Use of Geographic Information Systems in Managing Hazardous Materials Shipments

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The safe transport of hazardous materials is emerging as a significant concern impacting local, regional, and national transportation policy. For this reason, there is a pressing need to develop methods for evaluating alternative shipment routes, and for developing emergency preparedness and evacuation plans in the event that a hazardous cargo spill occurs. Because the analysis of hazardous materials shipping and handling necessarily involves a close interaction between the transport system and its surrounding environment, the advent of the geographic information system (GIS) provides important opportunities for providing improved decision support in managing safe transport. GIS applications are defined for hazardous materials transport problems, and the benefits that can be achieved through adaptation of GIS to this subject area are demonstrated. In this context, the following information is presented: (a) the decision environment for managing hazardous materials shipments, (b) GIS data availability to support analysis needs, (c) application of a first-generation GIS model to identify preferred hazardous materials shipment routes, (d) comprehensive approaches using GIS for emergency preparedness and evacuation planning, and (e) problems encountered in using GIS technology for hazardous materials transport applications. A GIS approach offers potential for addressing these subject areas. Models already operational today demonstrate the immediate value of using a GIS, and the future design of more comprehensive methodology should provide even greater benefits.

Each year, modes of transportation in the United States, excluding pipelines, together carry some 1.5 billion tons of hazardous materials—chemical and petroleum products, including acids, fuels, explosives, fertilizers, and a variety of industrial wastes (*1*). Of this, approximately 65 percent is carried by truck and rail from manufacturers to a vast array of users.

Faced with such widespread transportation and distribution of hazardous materials, and the associated potential for costly and health-threatening spills, government agencies at federal, state, and local levels, as well as industry, have been forced to address the regulation and routing of hazardous materials, in addition to emergency preparedness and response. These responsibilities have necessitated the development of comprehensive approaches to risk management that consider the physical and operational aspects of the transport system in concert with characteristics of the surrounding land use, such as population distribution and the location of environmentally sensitive areas. The advent of the geographic information system (GIS), therefore, provides an important opportunity for improved decision support for the safe management of hazardous materials shipments.

The objective is to examine the role of the GIS in analyzing hazardous materials transport problems, and to demonstrate the benefits that can be derived by adaptation of GIS to this subject area. This discussion is presented according to the following sequence: (a) the nature of the hazardous materials transport environment, (b) data needs to perform analysis requirements and the ability of GIS to support these needs, (c) illustration of a first-generation GIS-based model to select safe routes for movement of hazardous cargo, (d) discussion of future enhancements involving GIS to reach a more comprehensive approach to management of hazardous materials shipments, and (e) problems encountered in using GIS technology for hazardous materials transportation applications.

PROBLEM FOCUS

Transportation considerations involving hazardous materials can be conveniently divided into two basic categories, namely decisions involving site selection and those focusing exclusively on the transport operation. In site selection, the location of shipment origins and generated volumes are usually known, and the question focuses on location of the destination site and the capacity of the terminal facility. A typical example of this problem concerns the decision about where to locate a hazardous waste disposal facility. For the site selection problem, transport mode and route selection are also decision variables, although they are hierarchical decisions, anchored to each specific site location and receiving capacity alternative. Consequently, transportation impacts feed into a broader process that leads to a siting recommendation.

The transport operation problem, which is a far more common application, assumes that the location of the shipment origin and destination are known, as are shipment volumes and receiving capacities. In this instance, choice of transport mode and preferred route are the sole decision variables, and analysis of transportation impacts leads directly to policy formulation. A classic problem in this area is the routing of an extremely hazardous material by truck, rail, or barge between the shipment origin and destination, where each candidate route will expose different communities to the potential of a release. The complexity in technical representation of the transport costs and risks involved and the political attention devoted to the routing question present imposing challenges on decision support model development.

Closely related to the question of routing is the area of emergency preparedness and response. As a release can potentially occur during loading or unloading at a handling

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facility or while the shipment is in transit, the ability to effectively deploy emergency response personnel and schedule appropriate evacuation procedures (if necessary) is paramount. A considerable amount of preplanning may be needed so that appropriate actions can be taken in the event a release does occur; there is also the need for dynamic response while the incident is taking place. Knowledge of the location and capability of emergency response units, potential population requiring evacuation, and accessibility and capacity of the roadway system are all critical elements to an effective emergency preparedness and response plan. As it relates to the handling of shipments at facility sites, this problem has taken on added significance with the passage of the Superfund Amendments and Reauthorization Act (SARA). This legislation effectively requires local jurisdictions to develop emergency plans for dealing with specific hazardous materials (*2*).

Factors affecting decisions involving the management of hazardous materials shipments can be generally separated into economic and safety considerations. The chief economic consideration typically involves carrier/shipper operating costs to use the transportation system. Direct economic impacts are also associated with the costs of maintaining the infrastructure, developing and implementing regulatory policy, inspection/enforcement, and emergency response (including cleanup) programs.

Safety effects focus on the risks associated with the likelihood of an accident/incident that causes a container failure and subsequent materials release. In such instances, there is the potential for causing serious harm to the population and the environment. Consequence severity can be impacted by a number of factors, among which are rate of release, shipment size, toxic effects of the material, local demographics, and the response times and capabilities of emergency management personnel. Understanding the likelihood of different consequences is a fundamental part of risk assessment.

The analytical framework for addressing hazardous materials transport decision problems can be quite complex to represent mathematically. It can require identification and quantification of the state or condition of many transportation-related elements, including the following:

- Transportation infrastructure and use of the relevant transportation network.
- Transportation regulation and inspection programs affecting the transport facility.
- Characteristics of the population and environment adjacent to each network segment (link).
- Location and capability of emergency response units.
- Shipment and vehicle operating characteristics.

GIS provides an ideal environment for managing hazardous materials shipments because it involves the overlay of many transport network attributes as well as other GIS data layers (e.g., demographic, topographic, and weather) on individual network segments in order to properly characterize accident/incident likelihood and consequence to the population and environment. This application also involves the integration of the GIS with sophisticated mathematical models and search procedures to identify preferred management options (*3*).

INFORMATION REQUIREMENTS

The information required to support hazardous materials transportation analysis can be generally classified into the following three categories: (a) transportation network, (b) social/demographic factors, and (c) other geographical considerations.

Transportation Network

Transportation network considerations consist of physical dimensions (geometrics) of the transportation system and its associated use. Each network link (segment) and node (intersection) must be defined by its locational coordinates, so that these coordinates can be integrated with other geographical information to create a common referencing system.

Typical network attributes that are desirable to append to the transport network for hazardous materials transportation analysis include (a) distance, (b) average daily traffic, (c) number of lanes (tracks), (d) physical condition, (e) accident rate, (f) bridge and tunnel clearances, (g) curvature/grades, and (h) temporary restrictions. The geometric characteristics are important in defining each segment in terms of permissible traffic; for example, certain shipments may be restricted from passage on roads without sufficient clearance. Geometric characteristics are also used to classify transport segments into categories for subsequent analysis (e.g., accident likelihood may vary by curvature and grade).

Attributes more closely related to transport segment utilization correspond to the movement of traffic across the segment and the quality of service provided. Accident likelihood/severity and travel time are two principal outputs generated from the process of examining utilization in concert with design standards as determined through segment geometrics.

Most transport network information can be obtained through state agencies. The difficulty is in integrating this information and assigning it to the proper location of the physical network (*4*). As an example, difficulties can arise where traffic counts are taken at places that do not conveniently overlay with the locational framework in which accident statistics are compiled. Considerable progress is being made in this regard through the use of dynamic segmentation, a concept that allows for creation of interpolated segments and identification of points within a segment (*5*). Thus, an appropriate location reference system can be established.

Social/Demographic Factors

The interactions between the transportation system, the adjacent land use, and environment are defined herein as social/demographic factors. Included among these are (a) population within varying distances of the transport segment, (b) response time from the nearest first (and ultimate) responder and associated response capability, and (c) the distance to schools, hospitals, water supplies, and other ecologically sensitive areas.

Knowledge of the population distribution adjacent to the transport facility determines the impacted population that might be exposed to a potentially hazardous materials spill. The distance from the transport segment, as one would expect, has implications on the level of exposure that depend on the characteristics of the release event.

The response time from the nearest response unit and the ultimate response capability are indicators of how quickly a spill can be reacted to and controlled should one occur at a given point in the transportation system. An important distinction must be made between first response (on-scene arrival) and ultimate response (capability to control the release). Although both are important, first response is directed more at responding to the immediate consequences of the incident, whereas ultimate response focuses on containing the source of the problem.

Proximity of schools, hospitals, water supplies, and other ecologically sensitive areas identifies the presence of sensitive locations and their (impact) distance from the transport facility. This may prove particularly important in the determination of routing criteria as well as in the development of emergency preparedness and evacuation planning.

Social/demographic factors can be generated from GIS data describing the surrounding land use, overlaying this information on the transportation physical coordinates, and deriving appropriate measures for each transport segment using computational geometry and other mathematical derivations. These attributes, in essence, would be computer derived and subsequently added as fields in the record structure of the transportation network data base.

Other Geographical Considerations

Other geographical considerations refer to information on weather, topography, and geology, all available through a GIS, that can potentially be overlayed on the transportation and social/demographic data to permit a more precise assessment of health impacts from a transport spill. Important weather considerations include wind direction, wind speed, and temperature for the purpose of determining release dispersion. Topography adjacent to the transport facility plays an important factor in dispersion, whereas geological characterization of the surrounding area has important implications on ground and surface water contaminant flow.

As in the case of social/demographic considerations, it is expected that these measures can be derived from GIS data and appended as segment level attributes in the transportation network.

ROUTING APPLICATIONS

In moving towards an idealized GIS approach to hazardous materials transportation analysis, the authors have been engaged in the development of first-generation hazardous materials routing models that rely heavily on GIS technology. The GIS applications environment used in this research possesses the following features: (a) can be performed using a stand-alone microcomputer, (b) provides enhanced graphics output, (c) permits flexibility in evaluating alternative routes, (d) is designed to accommodate future data collection and model enhancements, and (e) provides an opportunity to integrate generic approaches with selective customization.

The transportation network used in this system is a GIS road network maintained by Oak Ridge National Laboratory, based on a U.S. Geological Survey 1:2,000,000 scale map. Several network attributes have been assembled from various public domain sources, and have also enhanced the data base through the addition of new attributes and substitution of certain attribute values where more detailed information (e.g., state accident files and traffic counts) have been obtained. The network can support both national and localized routing studies, and can accommodate other scales and formats, such as the U.S. Geological Survey 1:100,000 scale maps and the Bureau of the Census TIGER files.

The principal social/demographic factor that is operational in the referenced hazardous materials transportation routing model is population. This is a GIS data base of enumeration district centroids with attribute information, available through the Bureau of the Census. A comprehensive procedure has been applied to these data to create an enumeration district boundary file and to spread the population in each district nonuniformly across this area according to a gradient method (*6–9*).

The enumeration district boundary file for each district is established by drawing lines that bisect each adjacent enumeration district centroid. Through recursive use of this process, enumeration district borders are shaped such that every district occupies a unique area surrounding its centroid, and collectively the districts occupy the entire county area.

The gradient method that is subsequently applied is based on the premise that the population in a district is likely to be distributed proportionate to the population densities of neighboring districts. Consequently, of two equal-sized areas located within the same district, the area located closer to a neighbor with a greater population density will be assigned a greater proportion of the district population than the area located closer to a neighbor with a lower population concentration. This is done to preserve the continuity of urban and rural land use which is independent of the nature in which enumeration districts are defined by the Bureau of the Census.

Once the gradient method has been applied, the entire county is divided into cells, each of which encompasses an area of 30 sec of longitude by 30 sec of latitude. This corresponds to approximately an area of one-quarter square mile. The centroid of each of these cells effectively becomes the GIS population data base for exposure analysis.

The overlay of the GIS population data base onto the GIS transportation network is subsequently performed, and computational methods are applied to derive relevant population exposure measures for hazardous materials transportation analysis. This measure is defined as the population bandwidth (see Figure 1). The bandwidth corresponds to an impact band on each side of a transport segment, and is drawn as a continuous line along the segment to represent that an incident can occur at any point along a shipment path. Using either chemical dispersion models or expert judgment, the maximum exposure distance for a particular shipment and material can be determined, and subsequently used to define the appropriate bandwidth. The affected population is then derived for the selected bandwidth using the previously described method.

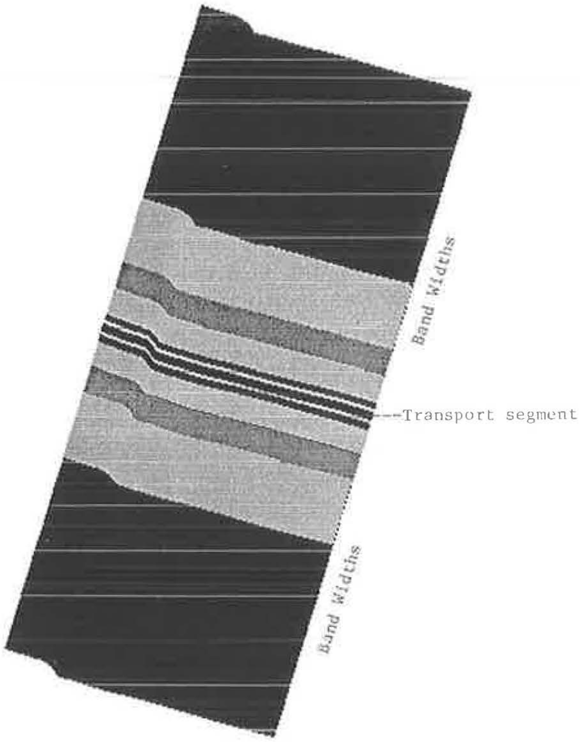


FIGURE 1 Spill exposure using transport band widths.

The search and solution process uses a network algorithm referred to as the "double-sweep method" (*10*). This algorithm provides an efficient search procedure and finds a global optimum, such that large-scale network (e.g., U.S. principal road system) applications can be solved in a matter of minutes. Network restrictions, such as prohibiting movement on certain transport segments, can also be easily accommodated in the solution environment.

The issue of routing is, perhaps, the most controversial regulatory question that federal, state, and local officials have had to contend with, as it relates to passage of hazardous materials through each jurisdiction, and considerable political pressure is being applied at several levels to impose routing restrictions on carriers. If imposed, restrictions typically force a carrier to seek a more costly routing but lower-risk alternative, creating an important tradeoff between economic and safety impacts in moving hazardous goods (*11*). The following application illustrates the use of the referenced GIS hazardous materials transportation routing model in revealing this conflict.

Figure 2 shows the results of an application of the GIS routing model to a shipment from Moses Lake, Washington, to Newport, Tennessee, in which the selected criterion was to minimize shipment distance. The same analysis is shown in Figure 3, except in this case the entire weight is placed on minimizing population exposure within a 3-mi band along the preferred route (POP 3), essentially a proxy measure for minimizing risk. Through comparison of these two alternatives that represent economic and safety criteria, respectively, some in observations can be made. Most notable are the different spatial routes involved in the optimal solutions.

In a policy context, not only would the pursuit of safety suggest a different preferred route, but it would also result in the impacts' being distributed to a different set of communities and states, causing a potential for political upheaval. The more circuitous route might also be a source of objection from industry. This, in essence, reveals the controversial circumstances in which routing regulation must be evaluated (*12*).

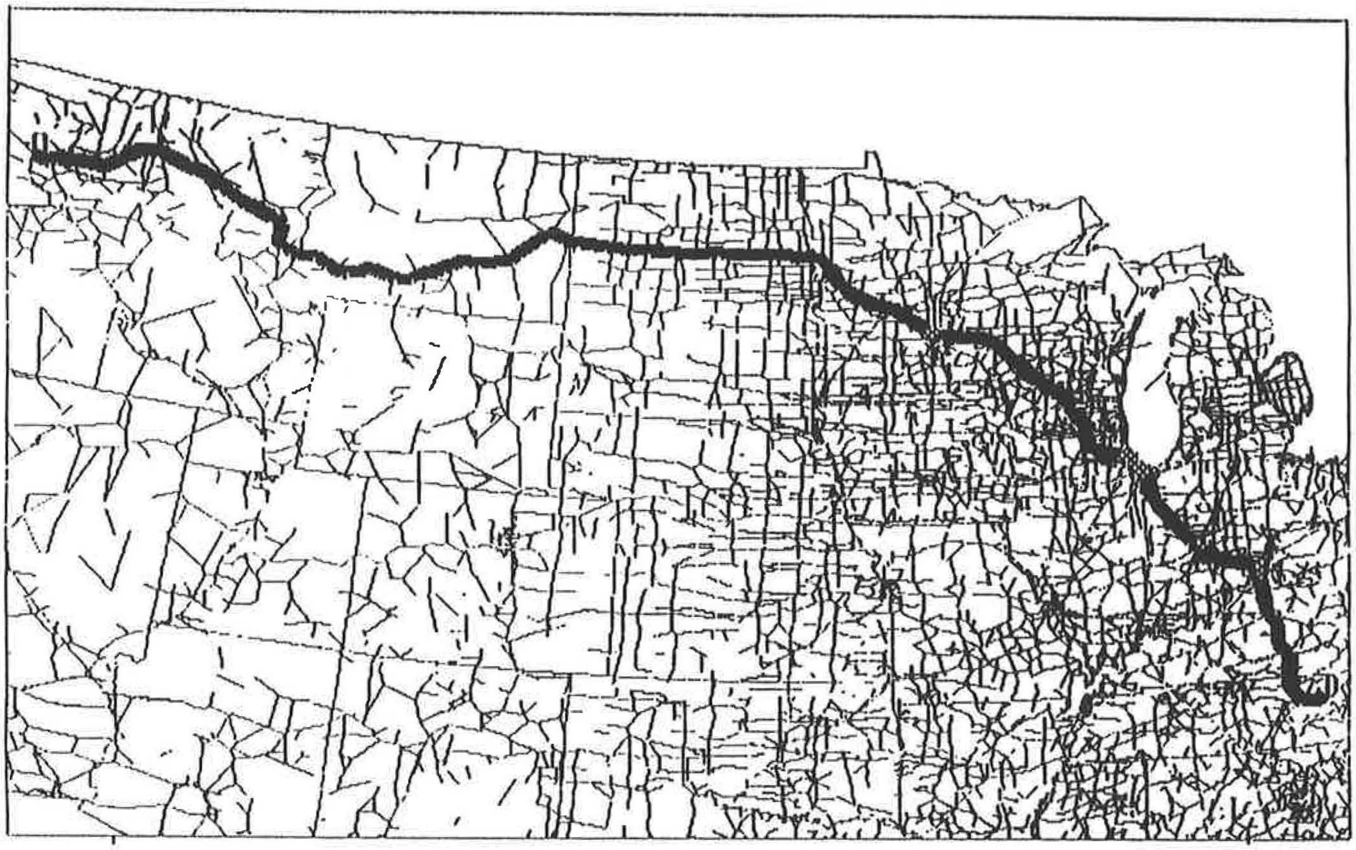
Compromise or negotiated solutions could be achieved through comparison of routing solutions prompted by the definition of different routing criteria. For example, in examining Figures 2 and 3, it appears that population exposure can be reduced by approximately 70 percent for an approximately 10 percent increase in trip distance, when moving from a totally economically based criterion preference to one in which exposure to population is the sole criterion. In both figures, several other impact measures are tabulated, so that the policy analyst can evaluate alternative routes on a multidimensional basis.

The legend used in these output tables is as follows:

- DISTANCE—total route distance (miles);
- POP_i—total route population living within i miles of the route;
- RELIABILITY—indicator of the level of operational safety on the route (formulated as a function of the inverse of the shipment accident likelihood);
- TIME—total route travel time (hours) under assumptions of uncongested, partially congested, and fully congested traffic, respectively; and
- COST—total shipment cost ($).

Other capabilities inherent in this first-generation GIS transportation routing model include the abilities to (a) zoom in or out from a geographical area, (b) label transport maps according to a choice among several descriptors (e.g., route number, segment number, segment distance), (c) select population exposure measures from bandwidths of 0.25, 0.50, 1, 3, 5, 10, and 25 mi, (d) make routing selections using criteria of minimizing travel time or accident likelihood in addition to minimizing distance or population exposure (or simultaneous consideration of multiple criteria), (e) require a shipment to pass through or avoid network segments or intersections where routing restrictions apply, (f) identify segments with outlier attribute values for a specified attribute (e.g., excessively high accident potential), and (g) define different transport network densities (e.g., Interstates only and all Interstate, state, and U.S. highways). These features permit the representation of a multitude of location-specific, hazardous materials transportation problems that agencies often confront.

Second-generation development is also underway to enhance the capability of GIS-based hazardous materials transport analysis techniques. These include (a) adding rail, marine, and intermodal transport to the routing and risk analysis system, (b) including emergency response locations in the mapping system and adding minimum emergency response time as a routing criterion, (c) including more comprehensive information on the transport network and surrounding area, such as weather data, topographic information, and location of environmentally sensitive areas, (d) inclusion of time-dependent attributes, such as assigning traffic congestion effects and interchanging employment and residential population exposure depending on time-of-day, and (e) developing chemical-



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WEIGHT    (1.00)         ( .00)     ( .00)     ( .00)     ( .00)     ( .00)
PATH    DISTANCE         POP .25    POP .50    POP 1      POP 3      POP 5
 1        2534.97        408666     1021193    2213361    9059513   17200706

( .00)      ( .00)        ( .00)      ( .00)     ( .00)   ( .00)
POP 10      POP 25      RELIABILITY  TIME 1    TIME 2    TIME 3      COST
 39027874   89706971     .9946374   2606.63  2887.30   3314.46   6975.00
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FIGURE 2 Shortest distance path between Moses Lake, Washington, and Newport, Tennessee.

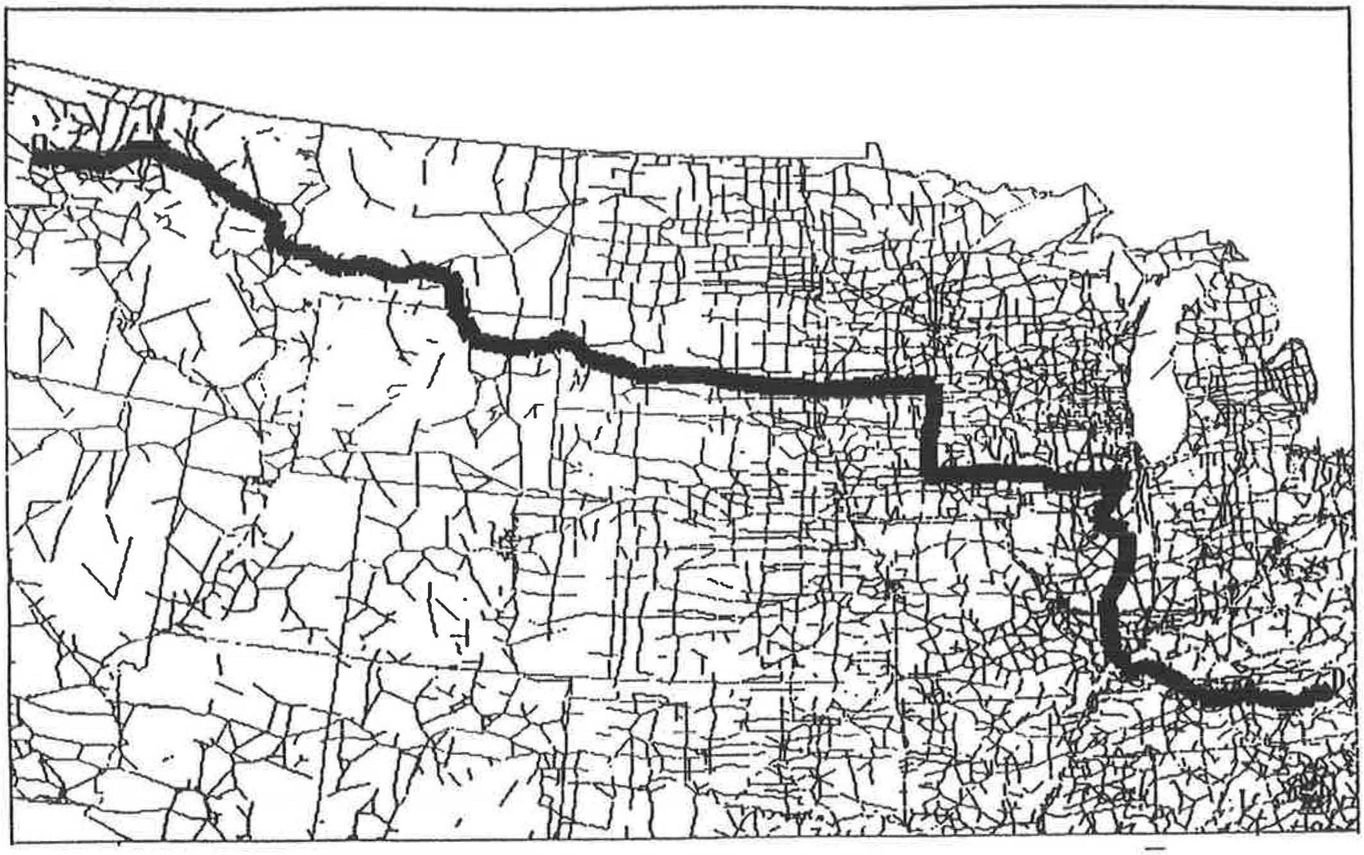
specific exposure measures using inputs such as wind direction and speed, temperature, physical behavior of the chemical under consideration, topography, and other relevant factors in understanding the size, shape, and movement of plume dispersion. These techniques will permit a more direct assessment of expected injuries and deaths on the basis of the toxic effects of a release.

EMERGENCY PREPAREDNESS AND EVACUATION PLANNING

As mentioned previously, another developing consideration closely related to hazardous materials routing is emergency preparedness and evacuation planning. These applications are complex because one must simultaneously monitor spill consequence, status of emergency response personnel, and availability and capacity of potential evacuation routes. Figure 4 shows these problems as defined in a GIS context for a release of hazardous cargo on the Washington Beltway. Four critical events are occurring concurrently that must be tracked and integrated for analysis purposes: (a) a spill has been reported and one or more emergency response units (with the Red Cross symbol) have been deployed and are en route to the scene, (b) a plume may be forming and spewing toxic fumes across land areas, (c) the possibility of evacuation exists and the identification of evacuation routes must be made, and (d) time is passing. Each of these issues is examined individually in the following discussion.

When a spill is reported, contact must be established with the first and ultimate responders, and these units are subsequently deployed to the scene. The identification of the appropriate response units can be identified using a GIS overlay of response unit location (with a capability attribute) onto the transportation system and location of the release site. Response times to the scene from each unit can be derived and the units with the minimum response time would be dispatched.

Plume formation depends on a number of factors related to the release, material involved, and site characteristics. As an output from an appropriate dispersion model, the plume size, shape, and direction can be overlayed onto the GIS data bases that represent the population distribution and location of environmentally sensitive areas. The number of people exposed at any given time can be determined, as well as the identification of affected schools, water supplies, etc. Most plumes contain inner portions in which the concentration, and



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WEIGHT    ( .00)        ( .00)     ( .00)     ( .00)    (1.00)     ( .00)
PATH    DISTANCE        POP .25    POP .50    POP 1      POP 3      POP 5
 1        2776.33       139561     301467     659863    2716954    5033517

( .00)     ( .00)       ( .00)      ( .00)     ( .00)    ( .00)
POP 10     POP 25     RELIABILITY  TIME 1    TIME 2     TIME 3       COST
  9111955  17331161    .9962405   2882.32   3094.89    3498.46    7645.50
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FIGURE 3 Minimum population exposure path (3-mi band width) between Moses Lake, Washington, and Newport, Tennessee.

consequently the dose to humans and wildlife, may be appreciably greater than on the outer edges of the plume. When these doses exceed the human threshold, the possibility of more serious health effects exists. Therefore, the ability to separate chemical exposure from more acute exposure that threatens human health is important and can be accommodated using the GIS. In Figure 4, separate computations are made for the population that has been exposed to a dose greater than the human threshold.

Because of the severity of the release and toxicity of the material, an evacuation may be necessary. The number of people who must be evacuated can be determined by overlaying the plume movement on the population as previously described. However, the ability of the network to accommodate evacuees depends on the capacity of the road system. Consequently, models allocating evacuees to specific evacuation routes must be developed. Moreover, the movement of the plume may be such that some potential evacuation routes may only be temporarily open until the time when the plume passes over the route in question, a condition that must be taken into consideration as well.

The passage of time makes this entire problem dynamic in nature, requiring agencies to take actions based on current, cumulative, and projected impacts across the entire duration of the release event. Significant occurrences during the event that could have a profound impact on the decision process include (a) the time at which emergency response personnel arrive at the scene, (b) the likelihood and time at which release containment can be achieved, and (c) abrupt changes in weather conditions.

The GIS approach to emergency preparedness and evacuation planning is evolving in two contexts, planning and real time. In the planning context, historical weather conditions can be used to form joint probability distributions of wind direction, speed, and temperature for the purpose of deriving probable weather scenarios for a particular transport segment. GIS release scenarios can then be subsequently simulated so that specific action plans are developed for each weather scenario in advance of when a spill might occur. These action plans could be maintained on file for reference should an incident occur, and given knowledge of the prevailing weather conditions at the time.

Real-time GIS analysis activities may be appropriate to monitor a shipment's location or to intervene in the decision process if and when a significant occurrence takes place. The technology for generating real-time information takes on two principal forms as it relates to this problem. Sensors that record up-to-the-minute observations of weather conditions can be strategically placed (with geographical location coordinates known) so that prevailing characteristics are immediately

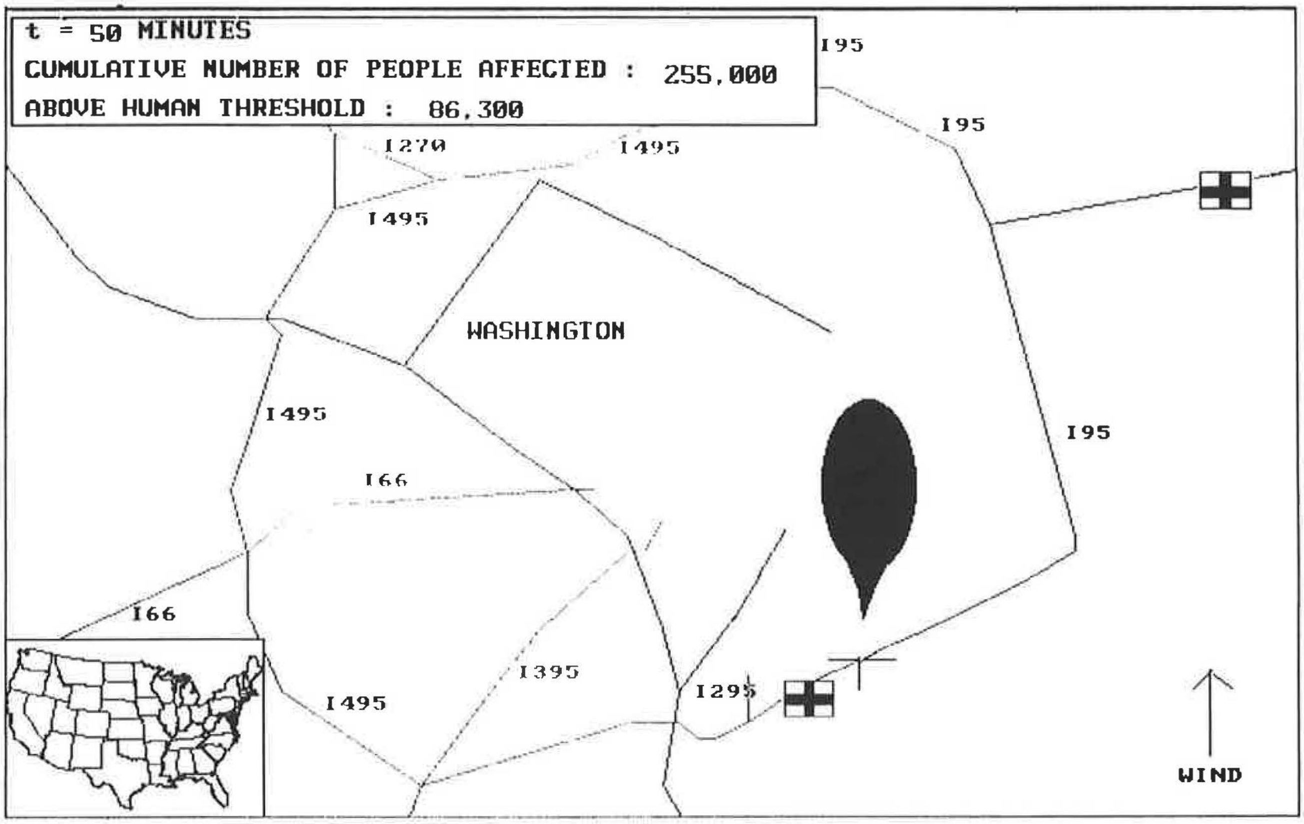

FIGURE 4 Consequences of and response to a release from a hazardous materials highway shipment.

recognized and can be used as model inputs in managing emergencies. Some chemical manufacturing plants, for example, are already using this technology. Real-time shipment monitoring based on GIS locational coordinates is also taking place through the use of satellite tracking and ground-based navigational systems. With increasing concern over managing transport safely and efficiently, one can expect the use of real-time GIS data collection to become more prevalent in the next decade.

Another area fertile for development is the overlap of topography on the transportation system. Plumes behave quite differently when terrain acts as a barrier to dispersion. GIS digital elevation files are available from the U.S. Geological Survey (USGS) to use in this context. However, in terms of using this information for application purposes, the problem becomes more complex because of the three-dimensional nature of plume formation. Methods for introducing topographic considerations into the emergency preparedness and evacuation planning context are beginning to be explored. Figure 5 shows current efforts to take digital elevation files and to portray the three-dimensional nature of the information. The files can be viewed from several different angles by rotating the axis of the images, as noted in the upper left-hand corner of the figure.

GIS TECHNOLOGY QUESTIONS

As the field of transportation is inherently geographic, GIS offers concepts and a technology with considerable potential for achieving dramatic gains in efficiency and productivity for a multitude of transportation applications. By its nature, managing the safe transport of hazardous materials requires integration of the full realm of issues involving the design and implementation of a GIS framework. As noted earlier, this is the case because comprehensive transportation risk assessment requires the collection and management of detailed attribute information on highway network geometrics and utilization, as well as spatial information on the surrounding land use, including population, topography, geology, and the location of special facilities. However, a multitude of methodological questions that focus on the underpinnings of GIS technology accompany such a comprehensive GIS applications environment. The principal concerns are presented in the following discussion.

Data Organization and Structure

The data bases used in the GIS application and methods by which multiple data bases are integrated can be constrained by the manner in which individual attributes are defined and measured. For example, the data collected to describe one highway network attribute may be measured at mileposts and assigned continuously along the highway, whereas another attribute may be measured according to fixed control sections. The resulting computer representation for each attribute is likely to be different, yet this information must be accurately merged where a GIS application requires access to both data elements (*4*). As mentioned previously, the use of dynamic

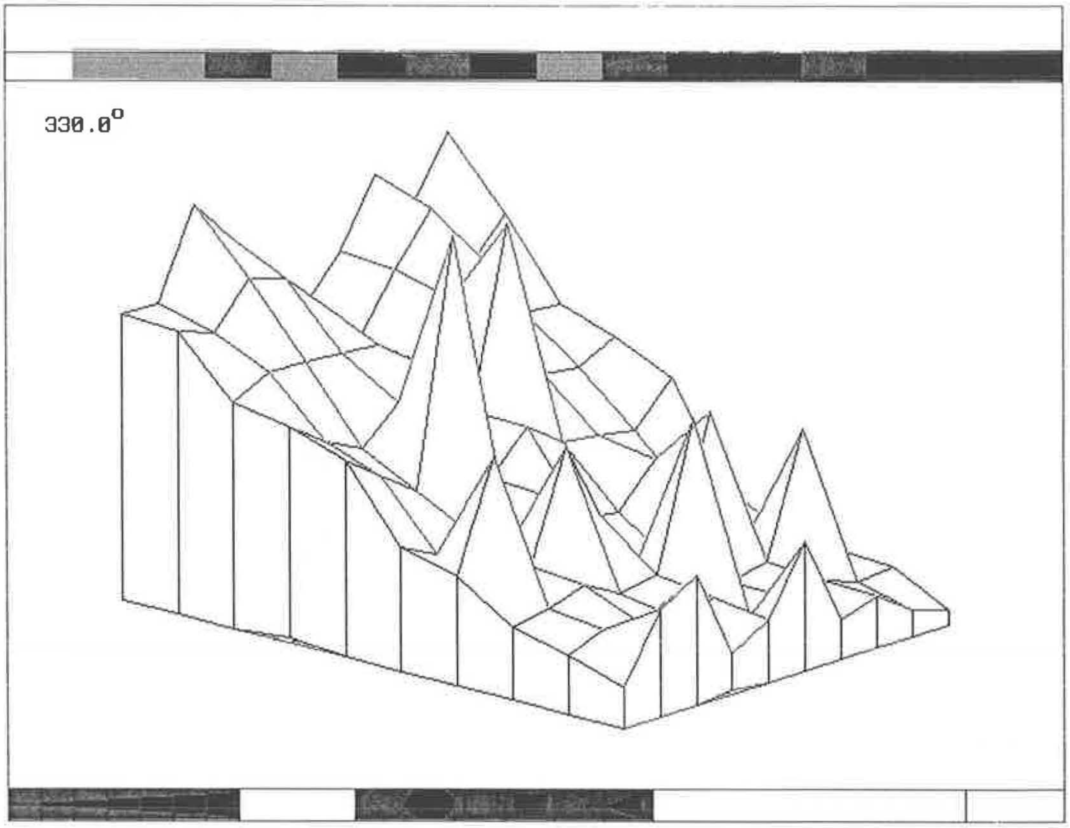

FIGURE 5 Digital elevation file for plume formation.

segmentation to create interpolated segments and identification of points along a string is a key to resolving these problems.

Map Scale

The scale of the map used for data capture affects the level of detail that one is able to extract from the map. A comparison of the USGS 1:24,000 scale map versus the 1:62,500 scale map shows, for example, additional levels of information because of the larger scale. Multiple thematic overlays required for hazardous materials transportation analyses could involve the use of maps with different scales' being transformed into the same base scale. However, this process does not translate to creating a GIS that has the same level of information throughout all the GIS overlays.

Location Reference System

Different databases may not possess the same location reference system. Common transportation reference methods include milepoints, reference points, feature based, and logmile systems (*13*). Latitude-longitude, state plane, and universal transverse Mercator are traditional reference systems for environmental studies. When GIS data bases to be overlayed use different location reference systems, the transformation between coordinate systems must be accomplished at an acceptable level of accuracy.

Data Conversion and Maintenance

Many agencies possess specialized digital data bases that are in spatial formats or that could be organized in such a manner. For example, Bureau of the Census files; digital elevation models from the USGS; and digital data from local, county, and state agencies offer the wise user a variety of sources of information that can be integrated into a GIS environment. Standard exchange formats must be used to expedite the transfer and useability of the data captured and archived at various locations (*14*).

From the standpoint of maintaining information so that it stays current, rather than attempting to include all data elements in one mammoth data collection effort, a better approach would be to establish a good cross-referencing system, with the responsibility for updates remaining with the agency that has jurisdiction for collecting this information. For example, updated accident rates could be derived interactively by tapping directly into accident counts, road inventory data, and volumes maintained by different agencies, but available through a common referencing system.

Data Accuracy/Quality

Inherent and operational errors contribute to a reduction in the accuracy of data contained within a GIS (*15*). Inherent error is present in the source documents and it is fair to say that every map contains inherent error based on the nature of the map projection, construction techniques, specifications, and symbolization of the data. Operational error is introduced during the process of data entry and occurs throughout data manipulation and spatial modeling. Multiplicative error effects can arise when operational errors are introduced where inherent errors previously exist.

The major concern of these GIS issues as they relate to hazardous materials transportation analyses is the extent to which they impact the accuracy of problem presentation and, consequently, the policy actions that emanate from use of a GIS decision support tool. As more scientific effort is placed on the development of national standards to enhance the quality of information as well as standardization in the definitions and references used, spatial data transfer specifications, and cartographic features (*14*), these problems will be better understood and hopefully resolved. In the meantime, however, one should maintain perspective by recognizing that inherent and operational errors exist today in traditional approaches to transportation analyses. Hence, the advent of a GIS actually provides an opportunity to achieve a greater level of resolution and accuracy than available heretofore.

CONCLUSION

This discussion has attempted to focus on the merits of applying GIS concepts and technology to applications involving the transport of hazardous materials. Three principal areas of policy concern, those of routing, emergency preparedness, and evacuation planning, were singled out for consideration. Characteristic of hazardous materials transportation analyses is the measurement of interactive effects between the transport system and its surrounding land use. Consequently, GIS concepts present a promising approach for problem representation, algorithmic solution development, and impact prediction.

On the basis of the successful implementation of first-generation routing models and progress in designing GIS-based methods in support of emergency preparedness and evacuation planning, it appears that GIS will significantly extend the frontier of hazardous materials transport research and practice. Developments to date have already introduced important advances to the applications environment, and this field of development will continually evolve as improvements are made to GIS data collection techniques and accessibility.

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