How Fire Risk Perception Impacts Evacuation Behavior: A Review of the Literature

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Abstract. Objective: The objective of this paper is to review the literature on the processes by which individuals respond to fires in order to identify the decision-making process between fire risk perception and evacuation behaviors.

Method: According to evacuation timelines, a conceptual framework is used to identify the mechanisms through which fire cues, the characteristics of the building in which the fire occurs, and the demography, personality, fire experience and training of the individuals may be interpreted as fire risks. The fire risk perception is used as precondition impacting on decision-making and human behaviors. The relevant literature has been searched through electronic databases, journals, and consultation with key informants.

Results: People respond differently to various perceived fire cues. Actions depend on the cues perceived, the interpretation of the situation, and the subsequent decisions taken. Occupants act based on these decisions, but new information can cause them to discard previous actions and begin new processes. In addition, many of the actual behaviors of occupants in fatal fires differ from occupants' response performance models.

Conclusions: The fire cues perceived by people would be interpreted as safe or risk.

This interpretation process is affected by several factors, including the features of the fire cues, the architecture of the building in which the fire occurs and personal characteristics. The interpretation also impacts importantly on the decision-making and responding behaviors.

Keywords: Risk perception · Building fire · Evacuation behaviors

1 Introduction

In many fires, research on fire injuries and deaths shows that over two-thirds of the injured and over half of the dead in building fires could have evacuated. But these people delay their safety inside the building [1, 2]. A solution to this problem is to make sense a comprehensive and validated theory on human behavior during evacuation from building fires. If the persons perceive a fire cue and think that is a risk, they will intend to evacuate. This decision indicates that fire risk perception impact potentially on persons' responds.

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This paper reviews the processes by which individuals respond to fires. These responses begin with the perception of fire cues. Fire cues may be interpreted as either safe or indicative of a fire risk, depending on the features of the cues, the characteristics of the building in which the fire occurs, and the demography, personality, fire experience and training of the individuals. Each individual incorporates these factors in a decision-making process to identify necessary protective actions and to form an adaptive plan or strategy. After decision-making, the individuals carry out the actions.

2 Method

2.1 Literature Search

For the purpose of the present literature review, we followed the steps for a systematic literature review. Firstly, we searched related database such as "Web of Science", "Google Scholar". The databases searched were about "building fire", "risk perception", "decision making", "evacuation behavior", "pre-movement time" and so on. Then the in-depth review took place. After that, main questions were proposed: the process of risk perception, the factors of impacting risk perception, the process of risk perception impacting on decision-making and so on. Finally, the literature was included if it was relevant to the topic.

2.2 Frame of the Review

The behavior of occupants during building fires has been shown to affect survival rates significantly. Survival probabilities are largely determined by occupants' responses during the fire [3]. Therefore, the relationships between the evacuation processes, fire development (including ignition, the initial period, the fire development period, the flourishing period and dying out) and safety should be investigated. It has been shown that after occupants have determined the fire status of a building, they estimate the risk involved, make decisions, respond to the fire and evacuate the building [4–6] (Fig. 1). If the required safe egress time (RSET) is less than the available safe egress time (ASET), occupants can evacuate safely. The pre-movement time critically affects the RSET. However, research has shown that the pre-movement time in actual evacuations can last from five minutes to over 25 min [7–9]. Longer pre-movement times represent greater levels of risk to the occupants. However, most evacuation models primarily focus on the purposeful evacuation of occupants and do not consider the perceptual and cognitive processes related to decision-making for real-life evacuation, which may delay evacuation time. Therefore, it is important to characterize how the perception of fire risk influences human behavior.

IG: ignition (start of the fire); AL: alarm (sounding of the alarm); RC: recognition (occupants perceive the alarm); RS: response (occupants respond to the call to evacuate); DD: dangerous (the fire or its products are deadly to the occupants); ET: extinguished (the fire is extinguished); ASET: available safe egress time; RSET: required safe egress time.

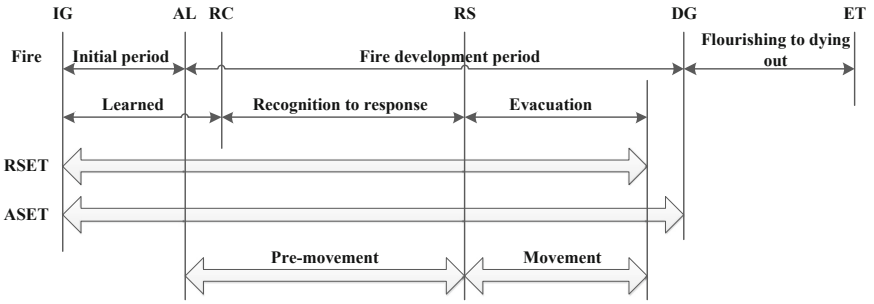

Fig. 1. Evacuation timelines

3 Results

3.1 Fire Risk Perception

Risk Perception in General. To define risk perception, the term "risk" itself must be explained briefly. There are many definitions of risk [10–12], but it is commonly considered to be the likelihood that persons will experience the effect of danger [13]. The various definitions of risk share one common element, that is, the distinction between reality and possibility [14, 15].

Risk perception is the subjective judgment by which people recognize the features of accidents and the severity of risks [14, 16]. The term risk perception emphasizes that risk is assessed based on experience as well as available information. In addition to the features of the risks themselves, personal experience, memory and other socio-demographic attributes or psychological dispositions influence the way people perceive risks, i.e., risk perception is a social construct [17, 18]. People have different comfort levels and adjust the riskiness of their behavior correspondingly [19]. Therefore, risk perception is not a constant but varies between individuals and contexts. Individual risk perception depends on the environment, as well as on the likelihood of the risky outcome and the individual's concerns about this outcome [20].

Perceiving Fire Cues. Afire risk can be defined as the probability that a fire causes casualties and/or property damage [21]. Occupants will evacuate only if they perceive a situation as dangerous. The situations perceived as normal or risky results in different activities. Therefore, ensuring the correct interpretation of fire risk is essential to an evacuation plan [22].

In a fire, the building occupants receive both physical and social external cues. Physical cues include features of the fire itself, such as flames, smoke, and explosions, along with fire alarms, such as tone alarms and automatic warnings. Social cues include communication with other people in the same building or outside the building, the actions of other occupants and/or yelling in the building. These cues can be perceived by multiple sensory modalities, including hearing, smelling, seeing and touching [23].

Research has shown that the occupants' characteristics and the nature of the cues affect the occupants' perception of the fire cues [24].

- Previous experience with disasters or fire training increases the probability that occupants perceive fire cues [25, 26]. Other factors, such as limited experience with the environment, perceptual limitations, and age or stress decrease the probability of cue perception [26–30].
- The perception of fire cues is affected by the ignition location, the physical characteristics of the smoke and the number of cues [23, 30–32]. Kobes, Helsloot, De Vries, and Post [33] found that occupants' perception were impacted by fire characteristics, such as the growth rate, the smoke yield, toxicity, and heat. The fire growth rate is a particularly important factor. Many fatal incidents can be attributed to rapid fire development despite the initial perception of fire cues [34]. Researchers have also found that the credibility of the source of a warning message, along with its delivery method, repetition and consistency, also influences occupants' perception [35–37].

After perceiving such cues, occupants become aware of changes in their environment [1, 38].

3.2 Interpretation of Critical Factors and Decision-Making

Interpretation. Individuals perceive cues that imply that the normal situation has been interrupted and disrupted, creating uncertainty: this information must then be interpreted by the individual [38]. Occupants organize the cues into a meaningful framework or story to make sense of their environmental situation. The construction of these frameworks and stories is called interpretation [26, 38–41].

There are generally three types of factors that influence human behavior in the event of a fire: the fire characteristics, the building characteristics and human characteristics [3, 33, 34, 42–45, 97]. The first two factors are external: the nature of the fire itself and the physical environment within which the occupants respond to the fire. The third factor of human nature is an internal factor. These critical factors are presented in Table 1. Previous studies have shown how these factors directly impact response performance; however, it is more accurate to say that these factors influence cognitive processes. The three factors affect how the occupants interpret the fire situation.

A signal is commonly disregarded as a clear indication of danger. However, occupants believe that they are at risk if they smell smoke or toxic gases or see flames and smoke [45]. If occupants are presented with several fire cues or a consistent set of cues, they will interpret the situation as posing a fire risk [22, 35, 46]. Warnings delivered with a tone of urgency are more likely to be interpreted as representing risk [47]. Hypervigilant persons are more likely to interpret emergency cues as dangerous [48, 49]. Occupants with previous experiences of fires or evacuation drills are more likely to define the situation in terms of a fire risk [1, 38]. However, if the occupants are familiar with the evacuation routes or have previously had frequent false fire alarm experiences, they are less likely to interpret the situation as risky [50, 51]. Researchers have also found that social cues, such as calls from friends and screams or evacuation activities of others, promote the interpretation of a situation as a fire risk [52, 53].

Table 1. Critical factors for perceiving a fire situation as presenting a fire risk

Fire characteristics	Human characteristics	Building characteristics
Perceptual cues • Visual Flame, smoke, deflection or collapse of wall or ceiling • Audible Cracking, broken glass, and objects falling • Smelling Smell of burning • Tangible Heat	*Profile* • Gender, age, and family composition • Education • Observation and judgment abilities, mobility, and physical and mental limitations • Culture	*Occupancy* • Occupant density • Building type: office, factory, hospital, hotel, cinema, college or university, and shopping center
Fire growth rate	*Experience* • Fire experience, fire training, and other emergency training • Familiarity with building	*Architecture* • Number of floors • Layout and building shape • Maintenance
Fire alarm • Alarm signal • Voice communication •Others' actions	*Situation* • Alone or with others • Awareness • Physical position • Working, sleeping, eating, and shopping • Stress and time pressure • Others' reactions	*Refuge area* • Complexity of evacuation route and wayfinding • Location of exits and stairwells
	Personality • Influence of others • Leadership • Negativity toward authority	

Perceived cues cause occupants to develop cognitive images of what they imagine is occurring [1]. Some researchers have found that interpretation methods include the recall of previous behavioral scripts, mental simulation and models [26, 54, 55].

Decision-Making. People respond differently to various perceived cues; however, even when presented with the same cues, people are likely to respond in different ways [56]. Actions depend on the cues perceived, the interpretation of the situation, and the subsequent decisions taken. Occupants act based on these decisions, but new information can cause them to discard previous actions and begin new processes [1].

An individual's actions primarily result from a decision-making process. Most evacuation models significantly simplify behavioral processes, either by assigning a delay time before evacuation rather than considering the situational decisions and interactions of the occupants, or by assigning a behavioral itinerary to the occupants [1]. If people cannot answer the questions that emerge in the course of

decision-making, they continue to seek information [36], i.e., people continue their original activities if the cues are not perceived as being sufficiently significant to interrupt these activities. Thus, people may not respond quickly to a fire alarm without additional confirmatory cues. Further investigation and research should be conducted to elucidate the additional information required and the forms and timing with which this information should be provided.

Gigerenaer and Selton [57] outline a two-step decision-making phase in which action options are first generated, followed by selecting one of these options. Action options are generated based on interpreting a situation, where searching for options involves mental simulation similar to that involved in developing interpretations [26, 58]. Although occupants are expected to search for a sufficient number of options during the decision-making phase, some researchers have found that occupants usually find very few options. Time pressure, mental resources and training and knowledge of procedures can lead to a deficit of options [26, 57, 59–61]. Two types of choice strategies may be used to select an option. The first is a rational choice strategy, by which persons optimize decision-making by choosing the best of all available options [62, 63]. The second is a satisficing strategy, by which individuals choose the first workable option [57]. Klein [26] hypothesizes that the rational choice strategy is more likely to be adopted by persons trying to optimize a decision, whereas the satisficing strategy is more likely to be used under time pressure, dynamic conditions and other stressors. People make decisions about risk by focusing on explicit cues and information rather than on all of the available facts. People conceive of risk as the result of a likely outcome or the probability that an outcome will actually occur [20].

Therefore, some researches [64–67] believe that risk perception can be understood as a threshold mechanism for evacuation decision-making. That means the evacuation decision-making is “triggered” if the perceived risk becomes unacceptable. Applied to the situation of fires, cues such as the smell of smoke or other people moving to an emergency exit may activate protective behaviors [68, 69].

During fires, people often make decisions according to their own interpretation schemas. However, researchers find that the people communicating with other persons or technology may change their decisions in the interpretation of cues. But potential influence of communication is under exploited at present [70, 71].

3.3 Human Behaviors

Behaviors in the Pre-movement Period. After hearing a fire alarm, occupants always spend a period of time in a non-evacuation activity. This stage is called the pre-movement period [1, 45, 72]. Kobes [3] combined the phases of clue validation and decision-making into this pre-movement period. Incident analyses indicate that pre-movement time and pre-movement behavior play key roles in the evacuation process [73]. This pre-movement time is a delay during which occupants attempt to gather information, alert others in the building, gather their personal belongings, assist or rescue other persons, wait, or fight the fire [1, 74, 75]. Research has shown that pre-movement delays are increased by certain actions such as searching for information or confirming information about an incident [9, 72, 76].

Kuligowski and Hoskins [72] investigate a fire incident and found that the main factors affecting the pre-movement time are the activities undertaken during this period and the initial floor location of the occupants. Another key factor is the information provided to the occupants during the fire. Occupants' past experiences with emergencies and their evacuation knowledge can affect their actions in this period [26, 36]. Researchers have found significant differences between the protective behaviors of women and men during this period. For example, women were more likely to gather their personal belongings, while men were more likely to fight fires or to rescue others such as family members and friends [77–79].

These behaviors show that mental processes and actions involve continuous information-processing and decision-making. During an evacuation, people are often confronted with smoke, toxicity and communication with other occupants. Under these conditions, people may change direction because of breathing difficulties, limited visibility or other reasons [58]. People constantly evaluate their options during an evacuation based on their perception of the following factors: time pressure, perceived safety, implementation barriers and the costs of taking an action [36]. People usually act in similar ways in dense areas such as shopping malls or indoor stadia, because group behavior plays a significant role throughout the evacuation process [80, 81]. Uncertainty before evacuation or other types of survival behavior causes people engage in additional information-seeking until they locate sources or channels that can enable them to make decisions [9, 82]. People do not necessarily progress through the aforementioned stages in order [36].

Evacuation Behaviors. There are three response performances exhibited in surviving a fire [51]: extinguishing the fire, waiting for rescue and evacuation. These strategies can be separated into those conducted during and after the pre-movement period. Research has shown that when visibility is limited, occupants prefer to walk alongside walls or jump out of a building rather than wait to be rescued.

Occupants' walking speed under smoke exposure is also slower than that under normal conditions [58, 83, 84]. Occupants who are familiar with a building prefer to take the stairs over the elevators during evacuation [49]. Occupants who are not familiar with the building exits follow other occupants to the stairs [85].

Individual behaviors in a crowd are always influenced by other persons. Studies of incidents show that most people act as followers. People do not react to a fire alarm until others take action [86]. A set of individuals in the same physical environment is considered to be a crowd [87]: crowd behavior corresponds to the dynamics of entire groups of people resulting from their interactions with the environment. The crowd mind propagates through the crowd by anonymity, contagion and suggestibility. Thus, the intentionality of the individual vanishes in preference to that of the collective [88]. Under some circumstances, individuals in a crowd may not able to conduct a task because their judgment abilities have been degraded to some extent [89]. Although there have been many studies on the effects of crowds, more in-depth research is needed to determine the process and mechanisms by which a crowd impacts individual behaviors and to evaluate the extent of this impact. Does the influence of the crowd increase with the emergency of the situation?

Software development has facilitated the construction of many evacuation models. However, few models have been based on human behaviors, such as escape route selection and information interpretation [33]. The deficiencies in these models can be attributed to the scarcity of relevant and quantitative research data. Various human behaviors have also not been sufficiently understood. The following aspects of human behaviors require further study [34]:

- the response performance and activity patterns of occupants upon hearing fire alarms,
- the occupants' response time and evacuation strategy, and
- wayfinding during evacuation: while most existing studies have focused on architectural construction and building layout, few studies have considered how the layout of the architecture or the building affects decision-making.

Disparity Between Response Performance Models and Actual Behaviors. Both the technical and social aspects of building fire safety policy are based on the paradigm of occupants' response performance; however, many of the actual behaviors of occupants in fatal fires differ from occupants' response performance models. The disparity between response performance models and actual behaviors significantly affects the ability of occupants to escape safely in the case of a fire. The disparity is primarily caused by three factors: fire characteristics, human characteristics and building characteristics.

- These models are based on the assumption that fire growth in a building follows the standard fire curve. In practice, fire growth depends on the materials used in building construction [90]. Thus, the combustion speed may be ultra-fast. Different fire growths produce different evacuation behaviors.
- Response performance models assume that occupants escape immediately upon hearing a fire alarm. These models also assume a constant walking speed for individuals in the course of the evacuation. However, the pre-movement period can exceed the evacuation time. Social rules strongly influence individual reaction times. While escaping from an incident, individuals can be confronted with many emergencies and therefore walk more slowly than they would under normal conditions. Thus, the occupants' walking speed is not consistent during evacuation [83, 91, 92].
- Designers of green escape route signs and researchers developing response performance models assume that occupants follow these signs to escape. While occupants notice the color, the pictogram and the location of the signs, they usually do not follow the signs in the course of escaping [83, 93]. Response performance models are also based on the paradigm that occupants escape via the nearest exit. However, in real-life incidents, people escape via familiar exit routes [94, 95]. Thus, the layout of the building interior significantly influences human behaviors under emergency conditions.

Fire safety policies are based on these response performance models; however, the disparities between these models and actual behaviors cast doubt on the soundness of the basic principles and the subsequent effectiveness of these policies. Therefore,

further studies or scientific experiments should be conducted on human behaviors in real incidents to clarify the reciprocal influence between fire characteristics and human characteristics and between building characteristics and human characteristics from the ignition stage to the end of the evacuation process. New sound basic principles of fire safety policy should consequently be developed in the near future from real observed behaviors. In addition, analyzing detailed information on decision-making for evacuation in sufficient depth can stimulate the development of practical models for the fire prevention design of buildings.

4 Conclusions

During a fire, people perceive fire cues to varying degrees. These perceived cues cause individuals to create mental models, which are used to interpret the situation as safe or presenting a fire risk. This interpretation process is affected by several factors, including the features of the fire cues, the architecture of the building in which the fire occurs and personal characteristics. Individuals then engage in decision-making processes to identify protective actions and to create an adaptive plan or strategy. The dynamic quality of fire situations results in a highly complex path from cue perception to response.

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