MANY ROADS TO TRAVEL: ALTERNATIVE APPROACHES TO ROUTE SELECTION FOR YUCCA MOUNTATION SHIPMENTS

Fred Dilger (fcd@co.clark.nv.us)
Clark County Nuclear Waste Division
Las Vegas, NV 89101

Robert J. Halstead (bearhalstead@aol.com)
State of Nevada Agency for Nuclear Projects
Carson City, NV 80906

ABSTRACT
This paper examines the routing implications of the potential shipment of spent nuclear fuel and high-level radioactive waste to the proposed repository at Yucca Mountain, Nevada. The authors describe a model which can be used to evaluate the impacts of transporting spent nuclear fuel nationally and in the State of Nevada. The authors used this model to evaluate the cross-country highway routes identified in the DOE's Final Environmental Impact Statement and three alternative routing scenarios. The authors evaluate these routing scenarios based on four attributes: counties, exposed populations, total county populations, and shipment miles. The authors further evaluate the impacts of these alternative routing scenarios on two selected corridor states. The authors conclude that routing decisions have significantly different impacts on different state and local governments.

INTRODUCTION
This paper argues that route selection decisions for the shipment of radioactive waste to Yucca Mountain would have differential effects nationally and therefore must be evaluated at a national level. There are several reasons why the program to ship nuclear waste to Yucca Mountain would be uniquely appropriate for a national route selection scenario. First, spent nuclear fuel and high level waste are potentially more dangerous than other kinds of radioactive materials. Although the probability of an accident resulting in a release is low, the human health and economic consequences could be severe. Even during routine transportation, there exists the potential for occupational and public health effects due to routine radiation. Second, the Department of Energy's (DOE) program would have an extremely long duration and intensity- 24 to 38 years with up to 40 times more waste shipped than the total shipped in the US between 1964 and 1998 (1). Therefore, training first responders and other considerations cannot be once-off events, but will have to be sustained. Knowing where effects are most severe will be important. Third, unlike other HAZMAT shipments, carriers of nuclear waste will have little flexibility, except in emergency situations, once routes are selected. Finally, there have been many stakeholder discussions of desirable route attributes (e.g. low population exposure, low accident rate), but the national effect of these attributes has not been systematically evaluated.

This paper reports the results of modeling four alternate routing scenarios to Yucca Mt. The scenarios are compared on four attributes: County population, number of counties, exposed population, and shipment miles. These attributes were chosen to illustrate how this approach to modeling route selection can generate meaningful results. The paper concludes by providing an overview of alternate route evaluation attributes and describing how these attributes can be applied at a national level. The results of this modeling effort support three conclusions:

1. Modeling HLW transportation routes at a national scale is desirable because of the differential effects between various routing scenarios. Where effects take place and how many people are affected vary.
2. "Routing scenarios," alternative methods for route choice, can be tested to evaluate route attributes.

3. The profusion of modern analytical tools and publicly available data enable sophisticated analysis that will be employed in a policy arena. There is a difference between policy oriented analysis and operational analysis. Analytical tools have to be tailored to fulfill their particular role in this area.

This paper confines its discussion to truck shipments. There is currently no rail access to the Yucca Mountain site. DOE has not yet formally specified a preferred mode for repository shipments, nor has DOE demonstrated that rail access is feasible. However, the same approach to modeling rail shipments would be desirable. A model of the alternate rail routes has been developed. It is necessary to draw a distinction between operational and policy analysis and to describe how the modeling was accomplished.

GIS AS A POLICY TOOL

The ability to prepare this model highlights the maturation of Geographic Information Systems (GIS) technology from being the "solution in search of a problem" of the mid 1990's to a critical technology that offers great promise for policymakers. Although this paper is not about GIS per se, it reports on four alternative routing policies that are evaluated using a GIS-based model. The orientation and development of the model are relevant to discuss because the approach to the problem is different than previous analytical efforts.

It is important to draw a distinction between different types of GIS. For the purposes of this paper, we identify two types: operational and policy. The systems that were developed to support ongoing DOE operations-notably TRAGIS are operational systems-they suit the day-to-day requirements for routing truck and rail shipments, and performing radiological assessments. The policy model developed in this paper was constructed to support ad hoc requests made by decision-makers. Although this model can provide the same service as an operational GIS, this model was built to support policy activities. There are important differences between the typical capabilities of operational and policy GIS.

The operational GIS is typically built to exact specifications to solve a specific problem. For example, the TRAGIS model was constructed at Oak Ridge to support DOE operations. Therefore, it had to fit within the specific, predetermined requirements set for it by the clients. These requirements make TRAGIS an extensive and robust GIS. The TRAGIS model creates outputs for RADTRAN and other radiological assessment programs and does this well. However, these advantages also tend to make the operational GIS less flexible. Operational GIS' typically fit into a specific organizational context and so the "place" of the GIS is predefined. For example, land ownership data is used the same way for the same purposes across the nation-it fulfils a clear function in the organization.

The alternative model reported on here was originally built only to determine the shortest paths from the origin sites to the Yucca Mountain destination. However, when the notion of the model was first considered, it was not clear what the ultimate data requirements would be. Unlike the operational model, the policy model must be built for flexibility. What is important to decision makers is seldom predetermined. It is also necessary to be prepared to incorporate new data in a way that will permit exploration of new policy alternatives or even to generate new alternatives. In practical terms, this means the model must incorporate new data, work at any geographic scale and have superior display capabilities. Because policy is time-sensitive, the model must also be able to adapt rapidly. To implement the model it was necessary to assemble the software and data on a suitable hardware platform.

The software chosen was the TransCAD software prepared by Caliper Corporation. This software is the most widely used transportation modeling software in the US because. It is a full-featured GIS with integrated transportation planning modules that support regional transportation demand modeling, advanced supply-chain management, and geospatial analysis. The software is most commonly used for regional travel demand analysis. The algorithms to solve Hickson's problem (minimizing some route attribute) are already built into TransCAD. The next step was to select the data for the model.

The data chosen came from three sources: the data contained in the Bureau of Transportation Statistics National Transportation Atlas provided 1:100,000 rail and highway layers, census data and other common information. The Department of Energy (DOE) provided data about the sources of the waste and number of shipments. The DOE's Yucca Mountain Project office provided information about the rail and highway

routes through Nevada. The end result is that using freely available data it was possible to construct an extremely sophisticated model that effectively describes the national impacts of transporting these materials. The source data was verified by comparison with the data in the FEIS. The results of the routing model were validated by comparing more than half of these route results with route results from the DOE's TRAGIS model.

ADVANTAGES OF A MODERN GIS

The primary advantage of the TransCAD software is that it is fully topological, that is, the data structures used by the software contain information that relate spatial location among different data types. This permits enhanced data analysis and geographic operations. An example of the way this topological advantage assists modeling is in the calculation of exposed population.

An important policy goal in comparing alternative routing scenarios is to minimize the population exposed during the safe, routine transportation of this waste. Therefore the most accurate method for calculating exposed population is optimal. The challenge is to determine how many people live within 800 meters of either side of the routes on which the casks are transported. This must also be done across the entire nation.

In this case, the routes were calculated by minimizing a route characteristic defined by the routing scenario. Next, the census tracts through which the routes passed were selected and a buffer of 1600 meters was calculated around each link of the entire route-this created a 1600 meters buffer around all of the routes. Finally, the buffer was overlaid on the census tract layer to calculate exposed population. The steps described above are routine geographic operations. One way in which the differences between topological and non-topological mapping systems are manifested is in the way in which population is calculated.

Non-topological operations rely on centroids that contain data to determine population. When the centroids fall outside the buffer, the data is not included. This problem becomes acute in the Western US where census tracts are relatively large and the centroids further from the route. The problem is illustrated below:

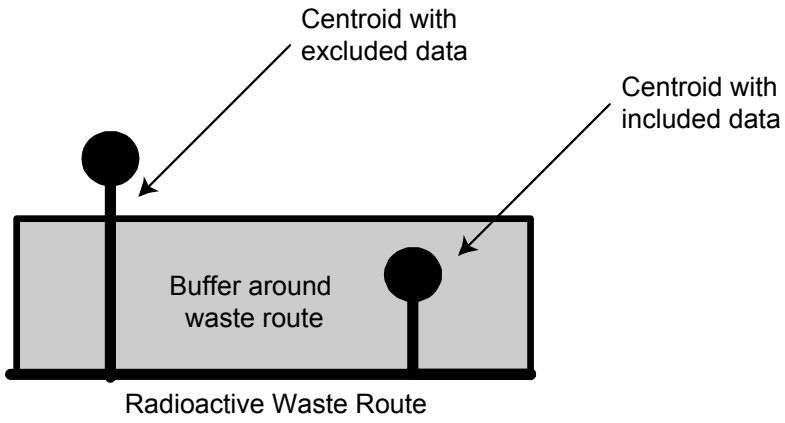

Figure 1 Problems with calculating population from centroids

For this model, a more sophisticated approach was taken. Exposed population was calculated by taking the percentage of the census tract's population included by the buffer. For example, if 1000 people live with the census tract and the buffer covered 20 percent of the tract, then the population calculated as exposed would be 200. This process is illustrated below.

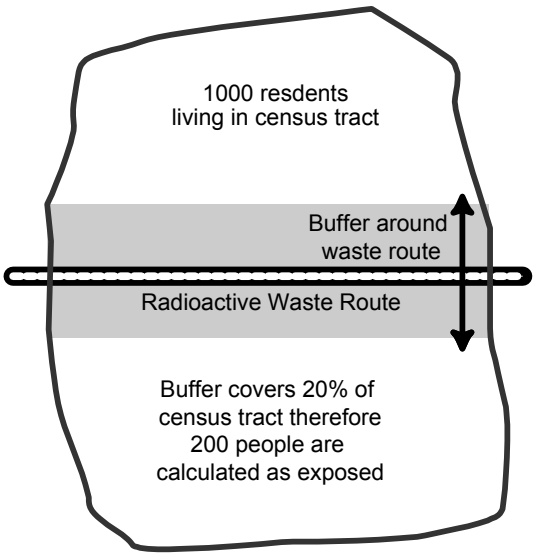

Figure 2 Buffer calculations of exposed population

There are two shortcomings with this approach. First, it includes only residential population. A previous analysis of a 16 mile long, potential route segment through Las Vegas estimated that total exposed population within one-half mile, would be three times greater than resident population when hotel/casino workers and guests were included (2). As the model develops, it will be possible to include time of day and to adjust exposed population numbers to fit to employment population data. Second, the distribution of population within the census tract is typically uneven. This problem is acute in the western US where development typically occurs close to the interstate routes. A percentage approach, taken in this paper is better than the centroid approach; however, it is well within current capabilities to determine where in a census tract the population resides. It will be relatively simple to incorporate aerial photography and pattern recognition to determine what percentage of a tract is developed and where the population resides. Despite these shortcomings, this method creates a better analysis number than using centroids.

One last comment on hardware is appropriate. The rapid improvements in hardware made all of this modeling possible on an obsolete laptop computer.

METHOD

The examination of the routes was deliberately constructed to support a decision science approach. By identifying and isolating specific route attributes that can be measured and compared, this kind of modeling supports a quantitative assessment of routes. The problem of radioactive materials route selection has already been famously treated by expert decision analysts (3). The rail routing modeling was used to construct a forecast of DOE's likeliest choice for the rail route to Yucca Mountain. However, this study demonstrates how this kind of modeling can be used to produce the inputs for structured decision-making. However, the authors did not present a formal decision analysis because the necessary value judgments-that are the key part of any structured decision analysis-would have to be inferred for a decision maker.

Evaluating routes nationally really means comparing alternative sets of routes. These sets are defined by some characteristic. The route evaluation began by creating four routing scenarios for comparison. A routing scenario is defined by the attribute chosen to be minimized from within the network of routes. The algorithm is applied to a network to determine the lowest value of some attribute from the origin to the destination. The TransCAD software by Caliper Corp. implemented the shortest path algorithm. TransCAD is also a full-featured Geographic Information System and so it allows a wide range of data to be incorporated into the model and complete presentation ability. The software uses two kinds of data types relevant for the analysis, first is a base network. The second is a route system that calculates the shipment routes and can then have shipment numbers assigned to each route for subsequent aggregation.

There is a wealth of other data that could have been included in this analysis that was omitted for simplicity: Indian reservations, metropolitan statistical areas, urban areas, environmentally sensitive areas, and accident rate data. All of this other data is readily available and can be used to improve analysis or to generate new alternatives. One of the critical benefits of this approach to modeling is that new alternatives (new routing scenarios) can be identified.

DESCRIPTION OF ROUTING SCENARIOS AND ATTRIBUTES

The choice of routing scenario is important because it ultimately sets limits on the analysis. In this case, each scenario was chosen based on previously published work or legally allowable action. This analysis examines questions of interest not only to Nevada, but also to dozens of potentially affected states and Indian tribes, and hundreds of local government jurisdictions.

Choosing between route attributes is important. There a number of different sets of attributes already at hand, for example, in the NWPAA and "The Guidelines for Selecting Routes for High Level Radioactive Waste Routes" (4, 5). In each case, the choice of route attributes appears to make a positive contribution to safety. For this analysis, the attributes were chosen based on available data related to near route populations, effected jurisdictions, and shipment miles (which are a surrogate for a variety of other attributes such as system costs).

The route attributes used are:

- County Population: the year 2000 census population living in counties through which the routes pass.
- Number of counties: the number of counties through which the routes pass. This is a useful measure of organizational complexity facing the routing scenarios.
- Exposed population: the year 2000 census population living within 1600 meters on either side of the centerline of the route.
- Shipment Miles: The cumulative number of miles traveled by the cumulative number of shipments.

These route attributes are intended to demonstrate that national modeling of these routes is possible. They are not presented as a conclusive set of routes. However, each variable was included for a specific reason. County Population is included to indicate the total number of people who may be affected by transporting these materials. The number of counties is presented as proxy attribute to indicate the degree of organizational complexity attributable to each of the routing scenarios. Counties are a relevant level of organization to consider because they are so important in emergency response. The exposed population is included for the obvious reason that it allows comparison of the number of people who will involuntarily receive doses of radiation. Shipment miles are a proxy indicator for other transportation system attributes such as costs and accidents. It is reasonable to expect that the more shipment miles, the greater the cost and the more likely an accident.

The remaining question is to show the national effects of different routing scenarios. The results of the analysis are displayed quantitatively and graphically using scaled symbol maps of the potential routes to Yucca Mountain that depict where the shipments will concentrate.

SCENARIO 1: SHORTEST PATH INTERSTATE ROUTES TO YUCCA MT.

The first map depicts how truck shipments of spent fuel would aggregate using the shortest, primarily interstate routes from the point of origin at the reactor sites (and DOE facilities) to the destination at Yucca Mountain. These are hypothetical routes only, since they ignore state designated preferred routes. This method was chosen because it depicts the most straightforward method of route selection.

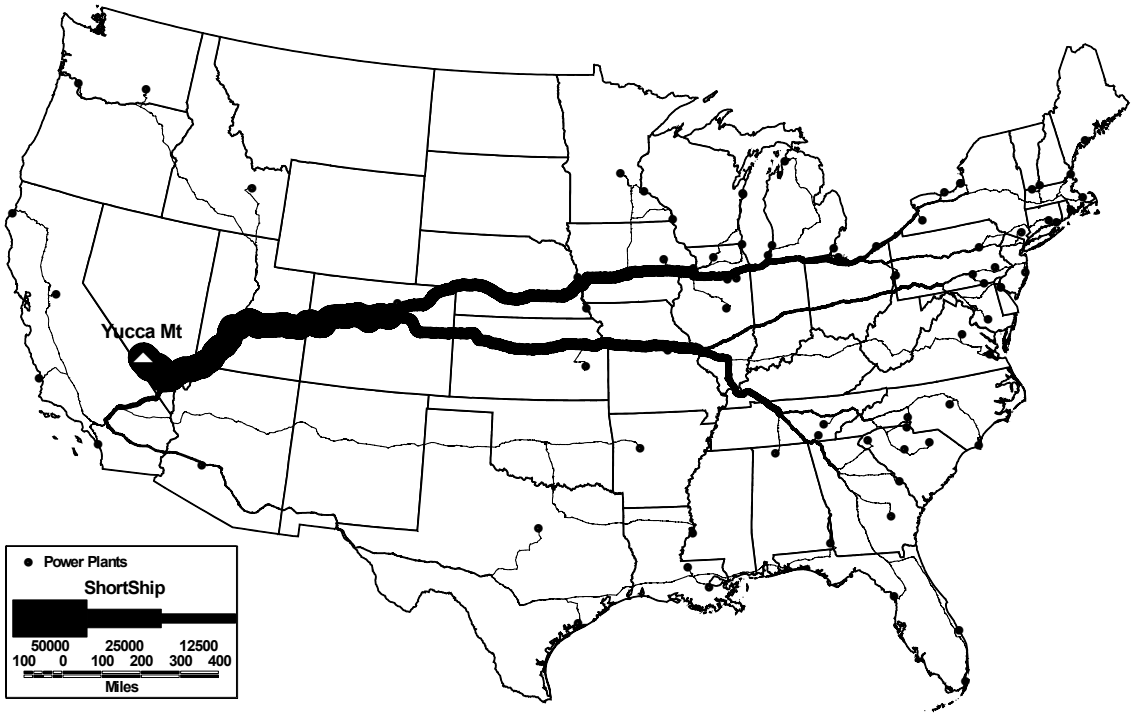

Figure 3 Potential interstate highway routes that minimize distance

The route attributes for this scenario are:

- County Population: 125,889,614
- Number of Counties 706
- Exposed Population: 15,180,685
- Shipment miles: 88,210,781

SCENARIO 2: REPRESENTATIVE ROUTES EVALUATED IN THE FINAL EIS

The second map depicts what DOE's FEIS called "representative routes" from the point of origin at the reactor sites (and DOE facilities) to the destination at Yucca Mountain. This set of routes conforms closely to the HM 164 exemptions that currently exist across the United States. That is, these routes take into consideration the state-designated preferred routes across the country.

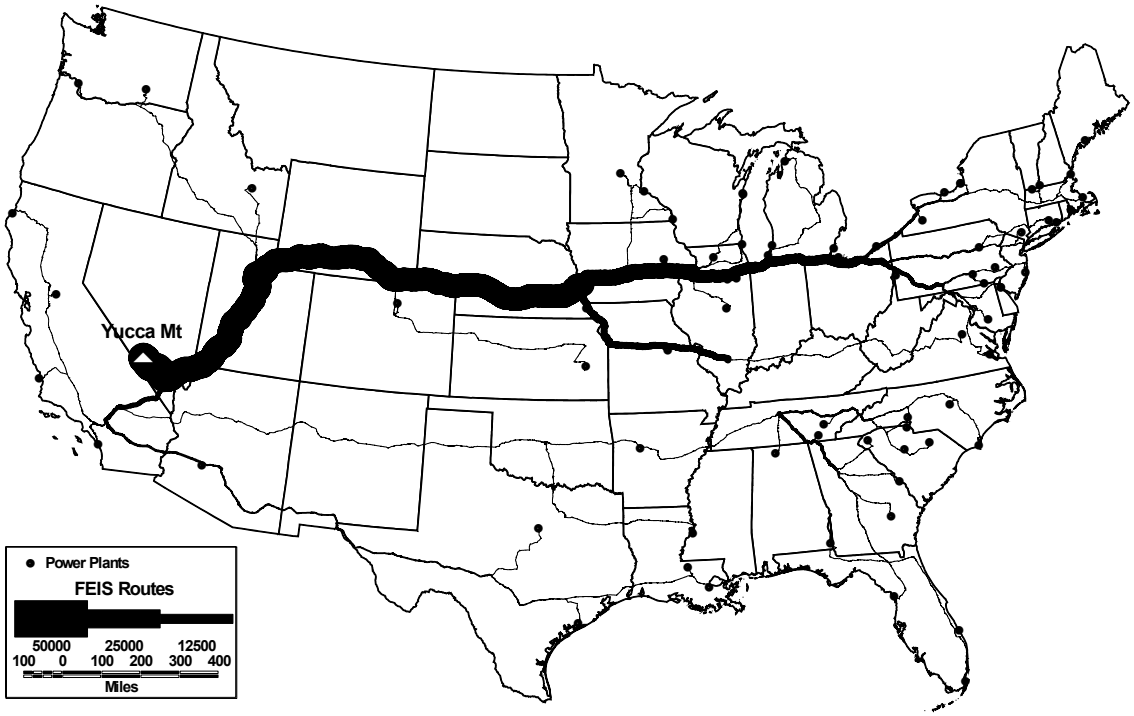

Figure 4 Potential Interstate routes identified in the Final EIS

The route attributes for this scenario are:

- Population: 124,144,342
- Number of Counties 687
- Exposed Population: 13,878,181
- Shipment miles: 92,212,284

SCENARIO 3: CONSOLIDATED SOUTHERN SHIPPING ROUTES

The third map depicts one potential alternative approach to cross-country routing identified in a 1996 contractor report for the State of Nevada Agency for Nuclear Projects (6). This scenario, developed by Planning Information Corporation, assumed that cross-country truck shipments might be consolidated on I-40 to avoid winter weather disruptions on I-80 through Nebraska and Wyoming, and to avoid conflict with the State of Colorado's intention to prohibit use of I-70 west of Denver to avoid shipments through the Eisenhower and Glenwood tunnels..

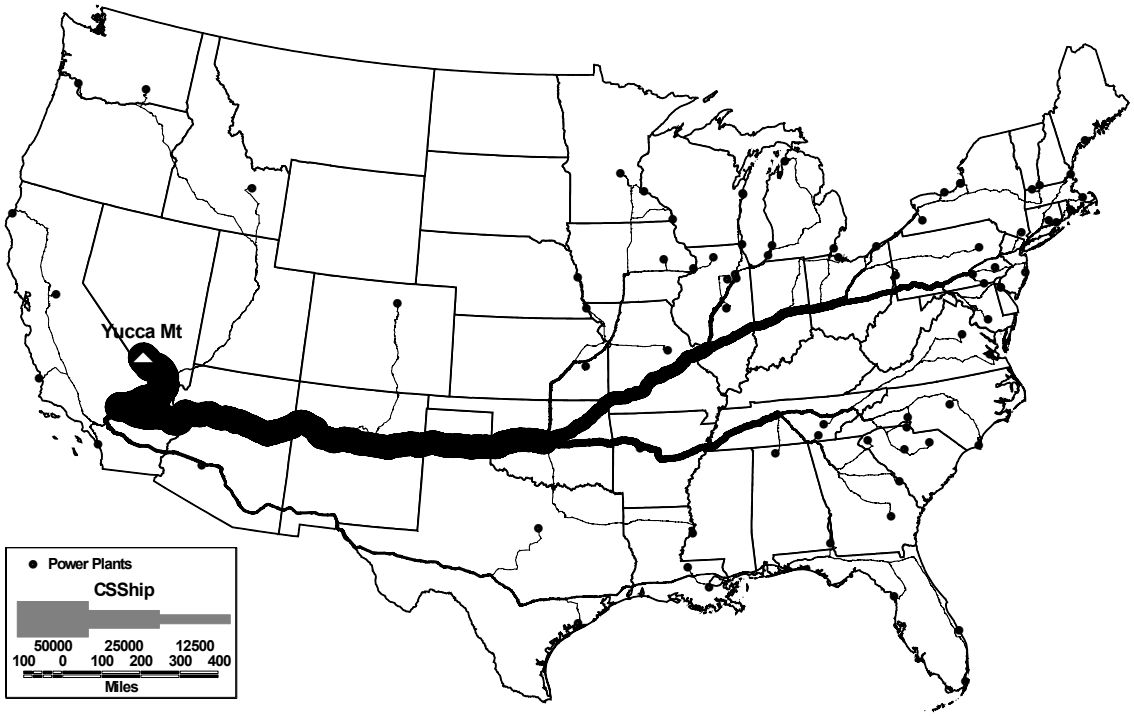

Figure 5 Potential Interstate routes that minimize use of I-70 and I-80

The route attributes for this scenario are:

- Population: 128,693,569
- Number of Counties 707
- Exposed Population: 12,252,469
- Shipment miles: 97,941,505

SCENARIO 4: HYPOTHETICAL NEVADA ROUTE DESIGNATION TO AVOID CLARK COUNTY

The fourth map depicts one combination of potential alternative routes identified in a contractor report prepared for the Nevada Department of Transportation (7). Under this scenario, there would be no shipments through Clark County. Most shipments from the east would enter Nevada from Utah on I-80. Shipments from California and the southwest would enter Nevada from California on SR 127. This scenario was prepared to test a State of Nevada designation, under HM 164, of routes that avoided the state's most populous county. It does not indicate any policy position taken by the State of Nevada. In the past, the State of California, and San Bernardino and Inyo counties have opposed the use of SR 127 for radioactive materials shipments.

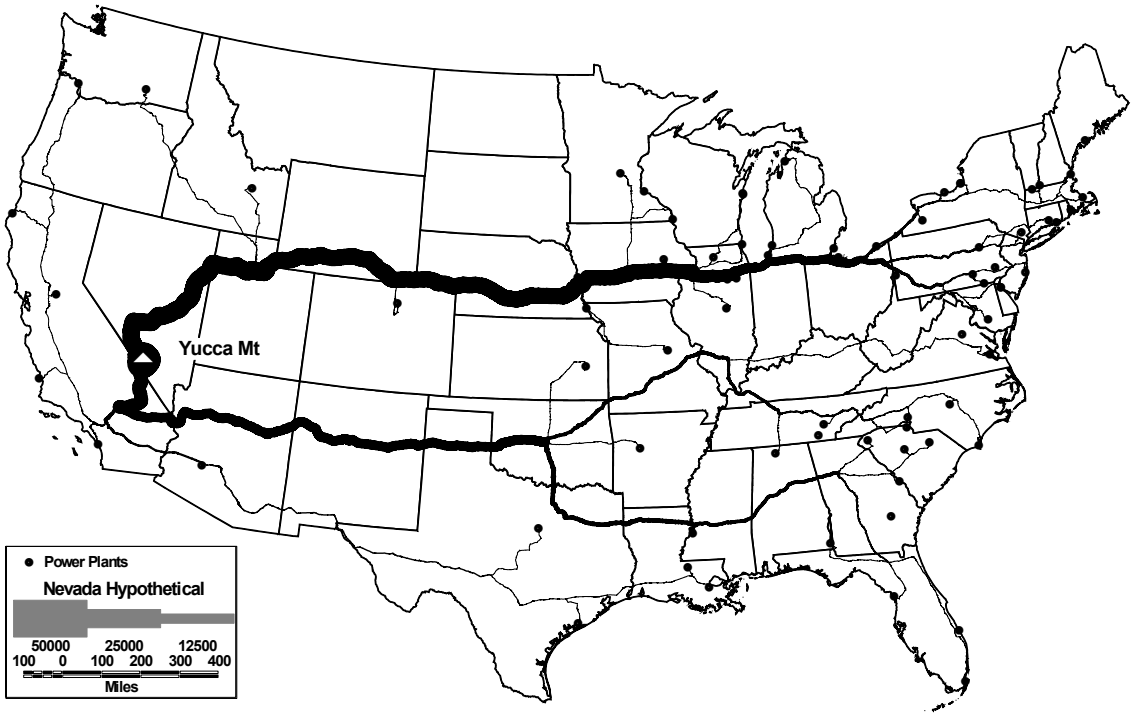

Figure 6 Potential Interstate routes resulting from hypothetical Nevada route designation

The route attributes for this scenario are:

- Population: 123,251,080
- Number of Counties 669
- Exposed Population: 11,393,646
- Shipment miles: 91,764,522

RESULTS OF THE APPLICATION OF THE ROUTE ASSIGNMENTS

The ultimate objective of this paper is to establish that evaluating routes on a national basis makes sense and to demonstrate that it is readily possible. The results of this evaluation are:

Table I Summary Table of Alternative Route Characteristics

	Population within 1600 meters	Shipment Miles	Population of Counties Traversed	Number of Counties Involved
Shortest Path	15,180,685	88,210,781	125,889,614	706
Final EIS	13,878,181	92,212,284	124,144,342	687
Consolidated Southern	12,252,469	97,941,505	128,693.569	707
Nevada Hypothetical	11,393,646	91,764,522	123,251,080	669

One of the main advantages of this analytical approach is that it quantifies the implications of various routing strategies on specific corridor states and counties. To our knowledge, such an effort examining the national impacts of realistic alternative routing scenarios has not been previously conducted.

DIFFERENTIAL EFFECTS ON SELECTED CORRIDOR STATES

A key conclusion of this paper is that the alternate routing scenarios have differential effects which vary from state to state. These effects vary considerably from state to state. To illustrate these differences, we

have evaluated these differential effects for the state of Utah and Illinois. The number of counties through which HLW will pass in Utah and Illinois are compared for each of the routing scenarios. Figures 7 and 8 compare only the representative truck routes in the FEIS with routes that avoid Clark County.

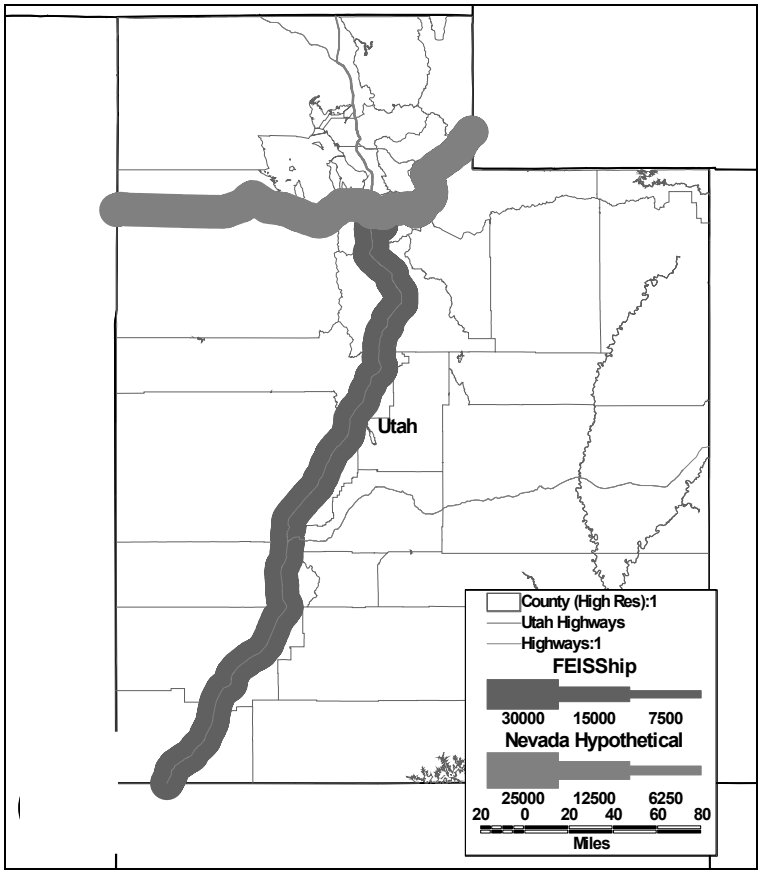

Figure 7 Alternative Routing Scenarios through Utah

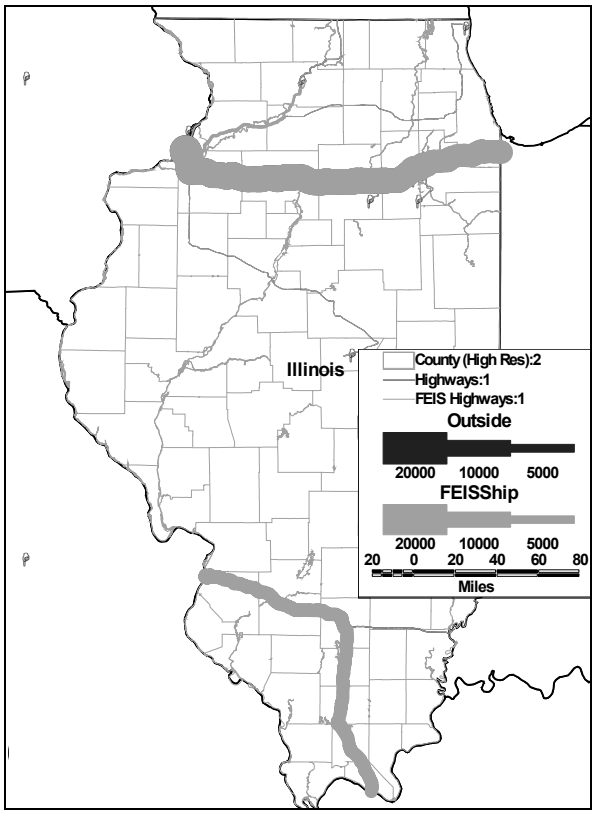

Figure 8 Alternative Routing Scenarios through Illinois

Table II Route scenarios compared for two states

	Utah Population within 1600 meters	Illinois Population within 1600 meters	Utah Shipment Miles	Illinois Shipment Miles	Utah Population of Counties Traversed	Illinois Population of Counties Traversed	Utah Number of Counties Affected	Illinois Number of Counties Affected
Shortest Path	211,662	804,619	12,524,447	4,679,737	1,495,949	9,315,508	13	37
Final EIS	142,846	2,112,776	12,848,862	3,593,633	1,480,809	10,743,664	12	66
Consolidated Southern	103,930	718,684	805,612	3,416,512	1,463,566	8,313,328	10	26
Nevada Hypothetical	119,344	2,112,776	4,719,434	3,593,633	1,152,556	10,743,664	7	66

The conclusion to be drawn from this comparison is that individual states and communities will be significantly affected by routing decisions and will therefore have an interest in how the routes are selected and optimized.

CONCLUSIONS

The authors conclude that it is necessary to examine route selection for HLW at a national level because of the differential effects those routes will have. Readily available analytical tools make it relatively simple to conduct such analysis and will be used to engage policy makers. The relative simplicity of constructing this model with accurate, readily available data suggests that the route selection process will have to be an open process.

The authors further conclude that future impacts of shipping HLW must be fully evaluated to help policy makers refine emergency management preparations, make appropriate changes to urban plans, as well as other changes that can mitigate the impacts of transporting these materials. The model described here can be enhanced to provide more useful insights into the effects of transporting these materials.

The most likely enhancement to the model will be to add additional data such as the established lists of route attributes included in the USDOT Guidelines. Some examples include: link-specific accident rate data, commodity flow data, Indian reservations, and environmentally sensitive areas. The purpose of adding this new data will be to test the attributes and determine the contribution the attribute makes to safety. Other improvements will be to identify new routing scenarios. The hypothetical example of Nevada's route selection suggests that direction. It is possible to evaluate any combination of routes for any of the attributes cited here as well as additional data for any affected state.

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