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HIGHWAY AND INTERLINE TRANSPORTATION ROUTING MODELS

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ABSTRACT

The potential impacts associated with the transportation of hazardous materials are important issues to shippers, carriers, and the general public. Since transportation routes are a central characteristic in most of these issues, the prediction of likely routes is the first step toward the resolution of these issues. In addition, U.S. Department of Transportation requirements (HM-164) mandate specific routes for shipments of highway controlled quantities of radioactive materials. In response to these needs, two routing models have been developed at Oak Ridge National Laboratory under the sponsorship of the U.S. Department of Energy (DOE). These models have been designated by DOE's Office of Environmental Restoration and Waste Management, Transportation Management Division (DOE/EM) as the official DOE routing models.

I. INTRODUCTION

The potential impacts associated with the transportation of hazardous materials are important issues to shippers, carriers, and the general public. This is particularly true for shipments of radioactive materials. Shippers are primarily concerned with safety, security, promptness and equipment requirements. The carriers are concerned with the impact that radioactive shipments may have on their operations—particularly if such materials are involved in an accident. The general public has also frequently expressed concerns regarding the safety of transporting radioactive materials through their communities. In addition, U.S. Department of Transportation (DOT) requirements mandate specific routes for shipments of highway controlled quantities of radioactive materials. Since transportation routes are a central characteristic in most of these issues, the prediction of likely routes is the first step toward the resolution of these issues.

In response to these needs, two routing models, HIGHWAY[1] and INTERLINE[2], have been developed at Oak Ridge National Laboratory (ORNL) under the sponsorship of the U.S. Department of Energy (DOE). Public access to both the HIGHWAY and INTERLINE models is provided by the TRANSNET system operated for Transportation Management Division of DOE's Office of Environmental Restoration and Waste Management by Sandia National Laboratories. DOE's Transportation Information Network, which is a communications network encompassing centralized computers, distributed workstations, and personal computing resources, supports the DOE nationwide transportation management mission and includes TRANSNET.

II. HIGHWAY

The HIGHWAY model provides a flexible tool for predicting highway routes for transporting hazardous and/or radioactive materials in the United States.

A. The HIGHWAY Data Base

The HIGHWAY data base is essentially a computerized road atlas that describes over 240,000 miles of roadways in the continental United States. The entire Interstate highway system, all U.S. highways (except those that parallel a nearby toll-free Interstate highway), most principal state highways, and a number of local and county highways are included in the data base. Data for each highway segment include highway designation, distance between end points, estimated average driving speed, whether a toll is charged, whether the link is located in an urbanized area containing over 100,000 people, whether the link is part of the routing network for route-controlled quantities of radioactive materials (HM-164), whether trucks are permitted to use the link, whether a tunnel is located on the link, and whether the link represents a ferry crossing. In addition to highway intersections, a number of nodes have been added to the HIGHWAY data base to represent DOE facilities, commercial nuclear power plants, and over 600 commercial airports around the U.S.

During fiscal year 1993, the HIGHWAY data base was extensively updated. This update included verifying the location of each link and node on state highway maps, the United States Geological Survey (USGS) 1:100,000 maps, Topologically Integrated Geographic Encoding and Referencing System (TIGER), or other suitable reference materials. Such data base checks are performed periodically to ensure that the data base is up to date and includes all newly constructed roads and existing highways that have been either renamed or rerouted.

The geographic information system (GIS) associated with the HIGHWAY routing model has also been upgraded to be consistent with TIGER data. The original HIGHWAY GIS was based on node points that were digitized from the USGS 1:250,000 scale topographical maps in the early 1980s. Under this system the links were represented by straight lines between the nodes. The enhanced HIGHWAY GIS system was generated by matching the existing straight line HIGHWAY links with the corresponding link information in the TIGER data set. The newly matched links, therefore have all of the attributes of the TIGER data including the road curvature between nodes. The enhanced GIS is currently being used to produce the map graphics for the HIGHWAY model. In addition to improving the representation of the link information, the new GIS system also includes the outline of all Indian Reservations in the continental United States. It is now possible to determine if a particular highway route would pass through an Indian reservation. These efforts will result in the issuance of a new HIGHWAY data base, (Version 94-1) later this year.

B. The HIGHWAY Routing Algorithm

The routing algorithms included in the HIGHWAY model permit the user to calculate several different types of routes by imposing one or more constraints during the routing calculations. Routes are calculated by minimizing the total impedance between the origin and the destination. Basically, the impedance is defined as a function of distance and driving time along a particular segment, and the program calculates the set of links between the origin and destination that minimizes these factors. The basic routing algorithm is shown in Eq. (1):

$$L = Min\sum_{i} (\alpha D_i + \beta T_i) \tag{1}$$

where

L = total impedance of a route;

α = distance bias;

D_i = distance of segment i, miles;

β = time bias;

T_i = time required to travel along segment i, minutes.

Setting the values of the time and distance biases defines a particular routing criterion. A number of different types of routes can be predicted. For example, if $\alpha = 1.0$ and $\beta = 0.0$, the shortest possible route will be calculated. Setting $\alpha = 0.0$ and $\beta = 1.0$, the most rapid or quickest route will be estimated. A compromise between these extremes is the "commercial" route, where α and β are defined to be 0.3 and 0.7 respectively. This criterion was used to generate the HIGHWAY-predicted routes that were verified through comparison with actual trucking routes used for a number of DOE shipments. Theoretically, the criteria outlined above could produce different routes between any two points. However, in practice, two or, occasionally, all three of the criteria will produce identical routes.

As noted earlier, one of the special features of the HIGHWAY model is its ability to calculate routes which conform to the DOT routing regulations for route-controlled quantities of radioactive materials, (49 CFR 177.825). Routes following these guidelines are frequently called HM-164 routes. Basically, the DOT regulations require that these shipments be transported over a preferred highway network, which includes: 1) Interstate highways, 2) an Interstate System bypass or beltway around a city, and 3) state designated preferred routes. State routing agencies may designate preferred routes as an alternative to, or in addition to, one or more Interstate highways. In making this determination, the state must show that the alternative preferred route is as safe as the Interstate route that it is replacing and must register all such designated preferred routes.

Frequently, the origin and destination of highway route-controlled shipments of radioactive material are not located on Interstate highways. The DOT routing regulations require the carrier to select the shortest distance route between the pickup location to the nearest preferred route entry location and the shortest distance route to the destination from the nearest route exit location. In general, HM-164 routes tend to be somewhat longer than the "commercial" routes discussed above.

Using these and other constraints available in the model, the user can find alternative routes or examine the impact of restricting movement through specified areas. The alternative routing capability is a useful tool for estimating a number of different routes between the same origin and destination. The HM-164 routing criterion was used to determine a series of alternative routes between Marshall, Michigan, and Phoenix, Arizona. These routes are shown in Fig. 1. The base route which passes through St. Louis and Oklahoma city extends for 1961 miles. The alternative routes are all longer routes with distances varying from 1982 miles to 2186 miles. Driving times for the routes shown in Fig. 1 vary from 39.67 h for the base route to 44.25 h for the longest alternative route. In addition to the mapping data, the HIGHWAY model produces a detailed route listing showing names of the highway traveled, distance, and estimated driving time.

The alternative routing algorithm will always generate different routes. However, some of the alternative routes may display only minor differences. Hence, it is necessary to review the results of the alternative routing calculations and reject alternatives that do not display meaningful differences.

In addition to the types of routes discussed above, several additional constraints can be imposed during the routing calculations. These constraints are frequently used to tailor routes for specific applications. An entire state can be bypassed, if necessary, to accommodate local legislation or to replicate specific carrier operating rights. Specific highway segments and/or highway intersections may be avoided by simply blocking transport along that particular road. Any combination of these constraints can be imposed at the same time.

In its basic form, the HIGHWAY data base is a computerized representation of the U.S. highway system. For routing analysis, the complete network is broken down, or decomposed, into a series of subnetworks representing highway systems in individual states, which are connected by border crossings. The use of state subnetworks allows some state-specific options, for example routing around a particular state, to be included in the model.

A modification of the shortest path algorithm is used in the HIGHWAY model to find the best route through a series of state subnetworks. The algorithm must route within a state and decide how to move between states. To do this, a two stage approach is used. The upper-level procedure treats states like nodes and border crossings like links. Once a state has been selected, the lower-level procedure then extends the tree within the selected state using a traditional shortest path approach. Routing constraints such as bypassing specific links and nodes are incorporated into the routing calculations by increasing the impedance of a link by a very large amount. When a route is constrained from passing through a specified node, the high-impedance penalty is applied to all links that emanate from that node. Once the high-impedance links have been defined, the routing algorithm will not use those links unless there is no alternative path with a lower impedance.

III. INTERLINE

The INTERLINE routing model is an interactive program designed to simulate the routing practices on the U.S. railroad systems. The railroad industry is composed of a large number of privately owned companies that compete economically while simultaneously cooperating through interchange agreements to efficiently move freight across the country. Each company generally owns its own network of rail lines. In some instances, a company may have operating rights on a rail line owned by another company. In order to simulate this aggregated system, the U.S. rail network is decomposed into a number of separate subnetworks. There are no specific routing requirements for rail shipments of radioactive materials,

Like the HIGHWAY program, a two-tiered shortest path algorithm is also used to evaluate rail routes in the INTERLINE model. The upper-level procedure is used to route between the various railroad systems and the lower-level procedure is used to generate the route within a specific railroad.

A. INTERLINE Data Base

The railroad network described in the INTERLINE data base is essentially a computerized rail atlas of the U.S. railroad system. All rail lines, with the exception of industrial spurs, are included in the network. Inland waterways and deep water routes along with their interchange points with the U.S. railroad system are also included in the network. The network contains more than 15,000 rail and barge segments and over 13,000 stations, interchange points, and other locations such as DOE facilities and commercial nuclear reactor sites.

The data base used in the INTERLINE model was originally obtained from the Federal Railroad Administration. This network has been extensively revised and is continually updated to reflect abandonments, company mergers, short line spin-off, and new rail-line construction. The network is composed of 93 separate subnetworks, where each subnetwork represents a separate railroad system. Additional subnetworks have been included to represent the waterway networks and the National Railroad Passenger Corporation, AMTRAK. The waterway network is divided into two components. All inland and intracoastal waterways are included in a single subnetwork known as the Barge/Intracoastal System. Deep water routes along the Pacific coast, the Atlantic coast, the Gulf of Mexico, the St. Lawrence Seaway, and the Great Lakes are included in the Merchant Marine subnetwork. In this subnetwork, the Panama Canal connects the Pacific coast deep water routes with those in the Gulf of Mexico.

The INTERLINE data base includes several characteristics for each of the rail segments. The most important from a routing standpoint is the mainline classification (MLC), which is a measure of the volume of traffic on a particular rail segment. Railroad companies tend to concentrate traffic on certain lines. These lines will have higher traffic densities than the less frequently used lines and by analogy the higher traffic density lines will generally be the better maintained lines. The routing algorithms use the MLC information to replicate actual routing practices. The mainline classifications used in the INTERLINE routing model are as follows: A-mainline—more than 20 million gross ton miles per year; B-mainline—between 5 and 20 million gross ton miles per year; A-branch line--between 1 and 5 million gross ton miles per year; and B-branch line—less than 1 million gross ton miles per year.

Another important characteristic included in the INTERLINE data base is the transfer locations where traffic may move from one subnetwork to another. Because transfers between railroads involve additional cost and delay, the routing algorithms include penalties for these movements to replicate the tendency of traffic to remain on a single railroad's line where possible.

B. INTERLINE Model

The user has the option of specifying a number of parameters to control the routing calculations. By varying these parameters, the user can find alternative routes or examine the effect of restricting movement through specified areas such as specific cities or specific railroad systems.

Rail routes are calculated by minimizing the total impedance between the origin and the destination. The impedance is defined as a function of distance, mainline classification, and the number of railroads involved in making the shipment. The INTERLINE program identifies the set of links between the origin and destination that minimize the impedance function shown in Eq. (2):

$$L = Min\left\{\sum_{i} (\sigma_i f_i d_i) + \sum_{n} (T_n)\right\} \tag{2}$$

where

L = impedance for route;

σ_i = railroad factor for link i;

f_i = mainline classification for the link i;

d_i = distance along link i, miles;

T_n = transfer penalty factor at node n.

The routing algorithm shown in Eq. (2) preferentially routes a shipment along the A- and B-mainlines, while minimizing interchanges between railroad companies. In general, shipments will only utilize the A- and B-branch lines as a connection between the mainline network and the origin or destination. Frequently, a number of railroads will provide service at the same location. Selection of an originating railroad has a major impact on the estimated route because the originating railroad will preferentially attempt to move the shipment on its own system before interchanging with another railroad in order to maximize its portion of the revenue.

The alternative routing capability included in the INTERLINE model is a useful tool for estimating a number of different routes between the same origin and destination. A number of alternative routes between Charleston, SC and Las Vegas, NV are shown in Fig.2. The base route, which is the normal route calculated by the INTERLINE model, travels on two major railroad systems, the Norfolk Southern and the Union Pacific. This route is 2844 miles long. Alternative routes 1 through 3 utilize different railroad systems and the distance associated with these routes vary from 2887 for alternative route 1 to 3170 miles for alternative route 3. The fourth and final route shown in Fig.2 is shorter than either the second on third alternative route—2952 miles. However,this route uses a significantly higher amount of B-mainline track than the other routes.

Another important capability included in the INTERLINE model is the estimation of short-line mileage which is the basis of freight rate calculations using class tariffs. In addition, the INTERLINE model is also able to predict likely barge and rail-barge intermodal routes.

IV. Summary

The HIGHWAY and INTERLINE routing models have been designated by DOE's Office of Environmental Restoration and Waste Management, Transportation Management Division as the official DOE routing models. Historically, the routing models have been used by DOE to define likely highway and rail routes along with their associated population density statistics for a number of risk studies. The HIGHWAY model has been used to plan and schedule shipments of classified nuclear materials and to verify that carrier suggested routes for route controlled quantities of radioactive material meet all DOT routing requirements. One of the major data base efforts has been centered on expanding the geographic detail associated with the data bases by incorporating geographical coordinates extracted from the TIGER data. Geographic information for recent highway construction is obtained from state data via a working agreement between several states and ORNL's subcontractor, the University of Tennessee Transportation Center.

V. REFERENCES

1. Johnson, P.E., D.S. Joy, D.B. Clarke, and J.M. Jacobi, *HIGHWAY 3.1 - An Enhanced Highway Routing Model: Program Description, Methodology, and Revised User's Manual,* ORNL/TM-12124, March 1993.

2. Johnson, P.E., D.S. Joy, D.B. Clarke, and J.M. Jacobi, *INTERLINE 5.0 - An Expanded Railroad Routing Model: Program Description, Methodology, and Revised User's Manual*, ORNL/TM-12090, March, 1993.

Fig. 1. Alternative highway routes between Marshall, Michigan, and Phoenix, Arizona

Fig. 2. Alternative rail routes between Charleston, South Carolina, and Las Vegas, Nevada

ORNL-DWG 93-5611

Fig. 2. Alternative rail routes between Charleston, South Carolina, and Las Vegas, Nevada.

ORNL-DWG 93-5609

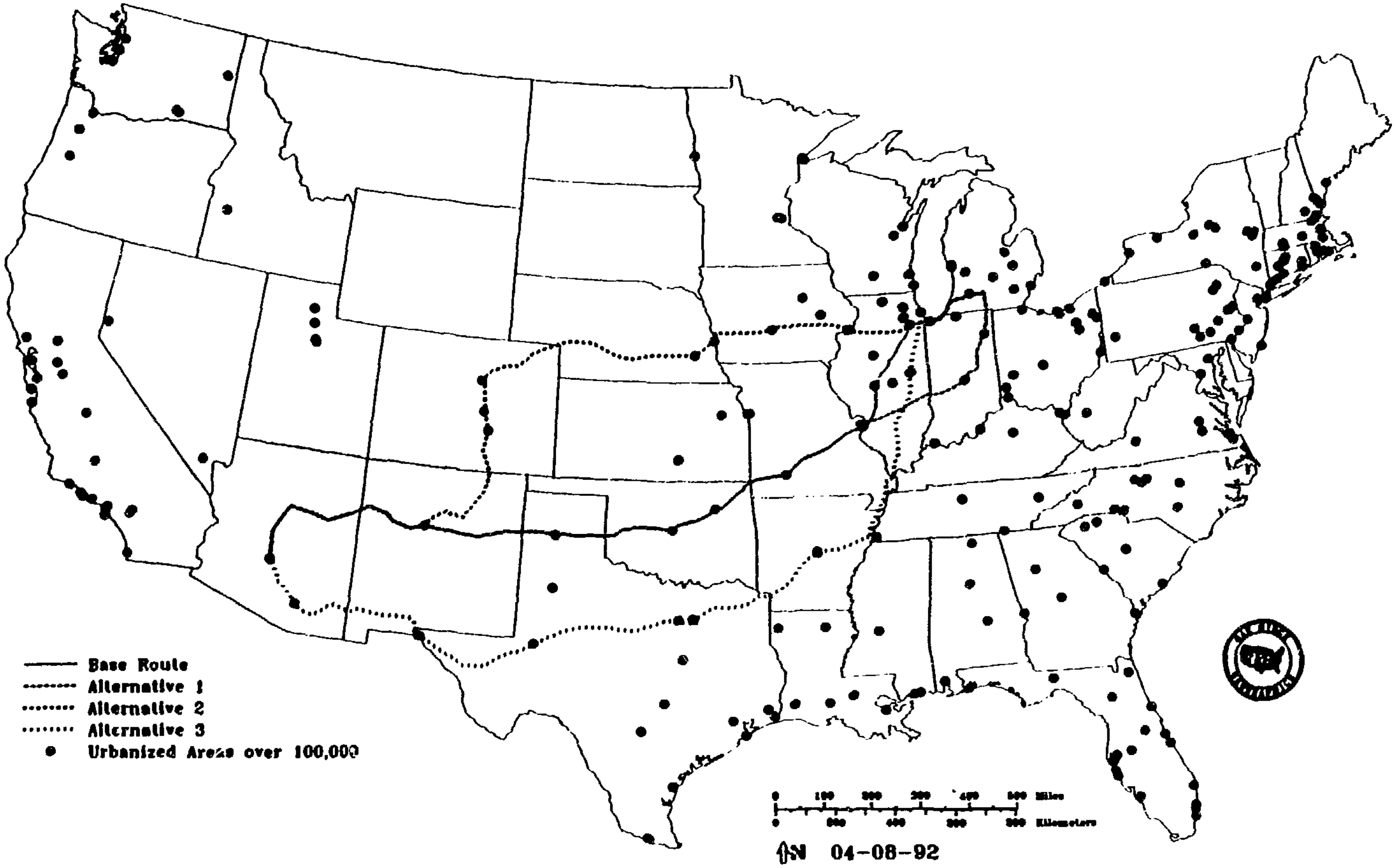

Fig. 9. Alternative routes between Marshall, Michigan, and Phoenix, Arizona.