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Understanding and representing staff pre-warning delay

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Abstract

In this article, the staff *pre-warning delay* concept is developed: the time between staff becoming aware of an incident by receiving a pre-alarm, or as a result of other cues, and the raising of a general alarm. This represents the potential delay in staff response as they interpret the cues received and engage in various response behaviors before warning the population and raising a general alarm; a delay that may be procedural and/or cognitive. The theoretical basis for this concept is discussed, examples of incidents involving this delay described and data from experiments and incidents examined to help demonstrate and estimate the impact and the effects upon the available safe escape time/required safe escape time calculation. Hypothetical examples of how pre-warning delay can influence required safe escape time are presented, along with a discussion of the aspects of emergency procedures that are particularly susceptible to this type of delay. A framework for understanding these susceptibilities is suggested, together with proposals for dealing with this aspect in engineering designs so as to evaluate and minimize its impact on escape time. This concept is considered important as the exclusion of a (potentially sizable) delay from the engineering design may lead to artificially optimistic results being produced.

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Introduction

Increasingly, a performance-based approach is adopted to demonstrate the safety level of a structure and the procedures employed in response to a fire. This requires a comparison between the available safe escape time (ASET – the time between the ignition of a fire and the time at which tenability criteria are exceeded), and the required safe escape time (RSET – the time between ignition of a fire and the time at which occupants in a specified space in a building are able to reach a place of safety) [1–3].

Various methods are used to enable this comparison including engineering calculations and computational tools. The results produced by these methods are then used to establish whether the time to reach safety for the population evacuating from the structure in question is acceptable. This is a challenging task made more difficult by relatively immature nature of the supporting theory, the data available, and the tools employed. It is critical to include the appropriate egress components when comparing these two calculations (ASET and RSET); otherwise, even the most sophisticated and credible tools may produce inaccurate or optimistic results.

Background

Historically, emphasis has been placed on the travel phase of evacuation, as occupants move toward and through escape routes. This remains the basis for most prescriptive codes and also performance-based design, involving mainly consideration of travel distances and exit provisions.

In recent decades, the time for the occupant population to respond to the call to evacuate has been recognized as a key factor in the time to reach safety [1–4]. Depending on the scenario, this pre-evacuation time (sometimes known as pre-movement time, initial delay or starting time), can be the dominant factor; for instance, if the individual in question was asleep when the alarm sounded. This delay in response may have cognitive components (e.g., interpreting the cues provided), and procedural components (e.g., actions being performed after the cues are provided that do not immediately move an occupant toward safety). The necessity to recognize and quantify these behaviors in performance-based design was developed in numerous pieces of research [1], informing the development of fire safety engineering standards in the UK [2] and internationally [3]. As a result, the time required for evacuation (time from a general alarm to that when occupants reach a place of safety) has incorporated two components: evacuation movement and the initial pre-evacuation delay. Experimental studies of evacuation behavior and more routine evacuation drills typically now assess both of these components.

During the research and the development of these standards it was also recognized that during an actual fire incident the evacuation phase itself (t_{evac}, made up from t_{pre} and t_{trav}, pre-travel activity time and travel time, respectively [3]) constituted only part of the total escape process. In practice the total escape time (RSET), also included the time from ignition to detection of the fire (t_{det}) and the time from detection to the provision of a general warning to affected occupants (t_{warn}). The whole process was conceptualized in Figure 1 [1,3], which has been reproduced in British [2] and International Standards [3] and in the SFPE Handbook [4].

One term in this representation, identified as 'warning time' (t_{warn}, see Terminology), depends upon the detection and alarm system present, and it was recognized that for some situations that the time between detection and the provision of a general alarm also depends upon the recognition and response behaviours of individual persons. One such situation occurs in larger buildings in which automatic detection triggers a private pre-alarm to security staff who then investigate and manually initiate a general alarm if and when considered appropriate (as part of their formal or informal procedure). A similar situation occurs in buildings with no automatic alarms (or only local detection and alarm), for which the initiation of

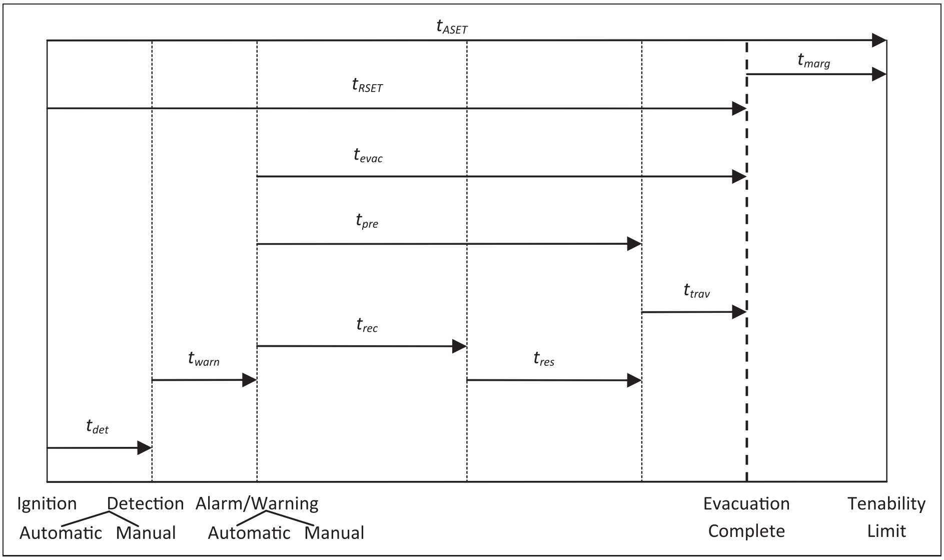

Figure 1. Standard representation of the ASET/RSET components. Reproduced with kind permission from the BSI [3].

a general alarm depends on the behavior of the first person or persons to become aware of the fire cues or local alarm. In both cases, the fact that this stage requires a human (usually staff) response introduces an additional delay time into the total escape time, which should be considered and quantified in any RSET evaluation. The concept of *staff pre-warning delay* relates to this period. The issue is then why do we recognize the potential delays in the purposeful response of the evacuee population and not of the staff population – especially when this can potentially have secondary effects upon the initial evacuee response? This article addresses the issue.

Although often better trained, more expert and with greater access to information than other occupants, staff will be subject to similar types of delay in their response. A delay in staff decision-making and response has been identified as a problem in several previous incidents. In a number of major multi-fatality fire incidents, members of staff were known to have been aware of the fire some time before a general alarm was raised to instigate evacuation of building occupants [5–12]. In addition, similar issues have occurred in the response to security breaches and subsequent staff response; e.g., universities, schools, hospital premises, etc [13–15].

In a typical example of this type of system, automatic detection of a fire results in an immediate pre-alarm to a location such as a security room or hotel reception desk. This is followed by a delay until the staff operative perceives/recognizes the alarm and decides what action is required. There is then a response period during which the operative takes action. The first action is likely to involve some form of investigation to confirm the information (requiring examination of the alarm panel), followed by investigation at the location of the alarm either in person or by contacting another staff member (for example by radio). Having arrived at the location of the fire, the staff member investigating then needs time to appraise the situation and report back, after which a further period is required for possible consultation and consideration before instigating a general evacuation alarm to affected building occupants. Even if a member of staff discovers the incident first hand (i.e., is not subject to the communication process described above), they will still have to go through the same decision-making process as a member of the general public before reporting the incident. This action will lead to a general alarm or warning, commencing the decision-making process of the general population.

Most compliance drills and experimental studies of building evacuations begin with the initiation of an evacuation alarm, so that the pre-warning component of total escape time is usually ignored, despite the fact that delays of this kind have been an important contributory factor to life loss in a number or major incidents [5–12]. This article therefore addresses a potential limitation in the typical RSET calculation: the exclusion of staff delays from the notification process that might postpone warning of the general population. This exclusion might lead to the RSET value being underestimated in certain situations, with the notification instead being assumed to be entirely based on technological performance.

Critically, this limitation may misrepresent the effectiveness of procedural variants during RSET comparisons, with the RSET value being underestimated in certain situations.

Terminology

Different authors and standards committees have independently identified similar phases of escape and coined terms for them, which presents some difficulties when describing and comparing them. In the following list of terms, the ISO term [3] is presented first (along with the associated abbreviation), followed by alternative terms for the same parameter in parentheses. The terms selected for use throughout the article are italicized:

- *Escape time*/t_{esc} (egress time): time from ignition to an affected occupant population reaching a place of safety. RSET is the calculated value for escape time used for design purposes.
- *Evacuation time*/t_{evac}: time from the general warning to when an affected occupant population reaches a place of safety
- *Detection time*/t_{det}: time from ignition to detection (by an automatic system or a person)
- *Warning time*/t_{warn} (alarm time, notification time): interval between detection of the fire and the time at which a general alarm or other *warning* is provided to all occupants in a specified space in a building some authors incorrectly fail to distinguish between detection time and warning time.
- *Pre-travel activity time*/t_{pre} (*pre-evacuation time*, pre-response time, delay time, pre-movement time): interval between the time at which a *warning* of a fire is given (e.g., alarm raised) and the time at which the first deliberate move is made by an occupant toward an exit.
- *Travel time*/t_{trav}: time needed, once movement toward an exit has begun, for an occupant of a specified part of a building to reach a safe location

Cue perception and decision-making

Recent developments in our understanding of human performance in fire have been characterized by a number of key elements [10]:

1. Panic-based evacuee response is not inevitable and is indeed rare. People do not necessarily panic should information be provided.
2. The time to reach safety is not necessarily dominated by physical factors, but can be significantly influenced by the individual's decision-making process and by interacting with the group of people around them.
3. An individual is sensitive to the information around them. An individual will process this information in accordance with their abilities, attributes, experience,

expertise, the situation, the surrounding environment (physical, social and procedural), and their objectives to formulate a response given the time available.
4. Physical, social, and psychological attributes influence performance (and the decision-making process) and these attributes vary across a population.

The speed with which the individual arrives at a decision (i.e., interpret external information, integrate it with existing understanding, and arrive at an appropriate response) will be highly influenced by their expertise, experience, the situation faced, and the nature and content of the information available [10,13,16,17]. However, the decision-making *process* will broadly be the same, although acting on different information, having different time constraints and leading to different situation awareness. Critically, both staff and the target population (i.e., those occupants that need to respond) will pass through this process during any decision-making process. Training can help make this process more efficient and even make it more likely to arrive at an appropriate outcome; however, it does not alter or remove the process entirely. In the context of this article, it may make this process shorter, but it will still exist and delay the final action.

Establishing RSET – engineering timeline

Typically, any performance-based analysis of a structure requires the comparison of the ASET and RSET for a particular scenario (Figure 1). The RSET calculation is formed from a number of essentially additive sub-components, relating to the procedural and evacuee performance [2,3,9,11,18]. The RSET value can be formulated as follows

$$\mathrm{RSET} = t_{det} + t_{warn} + t_{pre} + t_{trav} \tag{1}$$

where t_{det} is the time from fire ignition to detection, t_{warn} the time from detection to the general warning (alarm being raised), t_{pre} the time from the general warning until evacuation commences and t_{trav} the time from the start of this purposeful evacuation movement until safety is reached. Typically, t_{det} and t_{warn} are the determined according to the technological resources employed (e.g., manufacturer's guidance on sensor response) and often do not take staff activities into account.

It is apparent that the first two components of the RSET calculation (t_{det} + t_{warn}) can be formed from a combination of technological or human resources; i.e., that staff, other occupants or technology may be employed to detect an incident or commence the evacuation procedure. The selection of the procedural resources employed will be influenced by a number of factors (e.g., the cost, the infrastructure, the nature of the occupancy, the expected incident scenarios, etc.); however, it is certainly possible that staff (or other occupants) will be involved in the detection of the original incident and the raising of the alarm. This involvement may have a direct impact upon the time for information to be provided to the target population and thus, depending on the nature of the procedure, may be a prominent factor in the RSET calculation.

Depending on the scenario, each of the RSET phases can have a significant impact on the time for the target population to reach safety. However, it is contended here that the time between detection and the general warning is often simplified, subsequently overlooking key factors that, according to the scenario, may have a significant impact on the RSET time. For this reason, a pre-warning delay component should be introduced into this warning period to account for the staff decision-making and response activities. In effect, the warning period could be better represented by including the accumulation of individual staff decision-making processes and subsequent activities that go to delay the provision of the warning. The extent of the pre-warning delay will then be dependent on several variables related to the procedure employed and the decision-making capabilities of those involved.

The human element in pre-warning

The human element in establishing warning times therefore arises in any situation in which the behavior of an individual intervenes between the detection of a fire and the raising of the general alarm. This may involve situations such as those involving simple manual alarm call point systems, those where confirmation is required, or those where automatic detection triggers a pre-alarm to designated security staff, who are then required to instigate appropriate warnings [18]. The need to determine the times required for persons aware of the incident to engage in activities leading to the provision of warnings to all affected occupants is recognized in fire safety engineering standards [2,3]. However, limited guidance is available on the behavioral parameters involved, how the evacuee behavior should be managed and how they can be quantified in a design context.

In this article, a detailed consideration of the pre-warning delay concept is proposed for design cases: the time between the fire being noted and the eventual raising of a public alarm; i.e., notifying the target population that there is an incident and that they need to respond. Often, with the RSET calculation, this time period is represented by the performance of technological devices (e.g., sensors, alarms, etc.), which may be assumed to take a few seconds depending upon the alarm protocol for the system. In reality, depending on the nature of the procedure itself and the resources available, it may also include a significant human element. This includes the potential delay in staff response as they react to the provision of cues, confirm the existence and nature of cues, determine a response and then enact that response. This delay may be procedural and/or cognitive. It may also include the interaction between staff and technology. For instance, an alarm may be activated in response to a detected incident. The initial alarm is sent to staff in a command center. These staff members acknowledge the alarm and deploy to confirm the incident. The device in question may automatically go from private to public mode within a pre-determined period of time addressing the potential for the incident not being investigated or staff not being present. However, staff members often override this setting allowing them more time to investigate or get additional instructions; for instance, where false alarms are commonplace or the implications of a false alarm are severe. Therefore, in these situations, the assumed manufacturer's failsafe time is not a conservative indication of the potential staff delay; instead, the time for staff to confirm and then re-engage the alarm system may be more credible, especially where limited numbers of staff are available. Alternatively, an automatic detector may trigger only a local alarm (as is common in domestic systems), so that whether or not a general alarm is raised for other occupants depends upon whether a nearby occupant hears the alarm, and how and when they respond to it.

In reality, the pre-warning delay may consist of a combination of cognitive processes (processing information and then determining an action) and responses (the performance of the resultant action) that are much more significant than the equivalent technological performance times. This article focuses on the cognitive process given that the nature of this process is reasonably consistent between different actions, whereas the actions themselves may vary greatly according the structure, the procedure and the scenario.

Examples of the impact of staff decision-making

The pre-warning delay is not simply a theoretical issue: it has been observed in real incidents and in drills. Several examples are discussed where the delay produced due to the staff decision-making process affected the warning time.

Pre-warning delays have been a common feature of a number of major fire incidents in which staff were aware of a fire in part of a building but delayed or failed to warn occupants in other parts of a building until they were overtaken by rapidly deteriorating fire conditions [11]. In other incidents and unannounced evacuations involving rapid intervention by well-trained staff, short pre-warning delays have resulted in rapid and efficient evacuations [19]. Also, in some cases, not only did pre-warning delays occur, but once warnings were given, they were sometimes inappropriate, resulting in occupants failing to escape efficiently or even moving into more dangerous situations [6]. In such cases, even a relatively brief pre-warning delay can still lead to a protracted pre-evacuation period as evacuees compensate for the incomplete or inaccurate information provided. These features have been found to be common to different types of occupancies, so that a review of pre-warning behaviors in actual incidents and experimental evacuations [11] was used to develop the engineering guidance in this area [2,3]. In this article, the impact of the increased delay period is the focus. Some relevant examples are summarized in the following.

King's Cross underground fire 11/18/87 London, UK. The fire started on the underside of a wooden escalator leading up from a subway train platform into an underground ticket hall concourse [5]. The fire was detected by a member of the public who reported it at the ticket office. A station inspector was then telephoned who went to investigate. After 3 min of the first report, the police decided to call the fire service, but had to go to the street level to use their radios. No attempt was made to warn or evacuate passengers until 10 min had elapsed. After 13 min, the ticket staff was ordered to evacuate, but the bureau-de-change office staff and toilet occupants were not informed. Even 15 min after the fire was first reported, passengers were being directed up another escalator from lower level platforms into the ticket hall. Then, 16 min after the fire was discovered, flashover occurred in the ticket hall, which still contained many occupants.

This illustrates a common pre-warning behavioral sequence. The fire was detected independently by two members of the public at around the same time and reported to the authorities (staff) within a very short period, but the staff then spent a great deal of time communicating with superiors, investigating the source of the fire, and attempting to tackle the fire, before making any attempt to evacuate the area. When action was taken it was inappropriate, diverting passengers up via another escalator to the threatened ticket hall.

The staff behavior displays a common dilemma for staff in large public buildings such as railway stations and airports. In this case, the incident occurred during rush hour at one of the major interchanges on the London transport system. There was a serious 'cost' in shutting down the subway station for any trivial incident, and therefore reluctance on the part of staff to take any action to evacuate unless it was absolutely necessary. This resulted in a failure to warn the public and take action to clear the station for a prolonged period of 15 min, so that many were caught by the flashover event after 16 min.

Düsseldorf airport Germany 4/11/1996. This fire started as a result of 'hot work' on an access roadway above one of the terminals with the fire penetrating down into a void and then through the terminal ceiling near a flower shop [6]. The fire was detected as a smell of smoke and visible sparks by a taxi driver waiting on the taxi line. He reported the fire to airport control by telephone. After 2 min, two airport fire fighters were sent to investigate. They called for an electrician to investigate an electrical burning smell, but the fire and smoke gradually worsened so that after 12 min, a full attendance of the airport fire service was requested. After approximately 27 min, a flashover occurred and the automatic general evacuation alarm was triggered, as well as a fire shutter designed to separate the fire compartment from the adjoining hall, but the shutter descended too slowly to prevent fire spread. The evacuation alarm consisted of a taped message that instructed occupants to evacuate toward the area where the fire was active. There were 16 deaths including 8 in the Air France VIP lounge, 5 in a lift which descended from the car park and opened on the arrivals hall fire, 1 person who was in a toilet, and 2 who were in the main arrivals hall.

From a pre-warning perspective, this incident has a number of features in common with the King's Cross incident. As at King's Cross, the fire was discovered and reported to the authorities at an early stage by a member of the public. The fire authority then spent a very long time investigating the incident, making no attempt to initiate an evacuation. The evacuation alarm only sounded as a result of the flashover event, thereby resulting in the deaths of a number of persons failing to be evacuated or prevented from entering the danger area. Also similar to King's Cross, it was a busy transport hub (airport), with staff being reluctant to take responsibility to evacuate or close down the facility. There were also 'chain of command' issues in both incidents with a series of different staff being involved in investigating and requesting further investigation or assistance over a long period. In practice, despite the severity of the incident, the airport was not closed until approximately 54 min after the discovery of the fire.

Dupont Plaza Hotel fire, Puerto Rico, 12/31/1986. This fire was started deliberately in an area of stacked furniture under a ballroom balcony [7]. The fire was discovered within a few minutes and attempts were made by kitchen staff and security to extinguish it, but it grew rapidly to a large size. As the fire developed security staff traveled up to a security office in the hotel tower for instructions. No alarms were sounded (or the alarm failed to function). After some minutes, as the fire was obviously getting out of control, some attempts were made by a security officer to warn a large number of occupants of a casino near the ballroom, but being intent on their gaming he obtained little response. Around 8–13 min after discovery thick smoke broke through into the lobby area and a large window between the fire and the casino failed so that thick smoke followed by fire swept through the casino. The only means of escape from the casino was via the lobby and although some occupants escaped via this route the smoke and heat in the lobby soon cut off the means of escape, trapping the remaining casino occupants and resulting in a total of 97 deaths.

Although there were issues in relation to the alarm system and the response of occupants to warnings when these were eventually given, it is evident that a significant pre-warning period elapsed between discovery of the fire by security and any attempts to warn occupants or evacuate the threatened areas of the hotel.

Littlewood's store fire, Chesterfield, UK, 5/7/1993. This fire was started deliberately in clothing on racks against the wall on the second floor of a department store [8,9]. The front of the floor consisted of a restaurant and the remainder a clothing sales floor. The fire was detected by two shoppers when the flames were approximately 300 mm high. They immediately shouted, 'fire!' attracting the attention of the sales staff member at the sales desk. The sales clerk (who was also a volunteer firefighter), immediately left her station in the center of the sale floor, walked across to the manual alarm point and activated the fire alarm within approximately 0.5–1 min of ignition. She then walked across to the main exit stair and took up a position there, holding open the door and encouraging the customers to evacuate. The fire growth was very rapid, flames spreading along the wall which was lined with racks of clothes, resulting in complete smoke logging of the whole enclosure within approximately 2–2.5 min from ignition. Due to the poor building design, there was effectively only one exit and stair available to the occupants for egress, resulting in considerable queuing at the stair entry doors and a large number of occupants suffering a significant smoke exposure. Despite this, all the occupants were able to escape with relatively minor injuries, with the exception of two persons who were overcome and died at the scene from smoke exposure.

As with other cases, the pre-warning delays here involved early discovery by members of the pubic and rapid reporting to staff. However, in this case, the prompt action of the staff member in raising the alarm and initiating the evacuation significantly reduced the probability of multiple deaths.

Nagasikiya store fire (3/18/90) Amagasaki City, Japan. A fire started on the fourth floor of a department store and spread throughout the floor in approximately 10 min [12]. The fire spread to the third and fifth floors via two staircases and an elevator shaft. Occupants in the offices and the employee dining room on the fifth floor did not respond promptly and were forced to take refuge. The fire was detected by a smoke alarm system at approximately 12:32. The signal was automatically relayed to a fire alarm control panel in the emergency office on the fifth floor. This signal of detector activation on the panel was seen by the unskilled staff who then confirmed the signal with staff on the fourth floor by interoffice telephone (i.e., that it was a real fire).

Staff on the fourth floor quickly commenced evacuation of the people on their floor, while the staff in the emergency office on the fifth floor attempted to contact a senior member of staff via a coded message through the PA system. This contact was to ask for his decision given the nature of the incident and the procedure in place. While the staff member in the emergency office was waiting for the senior member of staff, he spent time securing valuables until 12:38, as he saw relatively thin smoke. Meanwhile, the fourth floor was evacuated. At 12:38, when the staff in the emergency office realized the rapid change of smoke density on the fifth floor, it was conveyed to employees in the dining room to commence a general evacuation and the staff on the fifth floor started to evacuate. Unfortunately, by this time the conditions had deteriorated precluding safe egress. In total, 15 people died all of whom were initially located on the fifth floor. The impact of the separate staff decisions are shown in Figure 2.

Staff training and response studies, Tokyo, Japan. A detailed study of emergency staff behaviors and of the distributions of times taken to complete different activities was carried out by the Tokyo Fire Department as part of the training program between 1998 and 2001 [20,21]. During simulated fires emergency teams received a fire pre-alarm in a control room and then investigated and responded to a fire on the 22nd floor of an office building. Teams consisted of six individuals, three of whom investigated the scene, while others managed the safety center. During these studies, involving 222 separate team responses, the times from pre-alarm to emergency announcement to the whole building varied. On average, this pre-warning time consisted of 120 s to arrive on scene (standard deviation 22 s); 42 s to confirm the

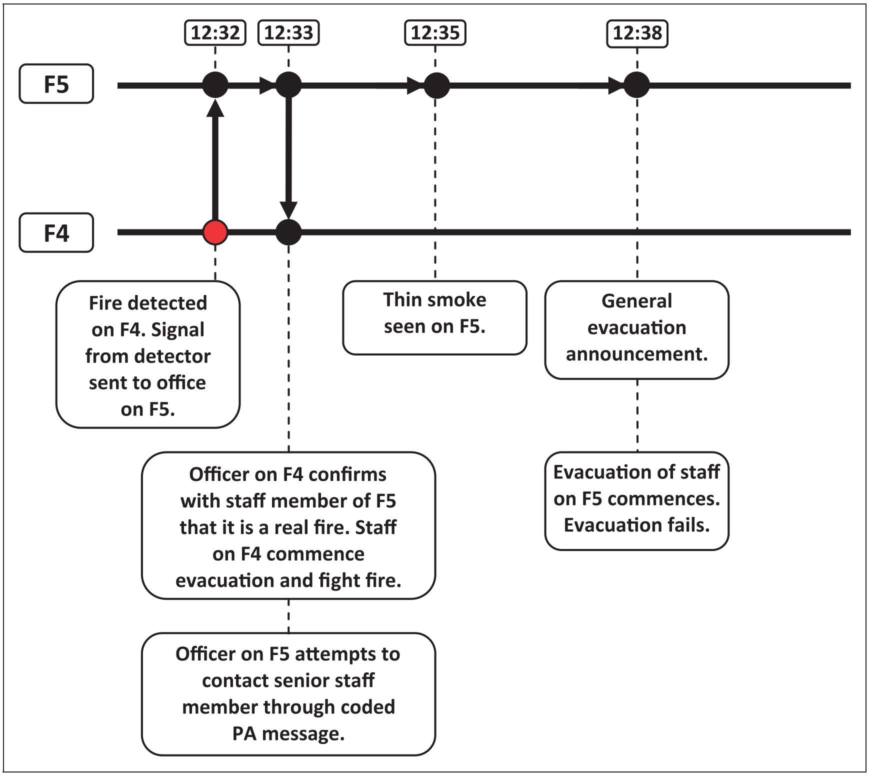

Figure 2. Passage of information in the Nagasikiya fire. Abbreviations: F# – floor number #.

incident (standard deviation 17 s); 71 s to evacuate the floor (standard deviation 60 s); and 167 s to evacuate the structure as required (standard deviation 99 s).

Unannounced evacuation drills from retail stores. Samochine et al. [22,23] examined the results from five unannounced evacuation drills conducted in four department stores in Ulster between 1995 and 2001. These drills were monitored in order to quantify evacuation performance, but also to gain insight into the procedural and behavioral components present. The format of these drills was different from the previous examples, given that the staff was responding to a public alarm, as opposed to private alarms. Therefore, the conditions under which the cues were received were slightly different from those previously discussed. However, this research is still indicative of the time for staff to respond to an alarm cue (irrespective of whether it was public or private). Also, given the reluctance of customers to respond to the bell alarm alone and the fact that many customers did not hear the bell at all, the response of staff was vital in encouraging customers to initiate their response.

During the original reporting of the trials [23], it was noted that it took the customer population on average 30.3 s to respond to the call to evacuate (ranging from 1 to 100 s). The 'pre-movement' (pre-evacuation) times of the staff were examined in Samochine et al. [22,23], where

> *staff pre-movement time is defined as 'the time interval between the warning of fire being given, i.e., the alarm, and positive evacuation activities by staff'. These activities could be, for example, open an emergency exit or direct customers to exit.*

This is important as this time relates to their participation in the procedure rather than only their self-evacuation; it therefore directly relates to the time for staff to interpret the nature of the event and commence their response. It was found [22,23] that the staff responded after an average of 18.1 s (ranging from 2 to 57 s). This is approximately half the time that it took non-staff members to respond. In addition, the first staff actions were established: 1% ignored the alarm, 61% waited or sought more information, 29% evacuated themselves or others, with the rest leaving their immediate area (most likely to find more information). Here, it is apparent that some of the staff's actions were to aid their decision-making process, rather than to employ the procedure expected of them. Also noted [22,23] was the significant impact that staff had on the response of the customer population

> *79.5% of the staff observed had an impact on customers' behavior. In the large majority of cases, customers did not evacuate until they were told to do so by staff.*

This represents a direct impact of the delay produced by staff processing the information provided to them, becoming aware of the situation and then responding. Indeed, 47% of customers received their first cue from staff during these trials.

The results of these incident and training examples demonstrate the importance of pre-warning behaviors and indicate the times involved in this phase of escape time. These are summarized in Table 1 along with the outcome of those events.

Table 1. Pre-warning delay times and numbers of fatalities during major fire disasters.

Fire incident	Pre-warning period (min)	Number of fatalities
King Cross subway station	~15	31
Düsseldorf airport	~27	16
Dupont Plaza Hotel	~10	97
Chesterfield Littlewoods department store	0.5–1	2
Nagasaki store fire	6	15
(Tokyo security staff training)	(3.9)	
(Ulster department stores)	(0.5–1.0)	

Understanding the impact of staff decision-making

It is now widely accepted that a key component in the time for evacuees to reach safety is the pre-evacuation time: the time between the target population being notified (or becoming aware) of an emergency and then initiating purposeful egress movement toward a place of safety [10]. Depending on the nature of the occupancy, the scenario, the procedure and the population, this pre-evacuation time can represent the majority of the time to reach safety; e.g., in hotels where occupants are sleeping. This is dependent upon the performance of pre-evacuation activities (i.e., action prior to a purposeful attempt to reach safety) and the cognitive process that assesses the information and the nature of the situation (i.e., that establishes an individual's situation awareness and then determines how they should respond).

Traditionally, the RSET calculation progresses from the time of ignition, to the time for detection, to the time information is received and then to the time for occupant response: occupants perceiving a cue, interpreting it, deciding to act and then moving to a place of safety (although this is simplified during the engineering calculations). The extent to which staff/public actions affect warning time depends upon the type of occupancy and in particular on the detection and warning systems used. In this context, three basic types of system are identified and classified into three performance levels in relation to the time required for notification [3,18]:

- *Level A1* alarm system – consists of automatic detection throughout the building, activating an immediate general alarm to occupants of all affected parts of the building.
- *Level A2* alarm system – consists of automatic detection throughout the building providing a pre-alarm to management or security, with a manually activated general warning system sounding throughout affected occupied areas and sometimes a general alarm after a fixed delay if the pre-alarm is not cancelled
- *Level A3* alarm system – consists of local automatic detection and alarm systems only near the location of the fire, or no automatic detection at all with a manually activated general warning system sounding throughout all affected occupied areas.

For a Level A1 system, once ignition has been detected, the alarm is automatically raised and evacuation can begin immediately, so the warning time is effectively zero. For a Level A2 system, the warning time depends at least partly upon the behavioral response of the staff. For a Level A3 system, the warning time depends upon the characteristics and behaviors of the person (or persons) discovering the fire. These concepts are expanded upon here.

For instance, a small office building may have a Level A1 system such that once a fire is detected by a (functioning) smoke detector the alarm will sound. In this instance, the delay in warning will be due to technological performance alone. However, in a domestic residence, automatic detection may trigger only a local alarm, which may be heard by only one nearby person, so that the warning of other occupants then depends upon the behavior of this individual (e.g., Level A3 system). In such situations, warning times may be long and unpredictable, presenting significant difficulties in estimating RSET values. In more complex structures/scenarios (such as transport terminals, hospitals, large hotels, high-rise structures, etc.), more sophisticated emergency procedures involving staff decisions/activities are often essential and put into practice to combat the complexities faced, to minimize disruption and/or to minimize security issues (e.g., Level A2 system). These procedures often require staff to interpret information, the notification of staff prior to the notification the general population (often referred to as private mode) and/or the (manual) confirmation of the incident by the staff prior (pre-signal) to the general population being notified. Pivotal in this type of procedure is the reaction and performance of the staff. It should be emphasized that this article is in no way suggesting that staff decision-making should be removed or minimized from emergency procedures. In many situations, this decision-making enables the procedure in place to function.

Although it has been identified as a key component of warning time within RSET [1–4], the time for the staff to go through the decision-making process is often omitted by engineers during their performance-based analysis, and when represented it is certainly not sensitive to the scenarios described above. Staff decision-making may occur in a number of situations; e.g., in discovering a fire, interpreting cues first hand (and recognizing them as indicating a real incident), or being notified of an incident (i.e., via the notification system at the fire panel, by other members of staff, by members of the occupant population, etc.). In these instances, staff members will need to perceive, interpret, determine an action in response, and then perform the action – in much the same way as other occupants; all of which takes time. Although trained staff may be more expert and have more experience (both of which will influence the extent of any delay), they would still have to go through this process, delaying their response and, in turn, the response of the general population of the building. The time during the warning period (i.e., the pre-warning delay) associated with staff response can be characterized as

$$\sum_{1}^{\#}(t_c + t_a) \qquad (2)$$

where # is the total number of decision making processes, t_c the time associated with cognitive/decision making processes, and t_a the time associated with the subsequent actions (which can approach zero in some instances). The following discussion focuses primarily on the t_c.

Procedural variants

The procedural response to an incident will be dependent on the procedural resources available, the type of occupancy and target population, the expected incident scenarios and the structure. Depending on the nature of the required response, procedures may require the immediate evacuation of the full population or require some pre-evacuation management in order to encourage success. This management may involve confirming the nature of the incident (e.g., that it is real and warranting response), determining the areas in the structure that require action (e.g., establishing which zones need to be evacuated in response to the incident), and determining when these zones should be evacuated (e.g., staging the response of zones in order to avoid egress routes being overloaded).

Broadly speaking, the procedure will require the detection of the incident and the notification of the population that there is an incident. However, the exact nature of these two actions is sensitive to a number of procedural attributes:

- Whether detection is through a sensor or a person (a member of staff or the public).
- Whether the signal detection automatically triggers a public alarm or provides a private signal to staff (e.g., whether the signal sets off an alarm or initiates a management procedure that is not immediately apparent to the occupant population).
- Whether the information is relayed to a central command or whether it is localized (e.g., an activated detector sets off a local alarm where the signal is not shared to staff or the occupant population outside of this area).
- Whether the report of the incident needs confirmation (e.g., given the propensity or the consequence of false alarms, that a detection signal must be confirmed prior to a public alarm).
- Whether the confirmation requires manual observation or whether remote observation is possible.
- Whether a confirmed incident leads to a full evacuation or requires a managed response (e.g., zoned, staged, partial, etc.).
- Whether the pre-alarm can be cancelled or defaults to a general alarm after a fixed delay
- Whether activation of more than one detector automatically activates a general alarm.

Staff decision-making in procedural variants

The categorization discussed above relating to procedural variants is further refined here to allow the impact of staff decision-making upon RSET to be estimated given a set of basic procedural requirements and the number of associated decision-making activities involved. Three main categories are considered from the list presented in the earlier section:

- the mode of detection (*Detect.*)

  - [Sensor | Staff | Public]
- the mode of dissemination (*Dissem.*)
  - [General Alarm (GA) | Local Alarm (LA) | Private Alarm (PA)]
- the mode of confirmation (*Confirm.*)
  - [None Required (N) | Remote Observation (R) | Manual (M)]

The complete set of additional activities required by staff as part of an emergency procedure are too numerous to list. However, they may certainly impact on the overall pre-warning delay and should be considered in an engineering assessment. Table 2 shows the number of staff and public decision processes associated with each of the procedural responses; i.e., the combination of the *Detect* (Sensor, Staff, Public)/*Dissem.* (GA, LA, PA)/*Confirm* (N, R, M) variables highlighted above. This type of approach may inform the development of engineering and regulatory guidance and therefore influence the manner in which RSET is calculated.

The expected delay time due to these processes will be highly dependent on the situation and the individuals involved. It is apparent that the various category permutations require a different number of decisions, each of which has the possibility of extending the time that it takes to eventually notify the general population of the response required of them. To demonstrate the potential impact, a staff decision time of 30 s is assumed (averaging the data collected in Tokyo and Ulster). This is purely to demonstrate the delay variants that might be expected. These calculations are presented in the final column of Table 2.

It is certainly not the case that procedures should be discarded because of the number of decision-making processes required within them. Indeed, it is the very ability of procedures to be sensitive to the incident and react accordingly that safeguard against unnecessary disruption or inappropriate response in complex situations. However, the potential delay incurred by these decisions should be represented within the engineering process of determining RSET. It should also be noted that the theoretical impact of the decision-making process upon RSET may have been underestimated. In many instances, confirmation and reporting may be even more of an iterative process as more information is required and processed, and the effect may therefore be more significant. In addition, no numerical assessment is made here of the actions that staff need to support a procedure; e.g., movement, operating communication devices, etc. that follow on from the decision-making processes. This will again add to the RSET value and should then form part of the consideration of *pre-warning delay*.

It is suggested that by using the type of framework presented in Table 2, the number of cognitive/decision-making processes expected for a given procedure can be estimated. A key component of the *pre-warning delay* could then be estimated by assuming a typical time taken for staff member's cognitive/decision-making process and multiplying this by the number of processes required. The associated activities could then be simulated in the same manner as the evacuation movement using engineering calculations, simulation tools, etc.

Table 2. Number of decision processes given the incident response.

Detect	Dissemination	Confirm	Description	Number of decision processes[a]		Example delay (s)
				Staff	Public	
Sensor	GA	N	No human decision-making (e.g., level A1 alarm)	[0]	[0]	[0] + [0]
	LA	N	Automatic detection. Local staff interpret signal and decide to: (a) activate the general alarm, or (b) notify control center staff who determine whether to activate general alarm, or (c) communicate privately with other staff to commence evacuation. (e.g., Level A3 alarm.)	(a) [1] or (b) [2] or (c) [2]	[0]	[30–60] + [0]
	PA	R	Automatic detection. Signal privately sent to control center staff. Signal requires confirmation through remote observation (e.g., CCTV) prior to: (a) public announcement to target population, or (b) announcement privately to staff to commence evacuation. (e.g., Level A2 alarm.)	(a) [2] or (b) [3]	[0]	[60–90] + [0]
		M	Automatic detection. Signal privately sent to control center staff who then require the incident confirmed through manual/human observation that is then reported to control center staff prior to: (a) public announcement to target population, or (b) announcement privately to staff to commence evacuation. (e.g., Level A2 alarm.)	(a) [3] or (b) [4]	[0]	[90–120] + [0]

(continued)

Table 2. Continued.

Detect	Dissemination	Confirm	Description	Number of decision processes[a]		Example delay (s)
				Staff	Public	
Staff	GA	N	Staff at site of incident interpret cues and raise general alarm that then alerts public. (e.g., Level A3 alarm.)	[1]	[0]	[30] + [0]
	LA	N	Staff at site of incident interpret cues and raise alarm, and then either: (a) local target population commences evacuation or (b) other staff are notified, interpret this signal and then act accordingly.	(a) [1] or (b) [2]	[0]	[30–60] + [0]
	PA	N	Staff at site of incident raise alarm and a private signal is sent to control centre prior to: (a) public announcement to target population or (b) announcement made privately to staff to commence evacuation.	(a) [2] or (b) [3]	[0]	[60–90] + [0]
Public	GA	N	A member of the public interprets fire cues and decides to activate the general alarm.	[0]	[1]	[0] + [Public]
	LA	N	Member of public decides to activate local alarm. Local staff interpret signal and decide to: (a) activate the general alarm, (b) notify control center staff who decide to activate general alarm, or (c) communicate privately with other staff to commence evacuation.	(a) [1] or (b) [2] or (c) [3]	[1]	[30–90] + [Public]

Notes: As with the rest of the RSET calculation, these delay times are assumed to be sequential.
[a]Decision processes prior to warning the public.

Example engineering response

From the material examined, it is apparent that the staff decision-making process required as part of any emergency procedure can affect the warning time and, therefore, the time for the general population to commence their movement to a place of safety. This delay is further extended (more intuitively perhaps) by the actions required of the staff after these initial decisions; however, the nature of this delay will be highly sensitive to the (scenario/procedure-specific) actions required of the staff, whereas a broadly applicable estimate for the decision-making process can be suggested. As with evacuee movement, this type of delay could be estimated through the use of simulation tools. Estimates are often used in the RSET calculation in order to represent the pre-evacuation times of the general population based on the nature of the notification system, population status, etc. For instance in PD 7974-6 and ISO TR 16738 [2,3] pre-evacuation times for the first occupants to start moving toward exits of 0.5—>15 min are suggested for offices and 5–10 min for residencies, depending mainly upon the characteristics of the occupants and the level of fire safety management and training [1–3,8]. To this is added a warning time depending upon the level of the alarm system. For a Level 1 system, the additional time is 'effectively zero', while for Level 2 stage systems, the recommended default is the 'timeout delay' to automatic alarm (usually 2 or 5 min). For a Level 3 system, it is suggested [3] that warning times are likely to be 'long and unpredictable' [3]. The approach described in this article should allow warning time estimates to be more sensitive to the required staff actions and the pre-warning delays produced.

The serious fire incident cases described above indicate that pre-warning delay has been a significant factor leading to multiple deaths in these incidents. The pre-warning delay often involved sets of different behaviors in a series by occupants and staff between discovery of a fire and the issuing of a general warning and the times involved in these activities varied from around 1–27 min.

As an example engineering application, let us assume a system with sensor detection, the use of private alarm from the sensor to a control center, the need for staff confirmation of the incident and then a private alarm to staff to commence evacuation of specific areas (an example of a Level A2 alarm). A 0 s sensor detection delay (t_d) is assumed for simplicity. The initial signal is sent to an officer in the control centre who has to interpret the information (decision – t_{c1}); no significant action time is assumed here. This officer then communicates with a staff member (communicate/action – t_{a1}) to move to the incident (move/action – t_{a2}) and then interpret the situation (decision – t_{c2}) before reporting back (communicate/action – t_{a3}) to the control room staff for them to assess the situation (decision – t_{c3}). The officer in the control room then communicates privately with other staff (communicate/action t_{a4}) to evaluate (decision – t_{c4}) and commence an evacuation (move/action – t_{a5}). Assuming the 30 s estimate for each cognitive activity, the following calculation can be made

$$RSET = t_d + [(120) + (t_{a1} + t_{a2} + t_{a3} + t_{a4} + t_{a5})] + t_{pre} + t_{trav}$$

where the 120 s represents the sum of the four decisions (t_{c1}–t_{c4}). As mentioned, t_{a1}–t_{a5} could be established through estimating message length (for the communication actions) or through the use of either engineering calculations or simulation tools (for the movement actions); however, it can certainly be assumed that these would be greater than zero and would contribute to the overall pre-warning time. Given the time taken to move to the incident and perform subsequent action(s), the final decision to evacuate may require several minutes, even in a well-designed and well-managed building. As revealed by several of the incidents discussed, in less efficient environments, this process has previously required more than 15 min. This may result in pre-warning delay constituting a significant fraction of the total RSET.

For general application the 30 s delay for each cognitive step may not be sufficiently conservative. A more conservative approach may then need to be adopted; for instance, deriving a representative value from the non-staff pre-evacuation data-sets available. The Samochine data suggest 50% of a non-staff pre-evacuation time may be representative, although such an assumption would require further analysis. If this were assumed then, given the extended non-staff pre-evacuation times often seen (Proulx [4]), the additional pre-warning delays incurred due only to staff cognitive steps would quickly become substantial.

Conclusion

The warning time incurred during an evacuation is not necessarily dependent only upon the performance of technology. There are a number of legitimate scenarios that require managed procedures to ensure a degree of flexibility and rigor in the procedure employed. However, these procedures, although essential, may have an inherent set of delays that are currently not addressed in the engineering calculations performed to estimate RSET values. It is the very strength of these procedures (i.e., that they employ the information available to help manage the procedure in a specific manner) that requires individual staff members to make decisions, which delay the overall notification process. These decisions are vital; however, they need to be accounted for in the RSET calculations. This can be achieved through the pre-warning delay concept, where the warning period is extended according to the estimated number of decisions required during a particular procedure.

There are several challenges relating to the pre-warning delay concept that need to be met: improving the theoretical understanding of the processes involved; the quantification of these processes with relevant data from drills and real incidents; and the representation of the concept within regulatory guidance, egress models and therefore within the engineering process.

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