5. PUBLIC RESPONSE TO WARNINGS

Eliciting effective public response is the objective of the warning process. Hence, the public, as receiver of the warning message, comprises a fundamental element of the warning process. The public component of the warning process begins when information concerning a potential threat reaches the general public, and it ends after the threat dissipates. Public officials may view the public warning process more bureaucratically; demarking the public component with the decision to warn at one end and the public receipt of the "all clear" signal at the other. This section discusses the receipt of a warning by the public, the response to warnings of chemical hazard, and the overall effectiveness of warning systems. The warning process is briefly discussed from the public's perspective.

5.1 THE WARNING PROCESS

Warning the public of the threat of an impending chemical hazard encompasses two steps: to make them aware of an abnormal set of circumstances characterized by an elevated threat and to provide information to elicit actions to minimize the dangers associated with the threat. The former is referred to as the alerting function; the latter constitutes the notification function, which involves alerting the public that a hazard is imminent. Notification involves communicating the warning message so as to prompt mitigative response to the hazard. The central focus of alerting issues involves the technical ability to make people aware of the threat, and the primary notification issues focus on the public's interpretation of the warning message.

Warning messages are passed along a series of pathways that can change their associated meaning. These pathways of warning communication involve cognitive functions as well as social structural considerations. The cognitive functions include the belief in the warning message, the personalization of the associated threat, the credibility of the source of warning, and the perception of the content. The social structural considerations involve the social context of the hazard, including the interactions with others in the social network, prior experience, extant social and physical environments, and existing conditions that interact with and influence the warning message. The response to an emergency warning is based on the degree of assessed hazard or danger, the threat, and the public's experience as placed in the social context. Therefore, the decision to accept, ignore, disseminate, challenge, or confirm the emergency warning message (Baker, 1979) rests on this social context.

Psychologically, emergency warnings that result in the recognition of threat, create discomfort and uncertainty of the impending event. The emergency warning process involves both the message and the characteristics of the receiver. Having received the message, it is evaluated in terms of certainty and whether the anticipated severity, timing, and location of impact are ambiguous. The message is personalized in terms of relevance; for example, "Is the threat likely to effect me?" The resulting relevance of the warning message is determined in the context of prior disaster experience, relative proximity, credibility of the source of warning, interpretation, and discussion with others. Hence the warning message is processed in the context of the social network.

Janis (1958) describes effective warning messages as those requiring a delicate balance between fear-arousing and fear-reducing statements. By describing the impending danger in sufficient detail, a vivid mental image of the impending crisis is evoked. This fear-arousing part of warning messages reduces the possibility of surprise, and invokes response. The realistic presentation of the mitigating factors of the potentially threatening situation provides information regarding both the actions of authorities and those of individuals. This fear-reducing component of the warning message provides the foundation for adaptive response. "The fear-arousing content of the warning message alerts the public to the potential for harm, while the fear-reducing statements consist of notification of appropriate mitigation action" (Rogers and Nehnevajsa, 1987: p. 358).

5.2 DESCRIPTION OF EVENTS

A relatively weak set of empirical data exists on human behavior in chemical accidents. At the organizational level, about 20 case studies document the response of public officials to an emergency (Quarantelli, 1981; 1983). Some of these studies include the warning process.

At the individual level, five events have been researched in which warning responses were documented. These include a nitric acid spill in Denver, Colorado (Perry and Mushkatel, 1986), a railcar derailment involving propane in Mt. Vernon, Washington (Perry and Mushkatel, 1984; 1986), the Mississauga, Ontario, accident involving chlorine (Burton et al., 1981), and two recent train derailments in Pennsylvania. These events are summarized in Table 2.

5.2.1 Mississauga Chlorine Gas Release

On Saturday, November 10, 1979, at 11:54 p.m., a series of tank cars including one car filled with 90 tons of chlorine, four cars filled with caustic soda, a string of cars containing propane, and three cars containing styrene derailed in Mississauga, Ontario, Canada. As the result of the derailment "... the propane cars were either ruptured or damaged, with their contents flowing off or exploding" (Burton et al., 1981:2-11). The chlorine car was punctured by the car following it, and the content of the cars containing styrene and caustic soda poured onto the tracks.

A number of local- and municipal-level emergency response agencies responded, including regional police, fire and ambulance services. Police units in the area at the time of the accident were alerted by the light from the explosions, and three or four police units converged on the scene. The first police units to arrive on the scene reported the accident to the radio dispatch. A constable and a detective sergeant arrived on the scene within several minutes. Within three minutes, the people on-the-scene requested additional personnel, but alerting fire personnel was not necessary because of the high visibility and recurring shock waves caused by repeated explosions. Ambulance services were also alerted by the explosions, with four ambulances being dispatched to the scene within four minutes of the accident. Ambulance service personnel stationed themselves strategically around the area as no initial injuries where reported. The repeated explosions also alerted the general public; however, many converged on the area until emergency workers cordoned off the area within 600 meters.

Table 2. Public response to emergency warning summary

	Pittsburgh	Confluence	Mississaug[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	Ad hoc	Ad hoc	Ad hoc	Ad hoc	Ad hoc
Available warning time	NA[b]	NA[b]	2 h[c]	2.5 h[c]	2.5 h[c]
Percent evaluated evaluated	40	85	98	67	82
Hazard description	Phosphorous oxychloride	Hazardous material residues	Chlorine	Propane	Nitric acid
Nature of hazard	Release/fire	Precautionary	Release/fire/ explosions	Precautionary	Spill/small fire
Day of event	Apr. 11, 1987 Saturday	May 6, 1987 Wednesday	Nov. 10, 1979 Saturday	Apr. 22, 1981 Wednesday	Apr. 3, 1983 Sunday
Time of event	12:25 p.m.	4:20 a.m.	11:54 p.m.	7:45 p.m.	5:30 p.m.
Time of warning	12:25 p.m.	4:20 a.m.	7:47 a.m.	10:00 a.m.	5:30 p.m.

[a]First area to be evacuated.

[b]Not available.

[c]Time to warn the total percent warned above.

Because the location of the chlorine tank car had not been determined; a visual check taking 20 minutes was made of each tank car. The search revealed that the chlorine car probably was engulfed in the jumble of cars at the center of the derailed section of the train. After consulting with railroad officials, fire department representatives, the procedural representative, and the advisor from Ashland Chemicals, emergency officials decided to evacuate the downwind areas (i.e., areas south and west of the site). At 1:47 a.m., nearly 2 hours after the accident, the first official evacuation was ordered. Police were instructed to go door-to-door and tell residents that dangerous gases were on the train and advise them to leave the area. Before the emergency was over (including the staged evacuation and re-entry), approximately 250,000 people were forced to evacuate their homes.

On Tuesday afternoon, re-entry began with those farthest from the accident site when erroneous media messages led to massive traffic jams. Final re-entry for those in close proximity to the accident site began on Friday afternoon after a lengthy control-group meeting. By 4:00 p.m., 18 tons of chlorine had been removed, leaving only 4000 to 5000 gallons. This led to a consensus decision by all experts that the remaining evacuees could safely return to their homes. To avoid concentration of potentially hazardous gas in homes people were instructed to open doors and windows for 15 minutes. Between 40 and 50 break-ins were reported upon return from the week-long evacuation.

The accident did not result in any deaths or major injuries; however, minor and temporary health effects were reported; including eye irritations, respiratory problems, chest pains, food poisoning, various psychological and psychosomatic illnesses, existing illnesses aggravated by the experience, and various bruises, sprains, and broken bones. All injuries occurred rarely, affecting less than 1% of the evacuees, except for nervousness and anxiety, which was reported by about 11% of those interviewed in August 1980.

5.2.2 Mt. Vernon Propane Tank Car Derailment

On Thursday, April 22, 1981, at approximately 5:45 p.m., a tank car carrying 25,000 gallons of propane derailed on a spur near downtown Mt. Vernon, Washington. "The tank car remained upright and appeared to be undamaged" (Perry and Mushkatel, 1986: p. 12). Initial efforts of railroad employees to get the tank car back on the track were unsuccessful. The railroad workers did not define the situation as posing any danger and decided to close off the spur for the night. They planned to right the tank car as part of the following day's work. At about 7:45 a.m. an employee of an adjacent business noticed a tank car marked "liquefied petroleum gas" and reported it to county authorities. The railroad crew's failure to notify local authorities was identified in retrospect as the single biggest mistake associated with the incident.

The local fire and police departments, the county emergency services agency, and the county police played key roles in handling the incident.

On-site inspections conducted by emergency responders indicated that no hazardous materials were being released into the environment. While the failure to report the incident resulted in a strained relationship between community emergency responders and railroad responders, it was agreed that the unmolested tank car did not present a major threat to the surrounding community. Community officials reasoned that lifting the tank car back on the track could produce sufficient strain to cause any preexisting weak spots to fracture, and release propane into the environment or cause an explosion that would be complicated by the existence of other liquid petroleum products stored nearby. Railroad officials argued that the operation posed no threat to the community. While there was no reason to suspect preexisting weak spots, there was also no immediate way to confirm that they did not exist.

About 16 hours after the derailment, at about 10:00 a.m., emergency officials started the process of a door-to-door, notification of surrounding residences and businesses advising people to evacuate the area. An elementary school and a nursing home also were evacuated. County police blocked off primary streets near the derailment site at 11:00 a.m., and by 12:30 p.m. approximately 2500 people had been evacuated. The tanker was returned to the tracks without further complications, and people were allowed to return to the area about 1:00 p.m. The evacuation was characterized as precautionary rather than a response to an extant disaster.

5.2.3 Denver Nitric Acid Spill

On Sunday, April 3, 1983, in a rail yard near the central business district of Denver, Colorado, a railcar coupling punctured a tank car containing 18,000 gallons of nitric acid. Initially, a small fire was ignited, and a cloud of nitric acid gas engulfed some nearby electrical transformers causing explosions and resulting in power outages in the surrounding areas. While the nitric acid spill itself presented little threat to nearby residents, the gaseous plume that formed over the rail yard was subject to rapid spreading by the wind. Emergency managers confirmed the existence of the toxic plume, plotted the downwind trajectories and identified the immediate need for evacuating threatened areas.

In coordination with the Denver Fire Department, the Denver Office of Emergency Preparedness decided to evacuate a 500 square block area adjacent to the rail yard. Part of the evacuated area is comprised of factories, warehouses, and industrial areas. In addition, there are a number of low-income inner-city residential areas, populated primarily by minorities (i.e., Mexican-Americans, Blacks, and a small number of Cambodian immigrants). By 5:30 p.m. the warning process had begun with the sounding of emergency sirens. Additional warnings were broadcast over television and radio, and emergency personnel engaged in a door-to-door alert in some areas and used portable loudspeakers in others. Official estimates indicated that more than 4000 people were evacuated, but only 2300 registered at public shelters. By noon of the following day, most of the nitric acid had been neutralized with soda ash, and the cloud had dissipated. A number of people were treated for minor eye irritations and respiratory difficulties in the course of the emergency, but no serious injuries were reported.

5.2.4 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 derailing, the westbound train sideswiped an eastbound train causing it to derail. Four of the derailed tank cars on the eastbound train contained hazardous materials. 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, Pennsyl-vania, April 11, 1987). Because of the involvement of hazardous materials, Pittsburgh emergency personnel initiated an evacuation when they arrived at the scene, about 20 minutes after the accident. Some local residents in the 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 that permitted between 30 and 100 gallons of lading to escape. Emergency response teams inserted a tennis ball in the vent pipe to prevent further release and neutralized the chemicals that had escaped with hot 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 degradation of the tank car. At 1:30 a.m. an evacuation order was issued affecting between 14,000 and 16,000 residents within one-half mile of the scene. 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.

5.2.5 Confluence Precautionary Evacuation

On Wednesday, May 6, 1987, at 4:10 a.m., 21 of the 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 nonstop siren blast was sounded, which primarily alerted the volunteer firemen; residents could not be expected to be aware of the siren-blast's specific meaning. 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, and local school buses and ambulances provided transportation for those needing it. The evacuation was complete within 45 minutes. With the assistance of area-wide emergency personnel, two leaking propane tankers were sealed by 9:48 a.m. The chance of explosion and/or fire during wreckage cleanup prevented the evacuees from returning until 6:10 p.m.

5.3 TIMING OF WARNING AND RESPONSE

In two recent train derailments (i.e., in Pittsburgh, Pennsylvania and Confluence, Pennsylvania), data regarding the timing of warning receipt were collected by the University Center for Social and Urban Research at the University of Pittsburgh. These data are summarized in Fig. 2 as the cumulative proportion of the population 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 event's occurrence. 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.).

Both warning situations are characterized as consisting of primarily route-alerting and door-to-door warning systems. Each warning situation is characterized by an S-shaped curve, with the Confluence event reportedly approaching 90% warned in about 2 hours, and the Pittsburgh event reportedly 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 situations in Confluence and Pittsburgh are characterized by rapid dissemination within 1-1/2 hours of the event, only 12.5% reported being warned within 15 minutes in Pittsburgh, and 36.8% reported being warned in the same period in Confluence. This may be attributed to a number of factors including the type of event, the size of the area to be warned, distance from the source, time of day, or a bias associated with attributable experience gained vicariously in Confluence when the Pittsburgh event occurred (about a month earlier). In Confluence nearly 70% report receiving a warning within 1 hour, while only 23% report having received a warning in the same period in Pittsburgh. Neither event is characterized by complete (100%) warning, and both events indicate that very rapid onset

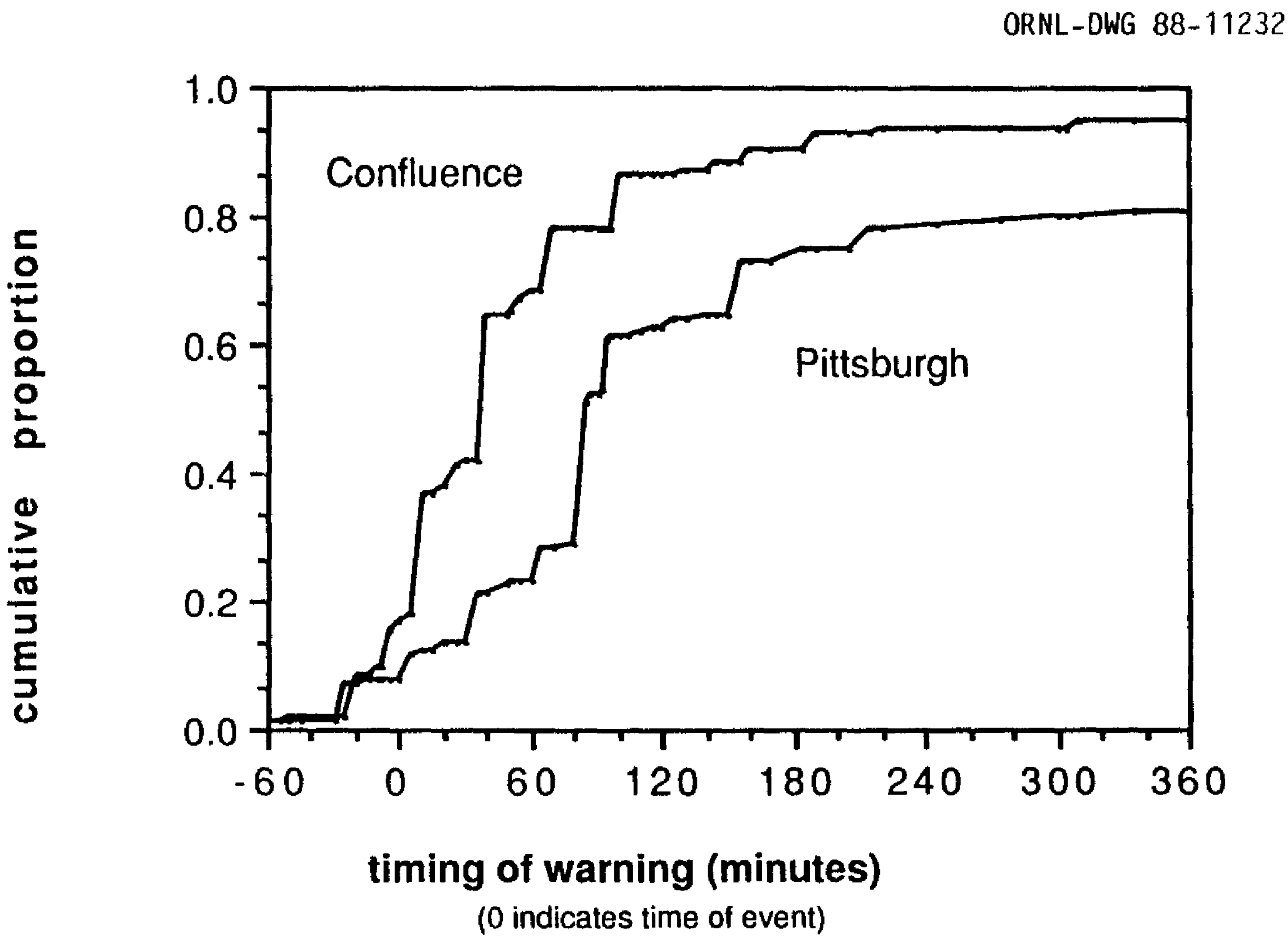

Fig. 2. Timing of warning received.

emergencies can result in people being engulfed in danger prior to receiving a warning.

Response may be characterized as the passage of time between when people receive the warning message and when they take action to avoid harm. In both the Pittsburgh and Confluence events, the principal response for individuals was to evacuate the affected area. In Pittsburgh, about 22,000 people were evacuated (Railroad Accident Investigation Report No. A-63-67). 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 curve representing receipt of warning in the Confluence event, while in Pittsburgh response was both slower and more limited. This may result from the simply defined area at risk (i.e., the entire Borough of Confluence), the simply defined response options (i.e., evacuate to ...), the vicarious experience of hearing about the evacuation in Pittsburgh, the perception and personalization of risk, or the social context associated with community size.

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. Some people were at home, (e.g., working in the yard), but many reported being away from other members of their families (e.g., shopping in the area, at community functions, and at work). In short, the social dynamics of the time 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.

5.4 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 (58.5 and 89.0%, respectively) (Table 3). This is in addition to the 66.7 and 27.5% reporting a visible or audible sign of the disaster in the two communities. All of these route-alerting methods of warning took 1 to 1-1/2 hours on the average in Pittsburgh; portable sirens in Confluence averaged just over 30 minutes and loudspeakers and door-to-door alerting took about 1 hour. 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. It is interesting that 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, respectively. Therefore, it seems evident that respondents associated special meaning to an emergency warning. They probably associated it with being told by officials and/or authorities.

Table 3. Average time warned by source of warning (in minutes into the event)

Source of Warning	Pittsburgh		Confluence	
	N	Mean	N	Mean
Friends, neighbors, and relatives	59	49		NA
Portable sirens	61	61	33	32
Door-to-door	38	70	27	66
Portable loudspeakers	89	87	21	68
Radio	21	95		NA
Television	33	96		NA
Other sources	19	92	10	92
Visible/audible sign	214	86	25	58

One of the primary protective actions used in each of these events was evacuation. The average response time among those evacuating was 24.2 minutes in Confluence and 26.5 minutes in Pittsburgh. Route alerting, characterized by officials either at the door or using loudspeakers, generated slightly faster responses than did portable sirens alone in both events (Table 4). In Confluence, 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 Pittsburgh, while portable loudspeakers took longer than other sources of warning in Confluence. Presumably, this is the time it takes to determine the nature of the event and what should be done about it.

Figure 3 illustrates the timing of warning and response for both events expressed as the cumulative percent hearing and responding to the warnings.

5.5 WARNING EFFECTIVENESS

An effective warning system, from a public response viewpoint, is one that provides both a timely alert and notification and a message that guides people to take the appropriate protective action. A timely alert and notification is one that gives the public sufficient time to implement the appropriate response. An effective message is one that has the appropriate content and style and is disseminated over multiple channels with frequent and up-to-date information. Previous research has identified the elements of both style and content that are thought, from a normative standpoint, to define effective message design.

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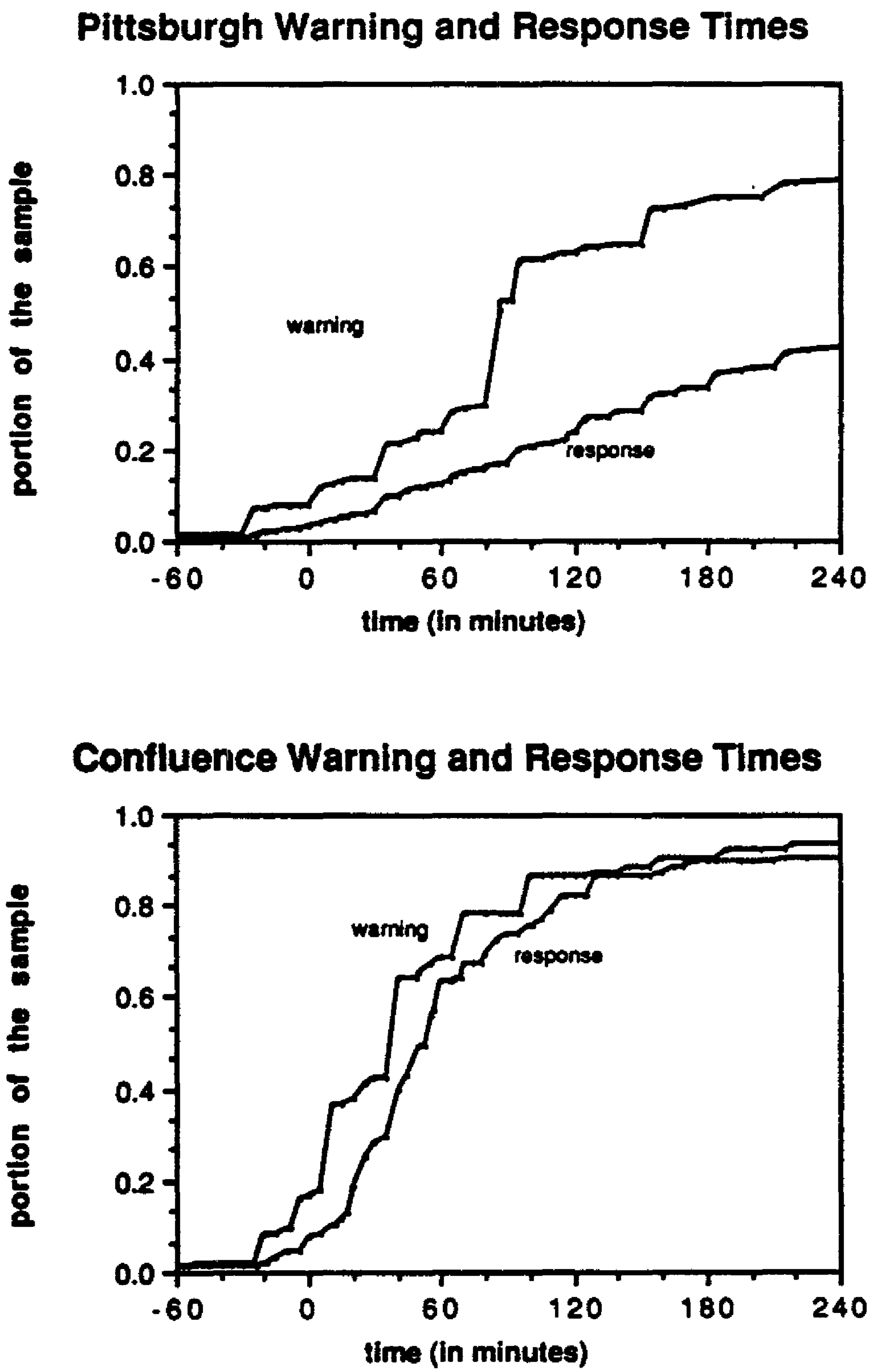

Fig. 3. The timing of warning and response for both the Confluence and Pittsburgh events.

Table 4. Average response time to emergency warning by source of warning (time in minutes)

Source of Warning	Pittsburgh		Confluence	
	N	Mean	N	Mean
Friends, neighbors, and relatives	59	54.4		
Portable sirens	22	73.4	33	21.5
Door-to-door	37	50.4	11	25.9
Portable loudspeakers	86	49.3	21	38.0
Radio	20	59.3		
Television	33	57.4		
Other sources	19	30.8	10	13.3

5.5.1 Timing and Source of Warnings

The speed at which an alert and notification can be disseminated to the public is largely a function of the following factors:

1. Type of warning system
2. Time of day
3. Area at risk
4. Population distribution
5. Season
6. Weather conditions
7. Reliability of warning system technology

From a series of historical events, the percentage of the population warned before an event occurred using an ad hoc warning system, which typically relies on (a) the media and EBS, and door-to-door or (b) route alerting, can be estimated from behavioral surveys conducted following the event (Sorensen and Mileti, in press; Sorensen et al., 1987). In these cases, the percentage warned ranged from 30 to nearly 100% of the population that was defined by the researcher to be at risk and included in the sample. The poorest warning effort documented by a behavioral study was at the Big Thompson, Colorado, flood where an estimated 30% received a warning before the flood waters came. In other disasters such as the 1976 Buffalo Creek, West Virginia, flood and the 1977 Johnstown, Pennsylvania, flood where behavioral surveys were not conducted, it is likely that lower warning rates would be found also. These were fast moving events with less than 1 hour lead time. At Buffalo Creek, no formal warning was issued, and the cascading water provided the only form of notification (Erikson, 1976). In the Johnstown flood, the failure of communications equipment led to a situation in which warnings failed to reach most of the public (NOAA, 1978).

In events where detection provides a lead time of a minimum of 3 to 4 hours, 90 to 100% of the population can be warned without the use of a highly specialized warning system in most events. The warning systems used for these events are ad hoc. They involve a combination of emergency efforts including door-to-door notification by law enforcement personnel, driving through affected areas using portable loudspeakers and sirens on emergency vehicles, and disseminating warning over radio and television stations including the EBS. Permanent sirens or other more sophisticated warning technologies were not used to warn the public in these events.

Figure 4 relates the level of warning to the available warning time for 14 historical events. The data is used to show three curves of warning penetration based on short-, medium-, and long-lead times. The curves were derived by fitting a logarithmic regression function to different sets of the observed warning rates. The logarithmic function is used because it best approximates the nature of the data in the Mt. St. Helens ashfall case. The penetration of warnings during the first 50 minutes of all warnings and for all warnings of 1 hour or less is believed to be best represented by the curve:

% warned = 81.83 * available time^3.488 .

For events with 50 to 3 hours of warning time, the curve is characterized by the equation:

% warned = 59.58 * available time^0.4753 .

Finally for events with warning times of 3 hours or greater, the curve is represented by the equation:

% warned = 66.63 * available time^0.2089 .

Because of the small number of data points that these equations are derived from, the reader should note that the uncertainties associated with the curves are quite large.

People were warned in most events by a combination of three message sources: emergency officials such as police officers or emergency workers who go door-to-door or through the streets with loudspeakers; informal sources such as friends, neighbors, or relatives who make personal or telephone contact; and the mass electronic media such as radio or television. The mixture of warning sources varies among events, although the reasons for variations are not well understood.

One factor that differentiates the various combinations is the available warning time (Fig. 5). In events with only a short amount of warning time, the prime mode of warning is local officials and informal contacts. Often these events may occur during the nighttime hours when people are not tuned to the media. The media plays a more important role in short-fused events that occur during the day or in the evenings. In addition, the media plays a significant role in events with long lead times. In such situations, officials do not provide the initial warning

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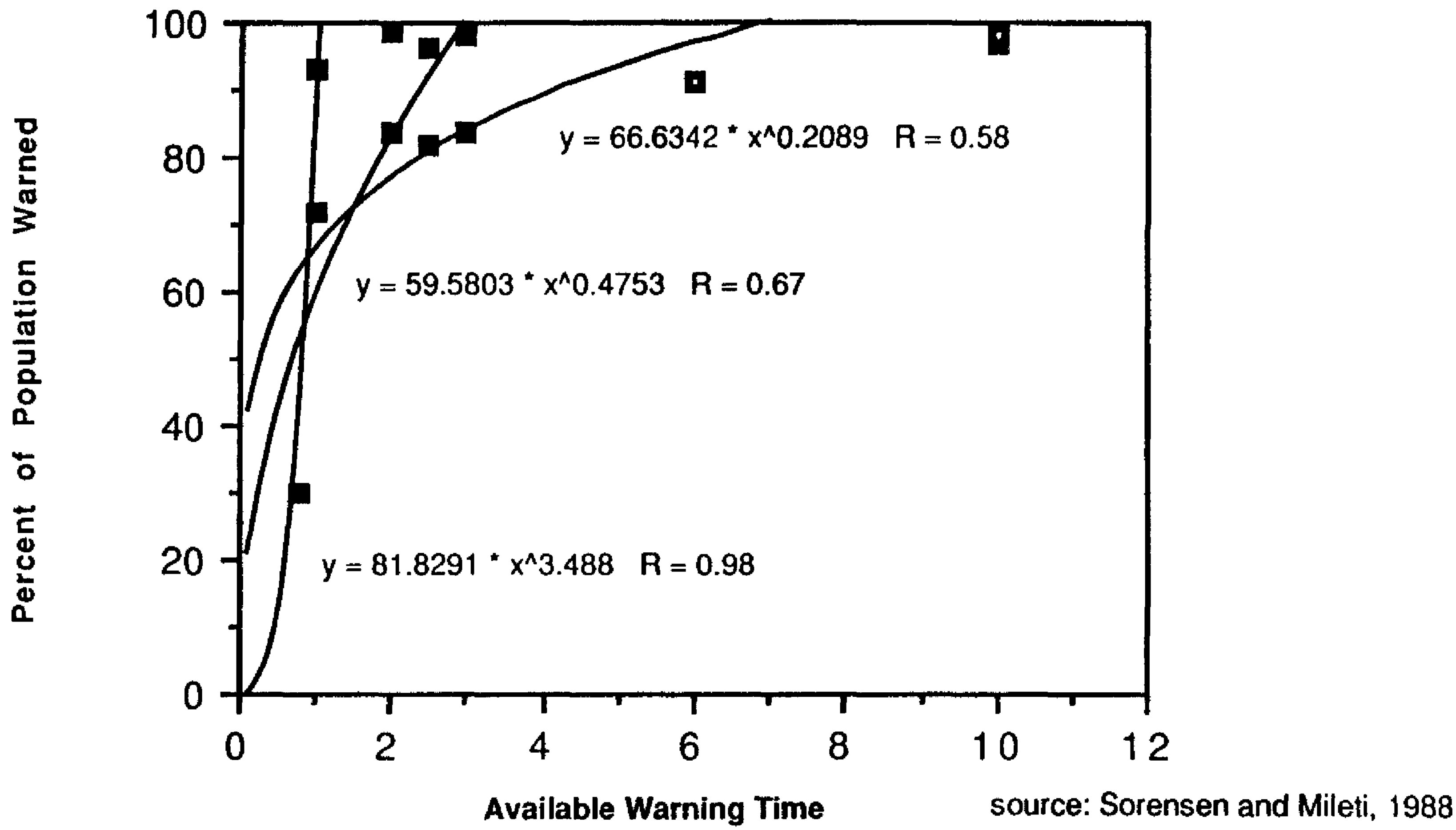

Fig. 4. Three warning rate curves.

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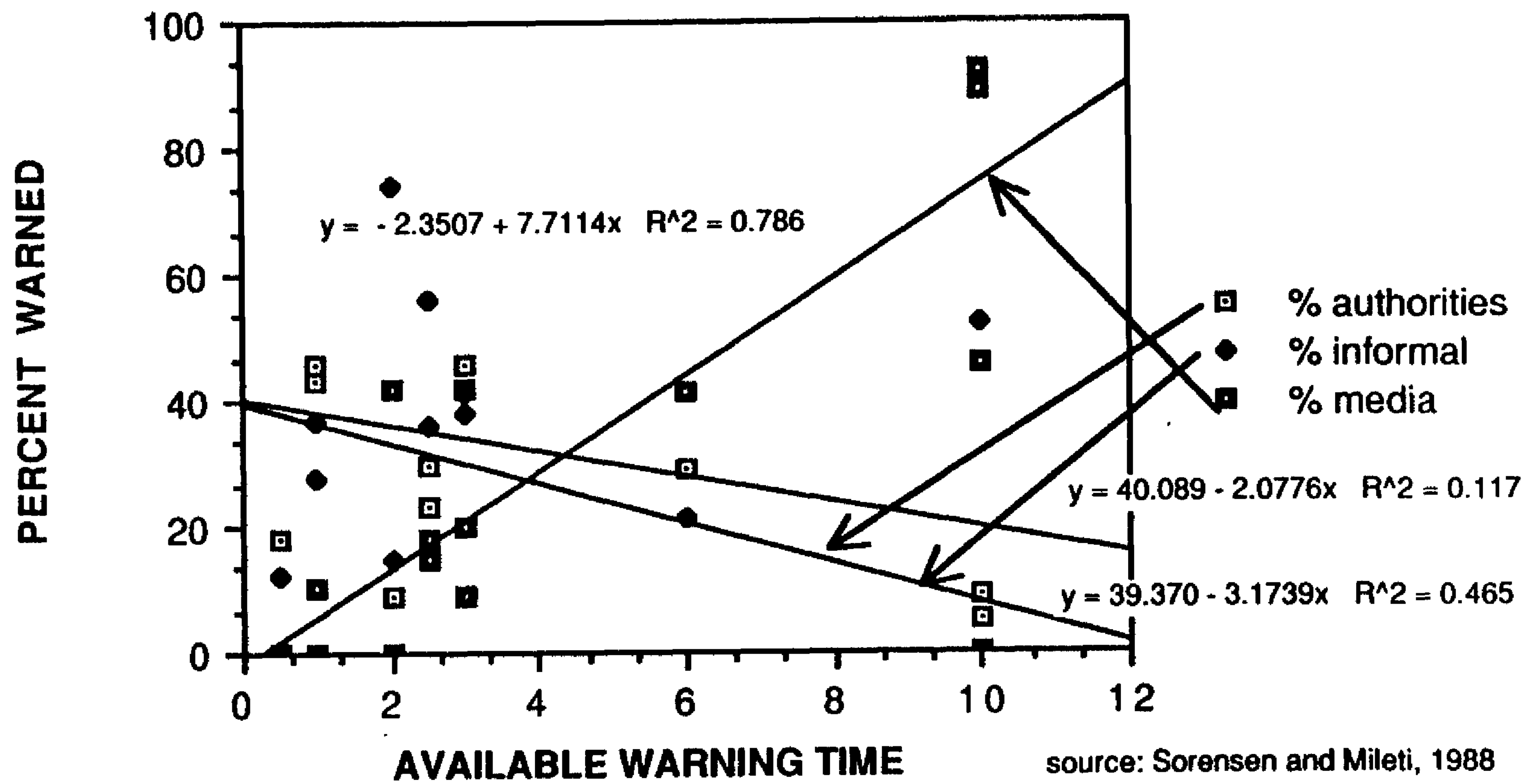

Fig. 5. Percent warned by source and time.

but may provide personal notification of people in high-risk areas. The data also suggest that informal warning is a likely social process in a warning situation. In the events that have a very short lead time, it appears that for about every household that receives a warning from an official another household is notified informally before officials can provide the warning. In more diffuse situations, the role of informal warning diminishes. Thus, the actual timing of the warning dissemination is greatly accelerated by social processes that seem to occur in most disasters. In longer events, warning information is exchanged on an informal basis by many of the people at risk even though the first notification is not from an informal source.

Another way of viewing the timing of ad hoc warning is to examine the rate at which the members of the public at risk are warned. Figure 6 depicts the rate of warning, measured as the number of households warned per minute by the amount of available warning time and the number of households warned for nine localized and fast-onset hazard events. In general, as the size of the population at risk increases, the rate of warning also increases. That is, the capability of the warning system expands as the population involved becomes larger. This reflects the fact that resources such as police and other emergency personnel are proportionate to the population in a community. Warning rates decreased as the amount of time available to warn increased. It appears from the data that a warning rate of 30 to 35 people per hour is a maximum for these types of situations. The warning rate in very large locations may be greater as would be the rate where media is used over a longer warning time period.

The historical data fail to reflect what is theoretically possible to achieve given specialized warning technology. The Lachman and Bonk (1960) study of the Hilo Tsumani indicated that 95% of the population heard the warning sirens within minutes. Studies around nuclear power plants suggest that the portion of the population that hears warnings from the test soundings range between 60 and 95% depending on weather, season, and time of day (Towers et al., 1982). The Federal Emergency Management Agency (FEMA) tests of siren systems around nuclear power plants indicate a similar range with a mean of 85% alerted by test soundings of sirens (FEMA, 1988). The larger problem is response to an alert mechanism. It is not known how many people actively seek information when they hear a siren. The length of time that it takes to receive a warning message following the alert is largely unknown, but it is likely to be a logistic function that falls between the function for the hearing of a siren and that for systems based on official notification.

Other specialized warning systems capable of rapid warning of a high percentage of the population include tone-alert radios and automatic telephone dialers that would have steep penetration curves. Both systems are capable of providing an alert and an instructional message. Recent experiences with tone-alert radios suggest that about 70% of the households served by such a system had operating systems that produced a warning that was heard by people at home at the time (FEMA, 1988). The major problem with tone-alert systems is having an operable receiver. No

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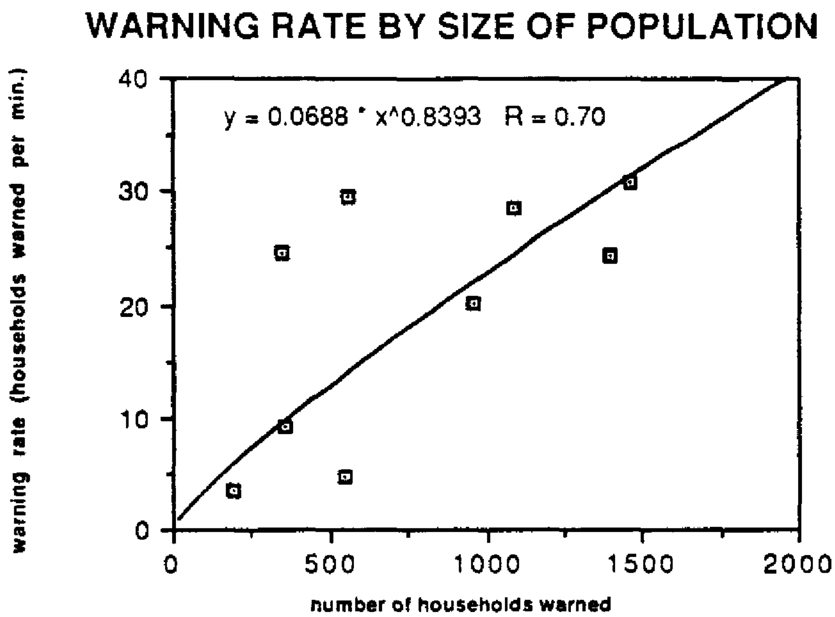

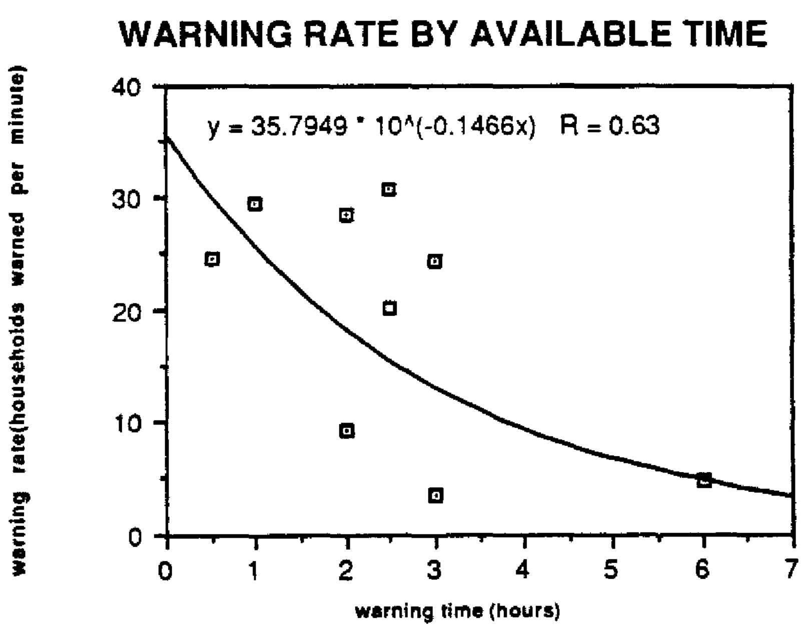

Fig. 6. Warning rate by size of population and by available time.

data exist on the actual performance of a telephone-based system in a test or in an actual emergency.

5.5.2 Notification Effectiveness

A large number of studies exist on factors that influence public response to warnings (see Sect. 2.3). An effective warning system will incorporate such information into the system design. Those factors can be divided into sender and receiver characteristics. Table 5 provides a categorization of those factors.

Sender characteristics are attributes of the actual warnings received by members of the public who will or will not respond to those warnings. Sender--or warning--characteristics fall into four general categories. These categories are attributes of the messages, attributes of the channels through which messages are conveyed, attributes of the frequency with which messages are given, and attributes of the person(s) and/or organization(s) from which the messages emanate (source attributes). Empirical findings from research on sender characteristics suggest that message attributes important to consider in understanding variation in human response to warnings vary in reference to both the content and style of the message. Message content that effects response includes information about the location(s) at risk or not at risk, the character of that risk (for example, effects of impact and time-to impact), and guidance about what people should and should not do in response to the warning and before impact. Both message style and message content are important considerations. Research suggests that the message style attributes that are important are specificity (the degree to which the message is specific

Table 5. Factors affecting warning response

Sender Characteristics

Message attributes (style and content)
Frequency attributes (number and pattern)
Source attributes (officialness, credibility, and familiarity)
Channel attributes (type and number)

Receiver Characteristics

Environment attributes (cues and location)
Social attributes (network, resources, culture, and activity)
Psychological attribute (knowledge, cognition, and experience)
Physiological attributes (disabilities)

about risk, guidance, and location); consistency (the degree to which a message is internally consistent, and the degree to which consistency of information exists across separate warning messages regarding risk, guidance, and location); accuracy (the extent to which message content about risk, location, and guidance is accurate); certainty (the degree to which those giving the warning message seem certain about what they are saying about risk, location, and guidance); and clarity (the degree to which risk, location, and guidance information in the message are given in words that people can understand).

In addition to message attributes, the characteristics of the channel used is significant. These include the type of channel used (i.e., personal versus impersonal) and the number of different channels used. Frequency attributes include the number of times a particular message is conveyed, the number of different messages, and the pattern between different conveyances (i.e., every 15 minutes, randomly, etc.). Source attributes include the level of familiarity of those giving the message to those receiving it, whether the message giver is an official, and the credibility of the message giver to those who receive the message.

Research also documents a variety of characteristics of those who receive warning messages and covariants of warning response process factors. These receiver characteristics are divided into four major categories of receiver attributes. The first of these is attributes of the environment of the warning recipient when the warning is received. The environmental attributes worth noting are physical and social cues (e.g., if there is smoke coming from the chemical plant when warnings are received, or if neighbors are seen evacuating when evacuation advisements are received).

Social attributes of the warning receiver that have been empirically demonstrated to covary with warning response and process factors have been grouped into five categories. Aspects of the social network of which the warning recipient is a member is one category that includes factors such as whether the family is united, social ties and bonds, the existence of close-by friends and relatives. Resource characteristics of the warning recipients is another category of social attributes that refers to physical resources such as having or not having access to a car in which to evacuate, economic resources such as having money to pay for a hotel, and social resources such as having or not having a local social support system. The role characteristics (i.e., sex and age) of the warning recipient are social attributes that affect warning response. Role characteristics include, for example, sex and age. Cultural characteristics such as ethnicity, language, and social class are another dimension of social attributes. The last category of social attributes of the warning recipient is activity characteristics; that is, the social activities in which the warning recipient is participating when the warning message is received. These include activities such as sleeping, working, and recreating.

The third set of attributes of the warning recipient revealed by past research as necessary considerations are psychological attributes. These include pre-warning knowledge about risk associated with a particular hazard, protective actions, and the existence of emergency plans; pre-warning cognition such as psycho-social stress level and locus of control of the warning recipient; and experience with the hazard, for example, the type of experience and its recency.

The last set of warning recipient attributes in the typology of attributes suggested by past research are physiological attributes. Although relatively scant, empirical research has been performed on physiological attributes, factors such as physical disabilities--for example, deafness and blindness--are a category of warning receiver attributes that can effect warning response and process.

From an emergency management standpoint, another way to look at warning system effectiveness is to measure the warning system's ability to provide populations at risk with adequate time to respond appropriately to the situation. The consideration of how much time it takes to warn the public is relatively unimportant until it is considered in conjunction with the onset of the hazard. Hence, it is the available time for effective response that is the single most important measure of warning system effectiveness. For example, a warning system that warns a population in 10 minutes, when the population is exposed in 8 minutes is less effective than a warning system that provides warning in 1 hour when exposure takes 1-1/2 hours.

Three hypothetical situations are used to characterize the onset of a hazard for comparative purposes. Let us posit hazards that emanate from a source at a rate of 1, 3, and 6 meters/second. These could occur as the result of a toxic vapor cloud emanating from a fixed chemical facility or a transportation accident. Historically, the accidents at Bhopal, India, and Institute, West Virginia, represent the former, and the accidents at Mississauga, Ontario, and Pittsburgh, Pennsylvania, provide historical examples of the latter. In accidents with airborne toxins such as these, the variable rates are attributable to differing meteorological conditions and, in particular, wind speed.

Rogers and Sorensen (1988) simulate the diffusion of warning for six types of warning systems, including systems based on fixed sirens and alarms, tone-alert radios, auto-dial telephones, media and the EBS, as well as combining systems based on sirens and tone-alert radios and sirens and auto-dial telephones. It is assumed that the process of deciding to warn can be improved to take about 10 minutes. Such a time is about twice as fast as the average time reported for communities to make the decision to warn under ideal conditions in a fast moving event of just over 18 minutes, which does not include facility time for detection, assessment of the hazard, and any subsequent decision-making time. Longer or shorter decision times change the probabilities of being alerted prior to hazard onset, but the relative performance of each warning system remains unchanged. Organizational decision-making time is variable given the nature of the emergency event. At Bhopal, approximately 20 minutes elapsed before the alarm, and the public alarm was apparently shut down completely for nearly 30 minutes after that (Morehouse and Subramaniam, 1986). In other types of disasters, such as the Cheyenne flash flood, public warnings began to be issued within 5 minutes of detection (Sorensen 1987a). Rogers and Sorensen (1988) consider a critical area of 35 km from the source of the hazard. Beyond that distance, no specialized warning effort would be needed to provide sufficient time to disseminate the warning using ad hoc warning procedures.

By combining the diffusion estimates for various warning systems with the hypothetical "downwind" travel speeds, the probability of warning people prior to exposure at various distances from the source of release is estimated (Table 6). These results indicate that the amount of time it takes an organization to decide to warn, including the detection of the hazard, is a critical component of warning system effectiveness. The resulting estimates demonstrate the critical nature of organizational decision making in all events but place even more emphasis on this crucial element of emergency warning where warning time is most limited. People cannot fully protect themselves from a hazard when they do not receive warning prior to exposure. These results also imply that the full range of potential protective actions be considered. In chemical emergencies, eight evacuees in every 100 are injured because of inhalation of toxic vapors (Sorensen, 1987b). Alternatives to formal evacuation in fast-onset events include escape and sheltering. Escape consists of the moving afoot out of the endangered area (Prugh, 1986). Sheltering involves movement to secure places in a structure and taking steps to keep the hazardous agent from entering the structure. In chemical incidents, sheltering may be an extremely effective way of self-protection. Both actions are viable alternatives to evacuation because of the relatively short time required to implement these actions.

The combination of either telephone ring-down or tone-alert radio warning systems with sirens provides the most effective warning system under conditions of very rapid onset, close proximity, or both. These results indicate that alternative individual systems provide adequate warning effectiveness when available warning time (to the public after detection and the decision to warn) extends to as much as 1 hour, and that tone-alert radios and telephone ring-down systems provide similar coverage at approximately 30 minutes of available public warning time.

The results indicate that a combination warning system is the most effective system in the 10-km radius. Given the instantaneous release at low onset speeds, most people in the 10-km zone will receive a warning. At the onset speed of 3 meters/second, the combination systems do not lead to adequate warnings within 2 kilometers, but they perform well within the 5- to 10-km range. Under very high onset speeds, it will be difficult to adequately warn people within 5 km.

Within 35 km some multiple method warning systems may also be desirable, although 100% overlap is not necessary. A combination of

Table 6. Available time and distance for warning system alternative (assumes a decision to warn in 10 minutes)

Warning system	Distance (km)				
	1-2	2-5	5-10	10-20	20-35
Windspeed of 1 m/s min (+0.5) +	15.5	48.8	115.5	240.6	448.9
Sirens and alarms	0.563	0.855	1.000	1.000	1.000
Tone-alert radios	0.811	0.939	0.999	0.999	0.999
Auto-dial telephones	0.882	0.971	1.000	1.000	1.000
Media/EBS	0.199	0.595	0.843	0.927	1.000
(A & B)	0.925	0.993	1.000	1.000	1.000
(A & C)	0.941	0.993	1.000	1.000	1.000
Windspeed of 3 m/s min (+0.5) =	-1.2	10.0	32.2	73.9	143.3
Sirens and alarms	0	0.296	0.809	0.922	1.000
Tone-alert radios	0	0.610	0.922	0.963	0.999
Auto-dial telephones	0	0.713	0.955	0.996	1.000
Media/EBS	0	0.102	0.473	0.693	0.893
(A & B)	0	0.759	0.977	1.000	1.000
A & C	0	0.816	0.977	1.000	1.000
Windspeed of 6 m/s min (+0.5) =	-5.3	0.3	11.4	32.2	66.9
Sirens and alarms	0	0	0.390	0.809	0.903
Tone-alert radios	0	0	0.697	0.922	0.957
Auto-dial telephones	0	0	0.792	0.955	0.989
Media/EBS	0	0	0.132	0.473	0.668
A & B	0	0	0.842	0.977	1.000
A & C	0	0	0.882	0.977	1.000

sirens, tone alert, and media/EBS warnings could be used to warn populations within 10 to 20 km. The exact mixture needs to be determined on the basis on local geography, potential hazard, and population distribution. Beyond 20 km, it seems appropriate to rely principally on the media/EBS systems, except for institutional populations that require prompt notification in the entire emergency planning zone.

This analysis provides a preliminary basis for planning warning systems for fast moving events such as chemical spills and for assessing the effectiveness of warning systems currently being used. Although this analysis has focused on the timing of a warning, it is recognized that the organizational structure for issuing the warning and the style and content of the warning are also critical factors in the overall effectiveness of the systems. As society creates more and more potentially dangerous hazards such as industrial facilities, chemical weapons, biotech facilities, nuclear power plants, and other unforeseen technologies, the need for careful planning for emergency warnings increases.