incorporation of body sway and personal space maintenance behavior into computations of flow capacity, there remain neither standard measures nor replicable models of these phenomena.

8.5 CONCLUSIONS

8.5.1 Overview

The primary objective of the investigation has been to assess available research pertaining to exit facility design and emergency escape provisions of the NFPA Life Safety Code (1976 Edition), in order to determine the technical support for such provisions. The intention of the authors is not to pass judgment on the validity or usefulness of Code provisions. Indeed, where technical support for individual provisions is either weak or unavailable, the authors do not recommend eliminating or otherwise modifying these provisions. In such instances, rather the authors suggest that code-writers approach their task with caution, and that further technical investigations be conducted. Substantive conclusions about available technical support for Code provisions, as drawn by the current investigators, are summarized below.

8.5.2 Provisions Affecting Pre-emergency Training and Preparation

Behavioral assumptions underlying code provisions affecting pre-emergency training and preparation may be evaluated by reference to psychological models of learning, experimental data reported in the psychological literature, and the growing body of evidence from post-incident fire investigations. To date, experimental and post-incident investigations provide mixed conclusions concerning the supportability of these assumptions. Moreover, available evidence does not often permit direct inferences to be drawn between research findings and the specific questions raised by code provisions. Future modifications to provisions affecting pre-emergency training appear to require additional research on the role of training and its relation to emergency behavior.

8.5.3 Provisions Affecting Perception of the Emergency Environment, and Recognition of Egress Facilities

A number of human behavioral assumptions about the perception of emergency environments and recognition of egress facilities underlie various provisions of the Code. These assumptions were evaluated by reference to several models of perception, to limited data from experiments on visibility, and to a small body of evidence from post-incident fire investigations. Taken as a whole, available data neither support nor refute behavioral assumptions about occupants' emergency perceptions at a level technically sufficient to permit a thorough evaluation of pertinent Code provisions. Where data are available in sufficient quantity, however, it has been suggested that behavioral assumptions underlying alarm provisions of the Code tend not to be supported. The Code provision specifying a maximum (10 second) switchover delay between standard and emergency lighting, on the other hand, tends to be supported by available technical data. Initial emergency perceptions are important, and their relationship to rapid escape has been shown. Consequently, future research which leads to more effective perceptions of the fire environment by victims is recommended.

8.5.4 Provisions Affecting Egress Strategy Formation

A number of assumptions about human information processing and decisionmaking behavior during fire emergencies underlie several provisions of the Life Safety Code. Such assumptions were evaluated by reference to models of cognitive behavior, as well as to data from recent psychological research on wayfinding behavior, environmental cue processing, disaster response, and stress. Few directly relevant technical data were found within the field of fire research itself. Taken as a whole, available technical knowledge is not sufficient to warrant statements specifically supporting or refuting Code provisions which may influence egress strategy formation. However, the literature generally supports the notion that the demands of occupying a burning building require individuals to efficiently sample information from fire environment, and to formulate effective and timely decisions about what to do. Depending upon the design and layout of a building, and upon the nature of given fire conditions, these processes will consume some sizable proportion of the time within which occupants must escape. Errors in judgment and decisionmaking will frequently consume even more time. A crucial gap in current knowledge about the time-based capabilities of building occupants to effect rapid emergency centers on questions of emergency information processing and strategy formation.

8.5.5 Provisons Affecting Disciplined Egress Behavior and Crowd Movement

A number of human behavioral assumptions about crowd movement and disciplined group behavior are believed to underlie selected provisions of the Code. These assumptions were evaluated by reference to several models of human collective behavior, data from research in experimental social psychology, field research on natural disasters, and post-incident fire investigations. In general, the technical literature suggest support for only those assumptions pertaining to leadership and direction-taking behavior. Behavioral assumptions pertaining to the effects of occupant loading and physical obstacles upon orderly and rapid crowd movement appear to be neither supported nor refuted by available technical literature. To the extent that impediments to crowd movement result in maladaptive collective behavior and panic, future research on the role of building design in facilitating crowd movement seems an essential precursor to Code development.

8.5.6 Provisions Accommodating Occupants' Capabilities to Safely and Rapidly Negotiate Egress Ways

Human behavioral assumptions believed to underlie Code provisions relating to occupant's capabilities to safely and rapidly negotiate means of egress may be evaluated by reference to biomechanical models of human movement, toxicological research, stair and ramp use field studies, physiological measurements and anecdotal evidence from actual fire incidents. At present, much of the evidence reported in the experimental and nonexperimental literature on occupants' capabilities presents contradictions and mixed opinions, and does not permit specific conclusions or inferences to be drawn. As a result, there appears to be no analytical basis upon which to unequivocally support or refute applicable Code provisions. It is left for future research to determine the specific domains (i.e. occupancies of fire senarios) under which particular data are valid and useful in this context.

8.5.7 Provisions Governing the Capacity of Means of Egress

Finally, a number of human behavioral assumptions underlying Code provisions which govern the capacity of means of egress were presented. These assumptions were evaluated by reference to several models of pedestrian movement, data from laboratory and field studies of walking behavior during normal occupancy conditions, and observations of stair use during fire exit drills in high-rise office buildings. With regard to Code provisions affecting the design of doors, available technical literature support only those assumptions concerning the deleterious effects of particularly severe constrictions or obstructions. However, behavioral assumptions underlying provisions governing the design of corridors and stairs are challenged by the technical literature. This is especially true of provisions depending on the validity of assumptions and the linearity of pedestrian movement and the 22 inch (0.56 m) unit width standard. Because there remain differences in reported data describing pedestrian behavior on stairs and level surfaces, inconsistent definitions of important variables, and nonstandardized techniques for measuring the performance of means of egress, it is not now possible to either support or refute existing provisions and their underlying behavioral assumptions on the basis of the available technical literature. The most important objectives for future research on the subject of means of egress capacity are: (1) the development and validation of standardized measures and measurement methods, and (2) the systematic analysis of complete egress systems emphasizing transitions between means of egress elements.

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APPENDIX B: INSTRUCTIONS TO REVIEWERS

MEANS OF EGRESS BEHAVIORAL ASSUMPTIONS REVIEW PACKAGE:

INTRODUCTION

Aim of the Study

To assess means of egress provisions of the LIFE SAFETY CODE (1976 edition), by evaluating the validity and plausibility of human behavioral assumptions believed to underlie these provisions.

Scope

The study addresses primarily means of egress provisions of the CODE, as well as related provisions concerning fire exit drills, lighting and signage, and emergency alarm. Under examination are provisions from: Chapter 5 of the CODE (Means of Egress), Chapter 8 (Places of Assembly), Chapter 11 (Residential Occupancies), Chapter 12 (Mercantile Occupancies), Chapter 15 (Business Occupancies), and Chapter 17 (Operating Features).

Approach

Current means of egress provisions are intended to achieve certain minimum levels of building and human performance during fire emergencies. Accordingly, many of these design provisions rest upon a series of expectations, or assumptions, about the emergency egress behavior of building occupants. In numerous cases, these assumptions are based on professional experience, analyses of egress problems, and research data. In many other instances, however, assumptions about human capabilities and performance are not always obvious, and may not be consciously considered by code writers and building designers. As a result, the application of some provisions may have the effect of achieving one level of performance in reality, while eroneously intending to achieve another level.

This study seeks to evaluate human behavioral assumptions believed to underlie particular provisions of the LIFE SAFETY CODE. To accomplish this goal:

(1) behavioral assumptions must be identified and stated, and

(2) these assumptions must be evaluated against state-of-the-art knowledge from a variety of technical fields.

This "review package" is intended to assist the project staff in completing step (1): the identification and statement of assumptions about emergency egress behavior.

Built-in Biases

The author's* several years experience in the study of human behavior during fires may have resulted in biases which are unavoidably reflected in behavioral assumptions listed in this package.

HOW TO USE THIS PACKAGE

Purpose

The purpose of the review package is to elicit your opinions about the correctness and completeness of a set of behavioral assumptions prepared by the author. These assumptions necessarily reflect only one interpretation of CODE provisons. Hence, the value of this exercise depends a great deal upon the quality of feedback it evokes from life safety professionals like yourself.

Therefore, we invite and encccourage you to comment on human behavioral assumptions WE believe underlie provisions of the LIFE SAFETY CODE, and to comment on our interpretation of that document. Moreover, any additional ideas and insights which you contribute regarding expectations about human behavior during fires would be highly useful and most welcome.

Please bear in mind that the function of this exercise is NOT to pass judgment upon the LIFE SAFETY CODE itself.

Organization and Format

The set of assumptions listed on the following pages is subdivided into 5 general categories. These were chosen to represent principal areas of human behavior believed to be relevant to emergency egress performance. The categories are:

(1) Pre-emergency preparation and/or training.
(2) Perception of the emergency environment, and recognition of egress facilities.
(3) Egress strategy formation.
(4) Initiation of egress behavior.
(5) Follow-through and completion of egress behavior.

Within each category, means of egress provisions and their related behavioral assumptions (as developed by the author) are listed as shown in the examples on the following page.

---

* F. I. Stahl, project principal investigator.

Instructions

Consider the examples on the following page. Then, please comment upon assumptions shown next to each of the CODE provisions listed on the remaining pages. Show any changes in word usage, structure or grammar you feel would make particular assumptions more complete or correct. Where you feel necessary, don't hesitate to change entire assumptions or to add new ones. Please use the backs of pages for any additional comments.

A SAMPLE SET OF CODE PROVISIONS, BEHAVIORAL ASSUMPTIONS, AND COMMENTS...

Provisions from NFPA 101 (1976)	Our assumptions, with your comments and suggestions	
5-10.1.2 Access to exits shall be marked by readily visible signs in all cases where the exit or way to reach it is not immediately visible to the occupants, and in any case where required by the applicable provisions of Chapters 8 through 16 for individual occupancies.	Direction signs are utilized by occupants ~~during stressful emergency situations.~~ when needed.	Rather: occupants move not knowing where exits are located; egress signs may be needed to promptly find exits.
5-10.1.3* Every required sign designating an exit or way of exit access shall be so located and of such size, distinctive color, and design as to be readily visible and shall provide contrast with decorations, interior finish, or other signs. No decorations, furnishings, or equipment which impair visibility of an exit sign shall be permitted, nor shall there be any brightly illuminated sign (for other than exit purposes), display, or object in or near the line of vision to the required exit sign of such a character as to so detract attention from the exit sign.	Occupants will see Overhead directional signs ~~will be readily visible~~ through smoke. The presence of clearly visible directional and exit marking signs reduces overall egress time.	Question: once smoke becomes so dense that exit signs no longer are visible, will people still be in any condition to find and use the exits?
5-10.3* **Illumination of Signs.** Every sign shall be suitably illuminated by a reliable light source giving a value of not less than 5 foot-candles on the illuminated surface. Such illumination shall be continuous as required under the provisions of Section 5-8, Illumination of Means of Egress, and where emergency lighting facilities are required, exit signs shall be illuminated from the same source.	The illumination of directional and exit marking signs improves their visibility and use, ~~even in a smoke-filled environment.~~	

Please comment on assumptions shown next to CODE provisions listed on the following pages...

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5. AUTHOR(S) Fred I. Stahl, James J. Crosson, Stephen T. Margulis

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10. SUPPLEMENTARY NOTES

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

11. 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 document reviews available technical literature pertaining to exit facility design and emergency escape provisions of the National Fire Protection Assocation's Life Safety Code (1976 Edition) in order to determine the technical support for such provisions. The report focuses on the time-based capabilities of building occupants to effect rapid evacuations, in relation to evacuation time available during fires. A number of functional criteria are examined in relation to Code provisions influencing the design of means of egress and fire protection and protective signalling systems for places of assembly, residential occupancies, mercantile occupancies, and business occupancies. Provisions affecting fire exit drill and building management practices are also considered. The technical literature bearing on applicable Code provisions is reviewed, the validity and generalizeability of findings presented in the literature are discussed, and the degree of technical support currently available for egress provisions of the Code are evaluated. In addition, gaps in the technical literature are identified, and recommendations regarding future research are offered. Finally, preliminary conclusions about the supportability of Code provisions are presented.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Emergency egress; fire protection; fire safety; human behavior in fires; human factors; Life Safety Code, means of egress.

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