Hazardous Materials Siting and Routing Decisions: Factors Affecting Preferences of Fire Chiefs

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Hazardous materials routing and siting decisions are based on multiple objectives, which often conflict. These objectives usually express risk, cost, and equity criteria. Multicriteria decision-making models for hazardous materials routing and siting are available. A common characteristic of these models is the generation of noninferior solutions. A solution is noninferior if no other solution can improve one of the objectives without degrading at least one other objective. Given the fact that only one of the noninferior solutions can be selected, it is necessary at a certain point of the decision-making process to consider the preferences of the decision makers. The preferences of decision makers are affected by their expertise and other nontechnical factors. A telephone interview survey of fire department chiefs in 95 Connecticut cities and towns concerned tradeoffs between cost and safety of hazardous materials transportation and their preferences for hazardous materials storage facilities in rural areas. The survey identified factors affecting these preferences and indicated that community self-interest is one determinant of fire chiefs' preferences.

The production and transportation of hazardous materials is an unavoidable process in any industrial society. A number of industrial activities of vital economic importance are dependent on the uninterrupted flow of hazardous materials shipments. Data from the Chemical Manufacturers Association, the Fertilizer Institute, and the Department of Energy indicate that a substantial hazardous materials volume is produced and transported every year in the United States (*1*). Surveys of hazardous materials movements indicate that approximately 1.5 billion tons were transported within the United States during 1982 (*2*).

Although hazardous materials production is associated with technological growth and economic development, the danger associated with its accidental release is substantial and sometimes catastrophic for humans and the environment. The high risk associated with hazardous materials transportation has drawn considerable attention at local, national, and international levels (*3–5*), resulting in a regulatory framework to enhance the safety of hazardous materials movements. Most of the existing regulations impose spatial or temporal restrictions, or both, on hazardous materials movement. The idea behind restricting the routing is to enhance the safety by (a) minimizing the accident probability, and (b) minimizing the consequences of accidents.

Route selection for hazardous materials shipments depends on the location of the origin and destination of these materials. Obviously, there is an interaction between decisions related to the location of hazardous materials production and storage facilities and decisions about hazardous materials routing to and from the facilities (*6,7*).

Besides risk, transportation cost is a major consideration in hazardous materials routing decisions. However, routes that may minimize the transportation risk may not minimize the transportation cost (*8*). In fact, there is a tradeoff between cost and safety. Finally, the distribution of risk is an important criterion that should be taken into account in selecting routes for hazardous materials shipments. Selection of routes on the basis of risk minimization may result in inequalities in risk distribution (*8*).

Hazardous materials transportation decisions involve a number of decision makers and require the consideration of multiple and sometimes conflicting objectives. The intervention of decision makers is required to resolve the conflict between the different objectives of groups involved in and affected by transportation of hazardous materials.

Multicriteria decision-making models for location and routing that incorporate the preferences of decision makers are important when dealing with hazardous materials transportation decisions. The orientations of the actors involved in this process are affected by a number of factors. Some of the factors influencing the preferences of a particular group of actors, namely fire chiefs, will be studied.

First, existing hazardous materials routing and siting models will be described. Next, the necessity of incorporating the preferences of decision makers in hazardous materials routing and siting decisions is explained. An empirical model is presented for the identification of some factors influencing the preferences of decision makers when they are examining tradeoffs between conflicting objectives. Finally, the findings and conclusions of this study are presented.

EXISTING MODELS FOR HAZARDOUS MATERIALS ROUTING AND SITING DECISIONS

In its general form, the hazardous materials routing problem can be expressed as follows: given a graph $G = (V, L)$, with a node set V, $|V| = v$, a link set L, a set of nodes O representing the origins of hazardous materials shipments (i.e., production facilities), and a set representing the destinations D of the hazardous materials shipments (i.e., storage or transshipment facilities), find the path or paths connecting the origin-destination pairs in such a way as to minimize a set of

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criteria *M* associated with the links of the transportation network. The following categories of criteria are usually used in hazardous materials routing models: (a) criteria expressing cost, (b) criteria expressing risk, and (c) criteria expressing equitable distribution of risk. When the origin or destination of the hazardous materials shipments, or both, is not predetermined, then the routing problem becomes more complicated, and the location decision for the production and storage facilities should be made at the same time as the routing decision. Combined location-routing models have been proposed (*9,10*) for the simultaneous location of hazardous materials production and storage facilities and the routing of hazardous materials between them. A common characteristic of the existing combined location-routing models is the consideration of multiple criteria. Mirchandani and List (*10*) presented a model that considers the following criteria: (a) total risk, (b) maximum risk per person, (c) transportation cost, and (d) cost of the treatment facilities. Zografos and Samara (*9*) presented combined location-routing models that consider the following criteria: (a) risk caused by the location of treatment and storage facilities, (b) transportation risk, (c) transportation cost, and (d) equitable distribution of risk.

Models found in the hazardous materials routing literature can be classified according to the number of criteria used to determine the best paths between origins and destinations. If only one criterion is used, the models are characterized as single-objective optimization problems, and the well-known shortest-path problem is used to find the best path connecting the origin-destination pair. Single-objective hazardous materials models have been proposed by Robbins (*11*), Brogan and Cashwell (*12*), and Batta and Chiu (*13*).

When more than one criterion are used for routing of hazardous materials, the models are characterized as multicriteria decision-making problems. Multicriteria routing models can be used to study tradeoffs between conflicting routing objectives (e.g., risk versus cost or total risk versus equitable distribution of risk). Multicriteria formulations of the hazardous materials routing problem have been proposed by Zografos and Davis (*8*), Abkowitz and Cheng (*14*), Robbins (*11*), and Turnquist (*15*).

INCORPORATING DECISION MAKERS' PREFERENCES IN HAZARDOUS MATERIALS ROUTING AND SITING DECISIONS

Multicriteria hazardous materials routing and siting models usually consider combinations of the following objectives: (a) minimization of risk, (b) minimization of cost, and (c) equitable distribution of risk. A common characteristic of these existing models is the generation of efficient (or noninferior) solutions. A solution of a multicriteria decision-making model is efficient if no other solution can improve one of the objectives under consideration without causing a degradation in at least one other objective (*16*).

As an example of the concept of efficiency in the hazardous materials routing environment, the two following objectives are assumed to be of interest in a routing problem: (a) minimization of risk and (b) minimization of cost. The set of efficient solutions for this example will contain routes that outperform each other in terms of risk or in terms of cost, but not both.

By this definition of efficiency, the set of efficient solutions contains a number of alternative solutions, only one of which can be implemented. Therefore, the selection of the implemented alternative requires the intervention of the decision maker. This requirement means that at a certain stage of the solution process the decision maker has to express preferences with respect to the conflicting objectives, implicitly or explicitly. The noninferior solution selected after the intervention of the decision maker is called the best compromise solution. Therefore, the best compromise solution is the solution that maximizes the utility of the specific decision maker.

The intervention of the decision maker in the solution process implies that the best compromise solution depends on the values, perception, and attitude of the decision maker or group of decision makers. Therefore, it is important to identify the factors affecting the judgment of decision makers involved in hazardous materials transportation decisions before trying to formulate their utility functions, which are required for the identification of the best compromise solution.

FACTORS AFFECTING PREFERENCES OF DECISION MAKERS

A comprehensive survey of fire chiefs was undertaken to (a) examine perceptions and attitudes of fire chiefs related to hazardous materials siting and routing decisions and (b) identify some factors affecting their attitudes and preferences. Fire chiefs represent only one of the groups of decision makers involved in hazardous materials management actions. However, they were selected as the survey population because of their high degree of involvement and responsibility in hazardous materials emergencies and because of their recognition as one of the major actors in the hazardous materials management process.

Data Collection and the Survey Population

During spring 1989, 95 randomly selected fire chiefs from throughout the state of Connecticut were interviewed by telephone (*17*). The data drawn examined the fire chiefs' preferences regarding tradeoffs between transportation risk and transportation cost, as well as the location of hazardous materials storage facilities in low-density areas. The design used fire chiefs to provide information concerning their fire departments and the status of programs serving Connecticut's 169 towns. The telephone interview data were used to measure fire chiefs' awareness, perception, attitudes, and experience with various aspects of hazardous materials transport in the state, including routing and siting issues.

Drawing on a list provided by the state fire administrator, interviews were conducted with chiefs of fire departments serving the state's 21 largest cities and towns. Another 74 interviews were completed with fire chiefs selected from half of the remaining 148 towns. This stratified random sample can be weighted to represent all 169 towns in the state (*17*).

Data Analysis

The collected data were analyzed in two stages. In the first stage, some descriptive statistics were derived to determine whether there was a universal consensus among the decision makers regarding the tradeoff questions. In the second stage, the data were cross classified according to a set of variables that described personal, demographic, and locational characteristics of these decision makers. This type of cross classification was deemed necessary to examine the effect of the classification variables on the preferences.

Descriptive Findings

The study population of fire chiefs had a median age of 45 years and served 60 small towns (1980 population up to 7,500), 89 midsized towns (7,500 to 39,999), and 20 big cities (40,000 and over). According to the State of Connecticut Functional Classification System, 65 percent of the sampled towns are in the path of an expressway, and another 67 percent have at least one principal arterial highway. In combination, 46 percent of the towns have both an expressway and a principal arterial highway, while another 40 percent have one or the other. Approximately 40 percent of the fire chiefs said they were well informed in dealing with hazardous materials transport problems, but the majority described themselves as only partially informed. They divided equally (49 percent well informed) in selecting these terms to describe how much they know about the hazards of specific materials such as gasoline, propane, sulfuric acid, and incinerator ash. About 43 percent had received over 40 hr of hazardous materials transport training during the past 3 years; they also reported an average (median) of 7 years of work experience related to hazardous materials transport.

Other survey questions measured the inevitable tradeoffs that affect public policy development (e.g., economics versus safety, risk distribution and safety, and risk-related siting decisions). The following question illustrates one of these tradeoffs:

> To maximize the safety of hazardous materials transported to manufacturing facilities, it may be necessary to raise the price consumers pay for certain products. All things considered, do you prefer increasing safety in hazardous materials transport even if that means increased prices, or do you want to keep consumer prices down even if that means there is no increase in hazardous materials transport safety?

Nine of 10 (93 percent) fire chiefs opted for increased safety and higher prices, and 5 percent endorsed no increase in safety or prices. The fire chiefs were clearly safety minded. At the same time, they were reluctant to support restricted routing regulations that would entail an economic cost to the town they serve (e.g., providing escorts for hazardous materials shipments on town routes). A meaningful comparison on safety versus price, of course, would involve a study population of shippers and carriers, manufacturers, and legislators.

Another tradeoff was described in the following question: "How often do you think putting a hazardous materials facility in a low-risk location means increasing the risk to people along the route leading to that facility?" Three out of 10 fire chiefs answered "all the time" to this tradeoff; the remainder (69 percent) responded "sometimes." The issues here are far more complex than those of the price versus safety question.

The final tradeoff question read as follows: "It's a good idea to store hazardous materials in rural areas, because most people live in cities and suburbs." In this instance, the sample was equally divided: 53 percent agreed, 45 percent disagreed, and 2 percent couldn't offer a response.

There are some factors that contribute to the cleavage among fire chiefs in their assessment of these different questions. The population size of the towns and cities fire chiefs serve is likely to offer insight into their approval of (or opposition to) rural hazardous materials storage facilities, as would self-described expertise and reported experience with hazardous materials transportation.

Bivariate and Multivariate Analysis

A set of classification variables describing (a) expertise of the fire chiefs in hazardous materials management, (b) experience of the fire chiefs, (c) location of the town in relation to the major transportation corridors, and (d) town population was used to account for the preferences of the fire chiefs. These variables were derived from the questionnaire survey as follows:

1. Index of expertise (EXPERT): This index was derived from two survey items. The first question was, "In dealing with hazardous materials transport problems, would you say you are well informed, only partially informed, or not informed at all?" (Well informed = 1, all others = 0). The second item read, "How well informed would you say you are on the hazards of specific materials such as gasoline, propane, sulfuric acid, and incinerator ash? Would you say you are well informed, only partially informed, or not informed at all?" (Well informed = 1, all others = 0).
2. Index of experience with hazardous materials (ZEXPER): This index measured experience with hazardous materials transportation from the following items: "How many hours of hazardous materials training have you had in the last three years . . .?" (41 hr or more = 1, 40 hr or less = 0); and "How many years of work experience have you had related to hazardous materials transport?" (8 years or more = 1, less than 8 years = 0).
3. Index of highway systems (HIGHWAY): This index measured experience with hazardous materials transport from the following items: "Expressway intersects town?" (Yes = 1, no = 0) and "Other principal arterial?" (Yes = 1, no = 0).
4. Town population, 1980 (POP3): (40,000 and over = 3, 7,500–39,999 = 2, under 7,500 = 1).
5. Store in rural areas (RURAL): (Agree = 1, disagree = 0).
6. Hazardous materials facility in low-risk area (RISKLOC): (All the time = 1; sometimes, etc. = 0).

Results

A series of two-way tables predicting RURAL and RISKLOC on the basis of the four independent variables produced the following results. Fire chiefs in the large and midsized cities and those scoring high on self-attributed expertise on hazardous materials matters were more likely than their counterparts to agree that it is a good idea to store hazardous materials in a rural area, away from population centers. The index of expertise used here is based on self-attribution and would be improved if information were available concerning certification of hazardous materials training. However, support for this policy position is not directly related to hazardous materials work experience or to a town's score on the highway system index. (Table 1 presents a summary of results.) At the same time, none of these predictor variables significantly predicted responses to the item concerning risk to nearby residents along routes leading to a low-risk location.

Risk estimation studies have indicated that the public-at-large and technical experts employed by large organizations differ substantially in their appraisals of risk. For example, state and local government agencies frequently make judgments about risk in conjunction with the development of policies concerning the siting of facilities considered obnoxious by the public-at-large. The hazardous materials transport system addresses these issues as well. For this reason, self-designated expertise is a significant factor in the support of rural hazardous materials storage facilities. That fire chiefs serving big and midsized communities would be twice as likely as their counterparts in small communities to opt for rural storage facilities is not surprising.

However, the larger the community the greater the likelihood of having self-contained breathing apparatus, encapsulating suits, and detection equipment to deal with hazardous materials. In addition, the larger cities probably maintain an array of fire suppressant equipment, trained emergency responders, and emergency room mitigation teams. In brief, notwithstanding their greater capacity for effective community response, metropolitan area fire chiefs favor exporting this form of risk to less populated areas.

The critical question concerning expertise is the following: Is judgment on the siting of storage facilities anchored exclusively in the self-interest of communities served by fire chiefs, or does expertise operate across the board, in towns of every size, on behalf of this policy? The data were disaggregated by city size to answer this question. The results are presented in Table 2. On a general linear model (*18*), the results clearly indicate that structural factors influence risk estimation. Expertise (self-defined) predicted support for rural hazardous materials storage locations among fire chiefs in the big and midsized cities, but not in the small towns. Table 2 also indicates the effect of expertise on support for this policy within the three categories of city size when each of the remaining variables is statistically taken into account.

In the small towns, none of the predictor variables (self-defined expertise, type of highway system, and work-related hazardous materials experience) accounted for the position taken by fire chiefs on this matter. In midsized and large cities, the results were noteworthy; only expertise explained the difference, and expertise predicted a preference for rural sitings among those fire chiefs serving large and midsized cities even when type of highway system and experience were taken into account.

CONCLUSIONS

Hazardous materials routing and siting decisions involve multiple and conflicting objectives. These objectives represent the interests of the various groups affected by the decisions.

Multiple-objective programming formulations, which have been proposed to solve the hazardous materials routing and siting problem, require the intervention of the decision makers to identify the best compromise solution. However, the determination of the best compromise solution is affected by the background of the decision maker and the size of the community served. One of the findings of this study was that fire chiefs assigned a higher priority to the safe transport of hazardous materials than to transport costs. There was general concern on this issue. When it came to the question of financial commitments necessary to achieve higher safety levels,

TABLE 1 CORRELATES OF SUPPORT FOR SITING AND ROUTING POLICIES

CORRELATE	RURAL (% AGREE)	RISKLOC (% "ALWAYS")
POP3		
"Big" City	60%*	35%
"Mid-sized"	62	27
"Small"	37	30
EXPERT		
"High" (2)	78%*	24%
"Middle" (1)	39	33
"Low" (0)	43	31
EXPERIENCE		
"High" (2)	58%	28%
"Middle" (1)	55	26
"Low" (0)	46	35
HIGHWAY INDEX		
"High" (2)	59%	31%
"Middle" (1)	47	29
"Low" (0)	50	25

Note: Chi square not significant at .05 level if asterisk is missing.

TABLE 2 REGRESSION ESTIMATES FOR RURAL VARIABLE BY TOWN SIZE WITH SELECTED CONTROLS

Dependent Variable	Independent Variables EXPERT HIGHWAY ZEXPER
RURAL	POP3 = 1 (Small)
b Value	-.020 -.073 .170
p	.923 .725 .407
RURAL	POP3 = 2 (Mid-Sized Towns)
b Value	.375 -.039 -.105
p	.025 .733 .520
RURAL	POP3 = 3 (Large Towns)
b Value	.456 -.039 -.076
p	.065 .869 .750

however, the fire chiefs also indicated that they were not ready to use strategies that would require municipal financial expenditures (e.g., escorts) to achieve this goal.

Another finding related to the siting of hazardous materials storage facilities. The survey question asked whether hazardous materials should be stored in low-density (rural) areas. The analysis of the survey data indicated that the fire chiefs were biased in siting decisions by the self-interest of the community they served. This conclusion stemmed from the finding that self-defined expertise predicted support for a rural location of hazardous materials storage facilities among fire chiefs in the big and midsized cities but not in the small, rural towns. Overall, these findings offered additional evidence that social and other structural criteria (*19*), as well as objective technical features of decision making, affect risk assessment in this policy arena.

ACKNOWLEDGMENTS

The authors acknowledge the support of the University of Miami, Office of Sponsored Programs, and the U.S. Department of Transportation, Region I, Transportation Centers Program, Massachusetts Institute of Technology, in the conduct of the research for this paper.

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