

WARNING AND RESPONSE IN TWO HAZARDOUS MATERIALS TRANSPORTATION ACCIDENTS IN THE U.S.

GEORGE O. ROGERS and JOHN H. SORENSEN

Energy Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831 (U.S.A.)*

(Received December 20, 1988, accepted March 22, 1989)

Summary

Warning system effectiveness is critically important in selecting an appropriate emergency warning system to alert to public to potential danger. This paper examines warning system effectiveness in terms of the timing of warning receipt and response. Warning receipt involves the analysis of when warning system information is received, which includes alerting the public and delivering a warning message. Response involves what people decide to do on the basis of the information provided in the warning message. Data from post-event surveys conducted in communities affected by two U.S. train derailments in western Pennsylvania, one in Pittsburgh and the other in Confluence, in the spring of 1987 are analyzed. The general logistic model of the diffusion of emergency warning specified in earlier works [1] is examined and found to fit the data from these events quite well. Warning penetration in these two events can be estimated as a function of the simulated models. While response can lag behind warning as much as 6 hours, the response occurs within an hour after warning receipt on average. Response time is found to be a function of when the warning is received, the warning message, and the source of the information.

Introduction

Even though U.S. communities are required to develop emergency response plans for fixed-site facilities under Title III of the Superfund Amendments and Reauthorization Act, there are no similar requirements for communities along transportation routes. For many communities, the transportation of hazardous materials presents a greater hazard than the fixed-site chemical hazards covered by Title III. Planning for both transportation and fixed-site chemical accidents depends on a means to warn the public in the event of a release. Unfortunately the warning system options are more limited for transportation accidents; the sophisticated technological systems (i.e., permanent sirens, telephone ring-down, and tone-alert radios) are not practical for the long and

*The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free licence to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

sometimes intricate transportation corridors. Emergency warning system effectiveness depends on a number of factors. How many people will be alerted to hazards presented by potential emergencies? How will they know what to do in response to warning signals? When will they receive the warning? This paper analyzes the dissemination of warning information and response to two train derailments involving hazardous materials in western Pennsylvania in the spring of 1987. Dissemination deals with alerting the public and delivering a warning message, while response involves how people evaluate the meaning of this information and respond.

Transportation accidents involving hazardous materials have become a major problem in the U.S. In 1984, it was estimated that a quarter of a million shipments of hazardous material take place every day in the United States [2]. Based on a systematic search of NEXUS, Sorensen [3] identified 295 chemical accidents in the 5-year period 1980 through 1984. Approximately half (49.1%), involved either truck or train accidents. While the data indicate that fixed sites, particularly industrial locations, accounted for an increasing share of the chemical accidents, truck and train accidents accounted for more than four out of ten accidents in each year. The Associated Press and United Press International reported on 532 accidents involving chemicals and the potential for evacuation between September 1985 and August 1988. A third (36.7%) of these involved the transportation of hazardous materials, and 43.6% of the transportation accidents involved the railroad system.

Of the 3351 jurisdictions described in the Federal Emergency Management Agency's Hazard Identification Capability Assessment and Multi-Year Development Plan (HICA-MYDP), 90% identified highway transportation as part of the hazards profile; 70% indicated that rail transportation posed a significant problem for their communities. Furthermore, of those identifying the highway transportation of hazardous materials as a problem, 39% indicated that they have incidents/accidents at least once a year; 63% indicated they had such emergencies at least once in 5 years; and 72% said that this kind of hazard affected their community at least one time in 10 years. Of the two-thirds reporting rail transportation of hazardous materials as a problem, 15% indicated that incidents/accidents affected their communities annually; 44% said it occurred in their communities at least once in 5 years; 60% indicated it happened about at least once in 10 years; and the remainder cited less frequent accident occurrences.

One of the critical elements in protecting the public from the danger associated with transportation accidents involving hazardous materials is warning the public when an accident occurs. Timely emergency warning is crucial in that the pro-active response required to protect or avoid is impossible without alerting the public to the potential for hazard and notifying them about appropriate response(s). This paper examines two train derailments, the associated emergency warnings and public response.

The warning process

Warning people of impending danger involves two conceptually distinct aspects – alerting and notification. *Alerting* deals with the ability of emergency officials to make people aware of an imminent hazard. Alerting frequently involves the technical ability to break routine acoustic environments to cue people to seek additional information. In contrast, *notification* focuses on how people interpret the warning message. Notification typically involves providing detailed information on the emergency situation including a recommendation on how to respond to the non-routine situation. People's interpretation of the warning message is critically important in their selection of appropriate behavior in response to emergency warnings.

Emergency warning messages are received through a series of pathways that color their meaning. Some of this coloring is the result of cognitive processes, some is the result of the social structure. People interact with others, forming social networks, even though the forms of these networks vary. The routine and established nature of social networks has led to widely accepted generalizations concerning their function in society [4–8].

Social networks also function in emergency situations and shape the response to emergency warnings. Two general propositions are strongly supported by the disaster literature [9]. First, people respond to emergency warnings in the context of prior experience and the existing social and physical environments that interact with the warning message.

Second, the extent to which the warning message is received depends on the nature of the warning message and the prior behaviors of all social actors, which are processed in the context of the social network. This means that people have existing estimates of the threats presented by their environments. Furthermore, these estimates, together with personal experience, provide the basis for selecting behavior (i.e., whether to accept, ignore, disseminate, challenge, or confirm the warning message) [10].

One of the results of an emergency warning is the recognition of threat, which creates psychological discomfort. Many people alleviate this discomfort by reducing the uncertainty associated with the message [11]. The warning process (Fig. 1) involves factors that affect both the message and the characteristics of the receiver [12] or the sender and receiver [13]. Once the warning is received, its contents are evaluated in terms of the certainty and ambiguity associated with the event – its estimated severity, timing and location of impact. This evaluation considers the likelihood of personal impact (will it affect me?), timing of impact (when will it occur?), and its anticipated effects (is the threat significant?) [14,15]. The evaluation of the warning message leads to the determination of its relevance, which, in turn, leads to the perception of personal risk. If the message content is deemed irrelevant (I am not at risk), no response to the emergency is likely to ensue. However, should the warning

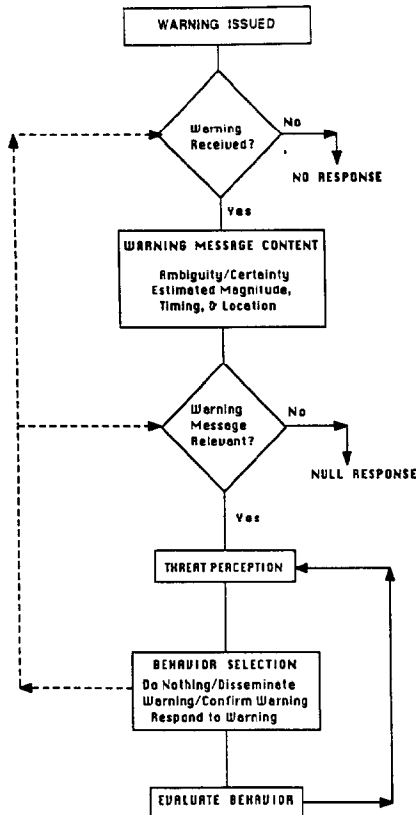


Fig. 1. Emergency warning and response process.

message be considered relevant (I may be at risk), the message is processed in the context of prior disaster experience, relative proximity to the source of disaster, confidence in the source of warning, interpretation of the warning, and discussion with members of the social network. The warning message is processed in the context of the existing social structure, which leads to the initial perception of threat. The cumulative process provides the foundation for the selection and evaluation of the public's emergency response behavior.

However, the warning response process is not a linear stimulus-response process [16]. The first issuance of warning sets in motion an information-seeking process by which people attempt to confirm and reconfirm the contents of the warning [17], and to discover what friends, neighbors, or relatives are doing in response to the warning [13]. As a result, members of the public become part of the informal warning system by disseminating the message further [12].

Public response to emergency warnings is heavily influenced by warning content. Janis [18] describes effective warning messages as requiring a bal-

ance between fear-arousing and fear-reducing statements. Empirical studies provide ample evidence of the message factors that shape response [13]. These factors include credibility of the warning source; clarity, consistency, accuracy, and detail of the information; and frequency of the message issuance.

Diffusion of emergency warnings

The diffusion of emergency warnings resembles diffusion of other types of information or communications, except that it occurs in a shorter time period and the consequences of not receiving the message are usually more severe. The basic mathematical function is a logistic function. The cumulative proportion of people receiving the warning forms an S-curve, which is determined by the exponential form of the initial alerting process and the logistic form of the subsequent contagion of the warning and message through the population [12].

The alerting is characterized as a “broadcast process” that disseminates the emergency warning, which is centralized in the sense that many are alerted simultaneously. Contagion, on the other hand, is characterized as a “birth process” whereby people first hear of the event and then sequentially tell others [19]. Because each warning system provides differing degrees of information concerning the appropriate action to avoid, to protect oneself from harm, or to mitigate the potential for harm, the broadcast and birth parameters represent the dependence of each system on centralized alerting and contagion, respectively. For example, the contagion parameter for a siren system will be relatively high because it depends on recipients to take an active role in their own

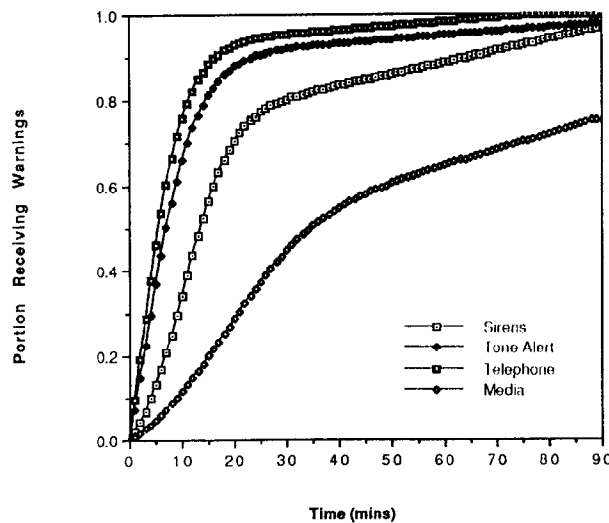


Fig. 2. Simulated time adjusted warning diffusion.

warning (i.e., they must do something). Usually this entails seeking further information via another (secondary) source.

This diffusion approach has been used to estimate the timing of warning dissemination for different warning technologies. The results of that analysis are found in Fig. 2. The calculation of the simulated warning dissemination times are described in detail elsewhere [1].

Emergency warnings for transportation accidents

The empirical evidence on human behavior in transportation accidents involving chemicals is relatively weak. At the organizational level, about 20 case studies document the response of public officials in chemical emergencies [20,21], which includes the warning process. Studies of three accidents involving the transportation of hazardous materials have documented warning response at the individual level. These include a nitric acid spill in a railyard in Denver, Colorado [22], a rail car derailment involving propane in Mt. Vernon, Washington [15,22], and the Mississauga, Ontario, accident involving chlorine [23]. This paper presents data on human response to warnings in two train derailments in Pennsylvania. The characteristic of all five events are summarized in Table 1. The notable difference between the previous studies and the two reported here concerns data about the timing of warning receipt. In the Pennsylvania accidents, data were collected on when people received a warning while in the other three events, data were only collected on whether people received a warning. The remainder of this section describes these two events.

TABLE 1

Public response to emergency warning summary

	Pittsburgh	Confluence	Mississauga ^a	Mt. Vernon	Denver
Population at risk	16,000-22,000	986	3500	3750	4900
Percent warned	73.2	90.5	99	82	96
How warned	Route/door	Route/door	Route/door	Route/door	Route/door
Percent warned in					
first hour	23.4	68.4	NA	NA	NA
Total warning time (hours)	NA ^b	NA	2	2.5	2.5
Percent evacuated	40	85	98	67	82
Mean response time (minutes)	26.5	24.2	NA	NA	NA

^aFirst area to be evacuated.

^bNA = Not available.

Pittsburgh phosphorous oxychloride release

On Saturday, April 11, 1987 at 12:29 p.m., a westbound Conrail freight train derailed in Pittsburgh, Pennsylvania. In the process of derailling, the westbound train sideswiped an eastbound train causing it to derail. Four tank cars containing hazardous materials on the eastbound train were derailed. Sparks resulting from the accident ignited a fire, however, "...contrary to reports circulated at the time of the accident, none of the hazardous materials ignited" (Railroad Accident Investigation Report, No. A-63-87, Consolidated Rail corporation, Pittsburgh, Pennsylvania, April 11, 1987).

Because of the involvement of hazardous materials, Pittsburgh emergency personnel initiated an evacuation upon arrival at the scene about 20 minutes after the accident. Apparently recognizing signs of potential danger, some local residents in immediate adjacent areas had already begun to evacuate. Up to 22,000 people were evacuated as the initial evacuation area was expanded to accommodate changing weather conditions. The fire was extinguished by 3:30 p.m., however, the primary concern centered around a derailed tank car containing phosphorus oxychloride. This tank car developed a crack in the dome permitting between 30 and 100 gallons (100–380 l) of phosphorus oxychloride to escape through the vent pipe. Emergency response teams inserted a tennis ball in the vent pipe to prevent further release, and neutralized the chemicals that had escaped with pot ash and sand.

By 5:50 p.m., the affected areas had been declared safe and the initial evacuation order was rescinded. Emergency officials planned a second precautionary evacuation for 1:00 p.m. the following day to upright the leaking tank car, however, a close inspection of the damaged tank car shortly after midnight detected continued deterioration of the tank car. At 1:30 a.m., an evacuation order affecting between 14,000 and 16,000 residents within a half mile of the scene was issued. This second evacuation order was not rescinded until 4:30 p.m. on Sunday, April 12, 1987. Approximately 25 people were treated for eye and throat irritation at area hospitals, and three people were hospitalized during the course of the accident.

Confluence precautionary evacuation

On Wednesday, May 6, 1987 at 4:10 a.m., 21 of 27 "empty" tank cars carrying product residues, including propane, chlorine, caustic soda, carbon disulfide, methyl chloride, chloroform, and isobutane derailed in Confluence, Pennsylvania. Because tank cars carrying residue can haul up to 3% of the load, emergency officials had no way to determine the exact amount of products remaining in the cars. Upon examination of the train's manifest, emergency management officials initiated a precautionary evacuation of the 986 residents. A 3-minute non-stop siren blast was sounded, which primarily alerted the volunteer firemen as residents could not be aware of the siren-blast's specific meaning; although it could serve as an alert to those who heard it.

At approximately 4:30 a.m., a door-to-door and portable loudspeaker alert and notification of the emergency began using volunteer firemen and untrained volunteers. Public shelters were set up in the area's high school, local school buses and ambulances provided transportation for those needing it. Within 45 minutes the evacuation was complete. Assistance from area-wide emergency personnel sealed two leaking propane tankers by 9:48 a.m., but the chance of explosion and/or fire during wreckage cleanup prevented return until 6:10 p.m.

Data and methods

Data collection

Two surveys of residents in the Bloomfield section of Pittsburgh were conducted [24,25]. The self-administered mail-back survey was distributed to 750 households in the emergency area in mid-June 1987, approximately 9 weeks after the April 11, 1987 accident. These households proportionally represent the 1980 population residing in each Census tract in the affected area of the city. Households were selected from each street in each Census tract in the affected area to assure even coverage. No follow-up letters or contact was initiated, although the cover letter gave contact information for respondent-initiated follow-up. A total of 220 questionnaires were returned by mid-August, yielding a response rate of 29.3%. An additional survey consisted of 129 telephone interviews conducted between July 14 and 22, 1987 with area residents. A random-digit-dialing procedure developed to represent various areas within the City of Pittsburgh proportional to population size was employed. A total of 195 working residential telephones were selected, representing households in the affected area and not selected for study via the mail-back survey. A three call-back procedure was employed which means three attempts to complete the interview are made at various times-of-the-day and days-of-the week for each selected number. This procedure yielded an effective response rate of 51%. Combined, the two surveys represent a population of 7000 households with 349 completed instruments with a combined response rate of 36.9%. Given the low-response rate, caution is required in interpreting the results of the Pittsburgh survey, even though comparisons of the mail-back and telephone surveys (with response rates of 29.3% and 51% respectively) revealed no significant differences.

Approximately 12% of the listed and unlisted residential telephone numbers in Confluence were sampled. The telephone interviews were conducted from October 20 to 28, 1987, approximately 22 weeks after the May 6, 1987 accident, and precautionary evacuation. Interviews were completed with 106 residents of Confluence resulting in an 89.8% response rate. The methodology is discussed in greater detail by Snyder and Schlarb [25].

Measurement

The receipt of first warning was constructed from responses to two questions; (1) at what time did you hear that you should evacuate?, and (2) was there any visible or audible sign of the train derailment from your home? The reported time that the respondent first heard they should evacuate was compared with the estimated time of the derailment based on official sources. Time of warning receipt was coded in minutes from the time the derailment occurred. If the respondent indicated that visible or audible signs of the derailment were observed, and was unable to indicate the time of first warning; the first alert or awareness of the event was assumed to have been instantaneous, because the respondent indicated that they heard the crash, or saw the smoke from the resulting fires. Many respondents heard or saw evidence of the event, but indicated a subsequent time when they first heard that they should evacuate. The respondents indicated the time of response to warning by estimating: how much time passed between the time you first heard that you should evacuate and the time that you left your residence? In both measures, the reporting of time passage is subject to the suspension of time often reported by disaster victims [12,26,27]. Time reports such as these are also subject to reporting bias associated with commonly used time intervals (e.g., 5-minute, 10-minute, 15-minute, 30-minute, 60-minute, and half-hour intervals), which results in concentrations of responses at frequently used intervals. In this kind of time measure, another form of bias is the result of the way people recall time in terms of a reconstruction of their activities at the time. For example, if a person is alerted while sleeping in the middle of the night, they might distort the time by recalling 3:00 a.m., even though it was actually 4:30 a.m.

The source and channel of emergency warning were combined in a single indicator resulting from the question; how were you first warned of the evacuation? The warning categories include official sources (i.e., channels involving officials at the door and on loudspeakers), social network sources (i.e., channels involving friends, neighbors, or relatives at the door or by telephone), sirens and a residual category. The residual category was classified to include media sources via both radio and television channels. In addition, the visual and audible signs of the emergency were used as environmental clues as a source of warning.

In addition to the time of response to warning, a descriptive indicator of what response entailed was elicited: what was your response when you first became aware of the evacuation? Did you decide to wait and see, seek additional information, evacuate immediately or disregard the information? While this indicator encompasses broad categories of initial response, it is indicative of the way the warning message, taken in the context of the situation, stimulated people to respond. Respondents were allowed to use as many of these categories as needed to describe their response. Special attention was given to the respondent's effort to inform others that might be affected by the event: did you make a special point of telling anyone else of the evacuation?

Findings

Timing of warning receipt and response

Data regarding the timing of warning receipt following the Pennsylvania train derailments in Pittsburgh and Confluence are summarized in Fig. 3 as the cumulative proportion warned by time of receipt in terms of minutes into the event. The measurement difficulties are clearly evidenced by the proportion of respondents that reported receiving warning prior to the occurrence of the accidents. This seems to occur at least partially because of the way people think about and recall time. For example, the noontime Pittsburgh event actually occurred at 12:25 p.m., but many of those reporting warning receipt prior to that time said they were warned at noon. It is not hard to construct that many people would recall the time in terms of what they were doing at the time (e.g., eating lunch) and report it as noon (i.e., 12:00 p.m.).

Warning in both situations primarily consisted of route-alerting and door-to-door warning. Each diffusion is characterized by an S-shaped curve, with the Confluence warning approaching 90% warned in about 2 hours, and the Pittsburgh event approaching 80% warned in about 3 hours. However, because of methodological uncertainties it is only possible to identify people that positively report having received some kind of warning. It is not possible to identify those not receiving warning. While the warning situation in both Confluence and Pittsburgh are characterized by rapid dissemination in the first hour and half of the event, only 13% report being warned in the first 15 minutes in Pittsburgh while 37% reported being warned in the same period in Confluence. This may be a function of a number of factors, including the type of event, the size area to be warned, distance from the source, the time of day, or a bias associated with increased sensitivity of residents in Confluence because of the Pittsburgh event having occurred about a month earlier. In Confluence, nearly 70% report receiving warning in the first hour, while only 23% report having received warning in the same period in Pittsburgh. Neither event is character-

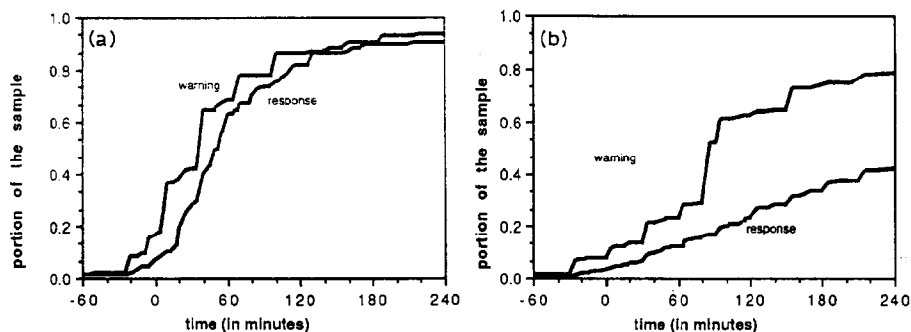


Fig. 3. The timing and warning response for (a) the Confluence and (b) the Pittsburgh event.

ized by complete (100%) warning, and both indicate that very rapid onset emergencies can result in people being engulfed in danger prior to receiving warning.

Response time may be characterized as the passage of time between when people receive the warning message and when they take action to avoid harm. Figure 3 also illustrates the timing of response for both events expressed as the cumulative percent responding to the warnings. In both the Pittsburgh and Confluence events the principal response for individuals was to evacuate the affected area. In Pittsburgh, some 22,000 people were evacuated (Railroad Accident Investigation Report No. A-63-67), while in Confluence all 986 residents were evacuated (PEMA, Western Area Office, June 3, 1987 report on CSX Train Derailment on May 6, 1987 in Confluence Borough). The response function closely follows the receipt of warning curve in the Confluence event, while in Pittsburgh response was both slower and more limited. This difference may result from a more simply defined area at risk (i.e., the entire Borough of Confluence), or the more simply defined response options (i.e., evacuate to ...), or the vicarious experience of hearing about the evacuation in Pittsburgh, or the perception and personalization of risk. The dynamics of the two events are also quite different in terms of the time of day. The Confluence event occurred at approximately 4:20 a.m. on Wednesday May 6, 1987. Most people report being at home in bed when they first received warning. In contrast, the Pittsburgh event occurred at approximately 12:25 p.m. on Saturday, April 11, 1987. While some people were at home (e.g., working in the yard), many reported being away from other members of their families (e.g., shopping in the area, at community functions, or at work). In short, the social dynamics of location by time of day and day of week are a contributing factor in the apparent difference in the warning and associated response for the two events.

Source of warning

In both the Pittsburgh and Confluence events, portable sirens and loudspeakers along with door-to-door warnings account for the majority of the warnings received (59% and 89%, respectively) (Table 2). This is in addition to the 67% and 28% reporting a visible or audible sign of the disaster in the two communities. While all of these route alerting methods of warning took 1 to 1-1/2 hours, on average in Pittsburgh, portable sirens averaged just over 30 minutes, with loudspeakers and door-to-door alerting taking about an hour on average in Confluence. The most effective warning source in terms of average time to warn in Pittsburgh was the contagion of the warning message through the social network. Unfortunately, comparable data are not available for Confluence. Interestingly, even among those that reported audible and visible signs of the events, average warning times are reported at 85 and 50 minutes after the event. Hence, it seems evident that respondents associated special meaning

TABLE 2

Average time before warned by source of warning (in minutes into the event) in the Pittsburgh and Confluence incidents

Source of warning	Pittsburgh			Confluence		
	Percent	No.	Mean time	Percent	No.	Mean time
Friends, neighbors and relatives	18.3	59	49	NA ^a	NA	NA
Portable sirens	19.0	61	61	36.3	33	32
Door-to-door	11.8	38	70	29.7	27	66
Portable loudspeakers	27.7	89	87	23.1	21	68
Radio	6.5	21	95	NA	NA	NA
Television	10.3	33	96	NA	NA	NA
Other sources	5.9	19	92	11.0	10	92
Visible/audible sign	66.7	214	86	27.5	25	58
Total sample		321	85		91	50

^aNA - Not assessed in the Confluence survey.

TABLE 3

Average response time to emergency warning by source of warning (time in minutes) in the Pittsburgh and Confluence incidents

Source of Warning	Pittsburgh		Confluence	
	No.	Mean time	No.	Mean time
Friends, neighbors and relatives	59	54	NA ^a	NA
Portable sirens	23	70	33	22
Door-to-door	37	50	11	26
Portable loudspeakers	86	49	21	38
Radio	20	59	NA	NA
Television	33	57	NA	NA
Other sources	19	31	10	13

^aNA - Not assessed in the Confluence survey.

to emergency warning, probably associated with being told by officials and/or authorities.

One of the primary protective actions utilized in each of these events was evacuation. Among those evacuating, the average response time was about 25 minutes in both Confluence and Pittsburgh. Route alerting, characterized by officials either at the door or on loudspeakers, generated slightly faster responses than did portable sirens alone in both events (Table 3). In Confluence,

TABLE 4

Initial response and associated delays to emergency warning

Initial response	Response (%)		Average delay (min)	
	Confluence No. = 91	Pittsburgh No. = 169	Confluence	Pittsburgh
Wait and see	11.0	11.2	13 ^a	31
Seek information	8.8	22.5	38 ^a	86
Evacuate immediately	8.8	21.3	34 ^a	67
Disregard information	81.3	58.6	19	32
Residual category	1.1	0.0	180 ^a	—
Told someone else	1.1	2.4	60 ^a	10 ^a

*Average delay based on very small cell size ($n \leq 10$).

these authority-based route alerting mechanisms generated response in 20 to 25 minutes on average, while in Pittsburgh these same sources achieved a response in about 50 minutes. Response to portable sirens alone took about 20 minutes longer in each event. Presumably this is the time it takes to find out the nature of the event and what should be done about it.

Initial response to warning

Initial responses to warning are summarized in Table 4. The most frequently mentioned response in both derailments was to disregard the information. In Confluence, 81% of the respondents said they disregarded the warning, and in Pittsburgh, 59% of the sample reportedly disregarded the information. Disregard of initial information, in both instances, failed to increase the overall response time. Evacuating immediately (i.e., 9% and 21% in Confluence and Pittsburgh, respectively) took almost twice as long in both cases, from 20 to 35 minutes in Confluence, and from about 30 minutes to over an hour in Pittsburgh.

Predicting warning receipt

Simulated warning receipt for siren- and media-based systems initially reported in Fig. 2 are compared with observed warning receipt in Pittsburgh and Confluence in Fig. 4. The greatest similarity occurs between simulated media warning system and warning in Confluence. The correlations between the observed and simulated results are presented in Fig. 5 (a) and (b). The diagonal axes represent a perfect correlation between prediction and observation. Points to the top left represent observed values that are greater than the simulated

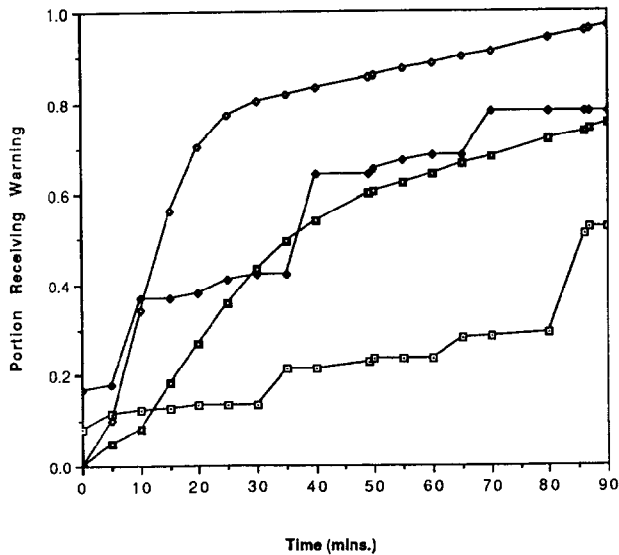


Fig. 4. Simulated and observed warning receipt results. □ Pittsburgh, ◆ Confluence, ○ simulated media, and ◇ simulated sirens.

values. Points to the bottom right represent observations that are lower than the simulated values. The regression lines graphically illustrate the difference between the predicted and observed values as well as show the goodness of fit of the simulation models.

As expected, data from both the Confluence and Pittsburgh warning events are more highly correlated with the media-based model than the siren-based model. This reflects that the general nature of the respective warning systems are principally comprised of media and route alerting mechanisms. Because neither of the warning events employed warning systems comprised of a single mechanism, it is reasonable to expect that the empirical results would differ from the simulated values. Warning systems, comprised principally of route alerting mechanisms disseminate warning messages more slowly than either media- or siren-based systems [1]. Siren systems are capable of faster warning dissemination than either a media or route alerting system.

The Confluence event is more highly correlated with both the media- and siren-based model; it explains 30 to 35% more variance than the correlations of the Pittsburgh event with the same models. This is reflective of the differing nature of the initiating accidents. The Pittsburgh event was less threatening with a greater amount of available response time. The Confluence accident was a greater threat to public health and safety and elicited a more urgent response.

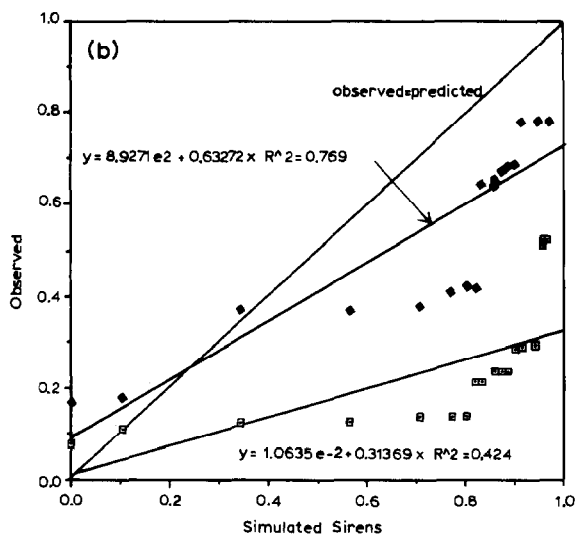
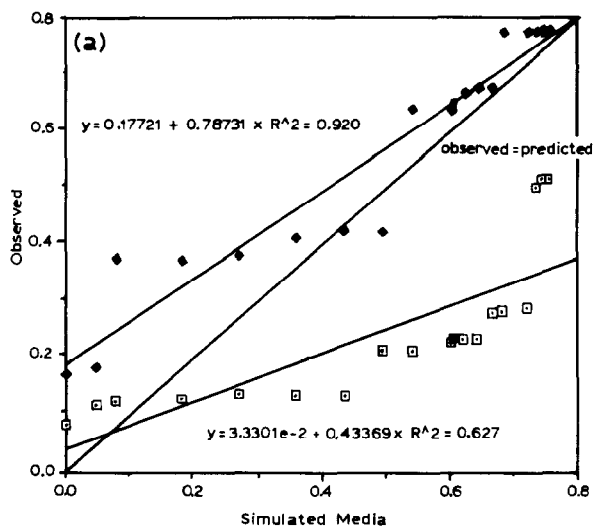


Fig. 5. Correlation between (a) simulated media and observed results; (b) simulated sirens and observed results. \square Pittsburgh and \blacklozenge Confluence.

Discussion and conclusions

Warning systems must both alert people to the potential for harm, and notify them about appropriate responses to be effective. Different warning systems accomplish alert and notification functions with varying effectiveness. For ex-

ample, siren-based warning systems alert people to the potential for harm quite well, but require other measures to disseminate a warning message. Previous work considered both alert and notification in their characterization of various warning systems [1].

From an emergency management standpoint, another measure of warning system effectiveness is the ability to provide people at risk with adequate time to respond appropriately to the situation. Hence, it is not necessarily the time it takes to warn people but the timing with respect to the onset of hazard that provides a measurement of warning system effectiveness. For example, a warning system that takes only 10 minutes to warn a population that will be exposed to hazard in 8 minutes is certainly less effective than a system that provides warning in 1 hour when exposure occurs in 1-1/2 hours.

The major finding from these two incidents and the simulations is that under conditions of rapid emergency onset, people may be engulfed in danger prior to receiving warning, others may have limited time to implement protective actions. The organizational decision to warn, which includes hazard detection, is critical to warning system effectiveness. The amount of time it takes to make the decision to warn is most critical when available warning time is limited.

These findings pose an especially difficult problem for the transportation of hazardous materials, because it is impractical to install sophisticated technological warning systems along transportation corridors. The empirical results from the Pittsburgh and Confluence surveys seem to indicate that smaller, tightly connected, rural communities may be better suited to respond to such transportation accidents than larger, loosely connected, urban or metropolitan communities. However, the results of these surveys remain inconclusive; the reported differences may be associated with the nature of the events, sequential timing, or timing by day-of-the-week or time-of-day. Furthermore, both events resulted in relatively minor injuries, which makes it impossible to conclude that the speed of warning dissemination and response was inappropriate for the circumstances. To the extent that the empirical results from the Pittsburgh and Confluence studies reflect maximum capacity to respond, they indicate that existing emergency systems are not sufficient to provide effective warning for fast moving events.

While some major concentrations of people located in urbanized areas may conceivably be singled out for sophisticated technological warning systems, relatively isolated residences along the corridors could be warned via relatively inexpensive tone-alert radios or telephone-based warning systems, but small towns along corridors are more problematic. Fortunately small towns and villages are typically characterized by strong social networks which can be of considerable assistance in providing emergency warning [1,28-30]. This approach to emergency warning for transportation accidents places the burden on the communities. While taking advantage of community warning systems developed for fixed-site chemical hazards, it leaves communities that have a

dominant transportation hazard to develop warning systems for transportation accidents. Some of these communities may derive very limited benefit from the transportation routes through their communities.

Another approach would be to require trains and trucks hauling hazardous materials to provide a limited alert and notification capability for the immediate vicinity, and communication equipment to notify local communities along the transportation route. This approach would require shippers to acquire material safety data sheets about the products they ship so that individual haulers could provide information about the nature of the threat, how far it might travel once released, major pathways to exposure, and possible medical treatments for those exposed. On the one hand this approach could lead shippers to concentrate larger amounts of hazardous materials in fewer shipments among qualified haulers, which could actually increase the risks. On the other hand, because of the increased potential to mitigate releases the risks might be reduced.

Although this analysis has focused on the timing of warning and response, it is recognized that the organizational structure for issuing the warning and the style and content of the warning and the possible availability of protective actions are also critical factors in the overall effectiveness of the systems. Another approach that would enhance overall warning system effectiveness for transportation accidents would enhance emergency warning system infrastructure. These enhancements would improve detection, hazard assessment, and decision-making capabilities among shippers and potentially affected communities, and enhance communication capabilities between haulers and emergency response personnel in communities.

Acknowledgments

Oak Ridge National Laboratory is operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

References

- 1 G.O. Rogers and J.H. Sorensen, Diffusion of emergency warnings, *Environmental Professional*, 10 (4) (1988) 185-198.
- 2 L. Abbott, G. Bulanowski, B. Foster and J. Jordon, hazardous materials transportation: A legislator's guide, National Conference of State Legislatures, Denver, CO, 1985.
- 3 J.H. Sorensen, Evacuations due to off-site releases from chemical accidents: Experience from 1980 to 1984, *J. Hazardous Materials*, 14 (1987) 247-257.
- 4 T. Parsons, *The Social System*. The Free Press, New York, NY, 1951.
- 5 J. Coleman, E. Katz and H. Menzel, The diffusion of innovation among physicians, *Am. Sociol. Rev.*, 20 (1957) 253-270.
- 6 M. Granovetter, The strength of weak ties, *Am. J. Sociol.*, 78 (1973) 1360-1380.
- 7 P. Blau, *Inequality and Heterogeneity: A Primitive Theory of Social Structure*. The Free Press, New York, NY, 1977.

- 8 R. Burt, Social contagion and innovation: Cohesion versus structural equivalence, *Am. J. Sociol.*, 92 (1987) 1287-1335.
- 9 H. Williams, Human Factors in Warning and Response Systems, in: G. Groesser et al. (Eds.), *The Threat of Impending Disaster*. MIT Press, Cambridge, MA, 1964, pp. 79-104.
- 10 E. Baker, Predicting response to hurricane warnings: A reanalysis of data from four studies, *Mass Emergencies*, 4 (1979) 9-24.
- 11 I. Janis and L. Mann, Emergency decision making: A theoretical analysis of responses to disaster warnings, *J. Human Stress*, 3 (June) (1977) 35-48.
- 12 G. Rogers and J. Nehnevajsa, Behavior and attitudes under crisis conditions: Selected issues and findings. U.S. Government Printing Office, Washington, DC, 1984.
- 13 D. Mileti and J. Sorensen, Why people take precautions against natural disasters, in: N. Weinstein (Ed.), *Taking Care: Why People Take Precautions*. Cambridge University press, Cambridge, MA, 1987, pp. 189-207.
- 14 R. Perry, M. Lindell and M. Greene, *Evacuation Planning Emergency Management*. Lexington Books, Lexington, MA, 1981.
- 15 R. Perry and A. Mushkatel, *Disaster Management: Warning Response and Community Relocation*. Quorum Books, Westport, CT, 1984.
- 16 D. Mileti, *Natural Hazard Warning Systems in the United States*. Institute of Behavioral Science, University of Colorado, Boulder, CO, 1975.
- 17 R. Leik, T. Carter and J. Clark. *Community Response to Natural Hazard Warnings: Final Report*. University of Minnesota, Minneapolis, MN, 1981.
- 18 I. Janis, *Psychological Stress*. John Wiley and Sons, New York, NY, 1958.
- 19 C. Lave and J. March, *An Introduction to Models in the Social Sciences*. Harper & Row, New York, NY, 1975.
- 20 E.L. Quarantelli, *Sociobehavioral Responses to Chemical Hazards: Preparations for and Responses to Acute Chemical Emergencies at the Local Community Level*. Final Report to the National Science Foundation. Disaster Research Center, Ohio State University, Columbus, Ohio, 1981.
- 21 E.L. Quarantelli, *Evacuation Behavior: Case Study of the Louisiana Chemical Tank Explosion Incident*, Disaster Research Center, Ohio State University, Columbus, Ohio, 1983.
- 22 R. Perry and A. Mushkatel, *Minority Citizens in Disaster*. University of Georgia Press, Athens, GA, 1986.
- 23 I. Burton, M. Kliman, D. Powell, L. Schmidt, P. Timmerman, P. Victor, A. Whyte and J. Wojick, *The Mississauga Evacuation, Final Report*. Institute for Environmental Studies, University of Toronto, Ont. 1981.
- 24 J. Nehnevajsa, *Bloomfield and Confluence Train Derailments*. Unpublished Report, University of Pittsburgh, University Center for Social and Urban Research, Pittsburgh, PA, 1987.
- 25 P. Snyder and J. Schlarb, A case study of a voluntary preventative evacuation: The May 1987 train derailment in Confluence, Pennsylvania. Annual Meeting of the North American Sociological Association, April, 1988.
- 26 J. Keating, E. Loftus and M. Mauber, Emergency evacuations during fires: Psychological considerations, in: R.F. Kidd and M.J. Saks (Eds.), *Advances in Applied Social Psychology* (Vol. 2). Lawrence Erlbaum Associates, Hillsdale, NJ, 1983, pp. 83-100.
- 27 G. Rogers, Role conflict in crisis of limited forewarning, *J. Appl. Sociol.*, 3 (1) (1986) 33-50.
- 28 G. Rogers and J. Nehnevajsa, Warning human populations of technological hazard, in: *Proceedings of the Am. Nucl. Soc. Topical Meeting on Radiological Accidents (CONF-860932)*. Oak Ridge National Laboratory, Oak Ridge, TN, 1987, pp. 357-362.
- 29 J.S. Sorensen, B. Vogt and D. Mileti, *Evacuation: An assessment of planning and research*, ORNL-6376, Oak Ridge National Laboratory, Oak Ridge, TN, 1987.
- 30 M. Lindell and R. Perry, Warning mechanisms in emergency response systems, *Int. J. Mass Emergencies and Disasters* 5(2) (1987) 137-153.