

Intermodal Transportation Network Custom Evaluators for Environmental Policy Analysis

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Abstract

We are leveraging the power of GIS-based transportation network analysis to provide tools for public policy analysts to understand the environmental impact trade-offs of intermodal transportation networks that integrate truck, rail, and inter-coastal waterway modes of transportation. We will describe the environmental policy analysis problem, the intermodal network model, and the creation of environmental network attributes and custom attribute evaluators. We will describe what drove our choice to use C# and the Microsoft .NET framework to design and develop evaluators that access external data from relational databases and that have their own evaluator configuration user interfaces. We will conclude with a description of possible next steps, including evaluator access of environmental data from external web services, a way for policy analysts to create new attributes and custom evaluators without any programming skills, and porting the desktop-based system to a web and server-based system for broad deployment.

Introduction

Freight Transportation represents about 7% of the U.S. Gross Domestic Product (GDP), and the volume and value of freight transportation has been growing for some time [1,2,3,4]. A majority of freight is transported by truck, less by rail, and even less by water. In 2002, 64% of domestic freight shipments, by weight, were transported by truck, 10% by rail, and 3% by water [5].

Freight transportation is a significant contributor to greenhouse gasses (GHGs) and other emissions. Currently, freight transport emits about 8% of fossil fuel CO₂ emissions and about 8% of total CO₂ emissions (CO₂ is a primary GHG) [6,7]. Freight transport is also a major source of local and regional air pollutants such as NO_x, SO_x, and particulate matter (PM). Freight transportation accounts for about 27% of all U.S. NO_x emissions and about 50% of emissions from mobile sources, and it accounts for about 30% of 10 micron diameter particulate matter (PM-10) from mobile sources [8].

Trucking consumes more energy and contributes more GHG and pollutants than rail or water-based freight transportation. Table 1 shows some operating cost, energy, and emissions values for containerized freight, where the values are per twenty-foot equivalent unit (TEU) freight container per mile traveled (TEU-mile) [9,10]. Table 1 shows that the costs of transport are essentially the same, but trucking contributes significantly more to energy and emissions concerns than rail or water transportation.

Table 1. Operating cost, energy consumption, and emissions for different freight transportation modes

<i>Mode</i>	<i>Cost (\$/TEU-mile)</i>	<i>Energy (BTU/TEU-mile)</i>	<i>CO2 (g/TEU-mi)</i>	<i>SOx (g/TEU-mi)</i>
Truck	\$1.70	12,850	1000	0.22
Rail	\$1.60	1,850	140	0.03
Water	\$1.50	3,400	290	3.96

A primary reason that so much freight is transported via truck is because trucking is faster and more flexible while being about the same cost as rail and water. The U.S. highway system allows trucks to move freight over large distances relatively quickly, and trucks can go virtually anywhere that there are good roads. To ship freight via rail and water is slower and requires the added time and expense of moving freight from one mode to another. Table 2 shows this more complete picture of intermodal transportation (note: intermodal transfer costs are per TEU) [9, 10].

Table 2. Intermodal transportation "costs"

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

With concerns of global warming due to greenhouse gasses and health impacts of airborne pollutants, time and cost may no longer be the primary factors to consider in freight transportation. Modes of freight transportation that reduce energy consumption and harmful emissions may become equally (or more) important to society and the economy compared to modes that reduce time and cost.

A policy maker, then, might ask, "What policy will encourage the use of transportation modes that better balance the concerns of time, cost, energy consumption, GHG, and airborne pollutants that impact health?" Taxes and rebates that change the cost structure among transportation modes might be one set of choices. Imposing pollution control technologies and emissions caps might be other choices (with associated cost impacts). Building more ports and other intermodal transfer facilities that enable freight to get closer to origin and destination locations before being transferred to trucks for the final leg of the journey might be choices, too. Educating consumers and shippers on the environmental impact of their purchase decisions might be yet another choice. There are numerous choices that have different impacts. To make informed decisions, the policy maker needs to analyze the impact of policy options to identify appropriate trade-offs.

Our goal, then, is to provide decision-support tools for policy analysts to study the cost and benefit of various policy options for intermodal freight transportation. We have

developed a system that uses shortest route-finding capabilities of a transportation network analysis system to identify the “cost” impact of various intermodal transportation options, where “cost” extends the traditional time and operating cost to also include energy consumption and emitted GHGs and pollutants. Figure 1 shows the results of a study of the trade-off of routes from New York City to Jacksonville, FL using the data in Table 2 [11].



Figure 1. Results of a case study of trade-off of cost, time, and GHG (CO₂)

The remainder of this paper describes the design and implementation of a system to support intermodal transportation policy analysis. The system, called the Geographic Intermodal Freight Transportation (GIFT) system integrates three separate transportation networks (highway, rail, and water) into an integrated intermodal network, it extends the network analysis features of ESRI ArcGIS by providing custom evaluators to assess energy and emissions costs of the three modes plus intermode transfers, and it provides a simple policy analyst user interface to understand the trade-off of “cost” factors of time, operating cost, energy, and emissions. Our initial success in using our early GIFT implementation has helped us identify future enhancements to make the system more usable by a policy analyst, to address a larger variety of policy options, and to make the system available on the Web to a broader audience of policy analysts.

The Intermodal Network Model

The 2005 version of the National Transportation Atlas Database (NTAD), from the Bureau of Transportation Statistics at the U.S. Department of Transportation, provides network models of U.S. road, rail, and waterway routes. It also provides some data on intermodal facility locations. Unfortunately, the networks are separate and the intermodal facilities database is incomplete and inaccurate. A network solver looking for a route from one location to another cannot move from one network mode to another.

To solve this problem, we created network features that connect the three modes. As Figure 2 illustrates, we created network nodes and segments near transfer facilities that serve to integrate the single-mode networks. The artificial connection segments are logically part of the networks that they connect, so a route solver can see these segments and transition from one single-mode network to another. Further, these segments have associated attributes that represent the time, cost, emissions, and other factors associated with transferring freight from one transportation mode to another. Table 2, above, shows the “costs” associated with intermodal transfer network segments. Further information on the construction of these transfer segments and associated costs is available elsewhere [11]

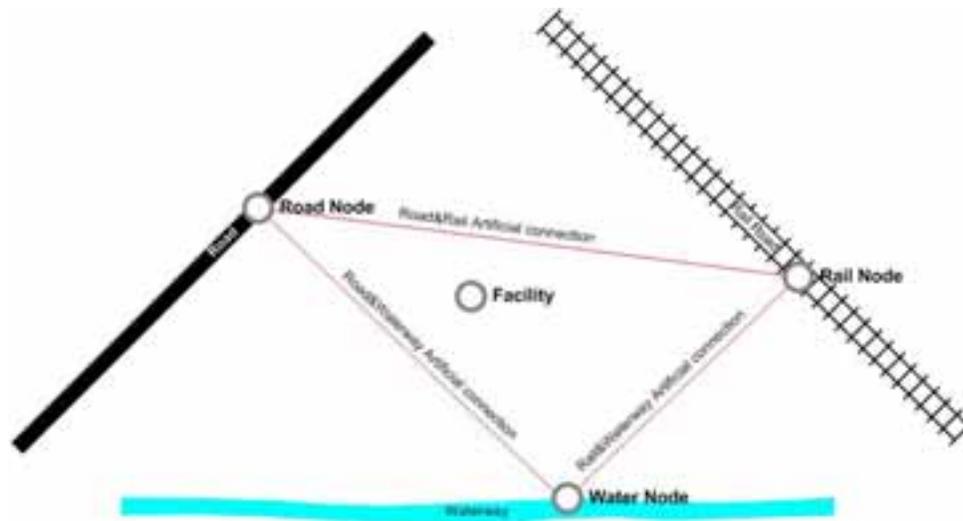


Figure 2. Network elements for intermodal transfers

Network “Cost” Attributes

Using ESRI’s ArcCatalog, we constructed a network dataset that merged the three single-mode networks and the intermode transfer segments into an integrated whole. For each segment, we defined attributes to represent travel time, distance, operating cost, energy consumption, and various emissions including CO, CO₂, NO_x, SO_x, VOC (Volatile Organic Compounds, which tend to create ozone), and PM (particulate matter). Figure 3 is an ArcCatalog screen snapshot showing these attributes.

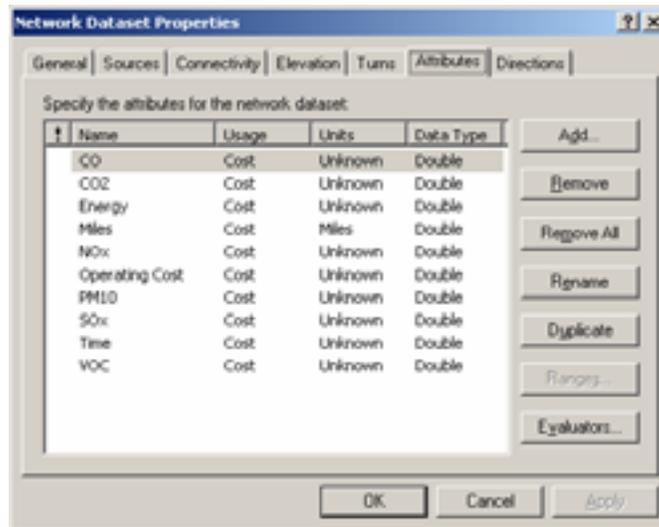


Figure 3. Network attributes for the intermodal network

The ESRI products offer a number of alternatives for defining how network costs are computed for network elements. The simplest approach uses ArcCatalog to define a default cost for each network element, or to retrieve the value of other network attributes for that element and use those in a cost computation. The most flexible approach is to implement a custom evaluator. A custom evaluator is a code module (written in C#, in our case) that implements the ESRI ArcObjects interfaces in Figure 4. This way, almost any computing technology available from a Microsoft Windows platform can be used to provide the run-time values of network costs. The custom evaluator can access information in the network data set and combine that with information from outside of the GIS to determine the cost of traversing network segments.

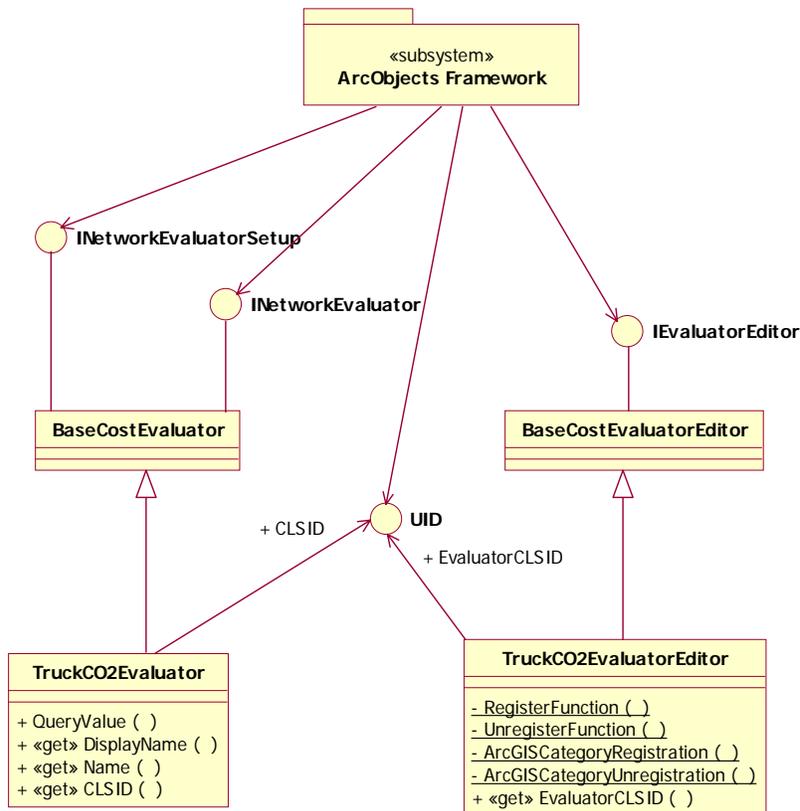


Figure 4. Base evaluators and evaluator editors are implemented and then specialized for each attribute and transportation mode

So, although the ESRI developer tools provide easy-to-use facilities for implementing straightforward computations as part of the network analysis and route solving, we need the flexibility to have relatively complex computations that access data resources outside of the transportation network and the ESRI ArcGIS run-time, such as external databases and Web services. This way, we can incorporate arbitrarily complex computations in determining the “cost” of traversing a network segment. Toward the end of this paper, we will indicate the types of “complex” computations that we envision.

For each custom network attribute and for each transportation mode, we defined a custom evaluator for the route solver to call to obtain the cost value for that attribute for a given network segment. Figure 5 is an ArcCatalog screen snapshot which lists the custom evaluators that evaluate the CO₂ emissions resulting from traversing a segment of the intermodal network. Similar evaluators were defined for each cost attribute in the network, for each transportation mode in the network.

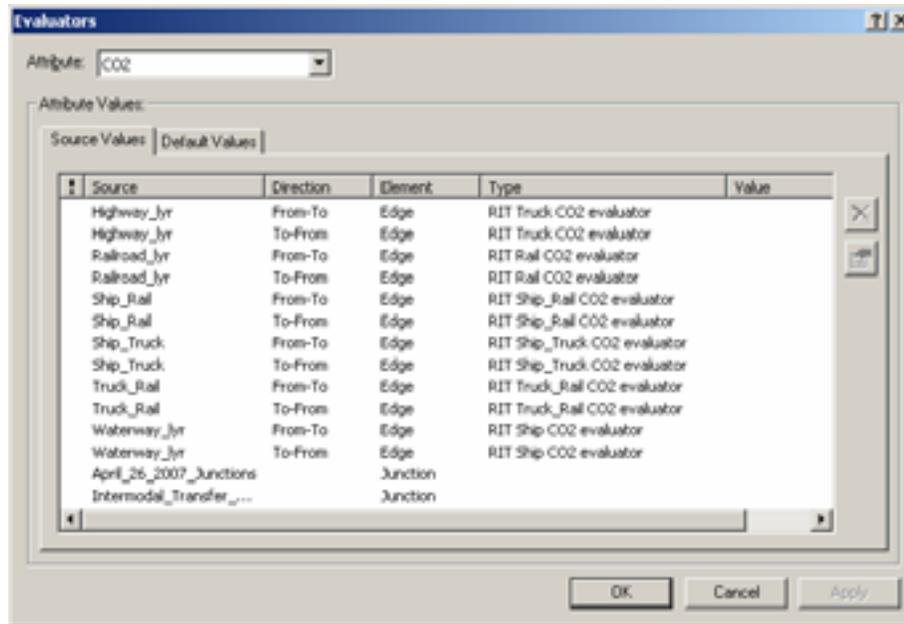


Figure 5. Custom evaluators for the CO2 attribute of each edge of the intermodal network

Since much of what a custom evaluator does is common for all evaluators in our network, we defined a basic cost evaluator and an associated basic cost evaluator editor, and then specialized what was specific to each transportation cost in a family of evaluator and evaluator editor specializations. As Figure 4 shows, each specialized C# class only needs to implement the items that are specific to their network mode and attribute or deal with registering each unique evaluator and evaluator editor in the ArcObjects framework. Each mode-specific and cost-specific evaluator and evaluator editor overrides or extends the behavior of its associated base class.

Each specific evaluator overrides the base evaluator's implementations of its unique name, its unique identifier, and, most importantly, the computation of the cost of traversing a network segment. Similarly, the specific evaluator editors override the functionality to associate themselves with the run-time identifier of their corresponding evaluator. In our implementation, there is no evaluator-specific user interface beyond providing the evaluator name and display name as part of the basic ArcGIS displays such as in Figure 5. We do, however, provide C# classes that implement a user interface to configure external network cost information, and we make that available in the context of the ArcMap user interface. The next section discusses this, including how intermodal network costs are computed to feed the network route solver.

Setting Up and Running a Policy Option Scenario

In our current implementation of GIFT, we use an external relational database to store the network costs such as those in Table 2. We provide a simple user interface, shown in Figure 6 and Figure 7, for freight transportation policy analysts to manipulate those costs and save them as policy-specific values. Figure 6 shows one set of values for analysis, capturing a specific combination of policy options. Figure 7 is a detail view of Figure 6,

showing example items in the drop-down list of available sets of analysis values, each capturing different policy options or analysis cases.

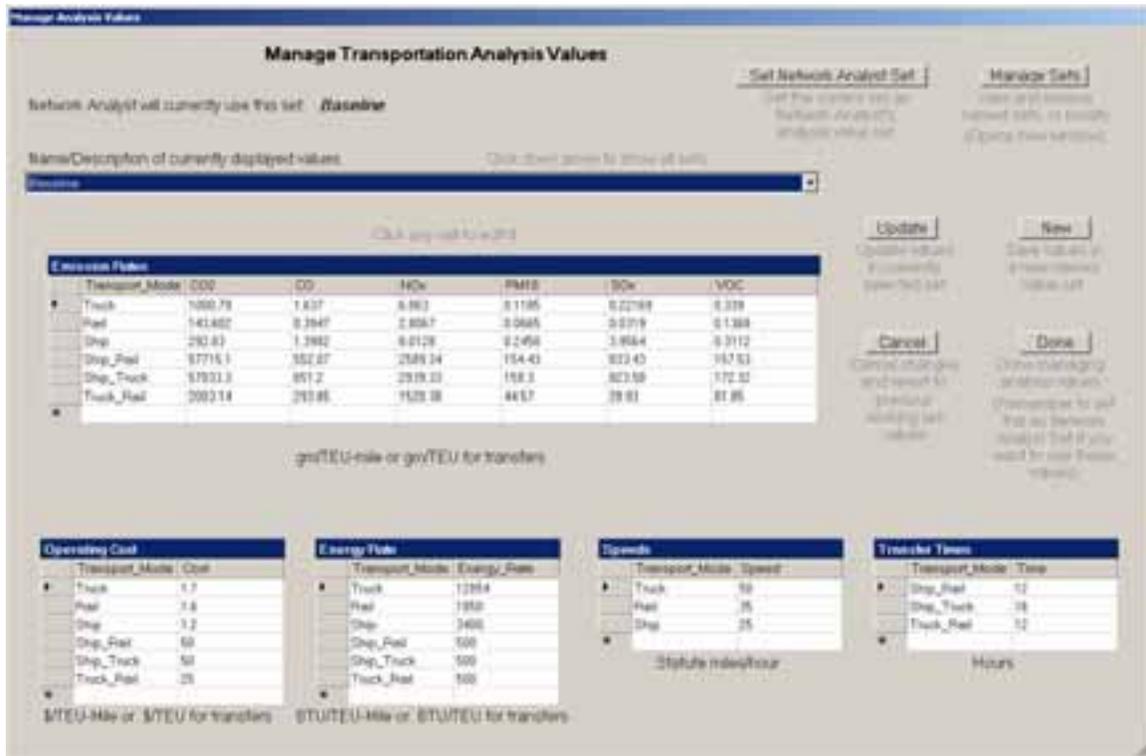


Figure 6. User interface to manipulate transportation "costs"

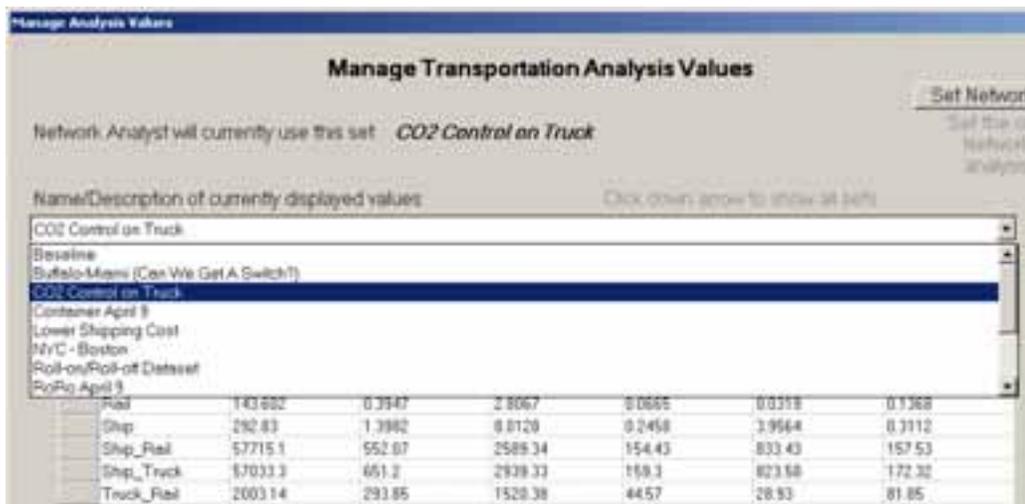


Figure 7. The policy analyst can define and manage multiple "cost" data sets

To display the user interface that the policy analyst uses to define and manage transportation network costs, the policy analyst clicks a button on the ArcGIS Network Analyst toolbar, as Figure 8 illustrates. As Figure 9 shows, this button corresponds to a C# class that implements the ArcObjects ICommand interface using a specialization of the BaseCommand developer class. This class then launches a C# form,

AnalysisValuesForm (Figure 6), which uses two other C# form classes to support managing network analysis value sets (Figure 10). When the policy analyst is finished setting up the network analysis costs for their policy scenario case study, the form data is saved to the external database.

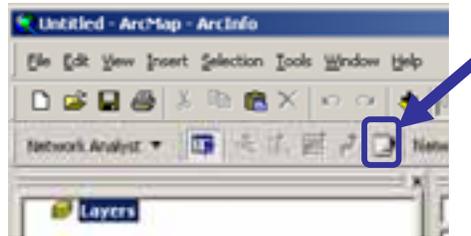


Figure 8. A command button provides access to the network costs table

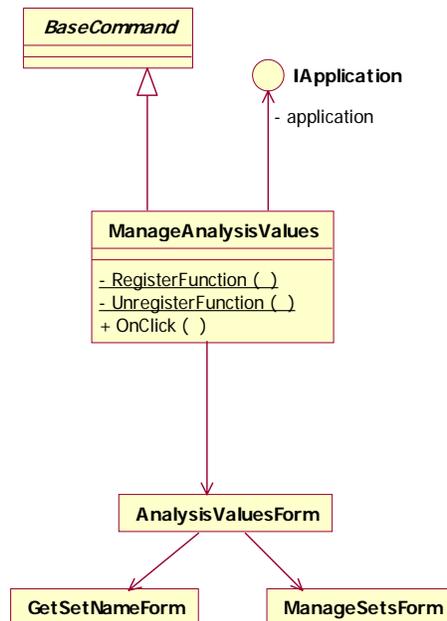


Figure 9. ManageAnalysisValues implements the ArcObjects toolbar command behavior, then launches a C# .NET form.

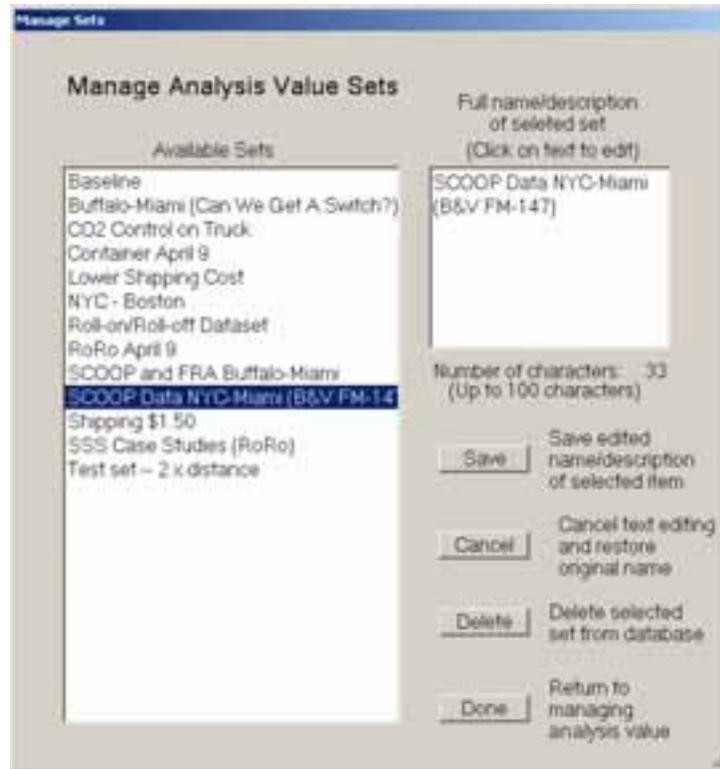


Figure 10. Forms to support managing network analysis value sets

The analyst then uses the normal ArcGIS network analysis tools to define and analyze a route. This includes selecting what attribute values to accumulate along the route (Figure 11) and which attribute to minimize when searching for the “shortest” (least-cost) route (Figure 12).

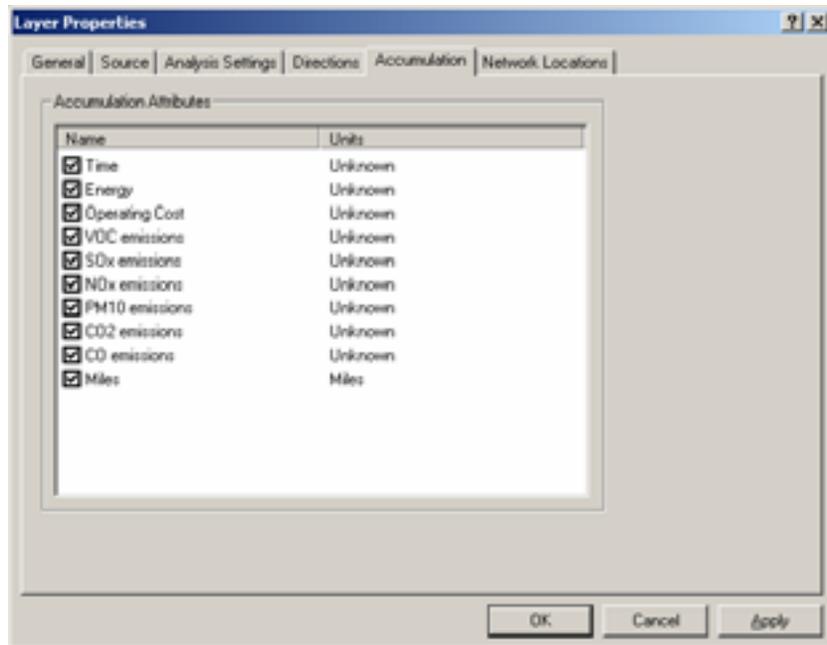


Figure 11. All network attributes can be accumulated along the route

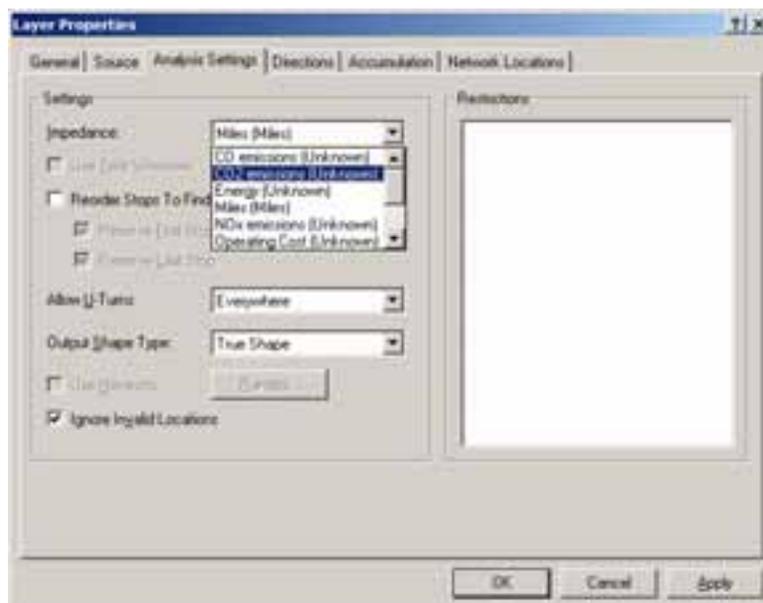


Figure 12. The policy analyst can select which "cost" to optimize in searching for the "shortest" route

After selecting locations on the map to include in the route (origin, destination, and intermediate waypoints), the analyst then starts the network route solver. We use the default route solver packaged with ArcGIS Network Analyst. As the solver traverses the segments in the transportation network, it calls the custom evaluators for each attribute in the segment to determine the segment costs. The custom evaluators access the database

of currently-selected policy cost values and combine them with network attribute values, such as segment length or location, to compute the cost of route segments for each of the defined network attributes (time, cost, energy, and emissions for each mode and intermodal transfer). The following C# code snippet (without error handling or other programmer precautions) illustrates how this is done: The solver calls the QueryValue method on the associated custom evaluator.

```
public override object QueryValue( INetworkElement element, IRow row)
{
    // Load cost factor values from database if not already loaded
    if ( ! CostFactors.loaded )
    {
        base.LoadCostFactors();
    }

    // Get length of the network segment from the network dataset
    double lengthValue =
        (double) element.get_AttributeValueByName(Common.LENGTH_ATTRIBUTE_NAME);

    // Compute cost using this attribute's cost factor and the segment length
    return (object) (CostFactors.Truck_CO2 * lengthValue);
}
```

After the solver finds the shortest route, we use the ArcGIS Network Analyst's built-in utilities to display the route (Figure 13), route costs (Figure 14), and turn directions (Figure 15). By adding network layer symbology and a map key, we can provide the analyst with a useful and visually appealing display of the impact of specific policy choices, as in Figure 1 at the beginning of this paper.

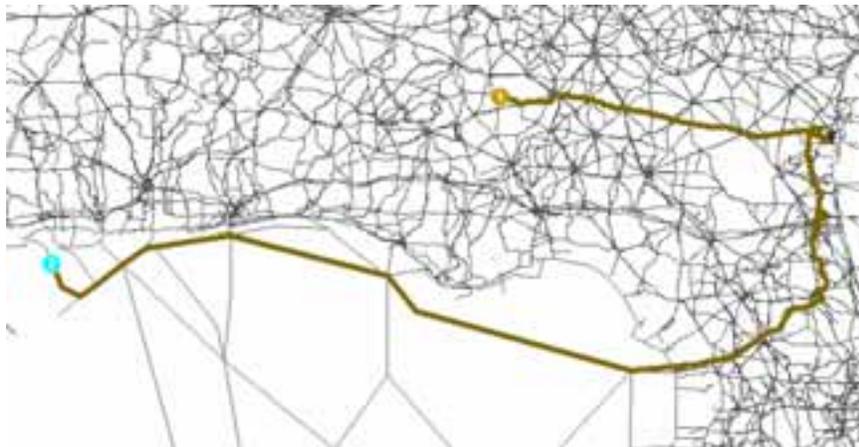


Figure 13. A multimodal route in the southern U.S.

Attribute	Value
ObjectID	2
Name	Graphic Pick 1 - Graphic Pick 2
FirstStopID	1
LastStopID	2
StopCount	2
StartTime	<Null>
EndTime	<Null>
Total_Miles	868.543041
Total_Time	89.753480
Total_Energy	4728760.110960
Total_Operating Cost	1484.804176
Total_VOC emissions	500.671604
Total_SOx emissions	3217.361210
Total_NOx emissions	10401.552395
Total_PM10 emissions	371.818386
Total_CO2 emissions	444251.601732
Total_CO emissions	2024.431874

Figure 14. "Costs" accumulated across the route.

Step	Instruction	Distance	Action
1:	Depart Graphic Pick 1		
2:	Go South East on S37	11.5 mile(s)	Map
3:	Bear left on S62	21.6 mile(s)	Map
4:	Straight on S91	2.4 mile(s)	Map
5:	Turn right on U19 B (U82 B)	2.7 mile(s)	Map
6:	Straight on U82 (S62)	101.9 mile(s)	Map
7:	Turn right on No name	8 mile(s)	Map
8:	Make sharp right on U1 (U23)	1.4 mile(s)	Map
9:	Turn left on U82 (S50)	51 mile(s)	Map
10:	Make sharp left on No name	1.1 mile(s)	Map
11:	Make sharp left on Transfer	< 0.1 mile(s)	Map
12:	Make sharp right on Colonels Island Railroad	0.7 mile(s)	Map
13:	Straight on No name	11.9 mile(s)	Map
14:	Turn left on Seaboard Coast Line Railroad	53.4 mile(s)	Map
15:	Straight on Sd Railroad	6.5 mile(s)	Map
16:	Straight on C L Railroad	3.3 mile(s)	Map

Figure 15. Built-in "Directions" for the route

Next Steps

By leveraging ArcGIS extension interfaces, we were able to quickly provide a functional policy analyst decision support tool. Custom evaluators allowed us to compute the environmental impact of intermodal freight transportation, and some simple user interface classes allowed us to provide a reasonably useful interaction between the policy analyst and the tool to set up and analyze policy options. Granted, the user interfaces illustrated above are a bit clunky (does the analyst need to know ObjectID and start and stop ID?) and sometimes amusing (“Make sharp left on Transfer;” “Make sharp right on

Colonels Island Railroad”), but they do provide a policy analyst with an understanding of the implications of policy choices. They also indicate significant opportunities for improvement.

We have identified requirements for and created mock-ups of an improved policy analyst’s user interface. Policy analysts need the following:

- A clean and intuitive display of their policy scenario (cost factors, route origin and destination, etc.) and results (accumulated costs for each of the transportation modes and visualization of the routes),
- The ability to visualize and compare results of different policy scenarios,
- The ability to save and restore scenarios for later modification and analysis,
- The ability to annotate, discuss, and create documentation of analysis sessions for inclusion in analysis reports,
- The ability to easily create, without having to write software, new network “costs” (additional emissions, congestion factors, etc.) and include them in their analysis.

Addressing the need to allow the policy analyst to easily create new network costs without software programming, we have developed a tool to automatically generate C# classes that implement specialized cost evaluators and associated evaluator editors (the specialized classes in Figure 4). The regular structure of the C# code allowed us to define “template” files with text strings, such as %TRANSPORTATION_MODE% and %COST_FACTOR%, which the code generators then replace with terms that the analyst enters (such as “Rail” for mode and “VOC” for cost). Since most of the costs are “per mile” costs, even the computation section (such as the `QueryValue` code snippet, above) can be auto-generated. This also aids the software developer, since changes in a specialized evaluator need to be implemented the same way in the over 100 evaluator and evaluator editor classes in the current system. What is needed next is to automatically update the network datasets with new attributes and to associate the auto-generated evaluators with those new network attributes.

Another change we are pursuing is moving the network analysis to a web server. Currently, the system is implemented in ArcGIS Desktop version 9.1. With the release of ArcServer 9.2 comes the ability to do network analysis on a server and make that available to transportation policy analysts via a web browser. This will save our analysts the cost and difficulty of having ArcGIS Desktop on their personal computers, and it will ease our maintenance by not having to install or update new evaluator software on all the policy analyst’s computers. On the down side, not only does this change require that we implement new user interfaces and port our evaluators to the server (which is rather straightforward), we must also move our development environment from Microsoft VisualStudio 2003 to VisualStudio 2005, we must update our ArcSDE 9.1 server and its underlying Oracle database, we must update our ArcServer 9.1 and its underlying web server, and we must regression test our other ArcGIS applications to assure that they continue to work on the ArcGIS 9.2 platforms. Migrating the cost evaluators is rather easy (we have already moved them to ArcGIS Desktop 9.2 with VisualStudio 9.2), but moving the servers to 9.2 is a risky undertaking that impacts more than our GIFT project, but it is an undertaking that we believe to be well worth the effort and risk.

Once we have moved to a server-based system and implemented the policy analyst user interaction enhancements, we plan to improve our network cost capabilities. Our computations are currently rather simple “cost per mile” computations, but having achieved the ability to create C#-based custom evaluators, we can now bring more computing technology to cost computation, especially accessing information and services from external sources. We plan to integrate a number of the following capabilities into our environmental cost computations and policy analyst interactions:

- Real-time and predicted (statistical) congestion models to reflect the increased emissions in congested highways, railways, and ports,
- Capacity models (from the U.S. Department of Transportation and elsewhere) so we can enable policy analysts to do “what-if” scenarios for infrastructure improvement or degradation (such as after a disaster), including new truck/train transfer facilities, new or improved ports, new or improved highways, or improved ship and barge canal locks,
- Emissions inventories and dispersion models and health impact models (from the Environmental Protection Agency and elsewhere) to further understand policy options that move emissions away from population centers,
- Access to a growing number of information sources available as Web services, such as the Federal Highway Administration’s Electronic Freight Management Initiative [12] and the Environmental Protection Agency’s AIRNow program [13].

Conclusion

The ESRI ArcGIS system gives us a powerful platform which we can easily use and extend. We have extended it to provide a policy analyst with decision support tools to understand the implications and trade-offs of environmental policy options in intermodal freight transportation. The extensibility of the user interface and network analysis computations allows us to provide basic features that address the needs of a policy analyst and to then add more powerful user interaction and environmental model computation that accesses and presents information from many sources. In our Geographic Intermodal Freight Transportation (GIFT) program, we have taken the first steps toward providing a useful environmental policy analyst decision support system for freight transportation, and we are on the path toward providing a powerful tool for understanding the myriad details and implications of environmental policy for intermodal freight transportation.

References

1. Schipper, L., L. Scholl, et al. (1997). "Energy Use and Carbon Emissions from Freight in 10 Industrialized Countries: An Analysis of Trends from 1973 to 1992." *Transportation Research Part D* 2(1): 57-76.
2. Greening, L. A., M. Ting, et al. (1999). "Decomposition of Aggregate Carbon Intensity for Freight: Trends from 10 OECD Countries for the Period 1971-1993." *Energy Economics*: 331-361.

3. Vanek, F. M. and E. K. Morlok (2000). "Improving the Energy Efficiency of Freight in the United States Through Commodity-Based Analysis: Justification and Implementation." *Transportation Research Part D* 5(1): 11- 29.
4. Bureau of Transportation Statistics (2005). *National Transportation Statistics 2005*. Washington, DC, U.S. Department of Transportation, Research and Innovation Technology Administration.
5. Office of Freight Management and Operations (2006). "Freight Facts and Figures 2006," U.S. Department of Transportation, Table 2-1, p.9.
6. U.S. Environmental Protection Agency (2006). *U.S. Greenhouse Gas Inventory Report, Annex 2*. Washington, DC.
7. U.S. Energy Information Administration (2007). *Annual Energy Outlook 2007 with Projections to 2030*. Washington, DC, U.S. Department of Energy.
8. Office of Freight Management and Operations (2006). "Freight Facts and Figures 2006," U.S. Department of Transportation, p.44.
9. Burnham, A., M. Wang, et al. (2006). *Development and Applications of GREET 2.7 -- The Transportation Vehicle-Cycle Model*. Oakridge, TN, Energy Systems Division, Argonne National Laboratory.
10. Winebrake, J. J., J. J. Corbett, et al. (2007). "Energy Use and Emissions from Marine Vessels: A Total Fuel Cycle Approach." *Journal of Air and Waste Management* 57(1): 102-110.
11. Falzarano, A. M., S. Ketha, et al. (2007). *Development of an Intermodal Network for Freight Transportation Analysis*. ESRI International User Conference. San Diego, CA.
12. Fitzpatrick, D., D. Dreyfus, M. Onder, and J. Sedor (2006), "The Electronic Freight Management Initiative," , Federal Highway Administration U.S. Department of Transportation, Report FHWA-HOP-06-085.
13. Blumenthal, D. "The Use of Real-Time Air Quality Data in Daily Forecasting and Decision-Making", *EM: The Magazine for Environmental Managers*, September 2005.

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