Systems for the Intermodal Routing of Spent Nuclear Fuel

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INTRODUCTION

The safe and secure transport of spent nuclear fuel (SNF) from shutdown and active reactor facilities to intermediate or long term storage sites may, in some instances, require the use of several modes of transportation. To that end, a fully operable multi-modal routing system is being developed within Oak Ridge National Laboratory's (ORNL) WebTRAGIS (Transportation Routing Analysis Geographic Information System). This study aims to provide an overview of multi-modal routing, the existing state of the WebTRAGIS networks, the source data needs, and the requirements for developing structural relationships between various modes to create a suitable system for modeling the transport of spent nuclear fuel via a multimodal network.

Modern transportation systems are comprised of interconnected, yet separate, modal networks. Efficient transportation networks rely upon the smooth transfer of cargoes at junction points that serve as connectors between modes. A key logistical impediment to the shipment of spent nuclear fuel is the absence of identified or designated transfer locations between transport modes.

Understanding the potential network impacts on intermodal transportation of spent nuclear fuel is vital for planning transportation routes from origin to destination. By identifying key locations where modes intersect, routing decisions can be made to prioritize cost savings, optimize transport times and minimize potential risks to the population and environment.

In order to facilitate such a process, ORNL began the development of a base intermodal network and associated routing code. The network was developed using existing intermodal networks and information from publicly available data sources to construct a database of potential intermodal transfer locations likely to have the capability to handle spent nuclear fuel casks. The coding development focused on modifying the existing WebTRAGIS routing code to accommodate intermodal transfers and the selection of prioritization constraints and modifiers to determine route selection. The limitations of the current model and future directions for development are discussed, including the current state of information on possible intermodal transfer locations for spent fuel.

INTERMODAL/MULTIMODAL TRANSPORTATION ROUTING

Technically, multimodal transport is the transportation of goods under a single contract (bill of lading) using at least two different means of transport. While such a contractual arrangement is possible for the shipment of used nuclear fuel, in this paper we will simply refer to multimodal transportation as the use of two or more modes of transport to effect a complete transport operation from origin to destination. The route solution is designated as a single output including the relevant routing detail for each mode used.

In general, intermodal or transloading operations involve a single contract move of primarily containerized freight that is transferred between modes by use of gantry cranes or other methods. For example, container ships arriving at a port are unloaded and the containers may then be transferred by crane directly to specially designed railcars or to a waiting set of wheeled chassis for movement by truck. Typical transloading operations are encountered during the multimodal routing of commodity goods such as coal, grains, or steel, and also for what is termed "*project*" *cargo* – the transportation and handling of large, indivisible goods of large weight that do not conform to conventional shipping standards. It is expected that used nuclear fuel transport would be designated as project cargo.

As project cargo, the shipment of spent nuclear fuel presents unique logistical problems. The unique weight and safety concerns involving spent fuel cask transport require terminals to have the capability and capacity to handle the physical transfer of fuel casks between modes safely and securely. As such, the multimodal network for spent fuel transport needs to rely on standard characteristics to identify the logistical requirements for transfers between heavy haul trucks, rail, and barge at terminal facilities. In many cases, the available knowledge about potential transfer locations is suspect due to either missing information, or the age of the data, and the lack of any on-site determination of transfer capacity and capability.

The purpose of developing a multimodal network within WebTRAGIS was to create a means for the seamless routing of spent nuclear fuel shipments across different transport modes from origin to destination. Until recently the WebTRAGIS spent fuel routing capability was limited to running separate analyses for each potential mode of transport (highway, railway, waterway). In doing so there was no explicit connection between the modal networks. The existence of such actual, valid connections was either assumed by the user or was reliant on sometimes dated engineering assessments of the desirability of various highway, railway or waterway network components to approximate a full set of transport operations from origin to destination.

Conceptual Model

A fully realized multimodal network joining the separate modal networks is dependent on a set of terminal node locations that defines the various connections between the underlying modal networks and the types of allowable transfers at that location. Illustrations of some of the different types of terminal connections are found in Figure 1.

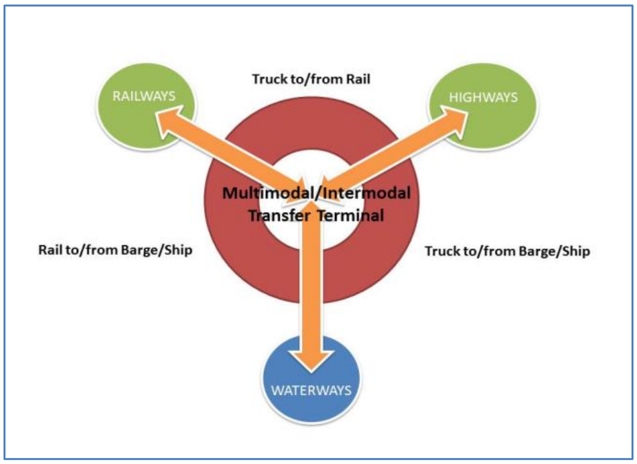

Fig. 1 Multimodal Transfer Terminal connections

The connections noted in Figure 1 define the conceptual modal network terminal at a particular node. The terminal node itself (the central circle) acts as a grouping buffer that associates the nodes of the three separate networks and defines the transfer relationships. The arrows define the existence of connections and transfers between modes at the terminal allowed by the multimodal buffer node. In this illustration it is assumed that all three modes are present and that each mode is capable of transferring cargo to the other two modes. In reality, many multimodal terminal locations are only represented by transfers between two modes or limited connectivity between modes even when all three modes are present. For example, some terminals would only allow for truck to rail, or rail to truck, transfers while others might allow only barge to rail, and still other locations might allow all of the modes to interchange and transfer freely with each other. A further consideration is the type(s) of commodity(ies) handled at existing multimodal terminals and the capability of the facility to handle project cargo transfers safely and securely. For example, all three transport modes might exist at a grain storage and transfer facility, but the capability of the terminal to handle spent nuclear fuel casks is doubtful.

ORNL recently updated the WebTRAGIS code to enable intermodal routes to be generated using the existing modal networks and a system of point locations representing transfer locations between modes. While the intermodal routing code has been developed, only a rudimentary intermodal node network has been established. The components and development of this initial network dataset are described in the following section.

CREATING AN INTERMODAL DATASET and GIS LAYER

An initial dataset of intermodal terminals that would facilitate the transfer of spent nuclear fuel between modes has been developed for WebTRAGIS. In developing the initial WebTRAGIS dataset two existing intermodal datasets were available for incorporation into the existing WebTRAGIS system. In addition, some additional sources of information were identified which may be used to update and review the initial WebTRAGIS dataset as needed.

The first source dataset referred to is the intermodal terminals dataset created in 1998 by the Center for Transportation Analysis (CTA) at ORNL [2]. The second source dataset is the Intermodal Terminal Facilities dataset found in the Homeland Security Infrastructure Program (HSIP Gold) infrastructure layers [3]. This dataset is sourced from the 2011 Bureau of Transportation Statistics (BTS) National Transportation Atlas Database (NTAD) [4]. The primary issue with these source datasets is that they are not necessarily current. The CTA dataset has been only intermittently updated since 1998, while the NTAD dataset contained information that was last updated in April of 2003. The database field information in the source datasets underwent a matching and reconciliation process to identify and map equivalent content from both datasets into a single uniform database structure. The resulting structured dataset was then used to establish the initial WebTRAGIS intermodal network. Both the source networks and the WebTRAGIS network are simple point layers. The following briefly describes the structure and data of the two source networks.

CTA Intermodal Terminals

The CTA network consists of 3104 records. The records have a Latitude-Longitude location, a name field, and an operational status field. The dataset also has several fields identifying the commodities handled at the facility and the transportation modes available at the facility. Up to 6 types of cargo are identified for each facility. There are also 4 modal transfer fields describing the operational characteristics of the terminal. These fields provide a shorthand classification of what modes are available at a facility and the direction of transfer between modes. In this classification scheme, R= Railroad, H=highway and W = Waterway. So H2R would indicate that there is the capability to transfer to and from rail to highway; H2R also implies R2H. If the transfer direction is only one way such as only from truck to barge, but not barge to truck, the designation would be H1W, with the initial mode listed first and the receiving mode listed second. The table also lists the railroads that are/were active at the terminal; it should be noted that these fields are not current and some of the railroads are no longer in business, or the terminals may now be served by other railroads.

Using the cargo classifications in the dataset, several commodity cargo types were identified as being most likely to have the necessary infrastructure and equipment to handle transfers of used fuel casks between modes. The cargo classes selected were those that service cargo types identified as Machinery, Motor Vehicles, and Special. Based on these classes 313 sites in the CTA database were identified as potential multimodal transfer locations. 212 of the terminal locations are classified as Motor Vehicle terminals and are typically autoramp facilities. While these terminals may not readily lend themselves to SNF cask transfers, these terminals are usually fenced and have adequate open space and track that could be amenable to transfers between heavy-haul trucks and railcars. Terminals that handle containerized cargo were also considered, but container facilities are often just truck ramps with simple cranes unsuited to transferring large project cargo. As a result, they were eliminated from the WebTRAGIS multimodal dataset.

NTAD Intermodal Terminal Facilities

The NTAD dataset contains 3280 records. Each record provides a facility name, the primary mode type of the facility, the transfer mode type (e.g., RAIL & TRUCK), the city, state, FIPS (Federal Information Processing Standard) and ZIP codes for the facility. Latitude and longitude for geolocation is also provided. There is also another field describing the rail lines servicing the terminal. Similarly to the CTA dataset, this information is dated and subject to review and updating as several of the railroads listed are no longer in business or might no longer service the terminal.

Of the NTAD terminals, 407 are classified primarily as AIR, indicating a transfer between an aircraft and a truck, while 271 are classified as PORT, 444 are classified as TRUCK, and 2158 are classified as RAIL. Associated with this dataset are separate tables that describe the cargo commodity information and direction of modal transfer for each terminal. The cargo type codes match the ones used in the CTA database. Further, the mode type field conforms to the mode designations defined in the CTA dataset. As the NTAD dataset is circa 2003, it was assumed to be more current than the CTA dataset, but still subject to review.

Initial Multimodal Network Development

In developing the intermodal network database for WebTRAGIS it was determined that the base network that would be the point of focus would be the waterways network. While use of the rail network has been the stated preference of DOE for routing of spent nuclear fuel [5], the rational for using the waterways network was three-fold:

1) terminals capable of handling large project cargoes were known to exist on the waterways network,
2) the use of waterways is the most cost-effective means of transporting large cargoes [6], and
3) once locations for truck and rail transfers between water borne transport were identified, the addition of truck-to-rail terminals capable of handling spent fuel casks would be simpler to integrate into the dataset.

In order to update the waterways network in TRAGIS, ORNL obtained a detailed set of node layers for the navigable waterways of the United States from the US Army Corps of Engineers (USACE). This dataset describes the port, associated facilities, the commodity handled at each port, and also notes the presence of rail service at the port. This information was used in constructing the available connection locations between the waterways system and the other transport modes. The USACE dataset provides information on the various terminals and ports that comprise the US waterways system. For some river systems it also provides a description of the commodities handled at particular terminals and/or docks.

Unfortunately, the CTA database was built in 1998 and has been only sporadically and partially updated since that time. Upon completion in 1998, the original Intermodal Terminals Database contained approximately 2,900 terminals with over 9,000 connections. Initial estimates noted that this listing was incomplete and that a complete listing of multimodal terminals would comprise 6,000 to 9,000 terminal records and would require a commitment to annual data maintenance. As a result, the consistency, accuracy and completeness of the resulting WebTRAGIS database required a comprehensive review and assessment. To assist in the review, assessment, and updating of the intermodal terminals dataset several additional, relevant datasets have been identified as reference sources and were used in developing the WebTRAGIS multimodal network database.

Data Structuring for Multimodal Routing in WebTRAGIS

A major focus of the development effort was in defining the structure of the network data. Following the relationships between modes outlined in Figure 1 above for multimodal terminal nodes, a preliminary set of data structures was identified. These were then integrated into the TRAGIS networks for multimodal routing.

In addition to defining the allowable physical transfer relationships between modes, it was also decided to identify the commodity types that are handled and transferred at a particular location. The rationale for doing so is that not all ports or dock facilities may be able to handle project cargo such as used fuel casks. Further, it may be of benefit from safety or security risk mitigation to avoid close proximity with port facilities handling particular commodities such as other hazardous materials or bulk foods. As a result, the data structure allows for the definition of both modal and commodity type connectivity at multimodal terminals. This will allow route planners to potentially include or exclude ports and dock facilities from selection due to the spatial location of the terminals in relation to other terminals and their associated commodity types. For example, certain terminals specialize in handling the transfer and shipment of coal, some in liquid or bulk fertilizers, others in grains, while others specialize in containerized freight. In addition, some terminals that handle multiple commodity types may not handle two-way transfers of all commodities; some liquid fertilizer terminals or grain terminals only transfer the commodity from rail or truck to storage silos and then to barges or directly to barge, but not barge to rail or barge to truck transfers. Finally, the shipment of used nuclear fuel will require specific handling capacity to be available to transfer casks between modes that may not be available at all terminals or may be in proximity to locations that transfer other hazardous or sensitive materials.

The initial WebTRAGIS multimodal network data system is structured around four basic, connected tables delineating the modal transfer possibilities at each multimodal node. This structure builds upon the basic structural connectivity found in the original CTA intermodal terminals database, but also allow for more specific terminal information regarding operations, commodities and capabilities. All of these elements are then reflected in a GIS layer that allows for visualization and analysis.

The network structure includes a Multimodal Node table describing the multimodal buffer node and associating that node with corresponding nodes in the three existing TRAGIS networks. An example of the information contained in this table is provided in Table 1.

Node ID	Name	RNode	HNode	WNode
000001	Port of Seattle Terminal 91	53033002047	530000089	3836
000002	Port of Seattle Pier 69	53033002077	530000098	3947
000003	Port of Seattle	53033002091	530000123	3812

Table 1. Multimodal Terminal Table

Another table provides the types of transfers that are allowed to take place at a particular multimodal terminal. An example of the Multimodal Transfer Table structure is provided in Table 2. The table lists the Node ID identifying the node from the Multimodal Terminal Table and then listing the allowable transfers between modes. For example, BNSF to TL indicates that BNSF railroad would transfer freight to a trucking company at this location. Port to BNSF indicates that shipments are transferred from ship to rail at this location. If a transfer is not listed, then that direction of movement is not available. In Table 2, no truck to rail transfers are allowed at the terminal. This system replaces the CTA designation of ‘H1W’ or ‘R2W’ by making the transfers explicit between companies and modes. This table structure mirrors the existing WebTRAGIS coding for transfers between carriers for the existing rail, water and highway modes. Using this structure simplified the updates to the WebTRAGIS code required to implement intermodal routing.

Additional information about allowable transfers may be determined by the type of commodity involved. Using the commodity information, additional terminals were excluded from the initial WebTRAGIS SNF terminals database. Some terminals may handle only grain shipments, for example, which would prevent other types of commodity shipments from utilizing that facility. In this case each terminal would have commodity classes and possibly sub-classes identified that would let the allowable transfer occur.

The third and fourth tables defining the multimodal network in WebTRAGIS are a transfer penalty or transfer bias table called the Transfer Delay Table and another table called the Cost Ratio Table. Examples of these tables are provided in Tables 3 and 4, respectively.

NodeID	Company 1	Company 2
000001	BNSF	TL
000001	BNSF	Port
000001	UP	TL
000001	UP	Port
000001	TL	Port
000001	Port	TL
000001	Port	BNSF
000001	Port	UP

Table 2. Multimodal Transfer Table

These tables provide constraint or friction parameters that bias the route toward particular modes depending on the features desired by the user. These parameters are estimates of the cost differentials between the modes set as weighting factors. For example, if a user is more cost conscious, they can select route cost factors that will bias the network to transfer to the low-cost waterways network at the closest transfer point and stay on the waterways network until a transfer must be made to complete the shipment. If a user is time constrained, then they can bias the route selection to use more of the highway or railway networks which have faster travel times. The routing code also allows for users to weigh the different factors in determining the constraints used to modify the route results.

Type	Delay
H2W	36
H1W	36
H2R	24
H1R	24
R2W	36
R1W	36
R1H	36
W1H	36
W1R	36

Table 3. Transfer Delay in Hours

MODE	RATIO
H	1
R	0.25
W	0.1

Table 4. Cost Ratio

Currently, the values in Tables 3 and 4 are arbitrary, but could be updated as more information becomes available. The Transfer Delay table provides a measure of the transfer time in hours that will need to transpire to complete a transfer between modes. The Cost Ratio table provides general estimates of transport cost differentials between modes with Highway being set at a value of 1, Rail at 0.25 and Water at 0.1. These parameters reflect general assumptions that rail transport costs are approximately one-quarter of those of truck and barge/marine transport is about one tenth the costs of truck on a per ton-mile basis. As new information on modal cost differences becomes available these values can change. It is also possible within the multimodal code to specify these values for particular transfer locations so that differences in available transfer equipment, operating efficiency, or congestion that might affect transfer delay or costs can be incorporated. Another factor that is not currently incorporated in the code or the data structures is a security component that would reflect differences in location security features as part of the routing parameters.

Additional Routing Considerations

Additional routing considerations for multimodal shipments may also be implemented in WebTRAGIS in the future. These elements would include constraining or optimizing route selection by explicit transportation cost, time of transit sensitivity, public safety of shipment security.

An additional consideration would be modal network capacity and congestion modeling. While the transfer penalties built into the system reflect the “friction” that occurs during transfers of custody, crew change time delays and traffic delays moving through rail yards or locks, total network congestion measures for each mode are not fully reflected in those parameter values. If and when modal congestion factors are determined they could be applied to the routing algorithms to take network congestion by mode into account when determining various route solutions.

FUTURE CONSIDERATIONS

One benefit of the development of a fully realized intermodal routing system would be in the delineation of secure transport of used fuel. The required data to determine secure transport would be located in the intermodal terminals database. Once the particular site requirements for used fuel transport, transfer and handling are determined including such variables as site capacity, mode accessibility, necessary infrastructure and facility security, those factors can be accounted for in the network node dataset. Ideally, this process would begin by focusing on the current shutdown sites and incorporate both the plant site information and assessments of various potential intermodal transfer locations.

Additionally, implementing a multimodal network that has site characteristic information for all types of facilities would assist in determining potential adverse co-location considerations. For example, used fuel material transfers might be possible at a particular facility, but if it is in close proximity to other terminals handling hazardous materials cargoes, such as anhydrous ammonia, the risk profile for the site changes. In the existing datasets multiple terminals, particularly at port facilities, are listed separately. Therefore liquid bulk facilities handling hazardous materials such as anhydrous ammonia might be located in close proximity to facilities that would be able to perform a used fuel container transfer. However, this proximity might represent an unacceptable security risk. Understanding the commodity mix and capabilities will be a critical factor in determining co-location issues. As a result, an accurate intermodals terminal routing network would allow for contingent proximity analyses to be performed to assess the full range of site characteristics when determining candidate locations for modal transfers.

Finally, the implementation of an intermodal routing capability would allow for the future development of a modal split/modal cost model. Once implemented, different cost factors for each mode could be added to the model as additional routing constraint parameters. The outcome would be a system that could calculate minimal time, minimal distance, minimal cost, minimal risk or some combination of factors to assist in determining desirable routes for used fuel shipments.

A ROUTING PRECEDENT FOR SPENT FUEL: ON-SITE MODAL ACCESSIBILITY STUDIES

At present, the Department of Energy and its contractors do not have current, up-to-date information on the status of rail, road and lift accessibility at most of the nuclear power plants in the United States. Site modal assessments were made in 1990 and 1991 by Oak Ridge National Laboratory (ORNL) and Nuclear Assurance Corporation for DOE's Repository Technology and Transportation Division. [1] Assessments were made of on-site rail and barge access and possible heavy-haul truck routes to potential rail or waterway transfer locations in the absence of rail or barge facilities at a facility. Some of the data used in these reports dates back to 1986. Also, the analyses conducted during this period were only for the older, smaller spent nuclear fuel casks. Assessments of infrastructure needs to accommodate the newer, heavier casks have not been done. While there has been a recent assessment of some of these factors at the shutdown nuclear sites [7], for the operating facilities no updates to these reports have been made since their initial development 21 years ago, so the current state of rail and barge accessibility, the quality of any infrastructure assets in place, or designated heavy-haul trucking routes for each facility is unknown.

ORNL does maintain location information in WebTRAGIS for each nuclear plant and orphan site. ORNL has also completed a thorough revision of its rail modal network using high resolution aerial imagery. However, the quality of any rail found on-site cannot be determined from aerial imagery analysis. While WebTRAGIS could potentially manage information on infrastructure quality and accessibility for each facility, it does not currently do so.

In order to validate a fully functional multimodal routing system for spent nuclear fuel a process similar to the site modal analyses needs to be done to identify locations where transfers of casks may be accomplished safely and securely. While, ORNL has compiled a database of possible locations, they have not been assessed for their true capabilities, suitability, security or other factors that would influence selection as a transfer site.

CONCLUSION

A fully functional intermodal network is a realizable goal. ORNL has developed a base intermodal database for the routing of spent nuclear fuel along with the associated code to route across modes. Many of the basic components of such a network are already developed and have been updated such as the underlying modal networks. Other components such as capable, secure transfer locations require extensive updating and validation, but are fundamentally sound. Finally, the routing capability of WebTRAGIS for highway, railway and waterways is well established. A newly developed intermodal capability would utilize the same routing algorithms across several modes to provide seamless routing analysis of transport of used nuclear fuel.

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