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Integrating Human Behavior Factors Into Design

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[CONTENTS]

FIRE PROTECTION Engineering

8 COVER STORY

Departments

Features >> Fall 2005

FIRE PROTECTION Engineering

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From the EXECUTIVE DIRECTOR

Dear Fire Protection Engineering Reader,

The Society of Fire Protection Engineers is excited to introduce to you the new and improved design of *Fire Protection Engineering* for the October 2005 issue, as well as highlight the many exciting new developments we've been working on to continue to advance the practice of fire protection engineering.

Since the first issue kicked off in 1999, we have continued to make strides to continually evaluate and improve upon the magazine. You've seen the results in increased distribution, increased partner support, high-quality editorial and now – improved graphics. We take great pride in where we are and how far we've come. Additionally, we are pleased to highlight some other new and exciting developments for *Fire Protection Engineering*.

OCTOBER 2005 – *Fire Protection Engineering* magazine will launch its new Web site, FPEmag.com. The Web site will host the new issue of FPE as well as all the archived back issues of the magazine. All articles can be searchable by keyword, making it easier than ever to find the content you want. The Web site will also host each issues'case studies, departments, news and events. Take a visit and let us know what you think.

Careers in Fire Protection Engineering launches. This new publication is an informational supplement to *Fire Protection Engineering*, highlighting the fire protection engineering profession and many career opportunities within. The guide is targeted to engineering students and will be passed out to engineering faculty and engineering departments across the country. To access a digital copy of the publication, please visit FPEmag.com/careers.

FEBRUARY 2006 – ***"FPE Emerging Trends"*** hits the streets. We are launching a monthly enewsletter, distributed on the off-months of *Fire Protection Engineering* magazine. This timely editorial piece will feature upcoming trends and topics in the industry. If you interested in receiving this free enewsletter, please visit FPEmag.com and subscribe.

As the only publication dedicated to the fire protection engineering industry, we are extremely excited to continue to provide our members, supporters and other readers with a variety of communication outlets to access information. We thank you for your readership and support and hope that you enjoy the new and improved FPE!

Sincerely,

Dave

David Evans, P.E., FSFPE
Executive Director
Society of Fire Protection Engineers

VIEWPOINT > Human Behavior IN CODES

By Edward J. Prendergast, P.E.

Several years ago, the author was involved as a witness in court in a code violation case. It was a pretty straightforward case. The primary defense used in the case was that the City's ordinance was arbitrary and, therefore, of no real merit. In response, the judge told the defense attorney: "Counselor, most laws are arbitrary."

That judge's observation contains a mountain of wisdom for those in the public safety business. The specific provisions of most ordinances are somewhat arbitrary.

Many of the specific provisions of fire codes may be described as arbitrary. The maximum travel distance to a fire extinguisher, the separation distances for hazardous materials, and maximum quantities for flammable liquid storage can all be described as somewhat arbitrary.

For example, the maximum travel distance to a fire extinguisher should ensure that an individual can get the fire extinguisher and return to the developing fire quickly enough that the fire can be controlled. But that is a function of how fast the individual can move and how fast the fire is developing. The speed with which an individual can move is a function of the physical ability of the individual, and the rate of fire growth is a function of too many variables to enumerate here. None of this is evaluated in the spacing of fire extinguishers. Extinguishers are placed within rules established in NFPA 10.

This is not to say that the specifically stated provisions of the codes are without value even if they are arbitrary. They are satisfactory in the greatest number of situations. They are readily understandable, enforceable, and code officers can apply them uniformly.

However, there are many situations where the specific provisions of a code are suspect. Exits are an example.

There is no more fundamental aspect of building fire safety than the simple ability to get people out of harm's way. If the prompt evacuation of occupants out of a threatened space could be assured in every case, the life safety aspect of fires would be solved.

As straightforward as the concept of exiting is, the actual provision of what are considered "adequate" exits becomes complicated in practice. The reason for this is twofold. First, the built environment is extremely diverse. All kinds of buildings are built to serve a myriad of functions. Second, humans are complex biological and psychological systems. It is easier to protect a warehouse full of washing machines than a room full of people. Washing machines, after all, don't breathe, and they don't try to flee.

In the field of fire protection, many researchers have contributed a tremendous amount of information on human behavior and exiting in fires. Much information has been developed on the subject of crowd movement. This research has shown that the movement of people is not a smooth, continuous process.

It has also been determined that social factors enter into the behavior of occupants in emergency situations. Codes make no provision for this. The assumption implicit in the codes is that people, like ball bearings, are all alike. Ball bearings also are not affected by a deterioration of the environment.

The challenge is to transfer the enormous amount of information that exists on the subject of evacuation into usable and administratively enforceable code provisions which can be objectively and effectively applied by code officials. An example of this is the tendency of people to exit an occupancy by the same means through which they entered. This behavior is provided for in codes by making the main entrance of an assembly occupancy accommodate a larger percentage of the occupant load than other exits. The actual percentage stipulated may be arbitrary however.

> There is no more fundamental aspect of building fire safety than the simple ability to get people out of harm's way.

In making the transition from scientific to practical, codes become largely deterministic in structure, and some provisions may be somewhat arbitrary despite the sincere efforts of the code writers. In the day-to-day work of code officials, designers ask for simple straightforward answers. Long scientific discussions don't work. A difference exists between the audience for a symphony and the audience of a rock concert, but a discussion of social differences is not what the designer wants.

The many variables which impact human behavior cannot all be accommodated in the wording of codes. For example, ceiling height in an occupancy will affect the rate at which the environment becomes untenable and, therefore, the allowable travel distance to an exit. However, ceiling height and travel distance are not interrelated in the codes. What can be done is to structure the exit provisions of codes very conservatively, based on the most challenging case with an added factor of safety. This is a sort of "Kentucky windage" approach but it facilitates code enforcement. Of course, the actual factor of safety would be determined arbitrarily.

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NFPA Key Safety Codes to Require Fire Sprinklers in Certain Buildings

The codes and standards development oversight body of the National Fire Protection Association (NFPA), known as the Standards Council, recently issued two key safety codes that will require fire sprinklers in all nursing homes, in new construction of one- and two-family dwellings, and in all new construction of nightclubs and like facilities, as well as for existing nightclubs and like facilities with capacities over 100.

The provisions apply to the 2006 editions of *NFPA 101®*, *Life Safety Code®* and *NFPA 5000®*, *Building Construction and Safety Code,®* and went into effect on August 18, 2005.

"The code provision for sprinklers in new one- and two-family dwellings is a milestone in fire protection," says James M. Shannon, NFPA president. "It is a significant step in reducing the rate of fire death and injury in the place where people are at most risk for fire – their own homes."

The nightclub provision for sprinklers was first added to *NFPA 101* and *NFPA 5000*, after a tentative interim amendment was approved by the Standards Council in 2003 following the Station Nightclub fire tragedy in Rhode Island.

Several nursing home fires in 2003 propelled the healthcare industry, along with NFPA, to respond with a push for better fire protection in these facilities as well.

For more information, go to www.nfpa.org.

UL Study to Focus on Improved Smoke Alarm Effectiveness

Underwriters Laboratories® Inc. (UL) is undertaking a new study to determine whether recent changes in household furnishings have changed the way fires behave in homes and, consequently, alter the way smoke alarms respond.

While smoke alarms continue to play an important role in reducing deaths and injuries from fires – an almost 50% drop in fire deaths have been attributed to smoke alarms since the mid-1970s – UL believes that the recent findings may offer an opportunity to make smoke alarms even more effective.

A study released last year by the National Institute of Standards and Technology (NIST) suggests that fires in homes today smolder longer before igniting and then burn hotter and faster than what was typical when smoke alarms were first introduced. The study concluded that because today's fires can be more aggressive, the time needed to escape some types of fires has been reduced from 17 minutes to just three.

"The inference is that fires behave differently now because homes now contain larger quantities and different types of materials," says Tom Chapin, general manager of UL's Fire Safety Division. "Our objective is a better understanding of how these newer materials burn in a residential setting and the types of smoke they generate. From the data, UL will develop fundamental information that could lead to new standards for smoke alarms that would help reduce the risk of injury or loss of life due to fires."

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Integrating Human Behavior Factors Into DESIGN

Daniel J. O'Connor, P.E., FSFPE

Like other engineering disciplines, fire protection engineering in building design routinely uses equations, calculations, and computer models to determine if fire protection systems or features will operate to an established set of specifications or criteria. Such engineering analysis and design efforts are typically quantitative and deterministic, and fire protection engineers avail themselves of their education and training in mathematics and physics to accomplish these objective tasks. Conversely, when it comes to human behavior, most building design engineers likely have little or limited background in social and behavioral sciences.

The common fire safety objective related to human life is simply that a building design affords sufficient time to evacuate or reach a place of safety before encountering fire conditions that would result in serious injury or death.

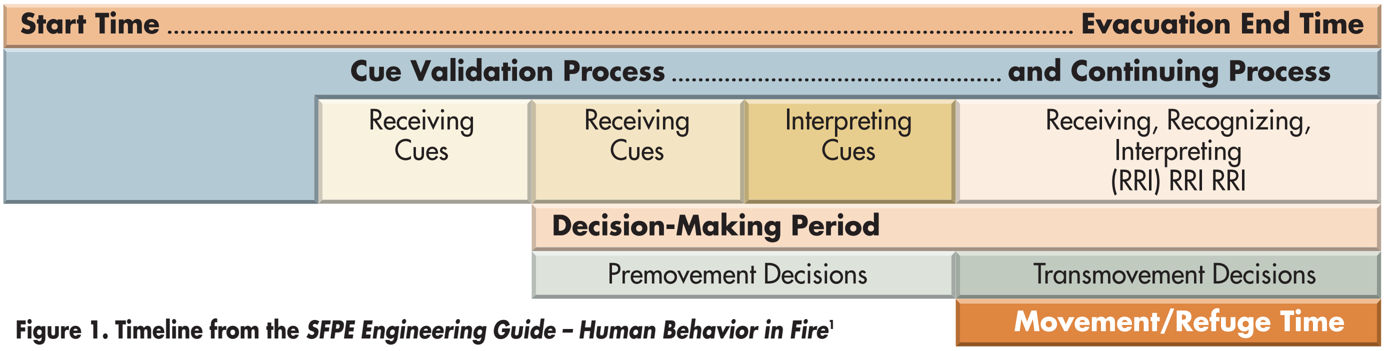

Figure 1. Timeline from the *SFPE Engineering Guide – Human Behavior in Fire*[1]

With a set of equations and objective criteria that reliably predict human behavior, the fire protection engineer could have no problem in calculating an end result. But the equations and the objective criteria can be difficult to find. In 2003, the Society of Fire Protection Engineers published the *SFPE Engineering Guide – Human Behavior in Fire.*[1] This document was developed with the significant and extensive input of individuals with backgrounds in psychology, behavioral sciences, and human factors. Significant also is that the *SFPE Handbook of Fire Protection Engineering*[2] contains five chapters related to human behavior and human responses in fire; three of these five chapters were in the first edition of the *Handbook*, which was published in 1988.

While much of this material is calculation-oriented, it is important to understand that integrating human behavior into the design process is not simply a matter of engineering calculations with demonstrable outcomes. The introduction to the *SFPE Engineering Guide – Human Behavior in Fire* acknowledges the importance of human behavior in building fire safety, but notes the limits of the current knowledge base.

> *To address the fire safety of occupants in a building, it is important to understand and consider the factors that may influence the responses and behaviors of people in threatening fires. The anticipation of human behavior and prediction of human responses is one of the most complex areas of fire protection engineering. Because the understanding of human behavior in fire is limited compared to other areas of fire protection engineering and behavioral study, it is difficult to predict accurately the responses and behaviors of people in fire situations.*

Although the current understanding of human behavior in fire may be limited and the uncertainty of human behavior is a fundamental concern, it is possible for engineers to give better treatment and consideration in design than has often been the case. Too often, engineers and architects have made basic assumptions about the population or occupant behavior that may have little or no basis in behavioral literature. An example is the often-cited assumption of occupants automatically and immediately evacuating a building upon the sounding of the fire alarm system. While the assumption may be appropriate for some occupancies having a practiced and leadership-oriented emergency plan (e.g., schools), such assumption has been shown to be erroneous for occupancies that lack such an organizational structure.[3, 4]

When considering human behavior related to fire, there are three key areas of interest as identified by Hall.[5]

1. Behaviors that cause or prevent fires;
2. Behaviors that affect fires; and
3. Behaviors that increase or reduce harm from fires.

The focus of this article is primarily behaviors related to evacuation and refuge-finding. These behaviors principally fall into the third listed category (behaviors that increase or reduce harm). However, human behaviors such as occupant firefighting and/or leaving doors open/closed that are associated with the second category can be critical to the evacuation/refuge process.

Time as Function of Behavior – The Fundamental Question

Time is the basic engineering measure of evacuation or refuge-finding, and the fire protection engineering community has focused in on time as a function of behavior as the key issue to be addressed when considering human behavior. The critical human responses or behaviors that contribute to the evacuation process are illustrated as depicted graphically by the timeline in Figure 1 from the *SFPE Engineering Guide – Human Behavior in Fire*. CIBSE *Guide E: Fire Engineering*[15] and the *Australian Fire Safety Engineering Guidelines*[6] contain similar timelines.

Although there are minor differences among the timelines, each timeline generally depicts the evacuation process wherein occupants become aware of a building fire emergency and experience a variety of mental processes/actions before and/or while they travel to reach a place of safety. Arriving at a place of safety is embodied in the concept of Available Safe Egress Time, or ASET. ASET is the

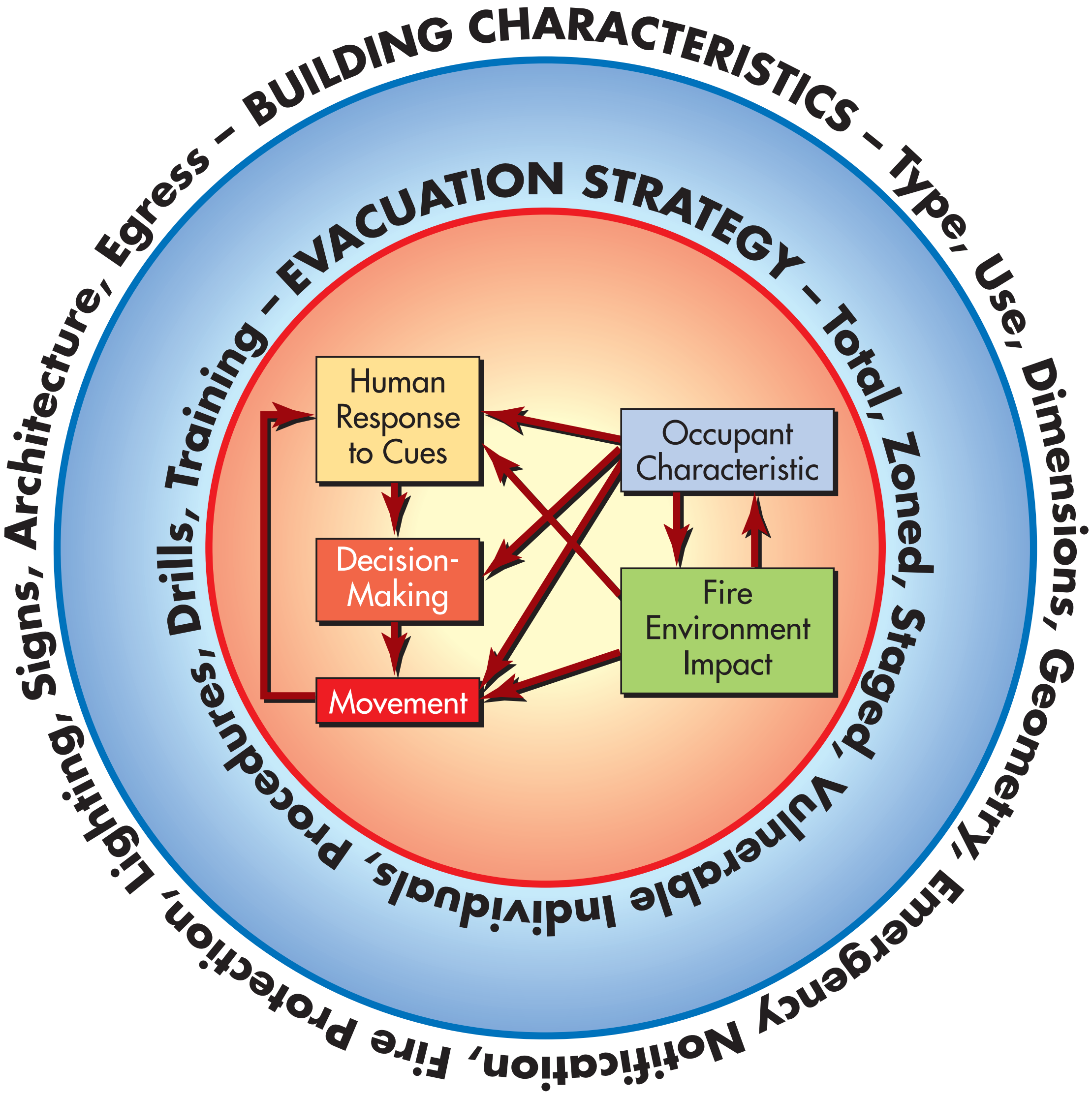

Figure 2. Context for Human Behavior

time period between the ignition of a fire and the onset of untenable conditions for one or more building areas, which is compared against RSET, or the Required Safe Evacuation Time. Prediction of RSET typically involves estimating the time that it would take for people to be notified that there might be a fire, the time that people would take for premovement activities such as alerting others, checking on family members, etc., and the time it would take for people to egress to a safe location. During the course of the evacuation, there may be other behaviors, actions, or inactions that extend the time for evacuation.

In terms of behavior, mental processes and actions are a continuum of information-processing and decision-making. This is an important distinction since, during any evacuation, occupants are subject to receiving, recognizing, and interpreting cues that may impact their decisions before and during their movement towards a safe location. Of course, during travel, many other cues (e.g., smoke, occupant communications) may be encountered that may influence the movement time and should not be discounted.

Performance-Based Design Shapes the World View on Integrating Human Behavior

With the proliferation of performance-based analysis and design methodologies and guides published during the last 15 years, there has been clear recognition of the need to address human behavior factors in fire protection engineering. From a worldwide perspective, there now exists guidance and methodologies for considering human behavior that had been lacking in the 1980s. On an international level, there are numerous code, professional, and standards organizations that have promulgated quantitative and qualitative guidance in issues related to human behavior. Organizations from Japan,[7] Australia,[6] the United Kingdom,[15] New Zealand,[8] the Nordic countries,[16] the United States,[1, 9, 10, 11] and ISO[12, 13] have contributed to this increased attention to human behavior. Some of the documents contain detailed discussion and engineering guidance.[1, 2, 6, 12, 15]

Common Themes Apparent Among Human Behavior Guide Documents

The common fire safety objective related to human life is simply that a building design affords sufficient time to evacuate or reach a place of safety before encountering fire conditions that would result in serious injury or death. Some codes[10, 11] do make the distinction that occupants intimate with the source of fire or burning materials are effectively excluded from consideration. Consequently, the scenarios of human escape addressed by various guides are those where the fire is at least detached, if not remote, from the occupants under consideration.

The guidance offered among the various performance codes and international documents addressing human behavior generally points to four topic areas that influence the analysis of human behavior.

- Building Characteristics
- Evacuation Strategies and Procedures
- Occupant Characteristics
- Fire Environment

As shown in Figure 2, the building characteristics provide the context within which the evacuation strategies and procedures are introduced. Both the building characteristics and evacuation strategies are relatively static features that should be easily identified and are ultimately key to anticipating and assessing occupant behaviors that may control evacuation time. Referring again to Figure 2, the analysis to be performed lies within the context of the building and evacuation strategy. Given a clear understanding of the building and evacuation strategy allows for occupant characteristics, cognitive (thinking) processes, occupant movement, and fire environment to be evaluated. As Figure 2 illustrates, there is a degree of complexity due to the interrelationship of the human factors that would suggest it is difficult to accurately and precisely predict behavior.

Such is the case, as analyzing human behavior requires an approach that integrates qualitative and quantitative data and engineering methods

TABLE 1
FACTORS AND CONSIDERATIONS IN HUMAN BEHAVIOR ANALYSIS

BUILDING CHARACTERISTICS	EVACUATION STRATEGY/ PROCEDURES
Building type and use Physical dimensions Geometry of enclosures Number and arrangement of Means of Egress Architectural characteristics/ complexity Lighting and signage Emergency information systems Fire protection systems	Total, zoned, or staged evacuation All or few occupants trained or drilled in procedures Provisions for those with special needs – infirm, disabled, incarcerated Frequency of training or drills Who is trained or drilled Defend-in-place Relocation
OCCUPANT CHARACTERISTICS	**FIRE ENVIRONMENT**
Population and density Individuals alone or in groups Familiarity with building Distribution and activities Alertness Physical/cognitive abilities Role/responsibilities Location Commitment to task Focal point Gender Culture Age Prior fire/evacuation experience	Smoke and toxic gases Temperature Visibility Transport, exposure, duration

to evaluate the time for evacuation or movement to a place of safety.

Five basic tasks are generally evident among the several noted human behavior guidance documents:

1. Define building characteristics and building evacuation strategy.
2. Review occupant characteristics and identify occupant groups' assumptions.
3. Develop premovement time assumptions.
4. Evaluate/calculate movement time.
5. Evaluate/calculate the fire environment impact on exposed occupants.

Implicit in this approach is an acknowledgement that no comprehensive, validated evacuation models exist to address occupant response, behavior, and movement during escape or fire evacuation. Yet, work continues in moving towards development of such models.[14] At this time, qualitative and quantitative information that can facilitate and guide the analysis and estimation of occupant evacuation or escape exists in the literature and research studies related to human behavior. Qualitative information is useful to defining the parameters of an evacuation scenario, identifying critical human factors, developing assumptions, and supporting engineering judgments. In some cases, the research or data found in the literature may fit the specific context of an evacuation scenario and provide highly relevant quantitative data applicable to the design situation.

TASK 1 – Define Building Characteristics and Evacuation Strategy

Weather and building characteristics during a fire emergency can influence the behavior of occupants. These factors are critical in evaluating the fire hazard exposure to occupants. The number, location, and arrangement of exits or refuge areas will directly impact the movement of occupants to a place of safety. The provision or lack of alarm systems and system type (e.g., bells, horns, or voice) will impact the analysis of how occupants will become aware of the fire incident and the timing assumptions on occupant response. Some building characteristics should be considered in qualitative terms such as whether egress routes are direct and obvious or complex and unfamiliar. Sometimes the location of the building and the climate conditions can be an influence on the evacuation. In adverse climates, there may be reluctance to evacuate, or the time spent to prepare for climatic conditions outside the building may influence the timing and procedures to be followed.

Evacuation strategies and procedures provide information that may be highly relevant to the determination of occupant egress behavior. For example, while an evacuation procedure may exist, if the procedure does not require any training or practice drills, then the expectation for occupants behaving according to plan may be a bad assumption. Conversely, where the occupants of a building are routinely trained and drilled on evacuation procedures, the expectation and assumptions for efficient occupant responses and behavior may be more appropriate. Of course, the evacuation data from drills can be useful to confirming the evaluation of occupant movement.

When reviewing evacuation strategies, the procedures and building features that address persons with disabilities may require independent consideration, as the disability or impairment may impact their behavior or require additional response and behavior of others in the building. The potentially encountered impairments include:

- Mobility impairments – wheelchair, walking disability
- Visually impaired and the blind
- Hearing impaired and the deaf
- Physically limited – asthma, heart condition, etc.
- Cognitive disabilities

TASK 2 – Review Occupant Characteristics and Identify Subgroups

Occupant characteristics can vary significantly among the variety of building uses. See Table 1 for a list of occupant characteristics.

To predict occupant responses and behaviors during a fire emergency, the occupant characteristics of a building's population should be reviewed to identify the nature of an occupant group or groups.

Not all listed characteristics are essential factors, but those that are critical and expected to influence the responses and behavior of a group or groups should be noted. In practice, it may be adequate to rely on a single defined occupant group that is recognized as the most critical and is conservatively characterized. However, additional analysis may be appropriate when two or more distinctive occupant groups are identified. The occupant characteristics and group determination are important to establishing reasonable assumptions on the timing of occupant response to cues or alarms, and the timing of subsequent actions or behavior prior to and during occupant movement.

TASK 3 – Developing Premovement Assumptions – Timing the Cue Validation and Decision-Making Process

The premovement time period of any evacuation (or relocation) occurs after fire-related cues have developed, but before occupants have made a decision to move or relocate to a place of safety. The psychology processes that influence this premovement period are the cue validation and overlapping decision-making processes. In cue validation, information will be processed as follows:[1]

1. Receiving the cue (sense the cue)
2. Recognizing the cue (identify the cue)
3. Interpreting the cue (give meaning to the cue)

This time delay associated with cue validation will depend on the variety of characteristics of the evacuation scenario such as the occupancy type, the nature of warning systems, the evacuation procedures, and, of course, the nature and number of cues developed at the time of a fire.

Cues that should be considered and assessed relative to the occupant group(s) in a building include:[1]

- Fire cues
- Building signaling or public address systems
- Cues from people alerting others
- Cues from building service disruptions

The cues for those close to the fire origin will likely be different than those distant or in another area of the building. Also, the effectiveness of cues will vary with the occupant characteristics, occupant location relative to cues, and other building factors.

For design purposes, one or several cues may be applicable to an occupant group. Given the selection of appropriate cues, the reaction for the cues and time for validation of the cues must be established using available research data, case histories, decision models, or engineering judgment. The various guidance documents on human behavior provide assistance in this area via discussion and reference to many literature sources and case studies that illustrate time delays associated with cue validation. In the CIBSE *Guide E, Fire Engineering*,[15] four of nine stated principles of human behavior are listed that address the importance and potential impact of the time delay. These principles are:

- Deaths in large-scale fires attributed to "panic" are far more likely to have been caused by delays in people receiving information about a fire.
- Fire alarms cannot always be relied upon to prompt people to move immediately to safety.
- The startup time (i.e., people's response to an alarm) can be more important than the time it takes to physically reach an exit.
- Much of the movement in the early stages of fires is characterized by activities such as investigation, rather than escape.

Closely tied to the cue validation process are the decision-making processes that can contribute further to the delay before evacuation. The premovement decisions may occur with or without the validation of cues. The cues may be ambiguous and result in an occupant's decision to seek new information or simply to ignore the cues. Some engineering guidance documents[15, 16, 17] have published tables of premovement times for various occupancies, and context-specific data can be found in other sources.[3, 18, 19, 20] The published tables cited can be useful but should be used with care, as the premovement times are generic and based on broadly subjective views. The context-specific literature and background sources may serve as the best sources for premovement delay times.

> An occupant's choice of exit is often affected by an occupant's familiarity with the building, the availability of exits, the tenability along an exit route, and the degree of difficulty of an exit route.[1]

TASK 4 – Evaluate/Calculate Movement Time

Generally, it is assumed that, during a building fire or evacuation event, occupants will make a decision to travel through the building's egress routes to a place of safety, such as an exit enclosure, a protected refuge area, or locations outside of the building. The assumption is generally routine for most public, nonresidential building scenarios; however, the decision time before occupants will move may be significant, and studies have shown that some occupants may decide not to move in what may be a more appropriate safety strategy. Suggested premovement times range from one minute to 30 minutes or more.[15, 16, 17] This behavioral decision to evacuate has been cited as playing a major role in the fatalities and injuries of high-rise residential buildings.[21, 22, 23, 24] Both of the authors of these studies have seriously questioned the appropriateness of evacuation of high-rise residential buildings, including hotels. Frequently, occupants who stayed in their apartments or hotel rooms were safe and uninjured, while those who evacuated became casualties. Both conclude that occupants of residential high-rise should use a stay-in-place approach.

For most other nonresidential buildings, movement by occupants is expected, and estimating this time element will often require the use of a suitable calculation method or evacuation model to estimate the movement time, which is most simply a function of travel speed and distance.

Time(s) = Distance/Speed

Although this is a simple calculation, it is important to recognize that numerous factors may impact the selection of speeds and distance traveled. Distance is a function of exit choice. An occupant's choice of exit is often affected by an occupant's familiarity with the building, the availability of exits, the tenability along an exit route, and the degree of difficulty of an exit route.[1]

Associated with travel speed is a longer list of potential factors:

- Occupant mobility
- Occupant mobility as affected by group dynamics
- Number and distribution of occupants

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RFC56 Concealer	16 x 16	26 gpm	21.6 psi
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F1RES 58 HSW & Recessed HSW	16 x 16	21 gpm	13.2 psi

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- Width of path restrictions (doors, stairs, corridors)
- Training or staff guidance

The above factors that impact considerations on distance and speed were determined from a review of either occupant characteristics or building characteristics. The designer or engineer may need to consider each factor explicitly or be prepared to justify why a factor is not relevant to the analysis at hand.

For any given design situation or building scenario, one or more movement time components may be relevant to the analysis. Movement times to consider may be the time for total building evacuation or more narrowly defined specific component times, as follows:

- Time to travel the longest/most remote egress path
- Time for occupants to reach the safety of exit or refuge area (floor clearing time)
- Time to empty stairways
- Time to clear the building

It many building evacuations, only distinct building areas would be subject to smoke while other areas are largely unaffected.

These movement time components can be evaluated using a variety of calculation methods or models. Total building evacuation can be estimated based upon the empirical method by Pauls,[17] which provides several algebraic relationships for calculating an estimate of evacuation times for uncontrolled total high-rise building evacuations. Movement of occupants on stairs, along corridors, and through doorways can be estimated based on approximation for crowd density, speed, and flow as developed by Fruin and Pauls.[17]

More-detailed analysis would recognize the impact of edge effects or boundary conditions posed by exit components. This is commonly known as the "effective width" concept. The "effective width" concept recognized that people move in a staggered arrangement that naturally allows pedestrians efficient use of space, permits people to see several steps ahead, and allows for lateral body sway. The Australian, New Zealand, Nordic, United Kingdom, and U.S. documents address human behavior, and recognize and adopt the "effective width" approach. Where edge effects are considered in a movement analysis, there are two SFPE references that provide a detailed discussion. Both the Chapter "Emergency Movement" of the *SFPE Handbook of Fire Protection Engineering* and the *SFPE Engineering Guide – Human Behavior in Fire* provide a detailed review that addresses parameters of boundary conditions at walls and handrails, stair geometry, travel speed, and people density. Designers and engineers should note that these calculation methods and the associated flow parameters have been based on carefully measured flows of persons in egress drills and crowd-movement situations having a range of variability.

TABLE 2
HYDRAULIC VERSUS BEHAVIORAL MODELS

	HYDRAULIC MODELS	BEHAVIORAL MODELS
Distance, Speed, Density, and Flow Considered	Yes	Yes
Occupant Characteristics/ Behaviors/Decisions Integrated	No	Yes
Occupant Responds to Fire Environment	No	Yes

The speed and flow parameters addressed by these calculations are for adult mobile individuals. Consequently, other data sources[25, 26, 27] become important for other occupant groups that include the elderly, the very young, disabled or impaired individuals, and persons exposed to smoke. The impact of considering others may or may not be significant. For example, the difference when comparing a travel speed (level travel) of adult, mobile individuals to that for a wheelchair-bound individual may seem significant. However, if the goal is to enter the safety of any exit door that is distant, the mobile individual travel time compared to that of mobility-impaired individuals may be moot if the travel route is tenable and occupants are in a queue to enter a door. In any case, the analysis of slow or impaired occupants is important where such occupants are routinely present.

Smoke is a factor in those building scenarios where hazard analysis demonstrates that occupants would be exposed to smoke. It many building evacuations, only distinct building areas would be subject to smoke while other areas are largely unaffected. The movement time analysis may need to account for reduced travel speeds or route redirections in those building areas having smoke-filled conditions.

Certainly, it is more apparent that a determination of movement time may require more detailed analysis than is suggested by the *"Time = Distance/Speed"* analysis. Today, numerous evacuation models are available to more effectively handle the many possible considerations and egress configurations of buildings. These computer-based models can be categorized as either 1) "hydraulic" or network models or 2) behavioral models. Table 2 identifies the characteristics and differences in these two approaches.

In both the hydraulic and behavioral models, movement of people is always a function of distance, speed, density, and flow – as would be the case in a homogeneous flow. When using hydraulic models, it should be recognized that there are basic assumptions that may require further consideration via an integration of safety factors or alternation of parameters to provide conservatism. For example, a hydraulic model assumes:

- all occupants start egress at the same time;
- occupant population will divide to the exits in an optimum balance;
- occupants will know building evacuation routes; and
- occupants will select the shortest egress path.

While these are optimistic assumptions, more-realistic assumptions can be tested. Once the parameters and methodology of a hydraulic model are understood, it is possible to modify the input parameters and perform a further analysis to bias the results towards more pessimistic assumptions such as a blocked exit, travel speed reduction, occupants using longer exit path.

With the advent of the behavioral models, the movement of people as fluid particles is modifiable by numerous other parameters that attempt to integrate behavior related to the population characteristics, building characteristics, individual decision-making capacities, and fire environment. A significant number of evacuation models have been developed, and a concern for the variability and uncertainty of the behavioral models has not been ignored.[14] Continued focus on these models will likely provoke improvements so they may eventually become common and useful tools for building design.

TASK 5 –
Evaluate/Calculate the Fire Environment Impact on Exposed Occupants

The first consideration when evaluating the impact of the fire environment on exposed occupants is to identify those occupants that are exposed.

Depending on the fire scenario (e.g., residential home, warehouse), either many occupants or very few occupants may actually be subject to the potential threats of the fire scenario in question, which include:[28]

- Exposure to asphyxiant gases, with CO being of primary concern;
- Exposure to irritant gases that impact eyes, nose, throat, and respiratory tract;
- Exposure to convective or radiative heat resulting in heat stroke, skin burns, or respiratory tract burns; and
- Impaired vision due to smoke obscuration.

The approach to evaluating the impact of fire gases, heat, and smoke can vary in complexity, and the selection of an approach will depend on the severity of the fire scenario, the time and nature of the potential exposure. For example, if the evacuation analysis for a large commercial building demonstrates that occupants are outside the building before the smoke layer descends to a breathable zone, then perhaps only the radiative exposure to occupants from the smoke layer may need to be evaluated. Conversely, analysis of an unsprinklered apartment building would suggest that flashover scenarios and potentially severe fire gas and heat exposures would require one or more cumulative exposure analysis methods. These methods are discussed more fully in the article entitled "Tenability Analyses in Performance-Based Design."

Changing Engineers' Behavior on Human Behavior

In past decades, the practicing fire protection engineer has not often encountered concerns for detailed and objective considerations of human behavior in building design. Usually, serious consideration of human behavior issues was relegated to behavioral scientists and human factors researchers. Today, with the promotion of performance-based design, the importance of human factors and behavior in building design has entered the mainstream of fire protection engineering practice as evidenced by the many international documents that now address the human behavior related to evacuation. As further evidence, the Fire Protection Engineering Professional Engineering examination administered in the United States now includes problems dedicated to the topic of human behavior. Practicing engineers should avail themselves of the many sources of information available today on human behavior, as much information is available to address human behavior issues related to building design and fire safety systems applications.

Daniel O'Connor is with Schirmer Engineering.

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The World Trade Center Evacuation:

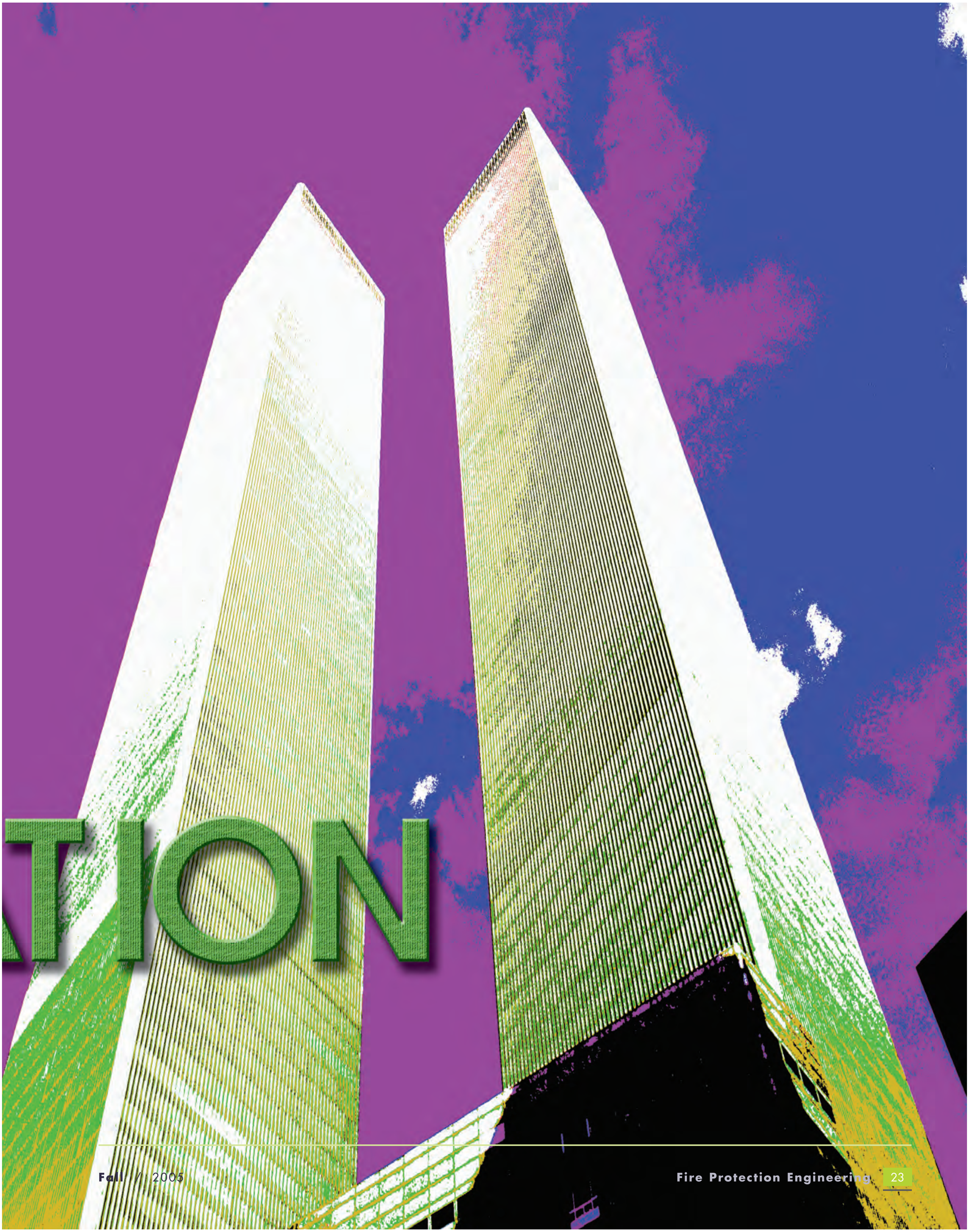
INTRODUCTION

The evacuation of the WTC complex represents one of the largest full-scale evacuations of people in modern times. As such, it is of fundamental importance to the understanding of the complex interaction between structure, procedures, environment, and human behavior, and how these factors interact to determine evacuation performance. The WTC evacuation provides an unrepeatable opportunity to probe into and understand the very nature of evacuation dynamics, and with this improved understanding, contribute to the design of safer, more evacuation-efficient, yet highly functional, high-rise buildings.

An Analysis of Human Behavior during

EVACUA

By E. R. Galea, Ph.D.


TION

Following 9/11, the Fire Safety Engineering Group (FSEG) of the University of Greenwich embarked on a series of studies centered on the evacuation of the WTC. These include a study of printed accounts from survivors of the WTC evacuation;[1, 2, 3, 4] numerical simulation studies of the evacuation of WTC Tower 1;[5] project HEED, a study to collect and analyze data from face-to-face interviews with survivors of the WTC evacuation;[6] and a proposal to investigate the possible use of elevators and sky bridges for the evacuation of high-rise buildings.[7] This paper reports on a selection of the published findings of the first study.

Background to Project

The survivors of the WTC disaster hold a tremendous amount of information concerning their experiences of the conditions within the structures and the evolving evacuation scenario. Ideally, this information should be gathered from face-to-face interviews conducted as part of a scientific study. An alternative, and less desirable, approach relies on firsthand accounts that have appeared in the mass media. These are usually the result of press interviews conducted by journalists or personal accounts produced by survivors in Web sites or books. The difficulties with relying on the media is that specific groups are not targeted, interviewees self-select, journalists tend to only report the more sensational parts of people's stories, questions posed are inconsistent, questions posed by journalists are not necessarily known, and an inability to ask specific questions.

Furthermore, individual survivor accounts of traumatic events may be influenced by the nature of the event, leading to an inaccurate perception of the facts by the survivor. One way of addressing this issue is through corroboration of facts from analysis of multiple survivor accounts. In effect, the accounts that appear in the mass media provide an uncontrolled snapshot view of the incident, and what is not known from these accounts is as important as what is known. Nevertheless, the data contained in such accounts can prove useful in providing insight into behavior during such incidents. Furthermore, these accounts were recorded very close to the event, some accounts being made a matter of days after the incident. Studies involving live interviews with survivors usually view the incident after the passage of a considerable amount of time (in the case of the WTC, years) and so may be tainted by information gleaned from other accounts that have appeared in the public domain, memory lapses, or selective amnesia. Therefore, the data collected from published accounts, while not ideal, potentially contain valuable information.

Following the WTC disaster, the Building Disaster Assessment Group (BDAG) of the UK Office of the Deputy Prime Minister funded FSEG to gather, collate, categorize, electronically store, and finally analyze data concerning human behavior during the WTC evacuation. Reports were gathered from the literature published in the public domain. Material sources ranged from survivor accounts printed in newspapers and newspaper Web sites, interviews in the electronic media, survivor Web sites, and books. Over 250 separate accounts were gathered that described occupant behavior. Information appearing in print newspapers represents 70 percent of the accounts, while information from Web sites (news and personal) represents 16 percent of the accounts. The remainder of the accounts have appeared in books, journals, and the electronic media. These accounts provided information concerning 120 people from WTC1 (north tower), 119 from WTC2 (south tower), and 21 of unknown origin.

Number of Occupants in the WTC Towers

There are various estimates for the number of people in the building and the number of fatalities. Denis Couchon of *USA Today* estimates that there were between 10,000 and 14,000 people in the buildings at the time of the impact,[8] while NIST, in their interim study, estimates that there were 17,400 +/- 1,200 people in the buildings.[9] Couchon estimates that 1,432 building occupants perished in WTC1 and 599 in WTC2,[10] while NIST estimates that 1,560 and

599 building occupants in WTC1 and WTC2, respectively, perished.[9]

The Database of Human Experience

The collected accounts were entered into a specially developed database. Each individual experience described within the account was stored and assigned specific behavioral references. This is similar to traditional qualitative analysis tools that allow users to categorize portions of textual accounts during the input process. The rationale for the database was that all information was centered on an experience. Each experience was assigned a main category and a subcategory that described the nature of the experience. A distinguishing feature of the database is that it is not only able to store experiences but also the location of the experience and a time reference for the experience.

The database contains reference to a total of 3,291 experiences from 260 people (1,869 accounts from WTC1, 1,411 from WTC2, and 11 from unknown locations). Gender information was available for 240 people, 164 of which were male and 76 female. The quality of these data varied enormously. While some accounts were several pages long, others were only a couple of paragraphs in length. Of more importance, some accounts provide important detailed information such as a detailed description of events, locations at which events took place, and reference to key time markers. The reports mainly came from occupants that began their evacuation in the upper floors of either tower. Within the database, 73 (61 %) and 91 (76 %) of the occupants from WTC1 and WTC2, respectively, were initially located on or above the 78th sky lobby. It is likely that this bias originates from the media's natural desire to focus on accounts that described the most extreme conditions during the disaster.

Data Analysis and Discussion

The database has been used to study a number of issues concerning the evacuation of the WTC. These can be broadly separated into two categories, preevacuation and evacuation. The preevacuation category is intended to cover behaviors prior to the physical act of attempting to evacuate, while the evacuation category is intended to cover those actions and behaviors during the physical act of evacuation.

The study has provided useful insight into the following issues: occupant response times in high-rise buildings; nature of occupant preevacuation activities; the use of telephones and other electronic devices for communications by the occupants during the evacuation; retrieval of items by occupants prior to evacuation; occupant assessment of the incident; occupant travel speeds on stairs during the evacuation; occupant interaction with firefighters during the evacuation process; usage of elevators for evacuation; group formation, cohesion, leadership, and behavior; response of fire wardens; and fatigue issues. Due to space limitations, only a summary of several of the key findings will be presented here; interested readers are directed to the BDAG report for a full account.[1]

• OCCUPANT PREEVACUATION TIMES

Of the 115 people who provided information on which a preevacuation time (also referred to as response time) could be estimated, 60 percent responded within an estimated 5 minutes of the assault on WTC1, and some 13 percent took longer than an estimated 17 minutes to respond (see Figure 1). Occupants in WTC2 responded quicker to the assault than occupants in WTC1 – the first tower to be attacked. This occurred in WTC2 despite instructions issued over the PA system in WTC2 instructing occupants that there was no need to evacuate WTC2. It is important to note that even under the extreme conditions of the terrorist attack on the WTC, occupant preevacuation times can be quite long. A lack of data prohibited a meaningful analysis of preevacuation time and proximity to the incident. While it is difficult to generalize due to the lack of data, the rapid response times of occupants in WTC2 relative to WTC1 may have contributed to the smaller death toll (not only in total but relative to the number of people who were in the buildings at the start of the attack) experienced in WTC2.

• OCCUPANT PREEVACUATION ACTIONS

1 – State of mind

On the whole, the description of personal behaviors provided by the evacuees can be categorized as rational. In describing their own actions and behaviors, none of the interviewees reported extreme behavior, or behavior that fits the academic

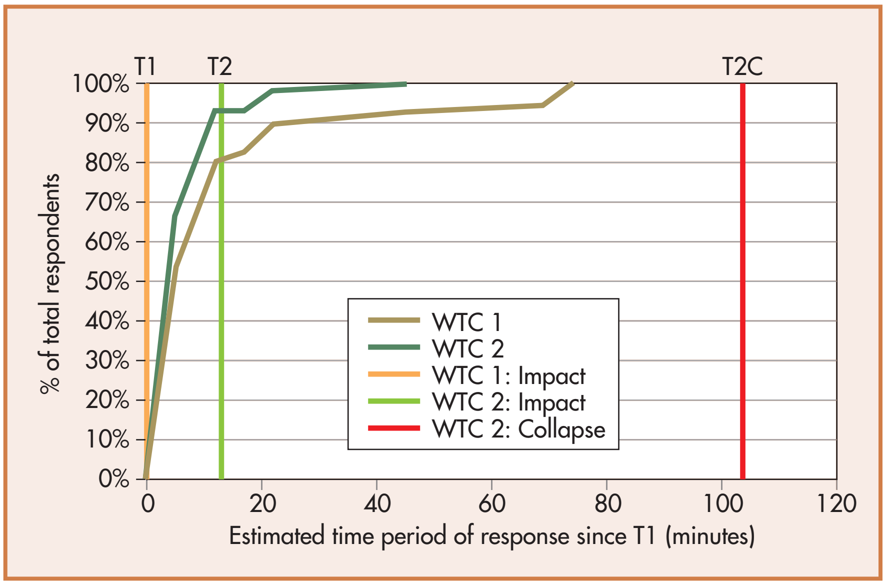


Figure 1. Percentage cumulative frequency distribution of occupant response

view of "panic." However, occupants did describe witnessing 5 events that may be interpreted as panic behavior. This is a surprisingly small number of incidents given the gravity of the event.

2 – Usage of telephones

Of the people who provided information relating to their actions, 20 percent stated that they made telephone calls. A significant number of these calls (75%) were not made to emergency services or colleagues but to family members, and the majority of the calls made by survivors were in the preevacuation phase. Surprisingly, most of these were to assure family members that they were OK – not to secure further information or advice. The propensity of occupants to make telephone calls is considered potentially significant as it is an action that slows occupant evacuation, especially as the majority of calls involved providing rather than receiving information. While it may be considered natural to inform "loved ones" of one's safety, undertaking this action is ill-advised while still exposed to potential danger. It is suggested that as part of regular evacuation training and safety briefings, participants should be advised not to make personal calls until they have safely exited the building as this can prolong evacuation, thereby jeopardizing their chance of survival. Consideration should also be given to harnessing the ubiquitous personal mobile phone as part of the emergency information system. Emergency information and advice could be sent via SMS messages to building occupants.

• EVACUATION PHASE

1 – Obstructions to flow

A number of accounts from WTC1 highlight situations in which noninjured occupants progressed down the stairs in single file, allowing injured occupants to be assisted down the unobstructed lane. This altruistic behavior supports the view that the evacuation was calm and noncompetitive in nature. A few accounts also describe the passage of firefighters up the stairs. The accounts that are available suggest that the firefighters may have hindered the passage of some occupants in WTC1, but it is not clear if this had a significant impact on overall evacuation times. The available accounts describe firefighters as constricting the effective width while moving up the stairs and while recovering from fatigue. It is suggested that as part of firefighter training, firefighters be instructed that during the ascent of tall buildings, prior to taking a rest period, they should move off the stairs, if considered safe, in order not to obstruct the flow of evacuating occupants. Several accounts describe the flow as coming to a complete halt. All of these reports were taken from floors below the 44th floor. These events may have contributed to the poor flow conditions reported in these areas of WTC1. Water was also reported by occupants below the 44th floor of WTC1. The presence of water would have served to slow occupant evacuation as movement rates would have been severely hindered by the presence of water, and several occupants reported slipping. Reports of the injured and firefighters impacting the flow conditions in WTC2 were far fewer.

Clearly, organizational managers and authority figures are likely to be figures of authority in emergency situations, so they should be well-versed in emergency procedures.

2 – Usage of elevators as a means of evacuation in WTC2

There are 95 occupant accounts reporting evacuation phase experiences in WTC2. Of these, 28.4 percent (26 accounts) report elevator evacuation usage prior to the attack on WTC2 and represent some 38 elevator embarkations. While this represents a significant usage of elevators, it is not possible to conclude from this information alone that the elevators played a significant positive role in the evacuation success of WTC2. However, it would appear reasonable to assume that the heavy reported usage of elevators in WTC2 prior to the assault on that building could have made two positive contributions to the evacuation. First, heavy usage of elevators would have assisted clearing large numbers of people from the upper floors of WTC2 prior to the assault on that building. Second, the usage of elevators by significant numbers of people would have eased the congestion on the stairs in WTC2, making movement on the stairs more efficient. However, a significant number of people may also have delayed their evacuation – possibly with fatal consequences – waiting for elevators, for example, some of the people in WTC2 78th floor sky lobby. Clearly, more research is required in exploring how elevators can be effectively used in large-scale building evacuations.

3 – Group Behavior

Of the WTC1 accounts that allowed an assessment of group formation to be made, 90 percent (62/69) suggested the formation of some type of group during the preevacuation phase. In WTC2 a similar trend was noted with 88 percent (69/78) of the population describing forming groups. Only 10 percent (WTC1) and 12 percent (WTC2) of occupants that made an evacuation reported evacuating by themselves. In WTC2, 90 percent (19/21) of the groups that formed were small (less than 5 people), and very few large groups formed. Indeed, 62 percent (13/21) of the groups involved only two people. In contrast, in WTC1, group sizes tended to be more evenly distributed between small (less than 5), medium (6 to 10), and large (greater than 10).

Of the groups in WTC1 and WTC2, 80 percent (12/15) and 71 percent (20/28), respectively, consisted of employees from the same office, and 13 percent (2/15) and 18 percent (5/28) of groups consisted of a mixture of office and adjacent office employees. This information, combined with the group size information, may suggest that in the WTC2 evacuation decisions were taken on a local/personal basis, perhaps involving small localized groups of colleagues. In contrast, in WTC1, larger groups tended to form, and this may have been based on collective decisions centralized on an office basis.

Group size was found to be dynamic in nature, expanding and contracting during the evacuation. When groups contracted in size, the predominant reason for this was the deliberate action of a group member, not adverse environmental or situational conditions forcing a group to split. In WTC1, a significant number of the groups that formed split during the descent (6/10), primarily for deliberate and individual reasons. In WTC2, a smaller proportion of groups split during the descent (8/20). Here again, the predominant reasons for breaking the group were based around deliberate actions by group members.

The vast majority of groups for which there is sufficient information were led by their line manager during preevacuation. Clearly, organizational managers and authority figures are likely to be figures of authority in emergency situations, so they should be well-versed in emergency procedures. If possible, line managers should receive fire warden training. However, due to the nature of their organizational roles, line managers and authority figures are likely to spend a considerable amount of their time away from the office. Thus, they should be considered an additional resource rather than the sole fire-trained asset.

The observations relating to group behavior are considered significant. However, because of the small size of the sample, the observations cannot be considered conclusive. If substantiated by more detailed studies into the WTC disaster, they should have a profound impact on evacuation planning and modeling, as groups can exert a significant influence on a range of evacuation parameters such as response times, travel speeds, way-finding, and overall evacuation efficiency and time. Furthermore, due to its nature, the type of group behavior noted in this study is unlikely to occur in evacuation drills or exercises. The study of real incidents, such as the WTC disaster, provides the opportunity to study group behavior that is extremely difficult, if not impossible, to reliably reproduce in "laboratory" or controlled experiments.

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What a User Should Know When Selecting an EVACUATION Model

By Erica D. Kuligowski and Steven M. V. Gwynne

In recent years, evacuation models have been increasingly applied in an attempt to understand the outcome of emergency egress scenarios. This has been due to the increased use of performance-based design and the availability of cost-effective, high-performance computer capability. The increase in the use of these types of evacuation tools requires that the important factors involved in the selection of an appropriate evacuation model are better understood. This article provides evacuation model users with the important questions and factors to consider for model selection.

Evacuation model users are faced with the choice of numerous modeling tools available across a variety of projects, i.e., applications with ships,

buildings, and cities, all of which vary in their requirements. The models vary in their background, capabilities/characteristics, and future developmental flexibility, which are all important issues that a user should take into consideration before selecting a model for application to a project or series of projects.

It is important to examine the nature and scope of the project in order to determine whether the model is able to cope with the requirements of that particular application area.

With all of these choices, what help is available to aid model users in the model-selection process? Currently, several evacuation model reviews exist[1,2,3,4,5,6,7,8,9,10,11,12,13] that aid in the categorization of evacuation models developed up until the time of their publication. However, in most instances, the user is left to distinguish which categories are significant for their particular circumstance and why this is the case. The *SFPE Handbook of Fire Protection Engineering*[1] provides a basic list of questions that a user should ask when selecting a model; however, the questions mainly focus on model sophistication and do not necessarily provide explanations as to why those factors are important. This article attempts to aid in the selection process of an appropriate evacuation model by identifying key factors and explanations regarding project requirements, the background of the model, the current capabilities and characteristics of the model for comparison with other models, and the future progress of a model for a specific application. For many of the key factors, associated examples* of evacuation models are presented in the text.

Project Requirements: What Are the Project Objectives?

Before selecting a model, the user should consider the specific project to which he/she is assigned. It is important that the user consider key questions relating to the suitability of the model to the requirements of the project in question. This is not an exhaustive list of the questions that need to be asked, nor are the questions necessarily mutually exclusive; however, by answering these four questions, the user should be able to ascertain whether the model is able to support the project requirements and whether it is appropriate to be used for the project at all.

- What are the nature and scope of the project?
- What are the deliverables of the project?
- What information is available within the project to frame the egress analysis?
- How much time and funding are available to complete the project?

It is important to examine the nature and scope of the project in order to determine whether the model is able to cope with the requirements of that particular application area. For instance, if a user is to model a ship evacuation, he/she may need to simulate mustering. The user should then ask whether the model's representation of mustering is sophisticated enough to answer the questions being posed within the project. Even though a project can be categorized by a specific application type (e.g., it involves a maritime vessel, an office building, an airport terminal, etc.), categorizing evacuation models is more difficult given that the use of the model can change over time.

The completion of any project involving modeling will require the production of a set of deliverables. The user should therefore be aware of both the output that can be produced by the model (and whether this matches up with the project requirements) and the techniques used within the model to generate these results. It may not be feasible to make use of a model when, for instance, a detailed understanding of the experiences of the simulated evacuees is required but only the final arrival time can be produced by the model. In addition, the techniques used within the model (whether artificial intelligence techniques, flow calculations, cognitive models, etc.) may not be capable of producing the output required by the project. For instance, a cognitive model may provide information on the decision-making process; however, it might not be able to provide a quantitative assessment of the overall evacuation time.

The amount of project information available to the user may influence the model selection. For instance, if the information that the user has on the project is limited, e.g., a vague description of the building floor plan or limited information on the occupants, then the user may want to select a less-sophisticated model with a limited number of user inputs.

Lastly, it is important for the user to understand the amount of time and funding allocated to the egress analysis of the project. This may influence the selection of the model, potentially precluding those models from selection that are financially and/or computationally expensive.

* Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

Background Research: What Is the Origin of the Model?

Understanding the origin of the model is important in the selection process because it establishes the constraints under which the model was produced (e.g., the commercial pressures), the expertise available when the model was created (e.g., mathematicians, psychologists, sociologists, etc.), and the extent of the efforts to validate the model. This information is useful because it allows the user to better establish the credibility of the claims made of the model.

By understanding the constraints under which the model was developed, the user may be better able to assess whether developments were driven by a need to improve the model or more driven by constraints, such as funding or time.

The user should be aware of the expertise involved in the development of the model. For example, some models may have been developed by an individual, whereas other models may have been developed by a team of people from diverse backgrounds, such as psychology, sociology, and engineering. The background of the development team may affect the abilities of the model to capture some of the more complex behaviors or actions of the occupants during an evacuation.

An important aspect of model selection is the level to which the model has been subjected to validation/verification. It is vital that the user obtain documentation from the developer and other agencies that have performed any type of validation to make his/her own judgments on the validity of the results produced and whether the validation is sufficiently detailed, reliable, and in an area comparable to that involved in the project. For instance, if the model has been validated using scenarios and/or data extracted from the built environment, would the validation performed be sufficient to warrant the use of the model in an aviation application? Validation studies help to identify the capabilities of the model as well as its limitations. These validation studies can investigate a number of different aspects of the model: quantitative performance,[14,15] qualitative performance, functional performance, component-based performance,[16,17] efficiency, speed, and scope. The availability of the supporting data required to perform such comparisons can limit these vital evaluations. The user should develop a verification suite of tests to provide a level of confidence in the validation process and in their understanding of the use of the model.

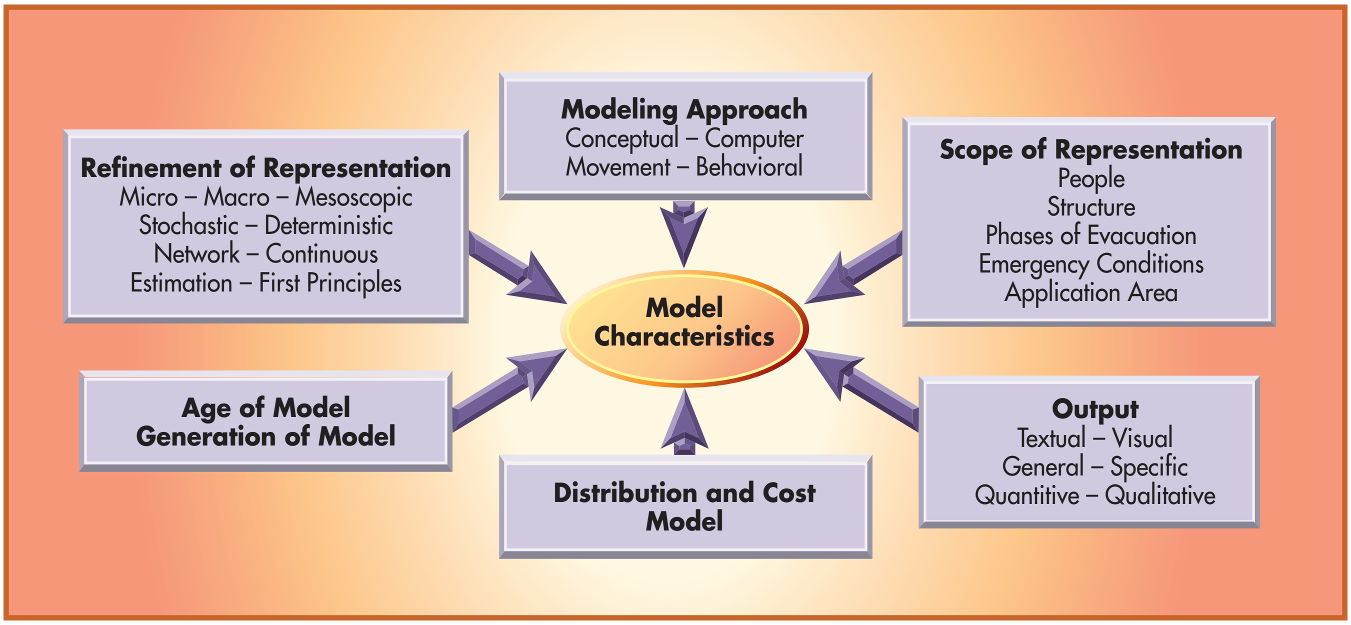

Figure 1. Current characteristics of evacuation models

Model Characteristics: Where "Is" the Model in Relation to the Others?

In addition to assessing the project's requirements and model's background information, it is important to understand the current modeling characteristics enabling a comparison between the models currently available. By identifying and understanding the important characteristics of the current evacuation models, the user will be able to make a more informed decision to choose the model that is most appropriate for the specific project. Key evacuation models characteristics are displayed in Figure 1.

The modeling approach describes the overall sophistication that the model is attempting to simulate. A user might choose a conceptual model to attempt to capture the relationship between processes at a theoretical level (e.g., the decision-making process, likely activities performed during an evacuation from a home, etc.).[18,19,20] It is often the case that these "abstract" models become incorporated into evacuation computer models through the development of dedicated algorithms. Alternatively, the user might choose a computer model to quantify human movement and (occasionally) behavior during fire emergencies. A principal objective of these models is to produce an evacuation time for a structure; however, these models have progressively been able to provide information such as flow rates, congested areas, etc. On another level of sophistication, these computer models may be subdivided according to whether they concentrate on the optimal movement of the evacuees, exclude a number of expected behaviors, or include a comparatively wide range of behaviors. The user would then have to determine whether their requirements warranted the inclusion or exclusion of these behaviors.

An evacuation model user should be familiar with the differences in the flexibility or scope of how the models represent aspects of the evacuation, including the occupants, the structure, emergency conditions, etc. Examples of the scope of representation include the simulation of the impact of occupants with disabilities,[21] the inclusion of certain aspects the structure (i.e., doorways, signage) via engineering plans,[14] the number of phases of the event simulated,[22] and the simulation of fire conditions and their impact on evacuees[21,23] against their performance under nonemergency conditions.[24] It is important to understand how a particular model represents/simulates certain aspects of an evacuation, especially if they are key components of the scenarios required for the project in question. For example, if the project requires the simulation of a population that includes people with differences in age, gender, mobility impairments, and size, the user should ensure that the model has this capability.

In addition to understanding whether certain aspects of the evacuation are simulated, the model user should understand to what level of detail these aspects are simulated. The user should be familiar with the refinement (or fine-tuning) of the evacuation aspects available among current models. The user should be aware that an increase in refinement may require an increase in the effort needed of the user and an increase in the computer time needed to run the simulation. Examples of methods of refined representation follow: representing the population as individuals[25] as opposed to representing them as a homogeneous population,[26] representing the structure as a continuous space on a vector grid[14] or dividing the structure into larger spaces (rooms, corridors, and staircases),[15] and representing certain actions performed during an evacuation as deterministic (defined)[27] or probabilistic (based on probabilities provided by the user).[28] For example, if the project requires the simulation of a primarily open structure with the presence of obstacles or several pieces of furniture (e.g., large theater), then it may be more appropriate to choose a model that represents individuals in a continuous or finely segregated space.

It is important for the model user to be aware of the age of the model and the developments/advancements since its release. In some cases, older models become dated, cease to advance in accordance with technology progress, and therefore can no longer be used[29] or become obsolete. On the other hand, if it is seen that the developing organization of an older model continually updates and maintains the software, the user may be interested in using a more "established" model that has been continuously developed and has been involved in a variety of projects over the years;[23,28] it has a proven track record of application. In the case of newly developed models,[12,16,30] the user should be cognizant of its validation efforts, specifically because the model may not have been used for practical purposes/projects since its release.

Many times, the interested parties will require more information from the simulation than simply the total evacuation time.

The output produced is an important characteristic to consider when selecting a model. Many times, the interested parties will require more information from the simulation than simply the total evacuation time. Current models can provide a variety of output, including textual output,[15] two-dimensional graphical output,[26, 31, 32] descriptive interpretation and graphs,[23,24] and three-dimensional/virtual reality interface.[25] In addition, several models are able to have the nature of their output modified in order to fit the project requirements.[30]

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Another important characteristic involved in model choice is the user's access to the models, i.e., the model availability. Some models are distributed for local application, whereas other models are employed by their developers centrally, with the results then distributed.[28] In the former case, the model user actually develops the input, runs the simulations, and then analyzes the output; and in the latter, the user works with the developing company and will have access to the output only. In reality, the model may be distributed in a number of different ways: the software is free of charge;[33] available on a consultative basis;[32] available via a flat-rate fee;[21] available under license control; or some combination of these methods.[23]

Future Considerations: What Should the User Be Aware of in Evacuation Modeling to Plan for the Future?

Any user or potential user should be aware that there are important factors regarding future projects and advances in the field that can influence the selection of models. Future considerations are especially important when a user intends to invest significant resources into using a model, possibly for multiple projects over several years, and therefore has a vested interest in the ability of the model to cope with future demands. This might not be the case if a user is only interested in short-term projects or if he/she has access to a number of models.

Future considerations are especially important when a user intends to invest significant resources into using a model, possibly for multiple projects over several years, and therefore has a vested interest in the ability of the model to cope with future demands.

Although the future of evacuation modeling is uncertain, it is possible to extrapolate from the current situation to establish what issues future developments will be sensitive of and therefore what capabilities the user should expect from future models. It is anticipated that the user will need to address the following questions relating to the future development of evacuation models and their suitability to the needs of the user:

Will the user attempt to model designs of a larger scale in the future?

The user may require that future projects involve larger and more complicated structural configurations inhabited by more diverse populations. The user should be aware that as the complexity of the scenario increases, so evacuation models will have to cater for the computational expense of simulating them. If the scale of future projects will be a factor, the user should select models that are flexible to this issue, for instance, models that are only constrained by the user's computing technology.

Is the evacuation model able to incorporate new data?

With future research projects developing in the area of human behavior in fire, the understanding of egress behavior will increase, providing additional datasets for application with evacuation models. The user should be aware of this potential increase in people movement and behavioral data, and choose a model that allows for flexibility of scope. For instance, the user may be interested in the impact of the performance of staff in their execution of a procedure during an emergency scenario, requiring that the evacuation model be extended to reliably reflect this aspect of an evacuation.

What type of scenarios might the user model in the future?

Given the potential for a variety of different emergency scenarios, the user may expect that the evacuation model in question should be flexible enough to cope with the set of scenarios in which they are interested. This may include the occurrence of a fire; an earthquake; an explosion; the involvement of biological, chemical, or nuclear material (accidental or intentional); as well as structural collapse. In determining the safety of a structure in the future, the user may wish to investigate a number of these scenarios, possibly examining multiple-event scenarios, requiring that the evacuation model being used is capable of reflecting these incidents and their impact upon the evacuating population. These scenarios should also take into consideration the procedural response of the evacuation. This might include a phased or controlled evacuation procedure and may also involve the use of vertical egress systems, e.g., elevators.

Will the user require that the evacuation model be better coupled with other modeling technology and allow for real-time manipulation?

In future applications, the user may wish to analyze the evacuation in conjunction with the evolution of the incident, the performance of the rescue services, the integrity of the structure, the activity of the suppression systems, etc. The user may therefore require that either the model is able to interact with other existing technologies or that it has the capacity to be modified in order to do so. In addition, the user may wish to adopt a more active role with the scenario development within the model; i.e., the user may require that the model have the capability to be manipulated in real time in order to investigate the consequences of these interventions or to establish a worst-case

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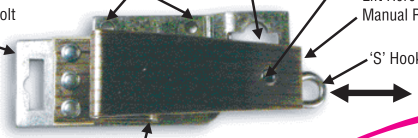

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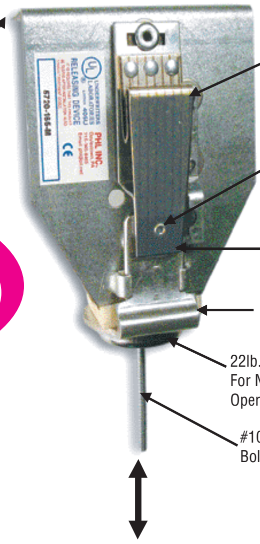

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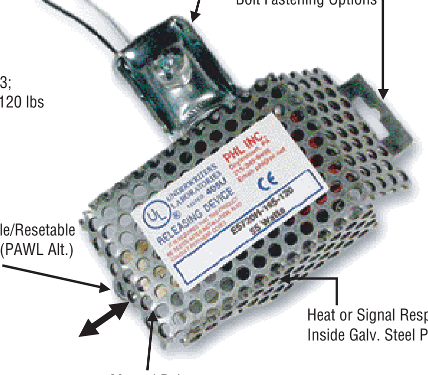

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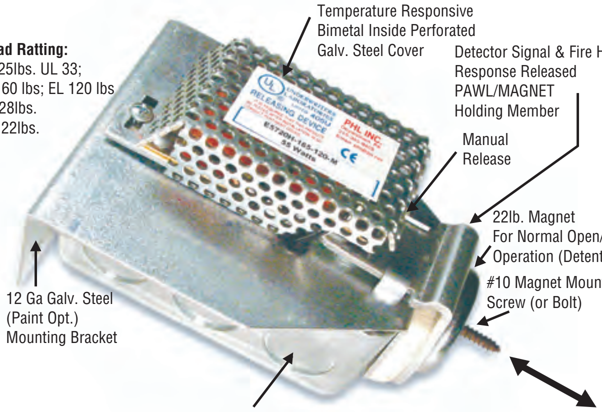

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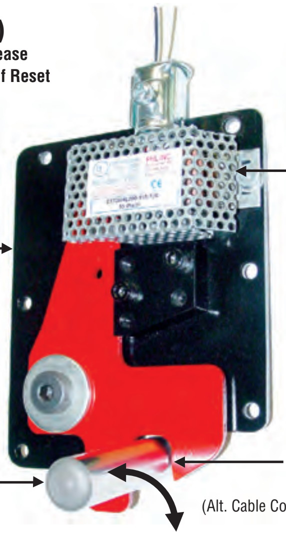

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scenario more effectively. For instance, the interaction between the user and the model may reflect simulated staff intervention (e.g., what happens if a member of staff closes an exit).

Is the model able to produce output flexible enough to cope with future demands?

It is important that the user establish whether the model is able to produce output that is sufficient for future applications. The requirements of future applications may differ from those currently addressed by the user as: 1) the application area of the user may expand to include new areas; 2) the regulations governing an application area may change; and 3) the expectations of the target audience may increase in light of technological developments. For instance, a user may take on a maritime project, where previously their application area involved buildings; the requirements of the regulations determining compliance for ships may be different from those controlling buildings; and the future audience for these results may expect that they be presented in a variety of different forms, e.g., numerical output, two- and three-dimensional graphics, interactive output, etc.

If a user (or potential user) intends to invest significant resources into selecting a model, acquiring support, licenses, documentation, and training staff to utilize the model, then the flexibility and long-term capabilities of the model would be of great interest.

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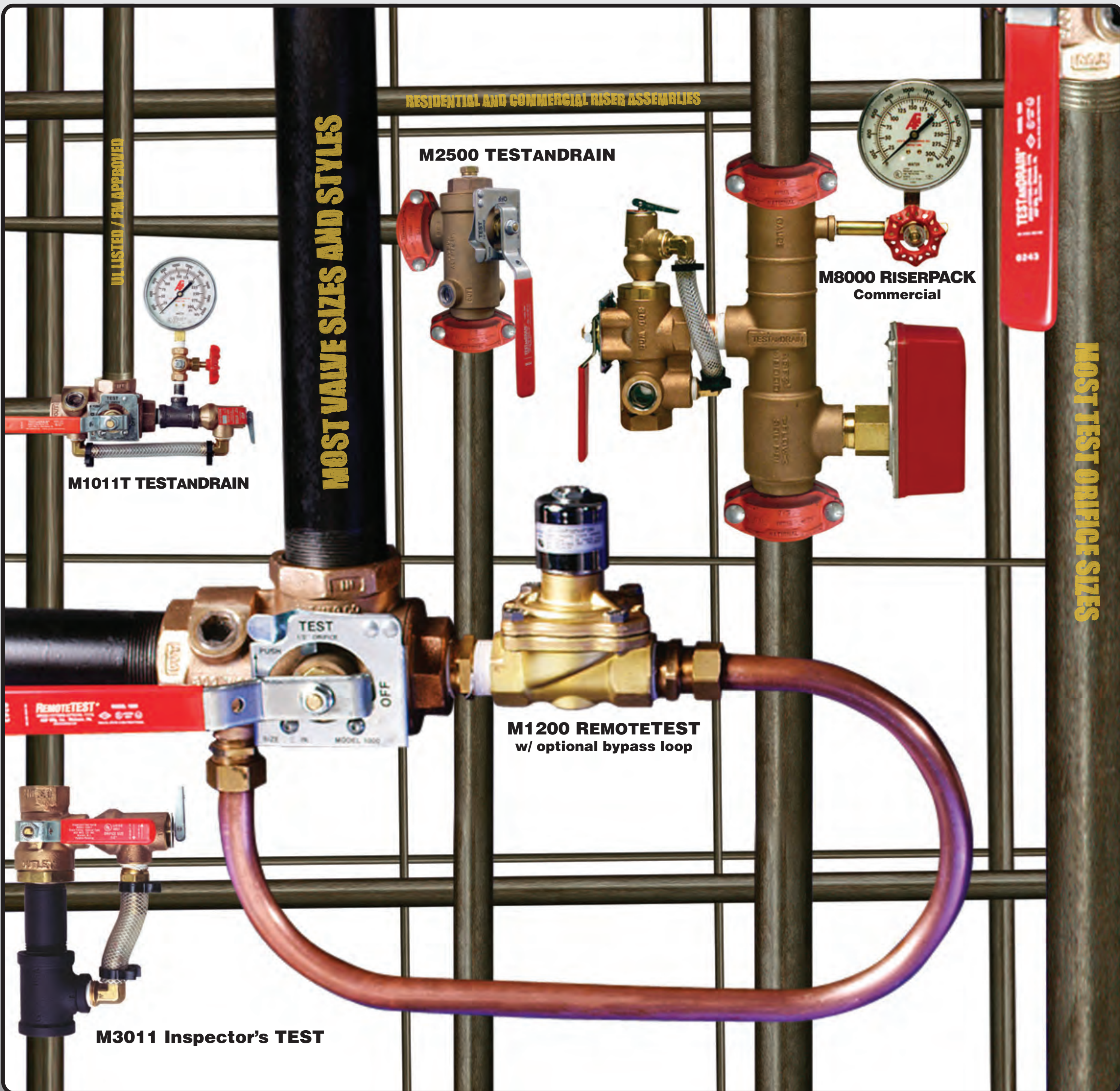
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Protected Elevators and the DISABLED

By Richard W. Bukowski, P.E., FSFPE

The Americans With Disabilities Act (ADA) was passed in 1990 to provide equal access to public buildings for all Americans. An objective of the ADA regulations was to permit people with disabilities access to the places where they live, work, and play with little thought of how they would get out in case of emergency. Fifteen years later, the fire protection engineering community is still addressing this important issue.

The purpose of this article is to present the issues that need to be addressed in the development of elevators that can be used in fires to safely evacuate occupants, particularly those with limited mobility that affects their ability to use stairs.

Accessibility

The ADA accessibility requirements are intended to result in public buildings that can be accessed and used by people with a range of limitations including vision, hearing, and mobility. The guidelines provide for signs that include Braille markings, strobe lights and other visible warnings, and doors with powered openers that are wide enough for wheel-

chairs. Smaller changes in elevation require ramps or platform lifts that eliminate barriers to wheelchair users.

Building codes contain special provisions for an accessible means of egress that either leads out of the building (including through a horizontal exit) or to an area of refuge, which may be served by an accessible elevator. Elevators are the primary means of routine ingress and egress for all occupants in most buildings and under most conditions, except during fires. Elevators are posted with signs warning that they are not to be used during a fire. Occupants and firefighters are relegated to stairways that may have only the capacity to carry the occupants from a few floors at a time, without the counterflow of firefighters trying to move up carrying equipment. And what about those people with disabilities (including both disabilities as defined by the ADA and those occupants who needed assistance to exit long distances) who now represent 6 percent to 10 percent of the occupant load?

Elevators and Fires

Beyond the direct impacts on the safe operation of the elevator, there are several interactions between the elevator system and the building during a fire. One is the hoistway as a vertical shaft spreading smoke through the building. Most landing doors open horizontally and are leakier than other types of doors. The shaft itself is subject to what is known as stack effect, which is a vertical airflow resulting from differences in indoor to outdoor temperatures and the height of the shaft. This shaft flow draws air into or out of the shaft through the landing doors depending on the position of the landing relative to the neutral plane and the direction of the shaft flow.[1]

Stack effect flows are driven by differences in indoor and outdoor temperatures with upward flows in winter (outdoors colder than indoors) and downward in summer (outdoors warmer than indoors). The greater the difference, the greater the flow; therefore, stack effect is larger in more extreme climates and for taller shafts. Even without a fire, stack effect flows can cause problems in tall buildings, resulting in strong flows and noise at landing doors near the top and bottom of the shaft. These flows can cause jamming of landing doors and may require seasonal door adjustments by elevator technicians. During a fire, stack effect flows can carry smoke and fire gases to remote parts of the building. For example, in the MGM Grand[2] and DuPont Plaza[3] fires, which both occurred near the ground floor level, there were fatalities on upper floors due only to smoke carried up elevator shafts by stack effect flows.

It is important to note that both examples occurred in unsprinklered (at least in the area of the fire) buildings. A recent analytical study[4] showed that stack effect flows sufficient to create safety problems on upper floors would not be likely in fully sprinklered buildings (with working sprinkler systems) or in buildings not tall enough (less than 22 meters under less than extreme weather conditions) to produce strong shaft flows. In some mission-critical applications, it might be appropriate to provide for the small likelihood of a failure of the sprinkler system.

Elevators and Water

Water from fire sprinklers or hose streams can result in safety problems for elevators during fires. Water can enter the hoistway and cause electrical shorts in safety controls, causing them to fail. Water on the drum of the elevator machine can cause the car to slip, although the safety brake would stop a car from overspeeding or falling down the shaft.

To address this situation, elevators protected by sprinklers in the hoistway or machine room are equipped with a shunt breaker to deenergize main power before a sprinkler activates. Connected to a heat detector that would activate before the sprinkler, the shunt breaker activation removes power and stops the elevator, but can result in entrapment. The shunt breaker will not protect the system from water from sprinklers or hose streams at landings leaking into the hoistway.

Firefighters' Emergency Operation

In the mid-1970s, the elevator industry developed Firefighters' Emergency Operation to improve the safety of the system during fires. Smoke detectors are installed in the elevator lobby within 6.4 m (21 ft) of any landing door on each floor. The smoke detectors protect the elevator system by detecting any encroachment of the fire and triggering Phase I recall. The elevator cars are sent immediately to the designated landing, which is generally the level of exit discharge. Once there, the elevators stop, the doors open, and the elevators are locked out of service. If a fire is detected on the designated landing, the cars are sent to an alternate floor.

Upon their arrival, firefighters are able to place individual cars back into manual service by use of a firefighter's key, in what is called Phase II operation. While operating in this mode, a light on the car control panel marked with the symbol of a firefighter's hat is illuminated. In this mode, the controls in the car operate in a special manner designed to protect the firefighter operating the car. For example, the car will move to a selected floor but the doors will not open. Depressing the door open button opens the doors but only as long as the button is depressed. Thus, if smoke enters the car and the firefighter reacts by jumping back, the door will close.

Additional smoke detectors installed at the top of the hoistway and in the machine room monitor the system integrity. If activated, the firefighter's hat light in the car begins to flash, warning the operator that the system may become erratic and to move to a safe location.

It is generally accepted by the experts that as long as the system is operating in normal service (before Phase I activates), the elevators are safe to use, even if there is a fire in the building. Such a fire would need to be sufficiently remote from the elevator lobby so as to not have activated a lobby smoke detector, triggering Phase I recall.

Elevator-Assisted Egress

In the wake of the September 11, 2001, attacks on the World Trade Center Towers, the concept of protected elevators for occupant egress and for fire service access from tall buildings received new interest. The primary issues are the need for more rapid egress from very tall buildings and additional capacity to support simultaneous evacuation of occupants who were now reluctant to await a

phased evacuation. Since even minimal additional egress capacity by stairs has a very large cost penalty in lost leasable space, use of the elevators that are already present is a logical approach. But arguably the most important issue is to provide for self-evacuation of people with disabilities and those for whom evacuation down long stairways presents significant difficulties.

1993 and 2001 WTC Evacuations

In the 1993 bombing at the World Trade Center, it was found that many more occupants experienced difficulties than just those with traditional disabilities. People with temporary disabilities such as broken legs and people with asthma, pregnancy, or obesity all reported difficulties in mobility or stamina that limited their own evacuation abilities and that of others behind them in the stairways.

Recently, Bukowski and Kuligowski[5] benchmarked evacuation times for egress systems designed in accordance with modern building codes. They found that for office occupancies it requires about 5 minutes to empty a floor and 1/2 to 1 minute per floor to egress down stairs without delays for queuing, congestion, or resting (total evacuation times would further need to include preevacuation times). Based on this benchmark, the World Trade Towers would have required 1 to 2 hours (without congestion delays). Observed evacuation time in the 1993 bombing and total evacuation time in 2001 estimated for a full occupant load of 25,000 by state-of-the-art egress models that included queuing and congestion was about double the best case times, or about 4 hours.[6]

One crucial observation from 2001 involves the evacuation of World Trade Center 2 (South Tower) in the 16 minutes between the aircraft strike on the North Tower and the strike on the South Tower. Having seen what happened to the North Tower, many of the occupants in the South Tower decided to evacuate. Since their building was undamaged, many used their normal procedure of elevators. NIST estimated that about 3,000 people evacuated from above the (eventual) aircraft strike zone using the stairs or elevators.[7] After the South Tower was hit, NIST estimated that only 18 additional occupants escaped from above the impact region.

Protected Elevators

NIST has been working on the development of protected (also called "hardened" or "Phase III") elevators in cooperation with the elevator industry, fire alarm industry, and key codes and standards organizations in the hope of developing the needed technology and code provisions to put these into practice. This work is making slow but steady progress and should be ready for demonstration in a year or two.

Early work focused on the issues discussed previously, including water sensitivity and protection of the elevator system from the fire. Enclosed and (real-time) monitored lobbies would provide a protected space for occupants to await the elevator as well as an additional layer of passive protection for the hoistway. Information displays and communication to the fire command station would provide reassurance to those waiting, and direct access to a stair would provide a second way out for those capable of using it. It is expected that people with disabilities would be given priority access to the elevator cars.[8]

An important benchmark of elevator evacuation performance can be seen in the typical design objective for elevator systems. The number, capacity, and speed of elevators are typically designed to move 15 percent of the total occupant load of the building in 5 minutes. This means that a typical system utilizing an efficient evacuation protocol (e.g., ignoring hall and car calls, and operating in a shuttle mode between a 3-floor fire zone and the level of exit discharge) would be capable of evacuating the entire occupant load of 3 floors of a 20-story building or 6 floors of a 40-story building in 5 minutes.

Layers of Protection

In order to protect the elevator system from compromise by the fire and provide a protected space in which to wait, protected elevator systems would incorporate enclosed lobbies on each floor above the level of exit discharge and would be found in fully sprinklered buildings. In a 1993 report done for GSA, Klote, et al.,[9] found that separate staging areas were not needed in fully sprinklered buildings, since the entire building remains tenable as long as the sprinkler system is operational and the fire is not shielded from the sprinkler. The addition of protected lobbies adds an additional layer of protection, not only for the elevator but also for occupants awaiting the arrival of the elevator. This is particularly important for occupants who cannot use the stairs and who need to be protected in place until they can egress using the elevators or be assisted by others.

Hoistway Pressurization

Another function of the lobby is to prevent smoke from exposing people waiting for the elevator as well as to prevent smoke from entering the hoistway. While the lobby enclosure can be made smoke-tight, the door will be opened repeatedly as occupants enter, so a pressurization system would be needed. Based on prior NIST work, it is important to minimize pressure differences across the landing door that might lead to jamming.[10] Thus, a system where the hoistway is pressurized and a positive pressure of the lobby (with respect to the rest of the floor) is produced by leakage through the landing door will provide the desired result. Pressurization of the order of 12 Pa (0.05 inches of water) is a reasonable design value.[1]

Real-Time Monitoring

An important layer of protection is the ability of the fire service to monitor the conditions within the lobbies, hoistway, and machine room in real time to ensure that there are no threats to people or systems. These monitoring functions will be carried out by the fire alarm system and displayed in the fire command station on a special fire service display. These displays comply with National Fire Protection Association (NFPA) and National Electrical Manufacturers Association (NEMA) standards so that they are consistent in form and operation across all equipment manufacturers. All conditions and functionality critical to the safe and reliable operation of the system are monitored.

Information Systems

Crucial to the safety and peace of mind of occupants using the system is the provision of real-time information on the system status. Displays in the lobbies will show waiting occupants that the elevators are in service and how long they will need to wait to be served. People who are capable of using the stairs will be free to do so if they feel the wait is too long, either taking the stairs to a lower level to reenter and await an elevator, or all the way to the street. Should it be necessary to take the elevators out of service, the lobby display would indicate that those capable should use the stairs and others could communicate directly with the fire command station to request assistance.

Evacuation Mode

Elevators are the most efficient at moving people in "shuttle mode," where the times associated with deceleration, loading, and acceleration are minimized. Thus, it has been proposed to establish an evacuation mode of operation that will optimize system performance. In general, evacuation mode would be triggered on a general alarm in the building. All elevators would be captured and returned to the level of exit discharge to unload any passengers. An automatic message in the elevators would explain that there is an emergency reported in the building and the elevators are being put into service to assist in evacuation. Signs on the discharge level would warn people not to enter. One (predesignated) car would be held for fire service access, and the rest would go into evacuation service, moving to the first priority floor group (fire floor, one above, and one below). Destination buttons in the car (car calls) would be disabled, and the buttons that summon the elevator to a floor (hall calls) would register where occupants are awaiting the elevator for egress but would not for direct service.

Once the first priority group of floors is evacuated, the system would serve additional floor groups in a logical order until all occupants have been evacuated. If Phase I recall is activated at any time in the process, evacuation mode would end, but cars could be put into Phase II service if the fire service considers it safe to do so.

Mobility-Impaired Occupants

The evacuations of the World Trade Center Towers in 1993 and in 2001 provided some common lessons regarding egress of people with impaired mobility. First, there are more people who have difficulty in moving long distances down stairs in very tall buildings than those who usually come to mind. People with temporary disabilities (broken legs/sprains using canes or crutches, pregnant, or those injured in the initiating event), asthmatic or other respiratory conditions, obese or other conditions that limit stamina – all have been observed to require extra time and frequent rest stops. In the WTC evacuation, 6 percent of the survivors reported having some preexisting condition that limited their mobility. Even women in high heels and men in new dress shoes were reported to have caused backups in stairs by moving more slowly.[7] While 6 percent is not unreasonable for traditional disabilities, designing for a disabled population of 10 percent would be conservative for many buildings. In some buildings, such as residences for the elderly, the proportion could be considerably higher. A recent paper[11] mentions a fire in Japan where 80 percent of the elderly occupants were unable to evacuate down the stairs and used the elevators successfully.

In the September 11, 2001, evacuation, first responders moving down stairs in WTC 1 after the collapse of WTC 2 found 40 to 60 mobility-impaired occupants on the 12th floor where they had been moved. About 20 of these occupants were being assisted down the stairs just prior to the collapse of WTC 1. It is unclear how many of these or the 20 to 40 others who had been staged on the 12th floor perished.[12]

Conclusions

Protected elevators that can provide for unassisted egress of occupants with disabilities can result in significant reductions in total evacuation times for tall buildings and more efficient flows in stairs by people capable of using them. Considering the optimum flow rates down stairs of 30 seconds per floor without congestion or the need to stop and rest, elevators designed to move 15 percent of the occupant load in 5 minutes could evacuate 60 floors (including wait times) in the same time it takes for occupants to descend 60 floors, or 30 minutes.

By reducing stair flow impediments through the use of elevators for up to half the population, it should be possible to totally evacuate buildings of any height in the order of 30 minutes. Those using the elevators would include all people with disabilities and those highest in the building, while the stairs would be used by the most physically capable from the lower floors. This approach is used by the 88-story Petronas Towers in Kuala Lumpur, Malaysia, where a total evacuation time in a drill was reported to be 32 minutes, utilizing a combination of stairs and elevators.[13]

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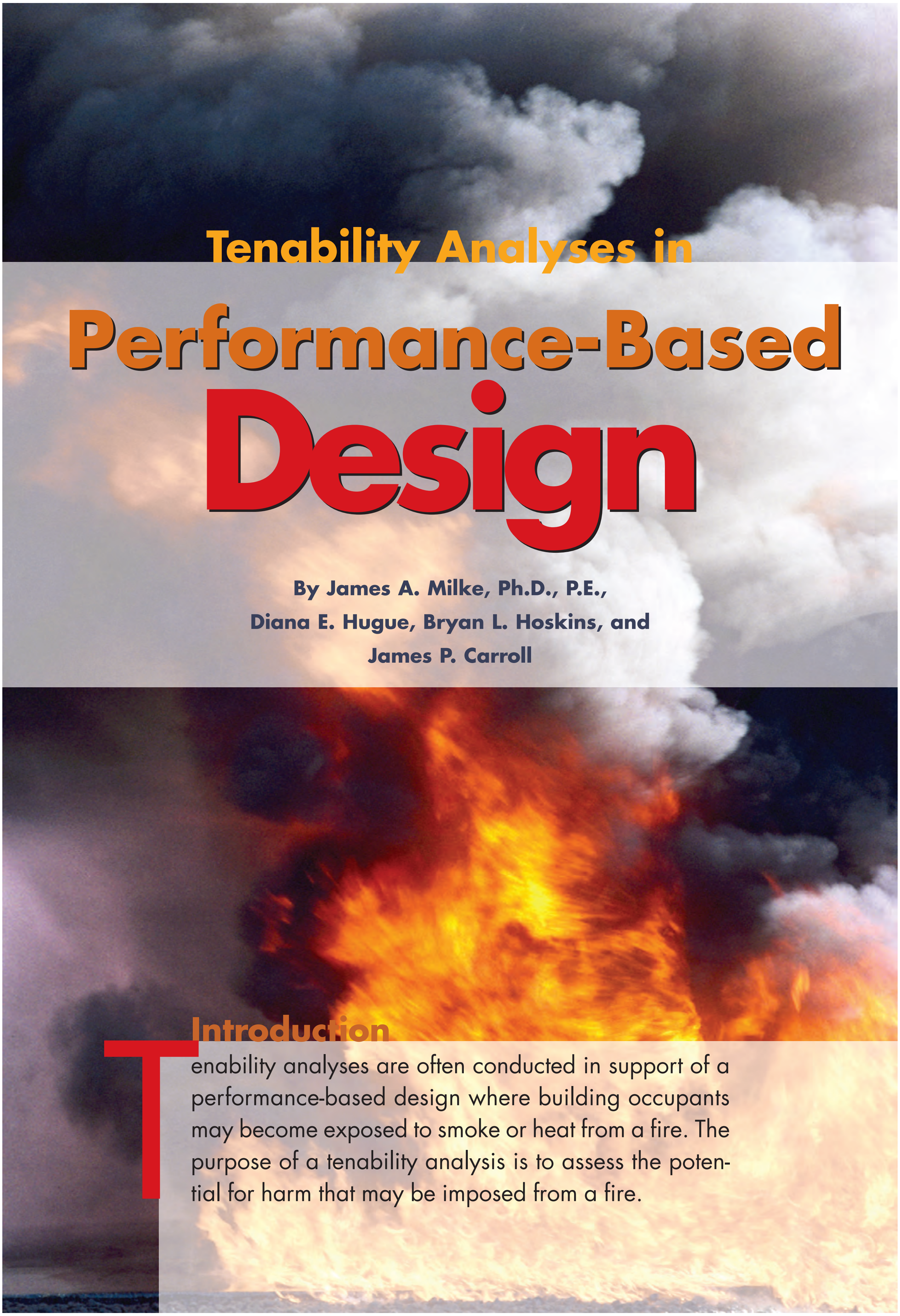

Tenability Analyses in Performance-Based Design

By James A. Milke, Ph.D., P.E.,
Diana E. Hugue, Bryan L. Hoskins, and
James P. Carroll

Introduction

Tenability analyses are often conducted in support of a performance-based design where building occupants may become exposed to smoke or heat from a fire. The purpose of a tenability analysis is to assess the potential for harm that may be imposed from a fire.


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A tenability analysis involves three separate analyses. First, an analysis of the source of the combustion products, i.e., the fire, is conducted to identify the combustion product constituents (gas species and heat) and their respective rates of production. Next, a transport analysis determines under what conditions and when building occupants might become exposed to the conditions. Finally, the effect of the exposure is examined. This paper will concentrate on the third part of a tenability analysis.

The reduction of visibility in a fire due to smoke obscuration is an important consideration in tenability analyses.

Source	Criterion	Notes
NFPA 101[2]	93°C	Area of refuge, smoke layer ≥ 1.5 m above the floor
	49°C	Area of refuge, smoke layer < 1.5 m above the floor
NFPA 130[3] NFPA 502[4]	60°C	short exposures (i.e., a few seconds)
NFPA 130[3] NFPA 502[4]	Average ≤ 49°C	for the first 6 minutes of the exposure
ISO TS 13571[5]	2.5 kW/m^2	short exposures
NFPA 130[3]	2.5 kW/m^2	exposure of 30 minutes
NFPA 502[4]	6.3 kW/m^2 for a few seconds Average ≤ 1.58 kW/m^2 for the first 6 minutes of the exposure Average = 0.95 kW/m^2 for longer exposures	

Table 1. Thermal endpoint criteria in codes and standards

Endpoint Criteria

Endpoint criteria are available in the literature to estimate lethality, incapacitation, and visibility reduction. Strict attention should be paid to the identified endpoints when comparing results or correlations in multiple papers. This paper will emphasize tenability analyses conducted to assess impairment of an individual's ability to self-evacuate, i.e., incapacitation and visibility reduction.

A single threshold magnitude or concentration of any particular combustion product does not exist. If a single value is presented in the literature, it is either incorrect or implicitly assumes a very short exposure, e.g., 5 seconds or less. Instead, valid approaches consider the combination of exposure time and concentration (or magnitude) of the combustion product.

Temperature/heat

Thermal effects are relevant for occupants who are in close proximity to the fire, or under or within the smoke layer. The consequences of the exposure may include hyperthermia, blistering, skin burns, and respiratory tract burns. For subjects submerged in heated smoke with a temperature less than 120°C, the principal limiting effect is hyperthermia, while if in excess of 120°C, pain from skin burns is the significant effect.[1] If the heated air contains less than 10 percent by volume of water vapor, both respiratory tract burns and skin burns are likely.

A summary of the thermal endpoint criteria specified in several codes and standards is provided in Table 1.

Gas inhalation

Asphyxiant gases impair an individual's ability to self-evacuate by decreasing the amount of oxygen available, causing disorientation and possibly unconsciousness.[1] These hypoxic effects can damage both the central nervous and cardiovascular systems. Exposure to CO leads to the production of carboxyhemoglobin (COHb) in the blood, resulting primarily in a decrease in the blood's oxygen-carrying ability.

Irritant gases can cause incapacitation as a result of sensory irritation, i.e., irritation of the eyes, upper respiratory tract, and lungs, and thus can inhibit the ability of an individual to evacuate. In addition, edema and inflammation may be induced, leading to post-fire difficulties or death.

Endpoint criteria for asphyxiant gases are included in *NFPA 101,® 130,* and *502. NFPA 130* and *502* specify the carbon monoxide (CO) tenability limit of 800 ppm, assuming a 30-minute evacuation period. *NFPA 101* specifies a CO tenability limit as an integrated dose, 30,000 ppm-min, e.g., a steady concentration of 1,000 ppm over a 30-minute period. No limits are provided for irritant gases in the standards.

Purser suggests a COHb limit of 30 percent to approximate incapacitation for the average person involved in "light activity."[1]

ISO TS 13571, *NFPA 101*, and *NFPA 130*, also refer to endpoint criteria using a Fractional Effective Dose (FED) analysis (described later in this paper). In that approach, incapacitation is expected for an FED greater than 0.3.

Visibility

The reduction of visibility in a fire due to smoke obscuration is an important consideration in tenability analyses, though it should be treated very differently than an exposure to gas concentrations or heated smoke. Exposure to gas concentrations or heat can directly lead to incapacitation. However, a reduction in visibility does not have such a direct relationship and thus should be treated differently.

The work by Jin[6,7] is often cited in establishing critical visibility levels. This study consisted of relating the walking speed of individuals to the extinction coefficient of the smoke as they walked down a 20-m corridor filled with smoke. Independently, an individual's walking speed in complete darkness was determined to be 0.3 m/s. Consequently, the optical density corresponding to a walking speed of 0.3 m/s for the smoke-filled experiments was considered to be the minimum visibility needed for people familiar with the building to safely egress. For people unfamiliar with the building, the assumed minimum visibility was defined as that which still allowed occupants to travel at the normal walking speed.

In another study by Jin,[8] subjects were seated and asked to push a stylus through different sized holes without touching the edges. Jin related the smoke density for safe escape with that which caused emotional fluctuations in subjects both familiar and unfamiliar with the test facility. These critical densities were 0.15 m^{-1} for people unfamiliar with the building and 0.5 m^{-1} for people familiar.

The difficulty with using these studies is the association of a very slow walking speed with incapacitation or an ability to move. As an example, people regularly walk through dark rooms at night to reach a known destination, perhaps very slowly, and do not become incapacitated, unless perhaps they trip over an object and become injured. In fire situations, a reduction in visibility to near-zero levels can be expected to cause a reduction in movement speed and may cause an individual to seek an alternative path for egress.[9] However, people do move through smoke to reach an exit, even though they cannot see their final destination, especially if the individuals are aware of the presence of an exit on the other side of the smoke volume.[9]

Other researchers have also proposed minimum visibility levels. Kawagoe,[10] Shern,[11] Rasbash,[12] and Kingman[13] proposed minimum visibility levels to be 20 m, 13.5 m, 4.5 m, and 1.2 m, respectively. Shern found that an extinction coefficient of 0.2 m^{-1} prevents safe egress.

Alternatively, Vaught, et al.,[14] addressed the issue of visibility loss in terms of a minimum fuel mass loss concentration in the smoke layer. For well-ventilated fires, Vaught, et al., and ISO TS 13571 proposed that occupants become disoriented at a fuel mass loss concentration of 20 g/m^3. For underventilated conditions, disorientation is anticipated at approximately 10 g/m^3. Vaught, et al., also correlated CO concentration to visibility, suggesting that a CO level between 10 and 35 ppm is equivalent to the critical level of smoke visibility. One interesting aspect of the visibility limits expressed as CO concentration is the small concentration of CO associated with a reduction in visibility. This has also been noted by Milke.[15]

Analysis of Impact of Exposure

The following assumptions are made for all of the methods.

- CO calculations are based on a 70 kg human performing light aerobic work.
- Most toxicity data comes from animal testing.[16]
- The testing considers "average" individuals; results differ for more or less healthy individuals.

Purser[1] outlines the FED and Fractional Effective Concentration (FEC) methods that determine the accumulating effect of a time-changing exposure. The fundamental concept of the FED approach is that when the summation of the proportional fractions of doses of toxicants that would cause an effect equals unity, the effect is expected to occur. The effect can be lethality or incapacitation, depending upon the choice of the correlation upon which the calculation is based. Generally, for tenability analyses, correlations for incapacitation are used.

In fire situations, a reduction in visibility to near-zero levels can be expected to cause a reduction in movement speed and may cause an individual to seek an alternative path for egress.[9]

The toxicological data upon which the equations are based are statistically derived to represent 50 percent of adults being affected. However, in a group of exposed individuals from the general population, some individuals would be more sensitive to the exposure. Consequently, a design relying on a tenability analysis that shows no effect on half of the population implies that half are affected. Such an outcome would not be acceptable. As a result, ISO TS 13571 suggests a tenability FED limit of 0.3 (or lower, depending upon the occupancy) to accommodate more susceptible individuals, as well as allowing for a greater percentage of occupants to escape.

The FED of asphyxiant gases is:

$$FED = \frac{\textit{dose received at time t (Ct)}}{\textit{effective Ct dose to cause incapacitation}} \quad (1)$$

If multiple gases are present, the FED equation is expressed as:

$$FED = \sum_i F_i \quad (2)$$

The expressions for F_{CO} and. F_{HCN} are provided as equations (3) and (4)[1].

$$F_{CO} = \frac{K C_{CO}^{1.036} t}{D} \quad (3)$$

$$F_{HCN} = \frac{1}{\exp(5.396 - .023 C_{HCN})} \quad (4)$$

For light levels of activity, e.g., walking, the value of K is 8.29×10^{-4} for an RMV of 25 L/min. Also, the COHb level at incapacitation is approximately 30 percent for an average person involved in "light activity."

The technical basis for equation (3) is greater than that for equation (4). The body's exchange mechanisms of CO are better known. Further, the time-dependent decrease in COHb levels in the blood following death is better understood than that for HCN. Adjustments to equation (3) are possible for different activity levels, though no such adjustments exist for HCN.

If the concentration of carbon dioxide is greater than 2 percent by volume, an individual's respiratory rate will increase. In such cases, the F_is determined from equations (3) and (4) should be increased by V_{CO_2}:[1]

$$V_{CO_2} = \exp \frac{[\%CO_2]}{5} \quad (5)$$

An alternative FED approach, presented as equation (6) is included in ISO TS 13571.

$$FED = \sum_{i=1}^{n} \sum_{t_1}^{t_2} \frac{C_i}{(Ct)_i} \Delta t \quad (6)$$

$(Ct)_i$ is the specific exposure dose in *ppm*min* that prevent an occupant's safe escape. The doses are summed for different species over the duration of the exposure. Considering CO and HCN as the asphyxiant gases with the most significant effect on available time for escape, the equation (6) becomes:

$$FED = \sum_{t_1}^{t_2} \frac{[CO]}{35{,}000\,ppm \bullet \min} \Delta t + \sum_{t_1}^{t_2} \frac{\exp([HCN]/43)}{220 \min} \Delta t \quad (7)$$

Where *[ ]* indicates the average concentration of a gas over the selected time increment, Δt.

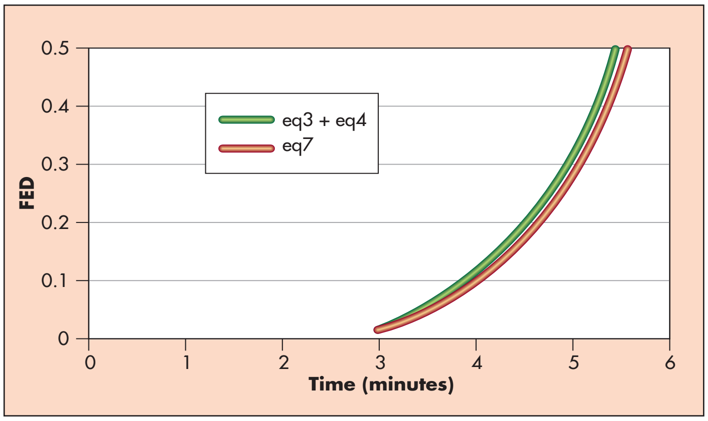

Figure 1. Comparison of FED estimates

A comparison of the results from the addition of equations (3) and (4) with those using equation (7) is presented in Figure 1. In general, the FED predicted by equations (3) and (4) are similar to those from equation (7), as expected given their common basis.

The effects of irritant gases can be calculated as an FEC. The FEC approach is based only on the concentration of each irritant, with the effects being considered instantaneous upon exposure.[1] Analogous to FED, the FEC concept is based on summation of the proportional fractions of concentrations of irritant toxicants that would cause an effect. Suggested criteria for significant irritant effects in 50 percent of the population are presented in ISO TS 13571. Again, ISO TS 13571 suggests the sum limited to 0.3 in order to avoid an undesired effect from the exposure. The FEC approach adds the effect of multiple irritant substances produced in smoke, as indicated in equation (8).[5]

$$FEC = \frac{[HCl]}{F_{HCl}} + \frac{[HBr]}{F_{HBr}} + \frac{[HF]}{F_{HF}} + \frac{[SO_2]}{F_{SO_2}} + \frac{[NO_2]}{F_{NO_2}} + \frac{[acrolein]}{F_{arcolein}} + \frac{[formaldehyde]}{F_{formaldehyde}} + \sum \frac{[irritant]}{F_G} \quad (8)$$

The numerators are the irritant gas concentrations (in ppm) generated by the exposure and the F_i in the denominators are the irritant gas concentrations (ppm) that are expected to seriously compromise an occupant's ability to take effective action in order to accomplish escape (see Table 2).

Purser[1] suggests that the FEC for irritant gases can be added to the FED for asphyxiant gases when both are present.

Irritant Gas	F_i (ppm)	Irritant Gas	F_i (ppm)
HCl	1,000	Formaldehyde	250
HBr	1,000	SO_2	150
HF	500	Acrolein	30
NO_2	250		

Table 2. F_i for common irritant gases in smoke

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Toxic Potency

An alternative to the FED method is Purser's method of toxic potency.[1] The toxic potency method takes into account the combined effects of irritant gases, asphyxiant gases, and lung inflammation. The advantage of the toxic potency method is that input is based solely on the fuel, not the individual combustion products generated. As such, the yields of individual combustion gases are not required. Because not many materials have been tested for their toxic potency, data for many fuels are not available.

A toxic potency analysis requires:

1. Description of fire scenario (smoldering, early flaming, or post-flashover).
2. The mass loss-time curve for the fire.
3. The rodent LCt_{50} (product of LC_{50} and exposure time), determined under the same conditions as those in the postulated fire scenario.

Because of limited space being available here, readers are referred to the description of the toxic potency analysis included in NFPA 269[17] and ISO TS 13571.[5]

Temperature/Heat

Wieczorek and Dembsey[18] developed correlations to estimate the time for the onset of pain (equation 10) and time for second-degree burns (equation 11) as a function of heat flux:

$$t_p = 125\dot{q}_r''^{-1.9} \quad (9)$$

$$t_{2b} = 260\dot{q}_r''^{-1.56} \quad (10)$$

NFPA 130[3] and ISO TS 13571[5] provide an FED model for thermal effects using the following correlations.

$$t_{Irad} = \frac{4}{(\dot{q}_r'')^{1.35}} \quad (11)$$

Assuming black-body radiation, the heat flux can be replaced by the temperature of the smoke layer:

$$t_{Irad} = \frac{2.72\text{x}10^{14}}{(T+273)^{1.35}} \quad (12)$$

The time to incapacitation for convective heating is:

$$t_{Iconv} = (4.1\text{x}10^8)T^{-3.61} \quad \text{fully clothed subject} \quad (13)$$

$$t_{conv} = (5\times10^7)T^{-3.4} \quad \text{lightly clothed or unclothed subject} \quad (14)$$

The combined effect of both radiative and convective heating for someone submerged in the smoke layer (from any of the above equations) is:

$$FED = \sum\left(\frac{1}{t_{Irad}} + \frac{1}{t_{Iconv}}\right)\Delta t \quad (15)$$

Nomenclature

- C_i : Concentration of gas specie "i" (ppm)
- c : visual contrast
- D : COHb concentration for incapacitation
- F_i : fractional dose
- L : the smoke-filled distance between an object and the viewer (m)
- K : $8.29\text{x}10^{-4}$ (for light activity)
- M : the mass concentration of smoke aerosol (g/m^3)
- Δm : mass loss (g)
- $\dot{q}_r''$: intensity of thermal radiation (kW/m^2)
- T : temperature (°C)
- t : time after flaming ignition (sec)
- t_{conv} : time in minutes
- t_p : exposure time to pain (sec)
- t_{2b} : exposure time to second-degree burn (sec)
- Δt : time increment (min)
- V : volume (m^3)
- Y_i : mass fraction of gas specie "i" (kg of specie "i" per kg of smoke)

James Milke, Diana Hugue, Bryan Hoskins, and James Carroll are with the University of Maryland.

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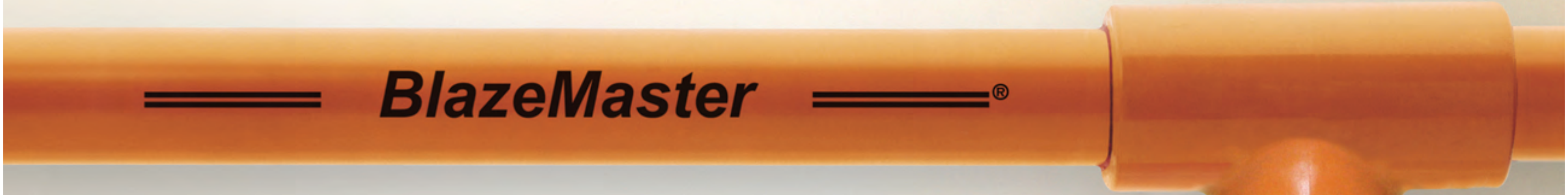

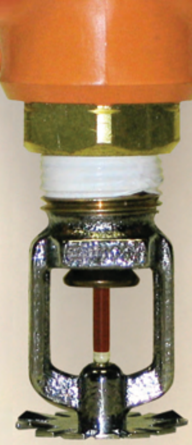

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MASS NOTIFICATION SYSTEMS

SCENARIOS: A truck parks outside of an apartment for military personnel; when approached by security officers, the occupants get into another waiting vehicle and speed away. A vehicle is car-jacked with a toddler still strapped into a car seat in the back. A railroad tanker car carrying chlorine gas overturns upwind from a residential neighborhood. A fire is detected in a laundry room on the third floor of a high-rise apartment building. An overnight boiler failure necessitates the canceling of high school classes. A disgruntled employee barges past security into an office building – possibly carrying a weapon. A motorist spots a distant tornado.

What do these scenarios have in common? Some are natural and others are man-made disasters. Some signify increased risk, while others are immediate hazards and emergencies. One of the scenarios is merely an inconvenience. However, the common thread is that they all necessitate a need to communicate to people.

Those who grew up in the 1950s and '60s are familiar with the old Civil Defense Warning System used to provide alerting to entire neighborhoods, towns, and cities. In many parts of the world, tornado, hurricane, and tsunami warning systems provide alerting and, sometimes, information. An effective detection and alerting system could have saved many lives during the recent Southeast Asia tsunami disaster. High-rise buildings often use Emergency Voice/Alarm Communication (EVAC) systems to alert and inform the occupants of fire and other emergencies. These are all forms or types of Mass Notification Systems.

Setting Standards for Excellence

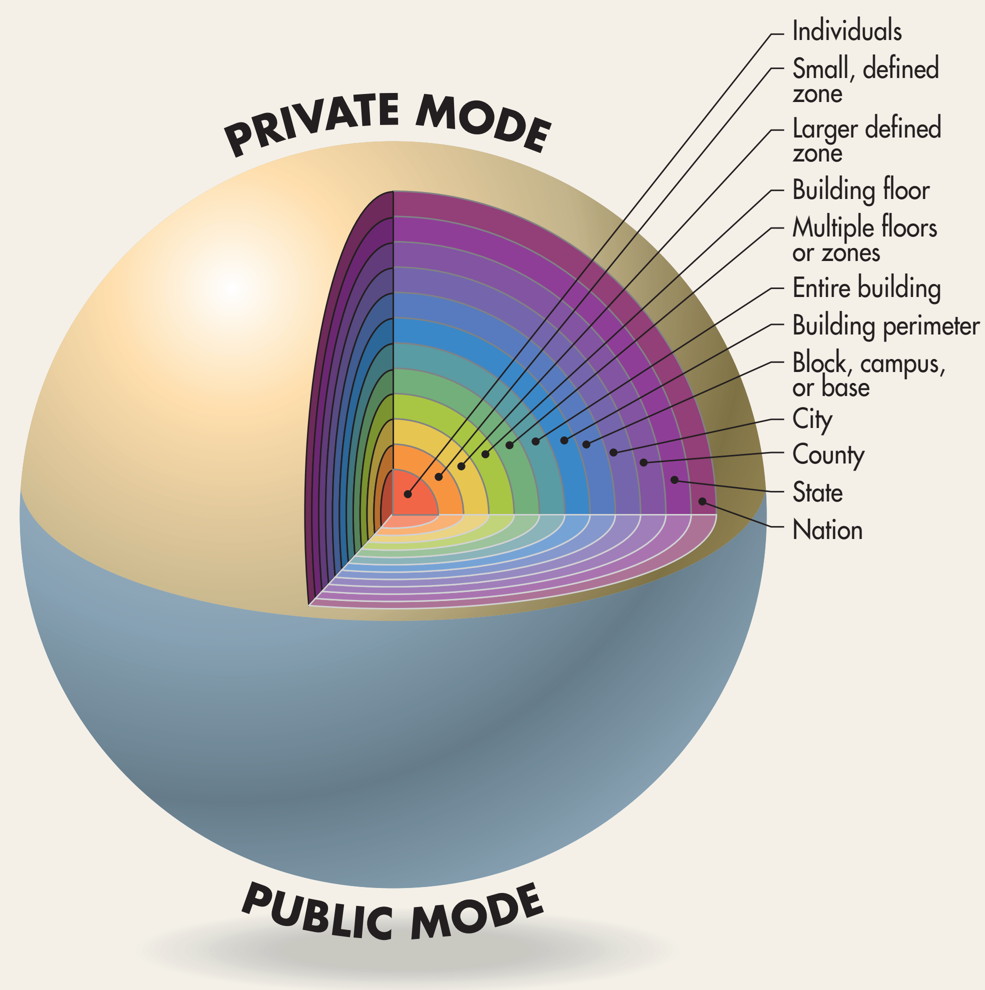
The world has changed since September 11, 2001. However, even before 9/11, events such as the bombing of the Kohbar Towers in June of 1996 emphasized the need for rapid, informative communications, both for prevention and for emergency management. One goal cited in the National Strategy for Homeland Security[1] is for a system "to ensure that leaders at all levels of government have complete incident awareness and can communicate with and command all appropriate response personnel." Similarly, the Department of Defense (DoD) Unified Facilities Criteria (UFC) Minimum Antiterrorism Standards for Buildings[2] mandates that almost all DoD facilities have some form of a Mass Notification System. A direct result of that mandate is the UFC 4-021-01 document for the design, operation, and maintenance of Mass Notification Systems.[3] The developers of that standard requested the National Fire Protection Association (NFPA) to consider a project to draft a complete standard for Mass Notification Systems. That task was directed to the committee on Signaling Systems for the Protection of Life and Property, which also has responsibility for *NFPA 72, The National Fire Alarm Code*.

The Technical Correlating Committee formed a Task Group composed of members of the existing technical committees as well as many persons already involved as users, designers, manufacturers, and installers of non-fire Mass Notification Systems. The Task Group has drafted a proposed Annex to *NFPA 72* for Mass Notification Systems. In addition, the Task Group and the regular Technical Committees of *NFPA 72* have worked to change, add, or delete existing language in *NFPA 72* to make the document more suitable and applicable for application to Mass Notification Systems.

A Mass Notification System (MNS) is used to provide information and instructions to people in a building, area, site, or other space using intelligible voice communications and possibly including visible signals, text, graphics, tactile, or other communications methods.[4]

In a broad context, an MNS is a communication and emergency management tool. In the simplest form, it may be used to manually alert or notify some or all occupants of a space that an emergency exists. Many fire

Figure 1



alarm systems fit this description – they provide alerting, but no additional information, and are intended to be used only for fire warning, leaving the recipient to take actions they deem appropriate or for which they have been trained or "programmed." However, the title and definition of Mass Notification Systems is meant to encompass greater possibilities for communication, information dissemination, and personnel management.

Depending on the situational needs, an MNS may be a simple alarm system, or it may be a highly secure command and control system suitable for use in a variety of situations including biological, poison gas, and nuclear terror threats; bombings; antipersonnel attacks; etc. Also, the system may be one-way or two-way. That is, it may be used only to give information to the target audience, or area, or it may be designed to also receive and transmit information to a command center in the form of real-time sensor data or text, voice, or video communications from the scene.

NFPA 72[5] defines the Public and Private Operating modes as:

<u>*Private Operating Mode*</u>

Audible or visible signaling only to those persons directly concerned with the implementation and direction of emergency action initiation and procedure in the area protected by the fire alarm system.

<u>*Public Operating Mode*</u>

Audible or visible signaling to occupants or inhabitants of the area protected by the fire alarm system.

Based on proposals received and processed by the *NFPA 72* Technical Committees, it is expected that these definitions will be modified slightly to reflect signaling for purposes other than just fire. An MNS may operate in either or both operating modes. In many situations, an MNS will operate in both modes simultaneously.

It must also be recognized that an MNS may be intended for signaling within a building or structure, or to a wide area such as a campus, industrial park, military base, or even a city. In a very broad context, an MNS could trigger nationwide alerting via radio, television, SMS (Short Message Services, such as mobile phone text messaging and Instant Messaging), Amber Alert systems, "giant voice" systems, Internet news alerts, automated telephone messaging, etc. The planning and design of an MNS begins with a Threat and Needs Assessment. As with a fire protection risk assessment, a Threat and Needs Assessment will identify specific and potential hazards and their estimated probabilities. Laws, codes, regulations, or corporate policies will establish specific goals for the protection of life, property, and mission. Combined, these goals lead the development of the system "needs," or the overall system scope and definition of the system. The threat and the needs must both be considered in the context of public versus private operating mode as well as the "extent", or area served by system. Figure 1 shows a segmented, multilayered approach for threat assessment, needs assessment, and communication.

In a simple form, an MNS will provide voice instructions. How will a system provide visible communications? Presently, most systems incorporate strobes as do fire alarm systems. However, unlike voice (whether prerecorded or live), a strobe does not impart information, it only provides alerting. A better solution for visual communication is the use of text appliances such as scrolling displays used in train stations and stadiums, or smaller LCD displays such as are common on today's fire alarm systems. These would be distributed around a property or located at specific stations. Systems may also make use of existing computer and CCTV networks. The problem is that the textual information cannot penetrate all spaces in the same way as audible signaling methods. So, strobes may continue to be used for general area coverage to mean "leave the building or area" or "get additional information."

Mass Notification Systems may also interface or incorporate other forms of textual communication. For instance, a system may interface to a computer network and cause a pop-up to occur on all networked computers, or it may broadcast a text message to cell phones and pagers.

The configuration and complexity of Mass Notification Systems will vary greatly depending on the Threat and Needs Assessment. Therefore, the actual components and the codes and standards that address Mass Notification Systems must be flexible and modular. How will all these different systems share information and interface with each other? One possibility is through the use of a CAP – Common Alerting Protocol.[6]

In 2000, a Working Group of the National Science and Technology Council issued a report titled "Effective Disaster Warnings."[7] The committee stated: *"A standard method should be developed to collect and relay instantaneously and automatically all types of hazard warnings and reports locally, regionally, and nationally for input into a wide variety of dissemination systems."* A Working Group was formed and developed a draft specification for a CAP to address this need. The CAP specification is a standard message format for emergency information to be packaged and sent in an XML format.

The Partnership for Public Warning[8] endorsed the CAP standard, which was then submitted to the Organization for the Advancement of Structured Information Standards (OASIS).[9] The Notification Methods and Messages Subcommittee of the OASIS Emergency Management XML Technical Committee has accepted the draft CAP standard and is in the process of reviewing and refining the standard.

The CAP standardizes the format and the exchange of emergency alert and public warning information over data networks and computer-controlled warning systems. One example of the use of the CAP is a community weather warning system that receives a message packet from the National Oceanic and Atmospheric Administration. Elements in the message packet may automatically trigger deployment of the message. The specific message content may be displayed, or it may be translated to audio/voice alerts.

Although developed for wide area use, the protocol can also be used by smaller system components forming a system for a building. For example, an incident commander may use a laptop computer with secure radio network capability to send either custom or predefined messages to a building's voice fire alarm system.

As more government, military, and civilian facilities and communities begin incorporating Mass Notification Systems into their emergency planning, codes and standards will evolve to meet the needs of the users, planners, designers, and installers. The 2006 edition of *NFPA 72, The National Fire Alarm Code*, is currently being developed, and Mass Notification Systems will be incorporated in a new Annex to the code. That Annex is published in NFPA's 2006 *Report on Proposals*. The use of CAP has not yet been considered by the NFPA Task Group on Mass Notification Systems. Similarly, many other features of MNS, such as the use of strobes, network security, matching of needs and system features, etc., have either not been addressed or have been kept flexible for the current draft.

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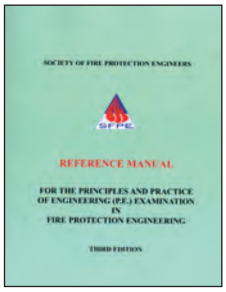
Editor's Note – About This Article

This is a continuing series of articles that is supported by the National Electrical Manufacturer's Association (NEMA), Signaling Protection and Communications Section, and is intended to provide fire alarm industry-related information to members of the fire protection engineering profession.

RESOURCES>>>

SFPE Reference/Answer Manual for the Principles and Practice of Engineering (P.E.) Examination in Fire Protection Engineering, 3rd Edition, 2005



This is the most comprehensive study guide available for those interested in taking the PE exam in fire protection engineering. It includes practical information on engineering licensure and provides suggestions on how to prepare for the exam. The reference manual includes information on all of the exam subject areas, including practice problems. A separate answer manual (included) provides solutions to the practice problems. 600 pages/78 pages.

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Designer's Guide to Automatic Sprinkler Systems

Robert M. Gagnon, PE, SET, FSFPE-Editor

This book provides in-depth instruction into the engineering aspects of automatic sprinkler system design. It is an excellent learning tool for engineers who are new to the design of sprinkler systems and a great reference for seasoned professionals. Subjects covered in the book include hazard and commodity classification, design of water supply, unique sprinkler system applications, protection of storage, specifications writing, shop drawing review, and many other topics. The *Designer's Guide to Automatic Sprinkler Systems* is a "must-have" for any engineer involved in designing automatic sprinkler systems.

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Authors: David Icove and John DeHaan

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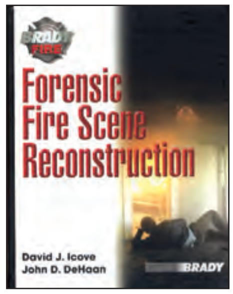

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SFPE Annual Meeting and Professional Development Conference
San Diego, CA
Info: www.sfpe.org

October 20, 2005
Fire Safety in Terrestrial Passenger Transportation
Santander, Spain
Info: grupos.unican.es/GIDAI

November 2-4, 2005
Fire Safety – Sea Road Rail International Conference
Melbourne, Australia
Info: www.rocarm.com/FSAS05CFP.htm

May 11-12, 2006
Fourth International Workshop Structures in Fire – SiF'06
Aveiro, Portugal
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PRODUCTS / LITERATURE >>>

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Imagine that two people, Mary and the person who is speaking, were taking a test. The choices for one of the questions were either a) "had," or b) "had had." The person who is speaking is discussing the choices that were selected.

Mary had "had." I had "had had." "Had had" had had the teacher's approval.

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From the TECHNICAL DIRECTOR

NIST Recommends FPEs on Building Design Teams

On June 23, 2005, the National Institute of Standards and Technology (NIST) released their draft "Final Report of the National Construction Safety Team on the Collapses of the World Trade Center Towers." This draft report contains 43 documents totaling approximately 10,000 pages, and represents 34 months of investigative analysis conducted by approximately 200 people. This investigation is the most in-depth study of building performance of the World Trade Center Towers on September 11, 2001.

Based on the findings of their investigation, NIST prepared a series of recommended changes in the way buildings are designed, constructed, maintained, and used, and in emergency evacuation and emergency response procedures. Particularly noteworthy is one of their recommendations, which states:

"NIST recommends that the role of the 'Design Professional in Responsible Charge' should be clarified to ensure that: (1) all appropriate design professionals (including, e.g., the fire protection engineer) are part of the design team providing the standard of care when designing buildings employing innovative or unusual fire safety systems, and (2) all appropriate design professionals (including, e.g., the structural engineer and the fire protection engineer) are part of the design team providing the standard of care when designing the structure to resist fires, in buildings that employ innovative or unusual structural and fire safety systems."

> Fire protection engineers bring unique strengths to the design process.

Fire protection engineers bring unique strengths to the design process. Fire protection engineers are the only design professionals that have a detailed understanding of fire, how fire impacts people and buildings, how fire protection technologies can be used to protect people and property, and how to integrate fire protection systems with other building features.

In the case of structural fire resistance design, the current prescriptive design techniques do not require an analysis of fire behavior, heat transfer, and structural response. While this design approach has served society well for quite some time, it may not be suitable in all design situations. Moreover, the current prescriptive structural fire resistance design techniques are frequently applied by professionals who have limited or no training or experience in fire behavior and who may not recognize circumstances where more in-depth analysis is required. Combining the strengths of fire protection engineers and structural engineers in the design of structural fire resistance brings a number of advantages. These include:

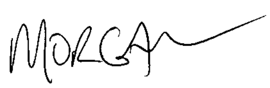
- Understanding the damage that could result in the case of fire;
- Ensuring that the structure can respond to the fire conditions to which it may be subjected; and
- Providing fire resistance commensurate with stated design goals for a structure.

However, fire protection engineers should not only be used on design teams for buildings that employ innovative or unique structural and fire safety systems. Just as specialized expertise is needed to design innovative or unusual buildings, the same specialized expertise is required to determine what constitutes an innovative or unusual design. For fire protection designs, only fire protection engineers bring the required expertise to determine if a traditional, prescriptive design approach is suitable or if more in-depth analysis is required. Because of the specialized expertise that fire protection engineers bring, some clients, for example, many U.S. government agencies, require a fire protection engineer on design teams where fire protection is within the scope of work.

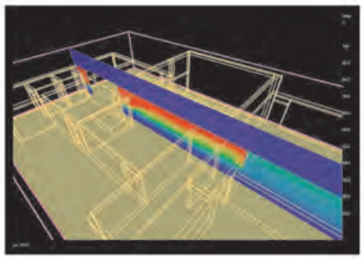
It is a position of the Society of Fire Protection Engineers that all fire protection designs should be prepared under the supervision of a fire protection engineer. Accordingly, we suggested that NIST expand their recommendation in their final report to include all fire protection designs.

In their comments to NIST, the American Institute of Architects stated it is presently standard practice to include appropriate professionals on the design team. The Structural Engineering Institute of the American Society of Civil Engineers commented that assignment of roles and responsibilities should be handled in contract documents, and not in codes and standards.

In an ideal world, all principal design professionals would recognize when a fire protection engineer (or other type of engineer) is needed on a design team based on the scope of work. However, this is presently not the case. Fire protection designs are sometimes executed by professionals other than fire protection engineers. Leaving the decision of whether to include a fire protection engineer on the design team to principal design professionals may not be the best course of action.



Morgan J. Hurley, P.E.
Technical Director
Society of Fire Protection Engineers



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