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Evaluation of the Responsiveness of Occupants to Fire Alarms in Buildings: Phase 1

FINAL REPORT BY:

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FOREWORD

The Fire Protection Research Foundation's Detection and Alarm Research Council research planning meeting 2016 indicated that people not responding to alarms in buildings was highlighted as a high priority topic that need to be studied. This project is phase 1 effort of the 'Evaluation of the Responsiveness of Occupants to Fire Alarms in Buildings' with an overall goal of developing guidance for best practices on emergency notification of occupants in buildings.

This Phase 1 effort will focus on literature review to gather information from the available materials on the effectiveness of fire alarm signals, voice alarms and mobile technology on notifying the building occupants in the event of an emergency and conduct a gap analysis to identify the existing gaps in support of planning future research.

The Fire Protection Research Foundation expresses gratitude to the report authors Dr. Bryan L. Hoskins and Nicholas Mueller, who are with the Fire Protection and Safety Engineering Technology department at Oklahoma State University, Stillwater, Oklahoma, USA. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, and all others that contributed to this research effort. Thanks are also expressed to the National Fire Protection Association (NFPA) for providing the project funding through the NFPA Annual Research Fund.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

NFPA's membership totals more than 65,000 individuals around the world.

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EXECUTIVE SUMMARY

This project is phase 1 of the 'Evaluation of the Responsiveness of Occupants to Fire Alarms in Buildings'. The Detection and Alarm Research Council of the NFPA Research Foundation highlighted people not responding to alarms in buildings as a high priority in their 2016 research planning meeting. The following questions were proposed to be answered by research: Why don't people respond to alarms? Is the signal recognizable? How do different types of voice alerts/warnings compare? How do we best leverage mobile technology? Are we using the proper stimulus to notify occupants in the event of an emergency in a building? The overall goal of the project is to develop guidance for best practices on emergency notification of occupants in buildings. This Phase 1 portion of the overall project gathered information from available materials pertinent to the subject and identified gaps that lead to the need for additional research.

Previous research has focused on the ability of auditory signals to effectively convey information to people. This includes determining the effectiveness of the T-3 signal as well as identifying the information needs of people receiving voice messages. The effectiveness of signals that target other senses or rely on systems other than the ones permanently installed in the building have not been studied in detail.

Current fire alarm system design practices might be inadequate at triggering the necessary human behaviors to expedite an immediate response to the situation. Properly designed voice messages could lead to a better response, but still have limitations. A building occupant will make a decision when they feel that they have received all of the information they are going to need. This process might be instantaneous from the start of a T-3 alarm or it might require time for an individual to gather and process more information.

The number of factors that affect the speed of decision-making varies greatly from occupancy to occupancy and from person to person. More research is needed to determine the most effective ways of delivering information that leads to prompt evacuation. Technological advancement is also needed to develop notification systems that effectively communicate relevant information to each occupant. New and different strategies need to be investigated that will lead to people evacuating in an earlier and more efficient manner.

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Oklahoma State University: Fire Protection and Safety Engineering Technology

FPRF Project

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Project Background

This project is phase 1 of the 'Evaluation of the Responsiveness of Occupants to Fire Alarms in Buildings'. The Detection and Alarm Research Council of the NFPA Research Foundation highlighted people not responding to alarms in buildings as a high priority in their 2016 research planning meeting. The following questions were proposed to be answered by research: Why don't people respond to alarms? Is the signal recognizable? How do different types of voice alerts/warnings compare? How do we best leverage mobile technology? Are we using the proper stimulus to notify occupants in the event of an emergency in a building? The overall goal of the project is to develop guidance for best practices on emergency notification of occupants in buildings. This Phase 1 portion of the overall project gathered information from available materials pertinent to the subject and identified gaps that lead to the need for additional research.

Introduction

Efficient evacuation of a building in an emergency is crucial to ensuring the safety of the occupants. In accounts of the events following the initiation of a fire alarm signal, building occupants have reported being unsure of whether the alarm indicated an actual fire (Proulx, 2001) or were observed to be engaging in activities other than evacuating (Ramachandran, 1990 and Shields and Boyce, 2000). In some instances, people will stay to finish a task because they do not personally understand the risk that they are facing (Sime, 1999 and Proulx, 2001).

When people do start to evacuate the building, they may do so in a way that is not consistent with the design of the system, especially if the intent is something other than a total evacuation of the building. While an occupant might recognize the need to evacuate, they are not aware of the locations of available exits or of the conditions along their chosen path.

Evacuation time is crucial to the life safety of building occupants. Building fires can develop and spread quickly, requiring people to evacuate early. Essentially, the required safe egress time (RSET) should be much less than the available safe egress time (ASET). RSET involves all aspects of the evacuation process- time until fire cues are received, pre-evacuation time, and movement time. Effective messaging can lead to people performing desired actions. With the increasing use of performance-based design, accurate estimates of the evacuation time are needed.

The most important factor for ensuring a quick and efficient evacuation of a building is how well the necessary information gets to the occupants. Not only does the person have to sense the alarm (e.g. hear the alarm bell, see a flashing light), he/she needs to personalize the risk that they are facing (Mileti and Sorensen, 1990). If people do not understand that they are in danger, they might choose not to follow the instructions that they are given. Effective communication of information leads to a better response (Mileti and Sorensen, 1990).

In order to develop a successful change in behavior, several key information-delivery needs must be met (Kuligowski et al., 2012). An alert needs to grab the attention of the people in the building. This requires it to stand out from the normal sounds in the building. Gaining people's attention enables them to pay attention to subsequent information. The people must then be provided with information that they can use to make an informed decision, they must trust the information in the message, and they must know what is expected of them.

Some systems rely entirely on a tone alert only (e.g. the temporal three signal). With this type of signal, the people hearing the tone must know, through training or education, what actions they are expected to take. Simply relying on tone alerts can lead to poor responses due to public ignorance (Mileti and Sorensen, 1990).

A verbal message can provide additional information about the event and what people are expected to do (Kuligowski and Omori, 2014). Messages should include the source, hazard, location, guidance, and time.

The information that people are given must be information that they trust (Kuligowski, et al. 2012). A lack of trust in the information, whether from the delivery method, type of signal, or from the source, will result in people questioning if they really should follow the instructions that they are provided (Mileti and Sorensen, 1990). In addition, people also need to know what is going on. If people are not provided with information, they will seek out additional cues and/or information in order to determine what actions they think are most beneficial (Fahy and Proulx, 1997). Finally, people also have to be aware of what their expected actions are (Mileti and Sorensen, 1990). In some cases, people might need to evacuate while others will need to defend in place or wait for further instructions. Confusion as to the desired actions will lead to people potentially making the wrong choice. This becomes even more critical if the desired communication is to avoid using certain egress routes.

The delivery method of the signal is also important in determining how people will respond. Traditionally, a simple alert was used to initiate building-wide evacuation. Many systems rely on audible-only alerts or a combination of audible and visual alerts. Usage of multiple modes of transmission reinforces the message and ensures that all (or most) occupants perceive a consistent message (Mayhorn, 2005). However, this type of alarm notification depends on the ability of occupants to derive the correct meaning from the different sensory inputs that they are given.

Simple alert tone systems employ one-way communication with all occupants in the area, who must know what action(s) to take based on training, education, or additional cues that they observe (Proulx, 2000). This means that if different groups in one area need different information (e.g. a person with a disability that cannot use the stairs when the general population is instructed to use the stairs), either multiple messages need to be provided sequentially or occupants will need to rely on training to know what it is that they are required to do.

Ultimately, the response to a fire alarm signal is dependent on human behavior. A well designed system will take into account the needs of the population and provide them with information that they can understand and apply correctly (Proulx, 2000). Failure to account for how people will actually respond will lead to the system not meeting all of the desired outcomes.

People typically have a poor understanding of the risks from fire and how much time is available for them to safely evacuate (Wales and Thompson, 2012). Thus, alerts and/or warning messages need to convey to people the information that they will need to make appropriate decisions.

Poor Alarm Response

Poor response due to a lack of alarm recognition can occur if the person is not familiar with the alert that is being given (e.g. believing that the fire alarm would make a different sound). A standardized alert signal has the potential to minimize this problem, but it would not ensure that all occupants would actually recognize the signal. Proulx and Laroche (2003) found that most people did not recognize the standard temporal three pattern nor did they find it to convey a high level of urgency.

While an alert tone requires training or education to understand, a warning message requires people to understand the words that are being used. The lack of response to a warning message could be the result of the individual not understanding the language in which the message is given (Wogalter, 2006). One solution is to make sure that the message matches the knowledge and abilities of the population. In some buildings, it might not be possible to match the language needs of all occupants and/or would take a significant amount of time to cycle through all of the required languages.

Even if people do recognize the alarm, they still have to choose whether to perform the actions prescribed by the alert. For example, Shields and Boyce (2000) found that some occupants remained committed to their tasks rather than evacuating. An occupant might choose an alternative action if the requested action is one that the person finds undesirable or less desirable. For example, a person at an airport terminal might choose not to evacuate to the unsecure side of the airport if they determine that the added time to repeat the security check process outweighs their perceived risk of not leaving the building.

The risk perception that an individual has can change over time (Kuligowski, 2011). The perceived risk can influence whether people choose to evacuate or not. A person could choose to evacuate when not perceiving risk or could choose to not evacuate despite perceiving risk (Kinateder et al., 2015). Factors that affect perceived risk include ones that are situational (all aspects of the given moment), individual (characteristics of the person), social (from others), and organizational (structure and safety culture) (Kinateder et al., 2015). Further research is needed to understand how all of the different factors influence the required safe evacuation time.

Signal Recognition

Many alarm systems rely on audible alerts or a combination of audible and visual alerts and messages. Within both the audible and visual alerts, the information that is provided could be a cue that requires the person to have additional knowledge (e.g. a tonal sound or a flashing light) or a cue that leads to detailed information (e.g. a voice message or written words on a screen). Each type of messaging method has limitations as to whether people will correctly recognize the signal. In order to get the desired response, people need to be alerted to the situation, be notified about what needs to be done, and be informed about the event.

Auditory alarms that produce a sound without words are quick and versatile alarms to gain the attention of most building occupants. These alarms can deliver different sounds to denote different situations. The drawback to different auditory alarms is that the general public will not comprehend the meaning or the alert or will misinterpret the alert to mean something contrary to what is expected (Kuligowski and Wakeman, 2017). However, even in these situations, too many different alarm signals can lead to additional confusion and delay. In order to have an audible alarm that will result in people consistently doing the desired action for a specific hazard or situation, people have to quickly be able to identify what the sound means and what actions they are supposed to perform.

To increase the ability of people to recognize the alert from a fire alarm system, standards have prescribed the audible alert from a fire alarm system. This was accomplished by requiring fire alarms installed after July 1, 1996 to produce the Temporal-Three, or T-3, alarm pattern. The intent was that this sound would be generalized by the population to mean that a fire is in the building and that they should evacuate.

Research has indicated that this signal may not be universally recognized to mean that there is a fire in the building. Proulx and Laroche (2003) found that the T-3 signal was not perceived as being urgent nor was it a signal that people readily associated with a fire. Only six percent of the 307 people surveyed were able to correctly identify the sound as coming from the fire alarm system. This study was conducted in Canada where the T-3 had not been standardized for a significant amount of time before the study was conducted and people were not in an environment representative of a building evacuation (they were listening to the sound from a CD via headphones). While this number might have increased as more buildings utilized the T-3 signal, potentially a significant number of people still do not recognize the signal. Overall, the T-3 performed poorly as a signal that triggers an urgent evacuation response in building occupants without some other form of information or sensory cue.

Similar issues are possible when using simple visual alerts, such as strobes; people must be able to recognize that the flashing light is a fire alarm. NFPA 72 requires a white light to be used for signaling fire alarms, and this can be used by building occupants, especially those that are hard of hearing, as a means of interpreting the signal. Colored strobes or lenses can be used to indicate other types of alarms. For example, a mass notification system could use an amber flashing light to indicate a security alert. Similar to the study done by Proulx and Laroche (2003), research should be conducted to study how people respond to white light as compared to other light colors. Existing research by Ronchi et al. (2016) found that green and white lights were more effective than blue lights at helping people identify exits. Also, more research is needed to understand how effective a flashing light is at communicating a recommended action, beyond gaining the attention of occupants. Ronchi et al. (2016) found that the worst performance of individuals in locating exits occurred where the building did not have flashing lights.

For the delivery of audible textual messages, the message must be distinct from ambient sounds and deliver information in a way that people will be able to effectively respond to the message (Kuligowksi, et.al 2012 and Kuligowski and Omori, 2014). People must trust the information that they are receiving and be aware of what is happening and what they are expected to do. Failure to deliver the message in a way that people will be able to recognize the signal as an emergency message could lead to a very poor response

Good system design increases the chances of the audio message being received and being intelligible. Other sounds and voice messages being played should be reduced or eliminated so that the emergency audio signal is the only message being heard by occupants. Voice announcements should be simultaneously accompanied by visual text (Stout, Heppner and Brick 2004). Similarly, tasks that might have the attention of the people in the building should be discontinued automatically (Proulx, 2000).

Providing multiple stimuli will result in a larger amount of occupants being reached. Reception of the warning will not always equate to comprehension. The wording of the message is as important as its clarity. A voice delivering a message should not be too heavily accented and the rate should be about 175 words per minute (Dudek et al. 1978). The speaking rate should also not be at or below 110 words per minute as this is considered too slow and perceived by the audience as unimportant (Dudek et al. 1978).

Occupants must not only hear and understand the instructions given to them but believe them enough to make the correct decision as well. Recordings are not perceived as credible as live messages (Proulx, 2000). Therefore, using a live announcer can increase credibility. Recorded alerts can be used to introduce a live message without loss of credibility. In occupancies where voice messages are regularly played, using the same type of message to convey an urgent alert might not be perceived as credible to the audience. The live message has the added credibility of being less likely that it is a malfunction or "false alarm." In occupancies where pre-recorded messages are the only option, the message should be recorded by a credible source, as appropriate for the specific building and the occupants of that building.

Live voice messages offer other benefits along with perceived credibility (Proulx, 2000). Information might need to be updated as the situation changes. While pre-recorded messages can be designed to change based on the activation of different detectors, a live message can be changed to suit the exact situation at any moment. Along with new information, live messages can deliver an appropriate sense of emergency. Faster speech rate, higher pitch, and using certain words can convey a sense of urgency.

Similar to the audible textual messages, Kuligowski, et. al. (2012) found that visual textual messages need to be displayed in a way that permits people to effectively understand them. Font size, distance, mounting height, and display duration are all critical factors. It is also essential that people's attention is drawn to the text.

For both the audible and visual textual messages, an important consideration is the language used and the complexity of the message (Subervi, 2010). When using simple tones and flashing lights, the meaning can be taught to the entire population and could be applied throughout the world. However, when messages require that the person be fluent in a language, new issues arise. Individuals that do not understand the message will not be able to correctly respond to the instructions, and they will rely on social cues from others that are nearby. Similarly, for nonnative speakers, advanced vocabulary and sentence structure can lead to problems with interpreting the appropriate response. In addition, people with cognitive disabilities might not be able to process the message. In all of these cases, the textual message is not effective as a fire alarm notification.

Mobile Technology Usage

Mobile technology has the possibility of being utilized in a number of ways in emergency evacuation. Smart phones and other devices such as tablets might be the best technology to reach building occupants. Many people carry mobile devices at all times, which could allow the emergency signal to be delivered directly to all occupants at almost all times. Occupancies with employees that work in set locations, such as office buildings, might be able to effectively employ a phone notification program. This could be as simple as a phone number list where emergency notifications are sent out to every number on the list, regardless of whether or not that person is in the occupancy at that given time. Universities and other open campuses across the US utilize different types of text, phone, social media, and email notification programs to alert their students and employees of urgent information (Elsass et al. 2016).

All of the above examples are methods that use mobile technology without applying global positioning technology. When events necessitate mass distribution of information (e.g. severe weather warnings), all of the people in the area are sent a wireless emergency alert. There is the potential to do this with a fire alarm as well. However, the character limitations of text messages and Twitter posts can make these notifications seem more like alerts than warnings (Kuligowski and Doermann 2018), which can reduce the perception of urgency.

Wireless Emergency Alerts (WEAs) are sent out over the Integrated Public Alerting and Warning System (IPAWS) by authorized government entities. These messages can use a pre-existing template that is completed with the relevant information for the current event or a free-form message that is created specifically for the event (Kuligowski and Doermann 2018).

Messages could also be distributed via Twitter or other similar forms of social media. Unlike WEAs, Twitter is an opt-in means of notification, and people would need to be following the message source in order to receive the message (Kuligowski and Doermann 2018). Twitter also has the added benefit of being a two-way communication tool, which can be used to update the emergency message with information provided by the public. While this allows the publication of contradicting or incorrect messages from the public, such problems are typically self-correcting (Kuligowski and Doermann 2018).

Use of these technologies requires the people in the building to have the devices and to be opted in (or not opted out) of the systems. Even if people do receive the message, they still need to receive the proper information. This includes information about the source of the message, hazard, location, timing, and guidance of expected actions (Kuligowski and Doermann 2018). While people respond best to messages that provide them with the necessary information, short messages can include additional information (e.g. internet link) that directs the person receiving the message to more detailed information.

Inoue, et. al. (2008) outlined devices and systems for indoor emergency evacuation using mobile technologies, such as a cell phone. The navigation system could function autonomously, and the occupant's device could receive wireless signals from the surrounding environment to detect the user's position. An indoor occupancy could be able to utilize an evacuation system with various sensors. This system of sensors could navigate occupants to safety in the event of an emergency. A system like this would have the potential to aid in the evacuation process of the building by providing individuals with personalized information. However, there are no known buildings currently use a system of this type.

Mobile technology offers an opportunity for redefining how alerts from the fire alarm system operate. Depending on how the technology is used, it could be possible to send all building occupants different messages. This would enable optimization of the egress system by directing some individuals to underused portions of the egress system while having others continue to use other routes. It could also eliminate some of the language barriers that exist with current devices if the devices can automatically translate the words into the occupant's selected language.

The use of mobile technology has the potential to enable systems that could both send and receive information. By being able to receive information, it might be possible to respond to changing conditions within the building. If nothing else, receiving information like which egress routes are congested could be used to direct people to other available egress routes.

The use of mobile technology is likely to increase over the coming years. These devices have already started to change how information about the conditions within buildings are communicated. They have the potential to individualize the alerts from the fire alarm systems that are currently sent out generically to a larger group.

Stimulus Selection

The selection of the proper stimulus is directly related to understanding the behavior of people as they evacuate. In order for the stimulus to be effective, it must be one that the person is readily able to perceive and know what the correct response should be.

What stimulus should be given has changed over time. Originally, the belief was that information should be withheld from people in order to prevent panic. It is now well understood that people typically do not panic in emergencies (Proulx, 2001). While firsthand accounts of the events of a fire might include the word “panic,” it is typically applied to situations where the individual felt scared or anxious, neither of which are panic behaviors.

Often, occupants are observed not taking any action upon smelling smoke or hearing a fire alarm. This avoidance or denial behavior results in delays in starting the evacuation of a building (Proulx, G. 2001). Multiple factors affect an occupant’s behavior (Kinateder et al., 2015).

The time it takes for occupants to begin evacuation can be a measuring point for both the effectiveness of an alarm as well as human behavior. More time between the start of the alarm and the beginning of occupant evacuation can point to a lack of training or decision making, an ineffective alert or message, and/or a defect in the system design. Generally, occupants need to receive the cues given to them, such as sounds, visuals, or even smells (Kuligowski, 2009). After the cues are presented to the occupant, the situation is interpreted and a decision is made about what action is necessary. That action is then performed. The timing of this process for the occupant depends greatly on how quickly the needed information reaches them. Without information, a decision to act could put the occupant into greater danger or a decision might not be made at all.

The more sources of information that are aligned, and the more senses that detect the cues, the greater the chance that an individual will perceive and respond to the information. Thus, providing the same information in multiple means is essential for improving the response of individuals to an emergency alert.

Gap Analysis

Future research is needed in multiple areas related to fire alarm effectiveness. Some of the needs relate to research gaps (e.g., a need to better understand how to make alert signals more effective) and other needs relate to technological gaps (e.g., a need for new or more widely adopted technology).

The T-3 signal has been a standard sound for a significantly longer period of time than when Proulx conducted her study about the perceived urgency and recognition of the fire alarm signal. As she found, when sounds were believed to be a fire alarm signal, they were rated as being more urgent. While it is possible that perceptions have changed as more people have been exposed to the T-3 alarm, additional research is needed to provide an update of the current understanding of this alert tone in the public. Any future changes to be made to fire alarm signals should begin with an understanding of how effectively people are currently at recognize the T-3 fire alarm signal.

Voice messages are better suited to ensure occupants have all of the information needed to comprehend the situation to take action but may not be able to catch the attention of occupants at first. Studies of the response of individuals in buildings to fire alarms need to be conducted in order to determine how much more effective these systems are when the appropriate messages are provided. This is especially true in situations where there will be a significant number of languages spoken and/or have people present with limited language skills.

Currently, fire alarm strobes only provide basic information about the presence of a fire in the building and that people should evacuate. More research is needed on visual cues related to the color of light, flashing frequency, and the ways to best implement visual textual messages. For example, having a static message displayed on a screen allows the person to read the message at their own pace. This is contrasted with a scrolling text display where the message disappears and reappears. A scrolling message must be read and internalized as a “voice”. A short, static display can be received as a picture to the human brain.

Similarly, there is a gap related to the use of messages that could be sent to mobile devices. Sending a message to a personal device would lead to a person having a message that they could view at their own pace and could review as needed, potentially leading to a better response. However, a system of this type has not been studied in any significant detail for building evacuations. For other events like tornados, these systems have been shown to be effective at providing the needed information (Kuligowski and Doermann, 2018). Significant research is needed to identify the means of incorporating mobile technology with fire alarm systems located within buildings and on campuses.

Along with traditional fire alarms, area wardens have been used successfully in different occupancies (Proulx et al. 1996). These are trained individuals that respond to the fire alarm and direct the other building occupants to designated fire assembly areas. A study to compare the effectiveness of these programs and standard auditory cues would determine which is more desirable for evacuating people.

In addition to the research needs, there are gaps in the current technology, such as the need for longer character strings in text-based communications applications. Other technological gaps include methods of reaching people that do not have mobile devices capable of receiving mass notification and methods of customizing messages based on all characteristics of the receiver and their current location.

Conclusion

Previous research has focused on the ability of auditory signals to effectively convey information to people. This includes determining the effectiveness of the T-3 signal as well as identifying the information needs of people receiving voice messages. The effectiveness of signals that target other senses or rely on systems other than the ones permanently installed in the building have not been studied in detail.

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The number of factors that affect the speed of decision-making varies greatly from occupancy to occupancy and from person to person. More research is needed to determine the most effective ways of delivering information that leads to prompt evacuation.

Technological advancement is also needed to develop notification systems that effectively communicate relevant information to each occupant. New and different strategies need to be investigated that will lead to people evacuating in an earlier and more efficient manner.

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