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TOPIC 3
SAFTETY ANALYSIS
AND POLICY (SIG)

DEVELOPMENT OF AN INTEGRATED HAZARDOUS MATERIALS EMERGENCY MANAGEMENT PLANNING SYSTEM

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Abstract

This paper describes the development of an integrated environment for supporting emergency response planning for hazardous materials incidents. The approach represents a combination of new methods development and use of existing data and models. The entire methodology has been embedded in a geographic information system (GIS) software tool to support its operational use.

INTRODUCTION

Increased concern for public safety and environmental awareness has motivated the need for improved practices to adequately plan for and manage emergencies. Among different types of emergencies, hazardous materials incidents have taken a prominent position. The manufacture and transport of hazardous materials have been subjected to increased public scrutiny because of the perceived consequences to health and safety that a major incident could cause. Whether natural or society-induced, emergencies typically involve several phases, from identification to clean-up, and normally require interaction among many public and private agencies. Adequate planning provides the basis for coordinating these activities and structuring appropriate interactions.

The importance of planning is reflected by several regulatory references to the development of response plans and procedures [3, 4, 5, 7, 10, 11, 12]. While each regulation addresses the issue of planning from a different perspective, all are designed to provide guidance on how best to reduce or mitigate incident-related impacts.

Within this legislation are requirements to acquire and use information as part of the planning process. A methodology and tool that can effectively manage and display this information would enable the development of comprehensive plans based on specific requirements and resources of a jurisdiction, whether local, regional or national. Because funds are limited, this system could also provide decision-support for cost-effective allocation of fiscal, personnel and equipment resources.

The goal of this research was to develop a methodological approach and a first-generation decision-support tool to provide these planning capabilities. Within this framework, questions to be addressed included: (1) which areas or facilities require more detailed risk assessment, (2) what routes to restrict from transporting hazardous materials based on inadequate response coverage, (3) where to locate new emergency response units (ERUs) or upgrade existing ERUs, and (4) what allocation of available resources most improves the overall safety of the jurisdiction.

ANALYSIS MODULES

The following problem-solving skills are needed to accommodate emergency management planning: (1) hazards identification, (2) vulnerability analysis, (3) emergency response capability assessment and (4) risk analysis. These are discussed, in turn, below.

Hazards identification

This initial step involves the identification of potential hazards within a jurisdiction. A hazard is considered any situation which presents the potential for causing human health, property or environmental damage. Hazards identification specifies:

(1) types and quantities of hazardous materials located in or transported through a jurisdiction;

(2) locations of hazardous materials facilities and transport routes; and

(3) the nature of the hazard (eg fire, explosion) most likely associated with a release.

Table 1 provides a list of possible locations that may contain hazardous materials. Inclusive within this process is consideration of production, storage, processing, transportation and disposal of every material at each location.

Table 1 Possible hazard locations

Industrial facilities
Storage facilities/warehouses
Chemical plants
Railroad yards
Vessels in port
Waterfront facilities
Hospitals, educational and governmental facilities
Major transportation corridors and transfer points
Refineries
Petroleum & natural gas tank farms
Trucking terminals
Waste disposal & treatment facilities
Airports
Nuclear facilities

Vulnerability analysis

Vulnerability analysis identifies the locations and features within a jurisdiction that are susceptible to damage should a hazardous materials release occur. The information extracted from this analysis includes:

(1) the extent of the vulnerable zone (significantly affected area) for a release, and the conditions that influence the zone of impact (eg release size or wind direction);

(2) the population within the vulnerable zone, in terms of size and type, including sensitive populations such as hospitals and schools;

(3) public and private property that may be damaged, including buildings and transportation corridors; and

(4) environmental features that may be affected, including sensitive natural areas, water supplies and endangered species.

Traditionally, this type of analysis has been performed on a map where the hazard location is identified and concentric circles are drawn representing different zones of impact. The populations, properties and environmental features are then identified within these circles and counted. In some analyses, shape modifications are made to represent geographic limitations such as cliffs or trenches that could block a gas cloud or contain a liquid spill, respectively.

Because of the limited time and personnel available to perform this type of analysis, only the most obvious hazard locations have typically been studied; this has generally excluded transportation corridors. In addition, the vulnerability of locations that have multiple hazard sites within a small area are often overlooked. Finally, what-if scenarios have proven to be cost-prohibitive in evaluating various management control strategies.

Capability assessment

Capability assessment is used to evaluate the quality of preparedness and response within a jurisdiction. The answers to a series of questions similar to those shown in Table 2 are often used to perform this evaluation.

Table 2 Capability assessment questions [16]

- Who are the agencies involved, the area of responsibility, the name of the contact, position, telephone number, and chain of command?
- Is there any specific chemical or toxicological expertise available in the community?
- Have the local emergency services had any hazardous materials training, and if so, do they have and use any specialized equipment?
- What is the average time for them to arrive on the scene?
- Does the community have specific evacuation routes designated? What are these evacuation routes?
- Are there specific access routes designated for emergency response and service personnel to reach facilities or incident sites?

Risk analysis

Risk analysis predicts the likelihood of a hazardous materials release at a particular location and the potential consequence that could be expected. The level of rigor varies from a general qualitative evaluation of various situations to detailed quantitative approaches [1, 6, 8, 11, 16, 17].

For planning purposes, most analysts prefer to use a risk screening approach. This typically involves use of a simplified expression of risk. Screening results enable the setting of risk—based priorities and identification of information needs for follow-up risk assessment activities. The following process is applied to each vulnerability area:

1. Carefully evaluate the likelihood that an accidental release will occur and not be contained or mitigated.
2. Assign a high, medium, or low ranking for the probability in Step 1.
3. Using the vulnerability zones, evaluate population at risk. This should include an estimated number of individuals, as well as types of populations such as elderly, children, infirmed, incarcerated, and transient.
4. Evaluate critical facilities at risk within the zones. This should include hospitals, other health care and communications facilities, environmental areas and property.
5. Based on Steps 2, 3 and 4, establish a relative ranking system for the expected consequences associated with potential hazards posed by facilities.

A major limitation with this approach has been the inability to consider emergency response coverage as part of the risk screening process. Some documents that include emergency response in the review process, incorporate it as a "risk reduction strategy", not as part of the actual screening task [2, 15]. This creates the possibility that resources would be wasted in performing a detailed risk analysis on a facility identified as high-risk that actually has adequate emergency response to mitigate a potential incident. Elsewhere, mention is made that emergency response facilities should be evaluated, but no procedure is provided for performing this assessment [6, 17].

Unfortunately, planners have been provided with little guidance on how to perform this task. For example, no distinction is made between first response and qualified response. In practice, first responders are often local fire departments or law enforcement agencies with little, if any, hazardous materials response qualifications. They generally have the authority to cordon off the affected area and possibly begin evacuation procedures. However, these units are not supposed to be exposed to the material and, thus, cannot contain the incident.

Qualified response comes from a properly trained and equipped emergency response unit (ERU), which performs the containment and mitigation efforts. The level of expertise and equipment which entitles a response unit to be designated as "qualified" is generally unclear. For example, an ERU that is capable of responding to an oil spill may not have the training or equipment to respond to a chlorine release.

Without a systematic procedure to assess the capability of emergency response units and to be able to evaluate differing levels of capability, emergency response cannot be used directly in risk screening or resource prioritization. As a result, response may be inadequate and resources unwisely invested.

THE DECISION-SUPPORT ENVIRONMENT

To provide planners with a cost-effective, decision-support environment, the need for an integrated approach combining current technology and existing planning methods was identified. This subsequently led to a decision to utilize a platform containing geographic information systems (GIS) with network analysis capabilities [14].

Such a system provides the ability to view and analyze, in a spatial environment, the information elements required to conduct emergency management planning studies as well as produce visual outputs. This presents the planner with an integrated tool to assist with problem identification and development of risk reduction strategies.

One advantage of using a GIS environment is that hazards can be sorted according to any information that exists in the database. For example, the planner could query the system to show all locations that present an explosion hazard for a radius of more than 1/4 mile. Similarly, the system could be queried to highlight all transportation routes that have been designated for radioactive material shipments.

System requirements for vulnerability analysis are broader. The planner must be able to view locations and their proximity to population centers, special facilities, other facilities with hazardous materials or sensitive environmental areas. The system should possess the capability to evaluate the effects of airborne releases by overlaying the results (footprint) of a dispersion model. Along the transportation network, specified bandwidths or other impact areas on either side of the route need to be characterized.

In addition to the integration effort, a major development activity in this work was the design of a methodology for evaluating emergency response capability [9]. An inventory survey of ERU's was developed, from which five levels of emergency response capability were defined (see Figure 1). Categories ranged from awareness that hazardous materials exist (Level 5) to response requirements for a poisonous gas release (Level 1). Ratings of teams to capability levels were based on the number of trained personnel, type of equipment, and standard team practices.

Risk estimates and emergency response capability ratings were then combined to support risk screening within a jurisdiction. An impact graph was developed to simplify the risk screening process while maintaining a degree of flexibility for the planner. Implementation of this process enables development of a prioritized list of facilities warranting more detailed risk assessment.

A first-generation software tool representing this entire process was developed as an application to support emergency planning [13]. The system was designed to be responsive to the needs of a broad range of possible users. The program has three main functions: (1) database management, (2) information systems operations, and (3) decision-support. Database management requires the maintenance of four databases: (1) the transportation network, (2) hazardous materials facilities, (3) emergency response units, and (4) hazardous materials. Information systems operations provide the user with knowledge about the elements in the database. Decision-support encompasses the planning analyses as previously described. The program results are organized by projects, analyses, maps and reports. These are interrelated to provide the user with the necessary information to perform planning functions. Windows—style menus and dialog boxes provide the interface to the software tool.

July 6, 1992

County:	HAZARDOUS MATERIALS	EM USE ONLY
City:	EMERGENCY RESPONSE	Team Level:
Region:	SURVEY	Date:
Date:		Rated By:

Instructions: (1) Please type or print clearly. (2) Complete a separate form for each station/substation with HazMat response capability. (Make additional copies as needed.) (3) Return completed surveys to:

1. General Information

Department/Agency: 1________________ Team Leader: 2________________

Mailing Address: 3________________ Business Phone: 4(__)________________

City: 5________________ State: 6______ Zip: 7______ Emergency Phone: 8(__)________________
(Other than 911)

FAX Number: 9(__)________________

Station Location (Street Address): 10________________

Location (if known) Latitude: 11________________ Longitude: 12________________

No. Paid: 13________ No. Volunteer: 14________ No. Assigned to Team: 15________ Avg. Response Time: 16________

2. Jurisdictional Profile *(please include a map indicating boundaries and response stations)*

Total Population Served: 17________________ Area (square miles): 18________________

Major Highways: 19________________ Major Railroads: 20________________

Navigable Rivers: 21________________ Airports: 22________________

Multi-jurisdictional Response? 23____Yes____No Industrial Mutual Aid Agreement? 24____Yes____No

List Jurisdictional(s) served by written mutual aid agreements:

25____

____

Comments:

26____

____

____

3. Capabilities Assessment

Planning: Has the jurisdiction completed SARA Title III Emergency Management Plan? 27____Yes____No

Has the plan been successfully exercised and evaluated? 28____Yes____No

Date of last excercise: 29________________

Medical Surveillance: Are team members participating in a medical surveillance program in accordance with OSHA 1910.120?
30____Yes____No

Figure 1 Hazardous material emergency response survey (page 1)

4. Training: *(List the total number of personnel currently trained to the levels listed below. Do not include anyone who has not received initial and/or refresher training in the past two years)*

	Awareness	Operations	ICS	Technician	Specialist	Advanced
Senior Officer: Check if Team Leader	31	32	33	34	35	36
Team Leader(s)	37	38	39	40	41	42
Team Members	43	44	45	46	47	48
Support Personnel	49	50	51	52	53	54
Totals	55	56	57	58	59	60

5. Equipment: *(List number of pieces in the appropriate blanks)*

PPE		Detectors		Respirators		Containment	
Turnouts (SFPC)	61	Combustable Gas	71	30 min SCBA	81	Booms/Pads	91
Level C	62	Oxygen Level	72	60 min SCBA	82	Plugs/Patches	92
Level B	63	Detector Tubes	73	Air Line	83	Plastic	93
Level A	64	Photoionization	74	1/2 Mask Cartridge	84	Shovels	94
Fire Res Coveralls	65	Flame Ionization	75	Full Mask Cartridge	85	Absorbants	95
Proximity Suit	66	Organic Vapor	76		86	Recovery Drums	96
Disposable Suits	67	CDV-777-1 Kit	77		87	Solidifiers	97
Cooling Vests	68	Rad Hwy Haz Kit	78		88	Neutralizers	98
	69	Strips	79		89		99
	70	pH Paper	80		90		100

Non-Sparking Tools? 101____Yes____No
Decontamination? 102____Yes____No
No. Reference Books? 103_______
DOT P 5800.5 1990 ERG 104____Yes____No
List Additional 105______________________________
106______________________________
107______________________________

SCBA Refill: Cascade: 111______Fixed 112______Portable
Compressor: 113______Fixed 114______Portable
Foam (enter no. of gal): Alcohol: 115______Protein: 116______
Light water: 117_____ Other: 118______
108______________________________
109______________________________
110______________________________

6. Communications/Information Management

Cellular Phone 119____Phone Number(s) 120______________________________
Radio: 121____Bands(s)/Frequency(s) 122______________________________
FAX: 123____Fixed: Phone Number 124______________ 125____Portable: Phone Number 126______________
Computer: 127____Fixed 128______IBM compatible 129______Apple/Mac
130____Portable 131______IBM compatible 132______Apple/Mac
Programs: 133____Cameo 134____Archie 135____Plume Modeling 136____EIS 137______________________Others

7. Survey Completed by:

Print Name ______________ Title/Rank ______________ Signature ______________
Date:______________ Phone Number:(____)______________

Figure 1 Hazardous material emergency response survey (page 2)

CASE STUDY APPLICATION

To illustrate the use of the process as well as the software tool, a case study was performed for a local planning application requiring review of hazards and existing emergency response capabilities in and around Hamilton County in the State of Tennessee. Risk screening techniques were then applied to determine which facilities and transportation routes to address in greater detail. Hamilton County and vicinity was selected because both rural and urban characteristics are represented.

Hazard identification

The first step was to review the locations of hazardous materials facilities and emergency response units within the region as shown in Figure 2. Using the software tool, each of the facilities was highlighted according to the type of response necessary for the material posing the greatest hazard. As an example, Figure 3 shows facilities that require Level 1 response.

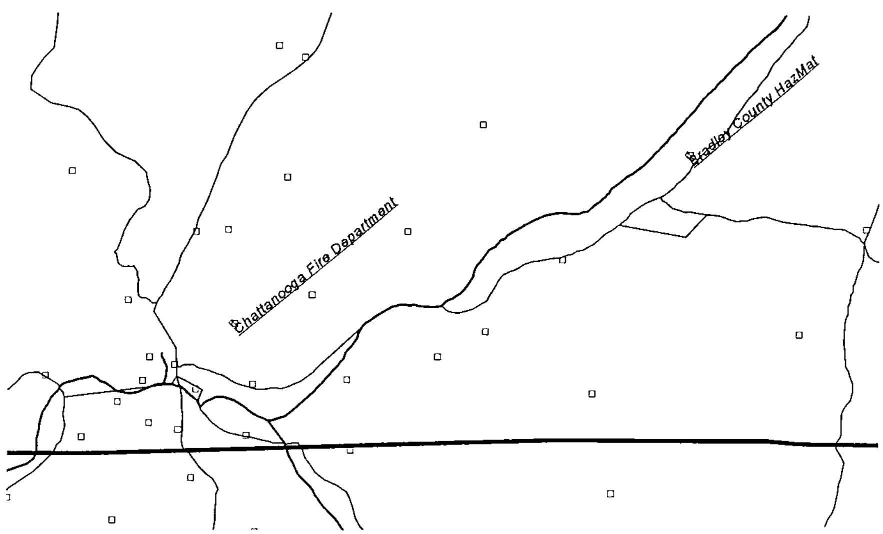

Figure 2 Location of current hazardous materials facilities and emergency response units

Emergency response assessment

Among the stations located within the region of interest, Chattanooga Fire Department was rated at Level 4, while the remaining stations were classified as not even having Level 5 capability.

Based on findings from hazard identification, it was concluded that at least one Level 1 team should be located within the jurisdiction. Because Chattanooga has a Level 4 rating and is centrally located to the populated part of the region, efforts should be made to upgrade this team. The primary investments would be in training and personal protection equipment. A list of necessary improvements is generated by the software tool.

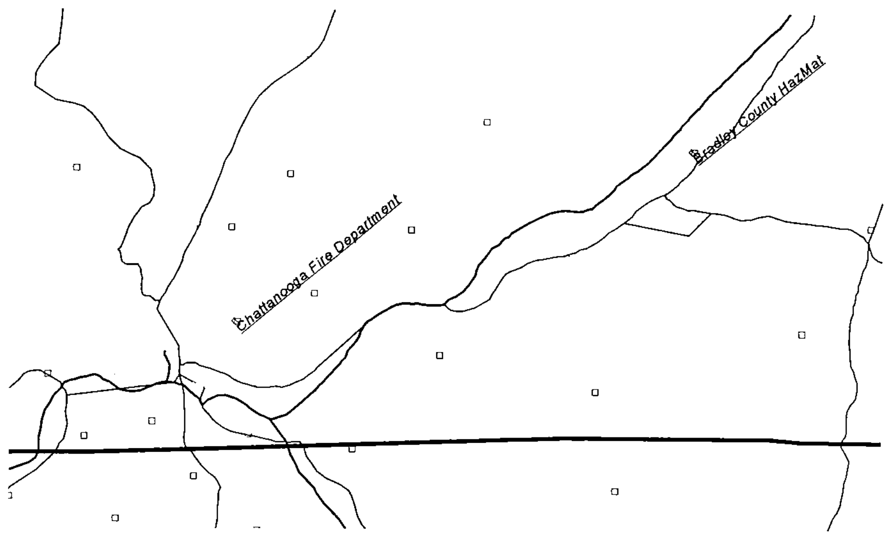

Figure 3 Hazardous materials that require Level 1 response

Overall coverage for the Chattanooga team is shown in Figure 4. As can be observed, the Chattanooga team can respond within 60 minutes to virtually every facility and to most of the highway network.

Risk screening

Using the software tool, all facilities in the region were ranked by a risk score generated by the following formula:

$$\text{Risk} = \text{Accident Likelihood} \times \text{Release Probability} \times \text{Consequence} \quad (1)$$

Ranking was also performed using response time. Table 3 provides a summary of the generated results which were subsequently used as input to the screening technique.

A risk screening evaluation graph developed as part of the planning methodology is shown in Figure 5 using normalized risk and response times for each facility. Facility risk is prioritized by measuring the perpendicular distance from the baseline to each facility using the following expression:

$$\text{Distance From Baseline} = Y + T\,(X-1) \quad (2)$$

where:

X = normalized risk values
Y = normalized response times
T = normalized acceptable response time

When facilities are plotted on the graph as described above, the planner obtains a rank ordering of the hazards within the jurisdiction based on risk and emergency response. Any facilities falling above both the acceptable response time line and the baseline should be placed in rank order by the results of Equation 2 if response time and risk are weighted equally.

Figure 4 Adequate emergency response coverage for Chattanooga Fire Department

However, because of the flexibility of using a graphical approach, the planner can place greater emphasis on either risk or response time. If greater emphasis is placed on risk, the facilities would be ordered from right to left on the graph. Similarly, if the planner places more emphasis on response time, facilities would be ranked from top to bottom.

Facilities falling below the acceptable response time line but above the baseline should always be placed after facilities above the acceptable response time. At the bottom of the priority list will be facilities that fall below both the baseline and acceptable emergency response time.

To demonstrate the significance of this evaluation method, acceptable response time was set at 15 minutes. Table 4 presents the resulting facility order for performing further risk evaluations. A close examination of this order indicates the reason why use of the graph is so important. Facilities numbered 18, 15, 9, and 2 actually have higher risk values than 6, 13, 3 and 5, but they fall below the acceptable response time line. All facilities with negative screening values fall below the baseline. The negative value indicates that the perpendicular distance is down from the baseline and that those facilities are within the acceptable limits. If risk were to be given a higher weight than response time, the order of the top nine facilities would be 8, 3, 6, 5, 13, 15, 18, 9, and 2. Similarly, if response time is weighted higher than risk, the order would be 8, 6, 13, 3, 5, 18, 2, 9, and 15. From these results, it is apparent that the definition of acceptable response time and weighting of risk and response time criteria, respectively, are policy decisions which significantly affect the planning process.

Table 3 Hamilton County risk screening input

Case Study 1 — Acceptable Response Time 15 min

No.	Name	Chem Class	ER Lev	NFPA	Exp Area	Exp Pop	Risk	Norm. Risk	Resp Time	Norm Time
1	Alco Chemical Corp	Poison	2	4	4 mi	37414	37.414	0.3060	5.88 *	0.228
2	Airco	Poison Gas	1	3	5 mi	59320	59.32	0.4851	10.22 *	0.397
3	Coors Electronic Package	Poison Gas	1	3	1 mi	3988	3.988	0.0326	15.92 *	0.618
4	Basf Corp	Poison Gas	1	3	1 mi	2929	2.929	0.0240	5.88 *	0.228
5	Basf Corp	Poison Gas	1	3	1 mi	3304	3.304	0.0270	15.77 *	0.612
6	Chattem Chemicals	Poison Gas	1	3	1 mi	3124	3.124	0.0255	16.51 *	0.641
7	U.S. Pipe & Foundry Co.	Poison	2	3	0.2 mi	77	0.077	0.0006	13.45 *	0.522
8	Southern Cellulose Produ	Chlorine	2	3	5 mi	86195	86.195	0.7049	16.51 *	0.641
9	Du Pont Chatt Site	Chlorine	2	3	5 mi	60690	60.69	0.4963	10.22 *	0.397
10	Abb Combustion Engineeri	Poison	2	3	0.2 mi	73	0.073	0.0006	12.91 *	0.501
11	Wheland Foundry	Poison	2	3	0.2 mi	75	0.075	0.0006	12.91 *	0.501
12	Mueller Co.	Poison	2	3	0.2 mi	0	0	0.0000	5.88 *	0.228
13	Ahlstrom Filtration Inc.	Poison	2	3	0.4 mi	957	0.957	0.0078	16.51 *	0.641
14	W.R. Grace & Co.	Poison	2	3	4 mi	41917	41.917	0.3428	5.88 *	0.228
15	Royal Inc.	Chlorine	2	3	5 mi	122285	122.285	1.0000	5.88 *	0.228
16	Synair Corp	Poison	2	3	0.2 mi	82	0.082	0.0007	5.88 *	0.228
17	Nu-Foam Products Inc.	Poison	2	3	0.2 mi	82	0.082	0.0007	5.88 *	0.228
18	Dixie Yarns, Inc.	Chlorine	2	3	5 mi	72248	72.248	0.5908	14.61 *	0.567
19	Standard Plant	Corrosive	3	3	0.4 mi	3167	3.167	0.0259	14.61	0.567
20	Na Industries Inc.	Corrosive	3	3	0.2 mi	176	0.176	0.0014	5.88	0.228
21	Double-Cola Co. USA	Corrosive	3	3	0.2 mi	0	0	0.0000	13.45	0.522
22	Buster Brown Apparel Inc	Corrosive	3	3	0.4 mi	318	0.318	0.0026	5.88	0.228
23	Central Soya Co. Inc	Corrosive	3	3	0.4 mi	279	0.279	0.0023	5.88	0.228
24	Taylor Lab. Inc.	Corrosive	3	3	0.4 mi	965	0.965	0.0079	13.45	0.522
25	Nabors manufacturing Cor	none id	5	2	0.2 mi	176	0.176	0.0014	5.88	0.228
26	Fabric Finishers Inc.	none id	5	0	0.2 mi	176	0.176	0.0014	5.88	0.228
27	Signal Alloys Co.	none id	5	0	0.2 mi	176	0.176	0.0014	5.88	0.228
28	D.M. Steward Manufacturi	none id	5	0	0.2 mi	310	0.31	0.0025	14.18	0.550
29	Southern Centrifugal Div	none id	5	0	0.2 mi	178	0.178	0.0015	5.88	0.228
30	Norton Co	none id	5	0	0.2 mi	11	0.011	0.0001	25.77	1.000

* Indicates Chattanooga Response Team would have to be upgraded.

Note: Accident rates for facilities was not included in TRI data. A representative value from Handbook of Chemical Hazard Analysis Procedures for fixed facility accident rates of 10e-3 was incorporated into the system until actual accident rates could be obtained.

FUTURE RESEARCH OPPORTUNITIES

This research effort has established a foundation from which more sophisticated and focused emergency response planning can evolve. Among the more interesting opportunities are:

(1) inclusion of additional data describing sensitive population centers (hospitals, schools, prisons), environmental areas (wetlands, reservoirs, tribal burial grounds), more detailed street networks, and a complete inventory of existing emergency response units;

(2) extended applications into other emergencies, such as forest fires, floods, earthquakes and hurricanes; and

(3) integration of this methodology to include real-time incident management.

Table 4 Recommended order for further evaluation of facilities in Hamilton County

No.	Facility	Risk Value
8	Southern Cellulose Products Chattem Chemicals	1.41
6	Chattem Chemicals	0.22
13	Ahlstrom Filtration Inc	0.19
3	Coors Electronic Package Basf Corp.	0.16
5	Basf Corp.	0.14
18	Dixie Yarns, Inc.	0.99
15	Royal Inc.	0.68
9	Du Pont Chatt Site	0.31
2	Airco	0.29
19	Standard Plant	-0.00
24	Taylor Lab. Inc.	-0.17
7	US Pipe & Foundry Co.	-0.18
21	Double-Cola Co. USA	-0.18
11	Wheland Foundry	-0.24
10	Abb Combustion Engineering	-0.24
14	W. R. Grace & Co.	-0.46
1	Alco Chemical Corp.	-0.70
25	Nabors Manufacturing Corp.	-0.71
4	Basf Corp.	-1.02
22	Buster Brown Apparel Inc.	-1.06
23	Central Soya Co. Inc.	-1.06
20	Na Industries, Inc.	-1.06
16	Synair Corp.	-1.06
17	Nu-Foam Products Inc.	-1.06
12	Nueller Co.	-1.06
28	D.M. Steward Manufacturing	0.00*
29	Southern Centrifugal Div.	0.00*
27	Signal Alloys Co.	0.00*
26	Fabric Finishers Inc.	0.00*
30	Norton Co.	0.00*

*Not identified as hazardous by the National Fire Protection Agency

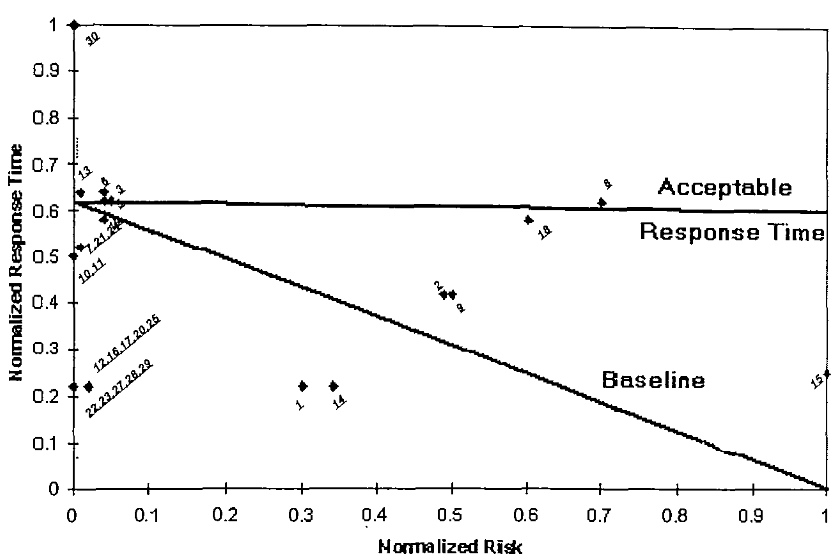

Figure 5 Risk screening for Hamilton County

CONCLUSIONS

The development of this emergency management planning environment presents a paradigm shift in how effective emergency planning can be used to enhance public safety, and how limited resources (eg money, infrastructure, personnel or equipment) can be used more efficiently. The availability of a tool with the ability to overlay and manipulate emergency planning information spatially provides a new dimension to this process.

At the local level, emergency response planning has been significantly enhanced. Required levels of response and areas of inadequate coverage can be determined for hazardous materials stored at fixed facilities and in transit, resulting in strategies to allocate resources in a more cost-effective manner.

When expanded to the regional level, this planning approach can be used to coordinate among neighboring jurisdictions to effectively combine their resources. Agreements between jurisdictions can be strengthened and expanded based on broader planning evaluations. Regional response teams can be developed as a result of this work, providing adequate protection at reduced overall cost.

Nationwide, an overall assessment of the level of emergency preparedness can be performed. Designation of hazardous materials routes and location of remediation centers are examples of national uses. This approach can also be used as a systematic method for allocating planning funds to jurisdictions based on need.

Privately, industries that handle hazardous materials, whether they are manufacturers, carriers, consumers, or disposers, can use this methodology for their own planning. Locating facilities, performing environmental impact statements, routing the transport of hazardous materials, or assessing worst-case scenarios are just a few of the potential applications.

The methodological development also contributes to the state-of-the-art in transportation and fixed facility risk management. A systematic procedure for quantifying the capabilities of emergency responders enables emergency response to be included directly in the risk screening process. Previously, risk assessment would be followed by evaluation of emergency response. Now, emergency preparedness is considered concurrently with other management controls, leading to identification of improved risk reduction strategies.

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