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Representation of Human Behaviour in Fire

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Abstract This chapter addresses the information available to current practitioners regarding how people typically behave during an evacuation, the tools used to represent this performance and how these tools might be properly implemented. The focus is on individual evacuee performance – what we know about it and how it might be represented. This chapter is then intended to encourage practitioners to ask questions of their assumptions and of the models deployed in order to produce credible and robust solutions.

1. Introduction

For a building to be constructed and occupied, the engineer must first establish that the building provides a sufficient level of safety during a fire incident. Structures are currently designed and constructed in accordance with prescriptive and performance-based (PBD) methodologies to ensure this level of safety.

Prescriptive approaches rely on the application of a predetermined set of rules that, if employed, typically allow the design to be *deemed* safe [1]. However, the achieved degree of safety is not always apparent. In contrast, performance-based designs rely on a quantitative assessment of the fire and evacuation performance levels achieved. This approach requires the quantification of both ASET (Available Safe Egress Time - the time before conditions become untenable) and RSET (Required Safe Egress Time - the time for the population to get to a place of safety, as represented by the required safe egress time). These are then compared to establish whether there is sufficient time, potentially including a margin of safety, for the population to reach safety before conditions become untenable.

Currently, anywhere from simple engineering equations to complex evacuation modelling techniques are used to estimate RSET for a building or other types of structure.

However, these models tend to simplify[1] the behaviour of occupants, if behaviour is simulated at all. Current models that provide the option to simulate behavioural aspects of evacuee performance place a heavy burden on the practitioner if this is to be done properly. Whereas theories of human movement in evacuation exist [2], and are incorporated into modelling techniques, a comprehensive, generalized theory of human behaviour in fire does not exist[2].

An understanding of human behaviour in fire when assessing the life safety of a structure is essential. In the past, evacuee decision-making process was assumed to be either panic-based and effectively unpredictable or too complicated to understand, and was then excluded from an assessment of performance. These contradictory positions were often employed simultaneously and, although anecdotal examples were identified to support both positions, were largely inaccurate. In the context of this chapter, it is important that we understand evacuee behaviour such that we can model it – and use it to quantify performance in the design process. It is certainly impractical (and likely impossible) to predict the actions of any individual with any confidence; however, it is possible to identify the factors that might influence performance and the types of responses associated with these factors. This will then enable us to determine where the decision-making process, as opposed to physical movement, determines the time to reach safety and quantify this process.

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[1] This simplification, in particular, the engineering timeline, is discussed in Chapter 1, where the engineering timeline is presented in detail.

[2] Work has been performed by behavioural researchers to develop conceptual models of human behaviour in fire. These models often reflect a specific incident [55] or behavioural from a specific type of building [65]. Work is still required to develop a comprehensive theoretical model for all types of fire scenarios and occupancies/buildings.

The Beverly Hills Supper Club fire [3] provides an example where both of these prior assumptions are not appropriate and demonstrates the importance of understanding human behaviour in fire. A fire developed in one part of the structure, while several hundred patrons were seated elsewhere, some distance from the seat of the fire. The fire developed and eventually smoke travelled along the adjoining corridor – the corridor used by patrons to enter the structure. The smoke reached the large number of patrons (seated in the Cabaret Room). This was their first notification of the incident and that their familiar means of egress was blocked. There were two emergency exits from the Cabaret Room that were unfamiliar to the patron population and recessed such that they could not easily be seen. A busboy (Walter Bailey) took it upon himself to direct the patrons to both exits. Although over 160 people died in that room, the death toll would have been much higher had the patrons not been made aware of the exits available. This indicates the importance of information to the evacuation process, somewhat contradicting the prevailing wisdom. In addition, Feinberg and Johnson examined the incident to establish the likely occurrence of panic in conditions that would be assumed to promote this behaviour [3]. They postulated that, if panic had occurred, social groups would have broken down leading groups to separate. In contrast, they found that social groups tended to escape or succumb together. This incident provides an example of the importance of understanding evacuee behaviour (e.g. familiarity, exit awareness, situational awareness, etc.) and the inaccuracy of assuming that evacuee behaviour will be dominated by a panic-based response.

Without a theoretical representation of human behaviour in fire, significant consequences can arise for evacuation model users, evacuation model developers, building owners, public safety officials, codes and standards development organizations, and those who judge evacuation analysis (i.e. the authority having jurisdiction). Not only are model users required to identify/describe the scenario, many current models also require the user to determine the expected behavioural response of the population to some/all of the scenario conditions faced[4]. Evacuation models are also limited in their representation of human behaviour during evacuation; often requiring users to provide a large amount of input data on evacuee behaviours. Input may include what behaviours are performed and potentially the outcome of the performance. In addition, the lack of a generalized theory of human behaviour in fire can result in a greater reliance upon default values/settings provided by the egress model, or an artificial focus on physical responses [5].

Therefore, what is needed is the development of a comprehensive conceptual model of evacuee decision-making and behaviour during fire events. Such a conceptual model could then be embedded into engineering and computational models to begin to predict human behaviour in fire situations. Insight on human decision-making and behaviour during fires can be gained from disciplines in the social sciences, such as sociology, psychology, and human factors and ergonomics.

To summarize:

– RSET models tend to focus solely on the simulation of human movement, rather than human behaviour, during evacuation.
– Evacuee behaviours can account for a significant portion of overall evacuation time; therefore an accurate representation is essential for many scenarios.
– An understanding of human behaviour is essential when calculating RSET, and the lack of such understanding affects many different stakeholders in the fire protection community.
– A conceptual model of human behaviour in fire is needed.
– Data on human behaviour in fire should be collected to confirm or refine this theory.

2. Chapter purpose

The purpose of this chapter is to identify the ways in which practitioners and model developers can account for human behaviour in fire, both now and in the future, in the use and development of evacuation models. This chapter begins with two sections that discuss our current understanding in human behaviour in fire. Section 3 discusses behavioural theory from the natural and technological disasters, not necessarily including building fires, that describes the ways in which occupants make decisions and take protective action during emergencies. Section 4 identifies "behavioural statements" or mini-theories from human behaviour in fire studies (or similar). Rather than reflecting a comprehensive theory, these statements provide a piece-meal view of our theoretical understanding of human behaviour during fire.

A discussion of current theory is important because it provides; 1) an indication of our current understanding of evacuee response, which in turn, helps to identify the gaps in our knowledge of the topics, and 2) a benchmark against which current model representation of evacuee behaviour, introduced later in the chapter, can be measured.

The next section, Section 5, provides an overview of methods that can be used to collect data on human behaviour in fire. This section is important because, without appropriately collected and sufficiently documented data, the development of a comprehensive theory on human behaviour in fire is not possible.

The chapter ends with Sections 6 and 7 that focus on representing human behaviour in fire within evacuation models. Section 6 discusses the different approaches currently used by evacuation models to represent evacuee behaviour. With the use of these current approaches, it is the hope that practitioners ask questions of their assumptions and of the models deployed in order to produce more credible and robust solutions. Section 7 concludes with an example of a conceptual model of human behaviour in fire, intended to get model developers and users thinking of the ways in which to incorporate these types of theories into current evacuation modelling techniques.

3. Theory of human behaviour in other disasters

In a fire emergency, individuals are required to make a concerted effort to create meaning out of new and unfamiliar situations, often under time pressure. From this meaning, a set of actions, different from those that have become routine, must be created. Emergent norm theory (ENT), explains the process of meaning-making in the face of uncertain conditions [6], stating that in situations where an event occurs that creates a normative crisis (i.e. an event where the institutionalized norms may no longer apply), such as a building fire, individuals interact collectively to create an emergent situationally-specific set of norms to guide their future behaviour. In other words, individuals work together to redefine the situation and propose a new set of actions, which is the product of milling and keynoting processes.

Milling is a communication process whereby individuals come together in an attempt to define the situation, propose and adopt new appropriate norms for behaviour, and seek coordinated action to find a solution to the shared problem at hand [7]. The group engages in both physical and verbal communication in order to ask the three following questions: 1) what happened? 2) what should we do? and 3) who should act first? (with the final question referring to leadership selection) [8,9]. Leaders emerge as keynoters, or those who advance suggested interpretations of the event or suggestions on what do to next [6, 10].

The consequences of the milling process are that individuals become sensitized to one another, that a common mood develops, and that a collective definition of the situation is decided upon that minimizes initial ambiguity [9]. Overall, in the face of new and uncertain situations, milling and the keynoting processes allow the group to define the situation and to propose next steps for alternative schemes of social action [6, 7, 10].

A decision-making model has been developed that extends and applies ENT's explanation of the meaning-making process in crises to disaster situations. The Protective Action Decision Model (PADM), which is based on over 50 years of empirical studies of hazards and disasters [11-15], provides a framework that describes the information flow and decision-making that influences protective actions taken in response to natural and technological disasters [16]. The model posits that cues from the physical environment (e.g. the sight of smoke) or the social environment (i.e. emergency messages or warnings), if perceived as indicating the existence of a threat, can interrupt normal activities of the recipient. Depending upon the perceived characteristics of the threat (e.g. what is going on and how dangerous is it?), individuals will either seek additional information, engage in actions to protect people or property, perform actions to reduce psychological stresses, or resume normal activities (as indicated above)[16]. In addition to perceptions of the threat, responses are also determined by the perceived feasibility of protective actions.

The PADM asserts that the process of decision-making begins when people witness cues from the disaster event. Individuals can encounter only one type of cue (for example, seeing smoke) or may be presented with a variety of different cues, including environmental cues, the behaviour of others, and warning messages. The introduction of these cues initiates a series of pre-decisional processes that must occur in order for the individual to perform protective actions. However, the PADM does not provide detailed information on the *types* of protective actions in which occupants engage and why they engage in these actions during emergencies.

The individual must receive the cue(s). In a fire, occupants are presented with external cues. These cues can be physical or social in nature, meaning that they arise from the physical environment or the social environment; e.g. breaking glass and actions taken by the building population, respectively. These cues can be presented alone or several at a time, depending upon the nature of the event. Physical and social cues produced in a building fire can be received by occupants through hearing (e.g. an alarm or authority warning), smelling (e.g. smoke), seeing (e.g. others running), tasting (e.g. sulphur dioxide or hydrogen chloride), and/or touching (e.g. heat). Given the nature of the situation and individual sensory capabilities, it should not be expected that all people will have access to the same external information or will perceive it in the same way [17]. Just because an individual receives a cue does not necessarily mean that s/he has paid attention to it. Therefore, the next step involves the individual paying attention to the cue(s). This pre-decisional process involves the individual cognitively registering that a cue has been received and beginning to provide the necessary attention, which leads to the last pre-decisional process, i.e. comprehension. Comprehension means understanding the information that is being conveyed. If the message uses a different language or highly technical terms, comprehension will be difficult.

Comprehension also refers to the development of an accurate understanding of environmental cues. For example, will the individual understand that the smoke s/he smells is coming from a building fire rather than from burnt toast in the kitchen?

After the three pre-decisional processes are completed, the core of the decision-making model consists of a series of five questions [16]:

1. Is there a real threat that I need to pay attention to? [If yes, then the individual believes the threat]
2. Do I need to take protective action? [If yes, then the individual decides that s/he needs to take protective action]
3. What can be done to achieve protection? [The individual begins searching for possible protective action strategies]
4. What is the best method of protection? [The individual chooses one of the action strategies developed in the previous stage and develops a protective action strategy or plan]
5. Does protective action need to be taken now? [If yes, the individual follows the plan developed in the previous stage]

Individuals must "answer" each question in order to proceed through the perceptual-behavioural sequence, in which the outcome of the process is the performance of a behavioural action. If, at any time, the individual cannot answer a question, they engage in actions to seek additional information – asking themselves or others: a) what information do I need? b) where and how can I obtain this information?, and c) do I need this information now? A graphic of the process is shown in Figure 1.

After the three pre-decisional processes, the individual first asks "Is there a real threat that I should pay attention to?" In this stage, the individual decides if there is actually something occurring that may require his/her action, sometimes referred to as warning belief [18], but referred to here as *threat belief* to account for people's reactions to all types of environmental cues [16]. If the individual's answer is yes, then s/he is said to believe the threat, and s/he subsequently moves on to consider the next question in the process. Second, a risk assessment is performed. Research has shown that a person's perception of personal risk is highly correlated with disaster response [16]. Here, the individual determines the personal consequences of the threat and asks [19]: "Do I need to take protective action?" At this point, the individual tries to gain insight into the potential outcomes of the disaster and what those potential outcomes mean for his/her safety (i.e. tries to improve their "situation awareness"[20]). The internal dialogue that takes place at this stage can be thought of as mental simulation, in which the individual develops a mental model of what is going on in his/her environment, based on perceived cues, and then expands the mental model to project forward and predict the personal consequences of the event [21]. The more certain, severe, and immediate the risk is perceived to be, the more likely the individual is to perform protective actions [22].

Especially in the initial stages of an event, individuals may have difficulty with the first two questions - identifying and assessing the risk. Even after receiving what many would consider obvious evidence of danger, some people disbelieve or disregard the threat altogether – thinking that nothing unusual is happening that places them at risk, known as normalcy bias [14, 23 ,24]. People may also think that even though there may be a threat present, it will not negatively affect them, known as optimistic or optimism bias [25]. Individuals often have trouble estimating the consequences or severity of an incident since they are likely unfamiliar with the potential speed of fire development or lethality of toxic smoke products.

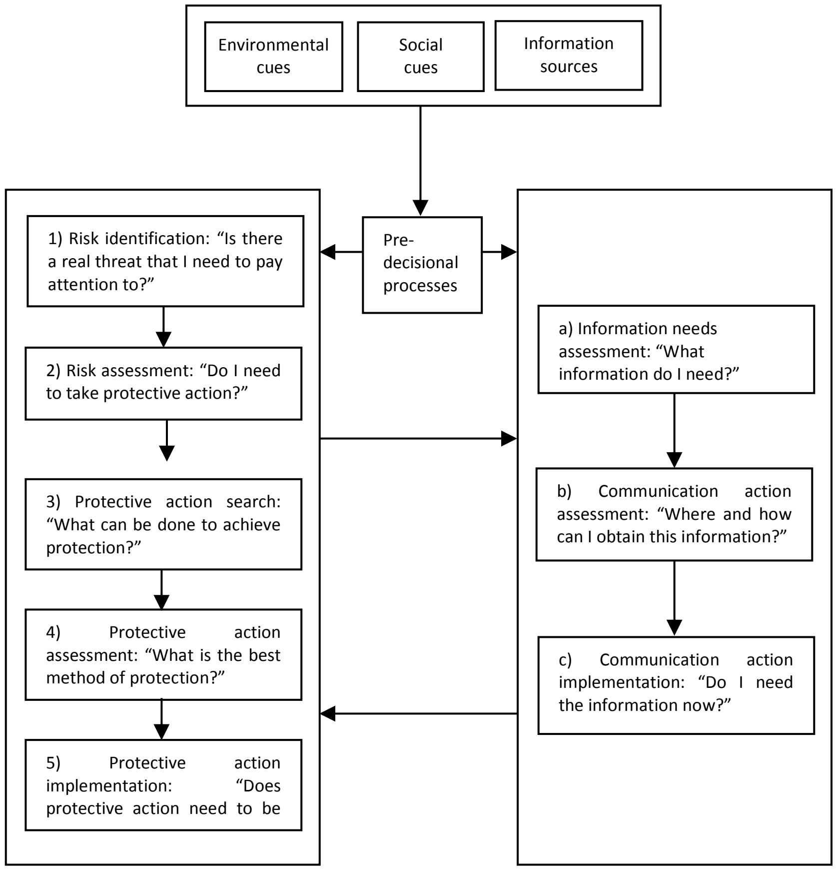

Figure 1. The Protective Action Decision Model (Source – [16] redrawn from p. 47)

In the third and fourth stages, the individual engages in a decision-making process to identify 1) what can be done to achieve protection; and 2) the best available method of achieving this protection. The outcome of the third stage is a set of possible protective actions from which to choose.

Research literature suggests that occupants develop their options by performing mental simulation [26, 27], similar to the methods of developing interpretations. Mental simulation [21] allows an occupant to mentally structure scenarios on what s/he would do and how s/he would do it in the current situation – project the current situation into the future and estimate possible outcomes. The search for options becomes the process of mentally developing scenarios of action before actually performing the act.

The search for options of what to do can also occur collectively [9, 28] – either collaboratively or through suggestion by a leader. In addition to interpreting an event, groups work together to plan a coordinated action that will solve the problem presented by the interpretation, if any. Suggestions for actions can come from any member of the group, although leaders are likely to emerge with suggestions of next actions [28, 29]. In the face of uncertainty and time pressure, people are likely to come together, share their interpretations, and define plans for collective action in an event.

Occupants or groups are unlikely to search for a large number of options during the decision-making phase. Research suggests that individuals and groups are likely to develop a narrow range of decision options due to the following conditions: 1) perceived time pressure [30-33]; 2) limited mental resources [34-36]; and/or 3) training and knowledge of procedures [21, 27]. Time pressure, likely in a fire event, causes occupants to perceive a fewer number of cues (termed perceptual narrowing), process the information less thoroughly and in turn, to consider a narrow set of options [30]. Also, people do not expend large amounts of intellectual resources envisioning the broad range of scenarios, but rather are likely to envision only the scenarios that they believe are necessary to reach a goal [35]. Finally, research suggests that occupants who are highly trained and/or know of specific procedures will be guided by training and will likely not develop more than one option at a time [21].

The fourth stage involves protective action assessment. This stage involves assessment of the potential option(s), evaluating the option(s) in comparison with taking no action and continuing with normal activities, and then selecting the best method of protective action.

Rationality-based research claims that occupants will attempt to optimize their decision-making by considering all options developed and choosing the best one – known as rational choice strategy [37, 38]. In a fire situation, weighing of multiple options is unlikely to occur. Research on decision-making under uncertainty indicates that occupants use a variety of heuristics to make this choice [21, 39]. Heuristics are simple rules to explain how individuals make decisions. Whereas some research might view the use of heuristics as a source of bias in decision-making [40], other researchers see heuristics as strengths based on the use of expertise [41]. Examples of heuristics that occupants employ in choosing options include anchoring or focusing on the first option developed [39], choosing the most available option (the easiest to develop or recall) [39], comparing all options with each other and choosing one based on the evaluation criteria [42-44], and satisficing [34].

Satisficing [45,35] is a method in which an individual chooses the first option that seems to work, though not necessarily the *best* option overall [21]– an option which produces results that are good enough rather than optimal. The satisficing heuristic actually combines the processes of option development and option choice together in one step. As the decision-maker develops options, s/he evaluates each one as it is developed and stops developing options when one is deemed to satisfy the search criteria.

Whereas the rational choice strategy is more likely to be used when people attempt to optimize a decision [21], satisficing is more likely to be used in situations with a greater time pressure, dynamic conditions, and ill-defined goals [21].

In emergencies, individuals at risk have two general options: taking protective action or continuing previous activities. Once an action is chosen, the end result of stage 4 is an adaptive plan, which can vary in its specificity. For example, for households under disaster threat conditions, an adaptive plan can include a specific evacuation plan that outlines the travel destination (e.g. a relative's house), a route of travel to that destination, and a means of getting there (i.e. some form of transportation).

After a protective action is chosen and the adaptive plan is developed, occupants *may* enter stage 5 and perform the action that they decided upon in the decision-making phase. If new information is presented before an action is performed, the occupant will reconsider and discard the current action and begin the behavioural process again. The action involves performing some type of physical act although the act could be waiting, or even inaction, that takes some amount of time to complete (or is conducted for a period of time). Both summary research (e.g. [46-48]) and research on specific incidents (e.g. [49-52]) highlight certain actions in which occupants are likely to engage [53].

These protective actions, depending upon the situation, can include waiting, alerting others, preparing for evacuation, assisting others, fighting the fire, and searching for and rescuing others. However, if information received is incomplete, ambiguous, contradictory, or causes uncertainty in understanding cues and which actions to take, then, individuals will likely engage in additional information-seeking actions (shown by the right-hand column in Figure 1). These can include milling, physically seeking information, and/or asking others for information. The greater the ambiguity perceived, the more likely that individuals will search for additional information that can guide their actions [28, 54, 55]. Any information gained will then act as social or physical cues to begin the decision-making process over again.

Note that individuals do not have to go through each stage or question in the decision flow chart shown in Figure 1. For example, if an individual is presented with information about the event from a credible source or if s/he is ordered to evacuate, s/he may move on to later stages in the decision process rather than going through each one in succession. Finally, individuals who decide that they are not at risk, may neglect to take protective action at all and in turn, terminate the emergency decision-making process.

4. Behavioural statements of human behaviour in fire

Section 3 described the process through which individuals make protective action decisions in response to fires and other types of disasters based on the PADM [16]. However, the PADM, and other supporting models, do not provide sufficient information on the specifics or the types of protective actions in which occupants engage and why they engage in these actions during emergencies, which is necessary for the development of a comprehensive theory of human behaviour in fire.

Given the absence of a comprehensive human behaviour in fire theory, the model users and developers are faced with the task of assembling disparate pieces of knowledge from available sources in the field or beyond. Data have been collected on human behaviour in fire; however, it is typically distributed across different resources, presented in different formats and placed in different contexts – producing an incomplete, disorganized, and disparate understanding of the subject matter. In this section, key human behavioural statements currently available for fires and other emergencies are presented and discussed. This discussion is intended to form a basis from which a practitioner may inform their work.

Behavioural statements, 24 in total, are presented here, derived from a variety of sources, to describe human behaviour in fire [46]. Even though the statements presented do not represent a complete picture of human behaviour during fire, they do provide important information about the following:

- behaviours that may occur during a building evacuation,
- factors that influence these behaviours,
- possible outcome of these behaviours (i.e. significant delay times).

The statements presented below are typically derived from incidents, (repeated) observations or aspects of existing theories in adjacent fields that have been co-opted into evacuation analysis. This list is by no means exhaustive, but represents the key behavioural conventions that are identified, understood, and employed within models and engineering practice.

In this section, the behavioural statements are organized to aid in both the understanding and location of the statements within the decision-making process.

[Phase 1] Perceiving or receiving cues and information

1) Content of the cue matters. The precision, credibility, clarity, comprehensiveness, intensity and specificity of the external cues will affect the assessment of the information in the individual's decision-making process [19].
2) Authority of the information source affects the perceived credibility of the information [56].
3) The actions of the surrounding population can influence the internal processes and the actions of the individual; e.g. the use of routes/space by others increases their attractiveness [57].
4) Some individuals exhibit hypervigilance that makes them particularly sensitive to certain cues [53].
5) Previous experience of false alarms or frequent drills can reduce sensitivity to alarm signal [58].
6) Habituation (where a process has become routine in nature), focus and stress can narrow the perceptual field, and thus, not all available cues will be internalized [59].
7) Sensory impairments can inhibit the perception of cues [60].

[Phase 2] Assessing the situation and perceiving some level of risk

8) Normalcy bias and optimism bias are commonplace. In other words, people often think that nothing serious is taking place, and that nothing bad will happen to them, respectively [24, 61].
9) Training may allow the incident to be defined more quickly by the evacuee and provide pre-determined viable responses [21].

[Phase 3] Selecting a response or action

10) People tend to satisfice rather than optimize. In other words, they are more likely to choose an option that is perceived as "good enough" rather than the best option [34].

11) Presence of smoke does not always preclude the use of a route [46].
12) Training and experience may increase an individual's familiarity with the use of components/devices and subsequently improve their use [47].
13) Pre-event commitment to a particular activity may cause individuals to decide against taking protective action [62].

[Phase 4] Influencing action selection

14) People have different abilities that influence action selection [60].
15) People seek information in situations where information is lacking or incomplete [46, 47, 53].
16) People engage in protective actions, including preparing to move to safety or helping to protect others from harm, before they initiate a movement towards safety [46, 48, 63, 64].
17) People move towards the familiar, such as other people, places and things [62].
18) People may re-enter a structure, especially if there is an emotional attachment to the structure, the contents and/or the inhabitants [46].

[Phase 5] Influencing the overall decision-making process

19) People will behave in a rational AND altruistic manner; panic is rare [46, 65, 66].
20) Uncertainty, time pressure and volume of information can increase stress levels [31, 35].
21) Pre-incident experience influences how cues are processed, how the situation is defined and how protective actions are selected [53].
22) Evacuation is a social process, in that groups are likely to form during an evacuation [67].
23) Social rules and roles in place prior to a fire event form the basis of those employed during the event. In other words, people's role before the incident will influence their performance during the event [8].
24) New norms may emerge where existing normative structure is incapable of addressing the new fire situation [6, 7].

The 24 behavioural statements just discussed represent qualitative mini-theories from over 50 years of research of human behaviour in fire and other emergencies. These statements provide practitioners with helpful guidance as to the elements that will need to be represented within an evacuation scenario when calculating RSET for a building or other type of structure. However, at present, these statements are disconnected, making it difficult for practitioners to account for human behaviour in fire when performing egress calculations and even more vital to develop a functioning, comprehensive conceptual model of human behaviour in fire, that will improve the techniques currently used to evaluate evacuation timing. Once a comprehensive conceptual model is developed, these statements will likely form the basis of a validation case against which a new conceptual model might be compared.

As mentioned previously, it is unlikely that we will be able to produce a conceptual model that can identify any specific individual's response with a high degree of confidence. However, we do need a model that can identify the process that an individual goes through, connecting the factors influencing performance to the actions forming evacuee response. Undoubtedly, some of the elements of the process will be better understood than others. Also, the eventual response selection may hinge on arbitrary/undocumented/coincidental factors that are unknowable and not represented in the model; i.e. the same individual may respond differently in similar situations. Given this, a stochastic element will likely be introduced to compensate for the lack of refinement of the model and the many known (and unknown) factors that might influence the outcome – both as a recognition of the limitations of any conceptual model and that scenarios will include factors that are novel and that fall outside of the scope of the model.

5. Data collection

The first step in the development of a fire-related behavioural conceptual model is data collection of human behaviour in fire data, which has been limited to date. Human behaviour in fire is a relatively new field that has emerged within the last few decades. Prior to this time, human response was assumed to be dominated by physical factors, to be panic-based, considered intractable, and/or was excluded from engineering practice entirely. A considerable effort has been required to convince practitioners of the need to understand and address human behaviour in fire within engineering analysis – it must be included in design solutions. As highlighted in the introductory section, recording the needs and responses of the evacuee can influence the time it takes for them to initiate their response, the routes adopted and then the time for them to reach a safe place (e.g. Beverly Hills Supper Club [52]).

Data-sets are the foundation of any comprehensive conceptual model or theory of human behaviour in fire, which can then support the tools employed in the field and inform practice [68, 69]. Along with theory, data also plays an important role in validation exercises, to ensure that the conceptual model developed represents an appropriate picture of real-world settings.

Behavioural datasets are difficult and expensive to gather [71]. This is because typical laboratory experiments (which are difficult enough to conduct) provide an artificial environment that will influence the relevance of the results produced by a test – therefore, real-world situations are required that are more costly, less controlled, and more ethically challenging. Therefore, it is important to optimize the collection and application processes. In other words, data collectors should be working to obtain data that are relevant and necessary for the development of the conceptual model, as well as provide the context under which the data were collected to ensure its appropriate use.

Table 1. Scenarios from which data can be collected.

Scenario	Description
Routine Conditions	Non-emergency situations, such as general circulation or routine operations.
Exercises / Drills	Non-emergency evacuation exercises from a structure, typically as part of the safety training/testing schedule. Occupants are evacuated in accordance with the building's emergency procedure as if an incident has occurred. Prior knowledge/warning is a key consideration, since the building management, the evacuating population and/or fire marshals may have been forewarned.
Experiments	An attempt to control for specific conditions of interest. The scenario would need to be managed by the researcher to ensure that the actions investigated were performed under representative conditions. An example of this is the use of virtual reality or gaming systems to collect information on what individuals might do in a particular (virtual) situation.
Actual Incidents	An actual evacuation from a real fire event. In this scenario, the researcher has no control over the scenario or the conditions present during the evacuation.
Simulation	The generation of evacuee responses given input scenario conditions by an evacuation simulation model. Simulation enables the researcher to control the scenario (s) modelled, according to the functionality of the model. [3]

Behavioural data can be derived from an array of different fire-related scenarios, shown in Table 1. An understanding of these scenarios provides the context under which these data were collected. Therefore, it is essential for the researcher to report the source of the data, as well as the data collection and analysis methods, to allow a third-party user to determine appropriateness to the intended applications. Table 1

[3] In some instances, a simulation is considered a controlled numerical experiment - where specific conditions are tested according to an experimental model, with the limitations of the model outlined, allowing the credibility of the results to be reasonably assessed. This approach may allow for conditions to be examined that might otherwise be beyond reach and also attributes to be controlled, allowing greater confidence in the scenario examined. The major question here, as elsewhere, would be the validity of the experimental model.

describes the scenarios from which data can be collected, including routine conditions, exercises or drills, experiments, actual incidents, and simulation studies.

Table 2. Data collection methods.

Data Collection Method	Examples of Data	Target / Timing
Video Camera: A stream of information is collected allowing action/event processes to be observed and recorded.	Velocity, flow, chains of events, actions, etc.	Dynamic or Static / During Event
Still Camera: A snapshot of an event is recorded allowing specific conditions at a particular time to be recorded, rather than the process by which they developed.	Conditions at a point in time; e.g. spacing between people in a crowd, location and size of a queue at a point in time.	Dynamic or Static / During Event
Manual observations: Observer records events, conditions or processes to a relatively crude degree of accuracy.	Existence of certain conditions, manual timing of arrivals.	Dynamic or Static / During Event
Survey / Interview: Individual experiences established (either directly or from reviewing reported events/data-sets [52] via secondary material) to build an understanding of the incident.	The "hows" and "whys", e.g. decisions to initiate evacuation, specific conditions experienced, actions taken, previous experiences/history.	Dynamic or Static / After Event
Sensor: Performs pre-defined, automated observations to record specific events over a period of time.	Arrival of evacuees at a pre-determined location (e.g. timing), biometrical measurements, physiological measurements, etc.	Static
Tagging: Performs pre-defined, automated observations to record movement of a specific individual over a period of time.	Arrival of evacuees each equipped with a sensor to denote their movement.	Dynamic (typically formed from a number of static devices that detect the arrival of a worn tag)

In addition to understanding the scenarios under which data can be collected, it is also important to understand the methods that can be employed to collect the data. There are a number of methods available to collect data, a selection of which is described in Table 2. In Table 2, some examples of the types of data that can be collected using each method are provided along with whether the method can only be focused on a fixed aspect of the event (*Target*), whether it can be applied during or after the incident (*Timing*) and whether the data produced is in a continuous stream or in discrete packets (*Nature of Data*). Each of the methods has their strengths and weaknesses, depending on the resources, access, and prior warning available to a researcher for a particular scenario.

Once collected, in most instances, only a sub-set of the data collected is shared. Often, data are shared in a reduced or distilled format, rather than in a complete format. Potentially more importantly, in the vast majority of cases, only a limited amount of information is provided on the background conditions evident during the original event; i.e. the event described by the data. The reduced dataset and limited context requires a greater degree of interpretation by the third party. This increases the potential for the underlying causal factors being misunderstood, the results being misinterpreted, and the dataset being inappropriately applied.

Therefore, the authors of this chapter suggest the standardization of data collection, analysis, and reporting of results in the field of human behaviour in fire. A need for such a standard tool – at least in the arena of measuring risk perception in fire and disaster events – has already been established in other publications [70, 71]. Similar efforts have already been developed for the collection and reporting of data collected for evacuation movement [68], and such efforts should be developed and followed in the area of human behaviour in fire. This will not only aid in the development of the conceptual model, but also the larger-scale use of these data for various purposes within the fire safety discipline.

6. Model representation

Egress models are an important tool – they allow evacuee performance to be quantified and simulation experiments to be performed to gain insight into the impact of scenario conditions upon the outcome of an evacuation. Egress computer simulation models adopt an array of different approaches to represent evacuee behaviour (i.e. behavioural data or statements). Of most relevance here, in this chapter, is how the models represent individual evacuee response. The current approaches of egress models in representing human behaviour in fire are discussed along with their implications for practitioners.

The authors have reviewed many of the evacuation models currently available, including components that contribute to the overall effectiveness of the model [72, 73]. In this section, the components that relate specifically to simulated behaviour are discussed.

As mentioned in Section 1 of this chapter, current evacuation simulation models are limited in their capabilities to represent human behaviour in fire. This limitation manifests in two ways: (1) some behaviours are represented, but in a partial manner; (2) other behaviours are excluded entirely.

The behaviour of the population is currently represented by evacuation models in a number of different ways, but can be grouped into five categories:

In a minority of models, especially the older models, there is *no representation of behaviour*. Only the movement of the evacuating population is simulated with no local decision-making processes represented. These models are often composed of a series of engineering calculations, where an evacuating population is treated like a laminar flow, unless the engineer manually represents evacuee behaviour within the scenario [72, 73]. For example, the user may remove an exit from the building configuration (i.e. an unfamiliar exit), and then calculate the time that evacuees might take if they used other available exits (i.e. the main or more familiar exit).

Most evacuation models represent behaviour *implicitly* by assigning certain response delays or occupant characteristics that affect movement throughout the evacuation and are deemed to take into account the delays that expected behaviours might have incurred. Should the explicit representation of behaviours be required in implicit models, it would be based on user input. The user input specifically represents behavioural performance (e.g. travel speed, route use, etc.) to be assessed by the model, rather than allowing the model to predict whether the action will occur at all. Therefore, behavioural actions are an input rather than an output. The process requires the practitioner to develop representative scenarios *and* impose credible evacuee responses. Both of these activities require informed engineering judgment.

Other (agent-based) models represent behaviour in a *conditional* manner, where the evacuee responses to certain conditions are pre-defined, such that individual responses are based entirely on local conditions. For example, structural or environmental conditions of the evacuation would influence evacuee response, possibly by influencing his/her route choice. Models tend to account for conditional behaviours using "if, then" statements or rules. Depending on the sophistication of the approach, this may be entirely deterministic or probabilistic. Additionally, behavioural statements or rules can be assigned based purely on random variables, defined here as *stochastic* behavioural modelling.

Conditional and stochastic approaches require the model to *generate* the evacuee response directly given the conditions faced. Current models often apply approaches derived from other physical sciences (representation through analogy) to describe the movement and interaction of the evacuating population, including approaches representing particle flow, granular flow, potential/magnetic fields [73]. Behaviours are represented on a stimulus-response basis (e.g. cue leads directly to action), rather than representing the complex cognitive, social and adaptive decision-making processes involved in predicting response (i.e. the PADM).

Finally, a few models represent behaviour in an *adaptive* manner, where behaviour is determined according to the experiences and knowledge of the simulated evacuee and the local environmental conditions. The adaptive method reflects an attempt to represent the adaptive capacity of the decision-making process. The user configures the implemented model to represent the scenario conditions. The simulated evacuee is then sensitive to conditions that influence the decision-making process (potentially in conjunction with existing internal information) and, in turn, an action is selected. This approach is:

- Sensitive to the impact of external and internal conditions,
- Establishes a response as the result of a process
- Produces conditions that emerge as a result of interactions between evacuees and their environment.

Currently, no model is entirely adaptive. Instead, some aspects of evacuee behaviour might be represented in an adaptive manner. For instance, exits may be selected by agents' assessment of the impact of the congestion at each exit or the presence of smoke along the route upon their evacuation.

In reality, current models adopt a range of these approaches for different aspects of the evacuation process – with an overall composite approach adopted. For example, an agent may start to evacuate after sensing smoke (*conditional*), move towards an exit according to a speed-density relationship (*implicit*) and then select an exit according to the conditions faced and the assessed impact on his/her performance (*adaptive*). This composite approach makes it difficult both to interpret the validity of model and the results produced.

To improve the current state of evacuation modelling there is a need to implement a comprehensive conceptual model that more accurately represents the decision-making process. This improvement would allow models to represent agent response, which would, ideally, address a broader array of initial conditions and allow for a more comprehensive set of responses. This development would need to be accompanied by a similarly comprehensive validation effort. A validated partial implementation ensures confidence in an incomplete representation of evacuee performance; an unvalidated comprehensive implementation provides a model with sufficient scope, but whose results may not be credible.

7. Conceptual model development

There is a need for the development of a conceptual model of evacuee behaviour. This will rely on data and theory to be embedded in an evacuation model to more credibly predict evacuee actions [53, 69-77]. There has been work done in this area, upon which the field can build; however, none of this work has been fully validated or covers sufficient subject areas to enable a comprehensive conceptual model to be fully developed and implemented.

It should be noted that much of this work pre-dated the use of evacuation simulation tools as a means to quantify performance. Therefore, the insights provided by these research efforts, while important, are not always easily translated into a format that can then be implemented within a computational tool; at least not without significant effort.

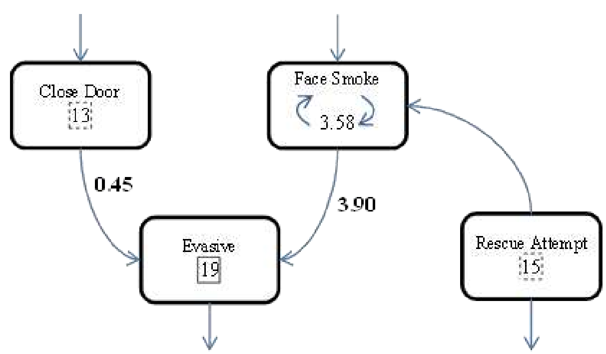

Figure 2.Section of decomposition diagram from Breaux et al. [74]. Arrows indicate association; linked probabilities indicated strength of associated. Reworked from [74].

An early set of conceptual models in the fire field was developed by Canter, Breaux, and Sime [74]. They developed decomposition diagrams for various types of fire events that identify the sequence of actions performed (see Figure 2). Critically, these diagrams charted the actions performed and the relationship between them; i.e. the probability of a particular action preceding or succeeding another action. Their UK study examined 14 domestic fires, eight multiple-occupancy fires, and six hospital fires, examining the actions of 198 evacuees in total. Interviewees were first asked to give a detailed account of their experience, after which interviewers focused in on certain issues, including recognition of the fire event, location of the occupant, ongoing behaviour, sequence of actions, perception of the situation, past experiences, and background information.

Canter, Breaux and Sime's decomposition diagrams begin to tie various sub-theories together, but focus primarily on the linking of evacuation actions together. Taking this further, Kuligowski developed a model that identifies the interpretations and levels of risk perception that are influential to occupant's actions –

specifically for the 2001 World Trade Center (WTC) Disaster [53]. Kuligowski's model is a qualitative model that predicts the pre-evacuation actions of survivors from the WTC incident. The research involved analysing transcripts (derived from the HEED database [78]) from 245 face-to-face interviews with survivors from both WTC towers. The goal of this research was to describe evacuation decision processes in greater detail than either research on building fires or studies on community-wide evacuation, focusing on how people perceive and interpret environmental cues and warnings, how they seek confirmation during sense-making and milling processes, and what they do before moving to safety.

Kuligowski's research produced five main findings:

- The WTC pre-evacuation period was divided into two main phases: the milling/sense making phase (where occupants either continued to work or sought information) and the protective action phase (where occupants engaged in actions that were focused specifically on protecting themselves or others. Both phases took place before the evacuees moved to the stairs or elevators.
- Risk perception, or the feeling of personal danger, was the main predictor of when individuals decided to evacuate. Both individual and environmental factors were identified as influential of risk perception development.
- Some individuals decided to evacuate relatively early. These were primarily higher-level managers, fire wardens, military personnel, or individuals who had experiences with or occupations in emergency situations. These individuals still required information that increased their level of perceived risk. However, they were more inclined to act before others because they felt responsibility for others and/or had previously experienced/witnessed negative consequences associated with fire or building evacuations.
- Certain factors, such as personal responsibility, social connections, and the actions of others, influenced which protective actions people engaged.

Kuligowski's model is not without limitations: (1) it focuses specifically on the pre-evacuation period of one building event; (2) the model does not incorporate any decisions or actions of the decedents; and (3) the factors that influenced each action performed were specific to an office building fire and subsequent evacuation, thus making it difficult to generalize the findings. It is then recognized that this work is a first start to developing a model to predict actions taken during building fires. This research should be expanded upon to include findings from analysis of other building fires, including fires in different types of structures and with different populations, as well as from analysis of other types of disasters, not limited to building fires.

Kuligowski's research was conducted during the current era when simulation tools are employed. Given this, Gwynne examined her research (and the underlying research on which it is based) to identify the types of structures that would need to be included within a model to reflect the elements of Kuligowski's conceptual model [69]. A simple schematic of this translation is shown in Figure 3. This is a modest development in the creation of a conceptual model that is implementation ready; however, it may help facilitate a discussion between researchers developing conceptual models and model developers who might implement them.

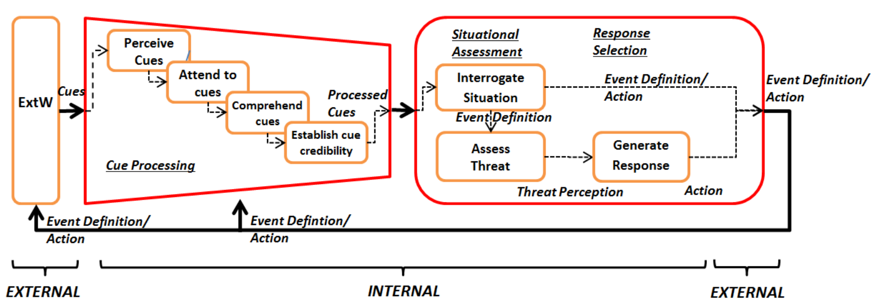

Figure 3. Outline for a conceptual model [69].

After the model specification, a key step in the transition from a comprehensive conceptual model to the implementation of such a model is to predict the timing associated with the performance of certain actions.

The extent to which the simulated environment will reflect the consequences of evacuee actions is beyond this discussion; however, the time taken to select and perform actions is critical in assessing the overall time to reach safety. The quantification process will allow the impact of specific actions on overall performance to be determined.

There have been several studies that attempted to predict how long people delay before evacuating [54, 47, 46], the constituent parts of this delay (e.g. [75]) as well as the time it takes individuals to evacuate via stairs [76], etc. This type of research would need to be compiled to support and quantify the decisions and actions suggested by the conceptual model. These decisions/actions (and resultant time delays) would be recombined depending on the decisions made by the individual in question to quantify their performance. Efforts have also been made at compiling empirical models based on existing data to reflect elements of the evacuation process (e.g. [77]). With due care, these types of models might be embedded within a comprehensive conceptual model to account for the delays associated with specific tasks, as opposed to determining the tasks actually conducted.

While these models do provide a path forward to identifying the methods that could be used in its eventual development, there are still significant conceptual and empirical gaps. There is much work still to be done to improve our understanding of human behaviour in fire; without this understanding, a comprehensive model is not possible. Listed here are just a few examples of areas in the field that require further study to enable us to better model evacuation from building fires:

- The influence of fire's toxic products and heat on decision-making and behaviour (before incapacitation or death occurs).
- An identification of all of the factors that influence risk perception and how they interact to increase or decrease risk perception levels.
- The types of protective actions that are performed.
- The factors that influence the various types of protective actions performed.
- The factors that influence the receipt of cues, the ways in which people pay attention to cues, and the comprehension of cues.
- The ways in which individual factors, such as gender, disability, age, body size, culture, marital status, past experiences, training and social role, influence decision-making.
- The timing associated with the performance of behaviour and the factors that influence this timing.
- The influence of urgency or other types of dissemination techniques on the response of building occupants.
- The influence of group dynamics on individual decision-making and group decision-making.
- The role of place (including building type or building characteristics) on decision-making.
- The role of psychological states, including stress or anxiety, on decision-making.

For the field to reach its goal and develop a larger understanding of human behaviour in fire, accurate, rigorous, and comprehensive research must continue. Thankfully, there is an array of researchers who are engaged in addressing many of the questions listed and subsequently the furtherance of our understanding of evacuee decision-making and performance.

8. Concluding remarks

The purpose of this chapter is to identify the ways in which practitioners and model developers can account for human behaviour in fire in the use and development and application of evacuation models, both now and in the future. Human behaviour in fire is an important part of the RSET calculation; however, not much in the way of guidance is provided to the practitioner, given the limited and disparate data available and the lack of a comprehensive conceptual model describing evacuee response. Given this, the inclusion of it within the modelling process is often reliant upon the capacity of the user to manually represent evacuee behaviour. Hopefully, this chapter has increased this capacity by encouraging the practitioner to scrutinize the theory, data, models and engineering practice employed in order to ensure the reliability and credibility of any assumptions made and any tools applied. Practitioners are often faced with the difficult task of identifying scenarios of interest, representing them within models and then assessing the results. Similarly model developers are faced with the task of assessing disparate data-sets and theories, and then combining them into a useful tool. Both of these tasks are extremely challenging and the efforts of these groups should not be underestimated. It is hoped that by identifying the key challenges faced that this chapter helps further the conversation between researchers, practitioners and developers to enhance current understanding and ensure that it is shared and employed appropriately.

Looking ahead, to enhance the representation of the simulated evacuee, more representative data-sets should be collected, described in a more consistent and comprehensive manner (i.e. in a comprehensive theory of human behaviour in fire) and made available to model developers and practitioners. None of these developments are trivial. However, there is a growing consensus that simulation models are and will remain a key tool in quantifying safety and a tool to help impact life safety when in the hands of informed and expert practitioners. Suitably enhanced tools would then better equip the engineering community to forecast and assess evacuee performance.

References

[1] *Approved Document B*, Vol. 1. 2006. Dwelling Houses, Building Regulations 2000, Communities and Local Government.

[2] Gwynne, S.M.V. and Rosenbaum, E.R.2009. *Employing the Hydraulic Model in Assessing Emergency Movement*, SFPE Handbook of Fire Protection Engineering, 4th Edition, DiNenno et al. (eds.), National Fire Protection Association, Quincy, MA, 2009, pp. 3-373 – 3-396.

[3] Feinberg, W.E. and Johnson, N.R. 2001. The Ties that Bind: A Macro-Level Approach to Panic, International Journal of Mass Emergencies and Disasters, v19, 3, November 2001.

[4] Engineering Guide to Human Behaviour in Fire. 2001., Society of Fire Protection Engineers.

[5] Gwynne, S. Kuligowski, E.D. Spearpoint, M. 2012. *More Faults with Defaults*, Proceedings of the 5th International Symposium, Human Behaviour in Fire 2012, Cambridge UK, 19-21 September 2012, Interscience Communications Ltd. pp. 263-274. ISBN 978-0-9556548-8-6.

[6] Turner, R.H. and Killian. L.M. 1987. *Collective Behaviour*. Englewood Cliffs, NJ: Prentice Hall, Inc.

[7] Aguirre, B.E., Wenger,D., and Vigo. G. 1998. *A Test of the Emergent Norm Theory of Collective Behaviour*. *Sociological Forum* 13(2): 301-320.

[8] McPhail, C. 1991. *The Myth of the Madding Crowd*. New York, NY: Walter de Gruyter, Inc.

[9] Turner, R.H. and Killian, LM. 1972. *Collective Behaviour*. Englewood Cliffs, NJ: Prentice Hall, Inc.

[10] Connell, R. 2001. *Collective Behaviour in the September 11, 2001 Evacuation of the World Trade Center*. Preliminary Paper #313. Newark, DE: University of Delaware Disaster Research Center.

[11] Sorensen, J.H. and Vogt-Sorenson, B, 2006. *Community Processes: Warning and evacuation.* pp. 183–199 in *Handbook of Disaster Research*, edited by H. Rodriguez, E. L. Quarantelli, and R. R. Dynes. New York, NY: Springer.

[12] Mileti, D.S. and Peek,L, 2001. *Hazards and Sustainable Development in the United States. Risk* Management: An International Journal 3(1): 61-70.

[13] Tierney, K.J., Lindell, M.K., and Perry, R.W., 2001. *Facing the Unexpected: Disaster preparedness and response in the United States.* Washington, DC: Joseph Henry Press.

[14] Drabek, T.E., 1986. *Human System Responses to Disaster: An inventory of sociological findings*. New York, NY: Springer-Verlag.

[15] Mileti, D.S., Drabek, T.E. and Haas. J.E., 1975. *Human Systems in Extreme Environments: A sociological perspective.* Boulder, CO: Institute of Behavioural Science, University of Colorado.

[16] Lindell, M.K., and Perry, R.W., 2004. *Communicating Environmental Risk in Multiethnic Communities*. Thousand Oaks, CA: Sage Publications.

[17] Gwynne, S.M.V. *Optimizing Fire Alarm Notification for High Risk Groups.* Summary Report, prepared for The Fire Protection Research Foundation, NFPA, Quincy, MA, June 2007.

[18] Mileti, D.S. 1974. *A Normative Causal Model Analysis of Disaster Warning Response*. Boulder, CO: University of Colorado Department of Sociology.

[19] Mileti, D.S. and Sorensen, J,H. 1990. *Communication of emergency public warnings: a social science perspective and state-of-the-art assessment.* Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge.

[20] Groner, N, 2009. A Situation Awareness Analysis for the Use of Elevators During Fire Emergencies. pp. 61-72 in 4th International Symposium on Human Behaviour in Fire: Conference Proceedings. London, UK: Interscience Communications.

[21]Klein, G. 1999. *Sources of Power: How people make decisions*. Cambridge, MA: The MIT Press.

[22]Perry, R.W., Lindell, M.K., Greene, M.R. 1981. *Evacuation planning in emergency management*. Lexington Books, Lexington.

[23]Sekizawa, A. 2004. *Human Factors in Fire Safety Measures.* Fire Science and Technology 23(4): 296-302.

[24]Okabe, K. and Mikami,S. 1982. *A Study on the Socio-Psychological Effect of a False Warning of the Tokai Earthquake in Japan.* A Paper presented at the Tenth World Congress of Sociology, Mexico City, Mexico.

[25] Kunreuther, H. 1991. *A Conceptual Framework for Managing Low Probability Events*. Philadelphia, PA: Center for Risk and Decision Processes, University of Pennsylvania.

[26] Gwynne, S., Galea, E.R., Lawrence, P.J., Owen, M. and Filippidis, L. 1999. *Adaptive Decision-Making in buildingEXODUS.* Journal of Applied Fire Science 8:265-289.
[27] Thompson, C.M.., Forester, J.A., Cooper, S.E., Bley, D.C. and Wreathall, J. 1997. pp. 9-13-9-17 in Proceedings of the IEEE Sixth Annual Human Factors Meeting.
[28] Turner, R.H. and Killian, L.M., 1987. *Collective Behaviour*. Englewood Cliffs, NJ: Prentice Hall, Inc.
[29] Connell, R., 2001. *Collective Behavior in the September 11, 2001 Evacuation of the World Trade Center.* Preliminary Paper #313. Newark, DE: University of Delaware Disaster Research Center.
[30] Karau, S.J. and Kelly, J.R. 1992. *The Effects of Time Scarcity and Time Abundance on Group Performance Quality and Interaction Process.* Journal of Experimental Social Psychology 28(6): 542-571.
[31] Zakay, D. 1993. *The Impact of Time Perception Processes on Decision Making Under Time Stress.* pp. 59-72 in *Time Pressure and Stress in Human Judgment and Decision Making*, edited by O. Svenson and A. John Maule. New York, NY: Plenum Press.
[32] Janis, I.L. 1982. *Decision Making Under Stress.* pp. 69-87 in Handbook of Stress: Theoretical and clinical aspects, edited by L. Goldberger and S. Breznitz. New York, NY: The Free Press.
[33] Ben Zur, H. and Breznitz, S.J. 1981. *The Effect of Time Pressure on Risky Choice Behavior.* Acta Psychologica 47(2): 89-104.
[34] Simon, H.A. 1956. *Rational Choice and the Structure of Environment*. Psychological Review 63(2): 129-138.
[35] Gigerenzer, G. and Selten,G. 2001. *Bounded Rationality: The adaptive toolbox.* Cambridge, MA: The MIT Press.
[36] Vaughan, D. 1999. *The Dark Side of Organizations: Mistake, misconduct, and disaster.* Annual Review of Sociology 25: 271-305.
[37] Slovic, P., Fischhoff,B and Lichtenstein,S. 1977. *Behavioral Decision Theory.* Annual Review of Psychology 28: 1-39.
[38] Peterson, C.R. and Beach, L.R. 1967. *Man as an Intuitive Statistician*" Psychological Bulletin 68(1): 29-46.
[39] Kahneman, D., Slovic, P. and Tversky,A., 1982. *Judgment Under Uncertainty: Heuristics and biases.* New York, NY: Cambridge University Press.
[40] Tversky, A. and Kahneman,D. 1974. *Judgment Under Uncertainty: Heuristics and biases.* Science 185: 1124-1131.
[41] Flin, R., Salas,E., Strub,M., and Martin,L. 1997. *Decision Making Under Stress.* England, UK: Ashgate Publishing Ltd.
[42] Orasanu, J. and Fischer.U, 1997. *Finding Decisions in Natural Environments: The view from the cockpit.* pp. 343-358 in Naturalistic Decision Making, edited by C. Zsambok and G. Klein. Mahwah, NJ: Erlbaum.
[43] Janis, I.L. and Mann,L., 1977. *Decision Making: A psychological analysis of conflict, choice, and commitment.* New York, NY: Free Press.
[44] Hammond, K.R. and Adelman,L. 1976. *Science, Values, and Human Judgment.* Science 194:389-396.
[45] Slovic, P., Kunreuther,H., and White,G.F. 1974. *Decision Processes, Rationality, and Adjustments to Natural Hazards.* pp. 187-205 in Natural Hazards, edited by Gilbert F. White. New York, NY: Oxford University Press.
[46] Bryan, J.L., 2002. *Behavioral Response to Fire and Smoke.* pp. 3-315 – 3-341 in The SFPE Handbook of Fire Protection Engineering Third Edition, edited by P.J. DiNenno. Quincy, MA: National Fire Protection Association.
[47] Proulx, G. 2002. *Movement of People: The evacuation timing.* pp. 3-342 – 3-365 in The SFPE Handbook of Fire Protection Engineering Third Edition, edited by P.J. DiNenno. Quincy, MA: National Fire Protection Association.
[48] Tong, D., and Canter,D. 1985. *The Decision to Evacuate: A study of the motivations which contribute to evacuation in the event of fire.* Fire Safety Journal 9(3): 257-265.
[49] Averill, J.D., Mileti,D.S., Peacock, R.D., Kuligowski, E.D., Groner,N., Proulx,G., Reneke,P.A. and Nelson,H.E., 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Occupant behavior, egress, and emergency communications.* Report NCSTAR 1-7. Gaithersburg, MD: National Institute of Standards and Technology. (Also available at http://wtc.nist.gov/NISTNCSTAR1-7.pdf).
[50] Isner, M.S. and Klem,T.J. 1993. *World Trade Center Explosion and Fire, New York, New York, February 26, 1993.* Fire Investigation Report. Quincy, MA: National Fire Protection Association.
[51] Bryan, J.L. 1982. *Human Behavior in the MGM Grand Hotel Fire.* Fire Journal 76:37-48.
[52] Best, R.L. 1977. *Reconstruction of a Tragedy: The Beverly Hills Supper Club Fire.* Quincy, MA: National Fire Protection Association.
[53] Kuligowski, E.D. 2011. *Terror Defeated: Occupant Sensemaking, Decision-making and Protective Action in The 2001 World Trade Center Disaster*, PhD Thesis, University of Colorado.
[54] Fahy, R.F. and Proulx,G. 1997. *Human Behaviour in the World Trade Center Evacuation.* pp. 713-724 in Fire Safety Science -- Proceedings of the Fifth International Symposium, edited by Y. Hasemi. London, UK: Interscience Communications Ltd.
[55] Mileti, D.S. and O'Brien,P.W. 1992. *Warnings during Disasters: Normalizing communicated risk. Social Problems* 39(1): 40-57.
[56] Proulx, G. and Sime, J.D. 1991. *To Prevent 'Panic' In An Underground Emergency: Why Not Tell People The Truth?* Fire Safety Science 3: 843-852. doi:10.3801/IAFSS.FSS.3-843
[57] Latane, B. and Darley,J.M. 1970. *The Unresponsive Bystander: Why doesn't he help?* New York, NY: Appleton-Century Crofts.
[58] Proulx, G., Latour, J.C. and MacLaurin, J.W. 1994. *Housing evacuation of mixed abilities occupants.* IRC-IR-661, Internal Report, Institute for Research in Construction, National Research Council of Canada.
[59] Bruck, D. 2001. *The who, what, where and why of waking to fire alarms: A review.* Fire Safety Journal 36:623-639.
[60] *Americans with Disabilities Act.* 1990.U.S. Code Chapter 126.
[61] Shepperd Helweg-Larsen, M. and Shepperd, J.A. 2001.*Do Moderators of the Optimistic Bias Affect Personal or Target Risk Estimates?* A Review of the Literature, Personality and Social Psychology Review,2001, Vol. 5, No. 1, 74–95.
[62] Sime, J.1984. Escape Behaviour In Fire: Panic' Or Affiliation? PhD Thesis, Department of Psychology, University Of Surrey.
[63] Canter, D. 1980. *Fires and Human Behaviour*. New York, NY: John Wiley & Sons.
[64] Wood, P.G. *Fire Research Note 953*, Building Research Establishment, Borehamwood, UK (1972).

[65] Quarantelli, E. L. and Dynes,R.R. 1972. *When Disaster Strikes (It Isn't Much Like What You've Heard and Read About). Psychology Today* 5(February): 67-70.

[66] Fischer, HW., III. 1998. *Response to Disaster: Fact versus fiction and its perpetuation: The sociology of disaster* (2^{nd} ed.). New York, NY: University Press of America.

[67] Santos, G. and Aguirre, B.E. 2004. *Critical Review of Emergency Evacuation Simulation Models.* pp. 27-52 in *Workshop on Building Occupant Movement During Fire Emergencies*, edited by R. D. Peacock and E. D. Kuligowski. Gaithersburg, MD: National Institute of Standards and Technology.

[68] Gwynne, S.M.V. 2010. *Conventions in the Collection and Use of Human Performance Data.* NIST GCR 10-928, National Institute of Standards and Technology.

[69] Gwynne, SMV. 2012. *Translating Behavioral Theory of Human Response into Modeling Practice*. NISTGCR - 12-972, National Institute of Standards and Technology, 2012.

[70] Kinateder,M.,KuligowskiE.D.,Reneke,P.A. and Peacock, R.D.2014. Review of Risk Perception in Building Fire Evacuation. NIST TN - 1840.

[71] McConnell, N.C., Boyce, K.E., Shields, J., Galea, E.R., Day, R.C. and Hulse, L.M. 2010. *The UK 9/11 evacuation study: Analysis of survivors' recognition and response phase in WTC1*. Fire Safety Journal, Volume 45, Issue 1, January 2010, Pages 21–34.

[72] Gwynne, S., Galea E.R., Owen M., Lawrence P.J., and Filippidis L. "A review of the methodologies used in evacuation modelling," *Fire and Materials,* **23** (6), Nov–Dec 1999, pp. 383–389.

[73] Kuligowski,E.D., Peacock, R.D., and Hoskins, B.L. A Review of Building Evacuation Models, 2nd Edition, NIST TN - 1680, 2010.

[74] Breaux, J., Canter,D. and Sime, J.D. (1976). Psychological Aspects of Behaviour of People in Fire Situations, pp. 39-50 in International Fire Protection Seminar, 5th. Karlsruhe, West Germany.

[75] Gwynne S, Galea E.R., Parke, J., Hickson, J. The Collection and Analysis of Pre-Evacuation Times from Evacuation Trials and their Application to Evacuation Modelling, Fire Technology, Kluwer Associates, US, pp. 173-195, Vol. 39, Number 2, 2003.

[76] Kuligowski, Ed,Peacock, R.D., Reneke, P.A.,Wiess, E.A., Averill, J.D., Hagwood, R.C., Ronchi, E., Hoskins, B. and Spearpoint, M. Movement on Stairs During Building Evacuations, NIST TN - 1839, NIST, 2014

[77] Reneke, P.A. Evacuation Decision Model, NIST Interagency/Internal Report (NISTIR) - 7914, NIST, 2013.

[78] Galea, E.R., J. Shields, D. Canter, K. Boyce, R. Day, L. Hulse, A. Siddiqui, L. Summerfield, M. Marselle, P. Greenall. 2006. "Methodologies Employed in the Collection, Retrieval and Storage of Human Factors Information Derived from First Hand Accounts of Survivors of the WTC Disaster of 11 September 2001." Journal of Applied Fire Science 15(4): 253-276 (published in Nov 2008).