DEVELOPMENT OF AN INTERMODAL NETWORK FOR FREIGHT TRANSPORTATION ANALYSIS

Aaron M. Falzarano, Sai Ketha, J. Scott Hawker, James Winebrake, James Corbett, Karl Korfmacher, Stephen Zilora

Laboratory for Environmental Computing and Decision Making
Rochester Institute of Technology

ABSTRACT

This paper describes a process for creating an intermodal freight transportation network within ArcGIS. In this process, ArcGIS Network Analyst is used to create an intermodal network and conduct optimal route analysis for various network attributes. In particular, the paper demonstrates how users can integrate highway, rail, waterway, and transit facility data from sources such as the National Transportation Atlas Database, as well as discusses existing database limitations to network analyses. We illustrate this network development using a case study that analyzes freight traffic along the U.S. Eastern Seaboard.

INTRODUCTION

Energy use and emissions from freight transport are increasing at a more rapid rate than other types of transportation (Ang-Olson and Schroeer 2002; Janic 2007). In 2005 freight transport in the United States accounted for about 6,800 trillion Btu (TBtu) of energy consumption, representing 25.7% of total non-military transportation energy use. Consumption is anticipated to increase at an average rate of 1.8% annually (compared to 1.4% for the transportation sector as a whole). By 2030 energy consumption from freight transport is expected to grow by nearly 60% to 10,850 TBtu, representing 28.6% of total transportation energy use (U.S. Energy Information Administration 2007). Accompanying the increase in energy consumption is a simultaneous increase in emissions of greenhouse gasses and other pollutants.

One way to address these trends is through careful consideration of routes along an intermodal freight system (Owens and Lewis 2002). Intermodal transport is defined as the concept of utilizing two or more modes of transport, in combination, to form an integrated transport chain (Lowe 2005). The goal of intermodalism is to be able to utilize the most cost-efficient use of modes of transport to move freight from its origin to its destination (Lowe 2005). Route selection based on environmental or energy criteria, as opposed to the traditional criteria of cost and time-of-delivery, could help identify energy- and environmentally-sustainable ways to move freight throughout the US and abroad since the environmental impact of freight is becoming more widely noticed (Ang-Olson and Cowart 2002; Kreutzberger, Macharis et al. 2003; Leonardi and Baumgartner 2004; Facanha and Horvath 2005; Hricko 2006).

Prior models have been developed to study freight flow across intermodal networks (Boile 2000; Southworth 2000; Standifer and Walton 2000; Luo and Grigalunas 2002; Arnold, Peeters et al. 2004; Janic 2007). The challenge faced in building intermodal models is in efficiently and accurately connecting disparate modal networks into an integrated whole. Our goal was to employ "artificial" nodes and links to connect water, rail, and highway networks. We used the best available data to capture actual intermodal transfers. We also apply custom evaluators to

find routes for freight based on energy and environmental attributes (Hawker, Falzarano et al. 2007)

This paper will discuss the development of the Geospatial Intermodal Freight Transportation (GIFT) model using ArcGIS 9.1. The model can be used to identify energy, environmental, operating cost and time tradeoffs associated with intermodal freight transport. GIFT uses an intermodal network built by the authors to connect various modes (rail, road, water) with transfer facilities and port terminals via artificial nodes and links. Routes along the network are characterized not only by distance, time, and operating costs, but also by energy (Btu) and emissions [carbon dioxide (CO_2), particulate matter (PM), nitrogen oxides (NOx), volatile organic compounds (VOC), sulfur oxides (SOx), and carbon monoxide (CO)]. Decision makers can use the model to explore tradeoffs between alternative routes across the three modes, and identify optimal routes for objective functions that feature energy and environmental parameters (e.g., minimize CO_2 emissions).

MODEL OVERVIEW

The following sections provide a detailed description of how the GIFT model was created using ArcGIS 9.1.

Creating "Artificial" Transfer Nodes and Modal Connection Links

Before an intermodal network could be constructed, four shapefiles needed to be created. These included the following:

- Intermodal Transfer Node
- Highway-Rail Connection
- Highway-Waterway Connection
- Rail-Waterway Connection

Using ArcCatalog, shapefiles were created using the above terminology. The intermodal transfer node needed to be identified as a point shapefile and the three modal connections as lines. These shapefiles were saved to a folder that contained all of the other shapefiles that were used in the GIFT model. Creating the shapefiles is essential because when using the editing tool in ArcMap there needs to be a "Target" noted when using the editing tool.

Connecting Artificial Transfer Nodes and Links

The editing tool provided by ArcMap allows the creation of the necessary connectivity. The highway, rail, and waterway routes are three separate layers. When these layers are placed into ArcMap they are layered one on top of the other and not as an integrated network. The transfer facilities and port terminals are not connected geographically to other features (highway, rail, waterway) in the network. Therefore, a network needed to be generated that connected the transfer facilities, port terminals, and three separate modes of freight transportation in order to create the intermodal network. Figure 1 demonstrates the problem encountered by the authors.
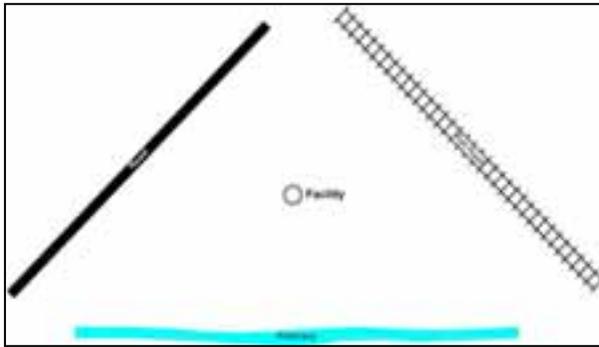
Figure 1. Three separate modes of transport

An approach was needed that provided users the ability to transfer from one mode of transport to another mode only at appropriate facilities or terminals. The approach explained is the best approach given the original problem of connecting different modes of transport and attaching to the network custom environmental evaluators.

As seen in Figure 1, the facility is not connected with the other features nor are the other features connected to each other. We needed to ensure that if a modal transfer was to take place the transfer happen only at or near the appropriate facility or terminal. In the above diagram, all of the features seen are the original features. Figure 2 is the representation of the network connectivity with the integration of artificial nodes and links.
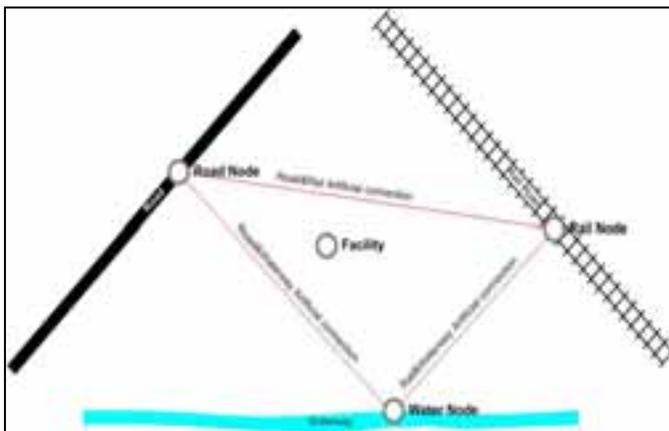
Figure 2. Network elements for intermodal freight transfers

As seen in the diagram (Figure 2), we have created four new features to meet our requirements. The four new features are:

- Road & Rail Artificial connection
- Road & Waterway Artificial connection
- Rail & Waterway Artificial connection
- Intermodal Transfer Nodes (Road, Rail, and Waterway nodes)

The road & rail artificial connection, road & waterway artificial connection and rail & waterway artificial connection are line shapefiles. The road node, rail node and waterway node are all the same node feature named "Intermodal Transfer Nodes" and saved as a point shapefile.

We created a triangular artificial network around the facility or terminal for transfers from one mode of freight transport to another mode. This simulates the facility or terminal participating in the network and the movement of freight between the different modes. The new node feature created acts as a point of transfer from one mode to another mode of transport in the network. The line features connecting the nodes facilitate the transfers within the network dataset. The artificial features are the link between the original features which allows for a holistic freight transportation network.

In order to create this connection within ArcMap, an editing session needed to be started as shown in Figure 3. Once the editing session had been started, the snapping rules and tolerances had to be set. For the purpose of the GIFT network, the snapping rule was set that only allowed features that were created to be snapped to endpoints as shown in Figure 4.
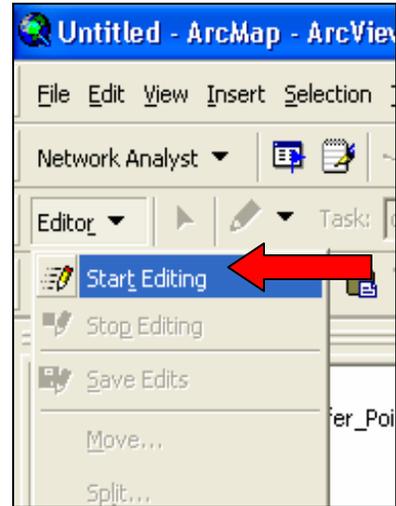

Figure 3. Starting an editing session

Figure 4. Setting the connectivity policy

After applying the necessary rules and tolerances to the snapping environment, new features were created. The first feature to be created was the "Intermodal Transfer Points" which needed to be the feature highlighted in the "Target" box located in the Editor toolbar as shown in Figure 5. The new points were created at the endpoints of the three (highway, rail, short-sea) transport modes or two (truck, rail) transport modes since this is the policy constructed for the snapping environment. For the GIFT model, great effort was taken in order to create the intermodal linkages at points where actual freight transfers would take place.

After the three (or two) intermodal transfer points are placed in the network, the artificial connections were created linking the different modes of transport. In the editor toolbar, it was necessary to change the "Target" drop-down selection to reflect the feature that was being created (road-rail connection, rail-waterway connection, etc…). A depiction of this is provided in Figure 5.

Figure 5. Setting your "Target"

After connecting the artificial nodes between the two different modes of transport, the ArcMap editing "sketch" was finished and this process continued until all of the necessary connections were constructed. Once all of the editing was complete, the edits were saved, and the process of preparing the data for building the network was started.

Preparing Data for the Network Dataset

The data had to be in a particular format in order to create a network dataset using the necessary features within ArcGIS. Figure 6 demonstrates the first phase of what the authors did in order to begin building a network dataset. In order to create the intermodal feature dataset a "Personal Geodatabase" needed to be created. Figure 7 demonstrates this. Once a "Personal Geodatabase" was created, a "Feature Dataset" was constructed which is shown in Figure 8.
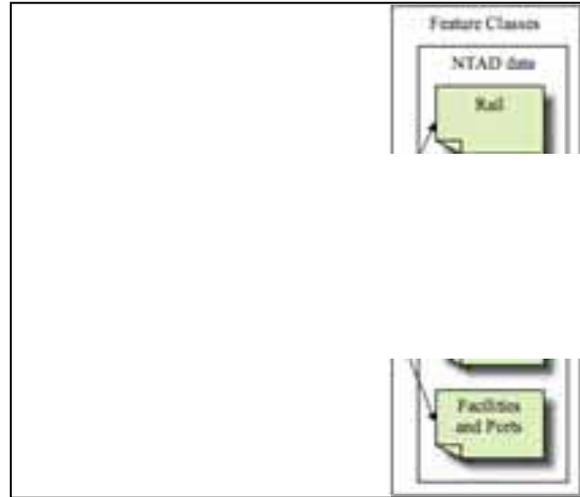

Figure 6. Elements in network dataset creation

A name was created for the "Feature Dataset" and a coordinate system was defined. The coordinate system that was chosen corresponded with the coordinate system that was used by the data in the network. This is shown in Figure 9.
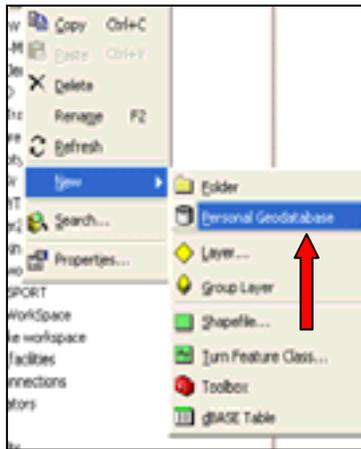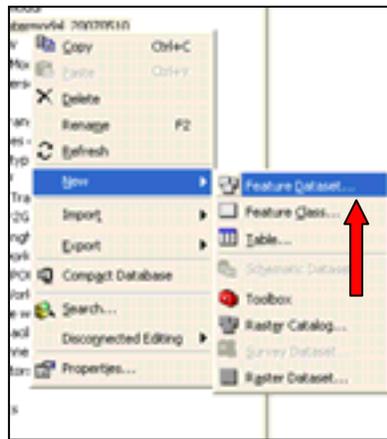

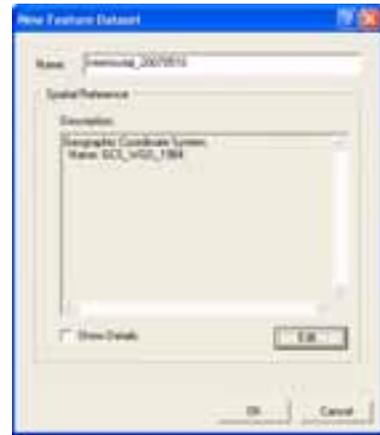**Figure 7. Personal Geodatabase**   **Figure 8. Feature Dataset**   **Figure 9. Naming new dataset**

Once a Feature Dataset had been created, the dataset was populated with the necessary data that was to be included in the network. This is shown in Figures 10 and 11. The data used in the GIFT model included network data from the National Transportation Atlas Database.
- Highway Network (NTAD)
- Rail Network (NTAD)
- Waterway Network (NTAD)
- Port Terminals (NTAD)
- Transfer Facilities (NTAD)
- "Artificial" Intermodal Transfer Nodes
- "Artificial" Intermodal Connection Links

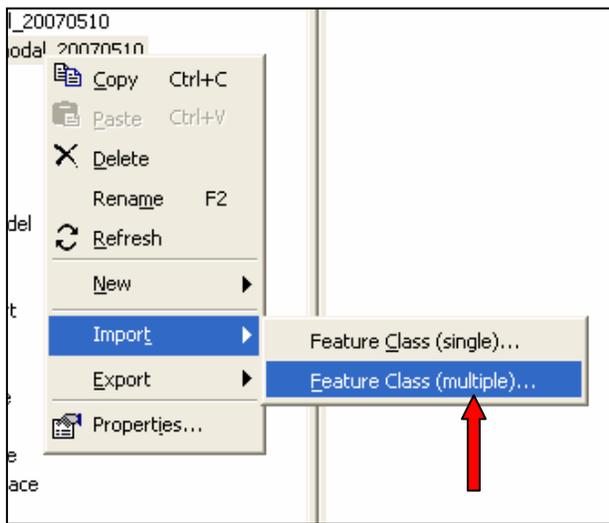The map background is loaded from the ESRI StreetMap file.
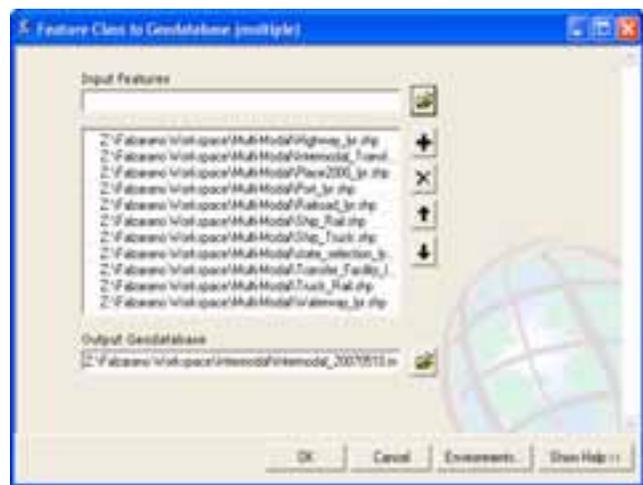
Figure 10. Adding feature classes

Figure 11. Importing feature classes to geodatabase

Constructing the Network Dataset

Once the files were imported into the new "Feature Dataset", the building of the network dataset could begin, as shown in Figure 12.

First, the network dataset needed to be named. Next, there was a determination of what feature classes were to be included in the network, as shown in Figure 13.
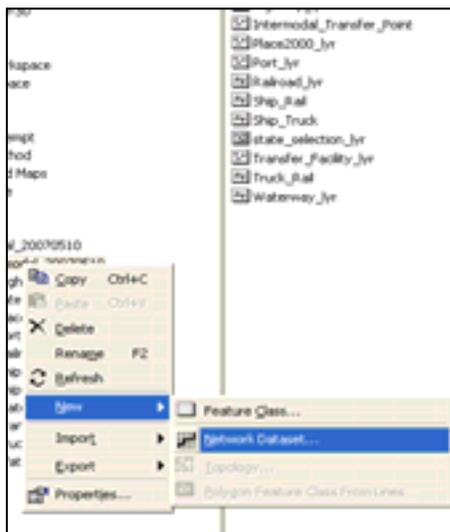

Figure 12. Creating a network dataset

Figure 13. Adding feature classes to the network dataset

After the features that would be participating in the network dataset were chosen, connectivity policies were input in order to connect each of the features in the network. This step is show in Figure 14. The hierarchical structure of the GIFT model meant that there would be three group

columns in the network. The model is grouped such that road is first, rail is second, and waterway is third. The intermodal transfer point is instructed to honor all three of the different modes of transport. Since the intermodal transfer point honors all three modes, the assignment of connectivity for the "artificial" connections is trivial.

Figure 14. Setting network connectivity policies

The next two prompts inquire about elevation data and global turns. For the purpose of the GIFT model the elevation data was left unchanged but global turns were honored in the network. The next important step required the adjustment of the evaluators in the network dataset. The GIFT network uses the standard evaluator of distance that the Network Analyst extension provides but also uses custom evaluators created by the research team (Hawker, Falzarano et al. 2007). The new evaluators need to be added to the network dataset. This addition is shown in Figures 15 and 16.

Figure 16. Assigning names to new attributes
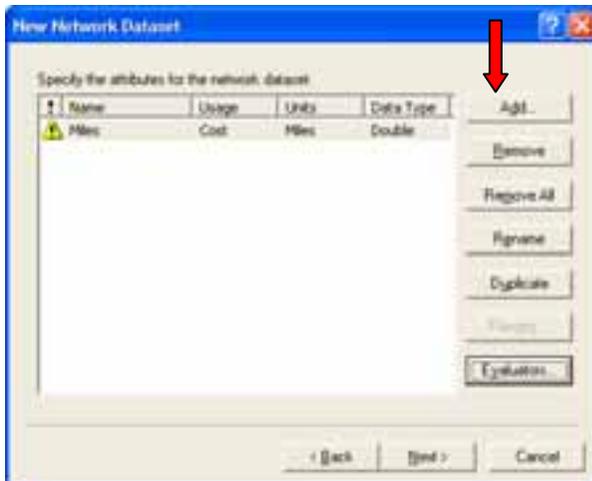
Figure 15. Adding new evaluators

Once all of the new attributes were added to the network dataset values were added to those attributes so that the network would be able to calculate correctly the new attributes. This is shown in Figures 17 and 18.
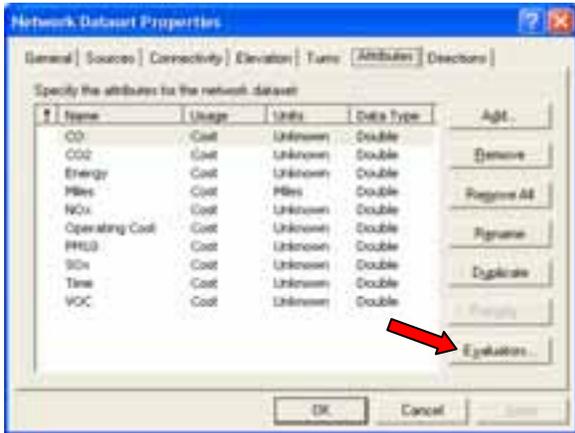
Figure 17. Evaluator properties

Figure 18. Defining evaluator types

Once the appropriate evaluator value was selected from the drop-down box in the column "Type" the value for that field was automatically determined since the evaluator type has a value pre-determined based on variables input by the user in the user interface. Provided the attribute that was currently being worked with, the evaluator that measures the attribute is what was selected from the drop-down menu. This process was repeated for all of the attributes that had been added to the network. For the "Miles" attribute, it should be noted that for the purpose of the GIFT model the transfer links that connect the various modes of transport have an assumed value of 0, as shown in Figure 19.

Figure 19. Assigning transfer link distance

After values were assigned to all of the attributes the evaluator process was complete. The remaining step allowed for the creation of directions for the network. Each mode has an attribute which distinguishes it, typically a name. Network Analyst identifies this attribute and uses it when creating a set of directions for your selected route. Upon completion of this task the network was ready to be built. Once completed, the network dataset was placed into the "Personal Geodatabase" as shown in Figure 20.
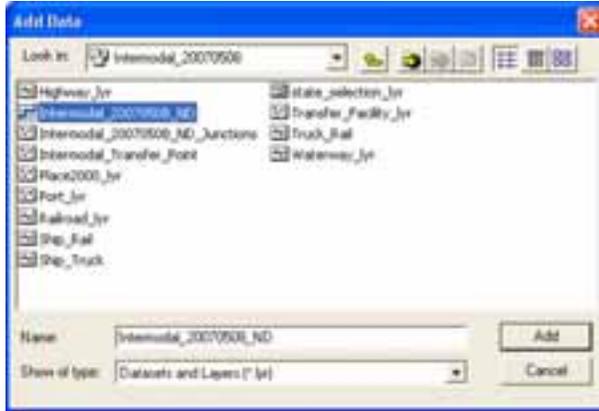
Figure 20. Accessing the new network dataset

In order to see the network dataset ArcMap needed to be loaded and the network dataset file needed to be uploaded to the map as shown in Figure 21. Once the network dataset loaded onto the map, the network could be used, using the Network Analyst extension.
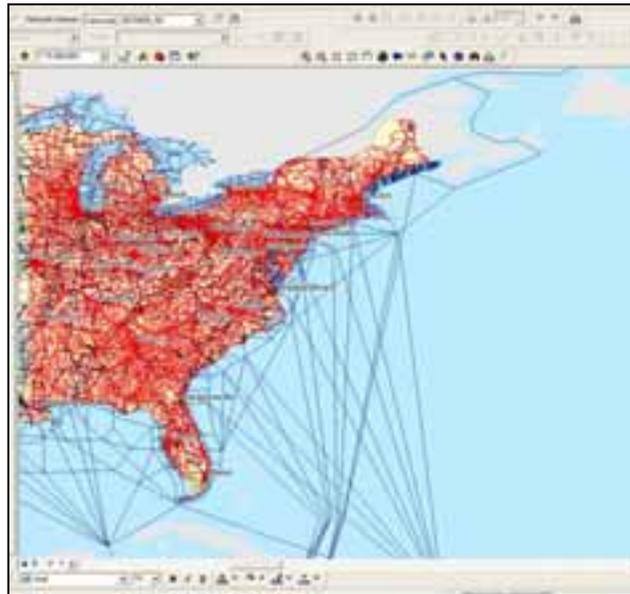
Figure 21. Display of the new network dataset in ArcMap

Application

With all of the necessary attributes added to the network and the network dataset built, the network can be used to analyze intermodal freight movement. The GIFT model features a user interface that allows users to input their own data in order to run multiple analyses and explore their own tradeoffs. Within ArcMap, a button was created, as shown in Figure 22, that allows users access to the user interface shown in Figure 23 (Hawker, Falzarano et al. 2007). The button

Figure 22. Accessing user interface

provides access to a user interface that allows users to create and save sets of data. The data that is input into the user interface is accessed by the Network Analyst extension and the data is used when solving to find optimal routes based on the impedance that is selected by the user. This is shown in Figure 24. The network also accumulates values for all attributes that are input into the network, as shown in Figure 25.
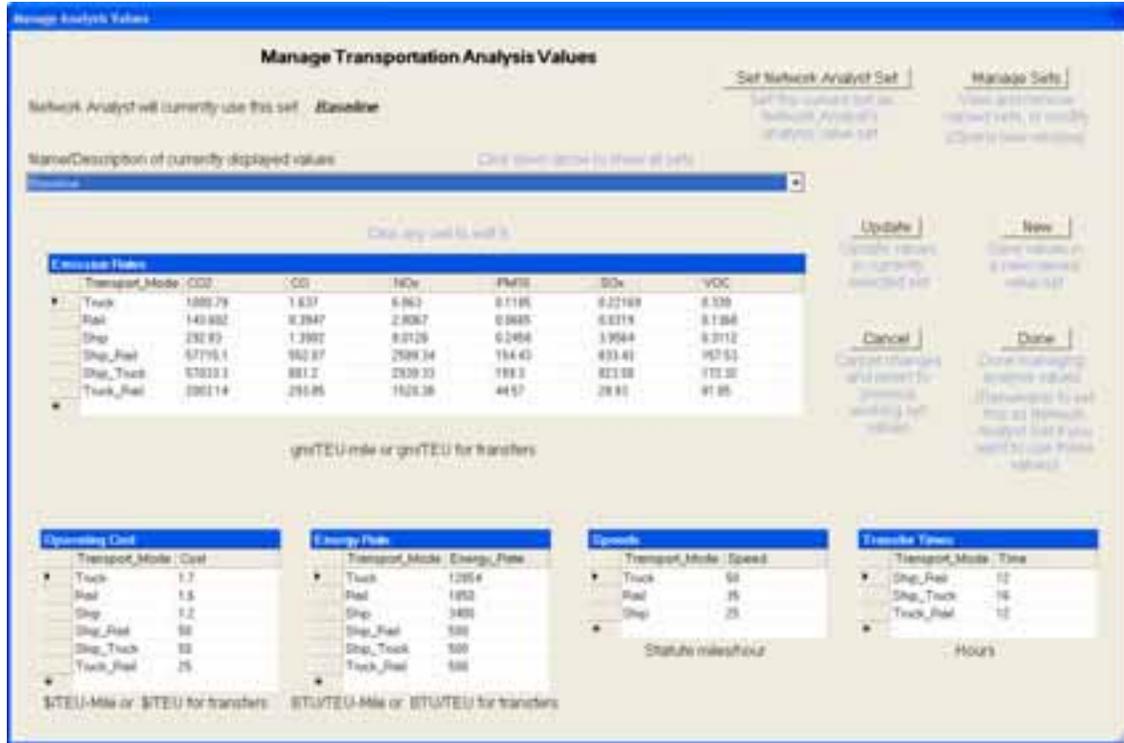
Figure 23. User interface
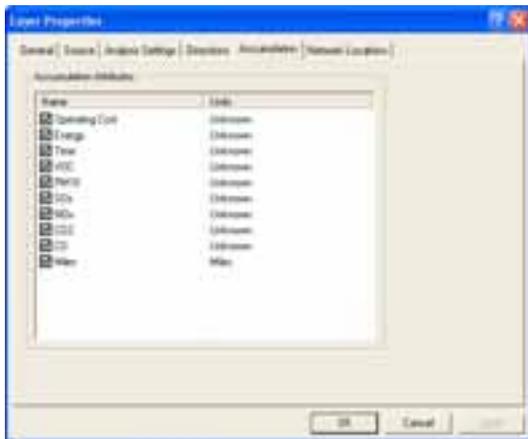
Figure 24. Setting network attribute
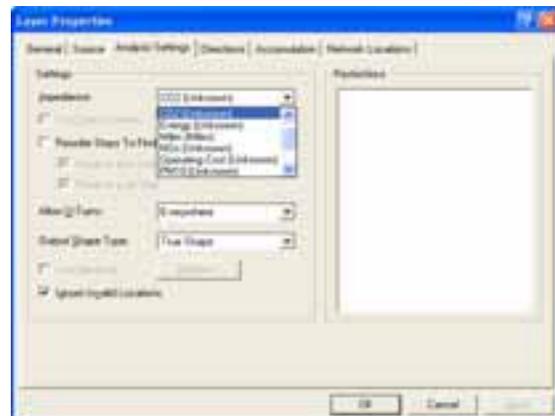
Figure 25. Defining network impedance

After data is input to the interface, layer properties are set, and points are inserted by the user signifying the origin and destination, the "solve" button was selected and the optimal route determined. The Network Analyst extension allows for a "Properties" window, shown in Figure 27, to be selected when the user "right-clicks" on the highlighted route. Also, directions can be accessed for the optimal route that has been generated as shown in Figure 26.

Figure 26. Route directions

Figure 27. Route attributes

Demonstration and Discussion

A demonstration of the GIFT model will be shown with an analysis of route selection from New York/New Jersey to Jacksonville. Three different cases were run that included: a least cost route, a least time route, and a least CO_2 route (Winebrake, Hawker et al. 2007).

The data used for these demonstration cases is outlined in Table 1. Table 2 displays the results obtained from the GIFT model for each of the three test cases there were run. Figure 28 displays a map that shows the three optimal routes in ArcMap.

Table 1. Data Used for Case Study Demonstration

Mode or Intermodal Transfer	Average Speed (mph)	Transfer Time (hr)	Cost ($/TEU-mile or $/TEU)	Energy (BTU/TEU-mile or BTU/TEU)	CO2 (g/TEU-mi or g/TEU)	SOx (g/TEU-mi or g/TEU)
Truck	50	--	$1.70	12,850	1000	0.22
Rail	35	--	$1.60	1,850	140	0.03
Ship	25	--	$1.50	3,400	290	3.96
Ship-to-Rail	--	12	$50.00	500	57,720	830
Ship-to-Truck	--	16	$50.00	500	57,030	820
Rail-to-Truck	--	12	$25.00	500	2,000	30

Table 2. Results for Case Study Demonstration

	A (Least Cost)	B (Least Time)	C (Least CO$_2$)
Distance (miles)	950	970	1010
Time (hours)	54	36	53
Energy (MBtu)	3.3	12.0	2.1
Cost ($)	$1,480	$1,690	$1,690
CO$_2$ (kg)	340	990	220
SO$_x$ (kg)	4.5	1.2	1.1

Figure 28. Demonstration of the GIFT model

The creation of the GIFT model has opened up many opportunities for research. Currently the model views freight only on the per TEU basis as opposed to being a cargo flow model. It is possible to run the model multiple times to attempt to simulate a cargo flow model, but the current model is built to simulate the movement of only one TEU at a time. The construction of the costs in the model is also being evaluated. There are a number of costs associated with intermodal freight, and modeling these costs is a very challenging task.

The model provides policy analysts with an opportunity to evaluate freight movement in a new and exciting way. No longer are analysts constrained with only least time and least cost routing. GIFT allows an analyst the ability to analyze the environmental impacts of freight movements and also analyze the impacts of different policies and new technologies. It is feasible to run a scenario in the model that simulates the effect of a congestion mitigation policy or the introduction of CO_2 reducing technologies. Given this flexibility, the GIFT model provides significant opportunities to analysts.

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Primary Author Information

Aaron M. Falzarano
M.S. Candidate Science, Technology, and Public Policy
Rochester Institute of Technology
Department of STS/Public Policy
Rochester, NY 14623-5608
amf8539@rit.edu