Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

Intermodal Freight Transport in the Great Lakes: Development and Application of a Great Lakes Geographic Intermodal Freight Transport Model

Final Report

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31 October 2009

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Research funded in part by the Great Lakes Maritime Research Institute.
This study was supported by the U.S. Maritime Administration
Grant # DTMA1-G-06-005

Acknowledgments

A number of exceptional students participated in the research described in this report. These students include, in alphabetical order: Garth Arnold, Bryan Comer, Aaron Falzarano, Arindam Ghosh, Sai Ketha, Bo Li, Colin Murphy, Sid Pendelberry, Chris Prokop, Udayan Sharma, Matthew Walter, and Ben Weisberg. We are grateful for their contributions. In addition, we would like to thank Ms. Debbie Steene, staff assistant to the RIT Department of STS/Public Policy, for her help in supporting the Laboratory for Environmental Computing and Decision Making on this project. We also acknowledge Dr. Donald Boyd, Vice President for Research at RIT, and Ms. Verna Hazen, Assistant Vice President and Director for Financial Aid and Scholarships at RIT, for providing additional funds to support this research. Lastly, we are grateful for the funding from the Great Lakes Maritime Research Institute and the assistance and support of Dr. Richard Stewart (Co-Director, GLMRI), Dr. James Riehl (Co-Director, GLMRI), and Ms. Carol Wolosz (Assistant Director, GLMRI).

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Executive Summary

The Great Lakes region is an important corridor for freight transportation in the United States (U.S.). The region serves as a connection between the Midwest and the Eastern seaboard and includes such major industrial cities as Detroit, Chicago, Cleveland, Buffalo, and Toronto, among others. Within this region, three modes of freight transportation dominate: rail, truck, and ship. Each of these modes presents a different set of attributes to shippers, consumers, and society, including: economic costs, time-of-delivery, environmental impact, reliability, and energy use.

For the most part, shipping decisions in the Great Lakes region (as in other parts of the country) are made by considering economic costs, reliability, and time-of-delivery. Unless mandated by law, environmental impacts are usually ignored, as they represent social costs that are not captured in the market prices for transportation services. Moreover, few tools exist that can help decision-makers characterize and evaluate the environmental impacts of their shipping decisions.

This project provides such a tool for the Great Lakes region by enhancing the Geospatial Intermodal Freight Transport (GIFT) model currently under development in a joint research collaborative between Rochester Institute of Technology (RIT) and the University of Delaware (UD). GIFT is a Geographic Information Systems (GIS) based model that integrates water, rail, and road transportation networks and intermodal transfer facilities to create an intermodal network that can be used to solve a variety of interesting problems. In particular, GIFT calculates optimal routing of freight between origin and destination points based on user-defined objectives. GIFT not only solves for typical objectives such as least-cost and time-of-delivery, but also for energy and environmental objectives, including emissions of carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur oxides (SO_x), particulate matter (PM_{10}), and volatile organic compounds (VOCs). This project focuses on the refinement and extension of GIFT for the Great Lakes region. We call this model Great Lakes-GIFT (GL-GIFT).

In this report we discuss our model development over the past year, apply the GL-GIFT model to two case studies in the Great Lakes region, discuss our 2009 GL-GIFT Summer Workshop, and describe our plans for model improvement.

There are three key model developments this year; (1) we have integrated a novel emissions calculator, (2) we have added a new graphical user interface to manage the output from the emissions calculator into the GL-GIFT model, and (3) we are developing online capabilities for GIFT. The emissions calculator allows the user to input specific information about the truck, locomotive, and ship they wish to model. The emissions calculator also contains a method to save characteristics for predefined trucks, locomotives, and ships to be called up at a later time. Therefore, even if a user doesn't know exactly what inputs to use, they can choose a predefined truck, locomotive, or ship to model. The output from the emissions calculator is contained in the Manage Analysis Values window. This output can be modified and saved as a separate file.

To exercise the model, we conducted two case studies. We had two objectives for our case studies as defined in our scope-of-work. The first objective was to conduct a "micro-level" case examining the energy, environmental, time-of-delivery, and cost tradeoffs associated with moving a single type of cargo among different modes in the Great Lakes region; Case Study 1 achieves this objective. Case Study 1 explores containerized freight transport between Montreal, QC and Cleveland, OH.

From the results of Case Study 1, we found that truck was the fastest mode of containerized freight transport but also the most cost- and carbon-intense compared to rail and ship. We also found that the type of vessel being modeled for the ship mode can affect the modal choice of the optimal least-CO_2 route. Depending on the vessel, the least-CO_2 route may be by rail or by ship. As a caveat, these results are dependent on the inputs chosen for each mode and the transfer penalties applied to intermodal transfers.

Our second objective was to conduct a "sectoral-level" case involving the tradeoffs associated with moving a set of cargo affiliated with a particular supply chain in the Great Lakes region; Case Study 2 achieves this objective. Case Study 2 examines Great Lakes coal sector freight flows from the Rosebud Mine in Montana, the 13th largest coal mine in the country in terms of total production, to the St. Clair Power Plant in southeastern Michigan. We model not only the total CO_2 emissions, operating costs, and time-of-delivery for one trip, but also the aggregate CO_2 emissions, operating costs, and vehicle-hours for an annual coal shipment from the Rosebud Mine to the St. Clair Power Plant. This gives a better understanding of the total emissions, economic, and temporal impact of modal choice for the transport of coal in the Great Lakes region. This is our first instance of performing a bulk cargo case study using the GL-GIFT model. We evaluate coal movement using three different modes: truck, rail, and ship (including intermodal movements). Although in this case truck is infeasible given the volume of coal being shipped, we include it in our analysis to help illustrate the economic, environmental and energy differences across modes in a bulk cargo example.

From the results of Case Study 2, we found that truck is the fastest mode of coal transportation; however, it also is the most expensive and most carbon-intense mode by far. Truck is expensive and carbon-intense because of its low maximum tonnage capacity compared to the other modes (rail and ship). The rail and intermodal rail/ship routes are much less expensive and carbon-intense per ton-trip. We also found that the fastest mode of annual coal transport is an intermodal rail/ship route since these modes have a much higher maximum tonnage capacity than truck. The rail/ship route costs the same as the rail-only route; however, there are some costs that are not captured in this case study such as intermodal transfer costs and fees associated with rail line ownership. The rail/ship route is also the least carbon-intense compared to a rail-only and truck-only route.

These results help to explain why coal is shipped via a rail/ship route from Montana to Michigan. The rail/ship route offers time savings (which could equate to further cost savings), operating cost savings, and CO_2 emission reductions. Carbon dioxide emissions reductions could lead to operating cost savings if a price for carbon (i.e. a carbon tax) were eventually implemented.

On August 17, 2009, members of the RIT and UD GL-GIFT team held our first GL-GIFT Summer Workshop at RIT. The workshop was a success, with representatives from GLMRI, energy and environmental consulting firms, universities, and U.S. and Canadian transportation agencies in attendance. The workshop aimed to introduce GL-GIFT to those unfamiliar with the model, allow for hands-on exploration of the model, and request suggestions for improvement of the GL-GIFT model. We recorded all comments made at the workshop and intend on addressing some of those comments in the coming year.

Our plans for future model development and improvement include:

1. *Integrate the STEEM model into GL-GIFT to allow for trans-oceanic freight route analysis.* The STEEM model was developed at the University of Delaware and includes international on-water shipping routes. The integration of the STEEM

model will allow for the analysis of trans-oceanic freight route analysis. Therefore, origins and destinations will not be limited to the U.S. and Canada.

2. *Enable metric conversion.* This will allow for easier analysis for international GL-GIFT users.
3. *Generating trip profiles by mode.* This would include data such as the percent of the route travelled by each mode and the emissions associated with that particular mode.
4. *Include more predefined vehicle, locomotive, and vessel choices.* This will allow users to select a vehicle, locomotive, or vessel to model from a drop down menu.
5. *Reduce unrealistic routes through major cities.* GL-GIFT may be generating optimal routes through major cities that are unrealistic based on real-world problems along the truck and rail networks such as highway and rail congestion.
6. *Enable multiple O/D pairs to be run programmatically to model the impacts of regional flows.*
7. *Refine speed limit data.* We expect to improve the resolution of data for each of our modes. For example, at this point we are limited to assigning one constant speed limit to our rail and waterway network. This is despite the obvious fact that certain sections of railroad tracks have a higher speed limit and railroad segments in urban areas are becoming very slow due to congestion. We are in the beginning phases of attempting to find quality data to allow for more realistic modeling of freight transport in the Great Lakes region and throughout the entire GL-GIFT network.
8. *Improve intermodal transfer time estimates.* It has become clear that a better understanding on the time it takes to transfer freight from one mode to another is necessary to improve the usefulness and accuracy of the GL-GIFT model. We plan to collect better data through various mechanisms in the future.
9. *Incorporate speed, traffic control, and congestion constraints.* Currently, the GL-GIFT model uses road classes to assign speed limits to the U.S. and Canadian road network rather than one constant speed for any road regardless of its classification. As of now, the speed limit for the entire rail and ship networks are one constant speed. We are in the beginning phases of incorporating more realistic speed constraints for rail across the GL-GIFT network, potentially based on rail class. To improve our road network, we are investigating methods for incorporating traffic control devices and congestion constraints. For example, we may be able to incorporate time penalties for intersections and traffic patterns throughout the network. We would also like to find ways to incorporate delays at locks for the water network.
10. *Conduct freight systems modeling.* We are developing ways to move from a single origin-destination analysis to a system-wide analysis that could be used to inform larger, system-wide decisions.
11. *Examine methods of modeling bulk freight transport.* Currently, GL-GIFT is set up to model containerized freight transport and adjustments need to be made in order to model bulk cargo.
12. *Limit intermodal freight transfer facilities based on their freight handling capabilities.* Currently, GIFT does not determine whether a given facility, such as a port, has equipment for the specific type of cargo, such as cranes for container movement, or bulk cargo load/unload capability.

With these and other improvements, we expect GL-GIFT to be an important tool for policymakers, planners, shippers, carriers and others interested in sustainable shipping in the Great Lakes region.

1 Introduction

The Great Lakes region is an important corridor for freight transportation in the United States (U.S.). The region serves as a connection between the Midwest and the Eastern seaboard and includes such major industrial cities as Detroit, Chicago, Cleveland, Buffalo, and Toronto, among others. There are also growing opportunities to connect with international locations [1]. Within this region, three modes of freight transportation dominate: rail, truck, and ship. Each of these modes presents a different set of attributes to shippers, consumers, and society, including: economic costs, time-of-delivery, environmental impact, reliability, and energy use.

For the most part, shipping decisions in the Great Lakes region (as in other parts of the country) are made by considering economic costs, reliability, and time-of-delivery. Unless mandated by law, environmental impacts are usually ignored, as they represent social costs that are not captured in the market prices for transportation services. Moreover, few tools exist that can help decision makers characterize and evaluate the environmental impacts of their shipping decisions.

This project provides such a tool for the Great Lakes region by enhancing the Geospatial Intermodal Freight Transport (GIFT) model currently under development in a joint research collaborative between Rochester Institute of Technology (RIT) and the University of Delaware (UD). GIFT is a Geographic Information Systems (GIS) based model that integrates water, rail, and road transportation networks and intermodal transfer facilities to create an intermodal network that can be used to solve a variety of interesting problems. In particular, GIFT calculates optimal routing of freight between origin and destination points based on user-defined objectives. GIFT not only solves for typical objectives such as costs and time-of-delivery, but also for energy and environmental objectives, including emissions of carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur oxides (SO_x), particulate matter (PM_{10}), and volatile organic compounds (VOCs). This project focuses on the refinement and extension of GIFT for the Great Lakes region. We call this model Great Lakes-GIFT (GL-GIFT). GL-GIFT can also model intermodal freight transport routes allowing the user to perform a tradeoff analysis between time, economics, energy, and emissions of modal choices.

In this project, we develop a detailed network characterization for GL-GIFT, and demonstrate how one can use GL-GIFT for answering important transportation planning and policy decisions. GL-GIFT connects U.S. and Canadian highway, rail, and shipping networks through ports, rail yards, and other transfer facilities to create an *intermodal, international freight transportation network.* This network is developed in ArcGIS 9.3, and captures network attributes such as costs, time, energy, and emissions. GL-GIFT allows for the analysis of optimal freight routing across a host of objective functions within the Great Lakes region. In this way, users can evaluate the tradeoffs associated with different goods movement choices, as well as explore how infrastructure development, technology adoption, and economic instruments may affect freight transport decision making.

Chapter 2 of the report provides background information and explains the state of freight transportation in the Great Lakes region. We refer the reader to last year's Annual Report for details about the environmental and energy use concerns associated with goods movement, and the need for novel tools that allow decision makers to integrate energy and environmental objectives into policy and planning decisions. Chapter 3 discusses the research methodology including the addition of our novel emissions factor calculator and graphical user interface. Chapter 4 provides case studies used to demonstrate and to validate GL-GIFT. Chapter 5 details our experience with the 2009 GL-GIFT Summer Workshop. Chapter 6 explains our plans for future work on the model. And Chapter 7 provides information on the potential economic impacts of the study results and information on all publications, presentations, and classroom material related to GL-GIFT model research.

2 Background

2.1 The State of Shipping in the Great Lakes

We adopt the Great Lakes region domain defined by the National Research Council [2]. This includes the entire St. Lawrence Seaway System (SLSS), which extends as far east as the Gulf of St. Lawrence and as far west as the Port of Duluth, encompassing all five major Laurentian Great Lakes (Ontario, Erie, Huron, Michigan, and Superior). This region is home to approximately 10% and 30% of the populations of the U.S. and Canada, respectively. The region is considered one of "the world's largest manufacturing and consumer markets" [1], and is a critical artery of commerce for the U.S. The Great Lakes region also plays a key role in international trade with goods entering the St. Lawrence Seaway from the Atlantic Ocean and goods entering from the west at ports such as Duluth, Minnesota and Thunder Bay, Ontario [1].

In 2008, approximately 114 million short tons of cargo were transported on the Great Lakes [3]. These data account for, and remove, duplicate records to ensure that cargo is not double counted. The majority of waterborne cargo in the Great Lakes is carried by a fleet of dry-bulk cargo ships and "self-unloaders". The latter type of ship is essentially a dry-bulk carrier with integrated lifts and conveyors to facilitate unloading without extensive shore-side infrastructure [4]. Tug boats are often used to push a small number of barges, which can be used on the lakes as well as on most of the waterways that communicate with the Great Lakes. Increasingly, integrated tug-barge combination ships are being used, in which the flat area of the barge is being included in an extended section of the tug boat hull [1]. The barge area can carry containerized freight, over-sized cargo, truck trailers, or other freight.

Coal is a major bulk commodity transported in the Great Lakes region. There were approximately 360 million short tons of coal transported into the Great Lakes region in 2007 from various other states [5]. Approximately 7.9 million short tons were transported on the Great Lakes by bulk vessels, of which, about 4.5 million short tons originated in Montana destined for Michigan [5]. The Superior Midwest Energy Terminal (SMET) owned by the Midwest Energy Resources Company is located at the Port of Duluth-Superior, MN and WI. SMET provides coal to the Detroit Edison Company's southeastern Michigan power plants [6] and is likely where the Montana coal enters the Great Lakes waterways to be distributed throughout the region.

Notably absent from the discussion of Great Lakes freight is containerization, which is a negligible component of Great Lakes shipping, with the exception of some regular activity at the Port of Montreal associated with trans-Atlantic shipments. Currently, almost all containerized freight in the region is carried by land-based modes of transportation, often by heavy-duty diesel trucks. However, there appears to be interest and room for growth for on-water, containerized freight transport in order to reduce highway and rail congestion in the Great Lakes region [1]. In fact, one estimate suggests that on-water goods movement could capture as much as four percent of containerized intermodal traffic in the Great Lakes region by 2050 so long as it is competitive with truck and rail [1].

3 Methodology

Our methodology for creating the GL-GIFT network was outlined in detail in our 2008 Annual Report. The report includes specifics on how the GL-GIFT model was built and connected using a hub-and-spoke approach, connecting the NTAD and Transport Canada road, rail, and water networks for the U.S. and Canada. We refer the reader to our 2008 Annual Report for details on model development.

3.1 General Approach

GL-GIFT is a network model that now operates on an ArcGIS 9.3 software platform. Previously, GL-GIFT operated on the ArcGIS 9.2 platform. The model applies the shortest path algorithm included in ArcGIS's Network Analyst to evaluate U.S. and Canadian freight movements from origin to destination. GL-GIFT includes two unique elements that make it useful for evaluating intermodal shipments. First, GL-GIFT includes an *intermodal network* that links publicly available U.S. and Canadian, unimodal network datasets (currently rail, highway, and waterway) through nodes identified at ports, railyards, and other intermodal facilities. This allows the user to model the transfer of goods from one mode to another at intermodal facilities.

Second, GL-GIFT includes energy, environmental, economic, and speed attribute information (by mode) on each segment of the intermodal network. Attributes such as emissions of various pollutants (e.g., CO_2, PM_{10} , NOx, SOx, and VOCs), energy consumption (e.g., Btu), time, and economics (US$) have been incorporated into GIFT. This feature allows the analyst to solve the network transportation problem for different objective functions, such as least time, least cost, and least emissions. The GL-GIFT model has been discussed in detail in previous work [7-9] and our 2008 Annual Report; we refer the reader to that literature for details about model development.

By analyzing the network using energy and environmental objective functions, we can identify and explore tradeoffs among these goals and more traditional ones (cost and time-of-delivery). We can also evaluate policy mechanisms that can be used to determine how they would affect the overall energy and environmental character of freight transport. Tradeoffs associated with modal choice are examined with particular focus on time-of-delivery, CO_2 emissions, and operating cost, demonstrating the GL-GIFT model's utility in tradeoff and policy analysis.

3.2 Model Development Progress over the Past Year

We have made some significant progress on the model since our 2008 Annual report. In particular, we have integrated a novel emissions calculator and a new graphical user interface to manage the output from the emissions calculator into the GL-GIFT model shown in Figure 3-1and Figure 3-2 respectively.

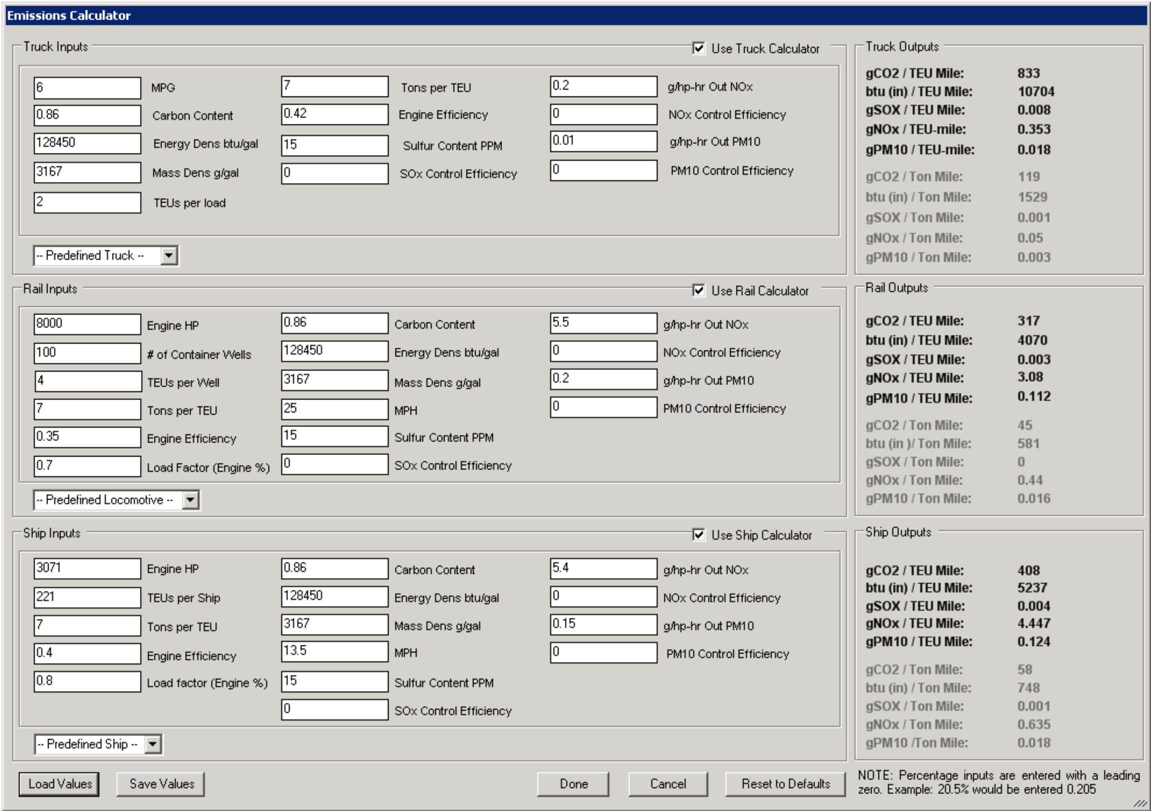

Figure 3-1. GL-GIFT Emissions Calculator. The analyst inputs vehicle attributes for each mode and generates per TEU-mi and per ton-mi emission rates for CO2 and other pollutants.

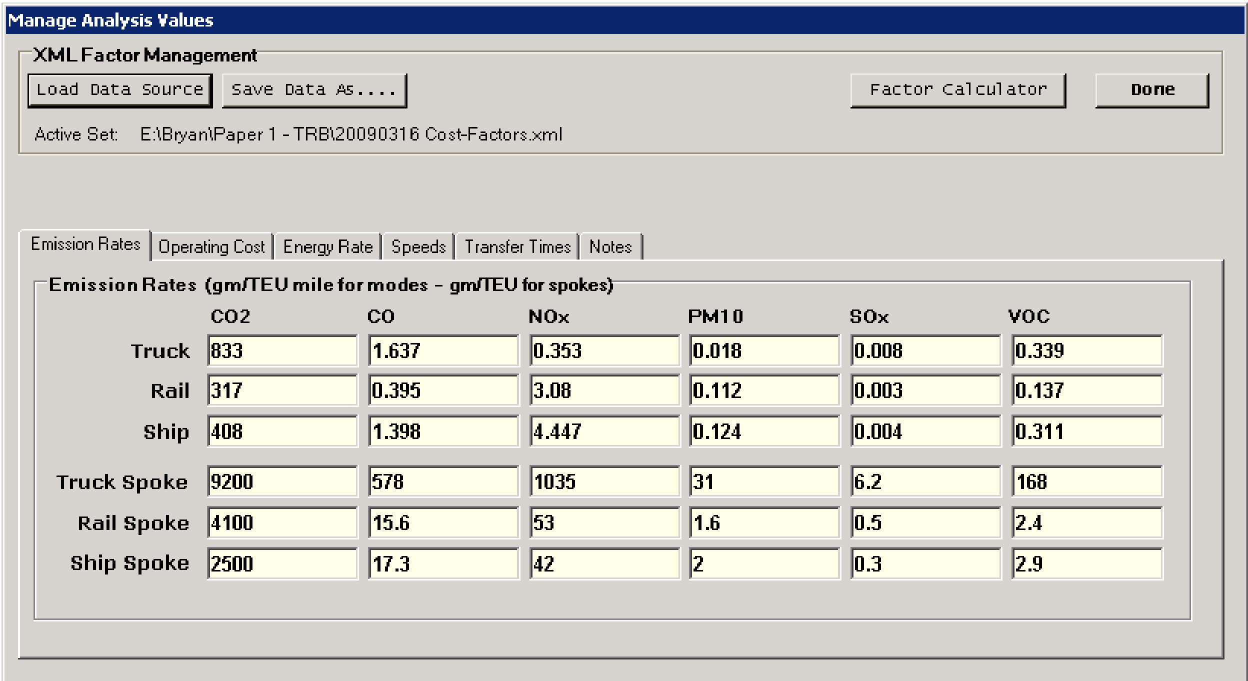

Figure 3-2. EXAMPLE GL-GIFT Emission Rates for Each Mode and Intermodal Transfers. In this particular case, we assume that the truck used is a Class 8 tractor-trailer, the locomotive (rail) has two 4000 hp diesel engines, and the ship is the Great Lakes container vessel the *Dutch Runner*.

The emissions calculator shown in Figure 3-1 allows the user to input specific information about the truck, locomotive, and ship they wish to model. The emissions calculator also contains a method to save characteristics for predefined trucks, locomotives, and ships to be called up at a later time. Therefore, even if a user doesn't know exactly what inputs to use, they can choose a predefined truck, locomotive, or ship to model. The output from the emissions calculator is contained in the Manage Analysis Values window shown in Figure 3-2. This output can be modified and saved as a separate file. If the user does not have detailed information about specific vehicles but have general information about the emissions, operating cost and other characteristics of transportation modes, they can enter this information into the form of Figure 3-2, and they can save and recall this information for later use.

4 GL-GIFT Case Study Demonstration

4.1 Overview of the Case Studies

We have conducted two in-depth case studies that exercise the GL-GIFT model in the Great Lakes region. We had two objectives for our case studies as defined in our scope-of-work. The first objective was to conduct a "micro-level" case involving the energy, environmental, time-of-delivery, and cost tradeoffs associated with moving a single type of cargo among different modes in the Great Lakes region; Case Study 1 achieves this objective. Case Study 1 explores containerized freight transport between Montreal, QC and Cleveland, OH.

Our second objective was to conduct a "sectoral-level" case involving the tradeoffs associated with moving a set of cargo affiliated with a particular supply chain in the Great Lakes region; Case Study 2 achieves this objective. Case Study 2 examines Great Lakes coal sector freight flows from the Rosebud Mine in Montana, the 13th largest coal mine in the country in terms of total production [10], to the St. Clair Power Plant in southeastern Michigan. We model not only the total CO_2 emissions, operating costs, and time-of-delivery for one trip, but also the aggregate CO_2 emissions, operating costs, and vehicle-hours for an annual coal shipment from the Rosebud Mine to the St. Clair Power Plant. This gives a better understanding of the total emissions, economic, and temporal impact of modal choice for the transport of coal in the Great Lakes region. This is our first instance of performing a bulk cargo case study using the GL-GIFT model.

4.1.1 Assumptions

For Case Study 1, we make the following assumptions for the vehicles modeled:
A Class 8 tractor-trailer with a fuel economy of 6 MPG with a speed that varies according to
to road class (see

- Table 4-1 below);
- A train powered by two 4000 horsepower (hp) locomotives and an average speed of 25 MPH[1];
- A container vessel called the *Dutch Runner* with 3071 total hp and a service speed of 13.5 MPH (ship 1) [11]; and
- A tug-and-barge combination vessel called the *Ellie J.* with 1550 total hp and a service speed of 9 MPH (ship 2) [12].

For Case Study 2, we make the following assumptions for the vehicles modeled:

- A Class 8 tractor-trailer with a fuel economy of 6 MPG with a speed that varies according to road class and a maximum tonnage capacity of 25 short tons;
- A train powered by three 4400 hp locomotives and an average speed of 22 MPH[2] and a maximum tonnage capacity of 13899 short tons;
- A coal laker vessel named the *Indiana Harbor* with 14000 total hp and a service speed of 16.1 MPH and a maximum tonnage capacity of 68757 short tons [13].

[1] This value is within the reported average operating speeds of freight locomotives as reported at http://www.railroadpm.com which reports railroad performance measures.
[2] This is based on a 53-week average ending 10/9/09 of average BNSF coal train speeds as reported on http://www.railroadpm.org.

Table 4-1. Road segment speed limit by road class.

Road Class	Speed Limit (mph)	Description
0	45	Unclassified/unknown
1	65	Rural Interstate
2	50	Rural Principal Arterial
6	50	Rural Minor Arterial
7	40	Rural Major Collector
8	30	Rural Minor Collector
9	30	Rural Local
11	65	Urban Interstate
12	55	Urban Freeway or Expressway
14	35	Urban Principal Arterial
16	40	Urban Minor Arterial
17	30	Urban Collector
19	25	Urban Local

Source: http://www.bts.gov/publications/journal_of_transportation_and_statistics/volume_09_number_01/html/paper_03/table_03_06.html

4.1.2 Summary of Energy, Economic, and Environmental Factors

Table 4-2 summarizes the environmental, energy, and emission cost factors we used for our first case study analysis. Emissions values were derived using a bottom-up approach, discussed in last year's report, which takes into consideration energy use, engine efficiency and engine load. Operating costs are based on a study by Global Insight [14], but will likely be different depending on the user's actual costs. Users can input their own average cost per TEU-mi or cost per TEU for intermodal transfers. Intermodal transfer (spoke) values are more difficult to derive.

Table 4-2. Environmental, economic, energy, and operational factors used in Case Study 1.

Transport Mode	CO_2 (g/TEU-mi or g/TEU)	Operating Cost ($/TEU-mi or $/TEU)	Energy Rate (Btu/TEU-mi or Btu/TEU)	Speed (MPH)	Transfer Times (hrs)
Truck	830	0.87	10700	Variable	--
Rail	280	0.55	3560	25.0	--
Ship 1 (Dutch Runner)	400	0.50	5200	13.5	--
Ship 2 (Ellie J.)	280	0.50	3560	9.0	--
Truck Spoke	9200	35	87000	--	1.0
Rail Spoke	4100	35	51000	--	1.0
Ship Spoke	2500	35	31000	--	1.0

Table 4-3 summarizes the environmental, energy, and emission cost factors we used for our second case study analysis. Emissions values were derived using a bottom-up approach which takes into consideration energy use, engine efficiency and engine load. Operating costs are based on Table 2.07 from the Energy Information Administration's Coal Transportation:

Rates and Trends in the United States, 1979-2001 [15]. We have not included transfer emissions, operating costs, energy, or times in our analysis; the GL-GIFT team is currently investigating these values.

Table 4-3. Environmental, economic, energy, and operational factors used in Case Study 2.

Transport Mode	CO_2 (g/ton-mi or g/ton)	Operating Cost ($/ton-mi or $/ton)	Energy Rate (Btu/ton-mi or Btu/ton)	Speed (MPH)	Transfer Times (hrs)
Truck	67	0.23	860	Variable	--
Rail	17	0.01	220	22.0	--
Ship (Indian Harbor)	4	0.01	56	16.1	--
Truck Spoke	0	0	0	--	0
Rail Spoke	0	0	0	--	0
Ship Spoke	0	0	0	--	0

4.1.3 Emissions Factors for Each Mode

The emissions factors for each mode were calculated using our emissions calculator shown in Figure 3-1. The emissions calculator uses a bottom up approach to calculate CO_2 emissions using inputs like fuel economy for trucks and energy intensity for rail and ship. Some adjustments had to be made to the emissions calculator for the second case study to ensure that route results for emissions and operating costs were displayed on a per ton-mile basis. Specifically, we entered a value of “1” in the tons/TEU field for each mode and a value of 25 [16], 13899 [6], and 68757 [17] in the TEU/load field for truck, rail, and ship respectively; these values would then represent the tons/load for different modes. The GL-GIFT model then uses these values to calculate the aggregate emissions and operating costs for a given route.

4.1.4 Penalties for Intermodal Transfers (Cost, Emissions and Time)

Penalties for intermodal transfers only apply to Case Study 1. We use an intermodal transfer cost of $35/TEU for each intermodal transfer facility spoke (or $70/TEU for a mode-to-mode transfer) based on the National Ports and Waterways Institute Report [18].

Emissions factors for intermodal transfers were only used in Case Study 1. With the hub-and-spoke approach, we estimate emissions from transfer activities for each of the three spokes (rail-, truck-, and ship-to-hub) using an activity based “Container Transfer Emissions Model” (CTEM). CTEM identifies the different pieces of equipment used to move containers from one mode to another, applies temporal and engine load factors for such transfers, and applies emissions factors from the OFFROAD model for each piece of equipment to estimate actual emissions for mode-to-mode transfers (for more information on OFFROAD, see: www.arb.ca.gov/msei/offroad/offroad.htm).

Estimating emission rates for intermodal transfers (spoke values) is a challenge because it is a factor of the type of vessel selected. In addition, the values we use are averages between modes. For example, a ship to rail transfer requires much less CO_2 than a ship to truck transfer. Also, if we have a Ro/Ro vessel (Roll-On and Roll-Off of truck trailers), then much of the equipment used for intermodal transfers is not required. The user of the GL-GIFT model may be in a better position to estimate the types of equipment and associated emissions, time, and operating costs necessary to transfer between modes for their particular case.

We use a one hour penalty for each intermodal transfer facility spoke (or two hours for a mode-to-mode transfer). Our future work may involve visiting intermodal transfer facilities and timing how long intermodal transfers take for each mode. This would add more realistic time penalties for intermodal transfers and make the GL-GIFT model stronger.

4.2 Case Study Results

4.2.1 Case Study 1: A micro-level case

The case study examines the CO_2 emissions, time-of-delivery, and operating cost tradeoffs of freight transport according to modal choice. We compare the truck, rail, and shipping options presented above, using an origin of Montreal and a destination of Cleveland. The model is run three times under the following objective functions: (1) least time; (2) least CO_2; and (3) least cost. Figure 4-1 shows the results of the analysis based on (a) the *Dutch Runner* case, and (b) the *Ellie J.* case. Table 4-4 shows the results of each model run. These results are depicted graphically in Figure 4-2.

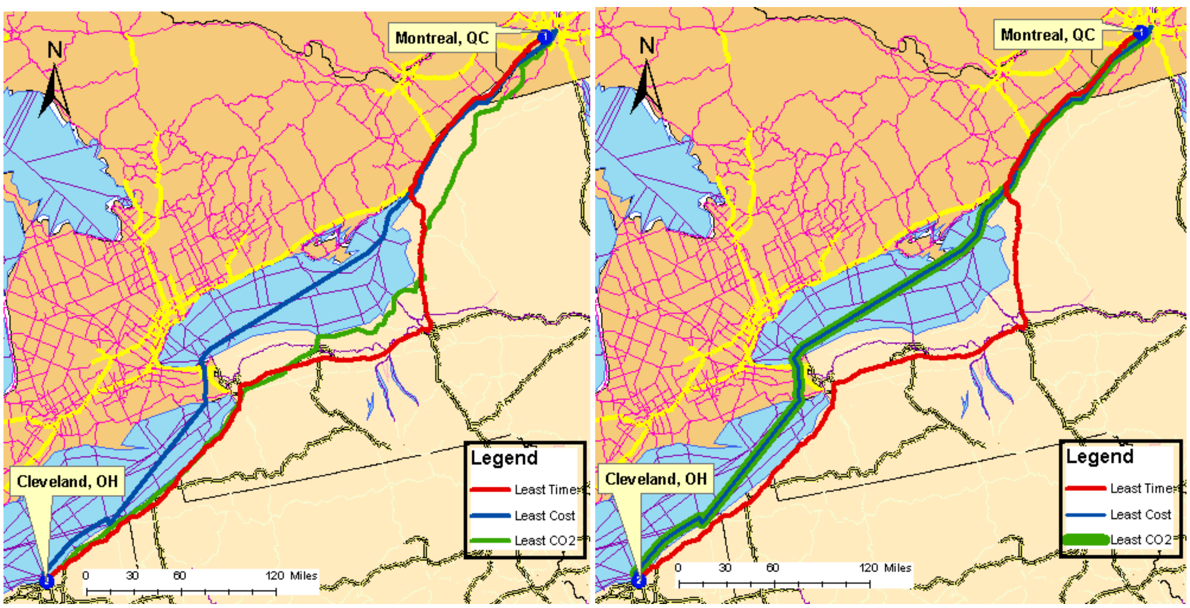

Figure 4-1. (a) Results of Montreal-to-Cleveland case where the ship is the Dutch Runner container vessel (left); (b) Results of the Montreal-to-Cleveland case where the ship is the Ellie J. tug-and-barge vessel (right).

Table 4-4. Case Study 1 Results

Case	Objective	Primary Mode	Total CO_2 (kg/TEU-trip)	Total Time (hrs)	Total Distance (miles)	Total Cost ($/TEU-trip)
(a) *Dutch Runner* container vessel	Least Time	Truck	460	8	552	480
	Least Cost	Ship	240	42	517	400
	Least CO_2	Rail	190	25	532	430
(b) *Ellie J.* tug-and-barge	Least Time	Truck	460	8	552	480
	Least Cost	Ship	160	60	503	420
	Least CO_2	Ship	160	60	503	420

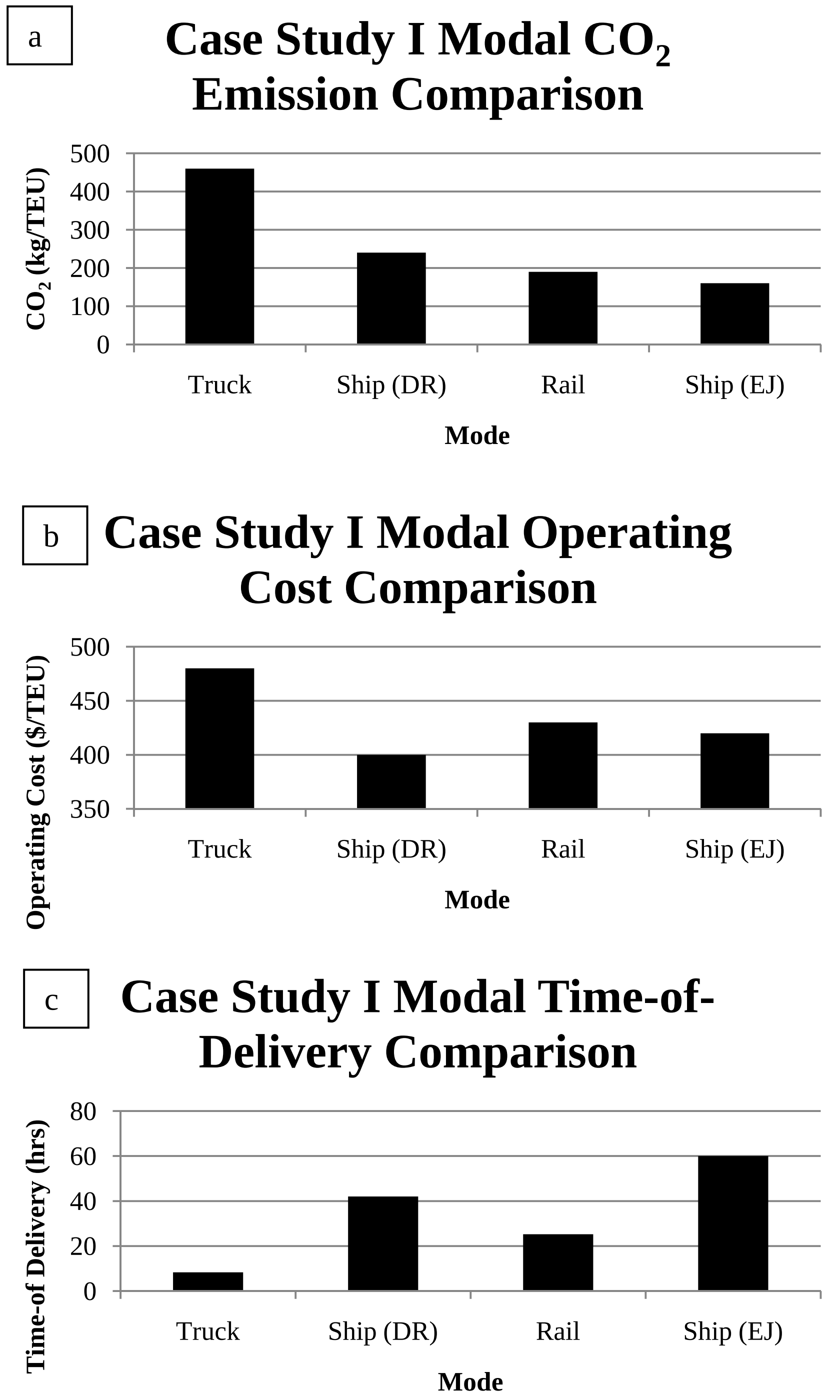

Figure 4-2. Results for the Montreal-Cleveland route based on a) least-CO2 objective function; b) least-cost objective function; and c) least-time objective function.

The most carbon-intensive mode of freight transport in this case is truck, followed by the container ship (the *Dutch Runner*), rail, and the tug-and-barge vessel (the *Ellie J.*). The *Ellie J.*

performs the best with respect to CO_2 emissions. We see from Figure 4-3 that the two marine vessels are the best choice when the objective is to minimize operating costs; however, the emissions and economic benefits come at a time-of-delivery penalty. Note that the time-of-delivery presented does not include delays due to congestion or border crossing or canal lock delays for any of the modes. Separate projects are developing this functionality within GIFT.

Results are dependent on the inputs chosen for each mode and the transfer penalties applied to intermodal transfers. Under alternate assumptions, it is likely that the least-time route will always be by truck in the Great Lakes region due to its faster average speed compared to rail and ship.

The modal choice for least-CO_2 and least-cost routes may vary. CO_2 emissions for the *Dutch Runner*, rail, and *Ellie J.* perform fairly similarly. CO_2 emissions per TEU-mile for rail and ship are dependent on the engine horsepower, TEU capacity, engine efficiency, load factor, and speed.

Truck remains the most expensive mode of freight transport in the Great Lakes region under published rate comparisons, and rail and ship may compete to be the cheapest mode, depending on the other service requirements imposed on these modes.

In addition, our origin and destination are located on truck delivery segments. If a facility at the origin or destination can directly load cargo onto ship or rail, transfer penalties associated with this routing may be reduced.

4.2.2 Case Study 2: A sectoral-level case

This case study examines coal sector freight flows in the Great Lakes region. We selected the Rosebud Mine in Montana as our origin and the St. Clair Power Plant in southeastern Michigan as our destination. We use GL-GIFT to solve for the least-time, least-cost, and least-CO_2 routes as shown in Figure 4-3. We present our results on both a per ton-trip (i.e. total time, dollars, and emissions required to move one ton along the route once) and a per year [i.e. the total time (measured in vehicle-hours), dollars, and emissions accrued moving a year's worth of coal from the Rosebud Mine to the St. Clair Power Plant] basis. Our per year results assume that 14.5 million tons of coal are shipped from the Rosebud Mine to the St. Clair Power Plant. The Rosebud Mine, in fact, does not produce 14.5 million tons of coal (it produced 13 million tons in 2008 [10]) but we know that 14.5 million tons are transported via the Great Lakes from Montana; therefore, we use the Rosebud Mine location as a general point of origin for all Montana coal transported on the Great Lakes. We use the St. Clair Power Plant to the same effect as a general destination for Montana coal transported on the Great Lakes destined for Michigan. Please note that our results do not include intermodal transfer costs of any type, including economic, emissions, or time penalties.

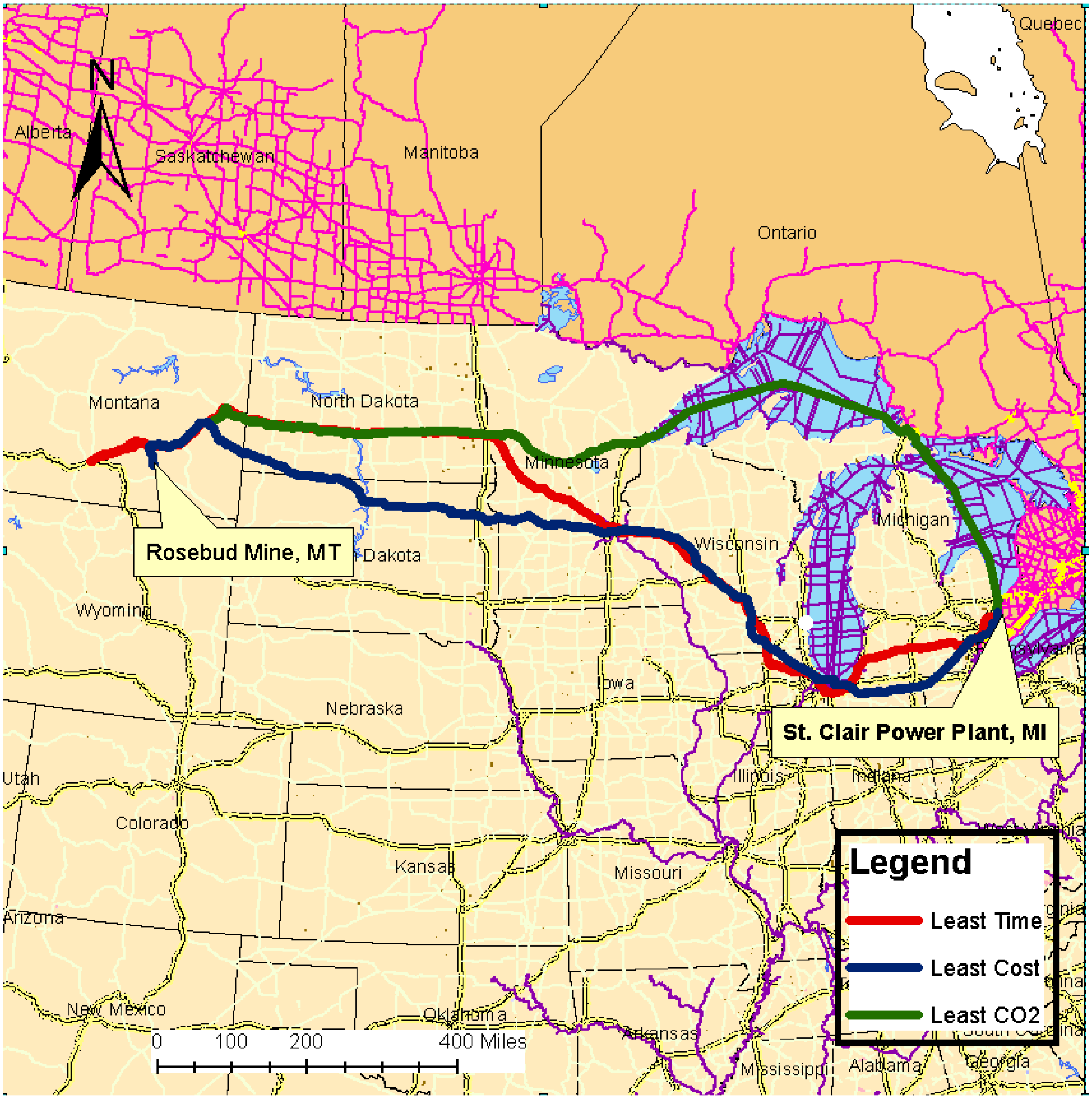

Figure 4-3. Results of the coal sector case from Rosebud Mine, MT to St. Clair Power Plant, MI.

Table 4-5. Case Study 2 Results

Objective	Mode(s)	Time-of-Delivery (hrs/trip)	Annual Time (thousand vehicle hrs/year)	Cost ($/ton-trip)	Annual Cost (millions of $/year)	CO_2 (kg/ton-trip)	Annual CO_2 (MT/year)
Least Time	Truck	28	5000	350	1700	100	500,000
Least Cost	Rail	66	20	14	65	23	110,000
Least CO_2	Rail/Ship	77	15	15	65	16	70,000

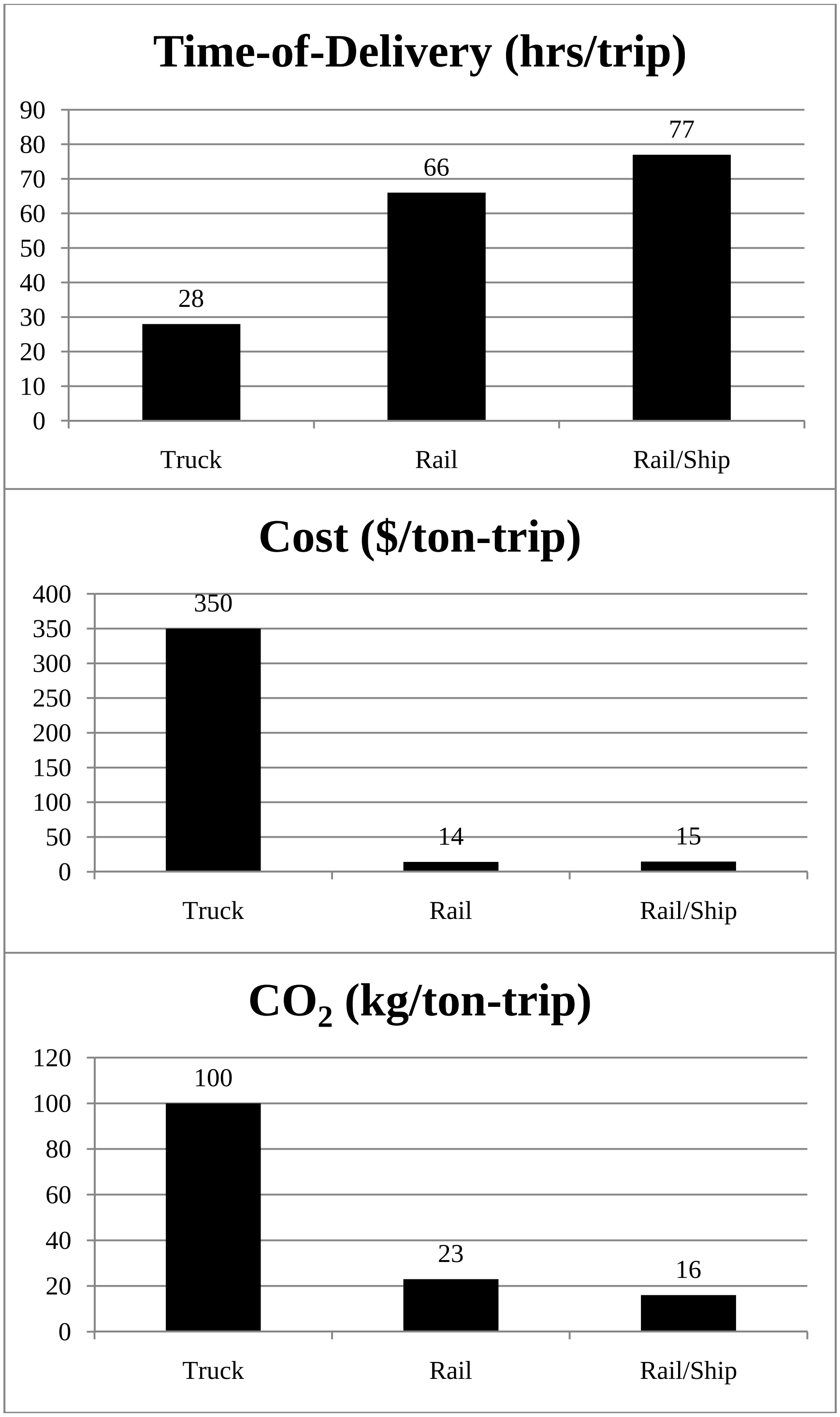

Figure 4-4. A comparison of time-of-delivery, cost, and CO_2 emissions per trip or per ton-trip for Case Study 2.

As shown in Table 4-5 and Figure 4-4, for one trip, truck is the fastest mode of coal transportation; however, it also is the most expensive and most carbon-intense mode by far. Truck is expensive and carbon-intense because of its low maximum tonnage capacity compared to the other modes. The rail and rail/ship modes are much less expensive and carbon-intense per ton-trip.

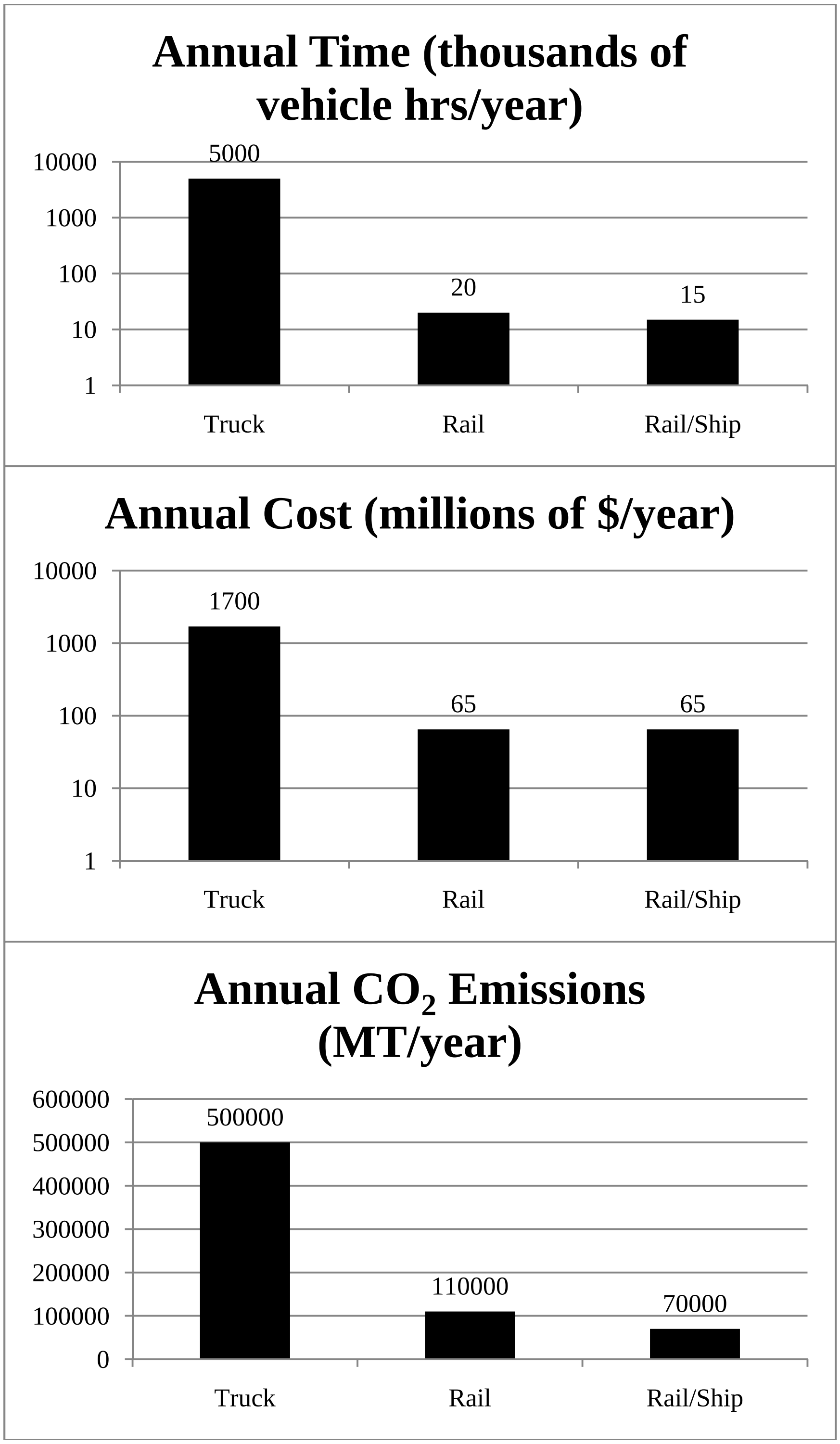

Figure 4-5. A comparison of annual time, cost, and CO_2 emissions for Case Study 2.

As shown in Table 4-5 and Figure 4-5, the fastest mode of annual coal transport is an intermodal rail/ship route since these modes have a much higher maximum tonnage capacity than truck. The rail/ship route costs the same as the rail-only route; however, there are some costs that are not captured in this case study such as intermodal transfer costs and fees associated with rail line ownership. The rail/ship route is also the least carbon-intense compared to a rail-only and truck-only route.

These results help to explain why coal is shipped via a rail/ship route from Montana to Michigan. The rail/ship route offers time savings (which could equate to further cost savings), operating cost savings, and CO_2 emission reductions. CO_2 emissions reductions could lead to operating cost savings if a price for carbon (i.e. a carbon tax) were eventually implemented.

5 The 2009 GL-GIFT Summer Workshop

On August 17, 2009, members of the RIT and UD GL-GIFT team held our first GL-GIFT Summer Workshop at RIT. The workshop was a success, with representatives from GLMRI, energy and environmental consulting firms, universities, and U.S. and Canadian transportation agencies in attendance. The workshop aimed to introduce GL-GIFT to those unfamiliar with the model, allow for hands-on exploration of the model, and request suggestions for improvement of the GL-GIFT model. The workshop provided user education, GL-GIFT outreach, and an opportunity for users to network with others interested in freight transportation research. We recorded all comments made at the workshop and intend on addressing some of those comments in the coming year. The following is a list of key comments that we will be working on for future version of GL-GIFT. We may not address all of these comments (due to feasibility, budget, etc.), but we feel it is important to report them.

1. *Enable metric conversion.* This will allow for easier analysis for international GL-GIFT users.
2. *Generating trip profiles by mode.* This would include data such as the percent of the route travelled by each mode and the emissions associated with that particular mode.
3. *Improve intermodal transfer time estimates.* It has become clear that a better understanding on the time it takes to transfer freight from one mode to another is necessary to improve the usefulness and accuracy of the GL-GIFT model. We plan to collect better data through various mechanisms in the future.
4. *Include more predefined vehicle, locomotive, and vessel choices.* This will allow users to select a vehicle, locomotive, or vessel to model from a drop down menu.
5. *Reduce unrealistic routes through major cities.* GL-GIFT may be generating optimal routes through major cities that are unrealistic based on real-world problems along the truck and rail networks such as highway and rail congestion.
6. *Enable multiple O/D pairs to be run programmatically to model the impacts of regional flows.*

6 Conclusion and Future Work

This report describes the GL-GIFT model and provides examples of how it might be used to facilitate sustainable freight decision making in the Great Lakes region. We plan on continuing to update and improve GL-GIFT. We received a lot of excellent suggestions from users at our first GL-GIFT Summer Workshop held August 17, 2009 at RIT. Some of those suggestions are reflected in this chapter. The following areas are likely areas of continued improvements:

1. *Integrate the STEEM model into GL-GIFT to allow for trans-oceanic freight route analysis.* The STEEM model was developed at the University of Delaware and includes international on-water shipping routes. The integration of the STEEM model will allow for the analysis of trans-oceanic freight route analysis. Therefore, origins and destinations will not be limited to the U.S. and Canada.
2. *Continue our efforts to bring GL-GIFT to the web.* This will allow more analysts to perform their own case studies, specific to their organization's concerns.
3. *Refine speed limit data.* We expect to improve the resolution of data for each of our modes. For example, at this point we are limited to assigning one constant speed limit to our rail and waterway network. This is despite the obvious fact that certain sections of railroad tracks have a higher speed limit and railroad segments in urban areas are becoming very slow due to congestion. We are in the beginning phases of attempting to find quality data to allow for more realistic modeling of freight transport in the Great Lakes region and throughout the entire GL-GIFT network. We are also looking to validate that our bottom-up and top-down approaches to calculating emission factors are accurate.
4. *Incorporate speed, traffic control, and congestion constraints.* Currently, the GL-GIFT model uses road classes to assign speed limits to the U.S. and Canadian road network rather than one constant speed for any road regardless of its classification. As of now, the speed limit for the entire rail and ship networks are one constant speed. We are in the beginning phases of incorporating more realistic speed constraints for rail across the GL-GIFT network, potentially based on rail class. To improve our road network, we are investigating methods for incorporating traffic control devices and congestion constraints. For example, we may be able to incorporate time penalties for intersections and traffic patterns throughout the network. We would also like to find ways to incorporate delays at locks for the water network.
5. *Conduct freight systems modeling.* We are developing ways to move from a single origin-destination analysis to a system-wide analysis that could be used to inform larger, system-wide decisions.
6. *Examine methods of modeling bulk freight transport.* Currently, GL-GIFT is set up to model containerized freight transport and adjustments need to be made in order to model bulk cargo.
7. *Limit intermodal freight transfer facilities based on their freight handling capabilities.* Currently, GIFT does not determine whether a given facility, such as a port, has equipment for the specific type of cargo, such as cranes for container movement, or bulk cargo load/unload capability.

With these and other improvements, we expect GL-GIFT to be an important tool for policymakers, planners, shippers, and others interested in sustainable shipping in the Great Lakes region.

7 Economic Impacts and Dissemination of Study Results

7.1 Potential Economic Impacts of the Research Results

The GL-GIFT model provides a tool for policymakers, planners, shippers, and others to explore optimal intermodal freight transportation under energy, economic, time-of-delivery, and environmental objectives. With the model, users can explore the potential impacts of infrastructure development, new technology implementation, and objective tradeoffs associated with goods movement in the Great Lakes region. Therefore, the tool can help the region identify and develop a sustainable shipping system that will enhance the long-term economic performance of the region.

7.2 Publications Related to or Referencing GL-GIFT

Comer, B.H., J.J. Corbett, J.S. Hawker, K. Korfmacher, E.E. Lee, C. Prokop, J.J. Winebrake, “Marine Vessels as Substitutes for Heavy-Duty Trucks in Great Lakes Freight Transportation,” Journal of the Air & Waste Management Association, (under review).

Hawker, J.S., “Modeling for Intermodal Freight Transportation Policy Analysis,” First Annual Workshop on Software Research and Climate Change, October 26, 2009.

Winebrake, J. J., J. J. Corbett, et al. (2008). "Assessing Energy, Environmental, and Economic Tradeoffs in Intermodal Freight Transportation " Journal of the Air & Waste Management Association **58**(8).

Winebrake, J. J., J. J. Corbett, et al. (2007). "Energy Use and Emissions from Marine Vessels: A Total Fuel Life Cycle Approach." Journal of the Air and Waste Management Association **57**: 102-110.

7.3 Presentations Related to or Referencing GL-GIFT

Comer, B.H., K. Korfmacher, et al. (2009). Geospatial Intermodal Freight Transport (GIFT) Model: A Policy Analysis Tool for Modeling Freight Transport Cost Emissions. ESRI International User Conference. San Diego, CA.

Falzarano, A., S. Ketha, et al. (2007). Development of an Intermodal Network for Freight Transportation Analysis. ESRI International User Conference. San Diego, CA.

Hawker, J. S., A. Falzarano, et al. (2007). Intermodal Transportation Network Custom Evaluators for Environmental Policy Analysis. ESRI 2007 User Conference. San Diego, CA.

Murphy, C., J. Winebrake, et al. (2008). Geospatial Emissions Characterization for Intermodal Freight in the Great Lakes. ESRI 2008 User Conference. San Diego, CA.

Murphy, C., K. Korfmacher, et al. (2008). Evolution of an Intermodal Freight Transport Model: A Hub-and-Spoke Approach. ESRI 2008 User Conference. San Diego, CA.

Various other, informal presentations have been made to academic and industry groups, such as at the RIT Innovation Festival, Xerox Corporation, Hewlett Packard Corporation, and the Great Lakes Maritime Research Institute Annual Affiliates Meeting.

7.4 Use of Material in Classroom or Graduate Student Work Related to GL-GIFT

- Bryan Comer (2009), *Sustainable Intermodal Freight Transportation*, Master's Thesis for the Department of STS/Public Policy, Rochester Institute of Technology.
- Udayan Sharma (2009) *WebGIFT--Geospatial Intermodal Freight Transportation Model on the Web: An ArcGIS Server Web-Application to Support Policy Analyst Case Studies,* Master's Capstone Project for Department of Information Sciences and Technology, Rochester Institute of Technology.
- Matthew Walter (2009) *WebGift: A Geospatial Intermodal Freight Transportation Model on the Web: Using ArcGIS Server and ArcSDE to Implement a System for Transportation Policy Analysis*, Master's Capstone Project for Department of Information Sciences and Technology, Rochester Institute of Technology.
- Colin Murphy (2008), *Health Impacts from Diesel Freight Emissions*, Master's Thesis for the Department of STS/Public Policy, Rochester Institute of Technology.
- Aaron Falzarano (2008), *An Evaluation of Energy Consumption and Emissions from Intermodal Freight Operations on the Eastern Seaboard: A GIS Network Analysis Approach*, Master's Thesis for the Department of STS/Public Policy, Rochester Institute of Technology.
- Case study for the course *1006-350 Applications of Geographic Information Systems*, Rochester Institute of Technology.
- Ben Weisberg (2008), *Geographic Intermodal Freight Transport: An ArcGIS Server Based Web-Application for Analyzing Environmental Costs of Transportation*, Master's Project Report for the Department of Information Technology, Rochester Institute of Technology.
- Sai Ketha (2007), *Multi-Modal Freight Transportation System*, Master's Project Report for the Department of Information Technology, Rochester Institute of Technology.

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