

**A Framework for Identifying Groups Particularly Vulnerable to Fire
and the
Effectiveness of Notification Technologies
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1. Abstract

As part of a project funded by the Fire Protection Research Foundation different sections of the general population were examined to establish two criteria: whether they were particularly vulnerable to dying in fire incidents; and whether these vulnerabilities could be reduced through developing and/or applying new notification techniques. This project was primarily conducted in order to direct research activities; i.e. to establish where there were omissions in our current understanding and where this coincided with technological solutions of particular interest. Therefore, an approach had to be developed to identify vulnerabilities, and prioritize them in order to focus future research. The approach adopted was able to achieve this goal, but also proved to be an invaluable tool in examining and understanding various aspects of the evacuation process. This paper describes the development of this analytical framework and an example application: examining the effectiveness of notification technologies in reducing the vulnerability to fire fatalities.

2. Introduction

For most of the 20th century it was widely assumed that during an emergency evacuation the public should be deprived of information (e.g. relating to a fire), as it would have led to panic [1]. This was particularly the case in public spaces. This has now been replaced by the view that the population should be informed of the event requiring their evacuation as early as possible, in order to increase their acceptance of the emergency procedures and inform their decision-making process [2,3].

An emergency incident can be a rapidly evolving situation in which current information is an invaluable commodity. Amongst other things, it is imperative that evacuees respond in a timely fashion, and that this response is based on the information available [2,4-8]. It is often the case that the time to respond to an incident can seriously prolong the overall time required to reach safety [2,4,9-10]. This time can be influenced by a number of variables: the environmental conditions; nature of the structure; training and familiarity; the surrounding population; the presence of staff; the level of information pollution; and the notification system in place.

Information can arrive (or be sought) from a variety of different sources that vary greatly in their reliability and accuracy. Where there is ambiguity or conflicting information, time can be spent confirming the existence of an incident, the nature of the hazard posed and then formulating an appropriate response. In addition, this information can be misinterpreted or missed entirely. The implementation of notification technology represents an attempt to compensate and correct for these omissions.

It is also vital that once the population evacuates they are aware of the egress routes available, use them efficiently, and waste as little time as possible wayfinding. Therefore, when designing an emergency procedure, two basic behavioral components need to be addressed: ensuring that people are alerted of the incident sufficiently quickly and in adequate detail; and ensuring that the population responds in the most efficient manner possible.

From the research literature it appears that the most effective means of informing an individual of an incident is through the presence of well-informed, well-trained, assertive [11, 12] and respected staff. The message is perceived as more credible [3]; the member of staff is able to update and adapt the information as the incident requires; and they are able to physically intervene to aid the evacuee response where necessary [4,11-12]. If sufficient numbers of staff are not present to inform the occupant population and manage the evacuation, then other means of influencing the evacuation needs to be provided. In the absence of staff, it is critical that an information vacuum be avoided. There will inevitably be situations where members of staff are unavailable, or where they need support. In these situations, notification technology is a critical tool. These systems (video, audio, tactile, etc.) are used to inform occupants of the existence of an incident and then, ideally, aid their response to ensure safe egress.

As part of a project funded by the Fire Protection Research Foundation different sections of the general population were examined to establish two criteria: whether they were particularly vulnerable to dying in fire incidents; and whether these vulnerabilities could be reduced through developing and/or applying new notification techniques. Given that being alerted to a fire early is a key factor in surviving a fire incident, existing notification approaches were examined to determine whether they were effective in alerting these groups of the existence of an incident and improving their chances of survival when responding to it.

This project was primarily conducted in order to direct research activities; i.e. to establish where there were omissions in our current understanding and where these omissions coincided with technological solutions of particular interest. Therefore, an approach had to be developed to identify vulnerabilities, and prioritize them in order to focus future research. The approach adopted was able to achieve this goal, and proved to be an invaluable tool in examining and understanding various aspects of the evacuation process. This paper describes the development of this analytical framework and an example application: examining the effectiveness of notification technologies in reducing the vulnerability to fire fatalities.

3. Limitations of the Existing Approach

The project required the development of an approach to identify and assess a range of vulnerabilities. It was established relatively early on in the work that these vulnerabilities were not equally supported by the data available; i.e. that some vulnerabilities were more likely to be recorded than others. This became apparent from examining high-level statistics, the methods used to collect and store the supporting information and from examining our understanding of human behavior in fire [2,4,13-16]. It was felt that this

issue may mask potentially important vulnerabilities that need to be examined and addressed. A novel approach needed to be developed to overcome this problem and in order to reliably assess these vulnerabilities. The approach adopted during this project is shown in Figure 1.

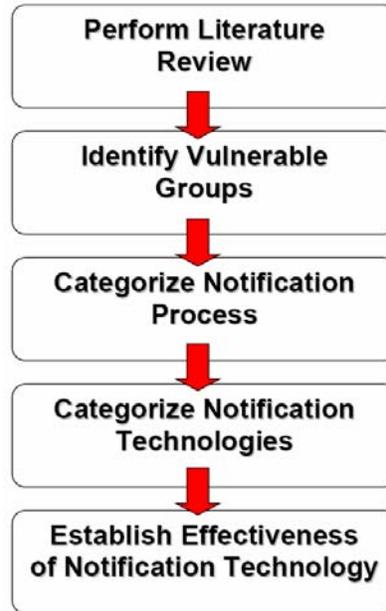


Figure 1: General Approach Adopted.

Initially, the approach required an extensive review of the available literature describing the notification process and how it fits into the overall evacuation process. This review was essential as it enabled us to identify vulnerabilities, understand their nature and place them in context with the overall evacuation process.

This iterative process also enabled the identification of vulnerabilities that arose from different sources; i.e. that could not all be attributed to the individuals involved. This was important as the nature of the vulnerability influenced the likelihood of it being recorded. These sources included

- *Innate vulnerabilities* – vulnerabilities that were an attribute of those involved (and are traditionally easier to identify and record); e.g. the individual was immobile, elderly, etc.
- *Experiential vulnerabilities* – vulnerabilities that related to the level of experience, knowledge levels, and procedural awareness; e.g. whether or not an individual is sufficiently trained.
- *Situational vulnerabilities* – vulnerabilities that related to the incident scenario; e.g. the individual was asleep or intoxicated, close to the fire, etc.).

Vulnerabilities were defined in this manner to better understand how they may arise, persist, develop and propagate (see Figure 2). For example, vulnerabilities need not be permanent; i.e., someone that may not otherwise be considered vulnerable may become

vulnerable (e.g. intoxication, the presence of background noise). These situations are particularly susceptible to being overlooked in the reporting process and are also less likely to have been prepared for by those involved; e.g. someone with a permanent and serious hearing impairment is more likely to have taken some measures to counteract this condition in comparison with someone who is occasionally intoxicated.

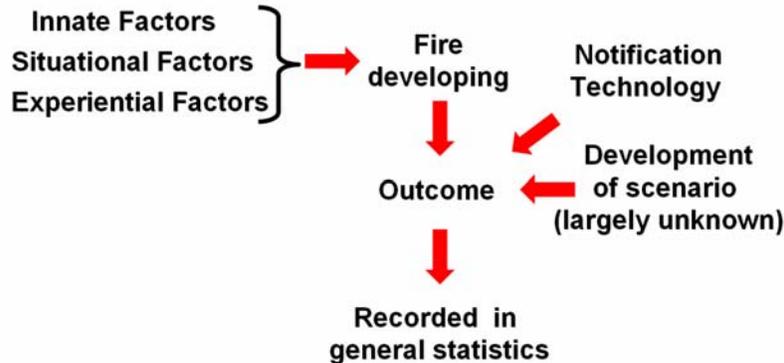


Figure 2: The factors leading to vulnerabilities.

It became clear that the groups identified as being vulnerable were not equally likely to be represented in the incident statistics collected. This discrepancy may have been due to difficulties in identifying the presence of a condition (e.g. the presence of partial hearing loss in a fatality); recording practices (e.g. whether all of information was recorded at the scene); and also establishing whether or not a factor actually influenced the fatality (e.g. whether being asleep contributed to the fatality or whether the individual would have died anyway, see Figure 2). Therefore, not only are there difficulties in extracting vulnerabilities during the fire investigation and through examining the reported material, but it is also difficult to assess the extent of the actual impact of reported vulnerabilities in a particular incident.

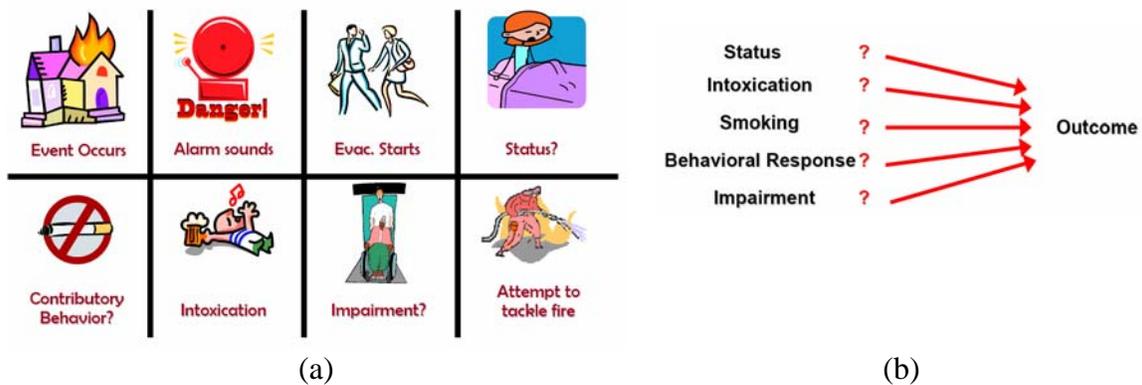


Figure 3: Hypothetical incident with 'contributing' factors.

An example will help illustrate this problem. Let us assume that an incident has occurred where fatalities have been recorded. The report of this incident records that several events, factors and behaviors were present during the incident; e.g. the alarm sounded, people were asleep, people were intoxicated, etc. (see Figure 3(a)). However, some factors are missed in the reporting process, given that there was no indication at the scene and there was no previous record of this factor existing; for instance, a fatality had an

unrecorded hearing impairment. Therefore, it is possible that an incomplete record exists of the factors that contributed to the number of fatalities. In addition, it is difficult to reliably assess whether the recorded factors *actually* contributed to the number of fatalities, whether they would have contributed but were dominated by the severity of the incident, or whether they were coincidental (see Figure 3(b)). This is primarily due to the absence of a detailed narrative account describing the incident. Therefore, the chain of events (e.g. causal factors, outcomes, etc.) is difficult to ascertain.

These issues can lead to certain vulnerabilities being misreported and misunderstood; it is possible that high-level statistical trends may misrepresent the importance of a particular factor, and may miss others entirely. To avoid these discrepancies, an analytical approach was developed to *complement* the existing statistical approach. It is contended that this analytical approach is able to identify factors that may fall through the statistical ‘net’ and may help explain why certain vulnerabilities exist in the first place.

4. The Analytical Approach

The analytical approach required that vulnerabilities be identified from the bottom-up; i.e. by analyzing their constituent components and identifying vulnerabilities, rather than employing the traditional approach of deriving trends from high-level statistics (see Figure 4). This depended on a comprehensive and detailed examination of the available literature in order to analytically derive vulnerabilities, rather than extracting them from general statistical trends.

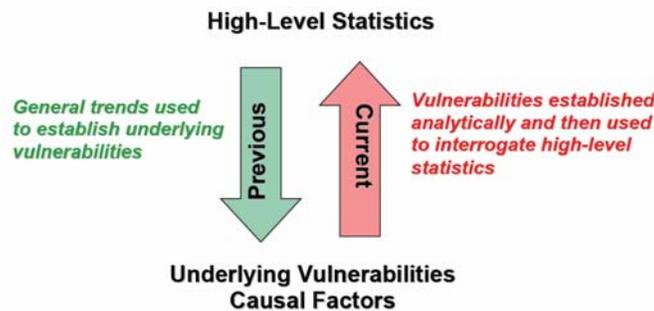


Figure 4: Comparison between the traditional and analytical approaches.

A broad literature review was performed of the evacuation process. This deliberately included a wide variety of subject areas in order to get an appreciation of the pre-evacuation process, the manner in which this influenced the evacuation response, and to place the potential impact of notification systems into context. It was also felt that vital information may be included in material that did not directly address notification issues; this examination increased the probability of recognizing previously overlooked vulnerabilities. This review included material addressing the following topics:

- *Anticipated evacuation behavior and influential factors*
- *Case Studies –reports describing real fires such as the Beverly Hills Supper Club incident [17]*
- *Theoretical Work –where researchers have attempted to explain the phenomena recorded in the data available including the work of Sime , etc. [2,16]*

- *Empirical data – where field researchers have engineered situations in order to produce data, including the work of Proulx, Shields, etc. [11,12,18]*
- *Notification principles – the factors specifically associated with the notification process.*
- *Notification technology – the technology available and the potential impact that this may have upon evacuee response.*
- *Incident scenarios – the types of situations that might arise and the impact of contributing factors such as occupancy type, the resident population, and other contributory behaviors/factors. It was important that a wide range of occupancy types were considered (i.e. the analysis was not just limited to residential situations). Again, this enabled a wider range of vulnerabilities to be identified.*

Both qualitative and quantitative material was examined in order to provide a more reliable foundation for the analysis. This was critical given the limitations with the high-level statistics highlighted previously. It was vital for this analytical approach that we not only understood where vulnerabilities existed, but understood why they existed and also understood the nature of the vulnerability itself. In support of this understanding, material was included that provided (or was based on) a narrative account of the fire incidents. Therefore, in these cases, the statistical evidence examined was both supported and informed by a descriptive account.

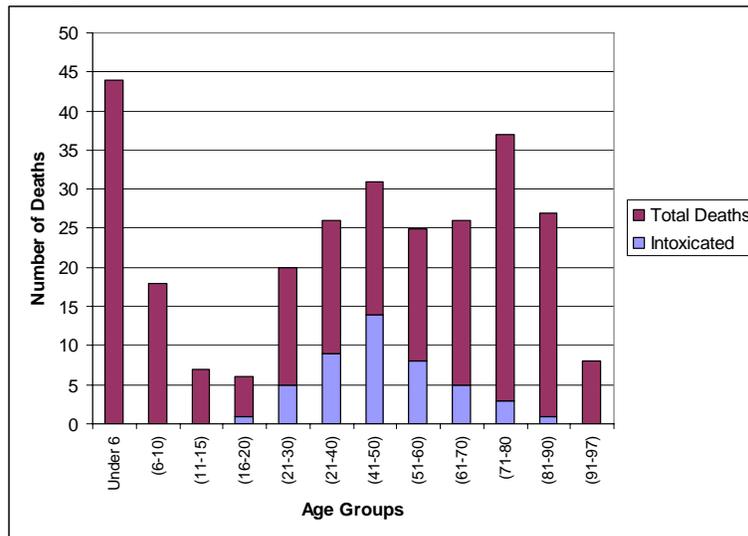


Figure 5: Low-level quantitative analysis provided by Fahy and Molis [19].

Examples of this can be found in the work of Fahy and Molis, and Purser and Kuipers [19,20]. In this work, the conclusions derived were not solely based on an overview of statistical trends, but were also influenced by a low-level analysis of quantitative data and an assessment of the contributory factors in each of the cases included in the analysis; they therefore attempted to understand the chain of events and explain why the statistics were produced as well as quantifying the results collected. An example of low level quantitative analysis (see Figure 5) from the work of Fahy and Molis is shown. In addition to providing this type of information, they also provided narrative accounts such as the one shown below:

“In a fire caused by a child playing with a cigarette lighter, the 67-year-old grandmother attempted to extinguish the fire with pots of water before going upstairs to awaken her 76-year-old husband and 90-year-old mother. All three died on the upper level of the house. Her daughter and three young children escaped from the ground floor.”[19]

These accounts were useful in and of themselves, but are indicative of the detailed low-level behavioral information to which Fahy and Molis had access [19].

Therefore, the analytical approach was based on detailed qualitative accounts, low-level quantitative analysis and also on the more traditional high-level quantitative statistical data. Vulnerabilities were identified in context with the incidents from which they were derived and an effort was made to understand how these vulnerabilities could have contributed to the outcome of that incident. This was achieved by understanding the nature of the vulnerability in question and then establishing how this may have constrained the performance of a population. In this manner, a set of vulnerabilities and vulnerable populations were identified.

5. Establishment of Vulnerable Groups

Vulnerable groups were derived through examining the research literature and from guidance provided by the expert technical panel established as part of this project. A variety of different groups were identified including, but not limited to:

- *Individual Differences/Attributes*
- *Children younger than 5*
- *Children older than 5*
- *Hearing impaired (identified /unidentified)*
- *Visual impairment (identified /unidentified)*
- *Untrained individuals*
- *Unprimed individuals*
- *Elderly*
- *Those asleep/awake*
- *Sleep deprived*
- *Drug impairment (medication)*
- *Drug impairment (illegal narcotics)*
- *Alcohol impairment*
- *Chronic Health Problems*
- *Fire safety not responsibility*
- *Fire not considered likely*
- *Those subject to false alarms*
- *Physically impaired*
- *Mentally impaired*
- *Presence of Background Pollution (e.g. noise, lights, distractions, etc.)*
- *Being Alone*
- *Engaged in an activity (i.e. attention focused elsewhere, level of commitment)*
- *Unfamiliar with signal/message*
- *Unfamiliar with surroundings*
- *Fearful of responding (e.g. institutions)*
- *People in large groups*
- *People in public spaces*
- *Non English speaker*
- *Those affected by security issues*

These groups were then examined using the analytical approach to establish the nature of their vulnerability and, crucially, whether this vulnerability could be ameliorated through improvements in the notification process. This examination was confined to the delivery

of the signal/message and therefore excluded issues of implementation, maintenance, or connectivity that may be related to the use of a particular notification system; although important issues, they were beyond the scope of the project.

This analytical approach required breaking down the notification process into four constituent components. These four constituent components were derived from the review of theoretical work associated with the notification process and was particularly influenced by the work of Mileti [3]. Each of the groups identified as being vulnerable was assessed according to these four components:

- a) *Receipt of signal/message by the target population* - the ability of the notification system to attract the attention of the target population; how effective is the notification system in alerting the target population?
- b) *Recognition of the signal/message* - Given that the target population receives the signal are they able to determine that the signal denotes an actual fire? Is the target population able to differentiate between the signal or message and others that they may received, such as car alarms, security alarms, etc.?
- c) *Identification of Response* - Given that the target population is able to receive the message/signal they are then able to identify the required response. Is the target population able to determine the appropriate response to the alarm signal?
- d) *Evacuee Response* – Given that the target population knows what response to perform, are they are actively able to do so?

This approach was important in order to establish which of the vulnerabilities identified were due to notification (a-c in the previous list) or due to some other vulnerability that could not be addressed through the improvement of notification technology. This process both clarified our understanding of the vulnerabilities and later assisted in the prioritization of the vulnerabilities required as part of this project. These vulnerabilities were then re-examined in order to categorize them according to the phase of the notification process that the particular group was vulnerable. A simple metric was produced to clarify this categorization process. This enabled the nature and the severity (no vulnerability, slight vulnerability, severe vulnerability) of the vulnerabilities to be better understood. An example of this is shown in Table 1. This process required a simplification of the vulnerabilities in question; however, this was essential in order to gain a general appreciation of the vulnerabilities and then make comparisons between them.

Table 1: Example of categorization for two groups deemed as vulnerable.

	<i>(1) Receipt of signal/message</i>	<i>(2) Recognition of signal/ message</i>	<i>(3) Identification of Response</i>	<i>(4) Evacuee Response</i>
Children younger than 5	STRONG	STRONG	STRONG	STRONG
Hearing impaired	STRONG	slight		

In the example shown in Table 1, children younger than 5 years old are deemed to be vulnerable in all phases of the notification process (indicted by a “strong” rating): receiving and understanding the message, knowing how to respond to it, and then being

able to perform this action. Therefore, a component of their vulnerability (i.e. their ability to respond to the incident) is beyond the direct reach of notification technology. In contrast, it was established that the hearing impaired were deemed only to have vulnerabilities related to receiving and possibly recognizing the notification message, and do not *necessarily* have innate vulnerabilities associated with their response. As such, technological improvements to the notification system may benefit the hearing impaired.

This approach was adopted to understand the nature of the vulnerabilities and also to focus on those groups that were deemed most vulnerable, but which could benefit most from the development of notification technologies.

The detailed review and the separation of these vulnerabilities into their four constituent parts highlighted how vulnerabilities were not necessarily static, nor independent of each other or the scenario; instead they were dynamic and could evolve and interact in complex ways. Importantly, the analysis also highlighted how the vulnerabilities may propagate; i.e. influence an individual and others involved in the incident. For each of the vulnerable groups, a set of factors were established highlighting the primary impact of this vulnerability upon their response (see examples in Table 2). In addition to this, the secondary impact of the vulnerability was established; i.e. the potential impact on others. In this manner, the capacity for the vulnerability to propagate to other members of a population was examined. Not only is it difficult to get a consistent assessment of the vulnerable groups from examining high-level statistics, but the secondary impact of these vulnerabilities may also be overlooked. This consideration was therefore important both in terms of understanding the impact of the vulnerabilities and their prioritization, but also in identifying vulnerabilities that might be overlooked but have an important secondary impact upon the outcome.

Table 2: Primary and Secondary impact of vulnerabilities.

	<i>Primary Impact on Emergency Response</i>	<i>Secondary Impact on Emergency Response</i>
Children younger than 5	Depth of sleep / sleep patterns. Inability to comprehend seriousness of situation / form appropriate response.	Responsibility of another. May require rescue potentially placing the other person at risk
Alcohol impairment	Difficult to arouse. Likely to be cognitive impaired. Potentially mobility impaired.	Likely to delay/prevent them from rescuing someone else in their care.

6. Notification Technologies

Once the vulnerabilities had been examined, the notification technologies currently available could then be categorized according to which of the four components of the notification process that they addressed (a general example of this type of categorization is shown in Table 3). The extent to which they addressed these components was also estimated from the literature review. A simple scale was derived:

- black - literature suggests that the technology can address this component of the notification process.
- grey - literature suggests that the technology has the potential address this component, or that it is likely to have a moderate impact.
- empty – the technology is not able to address this component.

This enabled the potential impact of the notification technologies to be better understood and some comparisons to be made. For example, a strobe system may be able to aid in the receipt of a signal; it may also help in the recognition that a fire incident is developing (see Table 3). It is not, however, able to help identify the required response or aid in this response. This should be compared with a member of staff who has the *potential* for helping in all of these four categories.

Table 3: Example of the categorization of various notification approaches.

	Technologies									
	Tone	Air Move.	Smell	Strobe	Adv. Tone (T-3)	Adv. Sound.	Voice	Vibr. dev	Graph. Display	Staff
Receipt	Grey	Grey	Grey	Grey	Black	Black	Black	Black	Black	Black
Recog.	White	White	White	Grey	Grey	Grey	Black	Grey	Grey	Black
Resp. Ident.	White	White	White	White	White	Grey	Grey	White	Grey	Black
Resp. Perf.	White	White	White	White	White	White	White	White	White	Grey

The examination of the vulnerable groups and the notification systems was then integrated to establish which of the notification approaches addressed the vulnerabilities in question. A simple metric was then established to represent the potential of these approaches at reducing these vulnerabilities. An example of this is shown in Table 4. The potential impact of the notification systems is represented using a three point scale: black indicating that either a significant benefit may be attained or that some benefit is likely; grey indicating that either some benefit may be gained; no color indicating that no benefit is likely. This represents a simplification, but enables some comparison to be made.

Table 4: Assessment of the potential impact of notification technologies upon vulnerable groups.

	T-3	T-3 (Var)	Voice	Vibr.	Strobe
Hearing impaired	White	White	White	Black	Black
Untrained/Unprimed Public	Grey	Grey	Black	Grey	Grey
Those asleep	Black	Black	Black	Black	Black
Alcohol impairment	Grey	Grey	Black	Grey	Grey
Presence of Background Noise	Black	Black	Black	Black	Black

By adopting this analytical approach, vulnerable groups could be identified in a manner that was independent of the process used to record the data at the scene; i.e. that could take into account the body of learning in the field of human behavior in fire, rather than rely completely on high-level statistics. This allowed vulnerabilities to be highlighted that might otherwise have been overlooked. This approach could then be used to compliment the existing method of identifying vulnerabilities through the examination of statistical trends. It also allowed the nature of the vulnerabilities to be better understood and suggested a means of potentially addressing the vulnerability in question through the application and development of different notification technologies.

7. Conclusion

Ideally, a notification system should be formed from technological and human solutions. Not only will these two sources of information act to reinforce the reality of the incident, it will increase coverage and introduce much needed redundancy into the system. Notification technologies provide a means to support staff activities, but also to alert the population and ensure a minimum level of information regarding an incident.

Vulnerabilities exist that make elements of the population more susceptible to fire than others. However, these vulnerabilities interact in complex manner, and need not be associated with the individuals involved. These points, along with limitations in the reporting and recording process, mean that not all vulnerabilities are equally likely to be recorded. A method was developed to support the traditional approach to establishing vulnerabilities that was based on a broader analytical approach. This took into account a broader base of information and tried to derive the vulnerabilities from underlying factors (i.e. from the bottom-up) rather than from general statistics (i.e. from the top-down).

This analytical approach provided a complimentary method of identifying, understanding and categorizing the vulnerabilities in question. It also provided additional information on the source of vulnerabilities and allowed an assessment to be made of the merits of different notification technologies in addressing these vulnerabilities.

It is felt that this type of approach may be useful beyond the subject matter described here. The analytical framework outlined may enable more rigorous expert analysis to take place, in support of other, more traditional approaches (e.g. simulation work, engineering calculations, procedural design, etc.). It may provide additional evidence in support of empirical or computational work, and/or provide a benchmark against which this can be measured.

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