Selecting Criteria for Designating Hazardous Materials Highway Routes

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Passage of the 1990 Hazardous Materials Transportation and Uniform Safety Act in the United States will result in state designation of hazardous materials through routes. Several alternative criteria have been recommended for consideration in implementing this policy, many of which represent explicit trade-offs in terms of safety and operating efficiency. The impact of using alternative criteria and criteria weighting for route selection is explored. This is examined through the use of a network analysis tool designed explicitly for hazardous materials distribution risk management. A study region consisting of the truck highway network in Southern California is used to illustrate several considerations that will need to be addressed during the implementation process. A number of findings are reported concerning route selection, risk equity, public perception, and emergency preparedness. Collectively, they identify the types of problems that may be encountered in the establishment of routing guidelines by the states, implementation of state route selection procedures, and issues related to federal preemption. Areas in need of additional study are also described, with an eye toward establishing some standardization in approach and perhaps analysis tools that would satisfy both state and industry concerns.

The safe movement of hazardous materials (including wastes) is receiving increased attention because of growing environmental awareness of the potential health effects of a release-causing incident. Pressure has been placed on the regulatory process to designate routes for dangerous goods transport that emphasize safety considerations. Notwithstanding the importance of operational safety, the efficiency with which these movements occur remains an important objective.

The significance of this problem is apparent. It is estimated that 1.5 billion tons of hazardous materials are shipped annually across the nation's transportation systems (excluding pipelines); moreover, these volumes are growing (*1*). As these shipments occur between large numbers of shipping and receiving points in the continental United States, routing policy will have a profound effect on the pattern and volume of hazardous materials flow.

The impact of using alternative criteria and criteria weights for the selection of designated hazardous materials transport routes is explored. This analysis has been motivated by the provisions of the 1990 Hazardous Materials Transport and Uniform Safety Act, in which multiple criteria have been suggested for consideration in determining highway route selection. Several important findings are reported that have the potential for significantly influencing policy and program implementation in this area.

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The analysis was performed using HazTrans, a risk management, routing, and emergency planning software tool, designed explicitly for application to the transport of hazardous materials. (HazTrans is a registered trademark of Abkowitz and Associates, Inc.) Although HazTrans is capable of representing any point-to-point movement by highway, rail, barge, or intermodal transport in the continental United States, this analysis was purposely focused on highway shipments of hazardous materials in Southern California. Restricting the geographical area of interest to a relatively small study region was sought to demonstrate that even for a limited application, major findings emerge with significant policy implications. Not only do these findings appear to be transferable to other geographical regions of the country, but the issues have the potential for becoming more contentious with increasing shipment length and number of states involved.

SYSTEM DESCRIPTION

Conceptually, HazTrans consists of two major components, a mapping system and an analysis methodology, which are fully integrated. The mapping system uses geographic information systems referencing that enables the user to display color maps of the continental U.S. highway network or subsystems (e.g., Interstate highway system only), and provides the capability for the user to "zoom" into or out from a geographical area at whatever level of precision is desired (*2*). The mapping system also permits labeling of the highway network from a choice of several descriptors, such as route number, city name, segment number, and segment length (*3*).

Once a routing analysis has been conducted, additional features are included in the mapping system to permit the user to observe the analysis results on the screen. These include color-coded drawings of the most effective route based on the routing criteria selected by the user, relevant evaluation measures for the selected route, and an ordered listing of route segments traversed from the point of origin to the shipment destination.

The routing analysis component consists of the following features: (*a*) system selection, (*b*) criterion selection, (*c*) origin and destination specification, (*d*) node/link inclusion or exclusion, and (*e*) highlight identification.

Criterion selection allows the user to identify which routing criteria to apply to the analysis. Presently, five criteria and several variations are available for selection: (*a*) minimize shipment distance, (*b*) minimize travel time, (*c*) minimize release-causing accident likelihood, (*d*) minimize population exposure, and (*e*) minimize "risk" as defined by federal routing criteria guidelines (*4*). Travel time on the road network is derived using formulas developed by the American Association of State Highway and Transportation Officials and the Federal Highway Administration (*5*).

If population exposure is selected as a routing criterion, the user is asked to specify the bandwidth of exposure from the transport segment from a choice of 0.25, 0.50, 1, 3, 5, and 10 mi. These distances correspond to evacuation distances for various hazardous materials according to the DOT *Emergency Response Guidebook* (*6*). Population is computed directly from U.S. Bureau of the Census digitized residential population files, overlaid on the respective transportation network (*7*).

If release-causing accident likelihood is selected, accident rates are derived on the basis of truck accident rates involving hazardous materials movements for the different functional classifications that appear in the U.S. highway network (*8*). Release probabilities are based on various container configurations and highway location (*9*).

Beyond representing the classic definition of risk (release-causing accident likelihood multiplied by exposed population), the analyst may also distinguish between technical and perceived risk, so that differences between public perception and technical judgment can be identified and addressed by the risk communication process.

The user is not restricted to a single criterion selection for each analysis. Rather, multiple criteria may be selected, and the user can adjust the weights on each criterion to reflect the importance of each in defining an effective route. This feature is extremely useful for assessing the implications of selecting preferred routes on the basis of alternative criteria and ranking of their importance (*10*).

Origin and destination selection permit the user to specify the movement under consideration. These shipping and receiving locations can be identified by either designating an appropriate point in the transport network or selecting an appropriate zip code.

Node/link inclusion or exclusion are powerful techniques for requiring a shipment to pass through or avoid specific locations during the conduct of an analysis. This permits the user to identify the most effective route if the shipment must pass through a location, either to drop off or pick up a partial load, or because routing regulations require the use of a certain transport segment. It also provides for avoidance of locations where routing restrictions apply or it is determined that the location is unsafe due to excessive accident likelihood, population exposure, or some other reason. In cases where the user wishes to perform a risk assessment on a specific route, the route restriction function can be used to designate this route for exclusive consideration.

Highlight selection allows the user to specify conditions of road segments, which, if not met, can result in either identification of these sites on the map or the exclusion of these segments from analysis consideration. For example, what might appear to be the preferred route for a shipment in terms of the entire movement from origin to destination could pass through individual network segments where accident likelihood or population exposure exceeds a level that the user may consider to be unacceptable. The user can subsequently determine whether to impose special conditions on these high-hazard locations, such as the use of escorts, or could remove the segment from subsequent routing consideration.

HazTrans also comes with a powerful editing capability that allows the user to query the characteristics stored within any physical segment of the road system. When this information is displayed, the user may opt to change certain characteristics to reflect updated status (e.g., new accident rates) or to handle "what if" scenarios (e.g., lane expansion). Both temporary and permanent changes to the system can be accommodated through the edit feature.

ANALYSIS METHODOLOGY

The five criteria available for consideration represent a wide range of safety and efficiency issues associated with hazardous materials shipments. Minimization of distance or travel time reflect the way in which hazardous goods would be moved in the absence of any constraints imposed by safety regulation. Most carriers would operate under minimum travel time conditions, favoring Interstate and other major highways in lieu of minor roads that may save a few miles but take much longer to traverse.

Minimization of release-causing accident likelihood and population exposure represent separate safety components. Taken collectively, however, they represent the traditional definition of risk, consistent with the definition of risk used in federal routing criteria guidelines (*4*):

$$\text{Risk} = \sum_{i=1}^{n} (\text{RATE}_i)(\text{POP}_i) \qquad (1)$$

where

n = total number of segments composing the route,
RATE_i = release-causing accident rate on Segment i, and
POP_i = exposed population within a specified distance band on Segment i.

This measure is unitless in dimension, although it is extremely useful for comparison purposes among various routing alternatives.

To structure the analysis methodology, therefore, travel time and risk were selected as criteria of primary interest. Population exposure embedded in the risk measure was defined as the population residing within a 5-mi band of the transport segment. This corresponds to a typical evacuation range for poisonous-by-inhalation chemicals such as chlorine.

The transport network selected for the analysis was the highway network in Southern California. All Interstate, state, and U.S. highways in Southern California were represented, and a variety of shipment origins and destinations were specified for analysis consideration. As mentioned previously, the limiting of the application to such a small region does not appear to have compromised in any way the transferability of the results to intrastate movements in other states or to interstate transport.

ANALYSIS RESULTS

The following discussion documents the results of a number of routing analyses performed in the study area on the basis of the prescribed methodology. Several cases are reported, each illustrating important findings from this exercise.

Case 1: I-10 at Arizona Border to Vandenberg, California

A number of analyses were performed on this shipment using alternative criteria and criteria weights. These ranged from a route designation based on minimizing travel time to one based on minimizing risk. Several additional applications were performed in which both criteria were considered simultaneously, applying corresponding weights to each criterion reflecting various levels of relative importance (e.g., 75 percent travel time minimization, 25 percent risk minimization; 50 percent travel time minimization, 50 percent risk minimization; etc.). In this fashion, the full spectrum of safety and economic trade-offs could be investigated.

Figure 1 shows a map of four distinct routes that emerged from this process. Route 1 represents the route that minimizes travel time. Route 2 was selected on the basis of applying routing criteria with a 75 percent weight on travel time minimization and a 25 percent weight on risk minimization (the same route was obtained when risk and travel time were weighted equally). Similarly, Route 3 represents an application of criteria with a 25 percent weight on travel time minimization and a 75 percent weight on risk minimization, and Route 4 is based exclusively on risk minimization.

Several observations are apparent when reviewing these results. First, the application of different criteria and criteria weights results in the selection of different preferred routes. Although this result may be intuitive, this finding confirms that when risk criteria are applied, routes other than what would currently be used by industry are selected. It also suggests that this may become a contentious issue since carriers would be required to take a more circuitous route if risk minimization is mandated or recommended as a route designation guideline.

Another important and related finding is that if designated routes are based solely on risk minimization, they result in selection of routes that are so circuitous that they appear to be economically infeasible. As noted in Table 1, Route 4 more than doubles the travel time compared with the minimum travel time route (Route 1). Furthermore, although this route minimizes risk because of the low population exposure, the likelihood of an accident actually increases because of the longer time exposure and use of lower-quality roads. This suggests that any reasonable system of designated routes must seek a compromise solution that introduces improved safety without making the trip extremely cumbersome. The important implication of this finding is that routing regulation should not be based exclusively on finding the least-risk route. This implies that regulators should focus on practical improvements to safety rather than risk reduction as an absolute goal.

Fortunately, this case also illustrates that this problem may be reconcilable by finding advantageous trade-offs between travel time and risk achieved by adjusting criteria weights. As can be seen in Table 1, Route 2 (75 percent travel time minimization, 25 percent risk minimization) identifies a route that, compared with Route 1, introduces only a 3 percent increase in travel time while reducing risk by 70 percent. This trade-off would improve public safety considerably with a negligible effect on carrier efficiency. Similarly, Route 3 introduces an 8 percent increase in travel time while reducing risk by 82 percent.

Emergency Response

The trade-off introduced by evaluating economic and safety criteria becomes even more complex when emergency preparedness is included in the decision process. A data base of California Highway Patrol response locations was used to evaluate response coverage to segments of the routes shown

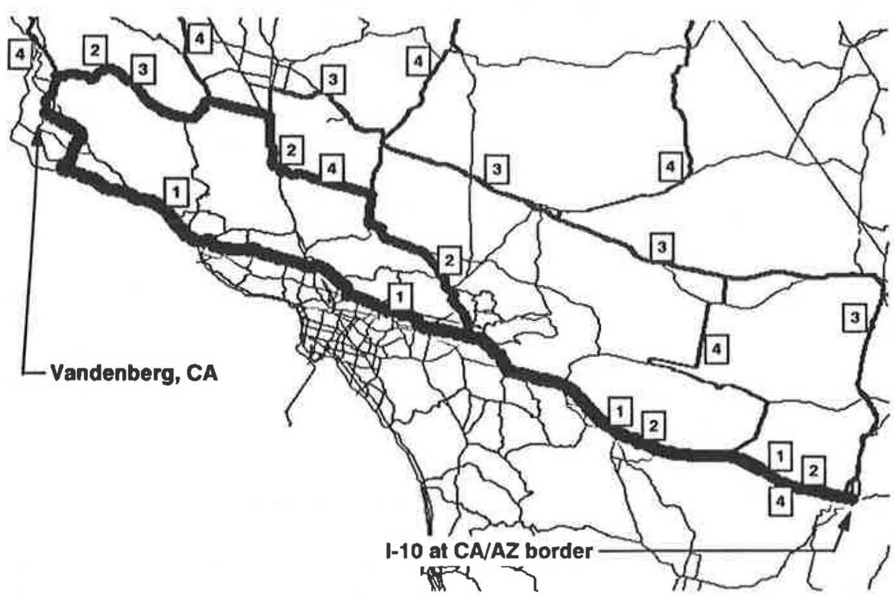

FIGURE 1 I-10 at Arizona border to Vandenberg routing application.

TABLE 1 CASE 1 ROUTE ANALYSIS IMPACTS

Route	Distance	Travel Time	Population	Accident Likelihood	Risk
1	388.88	7h 55m	3,059,409	0.000306	17.84
2	435.29 +12%	8h 11m +3%	819,688 -73%	0.000376 +23%	5.44 -70%
3	493.14 +27%	8h 32m +8%	214,961 -93%	0.000433 +42%	3.17 -82%
4	973.83 +150%	19h 27m +146%	311,859 -89%	0.000613 +100%	0.92 -95%

in Figure 1. For the purposes of this illustration, adequate response coverage was considered to be on-site arrival of a response unit within 45 min of incident report. The results appear as follows:

Route	*Percentage of Route with Adequate Coverage*
1	100
2	97
3	83
4	55

The implication of these results is that routes that travel through heavily populated areas are also likely to have better response coverage. The impact of routing along lower-risk alternatives, therefore, might lead to situations in which incidents that do occur will be subject to lower-quality response. From purely a risk standpoint, this may be considered acceptable. However, from the standpoint of the individuals that reside along these routes, the potential for more severe health consequences can be expected. This suggests that if routes are going to be designated where adequate response does not currently exist, a reallocation of resources to improve response capability in deficient areas is necessary.

Case 2: I-40 at Arizona Border to Vandenberg, California

The only adjustment made for this case is the movement of the shipment origin slightly north to the I-40 border entry from Arizona into California. Route maps are shown in Figure 2, and the route analysis impact is given in Table 2.

As in Case 1, alternative routes are selected depending on whether the criterion is exclusively travel time or risk minimization. However, in this instance, Route 1 prevails across a spectrum ranging from exclusively travel time minimization through a weighting of 25 percent travel time minimization and 75 percent risk minimization. Route 2 appears only when risk minimization is the sole criterion. The trade-off at that point is a doubling in travel time for a much lower percentage reduction in risk.

This case illustrates three additional findings. First, the "inflection" point, the place at which different trade-offs emerge when considering multiple criteria, occurs at different criteria weightings than in Case 1 (see Figure 3). This suggests that a routing policy that sets specific criteria weights to be used in designating routes is not advisable.

Second, this case, when combined with Case 1, illustrates that even minor changes in the location of shipping points modify the transport network and correspondingly the routing alternatives. This result, considered in the context of the hundreds of thousands of daily hazardous materials shipments with different origins and destinations, suggests that a sophisticated network analysis tool will probably be needed to address these considerations.

Finally, this case demonstrates that some shipments will present more reasonable political solutions than others in terms of the trade-off between carrier efficiency and public safety.

Case 3: Capistrano, California, to Thousand Oaks, California

For Case 3, a new origin-destination pair was selected, representing a trip through metropolitan Los Angeles. Two routing

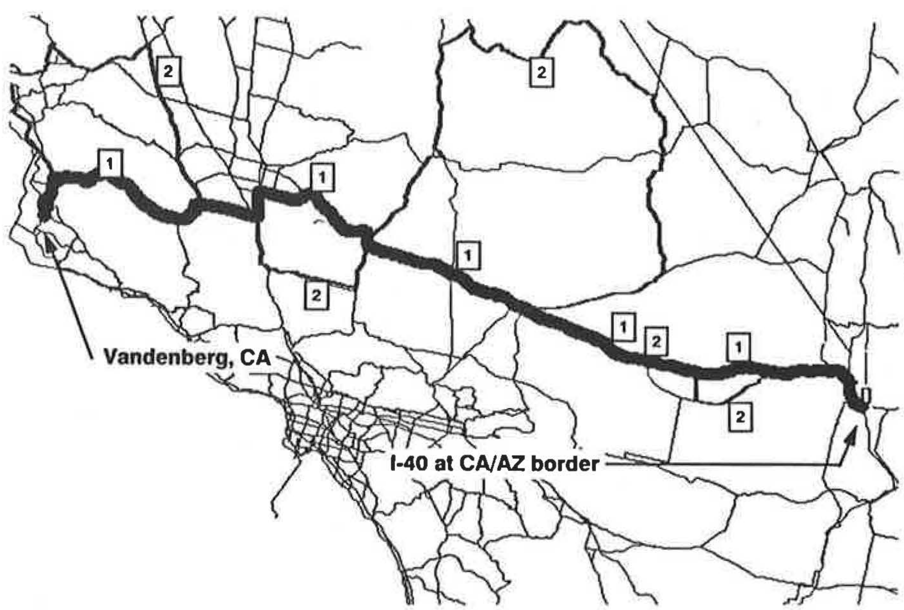

FIGURE 2 Routing from I-40 at Arizona border to Vandenberg.

TABLE 2 CASE 2 ROUTE ANALYSIS IMPACTS

Route	Distance	Travel Time	Population	Accident Likelihood	Risk
1	409.99	7h 5m	195,473	0.000350	2.37
2	864.65 +111%	17h 9m +142%	284,919 -46%	0.000540 +54%	0.76 -68%

analyses were performed, each focusing on the identification of the preferred route based on a criteria weighting of 25 percent travel time minimization and 75 percent risk minimization. The difference between the analyses is that in the first a risk-neutral risk preference is assumed, whereas in the second a risk-averse risk preference is represented. The population bandwidth used for this application was 1 mi.

Risk neutrality, or "technical risk," assumes that one incident causing 100 fatalities is equivalent to 100 incidents causing one fatality each, since in both cases one can expect a consequence of 100 fatalities. Risk aversion, on the other hand, associates a much greater risk with a single incident causing 100 fatalities than with 100 incidents each causing a single fatality. Risk-averse behavior is often thought to be more representative of public perception, particularly as the public views transportation safety. This is supported by public reaction to the very few airline accidents each year that result in multiple fatalities in contrast to highway accidents, which cause few fatalities per accident but result in nearly 50,000 fatalities annually on the nation's roadways.

Mathematically, risk preference is represented in the risk definition as follows:

$$\text{Risk} = \sum_{i=1}^{n} (\text{RATE}_i)(\text{POP}_i)^k \quad (2)$$

where

n = total number of segments composing the route,

RATE_i = release-causing accident rate on Route Segment i,

POP_i = exposed population on Route Segment i, and

k = risk preference.

In this formulation, a value of $k = 1$ would represent a risk-neutral position, whereas a value of $k > 1$ would represent risk-averse behavior, with greater levels of risk aversion associated with higher values of k.

The mapping and evaluation results of this analysis appear in Figure 4 and Table 3, respectively. As can be seen, the identified routes deviate from one another north of Los Angeles, with the risk-averse path traversing segments with greater accident likelihood but lower population exposure compared with the risk-neutral path. Although it might appear to be less desirable because of its higher accident likelihood, Route 2 emerges as the preferred choice under risk aversion because of the magnified effects of a small reduction in population exposure.

Although statistically the difference between these routes may not appear to be that great, it is important to recognize that the public would perceive a different preferred route in this instance than would be identified using a technical risk measure alone. This, in general, leads to a perplexing question as to which risk measure is more appropriate, since routing is inherently a public policy consideration. At a minimum, it suggests that if regulators use technical risk in their route designation studies, attention must be devoted to the identification of preferred perceived routes, with attempts made to educate the public to recognize the bias in their perception.

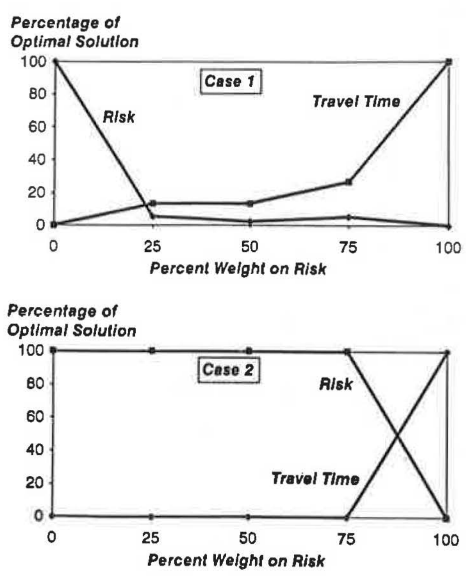

FIGURE 3 Comparative analysis of routing trade-off functions.

CONCLUSION

Several important findings have emerged in the course of this analysis:

- The application of different routing criteria and criteria weights results in the designation of different preferred routes. When risk criteria are included, routes other than those currently used by industry will be selected.
- Route designation based solely on risk minimization will result in the selection of routes that are so circuitous that they appear to be economically infeasible. Furthermore, they will typically lead to higher release-causing accident likelihood, although the consequences should an accident occur are likely to be less catastrophic. Any reasonable system of designated routes must seek a compromise solution that introduces improved safety without making the trip extraordinarily cumbersome.
- Routes that appear to offer reduced risk may often be accompanied by inadequate response coverage. If routes are going to be designated where adequate response coverage does not currently exist, resources should be committed to provide adequate safety standards.
- Advantageous trade-offs can be found among safety and economic criteria by adjusting criteria weights. However, the criteria weighting at which these benefits emerge and the magnitude of these benefits are shipment-specific. Consequently, rules that set specific criteria weights to be used for route designation are not advisable.
- Each origin-destination shipping pair defines a different network of routing alternatives, implying that preferred routes

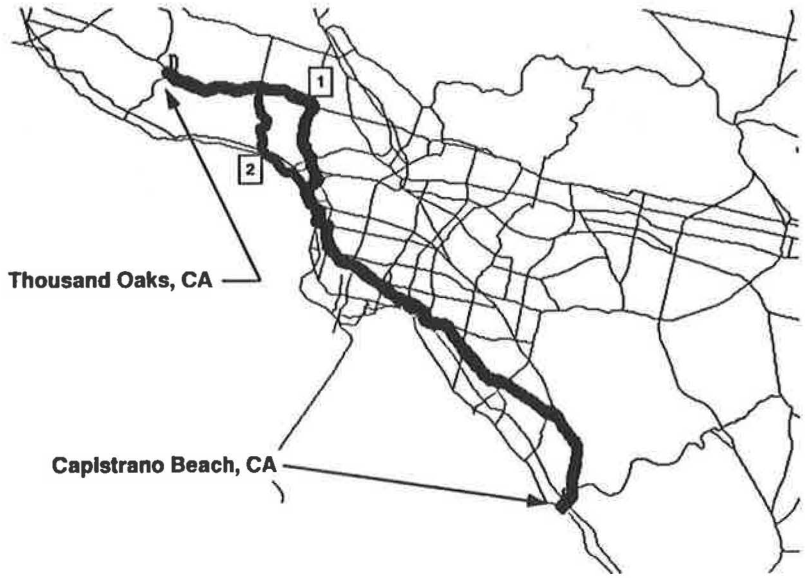

FIGURE 4 Capistrano Beach, California, to Thousand Oaks, California, routing applications.

TABLE 3 CASE 3 ROUTE ANALYSIS IMPACTS

Route	Risk Preference	Distance	Travel Time	Population	Accident Likelihood
1	Neutral	101.48	2h 47m	3,363,710	0.000064
2	Averse	101.33 -0.1%	2h 48m +0.6%	2,906,111 -14%	0.000090 +41%

could be shipment-specific. This raises the question of whether regulators should (*a*) designate a route network or (*b*) designate a methodology that shippers and carriers must use to select routes for the shipment under consideration, particularly for ultrahazardous materials. In either case, the use of sophisticated network analysis tools may be warranted.

• Public perception of preferred routes will differ from those identified on the basis of technical risk. These differences must be reconciled either through incorporation of risk perception into risk assessment methodology or through the risk communication process.

Collectively, these findings identify the types of problems that will be encountered in the establishment of routing guidelines by the states, implementation of state route selection procedures, and issues related to federal preemption. Additional study is clearly warranted, with an eye toward establishing some standardization in approach and perhaps analysis tools that would satisfy both regulatory and industry concerns.

ACKNOWLEDGMENT

Conduct of the analysis described herein was supported in part by the California Highway Patrol and Sandia National Laboratories.

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The views expressed in this paper are solely those of the authors and do not necessarily reflect those of the sponsoring agencies.

Publication of this paper sponsored by Committee on Transportation of Hazardous Materials.