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# VOCAL ALARM SYSTEMS FOR HIGH-RISE BUILDINGS – A CASE STUDY

**John P. Keating* and Elizabeth F. Loftus**

*Department of Psychology, University of Washington, Seattle*

In a time when sophistication concerning water delivery, smoke control, and fire fighting strategies in general has truly matured, it is deplorable that knowledge about human factors under fire conditions remains primitive. Few studies have addressed the problem of human behavior in building fires, particularly fires in high-rise structures. In an excellent review of the literature related to various aspects of fires in high-rise buildings, Rubin and Cohen (1974) summarized their findings by commenting that "the most striking feature which resulted from the review of psychological material was the dearth of relevant data" (p. 19).

Serious fires in high rise buildings are unfortunately all too common. In January 1970, a fire in the Conrad Hilton hotel in Chicago claimed two lives and hospitalized thirty-six people. In the summer of that same year a fire in the 50-story New York Plaza building killed two and injured thirty while causing almost 10 million dollars worth of damage. In February 1972, a fire in the 31-story Andraus Building in Sao Paulo, Brazil, killed 16 people and injured nearly 400 others. Finally, in South America from July 1973 to February 1974 there were 3 major high-rise fires resulting in 183 fatalities and nine million dollars in damages (Sharry, 1974).

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Fire in high-rises is a problem for safety experts. But when building codes are written, sprinkler systems installed, and architects have finished overseeing construction, fire-safety becomes a problem of people: how to inform them in emergencies, how and how many to evacuate, how to forestall panic, in a word, how to teach people to survive. While experts have not been specifically trained to deal with human problems during fire emergencies, several research areas of psychology provide information that can be applied to questions of human behavior in such emergencies. Findings from social, cognitive, and human engineering psychology suggest types of instructions which should be most effective in eliciting desired responses during emergencies as well as how people might behave under ambiguous, stressful situations. The present study suggests how such findings can be applied to the development and evaluation of vocal alarm systems in high-rise structures.

## THE PROBLEM

The initial ideas for a public address warning system for use in fire emergencies emerged from the International Conference on Fire-Safety in High-Rise Buildings, held in two sessions during 1971 (Proceedings, May and October, 1971). During the first sessions, a panel on Occupant Protection recommended that during an emer-

gency, if an occupant is ". . . reassured and informed by a public address system or other means, he is less likely to become excited or apprehensive" (p. 4–10). A total public confidence system was recommended which would include a communication network that might be activated manually or automatically to communicate with building occupants affected in an emergency situation (p. 4–12). In his examination of psychological factors related to occupant protection during fires, Gilbert Teal stated that automatic voice tapes capable of transmitting pre-recorded instructional messages to emergency areas should be an essential component of an effective warning system (p. A–19).

Consequently, a task force on emergency communications established at this meeting considered as its primary purpose the development of a total protection system involving oral communications. In describing such a voice alarm system (VAS), this task force highlighted the following characteristics:

(1) A voice alarm system can give precise instructions under varying emergency conditions (e.g., fire, bomb threat).

(2) Instructions can vary for different zones of the building.

(3) Recorded alerting sounds can capture attention of the people and alert them to emergency at hand by pre-conditioning.

(4) Pre-recorded messages can be used for pre-planned conditions.

(5) Pre-recorded voice announcements can be used automatically to respond to manual or automatic fire alarms.

(6) The voice system can be used to modify or update information.

(7) Number and types of speakers is dependent on the situation of the area covered.

(8) A voice alarm system may be combined with a music/paging system. If so the music system can be turned off and the emergency announce system can operate at predesignated volume levels.

(9) Manual voice directions can override or cancel automatic voice transmissions (p. 71-EC-3).

While the recommendation of a VAS was based on the combined experience of the assembled fire-safety experts, the actual definition of the most effective instructional messages, warning signals, voice qualities, etc., was not determined. While there was agreement that attention must be given to occupants' perceptual responses to auditory and visual signals, as well as to the social forces acting upon individuals during emergencies (Rubin and Cohen, 1974), research on these aspects of emergency behavior was sparse.

The General Services Administration of the U.S. government devoted its energy to plan a high-rise structure that would incorporate the recommendations for a total fire-safety system in its design. The 37-floor Seattle Federal Building was designated to be the model structure. The basic hardware of the fire-safety system was installed and several important decisions concerning personnel evacuation plans were made. First, fire-safety officials had decided that total evacuation of the building would be dangerous as well as impractical during fires. Instead "area evacuation" was recommended which meant that during fires only the affected and adjacent floors of the building would be evacuated. Secondly, the paths of area evacuation called for upward as well as downward personnel movement. Finally, and most importantly for our interests, it was decided that the evacuation plan required a system which included a public address component capable of broadcasting pre-recorded taped directions to communicate with building occupants who might be affected by a fire.

While the hardware of the Seattle Federal Building was designed to incorporate the nine characteristics of the VAS described above, actual definition of the most effective warning signals, instructional messages, and voice qualities of the communicator were yet to be determined. As psychologists we were asked to make recommendations concerning each of these aspects of the system.

## ALERTING TONE

Recommended as essential for a VAS was an alerting tone which could capture the attention of occupants and alert them to attend to subsequent directions which would affect their movement during an emergency. For use as such a signal we recommended that the U.S. Federal Communication Commission's 1000 Hz pure sine wave tone warning signal be used. In the U.S. this signal is currently used by the Emergency Broadcasting System to precede important announcements of emergency situations over designated radio stations. Normal radio broadcasts are interrupted by the tone and emergency announcements immediately follow.

### Rationale

According to the *Human Engineering Guide to Equipment Design* (1972), the human ear is most sensitive in the range of 500–3000 Hz The FCC tone falls comfortably in this range. The *Guide* further suggests that an oscillating tone provides a good warning signal when it must be presented over an intercom system. The FCC tone is oscillating. Finally, the *Guide* recommends an intermittent, pure tone signal if speech is necessary. As speech is one of the major components of the VAS, the FCC tone is ideal.

The 1000 Hz tone at @ 95 db. further satisfies the requirements specified in *Occupant Behavior in Building Fires* (Rubin and Cohen, 1974), that the tone is intense enough to be sensed, but not so intense as to cause permanent damage. Finally, such a signal should be appropriately interpreted as a warning tone, always followed by information directing the occupants about what to do next.

A more comprehensive statement regarding the qualities that should be part of an effective warning system can be found in *Human Factors Engineering* (McCormick, 1964). According to this source (p. 171–172), an audio warning signal should have the following characteristics:

(1) audible (heard above background noises);
(2) quick-acting (capable of evoking a quick reaction);
(3) alerting (catching people's attention);
(4) discriminable (easy to differentiate from other signals);
(5) informative;
(6) compatible (consistent with others in use);
(7) non-masking (not prone to interfere with other functions by drowning other audio signals);
(8) non-distracting (not startling);
(9) non-damaging (not cause irreversible damage to hearing).

When held up to these criteria, the FCC signal is an efficient device for alerting occupants to an emergency.

(1) The audible character of the signal will be secured by setting the sound-pressure delivery of the signal sufficiently above the expected ambient noise level. This would be at about 25–30 phons above the expected ambient noise level of approximately 65 phons that is usual for open office space.

(2)–(6) The FCC signal evokes quick action (attention to the message which follows) once occupants are trained to its use. Its purpose is to alert, and it will be used only in those circumstances demanding such an alert. The signal is compatible with the use currently made of it, namely, alert to an emergency. It is informative in that it will always signal an alert, and it is easily discriminable in that no other sounds that are likely to occur are similar to it. Finally, the connotation of the signal is already reasonably well understood.

(7) At the proper loudness level, the FCC tone is not likely to interfere with other functions. For example, it would be possible for someone speaking loudly to give verbal instructions during the tone if such instructions were necessary.

(8)–(9) The pain threshold for sound is about 120-140 phons. If the tone is delivered below this level (predicted delivery would be at about 90–95 phons) the audio signal would be harmless to human hearing.

A final advantage of the FCC tone is that it capitalizes on the pre-conditioning of the occupants to this signal as an emergency warning. Such pre-conditioning would be desirable as is implied by the report of the task force on emergency communication systems at the second session of the International Conference on Fire-Safety (p. 71-EC-3).

There is one potential cause for concern. Since the FCC tone on the radio is typically used in conjunction with a "test", "false alarm behavior" might be evoked when the tone is used in a VAS. Occupants might assume that "this must be a test, just like on the radio," and simply ignore the tone. In our opinion, such false alarm behavior would not be evoked since the immediate announcement following the tone will indicate that a fire evacuation procedure is in effect. This vocal message is markedly different from the silence that is usual following radio transmissions of the signal.

## VOICE QUALITIES OF COMMUNICATOR

An important consideration in the design of the VAS was what type of voice should present the instructional messages delivered to the occupants. It was recommended that the emergency announcement be introduced by a female voice, and that the instructions themselves be delivered by a trained male voice which was authoritative, calming, and not concentrated in the bass range.

### Rationale

Research suggests that switching from a female to a male voice will be noticed even when people are not really paying attention (Cherry, 1953; Cherry and Taylor, 1954). Such a switch will get through the "attentional barrier" of occupants who may be absorbed in conversations or their work.

A second reason for introducing the message with a female voice was related to the recommended alerting tone. Since use of the FCC warning signal may be preconditioned to an alert situation which never materialized in an actual emergency, such pre-conditioning could lead occupants to ignore the signal. The introduction of a female voice after the signal is dramatically different from the male voice that typically announces the FCC warning. This difference should eliminate even the small possibility of false alarm behavior, particularly since the signal is only used to tune people into the information that follows the signal (cf. Baker and Mack, 1960).

The instructions which are delivered should instill confidence that the communicator knows the situation and knows what should be done. At this stage in our society, males are stereotypically looked to as the ones who take charge in an emergency. Relying on this stereotype (however unjustified), a male voice was recommended for most of the directional delivery. In addition, the voice should be trained and exercised in the use of clear diction so that the information will be received clearly. The voice should also be calming since in most situations the avoidance of panic will be at least as important as the rapid dispersal of occupants from troubled floors. Finally, a higher ranged male voice was recommended since the majority of the message delivered by such a voice will reside in the 1000+ Hz range; this range is considered to be the most easily understood range of voice delivery.

After an auditioning procedure was conducted, a member of the Screen Actor's Guild was selected for the female communicator, and a radio announcer from a local radio station was selected as the male communicator for the system in the Seattle Federal Building.

## EMERGENCY MESSAGES

In this section examples of the messages along with the rationale used in their composition are presented. The first example is the message sent to the building's elevators at the time a fire is reported. Next, we present an example

of the messages sent to the occupants of the fire floor; for present purposes we assume a fire has been reported on the twelfth floor.

#### Elevator Message and Rationale

A modern "improvement" in elevator cars is the self-service elevator which is controlled by a computer and responds to the touch of a finger. The call buttons on these elevators are frequently heat- and pressure-sensitive. Consequently, when a fire occurs elevators may go automatically to the fire floor. In a recent fire in New York City three people took an elevator down from their offices in an attempt to escape from a fire. The elevator stopped on the fire floor, whereupon the doors opened, became warped from the heat and all three people died on the floor of the elevator that they thought was their vehicle to safety.

To correct for this potential problem a fire alarm in the Seattle Federal Building triggers an automatic capture of the elevators to the lobbies. Consequently, the "captured" occupants of these elevators need the reassurance of a quick message which will enlighten them about the situation.

The occupants of each elevator will receive the following message while the elevator is returning to the lobby:

> (Female voice) "May I have your attention please." (Male voice) "The building manager has directed all elevators to the entrance lobby. There has been a fire reported in the building, and the elevators may be needed. Please proceed to the lobby area for further instructions."

Several aspects of the message should be noted. The message tells the occupants (1) what is happening to the elevator, (2) why this is happening, and (3) what they are to do next.

The statement that the "building manager has directed all elevators . . ." gives the impression that an actual person is in control of the situation. In time of emergency most people would prefer that someone in authority personally take charge. The reference to "all elevators" is made so that the elevator occupants do not feel their elevator has been singled out for special treatment.

The occupants are told that there has been a report of a fire, rather than the more ambiguous term "emergency". The use of less ambiguous terminology to explain the situation to the affected people was suggested by research in social psychology which examined how people respond in simulated emergencies (Latane and Darley, 1970). It was the conclusion of this line of research that when people are in groups they tend to shunt responsibility for action to other members of the group. Such a failure to respond is especially noted during ambiguous situations. At such times people seem to look to others for cues on how to behave. It has been estimated (Phillips, 1973) that 15–25% of the population may perceive an emergency situation improperly and resort to some totally irrelevant negative mode of response. In an ambiguous situation if such improper responses become models for others to follow, the results could be potentially tragic. Consequently, it was decided to avoid any ambiguity in the delivery of the message.

"Fire" is the true situation; elevator occupants can then disseminate this accurate information to prospective elevator users in the lobby rather than create some vivid rumor which could induce a panic situation. And finally, the fact that the elevators "may be needed" should have a calming effect while it provides a perfectly rational argument for the redirection of the elevators to the lobbies.

#### Message to the Affected Areas and Rationale

When a fire is reported on any floor, several messages need to be transmitted. The occupants of the fire floor need to be told the facts and instructed where to go. The adjacent floors need to be cleared, and thus their occupants must also be given instructions. And finally, a message must be broadcast to the "receiving"

floors where the occupants of the evacuated areas are sent.

One important constraint imposed by the system's hardware capacity was that the three messages to the affected areas be recorded successively on a single tape, and take no more than 100 seconds. Since the messages sent to the fire floor, and to the floor below and above, are the most important, they receive a larger proportion of that 100-second allotment. During an emergency such messages must be quickly delivered, so such time constraints did not hinder the effectiveness of the emergency messages.

An example of one such message sent to a fire floor and the rationale used in its development follows. Similar messages and rationales were created for each of the affected floors.

> (Female voice) "May I have your attention please. May I have your attention please." (Male voice) "There has been a fire reported on the 12th floor. While this report is being verified, the building manager would like you to proceed to the stairways and walk down to the 10th floor. Wait on the 10th floor for further instructions. Please do not use the elevators, as they may be needed. Please do not use the elevators, but proceed to the stairways."

Several aspects of the message should be noted. The message tells the occupants (1) exactly what has happened, (2) what they are to do, and (3) why they should not use the elevators. It should also be noted that all essential instructions are repeated twice: two times it is pointed out that the occupants should proceed to the stairways, that the 10th floor is the place to go, and that the elevators should not be used. Numerous research studies have shown that repetition facilitates understanding and recall (Kruger, 1929; Hebb, 1961; Waugh, 1963).

It should be further noted that relatively common words are used in the message. Research has shown that words that are used commonly are more easily understood (Howes, 1957). This empirical finding is restated by the *Human Engineering Guide to Equipment Design* (1972) which states "other things being equal, the more frequently a word occurs in everyday usage, the more readily it is correctly identified when transmitted over a speech communication system" (p. 219). The word "evacuate" is never used since it may connote to some of the occupants that they should leave the building. And finally, a rationale is given why the elevators should not be used, making it less likely that occupants will attempt to use them.

The messages to the other affected floors are similar to that delivered to the fire floor. One important change is added to the message delivered to the floor above the fire floor. The evacuation plan calls for the removal of the floor above the fire floor upward one floor. Natural inclination and training has made such movement unusual to say the least. Consequently, while the message is essentially the same as the fire floor's, the added phrase that the floor above was a "safe area" was included. This inclusion was made to encourage personnel to confidently follow the directions as announced.

## METHOD OF EVALUATION

As with any system that is new, the VAS in the Seattle building needed to be tested under simulated emergency conditions to determine if what looked good on paper but was derived from related but independent research would effectively work under actual evacuation conditions. Such tests were conducted during the first week of occupancy of the new building.

Two fire drills were conducted during a period of one hour. There were two sections of the building (floors 20–24 and 14–18) whose occupants had fully moved into their new offices and were being visited by their clients. Two floors (16 and 22) were targeted as the floors on which a fire would be reported for purposes of the drill. Because of evacuation patterns used during emergencies, a fire reported

on these two floors would affect floors 14–18 and 20–24 either as floors to be evacuated or as receiving areas for evacuated personnel.

#### Orientation

The general safety plan for the building provided that all regular employees be given a training session which would explain the alarm system and emergency area evacuation procedures. For purposes of the evaluation, only the occupants of floors 20–24 were given such training on the day prior to the scheduled drills. No instructions on the new alarm system and evacuation were given to occupants of floors 14–18. Consequently, one drill would be conducted for personnel instructed about the vocal alarm system, and the other drill would be conducted for personnel with no prior instruction. Neither group was told that an emergency drill was planned for the near future.

#### Alarm

A fire alarm was turned in on the 22nd floor at approximately 3.15pm. This alarm triggered the entire emergency procedure including capture of the elevators to the lobby, and automatic message transmission to floors 20 to 24. When this drill was completed and personnel returned to their own floors, another alarm was turned in at approximately 3.40pm on the 16th floor effecting the elevator capture and the area evacuation of the fire floor and floors adjacent to it. Additional messages in both instances were broadcast to the receiving floors informing their occupants of the emergency and directing them to remain at their desks. To lend realism to the drill, firefighters in full firefighting outfits were dispatched to all floors involved in evacuation procedures. These men stationed themselves in conspicuous positions so that they were visible to most of the employees during the evacuation.

#### Evaluation Instrument

In addition to the observations made by the investigators, GSA personnel, and the Seattle fire department, questionnaires were distributed to all those involved in the drill after the "all clear" was broadcast. Two-hundred and five questionnaires, each with 16 questions, were returned by participants in the drill. This represented about 90% of the people affected by the alarm.

In completing the questionnaire respondents were asked to indicate where they were when the drill sounded, where they went during the drill, how the message directed them to go, if they needed assistance in understanding the directions of the messages, and the reason they were asked to evacuate their floors. The second part of the questionnaire consisted of eleven questions designed to assess the quality of the warning tone, voice of the communicator, content of the message, and how the VAS compared with other emergency drills. For each of the eleven questions the respondents were asked to check one of five possible response categories on a continuum that ranged from strongly agree to strongly disagree. These items were:

(1) The warning tone preceding the message was audible.

(2) The warning tone alerted me to listen for an announcement.

(3) The voice that announced the emergency was clear and distinct.

(4) The message was loud enough so that I did not have to strain to hear it.

(5) The message was too loud.

(6) The instructions concerning what you should do in the drill were clear.

(7) The reason for the evacuation was clear from the message.

(8) I feel that the message inspired confidence that the emergency was being handled properly.

(9) I found that the message concerning the emergency was calming.

(10) This fire drill was less confusing than most other fire drills I have been in.

(11) I would prefer this vocal alarm system to the bell alarm system to signal an emergency.

The answers of all respondents as well as the observations of the evacuation procedures were used to complete the evaluation of the vocal alarm system.

## RESULTS

### Observations

General Service Administration and Seattle Fire Department personnel were positioned on every floor affected by emergency evacuation procedures. There was a clear consensus that the vocal alarm system created minimum confusion and effected 100% evacuation of personnel directed to vacate their floors. All floors targeted for evacuation were vacated by visitors and federal employees within 1½ minutes after the alert tone was sounded on a floor. Personnel unhesitatingly went to the stairwells to evacuate, no-one attempted to use the captured elevators, nor was there any pushing, running, or other panicky behavior observed. Chief Graddon of the Seattle Fire Department summed up the observers' impressions when he offered that it was the smoothest fire drill he had witnessed in his years with the fire marshall's office in Seattle.

It should be emphasized that none of the participants in the drill were alerted to the fact that a drill would be conducted in the building. It should also be noted that there were no observable differences in the behavior and evacuation between persons given prior orientation about the new alarm system and those provided with no such orientation. From these observations, it seemed that the vocal alarm system itself was principally responsible for the swift and smooth area evacuation of personnel.

### Questionnaire Evaluation

As was mentioned above, 205 respondents completed questionnaires evaluating the alarm system and evacuation. Of these, 145 were collected from people who were asked to vacate their floors; the rest were received from personnel on the receiving floors. Ninety-seven percent of the vacating population indicated correctly the floor to which they were asked to move, that they went where the message directed, that they needed no help in understanding the message, and that they understood the reason for the evacuation. Those four people who missed one or other of these questions seemed to misread the instructions on the questionnaire. Ninety-five percent noted that they were instructed to use the stairways to vacate. Of the seven who did not correctly respond to this question, five were on floors which had received no prior orientation but where no-one was observed trying to use elevators to vacate.

Responses to the eleven questions assessing the VAS conveyed an overall feeling of confidence and satisfaction by participants in the drill. From responses to the two items concerning the warning tone, participants seemed in agreement that the tone was audible and alerted them to listen for an emergency announcement. It should be noted that while the question concerning the audibility of the tone was similarly responded to by those who were and were not oriented to the new alarm system, those who were not oriented seemed slightly less sure of the purpose of the alerting tone. However, it was interesting to note that those without orientation did seem to recognize the alerting nature of the tone. It is possible that, as we had predicted, a transfer of their experience with the alerting nature of the FCC tone to the tone used in the VAS took place.

The loudness and distinctness of the message was judged positively by all floors with the exception of the 24th, a receiving floor, whose response was one of uncertainty. On the 24th floor it was determined that several of the new

speakers were not functioning properly; they have subsequently been repaired, and now there is no problem with the audibility of the messages. Again there were no noticeable differences between floors receiving orientation and those that received no such orientation. The same positive response pattern was noted to questions concerning the clarity, rationale, and confidence of the messages with no noticeable differences between oriented and unoriented floors detected.

Question nine, which asked if the message concerning the emergency was calming, received an average response of "disagree". As was noted by participants in the comment section of the questionnaire, the reason for such a response is obvious: "No message can be calming when announcing a fire on your floor." That an announcement of a fire should be calming is not a realistic expectation of any alarm system. In the light of answers to the other questions on the instrument, a negative response to this question should not be construed as a negative assessment of the VAS, but rather a judgment on the credibility of the drill as simulating a real emergency situation.

The final two questions measured how respondents felt about the VAS compared to other evacuating systems with which they were acquainted. Respondents answered that this drill was less confusing than others they had been in, and expressed a strong preference for a VAS over a usual bell signal for an emergency. This response was especially gratifying since participants who had received no orientation toward the system were just as enthusiastic about the new VAS as those who received prior orientation.

#### Comparison of Oriented and Non-oriented Respondents

As was indicated above, during the drill no major differences were noted between those who had received prior orientation (20–24) and those who were occupying the building without such orientation to the emergency systems (14–18). There were no differences concerning evacuation time and behavior reported by those observing the drill. A statistical test of analysis of variance was performed on the responses to all the questionnaire items that were placed on the 5-point continuum from strongly agree to strongly disagree. No question yielded a significant difference between the two compared groups ($Fs = < 1$). This result was most gratifying since it lends support to the conclusion that the vocal alarm system itself and not the orientation was responsible for the orderly and quick evacuation observed and recorded.

## CONCLUSION

We began this paper by recognizing the fact that while there is no specific training that prepares experts to examine and facilitate positive behavior during emergency situations, there is an established body of research that gives them indications of the best way to evacuate personnel during emergencies. We attempted to review and apply such research findings to the construction and evaluation of the VAS for one high-rise building. From our evaluation it seems that the research findings were properly applied to make an effective evacuation system.

It would be a mistake to think that research on the problems discussed above should end with one demonstration of a working system. As was mentioned throughout the paper, the research utilized throughout this study was "borrowed" from various areas of psychology. This was done because of the lack of any direct research on problems associated with creating an effective VAS. Before we advance too far in the development of more sophisticated hardware for the delivery of messages to evacuate personnel, we must concurrently directly research the questions associated with the human response in emergency situations. It is time to stop borrowing research and start performing the necessary studies which will directly help answer the problems associated with vocal alarm systems.

The questions that need researching are easily enumerated: (1) Which words are best to use in emergencies, (2) What types of voices, (3) How explicit should instructions be, (4) Should recipients know that the messages are automated, (5) How best to instill calmness under emergency conditions, (6) What visual helps should be incorporated into a vocal evacuation system, and (7) How best to answer the problems associated with bilingual or deaf audiences. These questions are peripheral to the question of whether automated messages are better than live messages or no messages at all.

We hope that the above study is an example of how fire-safety experts and psychologists can co-operate in trying to construct an effective VAS. But more importantly, we hope that this study opens the door to continued cooperation between the two professions in developing substantiated answers to the many questions that surround human behavior during emergencies.

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