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Route Characterization for Risk Assessment of Highway Transport of Nuclear Materials

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ABSTRACT

A procedure is presented for developing the route characterization used to assess the risk for the highway transport of nuclear materials. The types of data needed for a risk assessment and the sources used to provide that data are discussed. An outline of the methods used to get from data source to the route characterization used for risk analysis is presented.

I. INTRODUCTION:

Risk analyses are becoming an increasingly common requirement in many businesses and that is certainly true for the Department of Energy. About two years ago, Sandia National Laboratories concluded the multi year DPTRA (Defense Programs Transportation Risk Assessment) study. The risk analyses done for this program involved detailed, route specific, risk assessment for highway shipment of nuclear materials. The models and methodologies developed for this study were programmed into the ADROIT computer code, which has become one of Sandia's principal analysis tool for doing risk assessments for the highway transportation risk for nuclear materials.

An important part of the ADROIT model is the characterization of the highways over which cargo travels. The physical and operational characteristics of the highways the areas adjacent to the route of travel have an important influence on the risk of transporting nuclear materials. This paper describes the way in which the route characterization files needed by ADROIT are generated. It should be noted that what is being described here involves characterizing predefined routes. Techniques for choosing an optimum route between two preselected endpoints are not within the scope of the work described here.

The ADROIT code was written as a MATLAB script in order to take advantage of MATLAB's computational power. MATLAB is a "High- Performance Numeric Computation and Visulaization Software" package available from The Math Works, Inc. Versions of MATLAB are available for all popular computing platforms making it available to anyone with an interest in risk analysis. For consistency, it was decided that any software needed for route characterization should also be implemented as a MATLAB script. No additional database or graphics software was used to keep user requirements to a minimum.

II. DATA REQUIREMENTS:

An ADROIT analysis considers the risks associated with both incident free shipments and with shipments involving accidents. The incident free risk is due to the very small radiation dose that the public receives as the cargo travels along the highway. The risk associated with an accident involves the potential for dispersal of radioactive materials into the atmosphere. A key element of the accident risk is the amount of radioactive material aerosolized as respirable sized particles.

The route characterization needed for the incident free ADROIT model must provide information on the population density in the area adjacent to the highways being traveled. To handle an accident scenario, the route characterization must also provide information on the factors that influence the probability of occurrence of a serious accident. The key parameters required by the ADROIT model are area description (urban or rural), road type, geographical location and the local meteorological characteristics at the accident location.

Adroit requires two data files for its analysis, a route file and a population data file. The route file

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contains coordinates (latitude and longitude) that define route location, operating environment, route mile marker, and meteorology station for every point on the route. The points that define the route are those provided by the data source and in general are not evenly spaced along the route. Highway location coordinates are essential because they provide a link to the population data. The operating environment parameter is a combination of the access control and rural/urban classification. At present ADROIT recognizes 4 classes of operating environment; limited access urban, limited access rural, other urban, and other rural. The route mile marker is a cumulative distance from the starting point of the route. ADROIT estimates the effects of material releases at several accident locations, and the route mile marker is a convenient measure from which to sample accident locations. Data from meteorological stations provides information on atmospheric stability conditions likely to exist at any location along a route. This information is used for estimating the dispersal characteristics of aerosolized material in case of an accident.

Population data files are used to provide a reasonable upper bound on the population density in the vicinity of the transportation route. These files associate a population density with every location along the routes. The population data and information about the radiation activity of the cargo being transported are the inputs needed by ADROIT to estimate the total incident free radiation dose to the public.

III. DATA SOURCES:

The original method for generating route characterization files used the 1990 Census TIGER/Line files and the 1990 Census PL94-171 population and housing data[1] The process involved laboriously searching through huge data files, extracting the required information and piecing together data for a complete route. It was not a highly automated process and was very labor intensive. The TIGER files were the main source of geographic information but they do not include information that would have allowed classification of points along the route as either urban or rural. The distinction between urban and rural accident rates is important in the ADROIT model. Urban/rural classification information was obtainable from the PL94-171 data, and so building a route required correlating data between the two data sources.

For the second generation route characterization procedure we have switched from the TIGER/Line files to the Federal Highway Administration's NHPN (National Highway Planning Network) database as the data source for the route characterization file. The NHPN is a significantly smaller database that contains much less (for our purposes) extraneous data. However, the NHPN database includes more specialized highway data than the TIGER files. The availability of this extra data provides motivation for developing a refined and upgraded second generation ADROIT model .

All of the data in the NHPN database is stored in simple ASCII files which can easily and quickly be obtained by anonymous ftp from a Department of Transportation internet site, ftp.dot.gov, in pub/fhwa/gis/nhpnv202. The NHPN data files are organized on a state by state basis rather than the county basis used in the TIGER files, making following a route much simpler. Finally, all of the information for generating the route file is contained in one database, so the problem of correlating between the TIGER and PL94-171 databases to determine urban/rural status is eliminated.

The NHPN database uses three files, a link, a node, and a geo file to describe all of the highways for a state. Each highway is made up of a series of links and each link is represented by one 121 character record in the link file. Nodes are the endpoints of links and like links, each node is described by a single record in the NHPN node file. The geo files contain sets of coordinate pairs that precisely define the shape of a link. Geo files can contain between 2 and 500 coordinate pairs to describe the shape of a single link. The accuracy claimed for highway coordinates is consistent with 1:100,000 scale maps, or about 80 meters.

IV. GENERATING A ROUTE FILE:

Link records describe the highway. They do not contain any location coordinates but they do provide the attribute information needed for constructing a route file. A cryptic description of a link record is given in Table 1. To provide some sense of perspective, links can be any length, but they are typically between 0.2 and 40 miles long. Node files contain information about the end points of links. They contain location (latitude/longitude) coordinates as well as information on why a node was placed at that location, e.g. county boundary, urban area boundary, intersection with another highway, etc. The geo files contain groups of records that correspond to a link. The first record identifies the link being described and specifies how many coordinate pairs belong to that link. The

Field	Location	Information
RECTYPE	1	"L" for link
VERSION	2–3	database version
RECID	4–11	ID of link
STFIPS	12–13	State FIPS code
CTFIPS	14–16	County FIPS code
ORNL-ID	17–24	Link to old DB
LGURB	25–27	Urban ID code
SMIRB	28–32	Small Urban ID code
FNODE	33–40	Start node ID
TNODE	41–48	End node ID
SIGN1	49–54	Highway Name
SIGN2	55–60	Alt. Highway Name
LNAME	61–96	Local Street Name
MILES	97–101	Link length
KM	102– 06	Link length
FACTYPE	107	One way/two way
TOLL	108	Toll road flag
LANES	109– 10	No. of lanes
ACONTROL	111	Access control
MEDIAN	112	Divided/undivided
SURFACE	113	Paved/unpaved/ferry
FCLASS	114–115	HPMS funct. class
ACLASS	116	Administrative info.
RUCODE	117	Rural/urban code
STATUS	118	Open/not open
NHS	119	Subnetwork
STRAHNET	120	Stratetic Hwy. Network
TRANSAM	121	Trans-Am Corridor

Table 1: Link Record Description

remaining records contain the latitude/ longitude coordinates for points belonging to the link.

The key to being able to access the links for a particular highway is the presence of the highway name (SIGN1 and SIGN2 fields in Table 1) in the link record. For each highway forming part of a route, the grep unix utility can be used to extract the link records that belong to that highway. Grep is a utility that can be used to search through an ASCII file for records that contain a match to a user specified search string. All records containing a match are returned to the standard output device or can be redirected to a file. The NHPN link file for a given state is "grep'd" using the highway name as the search string and the output is directed to a temporary storage file. The file of link records is then read in by a MATLAB script for further processing. Because MATLAB allows external programs to be executed from within MATLAB scripts, the whole process described here, including the use of operating system utilities, can be done within a MATLAB script. The grep and awk (used later) utilities are part of Unix operating systems and freely distributable versions of them are available for other systems.

When using the above procedure to collect the links for a specific highway, it often happens that the there are extraneous link records in data. Highways can fork or may be intermittent. To clean up the data, the link records are parsed to generate a list of beginning and ending node ID's. If the links form a simple unambiguous route, each node ID should appear in the list twice; once as the end node of one link and once as the beginning node of the next link. End nodes for the highway are, of course, exceptions since they appear only once. The MATLAB script checks to see how many times each node appears. If more than two nodes appear only once or if any nodes appear more than twice the problem can usually be solved by eliminating some extraneous links.

The MATLAB script allows the user to graphically edit out any extraneous links. The process begins by using Node ID numbers and grep to find the records in the NHPN node file corresponding to all of nodes associated with the highway links being processed. Once all of the node coordinates have been found they are use to display a plot of the links. Also on the plot, nodes that appear only once or more than twice are marked with * symbols to identify the locations at which the highway description needs attention. With the builtin MATLAB graphics functions, the user can "zoom in" on areas of interest and use a mouse or other cursor control device to select links to be deleted. Deleting links is also a way of designating the route starting and ending points. The user can manually eliminate the untraveled parts of the first and last highways along the route by simply deleting those links that the route does not traverse.

The next step in the route generating process is to order the links so that they are stored in the sequence corresponding to the actual travel along the route. To do this we have established a sign convention to designate a positive and negative sense of travel along a highway. This is done by considering the two end points of the highway (the nodes that appear only once). They are plotted as shown in Figure 1. From the most westerly of the two points, P1, two lines are drawn. One connecting P1 to the other endpoint, P2, and the other pointing straight north. If the angle between these two lines is less than 135 deg., then the positive sense of travel along the highway is from P1 to P2. If the angle is greater than 135 deg., the the positive sense is from P2 to P1. That is, travel from south to north or from west to east is positive.

The user is prompted to specify the sense in which the highway is traveled as part of the route. Once this has been specified, the script chooses the appropriate

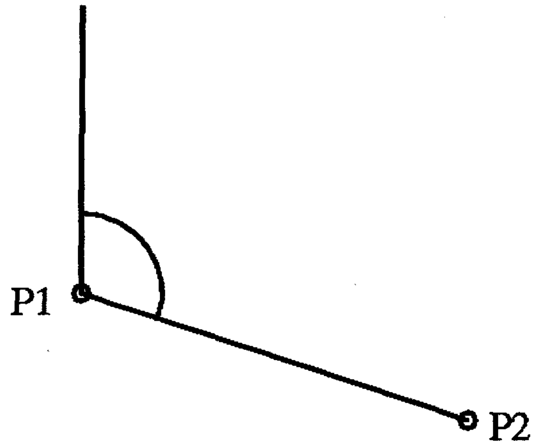

Figure 1: First node determination

starting node and first link. The second link is identified by matching it's beginning node with the end node of the first link. The process of matching end nodes of one link to beginning nodes of the next link continues until all the links in the file have been ordered and saved in a file.

A detail that must be handled in the link ordering process is to "turn around" backward links so that all links are ordered in the direction of route travel. Links are oriented from start node to end node, but all links for a given highway are not necessarily ordered in the same way. It can happen that an end node for one link may also be an end node for the next link. This is a sign that the next link is oriented opposite to the current link and must be reversed. When this happens the MATLAB script swaps the beginning and ending nodes of the the link to be reversed and adds an "R" character at the end of the link record as a flag to denote a reversed link. The flag is read later so that when geo the coordinates for the link are being read in, they are read in reverse order.

The link selection, cleanup and ordering process is repeated for all of the highways comprising the route. It should be noted that since the NHPN database is organized by states, a single highway that crosses several states is processed as a separate highway in each state. For example, a route from Albuquerque, NM to Amarillo, TX might involve only I40, but the processing described above would be done for two highways, I40 in New Mexico and I40 in Texas.

After the links for all of the individual highways have been ordered and stored in files, the next step is to combine all of the links into an ordered list for the complete route. The challenge in this step comes about because the individual link files usually contain data for the full length of a highway whether or not the full length of the highway is used by the route. When a route turns off of one highway and onto another, there are leftover links in the files of both highways that are not part of the route and must be thrown away. In such cases, the script looks for a common or intersection node in the data files of both highways. It can happen that many common nodes are found indicating that the two highways join for some distance and that several links are common to both highways.

The logic used by the script to select the switchover node and links from one highway to the other is given as follows. The last link used from the "earlier" highway is the first link in its ordered link list to have an end node that is one of the nodes common to both highways. Similarly, the first link used from the intersecting highway is the one having that same node as its beginning node. With these "switchover links" identified, links that are not part of the route are easily identified and are not added to the route list of links.

At this point we have an ordered list of links for the entire route. The final step in generating the route file is to parse the link records to extract the information used to determine the operating environment and also to build and execute a script of awk commands used to collect the multitude of route location coordinates from the geo files. Awk is a powerful unix utility that can be programmed to adapt to the varying number of coordinate pairs for a link in the NHPN geo file and to reverse the order of the coordinates for links that have been reversed. The awk script collects and saves all of the coordinate pairs for all of the links in a route to a temporary storage file. Once the coordinate file has been read in by the matlab script, the distance between points and the route mile marker for each point is calculated.

There are 51 upper air meteorological stations located throughout the United States that are located in the vicinity of routes used to transport defense program nuclear materials. The country was divided so that each station has a region of applicability. All of the highway segments within the region are assigned to the corresponding meteorological station. The criteria used to define regions for each station are given below:

- If there was only one station in a state, the entire state was within it's region.

- If there was more than one station within a state, the state was divided up as shown in Figure 2.
- States having no stations were assigned to stations located in adjacent states as shown in Figure 2 and described as follows:
  - Western Iowa – Omaha, NE
  - Eastern Iowa – Peoria, IL
  - Western Indiana – Peoria, IL
  - Eastern Indiana – Fairborn, OH
  - Western Kentucky – Huntington, WV
  - Maryland – Sterling, VA
  - Deleware – Atlantic City, NJ

The link records are parsed and if the link was within a state with only one meteorological station, all points along that link were assigned to the that state's meteorological station. Otherwise the location of each point was examined to determine the meteorological station it belongs to.

V. POPULATION DATA FILE:

The process of generating route population files is done within the ADROIT code using the route file and a population data file. Each record in the population data file (obtained from PL94-171 data) consists of the population in a census block and the coordinates of the internal block point. Census blocks are the smallest subdivision considered in the Census population data. The longitude and latitude of route points in the route file is the bridge that allows ADROIT to relate population information to a point along the route. Population files are used to give an estimate for the population density at each point along the route.

The first step in calculating population density is to draw a rectangular box around each point along the route. Edges of the box are oriented so that they are parallel to and normal to the highway at the point. The width of the box along the direction of travel is half way to the adjacent data points. Several different box lengths, up to 30 km, in the direction normal to the highway are tried. For each size box, the number of people inside the box is determined by the population associated with the internal block points enclosed by the box. Dividing the enclosed population by the area gives a population density. The maximum population density determined from all of the various size boxes is taken as the population density associated with that route point. The procedure is repeated for every point along the route to generate the data for the route population data file.

V. CAVEATS AND CONCLUSIONS:

The procedure described here has just been developed and therefore has seen relatively little use. It seems to work quite well but we are aware of some problems and inconveniences. The first and most important is that some highways that are of interest are not part of the NHPN database. For our use at Sandia Labs, we deal almost exclusively with interstate or major US and State highways which are in the NHPN database. However, there are numerous instances of routes that include short segments on non-NHPN highways between their point of origin and a major highway or between a major highway and the destination. In these cases the user must generate his own starting or ending link, node and geo records to complete the route. A second problem occurs when a highway has no endpoints. This can occur in "loop routes" around major cities. The solution here is to use the MATLAB graphics when processing the loop highway to throw away some of the links that are not used (assuming the route doesn't go around in circles). The remaining parts of the highway do have endpoints and processing can then proceed normally.

The data in the NHPN database is well suited to serve as the source for the data needed to generate route characterization files. As with any large database, some errors exist and the process of building route files would be extremely difficult to automate completely. However, the relatively minor problems can usually be corrected fairly easily as described above. The one tedious aspect remaining is the inclusion of the end segments for non NHPN highways mentioned above. Newer versions of the NHPN database will undoubtedly reduce the number of errors and may include more highways. Plans for future releases of the NHPN include link records expanded to include additional data. The availability of new data may provide motivation to expand and improve ADROIT and other risk assessment models.

VI. REFERENCES:

1. J. S. Phillips, "Route Characterization Using 1990 Census Data for use in Transportation Risk Assessments (U)", SAND93-0110, Sandia National Laboratories, Albuquerque, NM., April, 1994, The report is Classified.