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Application of a Decision-Support Tool for Evaluating Radioactive Material Transportation Routing Options and Emergency Preparedness

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Abstract

The U.S. Department of Energy, Office of Nuclear Energy is laying the groundwork for implementing interim storage of spent nuclear fuel (SNF) pursuant to the Administration's *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*. This effort includes planning to address technical and logistical aspects of transporting SNF to interim storage or disposal facilities. A key project component is the development and utilization of a decision-support tool to evaluate transportation routing options and identify preparedness training needs. The Stakeholder Tool for Assessing Radioactive Transportation (START) is a web-based application that utilizes geographic information systems (GIS) technology to represent transportation network operations as well as proximate features, such as political boundaries, emergency response capability, schools and environmentally-sensitive areas. Modes and routes between shipment origins and destinations designated by the user can be evaluated according to multiple routing criteria, and users can impose constraints that require the route to pass through or avoid specified locations. Route summaries and route detail reports are produced, describing route efficiency, safety, proximity to critical infrastructure and environmental exposure, enabling stakeholders to understand the implications of alternative route options. This paper describes START's capabilities and illustrates its use in supporting a variety of transportation planning activities, including: 1) stakeholder communication and information sharing, 2) methodology for route identification and analysis, 3) evaluation of preparedness training needs, 4) near-site infrastructure assessment, and 5) waste management systems analysis.

Introduction

The U.S. Department of Energy (DOE), Office of Nuclear Energy is laying the groundwork for implementing interim storage of spent nuclear fuel (SNF) pursuant to the Administration's *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*. Much of this activity is taking place as part of DOE's Nuclear Fuels Storage and Transportation Planning Project (NFST). An important component of NFST activity involves planning to address technical and logistical aspects of transporting SNF to an interim storage facility.

To support this endeavor, DOE initiated development of the Stakeholder Tool for Assessing Radioactive Transportation (START). START is a web-based, decision-support tool developed for the purpose of visualizing geospatial data relevant to large-scale transportation of commercial SNF, as well as generating and analyzing routing options for transporting commercial SNF from nuclear power plants to interim storage or disposal facilities. At present, DOE expects these shipments to move primarily by trains operating on mainline freight track. However, where mainline freight track access is not directly accessible to a shipment origin, the access leg might involve use of short line railroads, or involve an intermodal movement by heavy-haul truck and/or by barge.

START makes extensive use of geographic information systems (GIS) data and technology for performing spatial analysis and map creation. Embedded within START are a variety of features and functions that enable the user to explore a wide range of operating scenarios and performance objectives. In doing so, the user has the flexibility to explore transportation options and attributes from multiple perspectives and at varying levels of detail.

Description

START is built upon an ArcGIS server, which offers a web-map interface that can easily be manipulated by the user to pan, zoom, and select points of interest – similar to the user experience with Google Maps. Although platform independent, it is recommended that users run the application via the Google Chrome browser, as this is the browser for which the application has been quality-controlled. Also, certain data export features within START can only be utilized with a spreadsheet program (e.g., Microsoft Excel, Apple Numbers, Google Spreadsheet) and mapping software (Google Earth, Google Maps, desktop GIS). If those START functions are considered necessary to support the user's application needs, these respective software programs should be obtained.

Basemap Selection

START provides a basemap at all times that serves as background geography to provide the user with a spatial reference as well as a visual aid. Several basemap options are available for the user to consider in selecting the desired background. These include topographic, street, terrain, satellite imagery, and canvas options.

Feature Layers

A considerable amount of spatial information is provided that is available to support transportation planning. These feature layers define both the transportation network itself as well as characteristics of the surrounding area. The user is provided with an extensive list of layer options from which to choose (see Table 1). These layers represent locations and characteristics of: 1) potential shipping origins/destinations (yellow), 2) response assets (brown), 3) mass gathering places (blue), 4) educational institutions (green), 5) assisted living facilities (purple), 6) transportation systems (red), 7) environmentally sensitive areas (gray), and 8) political jurisdictions (white).

Table 1. START Feature Layers

Shutdown Sites	Shopping Malls	Locks and Dams
Potential Transload Sites	Schools	Water Terminals
Nuclear Reactors	Colleges/Universities	Coast Guard Districts
DOE & Other Facilities	Nursing Homes	Captain of the Port Zones
Fire Departments	Day Care Facilities	Federal Lands
Trained Radiological Responders	Rail Network	Parks
Police	Railroad Crossings	National Forests
Hospitals	Rail Freight Stations	Water Areas
Emergency Operations Centers	Rail Yards	Tribal Lands
Airports	Railroad Junctions	States
Amusement/Theme Parks & Zoos	Railroad Bridges	Counties
Casinos	Railroad Tunnels	Congressional Districts
Performing Arts Centers	Highway Network	State Legislative Districts
Stadiums/Arenas	Highway Bridges	Military Bases
National Monuments/Icons	Waterway Network	Urban Areas

When a selection is made, START automatically populates the map with icons (points, polygons or polylines) demarcating where the selected features are located (see Figure 1). Points are used when the feature is a specific facility, such as a school or fire department. Polygons define area expanses, such as a tribal land or state boundary. Polylines are reserved for representing freight transportation networks (rail, truck, barge), where each line in the network corresponds to a segment of the transportation system.

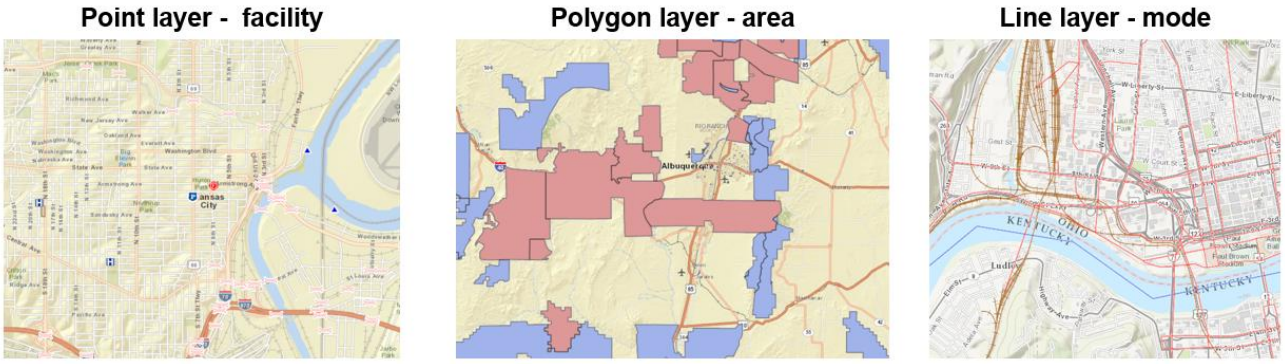
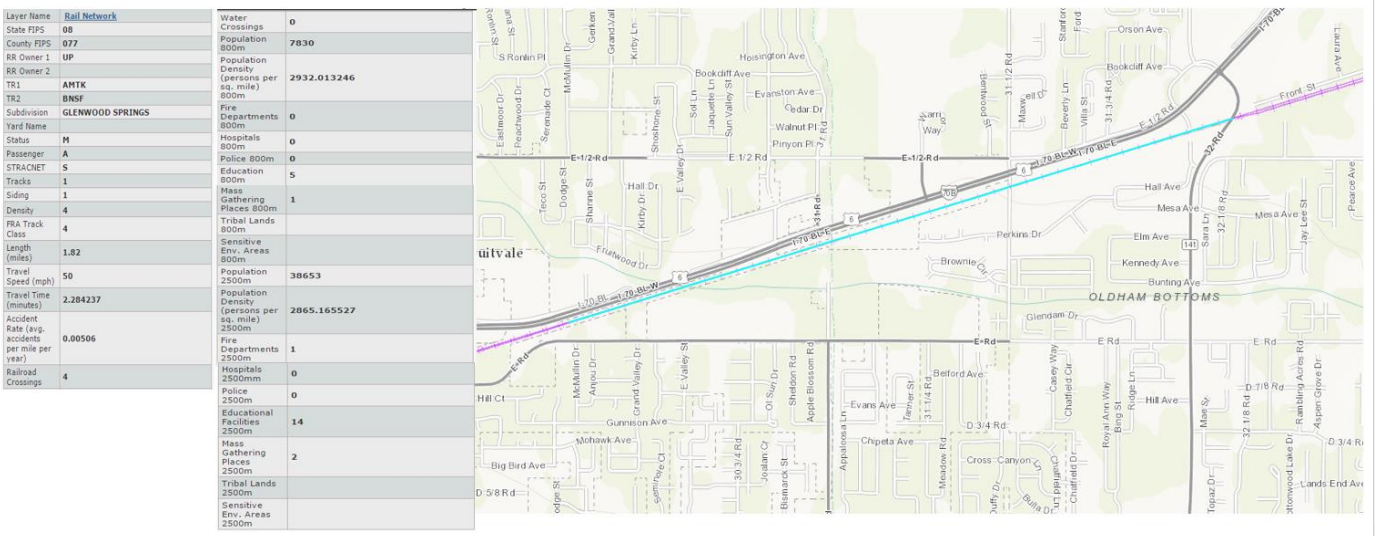


Figure 1. Representation of Point, Polygon and Polyline Layers

The attribute table within a feature layer contains associated information that is unique to each feature (e.g., rail segment, police station, tribal land). This information enables the user to access the descriptive characteristics of the specific feature, helping to ascertain the extent to which the location is important in the transportation planning process. Once a feature layer is selected to be displayed on the map, the user can click on any feature icon, segment or polygon that appears to display the attributes of that feature in a pop-up window. Examples of these attributes are shown for a rail segment and a fire department in Figures 2 and 3, respectively. In the case of the rail segment, note that several attributes have been appended to identify the extent of other features in proximity to the segment itself.



Layer Name	Rail Network
State FIPS	08
County FIPS	077
RR Owner 1	UP
RR Owner 2	
TR1	AMTK
TR2	BNSF
Subdivision	GLENWOOD SPRINGS
Yard Name	
Status	M
Passenger	A
STRACNET	S
Tracks	1
Siding	1
Density	4
FRA Track Class	4
Length (miles)	1.82
Travel Speed (mph)	50
Travel Time (minutes)	2.284237
Accident Rate (avg. accidents per mile per year)	0.00506
Railroad Crossings	4

Water Crossings	0
Population 800m	7830
Population Density (persons per sq. mile) 800m	2932.013246
Fire Departments 800m	0
Hospitals 800m	0
Police 800m	0
Education 800m	5
Mass Gathering Places 800m	1
Tribal Lands 800m	
Sensitive Env. Areas 800m	
Population 2500m	38653
Population Density (persons per sq. mile) 2500m	2865.165527
Fire Departments 2500m	1
Hospitals 2500mm	0
Police 2500m	0
Educational Facilities 2500m	14
Mass Gathering Places 2500m	2
Tribal Lands 2500m	
Sensitive Env. Areas 2500m	

Figure 2. Attributes Associated With a Sample Rail Segment

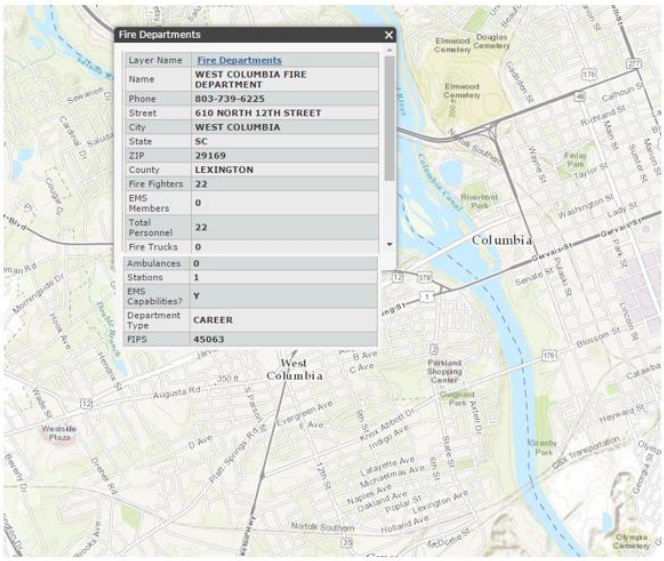


Figure 3. Attributes Associated With a Sample Fire Department

An additional component of a feature layer is the ability to associate electronic files with a specific location. This could represent photographs showing the physical characteristics of relevant infrastructure or might refer to documents that define operational practices at a facility. Figure 4 illustrates this capability in the form of a photograph showing the condition of a portion of the rail infrastructure at a potential truck-to-rail transload site.

Smart Mapping

Smart mapping is a function within START that provides the user with a powerful capability to sort, highlight and report features within a feature layer according to user-defined criteria. Two levels of smart mapping are available in the current version of START: 1) filtering, and 2) highlighting by theme.

Filtering provides the ability to select one or more attributes within a feature layer, and specify criteria to find only those locations within a feature layer that satisfy those conditions. Several operand options are available (e.g., equal to, greater than, etc.) and logic can be applied (and, or) when multiple criteria are utilized. START provides filtering results in both map and tabular form. Figure 5 shows a map of hospitals that have 500 or more beds, while Figure 6 provides a spreadsheet-compatible listing of those hospitals that met the criteria along with other pertinent information.

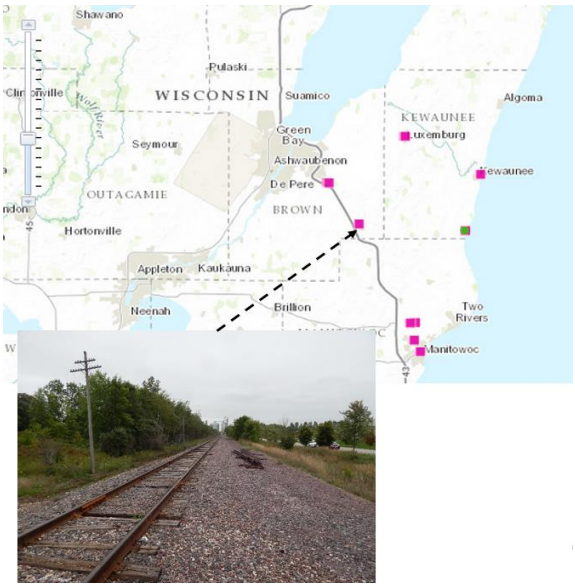


Figure 4. Condition of Rail Infrastructure at Potential Transload Site

Highlighting by theme is a technique for sorting a particular feature layer attribute by highlighting variations in the attribute values associated with locations contained within the layer. The user can select among several attributes within a feature layer to assess these considerations. Figure 7 displays the results of applying this technique using the number of fire department personnel attribute within the fire department layer. Note that START automatically creates the legend using a scaling function.

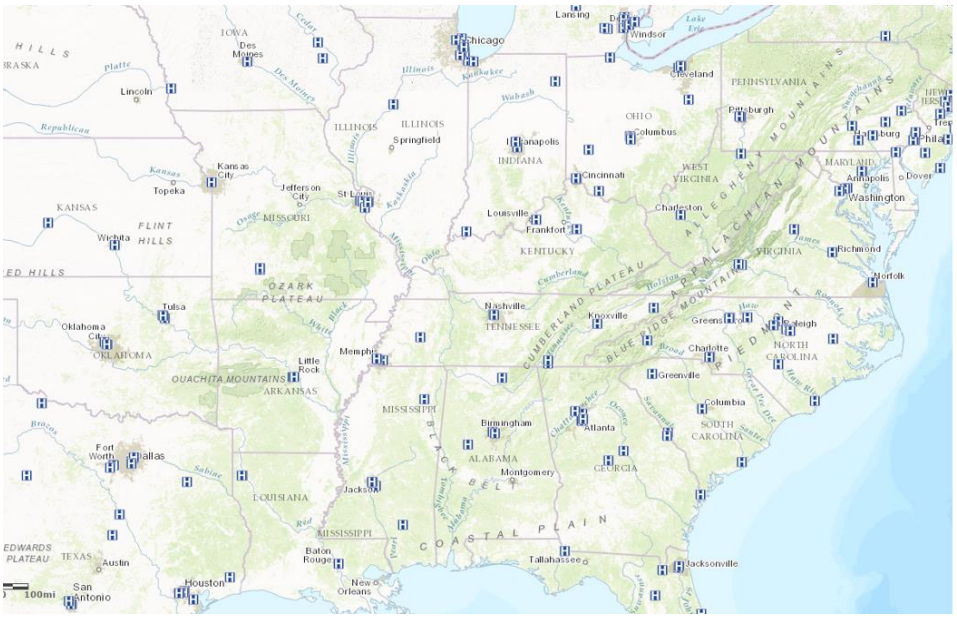
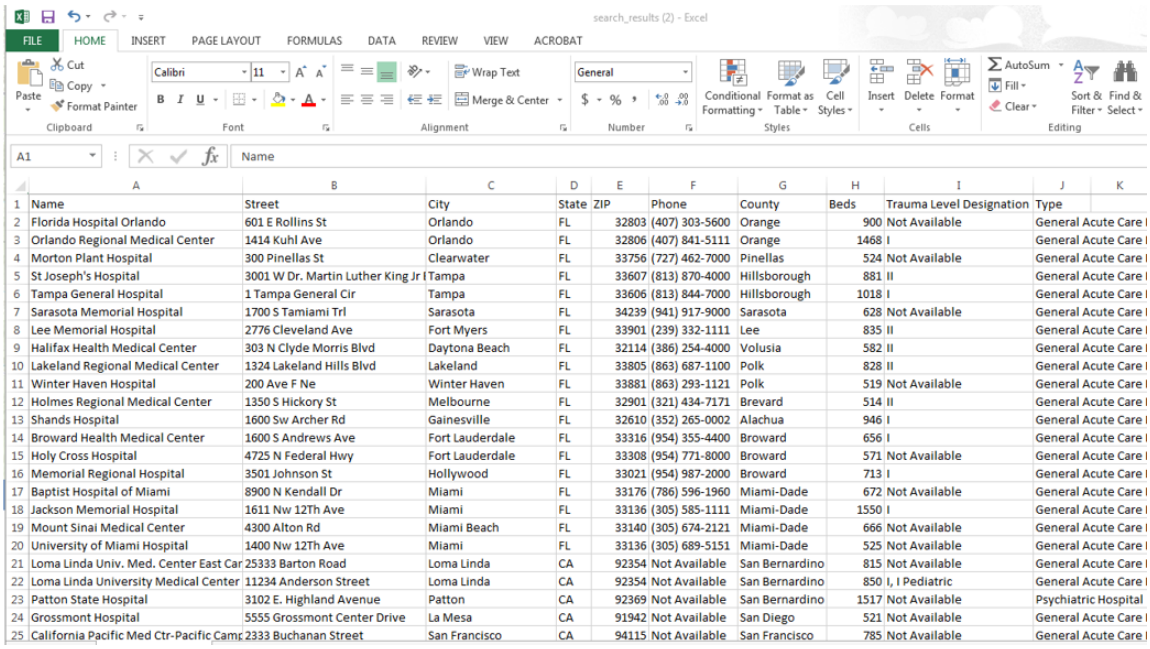


Figure 5 – Map of Locations Meeting Filter Selection



search_results (2) - Excel

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A1 | Name

	A	B	C	D	E	F	G	H	I	J	K
1	Name	Street	City	State	ZIP	Phone	County	Beds	Trauma Level Designation	Type	
2	Florida Hospital Orlando	601 E Rollins St	Orlando	FL	32803	(407) 303-5600	Orange	900	Not Available	General Acute Care I	
3	Orlando Regional Medical Center	1414 Kuhl Ave	Orlando	FL	32806	(407) 841-5111	Orange	1468	I	General Acute Care I	
4	Morton Plant Hospital	300 Pinellas St	Clearwater	FL	33756	(727) 462-7000	Pinellas	524	Not Available	General Acute Care I	
5	St Joseph's Hospital	3001 W Dr. Martin Luther King Jr I	Tampa	FL	33607	(813) 870-4000	Hillsborough	881	II	General Acute Care I	
6	Tampa General Hospital	1 Tampa General Cir	Tampa	FL	33606	(813) 844-7000	Hillsborough	1018	I	General Acute Care I	
7	Sarasota Memorial Hospital	1700 S Tamiami Trl	Sarasota	FL	34239	(941) 917-9000	Sarasota	628	Not Available	General Acute Care I	
8	Lee Memorial Hospital	2776 Cleveland Ave	Fort Myers	FL	33901	(239) 332-1111	Lee	835	II	General Acute Care I	
9	Halifax Health Medical Center	303 N Clyde Morris Blvd	Daytona Beach	FL	32114	(386) 254-4000	Volusia	582	II	General Acute Care I	
10	Lakeland Regional Medical Center	1324 Lakeland Hills Blvd	Lakeland	FL	33805	(863) 687-1100	Polk	828	II	General Acute Care I	
11	Winter Haven Hospital	200 Ave F Ne	Winter Haven	FL	33881	(863) 293-1121	Polk	519	Not Available	General Acute Care I	
12	Holmes Regional Medical Center	1350 S Hickory St	Melbourne	FL	32901	(321) 434-7171	Brevard	514	II	General Acute Care I	
13	Shands Hospital	1600 Sw Archer Rd	Gainesville	FL	32610	(352) 265-0002	Alachua	946	I	General Acute Care I	
14	Broward Health Medical Center	1600 S Andrews Ave	Fort Lauderdale	FL	33316	(954) 355-4400	Broward	656	I	General Acute Care I	
15	Holy Cross Hospital	4725 N Federal Hwy	Fort Lauderdale	FL	33308	(954) 771-8000	Broward	571	Not Available	General Acute Care I	
16	Memorial Regional Hospital	3501 Johnson St	Hollywood	FL	33021	(954) 987-2000	Broward	713	I	General Acute Care I	
17	Baptist Hospital of Miami	8900 N Kendall Dr	Miami	FL	33176	(786) 596-1960	Miami-Dade	672	Not Available	General Acute Care I	
18	Jackson Memorial Hospital	1611 Nw 12Th Ave	Miami	FL	33136	(305) 585-1111	Miami-Dade	1550	I	General Acute Care I	
19	Mount Sinai Medical Center	4300 Alton Rd	Miami Beach	FL	33140	(305) 674-2121	Miami-Dade	666	Not Available	General Acute Care I	
20	University of Miami Hospital	1400 Nw 12Th Ave	Miami	FL	33136	(305) 689-5151	Miami-Dade	525	Not Available	General Acute Care I	
21	Loma Linda Univ. Med. Center East Car	25333 Barton Road	Loma Linda	CA	92354	Not Available	San Bernardino	815	Not Available	General Acute Care I	
22	Loma Linda University Medical Center	11234 Anderson Street	Loma Linda	CA	92354	Not Available	San Bernardino	850	I, I Pediatric	General Acute Care I	
23	Patton State Hospital	3102 E. Highland Avenue	Patton	CA	92369	Not Available	San Bernardino	1517	Not Available	Psychiatric Hospital	
24	Grossmont Hospital	5555 Grossmont Center Drive	La Mesa	CA	91942	Not Available	San Diego	521	Not Available	General Acute Care I	
25	California Pacific Med Ctr-Pacific Camp	2333 Buchanan Street	San Francisco	CA	94115	Not Available	San Francisco	785	Not Available	General Acute Care I	

Figure 6 – CSV Export of Locations Meeting Filter Selection

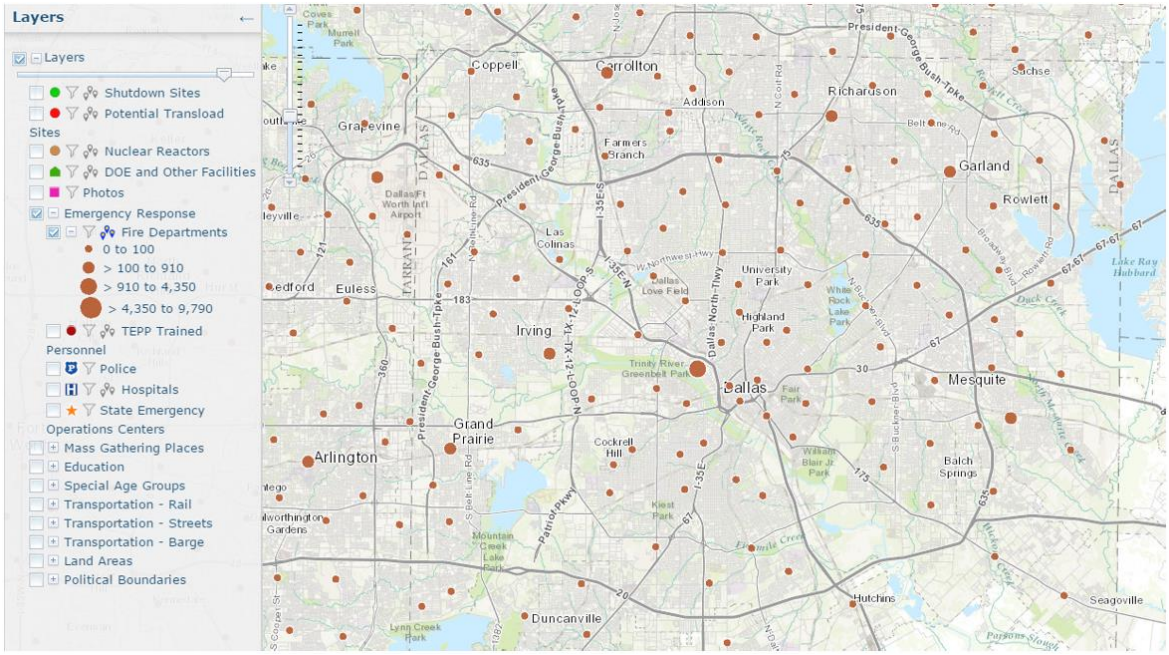

Figure 7 – Highlighting According to Number of Fire Department Personnel

Performing a Routing Analysis

In addition to visualizing geospatial data, START offers the capability to generate transportation routes from user inputs, using ArcGIS's Network Analyst Extension based on Dijkstra's algorithm for finding shortest paths. A routing analysis in START is initiated by prompting the user to select a shipment origin, destination and mode(s). Several options exist for the user to specify a shipment origin or destination:

- Shutdown (nuclear power plant) site
- Rail transload site
- DOE or other shipping facility
- Operational nuclear facility
- Draw origin

With the exception of the draw origin option, when any of the other selections are prompted, icons appear on the map showing eligible locations. Hovering over the symbol and clicking the mouse permits the user to specify the location as either a shipment origin or destination. By contrast, the "draw origin" option allows the user to place the cursor over any location in the continental U.S. and designate it as the shipment origin/destination.

Modal options include legal-weight truck, heavy-haul truck, rail and barge. Intermodal shipments can also be specified by selecting more than one modal option.

The user may also elect to require the route to pass through one or more specified point locations. Similarly, the user can impose barriers (either points or areas) requiring the route to avoid one or more specified locations.

The user is also presented with several options from which to select the method by which START searches for a preferred route. The user can opt to minimize one of the following:

- Travel time
- Trip distance
- Population exposure
- Various weighted combinations of travel time and population exposure

With this selection, the user is also prompted to choose a buffer distance associated with the analysis. This defines the distance on either side of the transportation network for which information on proximate features is desired. The current version of START allows for designating 800 or 2,500 meter distance bands.

Figure 8 displays the menu options that correspond to performing a route analysis.

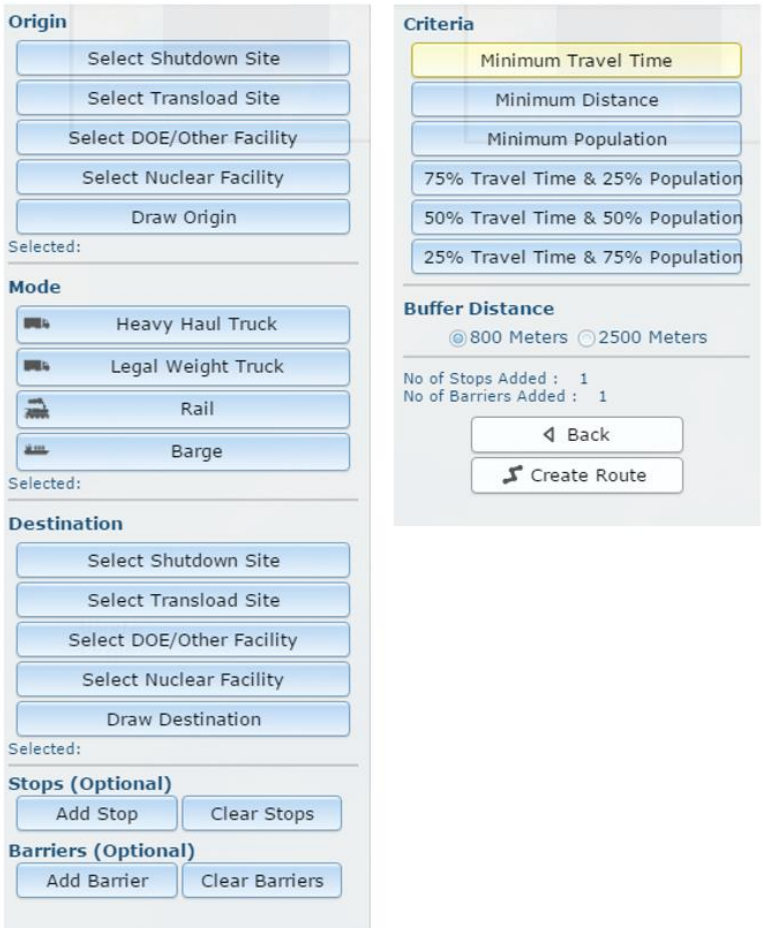

Figure 8. Route Analysis Options

START then begins executing the routing analysis based on the user's selections. If a feasible route cannot be found, for example rail access is not available at the designated origin or destination when a user opts to route exclusively by rail, START will return an error message indicating a route could not be found. Otherwise, the analysis is completed, with the route results made available in both map and tabular form.

Route Analysis Results

One of the outputs that START provides is a summary report, comprised of two sections: 1) a review of the user-defined routing inputs (i.e., shipment origin, destination, mode, criteria, performance measures), and 2) the overall route performance metrics for the identified route.

In the example shown in Figure 9, the user is considering a rail route from a hypothetical location near the mid-Atlantic coast to a hypothetical destination in eastern Colorado. Three separate routing analyses have been performed, each involving an 800 meter buffer: 1) minimize rail travel time (blue route), 2) minimize population in proximity to

the route (red route), and 3) minimize rail travel time subject to avoiding Kansas City and requiring the shipment to pass through Tulsa (green route).

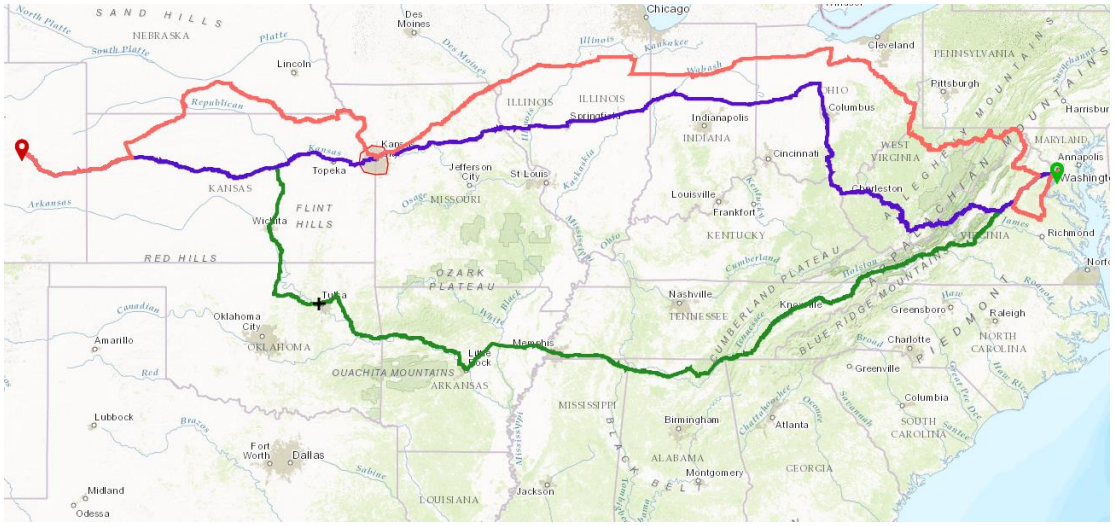

Figure 9. Alternative Routes Based on Different Criteria and Restrictions[1]

The corresponding route performance measures are shown in Figure 10. Note that a second set of route performance statistics can also be generated by a user prompt, covering counts of various features that fall within the defined distance band (e.g., number of schools, square miles of environmentally sensitive areas, etc.); this information is not included in Figure 10.

From a comparative analysis perspective, there are tradeoffs as to which route performs best depending on the measure in question. For example, as expected, the minimum travel time route is considerably shorter than the minimum population route and, conversely, the minimum population route has far fewer people located in proximity to the route. What is important to recognize is that while any route will have its pros and cons, understanding where the tradeoffs occur and the corresponding magnitude of their differences helps support an informed route selection discussion.

Also available as an output option is a route details table. This table presents, in sequence from the shipment origin to its destination, every transport segment associated with the identified route.

[1] These are example routes for illustrative purpose only and do not reflect a selected destination site.

Min Travel Time		Min Population		Min Travel Time (with restrictions)	
Your Selections:		**Your Selections:**		**Your Selections:**	
Origin	A user defined point	Origin	A user defined point	Origin	A user defined point
Destination	A user defined point	Destination	A user defined point	Destination	A user defined point
Transport Mode	Rail	Transport Mode	Rail	Transport Mode	Rail
Criteria	Minimum Travel Time	Criteria	Minimum Population	Criteria	Minimum Travel Time
Buffer Distance	800 Meters	Buffer Distance	800 Meters	Buffer Distance	800 Meters
Result:		**Result:**		**Result:**	
Total Population	1,514,420 persons	Total Population	973,298 persons	Total Population	1,707,263 persons
Total Distance	1784.5 miles	Total Distance	2164.9 miles	Total Distance	2006.8 miles
Total Travel Time	2617.3 minutes	Total Travel Time	4206.6 minutes	Total Travel Time	3039.9 minutes
Average Accident Rate	0.005207 per mile per year	Average Accident Rate	0.005473 per mile per year	Average Accident Rate	0.005186 per mile per year
Railroad Crossings	2,101	Railroad Crossings	4,817	Railroad Crossings	2,664
Water Crossings	196	Water Crossings	493	Water Crossings	263

Figure 10. Comparative Routing Analysis Results[2]

When a routing analysis is completed, the route map and corresponding performance metrics are automatically saved within START and labeled with the date and time the route was generated. Users have the option to edit saved route names and colors according to their preference. Since START provides the user with the ability to recall and overlay one or more saved routes, prior analyses can be reviewed, and route comparisons can be made.

START also provides the capability for the user to export route results as shapefiles, in a spreadsheet format using comma separate value (CSV) text file format, or to mapping software using keyhole markup language (KML), as shown in Figure 11. This enables the user to perform manipulations that can leverage the functionality that such tools offer.

[2] These are example routes for illustrative purpose only and do not reflect a selected destination site.

Spreadsheet (Excel)

FRA Link ID	State	State FIPS	County FIPS	RR Owner	Tracks	Signal	Siding	Direction	Density	Track Class	Miles	Schools	Population	Hospitals	Police	Fire Depts	Pop Density	Speed (km/hr)
258393	VA	51	510	NS	1	MAN	3	2	1	1	0.67	3	8844	0	0	1	13289.7	16.1
164057	VA	51	510	CSXT	3	CTC	1	2	6	4	0.24	2	7978	0	0	1	33830.2	80.5
258394	VA	51	510	CSXT	3	CTC	1	2	6	4	0.39	1	5752	0	0	0	14730.2	80.5
258394	VA	51	510	CSXT	3	CTC	1	2	6	4	0.12	0	4098	0	0	0	35594.2	80.5
258394	VA	51	510	CSXT	3	CTC	1	2	6	4	0.66	3	4515	0	0	0	6866.68	80.5
164167	VA	51	510	CSXT	2	CTC	1	2	6	4	0.05	21	1986	0	0	0	37366.7	80.5
164167	VA	51	13	CSXT	3	CTC	1	2	6	4	0.20	0	3024	0	0	0	15310.5	80.5
164164	VA	51	13	CSXT	3	CTC	1	2	6	4	0.54	1	7953	0	0	0	14832.5	80.5
164163	VA	51	13	CSXT	3	CTC	1	2	6	4	0.42	0	11905	0	0	0	28216.2	80.5
164163	VA	51	13	CSXT	2	CTC	1	2	6	4	0.25	0	10712	0	0	0	42337.9	80.5
164163	VA	51	13	CSXT	2	CTC	1	2	6	4	0.51	1	9037	0	0	0	17617.3	80.5

Google Earth

Figure 11. Sample Route Results Export Applications

Besides these export options, the user has the ability to produce maps within START by manipulating the base map, feature layers, routing analysis results and zoom feature to create the desired product (see Figure 12). These capabilities aid the user in understanding what is occurring on each route segment and may enhance communication with various stakeholders.

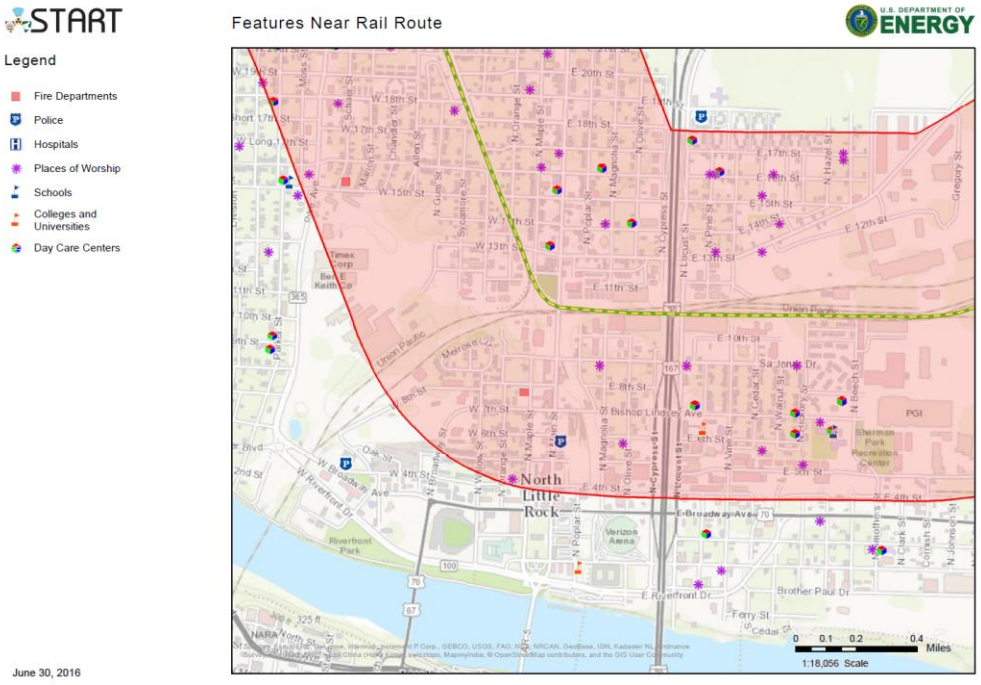

Figure 12 – Sample Map Production Using START Print Map Function

Further Discussion

START is served by Idaho National Laboratory, accessible via the following url: https://gis.inl.gov/start. As START has been designated for official use only, prospective users must register for an account when accessing the web site, and must meet certain eligibility criteria to receive access.

It is anticipated that a variety of NFST activities will utilize the capabilities inherent within the START tool. These include:

- Stakeholder communication and information sharing: START's maps, tables and analysis results are helping transportation stakeholders improve their awareness of routing options and decision-making considerations involved in the transport of radioactive materials.
- Route identification and analysis: START is supporting the development and implementation of a methodology for identifying potential transport routes based on selection criteria.
- Evaluation of preparedness training needs: States and Tribes are accessing information on the location and characteristics of response assets to evaluate where additional preparedness training is needed in proximity to prospective transport routes.
- Near-site infrastructure assessment: Physical and operational characteristics of the transportation network embedded within START, combined with photographs of specific infrastructure, are contributing to feasibility studies investigating the use of alternative modes and routes to move SNF from each shutdown site.
- Waste management systems analysis: Transportation system analysis capabilities within START are producing results that inform logistics considerations associated with broader waste management system studies.

The START development effort is ongoing, with data enhancements, routing algorithm improvements and additional functionality to be included in future version releases. An important driver of the development process has been and will continue to be feedback provided by federal, state, and tribal government officials; DOE support contractors; and other interested parties.

Acknowledgments

This information was prepared as an account of work sponsored by the U.S. Department of Energy. Neither the DOE, nor any of its employees or contractors, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the DOE. The views and opinions of authors expressed herein do not necessarily state or reflect those of the DOE.

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