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The timing of emergency decisions: Modelling decisions by community officials during chemical accidents

George O. Rogers

Hazard Reduction and Recovery Center, College of Architecture, Texas A&M University, College Station, TX 77843-3137, USA

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Abstract

Protecting the public from airborne chemical releases is limited by the timing of the implementation of actions taken and the capacity of those actions to avoid or reduce exposure. This paper examines the community decision processes during emergencies to identify critical factors associated with the timing of emergency warning, and protective action recommendations. This research examines the decision process by tracing emergency response from the outset of the community decision process, through the decision to warn the public, including the communication of hazard to the public, and the all-clear at the end of the emergency period. Both community authorities and the public cycle through hazard detection, assessment, communication, and behavioral response as they become aware of the hazard. A sample of emergency decisions during chemical emergencies was examined via post-emergency interviews with key community officials. Emergency responders in a systematic sample of events after 1984, but prior to 1990, were interviewed in the Fall of 1989. Finding that decisions in more recent events were more easily reconstructed, a randomly selected half of the significant chemical emergencies occurring during 1990 were interviewed within weeks of the chemical events. Previous work [1] shows that community decision processes are seldom immediate and often involve information seeking. This descriptive work is expanded herein to provide better models of the key factors effecting decision processes in chemical emergencies. Regression models of these data indicate that protective action and warning decisions occur more rapidly than all-clear decisions, and that each decision is influenced by different factors in the decision process. Moreover, these data indicate that the role of experts changes throughout the emergency response. When decisions lead to the active avoidance of exposure, officials seem to take evasive action more quickly, but when failure to decide results in passive avoidance of exposure and continued inconvenience of the public, the decision process is often protracted.

1. Introduction

Over 100 chemical releases a year in the US since 1985 have required emergency operations involving community decisions and public response (Fig. 1). Hence, events

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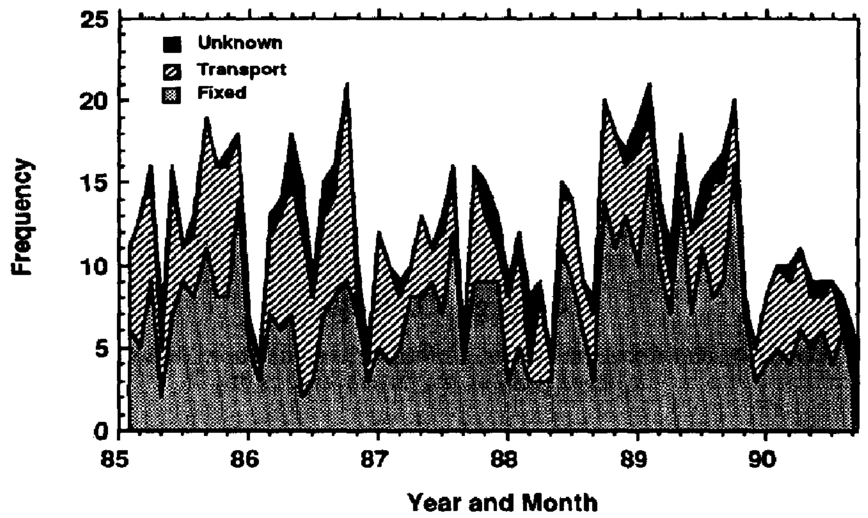

Fig. 1. Frequency of chemical accidents by year and month.

requiring protective actions at the household level occur every 2 to 3 days on average. The effectiveness of these actions taken to protect the public from airborne chemical releases depends on the timing of the implementation and the ability of those actions to avoid or reduce exposure [2]. The timing of implementation depends upon the facility and community organizations becoming aware of the hazard, assessing its severity, and selecting appropriate courses of action to protect the public. The decision processes of community officials are potentially influenced by a variety of factors, including the extent of emergency planning, the uncertainty associated with the release of hazardous chemicals, conflicts among decision makers, perhaps arising from the associated uncertainty, and the community context of emergency operations and preparedness, which might be characterized by available resources, population segments to be protected, and prior experience with similar incidents. In addition, the timing of the implementation of protective actions depends on the dissemination of emergency warning, the public response to the emergency warning(s), and implementation of the selected actions.

The extent to which protective actions effectively avoid or reduce exposure depends on the "structural" capacity of the prescribed actions, and the ability of the people to implement them. For example, the structural capacity of the road network determines the minimum duration required to evacuate an area, but evacuations require that people are either capable of driving, or that sufficient transportation be available to evacuate the impacted area. Community decision processes during emergencies are examined in this paper to identify critical factors associated with the timing of emergency response and the initiation of protective actions undertaken by the public. The effectiveness of protective actions depends on the timing of this "chain-of-activities" [3–5]. At one extreme, if the public is not warned, they cannot be expected to respond; if the public fails to understand the warning message they do receive in terms of what is expected of them, the response is likely to be ineffective. Protective action effectiveness is the result of multiple factors including the complete warning process from recognition of hazard to the decision to warn the public, the associated message that establishes both the extent of the hazard and what protective action(s) are appropriate to avoid harm. Effectiveness is also impacted by the receipt of the warning, the public's interpretation through the attachment of meaning to the message, and each household's decision to respond in a particular way.

2. Background

The communication of emergency warning is cyclical [5]; people begin the process with some form of detection, and cycle through hazard assessment, communication and behavior selection (Fig. 2). As more and more people become aware of the hazard, people assess (and reassess) the hazard, communicate with others regarding appropriate actions (which disseminates the emergency warning to other people) and select behaviors to protect people from harm. While this process is a necessary part of

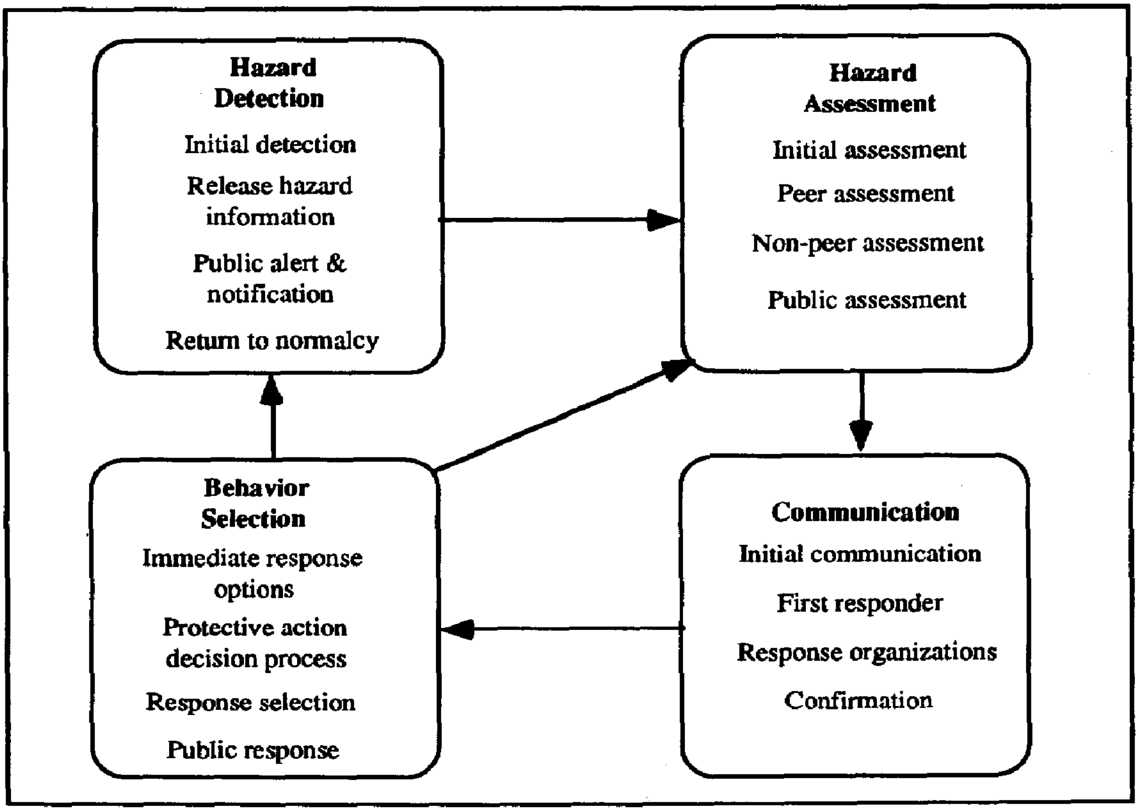

Fig. 2. A summary of the cyclical nature of emergency warning.

emergency response, it also takes time. Unfortunately, time is often limited in chemical accidents.

The effectiveness of actions taken to protect the public is to a large degree determined by the timing of emergency decisions [2]. For any protective action to achieve its design effectiveness, people must become aware of the potential for harm, decide to act, and implement the appropriate behavior to achieve protection. The community's decision to warn the public and the public officials' recommendation regarding appropriate protective actions are among the most important elements of that process. This paper addresses these two important decisions.

Decisions based on inter-organizational involvement tend to broaden both responsibility and perspective, which tends to make decisions more effective. Conversely, small group decision theory suggests that generally the larger the group, the longer it is likely to take to make decisions [6]. Inter-organizational decisions involve more people; hence, they are likely to lengthen the time it takes to reach a decision. Longer time frames for decisions in fast moving chemical emergencies tend to reduce protective action effectiveness. This article examines these countervailing forces in terms of the time it takes to make emergency response decisions in inter-organizational settings, the number of people representing those organizations, and the character of the decision process. This paper addresses the effect of the size and nature of the decision making organization on the length of the inter-organizational community decision process in chemical emergencies.

Experimental research on cognitive processes of decision making indicates that a variety of problem simplifications occur at the individual level that bias judgments under uncertainty [7, 8]. Kahneman and Tversky have even shown that people will reverse their choices of risky alternatives when equivalent alternatives are presented as a choice between a sure gain and a gamble versus a sure loss and a gamble [9, 10]. Psychometric studies, cognitive heuristics, and prospect theory suggest that decisions are affected by uncertainty. Hence, to the extent that emergency decisions are fraught with uncertainty they are likely to be affected by these individual level cognitive processes. Controversy over the assessment of public preferences for risk has also been generated over judgmental heuristics. People make initial estimates of numbers resulting from complex processes that are often at the heart of response to technological risk, and then adjust them to arrive at a solution or decision. This anchoring effect tends to bias choices when artificially high or low starting points initiate decisions [10]. These kinds of judgmental heuristics present challenges to a rational decision making model [11]; moreover, they present particular challenges in the emergency decision making process.

In free societies, whenever groups are involved in decisions, differing points of view are possible; these views can lead to various kinds of conflict with different functions [12]. Intra-organizational decisions during emergencies have been examined, but limited research on inter-organizational decisions exists [13]. This research focuses on inter-organizational decisions made in response to chemical emergencies during the crisis. The direct impacts of the emergency situation on the community decision process is examined [14], rather than the public response process [15–19]. In addition, this research focuses on the duration of the community decision process, which extends preliminary descriptive research on the community decision making process in emergencies [1].

The community decision process in chemical emergencies is examined, beginning with the recognition of hazard and continuing through the all-clear [14]. The major decisions reached during the emergency response period are the primary emphasis of this research, including the recognition of hazard, its assessment, the decision to warn the public, the selection of appropriate protective actions, and the reassessment of the hazard leading to an all-clear.

3. Models of group decisions

Classic experimental studies of group decisions are tested using contrived problems with known parameters (e.g., number of stages, precise solutions). The experiments are set up to control group characteristics (e.g., group size), and measure others (e.g., ratio of solvers to nonsolvers). Restle and Davis [6] posit four models of individual and group problem solving for individuals, simple groups, hierarchical groups, and equalitarian groups. The *individual model* of the timing of problem solution is a gamma function,

$$g(t;\lambda,k)=\frac{\lambda}{(k-1)!}\mathrm{e}^{-\lambda t}(\lambda t)^{k-1}$$

where t is the minute into the decision process, k is the number of steps in the problem or decision process, and λ is the probability of reaching a decision or solving the problem at any time, t. The simplest group decision model assumes that each person in the group contributes to the potential for a solution to the problem independent of other participants; hence, the *simple group model* multiplies the probability by the number of people in the group, r,

$$g(t;r\lambda,k)=\frac{r\lambda}{(k-1)!}\mathrm{e}^{-r\lambda t}(r\lambda t)^{k-1}$$

However, each person in a group does not contribute independently and equally to the group's decision or solution. In fact, Restle and Davis [6] argue that some people in the group may not have a solution to the problem at hand. These nonsolvers would not then be capable of contributing to a decision. The *hierarchical model* argues that solvers (A) form a hierarchy that renders nonsolvers (B) nonfunctional (i.e., they neither contribute to nor detract from the solution). The distribution of solution times can then be described as a density function over time:

$$f_{\mathrm{h}}(t)=\sum_{A=0}^{r}P(A)\,g(t;A\lambda,k)$$

where $P(A)$ is the probability of exactly A solvers in a group of size r,

$$P(A)=\binom{r}{A}a^{A}(1-a)^{r-A}$$

$g(t; A\lambda, k)$ is a gamma function defined above and a is the proportion of individuals in the population of potential group members that are solvers. Hence, a hierarchical group of r people with A solvers will be exactly equivalent to a group of A solvers, without the extra nonsolvers. The ***equalitarian model*** posits that nonsolvers (B) detract from the group by continuing to participate in the group, and thereby slow the decision process down, even though they do not contribute to the overall solution. Hence, the equalitarian model has a corresponding density function of

$$f_e(t) = \sum_{A=0}^{r} P(A)\, g\left(t; \frac{A^2}{A+B}\lambda, k\right)$$

Restle and Davis [6] conclude that the equalitarian model yields predictions that quite closely approximate the experimental evidence. The challenge of this paper is to begin to test these experimentally developed theoretical models using *ex post facto* data collected in the post-emergency period.

4. Data and methods

4.1. Sampling

In order to collect data from people who can report effectively on the conduct of emergency decisions during an emergency involving protective actions taken by the public, data must be collected while the events remain clear in the minds of the participants. Hence, this involves a two step process of identifying the events in the universe, and interviewing a sample of selected community officials who have recently experienced an event. To assure the latter, the sampling universe was iteratively generated, with interviews conducted within 2 to 3 weeks of the occurrence of the event.

The universe of events was identified by conducting periodic searches of the NEXUS listings of the Associated Press/United Press International news stories involving the evacuation (or other protective actions) of 10 or more people as the result of chemical accidents or events [20, 21]. These events are presented in Fig. 1. These events are of sufficient size to require more than a single household's response, and would thereby require decisions by public officials during the event.

4.2. Interviewing

Key community officials were interviewed via telephone. The officials were selected to represent organizations vital to the community's emergency response. The person responsible for reaching critical decisions was interviewed, as well as people with a direct role in emergency decisions when necessary. Fire department officials comprised more than 75% of the respondents, with more than 90% of these being fire department chiefs or deputy chiefs. County or municipal police departments comprise 14% of the interviews, and another 7% were with other emergency management organizations, health departments and political officials. These interviews focused on the timing of critical events in the emergency response, involvement of emergency response personnel in the decision process, examination of protection alternatives, the emergence of viable protection alternatives, and the resolution of any resultant conflict among personnel involved in the decision process.

Initial interviews consisted of 14 cases that had been previously examined regarding the use of in-place sheltering techniques in response to chemical accidents resulting in vapor clouds. In one community/event officials refused to participate, because the event and subsequent response were currently under litigation. These cases were used to refine the sample selection, interviewing, and coding processes. Because of the enhanced recall associated with more recent events, and the lack of confounding from other events occurring between the qualifying event and the interview it became evident during the pretests that by reducing the time period between the event's occurrence and the interview more reliable data would result. In September and December 1989, 10 cases were selected to pretest the guide used to interview community officials associated with all events occurring in these months. Sampling all events sometimes resulted in interviews being conducted long after the event. A simple random sample of approximately one-half of all qualifying events occurring in 1990 was drawn. This sample resulted in 51 events or communities being selected for study. Data regarding community response to 70 events were collected within weeks of the event. Five cases were unable to be contacted. Hence, more than 98% of those contacted completed the interview[1].

These 70 events involved 232 emergency decisions. Because we are interested in the full range of decisions in emergency response, these 232 decisions provide the data for some analyses. These 232 decisions include 69 decisions to warn the public of impending danger, 101 protective action decisions, and 62 explicit "all-clear" decisions declaring the emergency over. It is clear that almost all events involve decisions to warn the public, while many involve more than a single protective action decision. Meanwhile, some events end without benefit of an explicit all-clear decision.

4.3. Measurement

Data for events in each community examined the decision process in terms of three primary decisions: the "decision to warn" the public of impending danger, the selection of an appropriate "protective action", and the decision to issue an "all-clear". The decision to warn involves all the activities beginning with the first awareness of an event until the warning system is activated. These activities can include the initial identification, location and assessment of the hazard, the communication of this hazard to a decision group, the discussion of alternative responses to the existing hazard (which can give rise to conflict, and the resolution of that conflict), and the implementation of that action. The protective action decision involves the selection of

[1] Sincere gratitude is expressed to those community officials who not only participated but cooperated in the extreme – often enduring intensive interviews sometimes extending over several telephone calls.

appropriate action(s) to be taken in response to the event. While it is often explicitly or implicitly imbedded in the decision to warn, it is also frequently considered separately. For example, it may become clear very early that the public will have to be warned, but it may remain less clear as to what to tell the public to do in response to the event. The all-clear decision involves monitoring or reassessing the hazard as it progresses to determine when the danger associated with the event no longer exists.

Data concerning the timing of a number of key events in the emergency were reported. These key events include the time of the incident, the time the decision to warn was reached, the time the protective action was selected, the time the warning began and ended, and the time an all-clear was issued. All times were recorded in decimal for ease of calculation. Because these events mark the times at which decisions begin and end, the length of decision process is attainable. However, the events and communities are not uniform, thus making measurement more difficult. For example, some communities merged warning and protective action decisions, other events and communities required multiple warnings and decisions regarding a staged response. The length of response decisions is operationalized as the additional time required to reach the next decision in the process, beginning with the decision to warn (DW), followed by decisions about protective actions (PA), and concluding with an all-clear decision (AC). The length of the decision to warn is the most clear emergency response decision; the decision to warn's length m is

$$m = (\mathrm{DW}_t - I_t + d) \times 60$$

where DW_t is the time of the decision to warn the public in hours since midnight, I_t is the time of the incident in hours since midnight, and d equals 0 if DW_t and I_t occur in the same 24 h period and 24 if they occur on consecutive days. Multiplying by 60 converts the measure to minutes. Measurement is less clear for protective action decisions, primarily because the time the decision begins is less clear. The additional time required operationalization allows us to measure the time required for protective action decisions; the protective action decision's length m is

$$m = (\mathrm{PA}_t - \mathrm{DW}_t + d) \times 60$$

where PA_t is the time the protective action decision was reached in hours since midnight, and the rest are defined as above, except $d = 0$ if PA_t and DW_t occur on the same day and 24 if they occur on consecutive days. The beginning of the all-clear decision is also unclear. Respondents frequently link the reassessment of the situation to events (e.g., the capping of a leak, the containment or suppression of a fire, the off-loading of remaining chemical, or simply the arrival of an outside assessment team). This would indicate that once these activities are completed officials begin to reassess the situation to determine if people can return to normal activities; however, this fails to account for the process of determining that the activity (e.g., containment, off-loading, fire suppression) is critical to the all-clear decision. This study takes advantage of a fundamental given; officials cannot consider issuing an all-clear before they finish warning people of the impending danger. Hence, the time required to reach an all-clear decision m is measured as

$$m = (AC_t - WE_t + d) \times 60$$

where AC_t is the time the all-clear decision was reached in hours since midnight, WE_t is the time the warning process ended (i.e., the time public officials stopped warning people of the impending danger), and the rest are defined as above, except $d=0$ if AC_t and WE_t occur on the same day and 24 if they occur on consecutive days. Measuring decision times in this manner calibrates the timing of each event on the same scale and thereby allows comparison.

Four categories of factors potentially affecting decision processes are considered: type of decision, organization characteristics, situational factors, and the characteristics of conflict and its resolution. The type of decision influences the fundamental nature of the problem and is thereby expected to impact the decision process and its timing. Hence, binary variables representing each type of decision were created where the variable equals one if it is the particular type, else it is zero. Organizational characteristics are measured in terms of the number of people involved in the decision process (People), the reported use of standard operating procedures (SOPs), the number of organizations involved in emergency decisions (Orgs), and the use of external experts in the decision process (Exp). Situational factors are measured in terms of the time of day the decisions are made (TBEG) and the time of the incident (TIN). These organizational and situational factors provide the organization and the situational setting for the decision making process. Finally, the leadership of the response team is assessed in terms of the existence of conflict, and whether it was resolved by consensus approach to organizational decision making (Con), or tended to be resolved by leadership of a few individuals in the response team (Lead). Conflict potential is assessed in terms of the existence of multiple people from multiple organizations, because the existence of conflict is enhanced when many people, with various points of view, from different organizational structures, with their distinct reward structure, are involved in the decision process. Table 1 presents summary statistics for the resulting variables.

5. Findings

The length of time required to make critical decisions during the community's response to chemical accidents varies considerably. The decision to warn the public took an average of 79 min, ranging from less than a minute to more than 16 h. The 95% confidence interval around the mean time it takes to reach a decision to warn the public is from approximately 40 min to about 2 h. Protective action decisions took an average of 1 h and 45 min, ranging from no additional time spent on protective action decisions to over 24 h. The 95% confidence interval around the mean time it takes to reach a protective action decision is from approximately 1 h 15 min to about 2 h 15 min. All-clear decisions seem to take considerably longer, averaging 7.5 h, and ranging from under a minute to nearly 2 days. The 95% confidence interval around the mean time it takes to reach an all-clear decision is from about 5.5 h or more than

Table 1

Univariate statistics and Pearson correlation matrix

	Min	ln(min)	Rank	PA	DW	AC	SOPs	EXP	TBEG	TIN	Con	Lead	People	Orgs
Univariate statistics														
Min	0	−4.1[c]	1	0	0	0	0	0	0	0	0	0	1	1
Max	2490	7.82	232	1	1	1	1	1	23.93	23.93	1	1	9	5
Mean	190.6	2.4	116.5	0.44	0.3	0.27	0.36	0.53	12.3	12.26	0.55	0.18	2.87	1.72
Std. Dev.	389.77	3.75	67.12	0.5	0.46	0.44	0.48	0.5	6.37	6.57	0.5	0.38	1.6	1
Correlation coefficients														
Minutes														
ln(min)	0.528[a]													
Rank	0.656[a]	0.933[a]												
PA	−0.190[a]	−0.510[a]	−0.465[a]											
DW	−0.185[a]	0.157[b]	−0.023	−0.571[a]										
AC	0.404[a]	0.409[a]	0.545[a]	−0.530[a]	−0.393[a]									
SOPs	−0.272[a]	−0.243[a]	−0.310[a]	0.189[a]	0.138	−0.354[a]								
Expert	0.036	0.096	0.155	0.008	−0.238[a]	0.237[a]	−0.028							
TBEG	−0.154[b]	−0.056	−0.057	−0.065	0.028	0.045	−0.121	−0.095						
TIN	0.103	0.043	0.047	−0.024	0.031	−0.006	−0.118	−0.121	0.762[a]					
Consensus	−0.081	−0.040	−0.010	−0.127	0.061	0.079	0.144[b]	0.081	0.072	−0.044				
Leader	−0.080	−0.107	−0.157[b]	0.095	0.045	−0.152[b]	−0.114	−0.062	0.078	0.108	−0.510[a]			
No. of People	−0.110	−0.044	0.013	0.088	−0.126	0.032	0.060	0.203[a]	−0.032	−0.125	0.482[a]	−0.110		
Organizations	0.084	0.070	0.125	0.033	−0.104	0.070	0.021	0.114	−0.135[b]	−0.114	0.277[a]	−0.171	0.429[a]	

[a] $\alpha < 0.01$.
[b] $\alpha < 0.05$.
[c] The minimum of the minutes to make a decision is set to 1 s or 0.0167 min.

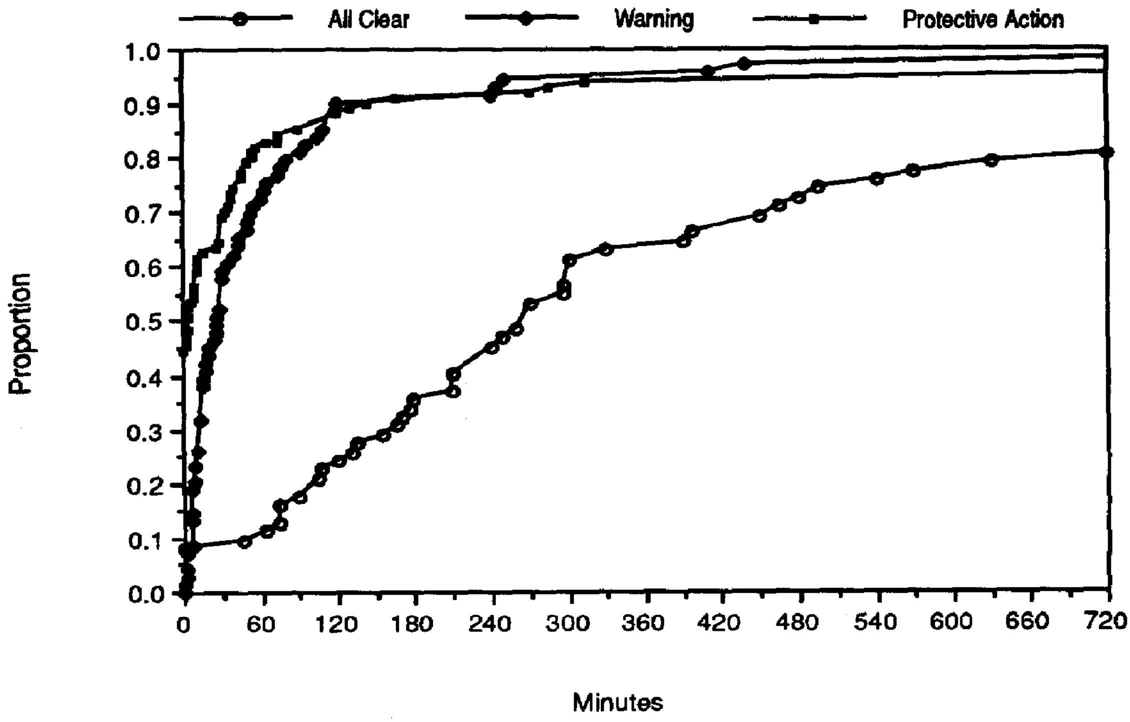

Fig. 3. Timing of decisions by type.

9.5 h. Fig. 3 summarizes the timing of community response decisions by type of decision in terms of the proportion having reached the decision by minute for the first 12 h of the process.

Most of the decisions to warn the public of impending hazard are made rapidly, 50% are made within about 30 min, about 75% are made in the first hour, and about 90% of the decisions to warn the public are made within the first 2 h. Because the protective action decisions are frequently incorporated in the decision to warn, about 45% of the protective action decisions contribute no additional time to the decision process. Seventy percent of the protective action decisions are made within 30 min, with about 85% being made within the first hour, and just under 90% being made within the first 2 h. Hence, protective action decisions occur most rapidly; however, this is consistent with the time added conception of decision process duration. All-clear decisions generally use more time than either protective action decisions or decisions to warn the public.

Given the nature of the decision to warn and the selection of appropriate actions to protect the public, it seems evident that decisions directed at the attainment of protection are arrived at more quickly than decisions that may (if made incorrectly) result in exposure. Hence, "safe-side" decisions seem to be made more quickly than decisions that might put people at risk. This finding is consistent with prospect theory that suggests that the choices people make are sensitive to the perception of the outcome.

In order to test the relationship between each of the factors considered important in the decision making process, zero-order Pearson correlations were calculated. Table 1 also presents the Pearson correlation matrix of the key factors of emergency decision process. These correlations show that taken alone the type of decision ($r_{pa}=-0.190$, $r_{dw}=-0.185$, and $r_{ac}=-0.404$), use of standard operating procedures ($r=-0.272$), and the time of the accident ($r=-0.154$) influence the amount of time spent in key emergency decisions. The correlations with type of decision ($r_{pa}=-0.510$, $r_{dw}=-0.157$, and $r_{ac}=-0.409$) are strengthened when related to the nonlinear form of the duration of emergency decision (ln(min)). Standard operating procedures ($r=-0.243$) are also significantly related to ln(min). These correlations confirm that decisions to warn the public, and to take particular protective actions are generally arrived at faster than all-clear decisions. Moreover, decisions using standard operating procedures are made more quickly than decisions without benefit of SOPs. Finally, these data suggest that the earlier in the day the accident begins, the more quickly decisions associated with that accident are made. This probably is the result of differing organizational structures available at various times of the day, and the operating procedures used by different organizational structures (e.g., skeleton crews).

6. Model development and discussion

How do these factors in the decision process jointly affect the amount of time required for emergency response decisions? Given that the average number of people involved in the decision represented here is 2.87 or 3, Fig. 4 presents an equalitarian model for decision groups of size 3, assuming that emergency decisions are two-step decisions, and that solvers outnumber nonsolvers about 2 to 1. These data show a remarkable fit of the theoretically derived equalitarian model, with the length of the decision to warn. In addition, the data observed for protective action decisions also fits the theoretically derived equalitarian model for a group of three decision makers quite well. All-clear decision may also fit the overall equalitarian model, but clearly would require different assumptions about the composition of the group and the nature of its operations.

In all observed cases, the amount of time required to make an emergency decision is a logistic process. Hence, three separate conceptualizations of the required time to arrive at a decision are considered: *m*, the minutes required to make an emergency decision, ln(*m*), the logistic function of required minutes, and the decision rank, where the fastest decision is ranked 1, and the slowest decision is ranked 232 (i.e., *n*). Decisions occurring in exactly the same number of minutes are randomly sorted one ahead of another until a unique order is established. Because data are not available regarding all the parameters of the Restle and Davis [6] equalitarian model of the group decision process, a series of general linear models is fit that assesses the effect of various characteristics of the decision group on the overall length of decision. Table 2 presents the results of the general linear models for each of these conceptualizations of decision time required.

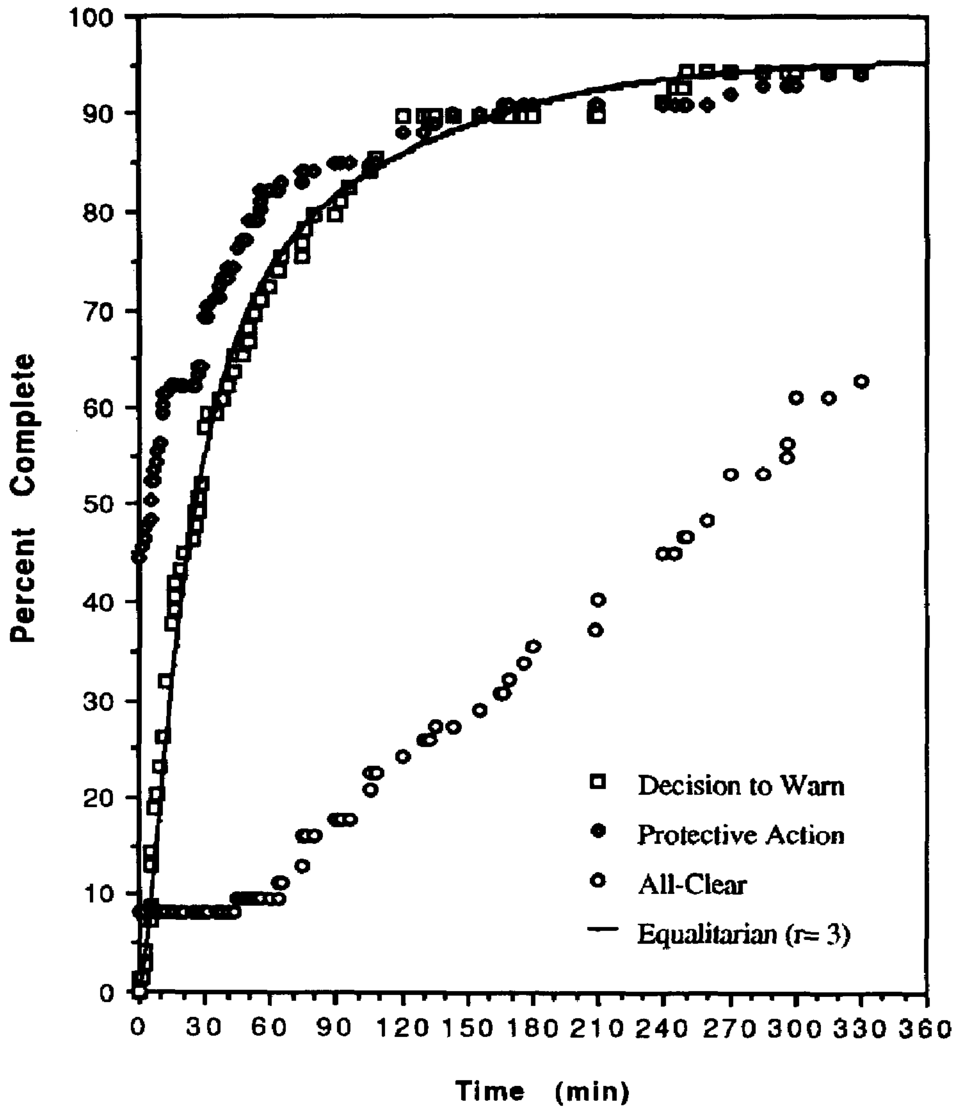

Fig. 4. Comparison of observed emergency decisions and theoretical model of an equalitarian group decision.

Each of these models seems to confirm that decisions to warn the public of impending danger are the most rapid decisions, with decisions about protective actions being the next most rapid decisions, and all-clear decisions being the slowest of the key decisions in emergencies. All models confirm that using experts to assist in the decision process for all-clear decisions, or using standard operating procedures for protective action decisions decreases the time required for these emergency decisions. In addition, all models indicate that decisions starting earlier in the day are likely to be completed faster than those beginning later in the day. This may have to do with operational decisions to maintain the status quo until day-light hours. Only the logistic and rank order models (i.e., which reduce the effect of extreme values) show

Table 2

Three general linear models of length of emergency decision

	Length of decision			log(min)			Decision rank[a]		
	b	β	$p(\alpha)$	b	β	$p(\alpha)$	b	β	$p(\alpha)$
Decision type									
Protective action	−551.0	−0.702	0.000	−5.61	−0.743	0.000	−110.6	−0.818	0.000
Warning	−651.7	−0.766	0.000	−2.79	−0.340	0.001	−83.0	−0.566	0.000
No. of People	−22.1	−0.091	0.091						
Experts				1.07	0.142	0.028	19.6	0.146	0.016
Time (24 h)									
of decision	−32.3	−0.528	0.000	−0.121	0.206	0.009	−2.2	−0.208	0.006
of incident^2	1.1	0.464	0.000	0.004	0.195	0.013	0.1	0.219	0.003
Conflict potential[b]							14.6	0.108	0.044
Conflict resolved									
Consensus				−1.04	−0.138	0.032	−19.0	−0.141	0.022
Leadership				−1.13	−0.116	0.069	−24.0	−0.137	0.006
Experts for all-clear	−342.8	−0.349	0.000	−2.22	−0.234	0.030	−42.5	−0.251	0.013
SOPs protective action	−166.8	−0.172	0.007	−1.30	−0.140	0.036	−28.5	−0.171	0.006
Constant		977.8			7.2			211.6	
n		232			232			232	
R^2		0.408			0.371			0.451	
Adj R^2		0.390			0.346			0.426	

[a] Community reaching the fastest decision is ranked 1 and slowest decision is ranked 232; decisions in the same minute are randomly ranked within a minute; logistic regression shows that the equation, rank $(y) = 76.2 + 38.4 \log(\text{min})$ accounts for 87% of the variance in rank.

[b] Conflict potential equals 1 if there are both multiple people and multiple organizations involved in decisions, else it is zero.

that decisions made by consensus and via leadership reduce decision process times; these same models show that expert-assisted decisions are typically slower decisions, except when it is an all-clear decision. This is probably related to the time it takes to bring in outside experts to assist in the emergency decision process. The number of people involved in the decision, which reached a maximum at nine people, is directly related to faster emergency decisions in only the model of minutes required for a decision.

Because of the relationship of the decisions to various phases of the emergency itself, each decision is likely to be comprised of different types of issues. Hence, the decision process is likely to result in decisions of various durations, and factors decreasing decision process time for one decision may increase decision duration for another, and have no impact at all on still other types of decisions. While Table 2 confirms that each of these major emergency decisions are different in nature and that these differences effect the decision's duration, Table 3 separates each of these types of decisions and examines how these differences are manifested in the factors impacting the duration of emergency decisions.

There are three fundamental factors that significantly impact decisions to warn the public of impending danger: the number of organizations involved, the resolution of conflict via leadership, and the potential for conflict. Both the resolution of conflict via leadership and the involvement of multiple organizations reduce the overall duration of the emergency decision. Because leadership is the ability to reach decisions when all people in a group do not agree, it is not surprising that it is related to faster decisions. The apparent anomaly of multiple organizations decreasing the amount of time it takes to make decisions to warn the public is probably a function of organizational structures that require emergency response personnel to warn the public with the authority of a high municipal authority, which is by definition from another organization. However, conflict potential is defined as situations when multiple people from multiple organizations are involved in emergency decision making. Because these multiple organizations bring to the emergency differing value structures and rules of operation, the potential for conflict is increased.

Resolving conflict via leadership and consensus both serve to reduce the duration of protective action decisions, but involving more people increases the duration of decisions about protective actions. A small, but significant effect of the time of incident on duration of protective action decisions indicates that protective action decisions for incidents occurring in the evening (e.g., after 7 p.m.) are delayed an hour or more, on average, when compared to protective action decisions for emergencies occurring early in the morning (e.g., before 7 a.m.). This probably reflects a tendency to delay the implementation of protective actions (e.g., evacuation) until day-light hours, when accidents occur late in any 24 h period. Only two factors significantly effect the duration of all-clear decisions: resolution of conflict via consensus and the use of experts. These both seem to be a reflection of an error on the side of caution decision strategy. In other words, emergency responders will tend to declare an emergency over only if (1) there is a consensus that no people will be put at risk by such a declaration, or (2) an expert's advice is sought to confirm that an all-clear decision is prudent, or

Table 3

General linear models of ln(*m*) for selected decisions during emergency response in chemical accidents requiring public response

	Decision to warn			Protective action			All-clear		
	b	*β*	*p*(*α*)	*b*	*β*	*p*(*α*)	*b*	*β*	*p*(*α*)
ln(Orgs)	−1.98	−0.658	0.043						
Conflict resolved									
Leadership		−0.95	−0.271	0.023	−1.79	−0.18	0.106		
Consensus				−2.82	−0.345	0.004	−1.51	−0.259	0.036
Expert							−1.66	−0.262	0.034
No. of People				0.72	0.273	0.011			
Conflict potential	2.49	0.837	0.011						
TIN^2				0.005	0.197	0.047			
Constant		3.29			−1.03	0.361		7.09	
N		69			101			62	
R^2		0.203			0.128			0.140	
Adj R^2		0.166			0.092			0.111	

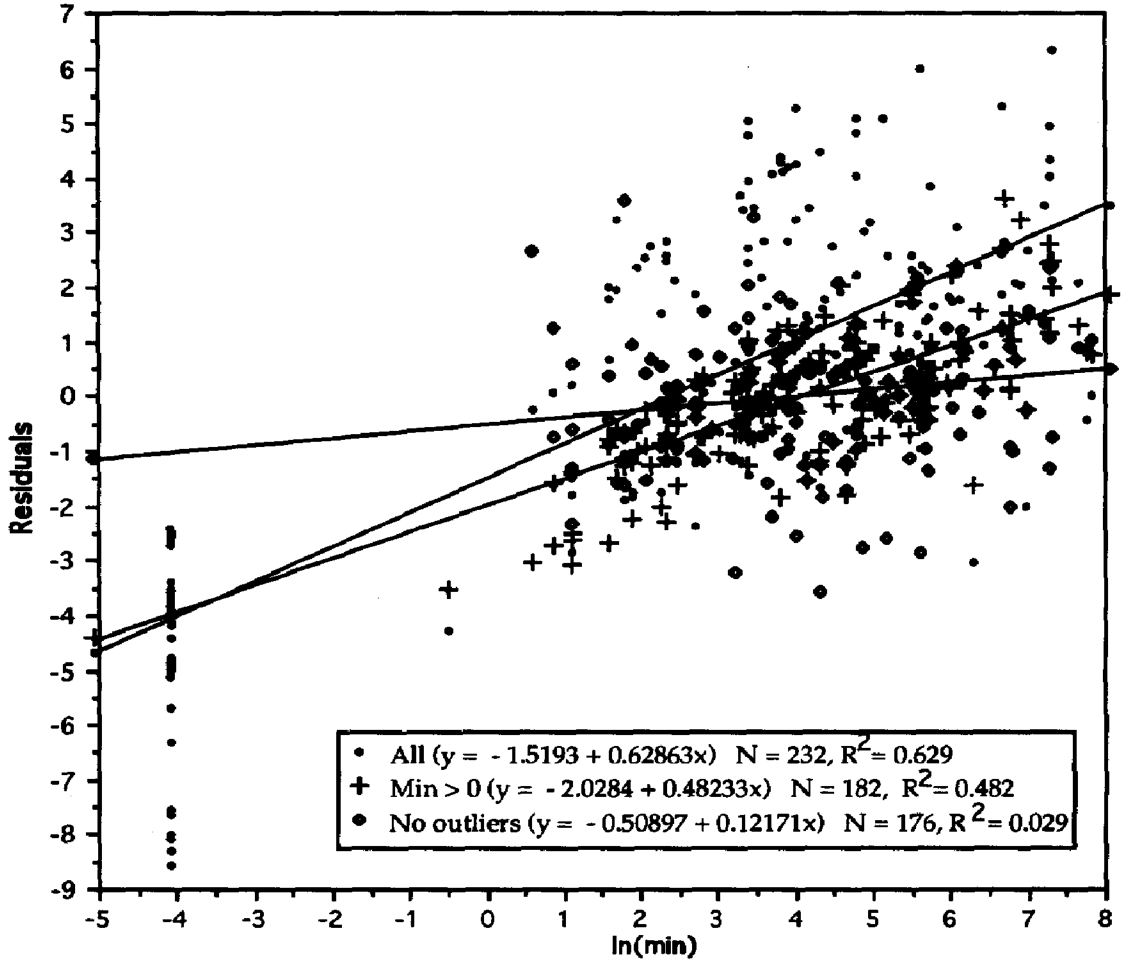

Fig. 5. Comparison of residuals for logistic models of decision time in emergency decisions.

both. Both consensus and expert advice significantly decrease the duration of the decision process.

The residuals associated with the general linear model of the ln(m) required to complete the decision process (Table 2) are presented in Fig. 5. Unfortunately, these residuals are related to the underlying dependent variable. Specifically, ln(m) predicts more than 60% of the variance in the residuals. A coding bias, introduced by the conceptualization of m, as the additional time required to make the particular emergency decision, is strongly evident in the residual plot, with a line of residuals corresponding to the responses that indicated no additional time was associated with the decision, which was subsequently coded as 1 s/60 s = 0.067 min. To examine the impact of this conceptualization on the elements in the model, decisions that did not contribute additional time to the emergency response (i.e., $m = 0$) were eliminated from the analysis. The new model of ln(m) is compared to the original conceptualization in Table 4 and the resulting residuals are plotted in Fig. 5. While the obvious

Table 4

Three logistic models of length of emergency decision

	All[a]			Time added[b]			Low leverage time added[c]		
	b	β	$p(\alpha)$	b	β	$p(\alpha)$	b	β	$p(\alpha)$
Decision type									
Protective action	−5.61	−0.743	0.000	−2.16	−0.571	0.000	−2.01	−0.534	0.000
Warning	−2.79	−0.340	0.001	−2.83	−0.788	0.000	−0.280	−0.785	0.000
Experts	1.07	0.142	0.028	0.625	0.179	0.008	0.561	0.161	0.019
Time (24 h)									
of decision	−0.12	0.206	0.009	−0.068	−0.250	0.001	−0.070	−0.254	0.001
of incident^2	0.004	0.195	0.013	0.002	0.242	0.002	0.002	0.242	0.002
Conflict potential[d]				0.52	0.148	0.007	0.518	0.147	0.008
Conflict resolved									
Consensus	−1.04	−0.138	0.032						
Leadership	−1.13	−0.116	0.069	−0.48	−0.102	0.060	−0.542	−0.116	0.037
Experts for all-clear	−2.22	−2.34	0.030	−1.02	−0.243	0.021	−0.995	−0.234	0.026
SOPs for protective action	−1.30	−0.140	0.036	−1.28	−0.248	0.000	−1.356	−0.263	0.000
Constant		7.2			6.2			6.2	
n		232			182			176	
R^2		0.371[e]			0.518			0.520	
Adj R^2 =		0.346			0.492			0.494	

[a] Each decision is conceptualized as the additional time it takes to make that particular emergency decision; dependent variable is ln(min).

[b] All decisions that are effectively zero additional time are eliminated; dependent variable is ln(min).

[c] Emergency decisions that add no time and cases that have high leverage are eliminated; dependent variable is ln(min).

[d] Conflict potential equals 1 if there are both multiple people and multiple organizations involved in decisions, else it is zero.

[e] R^2 increases to 0.453 with removal of 12 cases with high leverage indicating potential outlier; adjusted R^2 increased to 0.429; elements of the model remained relatively stable, but interactive terms and leadership were not significant at the 0.05 level.

bias of the conceptualization is eliminated, the relationship between the residuals and the amount of time to reach an emergency decision is reduced but still quite strong ($R^2 = 0.482$). Further eliminating six cases reported with high leverage and thereby identified as potential outliers virtually eliminates the relationship.

The models are very similar in that many of the same concepts are underlying the length of the decision to warn. There is a modest improvement in the amount of variance explained from left to right, as would be expected with the reduction in the number of cases. The effect of it being a protective action decision is most impacted by the reconceptualization, which is consistent with the fact that protective action decisions were the most likely decision not to contribute to the overall duration. The potential for conflict plays a significant role in the reconceptualized model, while it did not in the original model. Moreover, resolving conflicts via consensus is not significant in the reconceptualized model, while it was significant in the original model. Both these models confirm that the character of the group impacts the duration of the decision process in emergencies. This analysis shows that as corrective measures are taken to deal with measurement bias, model parameters remain relatively unchanged. Removing measurement bias in the dependent variable reduces the underlying correlation between the residuals and the dependent variable. The limited number of large leverage cases further supports the association of outliers with measurement bias. This suggests that the potential for specification bias in these models is low.

7. Conclusions

These data indicate that the community decision processes in chemical emergencies seldom result in immediate or instantaneous emergency decisions. Because these decisions are not routine decisions, handled daily by emergency personnel, and because chemical emergencies often involve the resolution of uncertainty, decisions in chemical emergencies often involve information seeking. Chemical emergencies often involve blame, culpability and potential litigation; hence, public officials are not entirely comfortable with information provided by industry representatives involved in the emergency. These events are rare enough that standard operating procedures have not been developed for all local authorities (or uniformly applied nationwide). The legal structure gives authority to undertake protective actions (e.g., evacuations) by the public to certain, often elected, officials. Community decisions are not made immediately, and they often take considerable time, involving hours and sometimes extending to several hours.

When decisions lead to the active avoidance of exposure, officials seem to take evasive action more quickly, but when failure to decide results in passive avoidance of exposure and continued inconvenience of the public, the decision process is often protracted. These limited data of emergency decisions indicate that active avoidance decisions (i.e., warning and protective action decisions), even though they may cause inconvenience to the public, are arrived at more quickly than passive avoidance decisions (i.e., all-clear). Hence, decision makers seem to error on the side of caution, protracting decisions where resulting inaction results in exposure avoidance and continued inconvenience, but shortening decision times when inaction results in exposures. Hence, active avoidance decisions are made more quickly than passive avoidance decisions in emergencies.

This article examined the nature of the decision making group as one important component in the duration of emergency decisions. Specifically, this article concurs with the conclusion of Restle and Davis [6] that additional people in the decision group who do not contribute to the decision tend to detract from the group's effectiveness, at least in terms of the amount of time it takes to reach a decision. Even though the organizations involved in emergency situations often have military type command and control structures (e.g., fire and police departments), the findings herein indicate that emergency decisions by community leaders are not command and control decisions, but rather equalitarian decisions where each group member adds to or detracts from the group process. Moreover, this article begins to find what makes groups of various sizes achieve decisions in different amounts of time. Passive avoidance decisions where inaction can do no harm, and action might put people at risk (i.e., all-clear decision) seem to rely more on consensus, and seem to be delayed at the expense of an inconvenienced public. Conversely, active avoidance decisions that potentially jeopardize lives if not made in a timely manner tend to be made, without consensus, sometimes using leadership, and always more rapidly.

This research is an exploratory examination of the role of the leadership/power structure of the decision group. It examines the mechanisms used to resolve conflicts arising from differences among the decision makers regarding the best alternative for protection. A number of important issues remain for future research. For example, these issues include the search for the optimal use of personnel in disasters, when should more people or organizations be added to the decision group? And when should people and organizations be excluded? The analysis herein suggests that people should be selected for inclusion in the decision making group based on their ability to contribute to the decisions, because non-contributors seem to detract from the group's effectiveness; however, these results require further study to be conclusive. Other questions to be answered include how can research get beyond the measurement problems associated with effectiveness, so that the concept includes both quality and timing of the decision? How do decisions by emergency officials effect public response? Do fast decisions lead to rapid (or slow) public response? Or conversely, do slow deliberate decisions lead to rapid (or slow) public response? What are the circumstances that lead to each, and why? These issues have tremendous consequences for public policy concerning emergency decision making by public officials.

References

[1] G.O. Rogers, Community decisions during chemical emergencies, Hazardous Mater. Control (1992) 34–38.

[2] G.O. Rogers, A. Watson, J. Sorensen, R. Sharp and S. Carnes, Evaluating Protective Actions for Chemical Agent Emergencies, ORNL-6615, Oak Ridge National Laboratory, Oak Ridge, TN, 1990.

[3] R. Perry and M. Lindell, The psychological consequences of natural disasters, Mass Emergencies, 3 (1978) 105–117.
[4] R.W. Perry and A.H. Mushkatel, Disaster Management: Warning Response and Community Relocation, Quorum Books, London, 1984.
[5] G.O. Rogers, Communication of emergency warning: Cyclical process involving people and technology, Disaster Manage., 1 (1989) 23–32.
[6] F. Restle and J.H. Davis, Success and speed of problem solving by individuals and groups, Psychol. Rev., 69 (1962) 520–536.
[7] D. Kahneman and A. Tversky, Prospect theory: An analysis of decision under risk, Econometrica, 47 (1979) 263–291.
[8] D. Kahneman and A. Tversky, The psychology of preferences, Sci. Amer., (1982) 160–173.
[9] J.G. March, Bounded rationality, ambiguity, and engineering of choice, The Bell J. Economics, (1979) 587–608.
[10] P. Slovic, B. Fischhoff and S. Lichtenstein, Rating the risks, Environment, 21(3) (1979) 14–39.
[11] H.A. Simon, Models of Bounded Rationality: Economic Analysis and Public Policy, MIT Press, Cambridge, MA, 1983.
[12] L. Putnam, Conflict in group decision-making, in: Herokawa and Poole (Eds.), Communication and Group Decision Making, Sage Publications, Newbury Park, CA, 1986.
[13] R.R. Dynes and E.L. Quarantelli, Organizational Communications and Decision Making in Crises, Report Series No. 17, Disaster Research Center, University of Delaware, Newark, DE, 1977.
[14] J.H. Sorensen and D.S. Mileti, Decision-making uncertainties in emergency warning system organizations, Internat. J. Mass Emergencies, 5(1) (1987) 33–61.
[15] I. Burton, M. Kliman, D. Powell, L. Schmidt, P. Timmerman, P. Victor, A. Whyte and J. Wojick, The Mississauga Evacuation, Final Report to the Ontario Ministry of the Solicitor General, Institute for Environmental Studies, Univ. of Toronto, 1981.
[16] G.O. Rogers and J.H. Sorensen, Diffusion of emergency warning: Comparing empirical and simulation results, in: C. Zerros et al. (Eds.), Risk Analysis Prospects and Opportunities, Plenum Press, New York, 1989.
[17] G.O. Rogers and J.H. Sorensen, Warning and response in two hazardous material transportation accidents in the US, J. Hazardous Mater., 22 (1989) 57–74.
[18] G.O. Rogers, B.L. Shumpert and J.H. Sorensen, Description of Interview Data Regarding the Pittsburgh and Confluence Toxic Chemical Accidents, Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM 11599, 1990.
[19] P. Duclos, L. Sanderson, F.E. Thompson, B. Brackin and S. Binder, Community evacuation following a chlorine release, Mississippi, Disasters, 11(4) (1987) 286–289.
[20] J.H. Sorensen, Evacuations due to off-site releases from chemical accidents: Experience from 1980–1984, J. Hazardous Mater. 14 (1987) 247–257.
[21] G.O. Rogers and J.H. Sorensen, Adoption of emergency planning practices for chemical hazards in the US, J. Hazardous Mater., 27(1) (1990) 3–26.