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THE ASSESSMENT OF COMMUNITY VULNERABILITY TO ACUTE HAZARDOUS MATERIALS INCIDENTS*

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Summary

The manufacture, storage and transportation of voluminous quantities of hazardous chemicals in the United States and Canada pose serious problems for local and regional planners. Part of the problem stems from the lack of recognition of these hazards by community personnel most responsible for their mitigation. The identification of these hazards through risk assessments can thus serve to provide objective confirmation of their existence and can outline the specifications of the problem.

Emergency planners, however, should not merely concern themselves with the physical hazard, "risk", that confronts them. In developing disaster mitigation strategies, both on the local and regional levels, planners should also take into account the existing state of preparedness of the assessed area, "vulnerability". For the local planner, knowledge of his community's response capability will indicate the extent to which local hazards pose a genuine danger and whether additional resources should be acquired and mobilized. This information also enables local policy-makers to decide whether to increase industrial regulation or to upgrade the extant level of preparedness. For regional planners, vulnerability assessments indicate the needs and resources of localities within their jurisdiction permitting the formulation of policies on rational grounds and the equitable allocation of resources. Furthermore, such regional assessments can identify the most sensitive localities where more precise hazard assessments can be performed.

These more specific analyses should isolate particularly vulnerable neighborhoods and should be applied to areas where emergency-related resources can be clearly identified. Regional evaluations, on the other hand, should consist of more basic vulnerability indicators for which data can be easily obtained. For both types of schemes, the final rating obtained should have relevance for emergency planning.

A regional vulnerability scale should consist of two components. First, a hazard assessment component where such factors as the density of chemical production and storage facilities in the community, their proximity to populated areas, the various modes of hazardous material transportation and the different forms of chemical threat are considered. The second component can comprise a checklist of activities to be performed for optimal emergency preparedness and the extent to which such activities are undertaken in a particular community.

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Introduction

The problem posed by hazardous chemicals manufactured, stored and transported in the United States and Canada has been well documented [1,2]. In the United States, acute incidents involving hazardous materials in 1977 resulted in 32 deaths and 543 injuries [3]. In 1978, the two railroad incidents in Waverly, Tennessee and Youngstown, Florida alone produced 24 deaths, 159 injuries, 3.3 million dollars in property damage and resulted in legal claims amounting to 550 million dollars [4]. In Canada, the total number of incidents involving hazardous products has been said to be approximately five thousand annually [5].

In the United States, over 1,000 new chemicals enter the commercial market annually [25] and, at any given time, 70,000 trucks carrying hazardous materials are on the road [6]. In addition, extensive railroad as well as barge, pipeline and air cargo transportation is undertaken in both countries. It has been estimated that four billion tons of hazardous materials are transported annually in the United States [7].

Despite the magnitude of the chemical problem, it has been found that different sectors of even highly vulnerable communities frequently perceive different levels of threat. A preliminary finding of the Disaster Research Center's current study of chemical hazards indicates that public sector emergency-relevant organizations tend to view chemical hazards in their community as posing a greater threat than do industrial safety personnel in these cities [8]. Clearly, consensus on the magnitude of the chemical hazard present in a community is a precondition for appropriate preventive and response-related measures.

Similarly, there does not appear to be a simple linear relationship between the objective risk to which a community is exposed and public awareness of that risk [9]. First of all, the perceptions of the public seem to be influenced by the public relations efforts of the industrial community, the media, other influential persons in a community and so on. Also, it appears that where the objective level of threat is extremely high for a sufficient period of time and the affected population is forced by circumstances to subject itself to that threat, a desensitization process seems to take place. Consequently, an intense level of threat of long duration may reduce anxiety relating to that threat. This phenomenon has been noted in discussions of disaster subcultures [10]. and is corroborated by much of the behaviorist [11] and psychodynamic [12] literature. Clearly, public support for community preparedness rests on the extent of its recognition of the objective risk situation.

Due to the serious nature of the chemical problem in general and the perceptual problems arising among agencies responsible for mobilization for such threats, the objective assessments of risk are invaluable for focusing the problem and removing perceptual impediments. Through such assessments, the sites of hazardous material production and storage and the major transportation routes, constituting the highest risks in a community, can be identified.

The meaning and implications of risk and vulnerability

The term "risk" has several connotations and will be used here to denote the threat of hazards which chemical agents, *per se*, pose for a community, independently of community-wide measures or preparations to reduce the probability of an occurrence or to mitigate the impact of an incident already underway. The term "vulnerability", on the other hand, will be used here to indicate the status of a community as a totality. Vulnerability, therefore, will refer to the threat to which a community is exposed taking into account not only the properties of the chemical agents involved but also, the ecological situation of the community and the general state of emergency preparedness at any given point in time.

In the case of natural disasters, one can easily distinguish between the threatening agents themselves (earthquakes, hurricanes, etc.) and community-based initiatives with respect to hazard mitigation. However, where hazardous materials incidents are concerned, an inextricable relationship exists between the role of the chemical substances involved and the preventive measures employed (or lack thereof). This is due to the fact that such problems are technological by definition, being regarded as preventable due to the human errors necessarily involved at some level. This would imply that the notions of "risk" and "vulnerability" could not be empirically separated since complex interactions occur between the physical agents, technological processes and safety-related efforts during a hazardous materials episode. This distinction has nevertheless been made as it serves to illustrate the different strategies community planners can pursue according to the relative importance of the two sets of factors in a given situation.

The first observation that can be made on the basis of this conceptual distinction is that community planners should generally concern themselves with the question of vulnerability as this refers to a community's overall sensitivity given the existing level of threat and its coping ability. In extreme cases, however, the risk posed by chemical agents are so severe as to virtually neutralize community planning efforts, given the numerous sources of hazards and the potential magnitude of incidents in these communities. In such cases, the

		Preparedness	
		High	Low
Risk (Hazard)	High	Moderately high (wide range)	High
	Low	Low	Moderately low (wide range)

Fig. 1. Community vulnerability.

focus of planners should primarily concern the risk factor (the hazardous products themselves) and the prevention of such a threat, rather than upon community-related coping measures. This may involve, for example, an increased regulation of industry and, possibly, the modification of industrial processes themselves. Conversely, the level of community preparedness may be so high that an extreme risk factor would nevertheless leave overall vulnerability at a low level. Therefore, if zoning laws exist and industrial facilities are separated from populated areas by industrial parks, if the community-wide emergency response capability is optimal and so on, then the presence of high volumes of high-risk substances will, to a great extent, be nullified.

Figure 1 illustrates the four basic combinations of risk and community preparedness subsumed under vulnerability analysis. The implications of the first cell, where both risk and preparedness are high, have been discussed. Generally, given realistic budgets for community preparedness, a moderately high level of vulnerability would result. In this case, a balanced emphasis on the agent and emergency response capability could be pursued by community planners. In the situation where the risk factor is high and preparedness low (Cell 2), vulnerability, clearly, is high. This vulnerability level can be reduced by either lowering the risk factor or improving community preparedness. However, communities of this type are frequently characterized by industrial domination of community political life and resistance to changes in industrial processes or community preparedness (which may be an admission of industrial hazards) may be anticipated [13].

Where the risk factor is low and preparedness high, the resultants vulnerability is low (Cell 3), This situation, which is exemplified by some affluent communities, results from a combination of strict legislation regarding the manufacture of chemicals, an advanced state of local planning, modern autoroutes and high response capability (frequently a by-product of other hazards) [14].

In cities where low levels of risk and preparedness prevail, a moderately low level of vulnerability will generally result (Cell 4). Here again, as in the first case, extreme situations may considerably alter the vulnerability level. An extremely low degree of preparedness (e.g., populated areas located adjacent to chemical plants, a lack of basic resources for the containment of chemical spills, etc.) may pose problems in the case of even minute incidents. Similarly, an extremely low level of risk would produce little danger for even a relatively unprepared community.

Varieties of risk vulnerability models

Figure 1 is merely a conceptual representation of basic points on the vulnerability continuum. In reality, of course, vulnerability is a continuous variable and a community may be located on any of an infinite number of points on the continuum.

Attempts at more precise determinations of community hazards have been performed in diverse ways. Most of these analyses could, according to our criteria, more accurately be termed risk rather than vulnerability assessments. They predominantly focus on the characteristics of the chemicals involved, prevailing meteorological conditions and, as far as community-related variables are concerned, tend to take into account only population related data — the population density of a community and the proximity of high risk sites to population centers.

Analyses have been performed to assess the status of site and communities both prior to [15,16] and following [17] disasters. Whereas the functions of the former are obvious, post-disaster analyses have focused on the manner in which organizational recovery operations affect the eventual outcome of an incident and, hence, the general vulnerability of a community. The most prevalent form of risk assessment, however, has been that undertaken in an ongoing emergency situation to predict the outcome of an incident. The U.S. Coast Guard marine spill system is an example of this type [18]. In addition, risk models are varied in complexity, data input and in their purposes ranging from a specific analysis of a single mode (i.e., transportation, manufacture, storage) to, as mentioned, the assessment of an entire community.

The data used to formulate a risk model may be obtained from a data base compiled from previous incidents [19] or through the computer simulation of events as they are expected to occur given a theoretical framework and the specifications of the incident simulated [20]. The phenomena to which risk or vulnerability assessments have been applied, range from a specific site, as in the analysis used for determining building safety levels in earthquake-prone areas [15], to routes used for the transportation of hazardous commodities as in the Simmons et al. [21] analysis of the relative risks incurred by various communities alongside a railroad, and, finally, to the pre-disaster assessment of an entire community as in the Zajic and Himmelman [16] comprehensive community vulnerability model. Also, as Benner [22] has noted, risk analyses have been used for land-use guidance as evidence in litigation and for environmental impact assessments.

The innumerable forms and functions of risk or vulnerability analyses are, therefore, evident. The primary concern of this paper is the implications for disaster planning posed by the manufacture, storage and transportation of hazardous materials. The subsequent discussion, consequently, involves only those techniques developed to assess the vulnerability of populated areas which are sites for hazardous chemical production, storage and/or transportation. Policy planners, whether on the state (provincial) or local levels, must not only be informed of existing risks to communities but also the response-related capability (including resources) already present in those communities if equitable levels of vulnerability are to exist in a region.

One of the true vulnerability assessment techniques is Zajic and Himmelman's community rating system [16] which attempts a reconciliation of threat-related factors with a community's ability to cope with such threats. Their index arrives at a maximum disaster rating for a community taking into account the extent of manufacture, storage and highway, rail, marine and pipeline transportation of hazardous chemicals; the hazard classification of the chemicals involved in each case; the population densities surrounding each chemical complex or transportation route and the hazard level of each route. In addition, the authors provide a series of standard criteria to ascertain the degree of community emergency preparedness.

The objective here is not to provide a substantive critique of this rating system but, rather, to raise several points regarding its application. Toward this end, the authors have stated the following: "There is a need for various municipalities to be able to assess the hazards that exist in any community with regard to exposure to hazardous materials" [16; p. 143]. It is difficult to discern from this statement whether the authors recommend the application of their rating scheme to entire municipalities or to specific localities within larger metropolitan areas. Notwithstanding this ambiguity and despite the aforementioned merits of their system, the system may be too specific for a large scale regional assessment and not sufficiently comprehensive for the assessment of a more focalized geographic area. If a large metropolis is to be assessed, the scheme is too cumbersome with respect to the resources generally available to city officials, as it relies heavily on visual counting and other observational procedures. The application of the system on such a scale would be prohibitively expensive, given budgetary constraints. On the other hand, if the scheme is to be applied to communities of more manageable size for which highly specific determinations of vulnerability are desired, then this model appears to be at too high a level of generality. As an example, in their determination of a hazard rating for autoroutes, the only factor taken into consideration is the presence or absence of a median. Admittedly, this has been recognized as a crucial factor; however, numerous other factors should be considered to capture the construct adequately [23].

An additional function of vulnerability models

Vulnerability assessments are needed for at least two levels of use. First, assessments of large geographic entities (metropolises, counties, etc.) should be performed within larger political jurisdictions which have input into local disaster planning (e.g., states or provinces). The distribution of ratings within a state or province can serve as a guideline for the development of policies regarding acceptable levels of vulnerability taking into account the resources of that state or province. Such assessments would determine the relative sensitivity of different regions providing a rational basis for the allocation of resources to the localities. Such analyses would also identify particularly vulnerable areas where more focused, localized assessments would be warranted. Areas needing these more specific vulnerability analyses chould then obtain the funding to perform the costly data collection procedures involved. The haphazard application of comprehensive assessment techniques in large areas ensures both increased expenditures for state or provincial residents and the assessment of only those communities that can afford them.

Whereas the objective of more general assessments is to provide state or provincial authorities a rough idea of regional differences, the goal of more thorough analyses should be to identify highly sensitive neighborhoods with implications for legislation, emergency response and so on. It is of limited utility for city planners to indicate that city X is highly vulnerable to chemical emergencies. In most cases, the production and transportation of hazardous materials are not evenly distributed throughout a city. High risk areas must be identified as substantial variations may exist among city districts. Zones for analysis should be selected on the basis of their accessability to emergency-related resources, the locus of formulation of disaster plans, political jurisdictions and on the basis of the manner in which environmental manipulations (the rerouting of hazardous material traffic, the deployment of emergency response personnel, etc.) can be undertaken. In short, communities selected for assessment should be relevant to ecological realities and the manner in which resources are distributed in a region. It is of little use, therefore, to select for assessment a neighborhood where, geographically, few environmental modifications can be made and which is serviced by emergency-relevant agencies based outside of its boundaries. In such cases, the area to be assessed should be extended to one which is a relatively self-contained unit but which, nevertheless, is sufficiently confined to render comprehensive analyses relevant.

Assessments of the more general type should comprise basic factors which would provide sufficient differentiation between cities with the ratings obtained being of relevance to planners. Zajic and Himmelman have arrived at five-digit figures such as the 11, 134 point rating for one Ontario city. The practioner cannot readily ascertain whether a significant difference exists between that figure and, say, ratings of 10,500 or 9,000 or 14,000. No guidelines for the interpretation of the ratings were provided. In this case, can one assume that the differences between ratings are proportional? In other words if one city obtains a rating of 10,000 and another of 9,000 then is the first city ten percent more vulnerable than the second? This cannot be claimed, due to the nature of the computations involved in their system and due to the fact that their index is not a ratio scale — no absolute zero value exists.

For the more general assessments, simple scales can be constructed from which different ratings would have clear, policy-related relevance. The factors should be so basic as to provide identical ratings for cities of similar status. The objective, therefore, would be to classify cities or countries within a larger jurisdiction attempting to minimize the number of categories and to maximize the difference between them. Such simple rating schemes could be easily applied and, hence, met by less resistance from local officials. The application of such schemes would serve to acquaint these officials with local hazards and their comparative standing in relation to other communities and could influence their general policies with reference to industrial regulation, zoning laws and so on.

A preliminary proposal for large-scale assessments

Some of the recurring factors used in community ratings include the number of chemical plants and storage facilities in a given area, the proximity of these to population centers, the modes of hazardous material transportation used in a city and the types of chemical threat to which the community is exposed. On the basis of these factors, a 0—10 point scale can be constructed with different weights being given factors of varying importance. Such a scale, if it is to remain relatively simple, can be based on nominal or ordinal level measurement depending upon the number of groups or categories of cities desired. An additive model can be used for simplicity.

The first factor could involve the density of manufacturing and storage facilities in a community. As the term density suggests, this would not comprise a mere absolute counting of facilities within a specified area as has been done in the past. Consideration would be given to the total land area of the region assessed. As the computation of the total acreage of land used by production and storage facilities would be irksome defeating the purpose of the scheme, one can select the total number of employees engaged in production and other blue collar work in such facilities as a reasonable indication of their size. Such data is collected routinely by Chambers of Commerce and various federal agencies. The resulting figure could then be divided by the size (in square miles) of the area assessed. At this point, the figure obtained could either be placed in a high or low density category providing a rating of one point to a community in the first category and a zero rating for a community in the second. Or, if ordinal measurement was desired, five levels of density, for example, could be established *a priori* providing a city in the lowest density category with a zero rating, one in the next with a 0.25 rating, one in the next with a 0.50 rating, one in the next with a 0.75 rating and a city in the highest category would obtain a 1.0 rating.

The density factor would probe both the likelihood of an incident originating from a community and the probability that such an incident would impact the population therein. Impact, as it is used here, refers to the economic as well as the physical harm inflicted upon the community. The density figure also incorporates (because of its consideration of plant size) the volumes dealt with a chemical facilities and, hence, the potential magnitude of an incident.

The second factor that could be employed in the rating scheme is the general proximity of production and storage facilities to residential and commercial areas. This factor is also concerned with the likelihood of an incident's direct physical impact upon a community. Although this factor appears to be closely related to the first, the density factor frequently does not probe proximity. Where industrial plants are clustered in one section of a city, the overall density figure for the city may be high (if such plants are numerous and/or large) although few, if any, may threaten the general community. On the other hand, another community may possess the same density of facilities; however, these may be diffuse threatening various localities.

Proximity can be calculated by using as a standard a distance which would be considered as safe from flying debris and tremors caused by plant explosions involving volatile substances. One can select the figure of 2,000 feet claimed by the National Fire Prevention Association in the United States to be safe (free of fatalities) in 99% of explosions [24]. As toxic fumes may disperse considerably in excess of this 2,000-foot radius, the nature of the chemical substance(s) dealt with, in addition to prevailing wind currents and other factors, may warrant the modification of this criterion. Through simple mapping, one can compute the percentage of facilities located within the prescribed distance from residential or commercial areas. One could again arrive at a high or low proximity determination or ordinally categorize the proximity of a city as extremely low to extremely high. The maximum rating for this factor would also be one point.

Next, the transportation factor would have three constituents. Since hazardous chemicals are primarily shipped by road, rail or barge, the determination of whether a community is traversed by such routes is crucial. If a simple nominal scheme was used, an affirmative answer in each case would yield a one point rating for each type (of the three mentioned) of major route that crosses or bypasses a city. Or, through more detailed observation, one could determine the mileage of such routes in a city and then rate the city depending upon the extent of each mode of transportation from a minimum of zero to a maximum of one point.

The transportation threat is given greater weight on the ten-point scale (three points) than are the threats produced by manufacturing and storage for two reasons. First, transportation incidents are the most frequent. Second, since vulnerability is of interest here, transportation incidents through their complexity complicate the tasks of emergency preparedness and response. Such incidents may occur at a multiplicity of locations in a city; the identification of spilled chemicals is more difficult; resources for the neutralization of the chemicals are not as readily available; and the incidents are frequently interjurisdictional, introducing problems involving the coordination of response.

While the first three factors dealt with the different sources of hazard in a community (production, storage and transportation), a fourth factor can deal with the types of threat to which a community is exposed. This essentially refers to the types of chemicals produced, stored and transported. Forms of hazard include fire or conflagration, explosions (vibrations and flying fragments), toxic releases (air or water) and damage through sudden corrosion. Each of these five threats, if present on a major scale, could be provided a one point rating. Therefore, this fourth factor (dealing with the quality of the hazard) would have a total weight of five points which is equivalent to the weight of the first three factors (which dealt with the likelihood and potential magnitude of hazards of differing sources). A ten-point "risk" scale would then be complete.

If a vulnerability index is desired, bearing in mind that vulnerability here is regarded as a combination (product).of risk and community preparedness, a ten-point scale to determine preparedness must be devised. Such a scale could rate a community on the basis of the presence of an overall disaster plan, emergency procedures for major manufacturers, a local mutual aid system for resource sharing, physical resources and expertise to counteract the variety of threats existing in the community, community-wide disaster drills and so on. The community's rating on the ten-point risk scale can then be divided by its preparedness index to arrive at a final rating on a ten-point vulnerability scale. The entire procedure is summarized in Fig. 2.

Factor		Maximum weight (Points)
Density		1
Proximity		1
Transportation	(a) Road	1
	(b) Rail	1
	(c) Barge	1
Forms of Threat	(a) Major fire	1
	(b) Explosion	1
	(c) Toxic release (Air)	1
	(d) Toxic release (Water)	1
	(e) Acute corrosion	1
	Total	10

Risk index = $r/10$
Preparedness index = $p/10$
Vulnerability index = $(r/10)/(p/10)$
= r/p

Fig. 2. Regional vulnerability scale.

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