OHIO RIVER DENIAL AS A TRANSPORTATION CORRIDOR AND ITS ECONOMIC IMPACTS ON THE ENERGY INDUSTRY

THESIS

Çağlar Utku GÜLER, 1st Lieutenant, TUAF

AFIT/GLM/ENS/09-5

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GLM/ENS/09-5

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Çağlar Utku GÜLER, BS

1st Lieutenant, TUAF

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Çağlar Utku GÜLER, BS
1st Lieutenant, TUAF

Approved:

// SIGNED // 23 FEB 2009
Alan W. Johnson, Dr (Chairman) Date

// SIGNED // 23 FEB 2009
Martha Cooper, Dr (Member) Date

AFIT/GLM/ENS/09-5

Abstract

What if the Ohio River is disrupted or denied partially or completely as a transportation corridor? A disruption may be either a natural or man-made disaster or a planned outage on the river's lock and dam structures. Recent history is full of water transport disruption events having significant economic effects on the waterside industries. To assess coal-based economic impacts, we developed a network flow model to represent waterside coal-fired power plants situated along the Ohio River, their respective coal supplying mines, and the various transportation modes that connect them. We show that significant transportation-centric insights can be derived by using only commonly available spreadsheet-based analysis tools, open-source information systems, and web-based geographic tools.

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I dedicate this thesis to my beautiful wife. Her support, understanding, wonderful cooking, and love made all of this possible.

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OHIO RIVER DENIAL AS A TRANSPORTATION CORRIDOR AND ITS ECONOMIC IMPACTS ON THE ENERGY INDUSTRY

I. Introduction

Chapter Overview

The introduction chapter begins with a brief background of the Ohio River Basin. The background section contains information about the basin's geography, the leading resources and commodities transported through the river, the major industries, and the most populated areas. It aims to enlighten the reader about the matter of subject. The research focus is determined according to this background information.

After the research problem is stated, the research question is asked and it is supported by investigative questions to justify the research objective. Then the methodology is explained briefly taking the assumptions and limitations into consideration. Finally, a summary of chapter is given and the research's likely areas of implementation are put forward.

Background

The Ohio River flows from where the Allegheny River and Monongahela River join at Pittsburgh, PA to the point that it joins the Mississippi near the city of Cairo, IL.

The total length of commercially navigable waterways of the Ohio River with its tributaries consists of more than 2600 miles (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004). Figure 1 displays the navigation system of the Ohio River. The navigation through the mainstem is provided by a system of 20 locks and dams (L/D) that are illustrated in “T” shapes. This system is mainly used to make the river navigable by raising or decreasing the water level in some places.

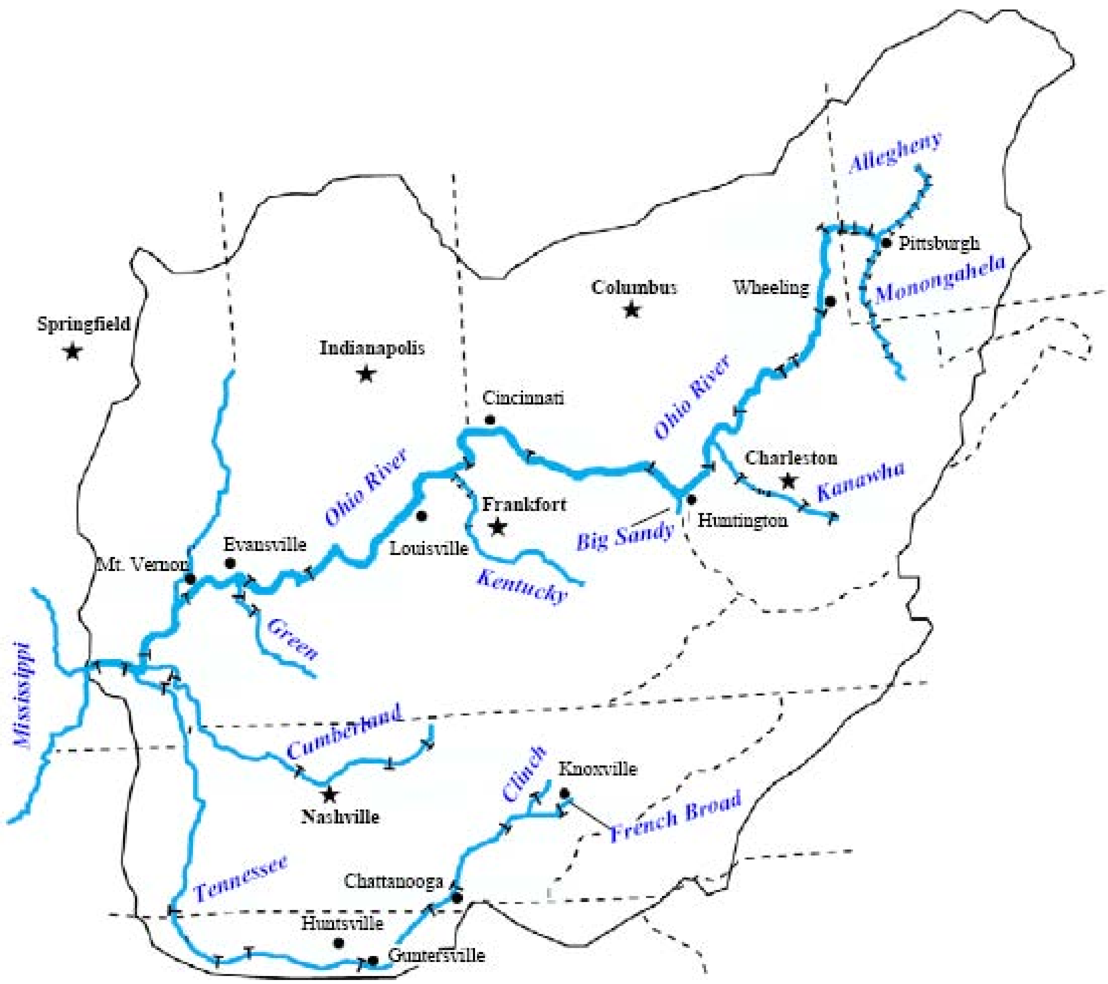
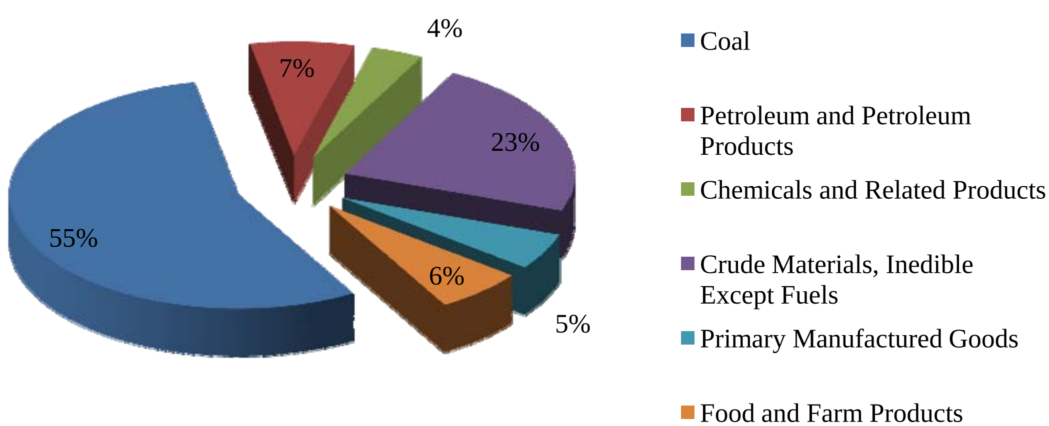


Figure 1. Navigable Waterways and Locations of Lock and Dam Structures of the Ohio River (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004)

Hence, the Ohio River provides a significant annual benefit both to the region and to the country. In 2006, over 270 million tons of cargo, worth $31 Billion, was shipped on the Ohio River Navigation System (U.S. Army Corps of Engineers Huntington District, 2008). This is because the river transport is known as an extremely economical method of moving raw materials and bulk goods. Especially barge transportation is an energy-efficient way of transporting bulk commodities. A typical jumbo barge's freight capacity is equal to 15 rail cars or 58 large semi-trucks for about the same energy per ton-mile (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004).

However, among all commodities in terms of bulk commodities and raw materials shipped and received through the river, coal's portion takes the lead with 55% (The Institute for Water Resources U.S. Army Corps of Engineers, 2006). Figure 2 displays the distribution of main commodities transported through the Ohio River. Due to this high proportion, many studies on the basin focus on coal transportation. This research, too, will use the same approach.



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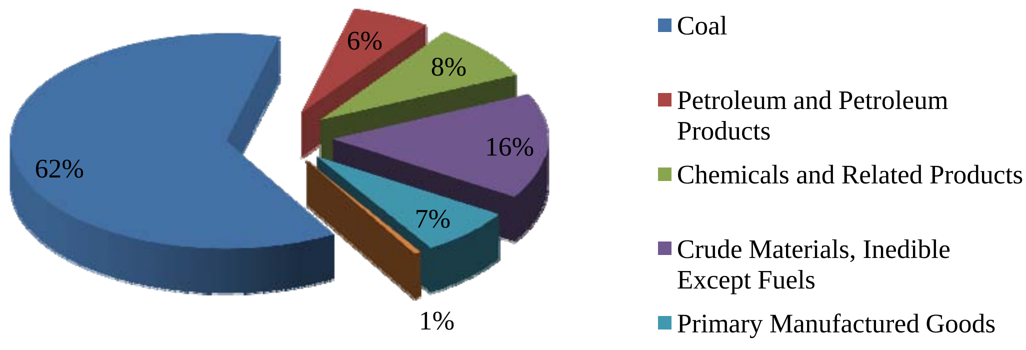

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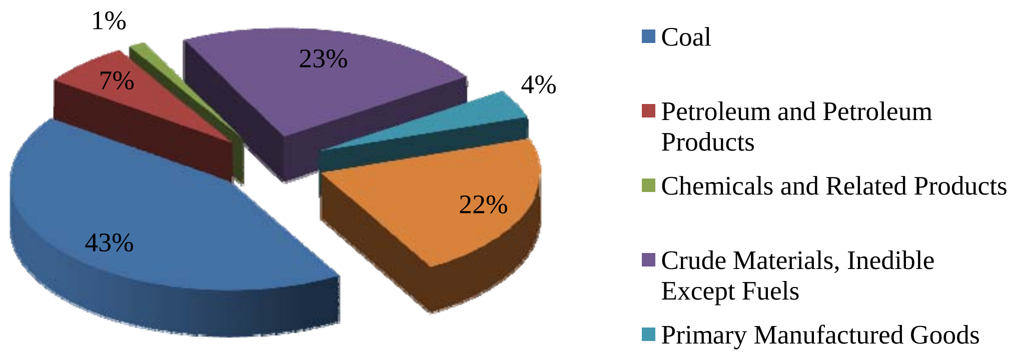

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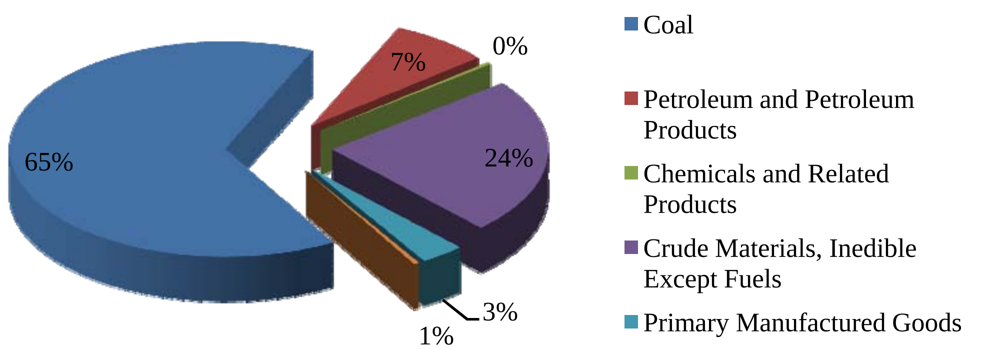


Figure 5. The Commodity Shipped within the Ohio River Basin Flowing through the Ohio River in 2006 (The Institute for Water Resources U.S. Army Corps of Engineers, 2006)

A small analysis on the 2006 waterborne commerce data of the Ohio River mainstem shows that, out of 66.6 million tons of commodities were received out of the basin, coal's portion reserves 62% of all commodities (See Figure 3); out of 54.6 million tons of commodities shipped out of the basin, 43% consists of coal (See Figure 4); and out of 80.9 million tons of commodities transported within the basin, the coal consists about 65% (See Figure 5) of all (The Institute for Water Resources U.S. Army Corps of Engineers, 2006).

There are two major coal reserves in the Ohio River Basin, accounting for nearly one-half of the national coal production: The Appalachian and the Illinois Basin (U.S. Army Corps of Engineers, 2006). The Appalachian region accounts for 35% of total U.S. coal production alone. From the use of transportation mode standpoint, 37% of this coal is shipped by waterway, 41% by rail, 16% by truck, and 6% by conveyor/slurry. Both coal regions supply many of the coal-fired cement, steel, and power plants situated waterside (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004). However, among these industries, power plants consume the majority of coal (80%) transported via the Ohio River. This is because both Appalachian and Illinois basins deposit bituminous coal reserves having relatively high energy content, especially compared with Wyoming's Powder River Basin (PRB) coal (U.S. Army Corps of Engineers, 2006). Waterside electric power plants located in Ohio River Basin and their electric generation capacity are illustrated in Figure 6.

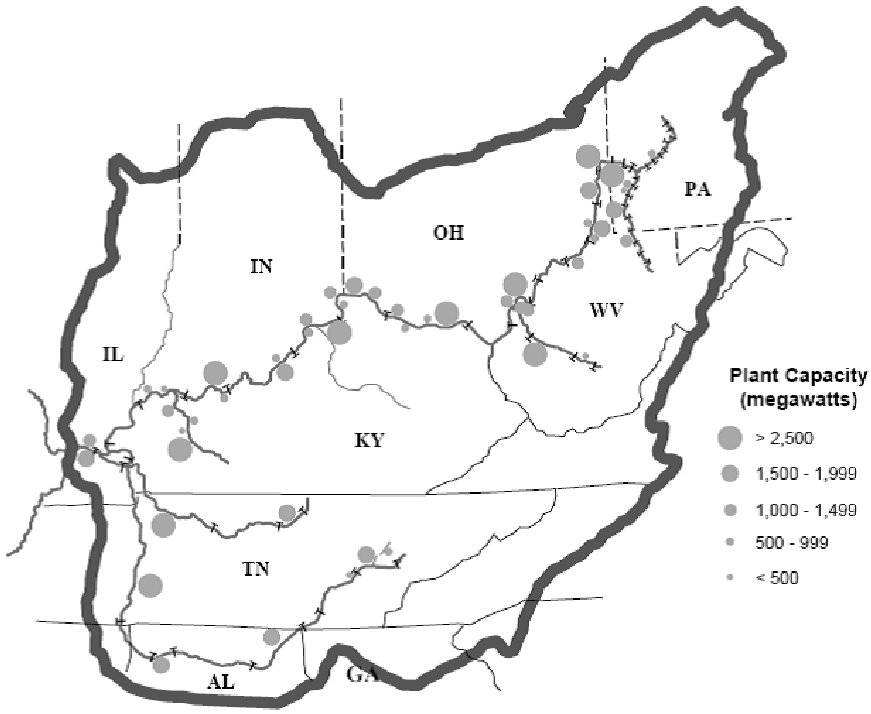


Figure 6. Waterside Electric Power Plants in the Ohio River Basin (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004)

There is kind of a ripple effect caused by the significance of the river transportation. The low cost of coal transportation leads to cheap electricity, cheap electricity attracts industries to the region, and these industries, creating employment opportunities, leads to population increase in the region. The main economic areas in the Ohio River Basin that are essentially affected by the river transport consist of 9 states: Alabama, Illinois, Indiana, Kentucky, Mississippi, Ohio, Pennsylvania, Tennessee, and West Virginia. The total population of these states according to the 2007 estimates is about 63 Million, almost 21% of the total U.S. population (U.S. Census Bureau, 2008). Table 1 shows the 2007 population estimates by the U.S. Census Bureau. Among these states, there are six major populated regions: Columbus, Indianapolis, Nashville, Pittsburgh, Cincinnati and Louisville. The last four of these regions are located along the Ohio River and have access for waterborne navigation (U.S. Army Corps of Engineers, 2006). The traffic in and out of the docks located throughout these regions is a good indicator of basin's growing waterborne economy. However, the State of Ohio is the leading state in terms of receiving waterborne barge traffic, with almost 51 million tons of commodities worth $3.8 billion, followed by Kentucky (U.S. Army Corps of Engineers Huntington District, 2008).

Table 1. 2007 Population Estimates of 9 Ohio River Basin States (U.S. Census Bureau, 2008)

Rank	State	Population	Percentage of Total U.S. Population
1	Alabama	4,627,851	1.51%
2	Illinois	12,852,548	4.20%
3	Indiana	6,345,289	2.07%
4	Kentucky	4,241,474	1.39%
5	Mississippi	2,918,785	0.95%
6	Ohio	11,466,917	3.75%
7	Pennsylvania	12,432,792	4.06%
8	Tennessee	6,156,719	2.01%
9	West Virginia	1,812,035	0.59%
	Total	**62,854,410**	**20.53%**

To summarize, the Ohio River Navigation System improves contact between internal and external markets, reduces energy costs for commercial and industrial activities, links producers and markets for raw material inputs to production, supplies of recreational and industrial water, and derives commercial and support activities. However, the degree of these industries' reliance to inland water transportation differs according to the type of industry. Major industrial users of the waterways are coal miners, electric producers, steel producers, and coke producers (U.S. Army Corps of Engineers, 2006).

Especially, the coal mining and the electricity generating industries are the first two leading industries that have the highest dependencies on waterways. Although they can also develop under the absence of inland water transportation, it is clear that the extent of production capacity they have today would be difficult to reach without the existence of the Ohio River (U.S. Army Corps of Engineers, 2006). For example, electric generating costs in the basin are among the lowest in the nation just because of the low transportation cost of waterways and the existence of abundant coal reserves. Figure 7 displays the distribution of U.S. average retail price of electricity by state according to the U.S. Department of Energy, Energy Information Administration’s latest (2006) statistics. It can be easily seen that although the U.S. total average price per kilowatt-hour is 8.9 cents, it is 5.04, 5.43, and 6.46 cents successively for West Virginia, Kentucky and Indiana. And, all other states in the basin have even lower values than the nation’s average (U.S. Department of Energy, Energy Information Administration, 2007).

Therefore, although all other resources and industries in the basin are significant to the basin’s economy, our research will focus on the coal transportation of the electricity industry as it has the biggest fraction in the basin’s overall commerce. To justify the selection of the research focus, the background is mainly concentrated on the coal production and the coal-fired electric generating power-plants throughout Ohio River Basin.

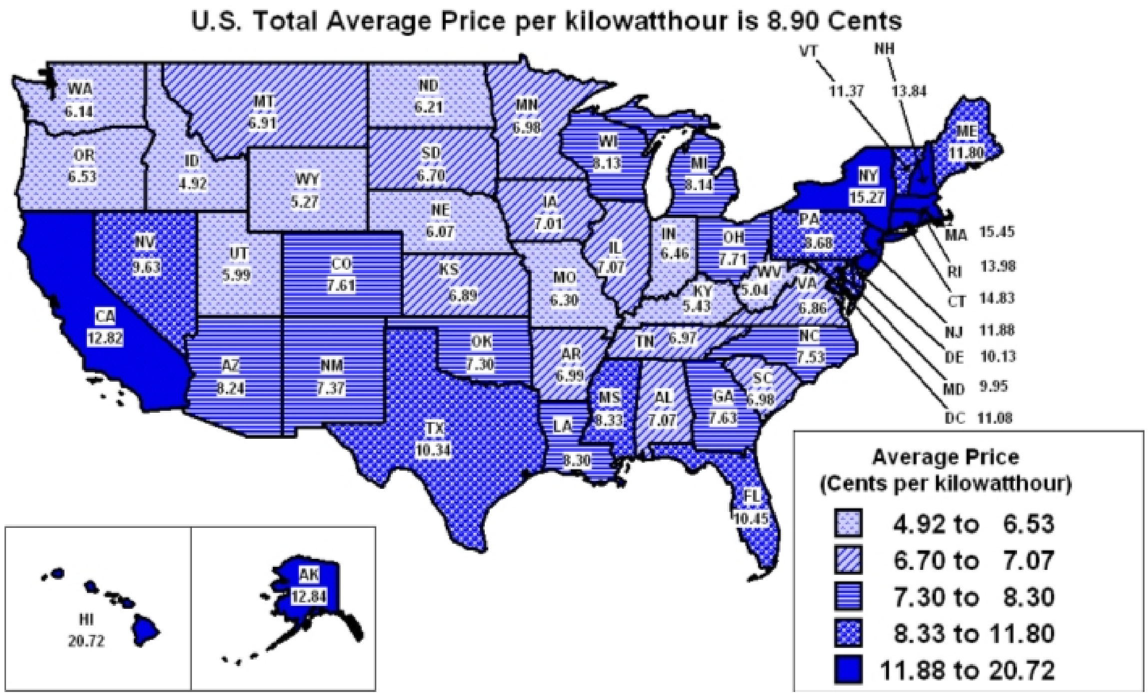


Figure 7. U.S. Average Retail Price of Electricity by State, 2006 (U.S. Department of Energy, Energy Information Administration, 2007)

Problem Statement

The Ohio River may be disrupted or denied partially or completely as a transportation corridor. The reason of such a disruption may be either a natural or man-made disaster or expected failure on the L/D structures. In case of such a disruption on the Ohio River, shippers are most assuredly expected to switch to the best alternative routes and modes of transportation to minimize their cost of shipping. Hence, the possible economic impacts and the outcomes should be enlightened by evaluating the alternative transportation modes satisfying the required constraints in a cost-effective manner.

Research Objectives/Questions/Hypotheses

The research objective is to determine the economic impact of denying the inland water transportation between the coal mines and the power plants. Each alternative route between the coal mines and the power plants is defined as a transportation arc. Then, the research question is defined as what if the Ohio River is disrupted or denied partially or completely as a transportation corridor.

The tested hypothesis is that the ability of delivering coal via river transportation directly affects the cost of generating electricity.

Research Focus

This study will focus on inland and overland transportation routes to the power plants throughout the State of Ohio's south border, covering 452 miles of the Ohio River, from the milepoint 41 through the milepoint 492. The waterside power plants and transportation of coal through inland and overland transportation modes are taken into consideration.

Investigative Questions

Some investigative questions that support our research question are: (1) How can a coal distribution network be optimally established to minimize coal transportation costs? (2) What are the best alternative coal supplies and modes of transportation in case of water transportation denials? (3) What is the most critical lock or locks that can make the biggest economic impact? (4) What if there wasn’t the Ohio River and its tributaries?

Methodology

In order to test the hypothesis and to answer our investigative questions, a series of network flow, linear programming models are built for the delivery of coal from the surface/underground coal mines to the power plants situated waterside. The transportation arcs representing the shipment amount that each transportation mode handles between two nodes are defined as decision variables. The lock and dam structures are then denied one by one until whole water transportation is disrupted and the results are recorded. The model is subject to the historical upstream and downstream annual traffic flow limits, the transloading terminal’s capabilities, and the annual quota condition for the coal mines.

Assumptions/Limitations

It is assumed that the State of Ohio’s waterside power plants are and will be sustained from the Ohio River Basin’s coal reserves provided in historical data. No congestion effects on Ohio River traffic are taken into consideration. In the denial process of the locks, main and auxiliary chambers are assumed to be failed simultaneously. And, timing restrictions as in JIT production is not taken into consideration as a constraint.

Other than these, ceteris paribus condition is fully respected as no effect of possible price adjustment can be made according to the competitive environment of the existing transportation modes (Beuthe, Jourquin, Geerts, & Koul à Ndjang'Ha, 2001). Further assumptions will be stated in methodology.

Implications

The results of this research are expected to enlighten the U.S. Army Corps of Engineers and the Waterways Council in prioritization and budgeting of construction and modernization projects of lock and dam structures. Besides, the Congress can use the outcomes of this research in approving and authorizing future fiscal year's budgeting on maintenance and modernization of locks and dams. Another implementation area might be for the coal-fired power plants situated in Ohio: They can modify or readjust the routing of coal delivery and prepare an emergency plan for a series of likely disruption events on the Ohio River. Moreover, future researches can be done based on the results of this study.

Consequently, although the importance of the inland water transportation on the Ohio River is underestimated, and is remembered whenever there is a considerable disruption; this research's outcomes will add one more block to the existing efforts to understand its importance.

Summary

In this chapter, first a brief background about the Ohio River Basin's economic parameters and factors that reflect its present situation are provided. After the statement of the problem, research objective and investigative questions are determined. Then the selected methodology is described shortly and some of the assumptions/limitations are put forward. Finally, the implication areas of the research results are discussed.

Thereafter, the thesis is organized as follows. We first provide a review of the literature in terms of prior disruption events, the transportation mode selection studies, and the recent research on the Ohio River transportation system. The third chapter consists of the journal article that is submitted to the Elsevier's peer-reviewed publication "Omega". How we establish the data and the modeling approach, the description of the mathematical model, calculations and the findings of our study which are linked to our investigative questions are presented within the journal article submission chapter. Finally, a summary and the conclusions are provided expanding the concluding remarks of the submitted article along with possible directions for future research areas.

II. Literature Review

Chapter Overview

The literature review consists of five sections: Introduction, Prior Closures of the Ohio River and their Outcomes; Waterway Transportation Demand Elasticity and Alternative Mode Selection Studies, Recent Researches on the Ohio River Transportation System, and Conclusion.

Before providing a framework of recent studies on the Ohio River Navigation System, it is better to take a look at the Ohio River's prior disruptions and their economic outcomes. Thus, we can clearly understand why and to whom these studies are important. Some major disruption events like lock and dam closure, flooding, icing, and temporary closures of waterways due to accidents are examined chronologically.

In the third part of the literature review, recent researches about the relationship between inland water transportation demand and supply were discussed. In addition to this relationship, the studies about shippers' and carriers' perceptions in transportation mode selection were examined.

In the fourth part, the studies about investment investigations and researches about the possible economic impacts of such disruption events are summarized and evaluated. In all parts, the papers' relevant research and investigative questions, their implemented methodologies for answering these questions, their pitfalls and successes are examined. In the very end, a conclusion part is added to summarize the literature review.

Prior Closures of the Ohio River and Their Outcomes Overview

Until the civil war, Ohio's economy was mainly based on agriculture and farming, even though the key to the Ohio's development was none of them but transport (The Ohio River: A tale of three cities.1990). The Ohio River had been the largest tributary by volume of the Mississippi River through history and it was used as the primary transportation route during the westward expansion of the early United States (Wikipedia contributors, 2008). It preserved its increasing importance and became one of the commerce routes of today. The only difficulty was the shallowness of the river in some regions, until locks and dams (L/D) were then considered to overcome this problem. These constructions served as stairways allowing barges and boats to navigate the 981-mile-long waterway's changing elevation (The Associated Press, 2004). Today, there are 20 L/Ds on the Ohio River mainstream excluding its tributaries and one other is still under construction to ease the traffic.

As shipping of large amounts of bulk commodities via barges was more cost effective than using other modes of transportation, many sectors of commerce including manufacturing and power plants appeared to be more and more dependent than before on the Ohio River transportation. However, disruption events on the river like maintenance of an L/D, a temporary closure of a port, icing or flooding started to make huge economic impacts to the region and to the country. Even a terrorist attack to one of the nine L/Ds along Ohio's borders could also be the reason of a possible disruption (Ohio Homeland Security Strategic Planning Committee, 2004). But, just as Barry Palmer, president and chief executive of Waterways Council Inc. said in 2005, "It was obvious that the waterways wouldn’t get any attention until coal couldn’t get to the Ohio River power plants or grain couldn’t be exported and rots in the field" (Biederman, 2005). To better understand the importance of the Ohio River’s absence, some of the prior disruptions related to water transportation are discussed below.

In March 1997, flooding, one of the natural disasters, interrupted coal mining and transportation on the Ohio River and its tributaries for more than a week. About a 400-mile long stretch of the Ohio River from Cincinnati to Uniontown, Kentucky was closed to barge traffic, and Crounse Corporation, a barge company that transported coal until that day was shut down due to the extreme disruption. Some surface mines were still operable, but getting coal to the customers was almost impossible (Ohio River floods halt Kentucky coal production.1997). Icing is another type of natural disaster example. In 1999, the Illinois River barge transportation slowed down because of icing conditions. The river was still technically open to traffic, but there was somehow an imaginary halt, affecting the volume of coal and grain shipped through the river leading to an increase to shipping costs (Boyd, 1999).

In late 2003, a lock on the Ohio River named Greenup near Louisville, Kentucky was shut down for two weeks due to routine maintenance. Because of 2 weeks delay, Marathon-Ashland Petroleum spent $2 million to cover the expenses of using alternative routes to deliver fuel from its oil refinery to customers normally reached by the river (Ostroff, 2005). The closure repeated in August 2004 (Armistead, 2004), and at that time, because of using the adjacent, smaller, auxiliary chamber, queue delays approached 40 hours at one point and caused about $14 million in direct tow-operating costs (Grier, 2009). A side info; the reason of these delays is that auxiliary locks can't handle the required length, so the towboats split the tow into two (Hickey, 2001).

When U.S. Army Corps of Engineers (USACE) decided to close McAlpine L/D in Louisville for 11 days in 2004, about 180 companies, who used the Ohio River to transport commodities to and from their plants in the Mountain State, West Virginia, scrambled and started to find alternative ways (Harris, 2004). One of USACE officials mentioned that generally about 14 tows, carrying 100.000 tons of goods on each one, passed through McAlpine a day (The Associated Press, 2004). The Ormet Corporation, a totally integrated aluminum producer decided to close one of its 4 potlines in Hannibal, OH and mentioned that it would remain down for the time being. Wheeling-Pittsburgh Steel Corporation had made alternative arrangements and decided to use railcars to ship the iron ore needed for their steel making operations adding their operating costs as much as $3 million. Furthermore, CONSOL Energy who moved about one-third of its coal by water thought that the closure was going to be a very big issue (Harris, 2004).

At that time, closure of McAlpine L/D was of great concern to many users of the waterways system because, unlike most L/Ds on the Ohio River, there wasn't an auxiliary lock available at McAlpine and this closure meant a standstill to all navigation at this location (Colbert, 2004).

In 2005, Mississippi and Ohio Rivers had the Midwest's worst drought since 1988 (Kotlowitz, 1988), and several barges ran aground on both rivers. A seven-mile stretch of the Ohio River was shut down for several days (Waterways running aground.2005). More than 60 boats and 600 barges were stopped for three to four days (Drought halts Ohio river barges.2005)(Ohio river reopens after corps repairs McAlpine cofferdam.2005).

Lately, barge operators were forced to limit the tonnage of barges and delays caused a $10,000 loss a day, estimated by the American Waterways Operators (Waterways running aground.2005).

The year 2005 also witnessed a barge's crash into Belleville lock in Reedsville, Ohio. Its consequence was such a ripple effect as each passing day the economic disruption grew. The Ohio River's shutdown cost $4.5 million a day to the businesses in the area; General Electric closed its plant because of not being able to receive and ship supplies laying off countless employees; the chemical and petroleum giant Ashland admitted this accident was a "crisis". The delay of goods entangled supply chains and caused shortages of products in Pittsburgh business area. The closure affected commerce even far beyond the Ohio River Basin (Keane, 2005).

Waterway Transportation Demand Elasticity and Alternative Mode Selection Studies

In this part of the literature review, freight transportation direct and cross-demand elasticities for three transportation modes were examined. A concentrated review showed that most efforts on estimating the choice of modes had been realized by the help of discrete, continuous, or a mix of discrete and continuous models. The main problem could be the lack of data on goods movement.

To overcome the lack of data, an econometric modeling approach was proposed by Abdelwahab and Sargious (1992). In their paper, they described a simultaneous equations model called '3-equation system' and they tried to evaluate simultaneous decision-making for the choice of freight transport mode and shipment size (W.

Abdelwahab & Sargious, 1992). With their approach, significant evidence was provided on the existence of simultaneity in the decision-making framework of mode and shipment size selection. The statistical tests that they conducted through their study validated their hypothesis of interdependence between the two decisions on mode and shipment size, and showed a satisfactory performance (W. M. Abdelwahab, 1998). The highlight on their research was that a significant bias would arise in case of single equation estimation of mode choice or shipment size (W. Abdelwahab & Sargious, 1992).

However, in the introduction of his next published research, Abdelwahab (1998) criticized this previous study because neither sensitivities of mode choice probabilities, nor the market elasticities of demand were reported among the key economic measures (W. M. Abdelwahab, 1998).

This time, in his paper, he discussed the interpretation of these economic measures and focused on the derivation and estimation results of them with a new approach. By presenting this new approach for the key measures, such as empirical estimates of freight transport market demand elasiticities, and mode choice probability elasticities of rail and full truck load carriers in the intercity transportation market, he aimed to increase the available information for further researches. He also compared his assessments with prior modeling studies and approaches (W. M. Abdelwahab, 1998). The methodology he used was the same with the one he previously used in his study with Sargious (W. Abdelwahab & Sargious, 1992). The general observations he made on the values of the estimated demand elasticities for the choice of transportation mode were important, as in the case of a potential disruption of inland water transportation, there would remain only truck and rail transportation modes to choose and to easily adapt.

Beuthe et al. (2001) took this study one step further and presented direct and cross-elasticity estimates of the demands for rail, road and inland waterway freight transportation modes together. They compared their estimates with previous studies, particularly with Abdelwahab's (1992) and Abdelwahab's (1998) published results, providing insight for the reason why and under which conditions, inland waterway transportation was strongly preferred. This study was important as a few estimates on cross-demand elasticities were available for freight transportation for these three competitive transportation modes (Beuthe et al., 2001).

Unlike the previously reviewed studies, the computation of these network elasticities was not computed by more classical statistical methodologies. In contrast, a different methodology based on a network model of Belgium freight transportation called Geographic Information System (GIS)[1] was used (Beuthe et al., 2001). The model was developed with the NODUS software (Beuthe et al., 2001; Jourquin & Beuthe, 1996; Jourquin, Beuthe, & Demille, 1999). In this network model, not only the means and modes of transportation but also all the operations like the loading, unloading, transiting and transshipping were identified with a virtual link. The generalized cost of corresponding transportation tasks was the sum of all these successive operations over this virtual network. Therefore, generalized cost elasticities rather than market price elasticities were computed according to a 3-step-reference scenario describing the model of actual freight flows inside and through Belgium in 1995 (Beuthe et al., 2001).

[1] "**Geographic Information System (GIS)**—GIS is a system for creating, storing, analyzing, and managing spatial data and associated attributes. It is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information." {{134 Anonymous; }}

The obtained results of the simulation matched very well with actual market shares meaning that the model's performance was significantly high. Another way to evaluate the performance was the correlation values between the observed and assigned flows. They had correlation coefficients ranging between 0.86 and 0.92 for waterway, railway and road flows. Note that elasticities considered by Abdelwahab (W. M. Abdelwahab, 1998; W. Abdelwahab & Sargious, 1992) were real price elasticities, not generalized cost elasticities, but were of almost the same order of magnitude (Beuthe et al., 2001).

However, the model was still static and was measuring short run elasticities. In addition to this, it didn't have any solutions for modes and routes with capacity constraints of vehicle types used (Beuthe et al., 2001). Despite the existence of these deficiencies, these elasticity studies were deemed good enough to give an insight for our research to determine the economic foundations of transportation mode selection in case of a disruption on the Ohio River Navigation System.

On the other hand, although price elasticities and cost seem dramatically significant to guide the shipper's choice, such economic foundations and key measures might not be enough to decide the best transportation mode alternative. Perceptions of shippers and carriers should also be taken into account as a whole. Evers, Harper and Needham (1996) made a research to find out the determinants of shipper perceptions of modes. In their study, they tried to identify the impacts of shippers' perceptions on individual transportation service characteristics on the overall choice of transportation modes (Evers, Harper, & Needham, 1996). But, before examining Evers et al.'s (Evers et al., 1996) study in detail, it is better to take a look at McGinnis' (McGinnis, 1990) and

Bagchi et al.’s (Bagchi, Roghunathan, & Bardi, 1987) research and their reviews of prior studies concerned with transportation mode choice as they prepared the basis for Evers et al.’s (1996) study.

In his study, McGinnis (1990) compared 12 prior studies in terms of relative importance of cost and service in transportation choice categorizing them before 1980 and after 1980 when deregulation occurred in the U.S. Hence, every research he investigated had its own methodology. McGinnis found that although there was an incremental emphasis on cost by post deregulation literature since 1980, shipper priorities in the United States didn’t change fundamentally, and service was generally valued more than cost in the freight transportation modal choice process (McGinnis, 1990). He claimed that transportation mode decision was affected by six primary factors: “(1) freight rates - costs, charges, rates, (2) reliability - delivery time, (3) transit times - time-in-transit, delivery time, (4) over, short, and damaged - loss, damage, claims processing, and tracing, (5) shipper market considerations - customer service, user satisfaction, market competitiveness, and market influences, and (6) carrier considerations - availability, capability, reputation” (Evers et al., 1996). The elasticity studies that were mentioned in previous paragraphs were one of McGinnis’ (1990) further research suggestions (McGinnis, 1990).

Yet, Murphy and Hall (1995) didn’t agree with McGinnis’ (1990) considerations and published a research paper in terms of update to his before/after deregulation approach. Because they were re-evaluating McGinnis’ (1990) framework, they started with summarizing his paper and described his representative variables once again. At the end of their study, they came up with several propositions and with a dramatically different ranking order of McGinnis’ (1990) six-factor framework. According to them, reliability should have the primary emphasis and transit time should have been second. Freight rates and shipper market considerations were supposed to be the last two (Murphy & Hall, 1995).

Furthermore, in one of the studies before of McGinnis’ (1990), Bagchi et al. (1987) approached this selection process in a different point of view. He examined the effects of Just-In-Time (JIT) inventory systems on carrier selection (Bagchi et al., 1987). In accordance with McGinnis’ (1990) results, this study had presented the most relevant insight of understanding to the emergency decisions on transport mode selections. Because, as we recall from the historical effects of the Ohio River’s prior disruptions to the manufacturing companies, JIT plays a significant role in decision making framework.

Bagchi et al. (1987) used a questionnaire to investigate the influence of JIT. 90% of respondents were presidents, vice-presidents, directors, and managers of manufacturing organizations. They focused on four factors: (1) rate-related factors, (2) customer service, (3) claims handling and follow-up, (4) equipment availability and service flexibility. They analyzed the statistical significance of these variables for the JIT and non-JIT firms. What they concluded was, although both JIT and non-JIT firms placed a great emphasis on these factors, JIT firms assessed them more significant importance (.05 level of significance) then non-JITs (Bagchi et al., 1987). The point was that those firms using JIT considered customer service in the first rank and rate-related factors in the second. Future researches on the detailed roles of these four factors in carrier selection process had been suggested (Bagchi et al., 1987).

After this short skim of basic studies, we can turn back to Evers et al.'s (1996) research. In their research, survey method was used and a survey was sent to 695 high-level executives of manufacturing firms located in Minnesota. With the use of this survey, the perceptions of shippers on seventeen individual transportation service characteristics of three transportation modes- intermodal, rail and truck were asked of the respondents. Having the data, they performed a regression analysis to identify the most important ones (Evers et al., 1996).

The rankings of relative importance of individual factors to overall perception varied for each mode. The most important two factors for all three modes of transportation were availability and timeliness, and that result was meaningful for our study as there was no importance of cost if the mode was not available in a short term of disruption of inland transportation. Here note that there were two important limitations of this research. First one was that only shippers' perceptions were taken into account, not the carriers', and the second limitation was that there wasn't enough data on the perceptions of manufacturers. Any future research, aiming to overcome these limitations, was suggested by the author (Evers et al., 1996).

Nevertheless, another question arose after these elasticity studies: Was there a willingness to pay for transportation in the Ohio River basin? Why should it be? Bray et al. (2004) sought the answer to these questions in 2004. In the very beginning of the study, the maximum amount willingness to pay referred to the maximum dollar amount that a shipper would continue to pay for barge transportation. That was, if barge transportation cost would pass the cost of the second least-cost alternative, they would probably divert to the overland transportation mode (Bray, 2004).

As it was seen in the cross-elasticity studies, demand was the most significant issue for every feasibility and maintenance projects for inland water transportation. There would be more than proportionate reduction in traffic in case of a rise in barge freight because of existence of elastic demand. On the other hand, under inelastic demand conditions, there would be no or a little diversions to overland transportation modes until the willingness to pay limit was exceeded. The purpose of this research was to provide information about the shippers' willingness to pay for barge transportation and also to provide empirical methods to determine the demand elasticity for barge transportation in the Ohio River Basin (Bray, 2004).

The study was built on the interviews asked to shippers of various categories of goods like coal, petroleum and oil regarding their willingness to pay. They were asked why and to what limit they would continue to pay for barge transportation. Every commodity group gave different answers, but one response that was primarily received in common was that shipping decisions were not made only based on accounting costs and opportunity costs must also be considered. For example, the shippers of petroleum products, minerals, and chemicals were generally inflexible in transportation mode selection and their willingness to pay was more than the overland rate (Bray, 2004).

The research, based on the surveys, provided significant information on decision-making process, and positively contributed to understand shipper's perceptions (Bray, 2004). As a conclusion, one could say that the price elasticity studies alone were not enough to make a good decision in transportation mode selection. However, a potential pitfall in this study would be the assumption of short run decisions. Recall that there were some companies who had multi plants that they could shift production from one to another to overcome such a hard decision in the long run. The Ormet Corporation's reaction in the case of the McAlpine L/D closure could be given as an example to this shortfall (Harris, 2004).

Another factor that measured shipper responses was studied by Wang et al. (2006). The question was what if the closure of a lock was announced in advance? That is, does an informed disruption change the behavior of shippers especially if they know the duration of the disruption? Wang et al. (2006) tried to answer these questions and modeled the shipper response under three different scenarios of scheduled waterway lock closure (S. Wang, Tao, & Schonfeld, 2006).

This study was again based on demand analysis. Until that time, changed traffic behavior was never taken into account. But it was obvious that under real conditions, travel demand would alter if time and duration of delay could be anticipated. First, cost of delay was defined, and then cost interaction between modes had been investigated. Here, an important assumption was made to simplify the mode shift process. Although in real life, there were real costs for mode shifting, it was assumed that there was no cost for switching from barge to rail (S. Wang et al., 2006).

As it was mentioned before, the demand analysis was conducted for three scenarios: PS, PM, and PSM. P stood for scheduled preventive maintenance, S stood for scheduling changes in traffic, and M stood for mode shift in traffic. In each case, the shipper was notified earlier for maintenance time and duration. In the PS model, demand change with earlier departure was examined assuming that there was no alternative mode to switch. In this case, earlier departures were expected. In the PM model, it was assumed that railroads were a transportation mode alternative and shipments departed on time.

This time, the traffic was expected to shift to rail mode not using the waterway during disruption. And in the third case, demand analysis was conducted under the assumption of an alternative transportation mode existence and earlier departure. The decision of the shipper was expected to shape according to the transportation cost. First, some shipments were sent earlier, but then, the share of transportation mode was calculated according to the pre-determined cost equations (S. Wang et al., 2006).

The model's reliability was investigated by conducting numerical tests and sensitivity analysis of total transportation cost to demand. Total transportation cost function showed that the earlier the delay notice was made, the lower the total cost that was realized. Furthermore, as warning time increased, the waterway and railroad traffic reduced (S. Wang et al., 2006). It was important that this study's results met with the results of above mentioned shipper perception studies. Note that Wang et al. (2006) only considered user responses to service interruptions to analyze the demand. However, one year later, they would take their study one step further.

Until that time, demand elasticity was embedded in simulation model studies considering demand changes due to reasons like economic growth, shipper perceptions, congestion levels, or seasonal variations. Sometimes lock capacity changes, sometimes demand varies, and sometimes optimization of several investment projects were modeled. However, when it came to compare different scenarios, a total cost approach was used. In their research, S. Wang and Schonfeld (2007) considered to maximize the net overall benefits instead of minimizing total cost. They used a demand model with elasticity embedded in a waterway simulation model and tried to estimate demand variations due to changes in lock operations (S. Wang & Schonfeld, 2007).

First, they considered the factors that could affect demand and formulated these factors to build a demand function. The demand function for each simulation replication was expressed in terms of duration of the simulation interval, simulated travel time for this interval time, and expected travel time. Then the demand function was used to express the overall benefit for the entire analysis period. The objective was to determine the net benefit, which was identified as the total cost minus total benefit. User benefits were estimated using a demand function and cost was determined by using a model for various travel, lock service and delay times (S. Wang & Schonfeld, 2007).

The waterway simulation model used the Ohio River to test a dynamic demand module derived by S. Wang and Schonfeld (2007) with a 7x7 origin-destination matrix. In that demand module, demand elasticities ranging from -.01 to -.1 was used in origin-destination matrix format. Four scenarios considering with/without lock capacity reductions and with/without demand elasticity effects were considered and finally, the results showed that the bigger the demand elasticities with respect to travel times were, the more reductions in traffic (user benefits) during disruptions due to lock maintenance or closures. But they noted that the traffic increased significantly right after the disruption (S. Wang & Schonfeld, 2007). The net benefit approach was close enough to reality, and could be used in other simulation based optimization studies.

The researches that were studied particularly on the Ohio River also used the same conceptual approach that was used in elasticity and mode selection studies. However, it is better to discuss them in a different section as their main objective differs from elasticity studies.

Recent Researches on the Ohio River Transportation System

Most studies in terms of inland water navigation had been made to analyze the selection or scheduling process of lock reconstruction / maintenance projects, and to investigate the potential effects of required investments for incremental improvements. Although such researches were based on economic foundation studies, they weren't adequate to give a strong insight of understanding the relevant economic impacts of a disruption to the region and to the manufacturers. On the other hand, several economic analyses were put forward in the leadership of U.S. Army Corps of Engineers (USACE), although a few of them published in refereed journals. Despite the fact that they were mostly appendices of technical reports, or official documents, they were more than enough to enlighten the economic issues that we were looking for. Hence, in this part of the literature review, the most relevant papers and USACE's reports that could give insight to our research objective were examined in detail.

The Oak Ridge National Laboratory (ORNL) assisted the USACE through several years in analyzing its investment projects along the Ohio River System (ORS). In fall of 1997, the first phase of a model, that was called the Ohio River Navigation Investment Model (ORNIM), had been completed in cooperation of these two organizations. The purpose of this model was to estimate the benefits of incremental navigation improvements on the Ohio River (Bronzini, Curlee, Leiby, Southworth, & Summers, 1998).

Bronzini et al. (1998) described the proposed, expected and developing features of ORNIM. First, objectives to be achieved by this new model were evaluated. Secondly, the resulting system requirements for the model were constructed both from the business and analysis perspectives. After that, the calculation approach of alternative improvement combinations of benefits were discussed through comparison of legacy models. They were used by the Corps to estimate potential benefits of incremental improvements up to that day. These legacy models were Waterway Analysis Model (WAM), the Tow Cost Model (TCM), and the Equilibrium Model (EM). They were exercised iteratively, balancing waterborne transportation delay costs versus alternative modes of shipping (Bronzini et al., 1998).

WAM was used for simulating the movement of tows to measure infrastructure performance. TCM and EQ models were used to determine the type of commodities shipped in a given year, and to investigate the cost savings in case of using the land alternative. A model called Life Cycle Lock Model (LCLM) was used to test the reliability of lock infrastructures. In addition to these models, two ecological models, NAVPAT and QUEPAT were also examined (Bronzini et al., 1998).

Finally, a proposed ORNIM system design, which was considered with a navigation system hazard model, was described through the research evaluating optimal features needed. This navigation system hazard model was used to identify possible waterway event scenarios, taking into account their repair periods and related costs with a probabilistic approach. By the time Bronzini et al.'s (1998) paper was released, the first phase had already been completed and the completion of the second phase had been scheduled (Bronzini et al., 1998).

In legacy models, no vehicle capacity constraints were assumed for overland modes. They didn't have the capability to model all locks and dams (L/D) on the Ohio

River. They also did not estimate the benefits of major maintenance, as well as new construction. Moreover, environmental analysis was being conducted separately. In addition to those gaps, transportation rates weren't taken into consideration in assessing the commodity traffic (Bronzini et al., 1998). Those deficiencies were expected to be overcome by the use of ORNIM.

T. Randall Curlee et al. (2004) released a paper in 2004 identifying the economic assumptions within ORNIM and provided the rationales and biases for them. They addressed how these assumptions might alter the benefit and cost estimates compared to the theoretical data (Curlee et al., 2004).

In their research, they first recalled and discussed that the ORNIM model was based on the Tow Cost Model (TCM) and the Equilibrium Model (EQ) as a starting point. These precedent models were developed by the Corps. Then, the three basic modules of ORNIM were described: the Waterway Supply and Demand Module (WSDM), the Lock Risk Module (LRM), and the Optimization Module. The WSDM used the information derived from random lock closure probabilities, cargo forecasts, towboat/barge operations, river network, construction plans, and lock operations. The LRM used a Monte Carlo process to estimate lock reliability, and the Optimization Module was used to figure out optimal investment for projects and maintenance plans (Curlee et al., 2004).

The WSDM model's required calibration and validation process was covered in Langdon et al.'s (2004) research. This validation process was necessary because WSDM was both a behavioral and a predictive model. The Waterborne Commerce Statistics Center didn't give the historical information about tow size, tow utilization and empty return characteristics; instead of that, the Lock Performance Monitoring System's recorded data was used to determine whether the values of produced distributions of tow characteristics matched to historical distribution, or not (Langdon Jr., Hilliard, & Busch, 2004).

Calibration process was sequential and was done in several steps. At each step, the model's related static components were adjusted, the model was run, and the results were compared with the historical distribution in the year base. The derived values were close enough to the targeted ones showing that ORNIM was robust and adequate to improve the analytical process of simultaneous investment optimization (Langdon Jr. et al., 2004).

Although ORNIM was expected to be designed to estimate the overall benefits of the Ohio River System, it couldn't. However, it was useful to estimate the benefits of incremental improvements on locks. On the other hand, while ORNIM's main focus was on optimal modal choices between only rail and water transport, its major advantage over previous models was its ability to analyze thousands of possible investment choices in a cost-effective manner (Curlee et al., 2004). The economic basics used and presented in Curlee et al.'s (2004) paper, defended ORNIM's appropriateness to its assumptions and objectives.

It was very important to note that the ORNIM's purpose of design was a trade-off between estimating the total benefits of a river system and estimating the benefits of incremental improvements. ORNIM measured the benefits of relatively small infrastructure improvements. Therefore, it couldn't estimate the total benefits and this was still one of its shortcomings. In addition to this, although river transport might be subject to market failures, as some examples are previously mentioned under ‘Prior Closures and Their Outcomes’ section, ORNIM didn’t consider the implications of these failures and that was another deficiency. Last of all, unlike the reality, it assumed a perfect competition to explain the economic foundations. Nevertheless, other than those deficiencies, its basic assumptions were appropriate and robust both in the long run and in the short run, and it was successfully used to develop the 2006 System Investment Plan for the Ohio River Mainstem Study by USACE (Hammond, 2007).

Before discussing the USACE’s investment plan of 2006, it is better to examine the latest commerce report on the Ohio River. The most updated commerce report on Great Lakes and Ohio River Navigation Systems was published by USACE in 2004. This report consisted of four parts and the third part was allocated for the Ohio River Navigation System. The report offered a detailed source of descriptive statistics and organized information. After making a brief introduction about the geographical and physical description of the Ohio River basin, it offered some facts about barge transportation and made a comparison with other rival transportation modes in terms of capacity equivalence. The comparison depicted in Figure 8 was very practical to use in further studies (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004).

Here, also note that another illustration with a more detailed approach was provided through an article of Tarricone (1991) giving a deeper insight of understanding for capacity equivalence. (See Figure 9 below):

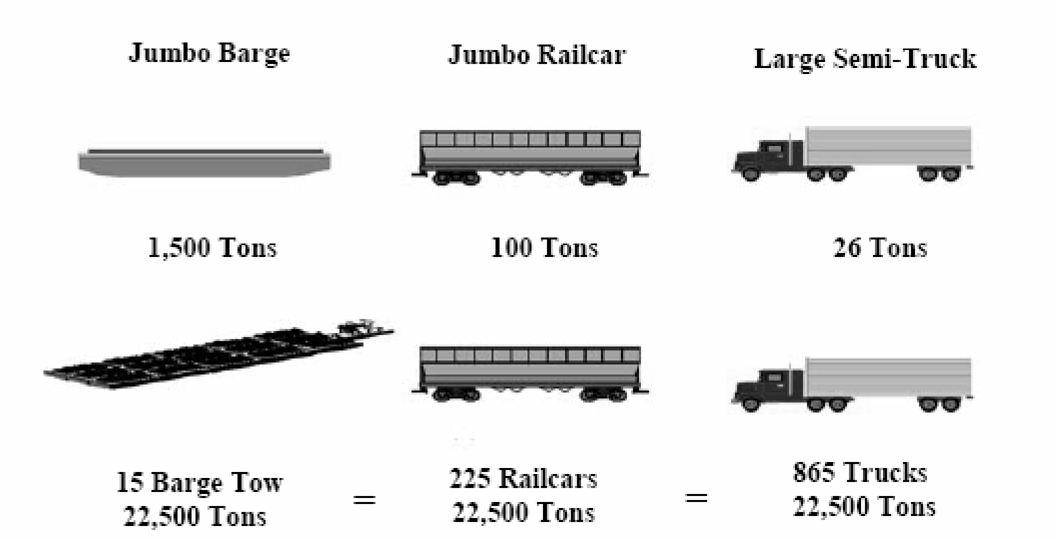


Figure 8. Modal Carrying Capacity (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004)

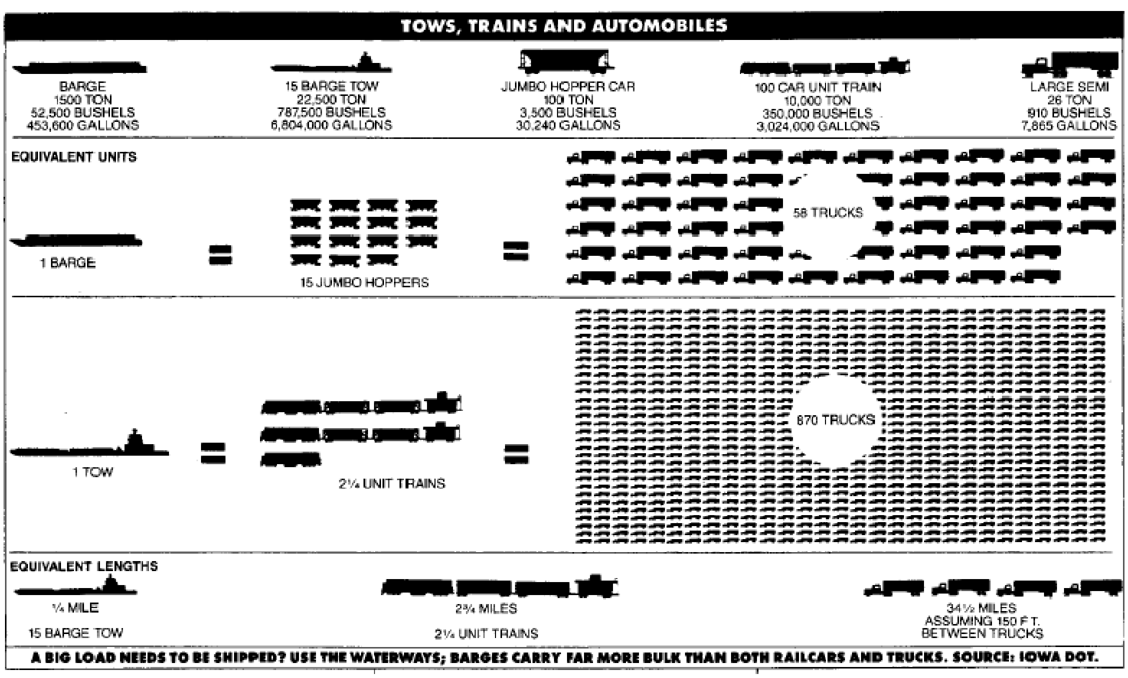


Figure 9. Tows, Trains and Automobiles (Tarricone, 1991)

When it came to the question to describe the relevant industries and natural resources, most importantly, coal was examined as it was the major commodity that was transported through the Ohio River Navigation System. In the Commerce Report (2004), major coal fields, principal coal routes, and the importance of the Ohio River for coal production were emphasized in detail (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004).

Two further research questions could be investigated taking into consideration these facts about coal: (1) what could be the economic impacts of short and long L/D closures on the Ohio River to the dependent industry of Appalachian coal, and (2) what could be the economic impacts of short and long L/D closures on the Ohio River to the dependent industry of Illinois Basin coal. These industries could be consisted of coal-consuming cement, steel, and power plants situated along the Ohio River System.

Waterway improvements and project statistics sections in the report were not reviewed as they were out of our study's scope. But the waterway impact on the regional economy section opened a new window by identifying seven activity areas that the economic development was facilitated by the inland waterway system. According to the Corps, these facilitation areas were: (1) Lowering transportation costs for bulk commodities, (2) Improving contact between internal and external markets, (3) Reducing energy costs for commercial and industrial activities, (4) Linking producers and markets raw material inputs to production, (5) Supplying recreational and industrial water, (6) Deriving commercial and support activities, (7) Creating and providing jobs (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004).

Each of these activities could present a different future research area to better understand the overall economic impact of the Ohio River to the region.

It was also enlightening that, in 2002, of the 279.1 million tons of goods shipped, 234.4 million tons was from the Ohio River Basin states and 44.7 million tons was shipped from states outside the basin (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004). Another further research could be on how simultaneous L/D closures on the Ohio River would affect the transportation mode decisions of these states and how its impact on national economy would be lessen. The data provided by the Bureau of Economic Analysis (BEA) could be used to answer additional investigative questions.

Finally, another broad study was driven by USACE called the Ohio River Mainstem Systems Study (ORMSS) System Investment Plan/Programmatic Environmental Impact Statement-Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia. At the end of the integrated main report, there were several appendices like economics, engineering, environmental, and communications (U.S. Army Corps of Engineers, 2006). Among these appendices, the economics appendix was examined in detail.

The purpose of this document was to explain the economic foundations and impacts of possible investments for the Ohio River Navigation System in terms of benefits and costs. With its contents, it was good enough to enlighten further relevant studies. As already mentioned in historical part of literature review, closures of the main chambers lasting more than two days could lead to serious disruptions in barge traffic, especially if there was no auxiliary chamber. That’s why the improvements of potential unreliable L/Ds were the main concern of this study (U.S. Army Corps of Engineers, 2006).

The appendix began with a theoretical framework of economic foundations. The relationship between transportation supply and demand was investigated for different improvement scenarios. Here, it was noticeable that unlike the previous studies, a distinction of demand for different commodities (coal, grain, chemicals, etc.) was made. The above discussed spatially-detailed, partial equilibrium models ORNIM and WAM were used to estimate the benefits of incremental improvements (U.S. Army Corps of Engineers, 2006).

It was important that in this study, the Ohio River basin's resources and their economical importance were evaluated in detail. Major users of waterway transportation and their relative dependencies were determined as coal mining, electric generating, coke production, steel production, petrol-chemicals, and construction industries in order of their dependency levels (U.S. Army Corps of Engineers, 2006). Some companies sought ways to lessen this dependency. Note that mergers had been at work to minimize transportation costs in 2002. For example, Ingram Industries acquired the ownership of Midland Enterprises, meaning that Ingram would possess many open hopper barges available (Morton, 2002). All these industries and their importance on the region's and the country's economy were explained separately n the appendix (U.S. Army Corps of Engineers, 2006).

Although this study had ten different sections, some of them were out of our study's scope as the appendix' main purpose was to measure the effects of candidate L/D improvement projects of USACE. Yet, one should admit that the research framework and presented data gave a significant insight of understanding.

There had been some other studies to understand the economic importance of the Ohio River, which were not driven by USACE. In 1993, Fuller and Grant (1993) evaluated the effects of lock delays on Upper Mississippi and Illinois Waterways on North Central America’s grain market. Despite the fact that the delays in this paper didn’t mean a full disruption, it was important as well to understand the effects of potential temporary disruptions on grain market. About 40% of the U.S. grain exports used these two inland waterways due to the least-cost grain transportation in North Central U.S. was barge transport. That’s why a delay or closure of a lock and dam system had significant economic influences on grain producers (Fuller & Grant, 1993).

The point was that every delay in locks increased barge transportation cost. Fuller & Grant (1993) used a multi-commodity, least-cost network flow model, which was first described and modified through previous researches, to minimize total cost to fulfill the estimated domestic and foreign grain demand. Two main scenarios and one alternative scenario for each main scenario were presented; one was for year 2000 and the other was for year 2020. Alternative scenarios evaluated reductions in delay times. These analyses showed that increases in water transportation cost resulted from congestion and delay of locks, diverted the grain transport to less efficient transportation modes and alternative ports. This diversion increased overland shipping cost as well. Further analyses also showed that optimization of these lock delays might have a significant cost reduction effect on the grain market (Fuller & Grant, 1993).

In another recent research that was implemented in 2005, Watkins and W. Kelz (2005) tried to forecast the coal traffic on the Ohio River System (ORS) based on the results of a pre-existing project that Hill & Associates, Inc. (H&A) conducted in 2002. Their paper represented a substantial refinement over previous forecasting studies (Watkins & Kelz, 2005).

H & A had developed forecasts of coal demand by type of coal for electric generation based on the interaction of two major linear programming models: the National Power Model (NPM) and the Utility Fuel Economics Model (UFEM). These models produced a forecast of coal, electricity rates and demands. Watkins and Kelz (2005), using the results of this pre-existing project of H&A, projected coal usage by type and origin at individual coal-fired power plants in the U.S. and mapped each plant's coal usage projections into river basins for those plants whose transportation routings typically involve waterborne shipments on the ORS. This mapping had been exercised for three different environmental regulation scenarios. Using their system's forecasts, they traced the effects of the various provisions of the regulations (Watkins & Kelz, 2005).

According to Watkins and Kelz' (2005) findings:

> In the 2002 projections, any price elasticity in electricity demand was ignored and the same pattern of year-by-year electricity demand was used regardless of the case and its resulting marginal cost (and hence price) of electricity. This assumption allows a very straightforward "apples-to-apples" comparison of effects, for example, under identical load conditions. (Watkins & Kelz, 2005)

They tried to overcome the above mentioned assumption and succeeded, but on the other hand, they failed to take into consideration the possible restrictions of locks due to the congestion effects caused by coal sourcing differentiation.

In September 2007, impacts of lock failures on commodity transportation on the Mississippi and Illinois Waterway were investigated. Although this study was held on a different waterway, it was very important as it gave insight for the disruption concept.

The research was conducted by representatives of three different institutions. These were The Food and Agricultural Policy Research Institute (FAPRI), Texas A&M University and Global Insight. They assessed the impacts of two particular lock failures on commodity producers and suppliers covering both agricultural and non-agricultural commodities. After the total commodity volume handled by these particular locks had been determined, the cost of alternative shipping modes including rail and truck transportation had been evaluated. A detailed analysis was conducted for a particular range of rates charged by each mode (Meyer, Fellin, & Stone, 2007).

In the event of a lock failure, an increase in transportation costs and commodity prices at the destination and a decrease in commodity prices at the origin was observed affecting both producers and consumers. To investigate this differentiation in price, a spatial model covering 144 regions in the contiguous U.S. and 23 foreign regions was used and the response of corn and soybean prices was examined by modifying transportation costs (Meyer et al., 2007).

Under each scenario, increasing rail rates also increased producer losses. Even with no rate increase, the amount of producer loss was dramatic. Although this study gave an insight for the economic impacts of a potential disruption, its pitfall was to consider only the impacts on corn and soybean movement. By means of economic loss, only the impact on the producer was examined instead of an overall approach. Another pitfall was that only the short run impacts were captured by the model, but it should be noted that in the long run, rail rates could differ.

Conclusion

In the literature review, a sequential order is followed to be able to provide a comprehensible mapping of events and major studies about the effects on inland water transportation. Although prior disruption experiences are given chronologically, it is not reasonable to examine recently performed researches using the same methodology. That is because the focus areas of researches differ in several directions from each other.

The historical disruption events and their economical effects are used to attract the reader's attention to the importance of the Ohio River in terms of economy. After that section, it is aimed to explain for whom and why inland water transportation is important. Demand elasticity and mode selection studies provide an insight of understanding to the shipper to make the right decision.

Finally, the objective to analyze recent researches with their gaps and benefits is to find to best method to use in future researches. It is concluded that although there were some implications, there was no specific study on the Ohio River that considers its economic impacts to the basin. Even the broadest study of U.S. Army Corps of Engineers focused only on system reliability and environmental sustainability. Besides, no study concentrated on the use of Ohio River as a transportation corridor for bulk commodity transport to coal-fired power plants. In addition to these, data integrity and availability had been a big problem in all researches.

Our study will try to overcome these gaps and to try to carry present works one step further. Some precautionary steps: (1) Lack of data on goods movement will be overcome by focusing on a particular commodity like coal, (2) The data integrity and consistency will be provided by a cross-checking in every step through the research, and (3) Instead of focusing on incremental improvements, total benefits of inland water transportation will be investigated.

III. The Submission of the Journal Article

The Chapter Overview

This chapter consists of the article manuscript that is submitted to the Elsevier's peer-reviewed journal named "OMEGA". The methodology and analysis parts of the research are imbedded in this chapter while it also provides the introduction, literature review and conclusions. The detailed data to reproduce the research is presented in the Appendices. The article was submitted on February 4th, 2009 and it is still is in review process.

The Submitted Article to the OMEGA

Ohio River Denial as a Transportation Corridor and its Economic Impacts on the Energy Industry

Çağlar Utku Güler, Alan W. Johnson, and Martha Cooper

Department of Operational Sciences, Air Force Institute of Technology, 2950 Hobson Way, Wright Patterson Air Force Base, OH 45433, USA

Abstract.

What if the Ohio River is disrupted or denied partially or completely as a transportation corridor? A disruption may be either a natural or man-made disaster or a planned outage on the river's lock and dam structures. Recent history is full of water transport disruption events having significant economic effects on the waterside industries. To assess coal-based economic impacts, we developed a network flow model to represent waterside coal-fired power plants situated along the Ohio River, their

respective coal supplying mines, and the various transportation modes that connect them. We show that significant transportation-centric insights can be derived by using only commonly available spreadsheet-based analysis tools, open-source information systems, and web-based geographic tools.

Keywords.

Routing; Decision making/process; Energy; Optimization; Resource management

Introduction.

The Ohio River flows from where the Allegheny River and Monongahela River join at Pittsburgh, PA to its merging with the Mississippi near the city of Cairo, IL. The total length of commercially navigable waterways of the Ohio River with its tributaries consists of more than 2600 miles (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004). It provides a significant annual benefit for both the region and the country: in 2006, over 270 million tons of cargo, worth $31 Billion, was shipped (U.S. Army Corps of Engineers Huntington District, 2008). Water transportation on the Ohio River is enabled by a series of 20 locks and dams (L/D) that render it navigable.

Water transport is extremely economical: a typical jumbo barge’s freight capacity is equal to 15 rail cars or 58 large semi-trucks for about the same energy per ton-mile (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004). Among all commodities shipped and received through the Ohio River basin, coal leads with 55% (The Institute for Water Resources U.S. Army Corps of Engineers, 2006). Because of this high proportion, many studies on the basin focus on coal transportation.

The Appalachian and the Illinois Basin coal reserves within the Ohio River Basin, account for nearly one-half of national coal production (U.S. Army Corps of Engineers, 2006). The Appalachian region accounts for 35% of total U.S. coal production alone. In terms of transportation modes, 37% of this coal is shipped by waterway, 41% by rail, 16% by truck, and 6% by conveyor/slurry. Both coal regions supply many of the coal-fired cement, steel, and electricity industries situated waterside (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004). However, among these industries, coal-fired power plants consume the majority of the coal (80%) transported via the Ohio River.

We examine the transportation impact of partial or full disruption of the Ohio River as a transportation mode between coal mines and coal-fired power plants in the Ohio River Basin. We test the hypothesis that the ability to deliver coal via river transportation directly affects the cost of generating electricity, by answering the following investigative questions: (1) what coal distribution network minimizes coal transportation costs? (2) What are the best alternative coal supply points and modes of transportation if water transportation is denied? (3) What is the most critical lock or locks whose denial can make the biggest economic impact? (4) What happens if the Ohio River and its tributaries become unusable for coal transportation?

Our focus area is bounded by the inland and overland transportation routes throughout the State of Ohio's south border, which covers the Ohio River from mile 41 through mile 492. We consider the waterside power plants located along the Ohio River and their coal supplying counties.

Our paper is organized as follows. We first review the literature in terms of prior disruption events, transportation mode selection studies, and recent research on the Ohio

River transportation system. We then describe our data collection process, modeling approach, and results. We conclude with possible directions for future research.

Literature review.

Historical river disruption events, like routine L/D maintenance, temporary closure of ports, icing, or flooding, have caused huge economic impacts both to the region and to the nation. A terrorist attack could create a possible disruption (Ohio Homeland Security Strategic Planning Committee, 2004). Recent natural disaster-based disruptions include (Ohio River floods halt Kentucky coal production.1997; Armistead, 2004; Boyd, 1999; Grier, 2009; Harris, 2004; Kotlowitz, 1988; Ostroff, 2005).

We found that most studies on modal choices suffer from a lack of data on goods movement. To overcome that problem, Abdelwahab and Sargious propose an econometric modeling approach (W. Abdelwahab & Sargious, 1992), and identify a link between modal choice and shipment size. However, Abdelwahab notes that neither sensitivities of mode choice probabilities, nor the market elasticities of demand were reported among the key economic measures (W. M. Abdelwahab, 1998). Beuthe *et al.* present direct and cross-elasticity estimates of the demands for rail, truck and inland waterway freight transportation modes. Their network model identifies the means and modes of transportation and cargo loading, unloading, transiting and transshipping operations (Beuthe et al., 2001; Jourquin & Beuthe, 1996; Jourquin et al., 1999). However, these studies generally found that the demand elasticity information was hard to obtain and wasn’t adequate to optimize commodity flow.

Factors that affect transportation mode selection such as perceptions of shippers and carriers, shipper response for advanced notification, freight rates, reliability, and transit times were taken into consideration in similar studies (Bagchi et al., 1987; Evers et al., 1996; McGinnis, 1990; Murphy & Hall, 1995; S. Wang et al., 2006; S. Wang & Schonfeld, 2007). But although these studies examined the impact of a disruption on traffic flow, they didn't seek to minimize transportation cost, and did not report actual cost information for comparison purposes.

Several economic analyses were sponsored by the U.S. Army Corps of Engineers (USACE). In 1997, a model, called the Ohio River Navigation Investment Model (ORNIM), was completed for USACE and the Oak Ridge National Laboratory. ORNIM is a spatially-detailed partial-equilibrium mathematical model, and was designed to estimate the benefits of incremental navigation improvements on the Ohio River (Bronzini et al., 1998; Hilliard, 2008). USACE used it to develop the 2006 System Investment Plan for the Ohio River Mainstem Study (Hammond, 2007), which explains the economic foundations and impacts of possible investments for the Ohio River Navigation System in terms of benefits and costs. The antecedent of this investment plan, the USACE 2004 Commerce Report, examined major coal fields, principal coal routes, and the importance of the Ohio River for coal production (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004).

Fuller and Grant evaluated the effects of lock delays on Upper Mississippi and Illinois Waterways on North Central America's grain market. They used a multi-commodity, least-cost network flow model to minimize the total cost to fulfill the estimated domestic and foreign grain demand. They found that every delay in locks increased barge transportation cost (Fuller & Grant, 1993). Sherali and Puri propose a coal flow decision tool that minimizes operations cost, subject to variations in production, ore quality, and demand requirements over time (Sherali & Puri, 1993). Their method supports daily production operations decisions, and relies on an existing, fixed supplier and transportation routing infrastructure. Mohapatra and Dutta present a multiple objective goal programming model to support Indian intermodal transport investment decisions (Mohapatra & Dutta, 1990). It is designed to support the establishment of a national transportation infrastructure for developing countries, but does not consider disruption effects.

Data and Method.

We used a network flow approach to model the coal delivery network of the 43 coal supplying counties in Ohio, West Virginia, Kentucky, Pennsylvania, and Virginia, 36 transshipment points (9 transloading terminals and 27 L/Ds), and 18 coal-fired power plants located along the Ohio River between mile points 41 and 492. Our model minimizes total system coal transportation cost while meeting service and capability constraints, using an approach similar to Vemuganti *et al* (Vemuganti, Oblak, & Aggarwal, 1989). Our data were acquired through open-source information systems or manually produced using free software: we used Google Earth® to verify geographic data and to measure the modal transportation distances between nodes.

Data

We identified the coal mines and their associated transportation modes which replenish the 18 power plants from the 1993 – 2001 Coal Transportation Rate Database of the Energy Information Administration (EIA) (Energy Information Administration, 2001). Data for transloading terminals were obtained through the CSX Corporation Official Website Interactive CSX Map System (CSX Official Website, 2007). We gathered location information of coal-fired power plants and locks and dams situated along the Ohio River and its navigable tributaries from the U.S. Army Corps of Engineers Huntington District Official Website under Ohio River Basin pages (U.S. Army Corps of Engineers Huntington District, 2008).

Figure 10 depicts the respective coal supplying counties, coal-fired power plants, and transloading terminals modeled in our study. We found that 603 different mines supply coal to the power plants modeled. To keep our problem size manageable, we aggregated these mines into 43 supply points, each defined as the centroid of the respective mining activity in each county.

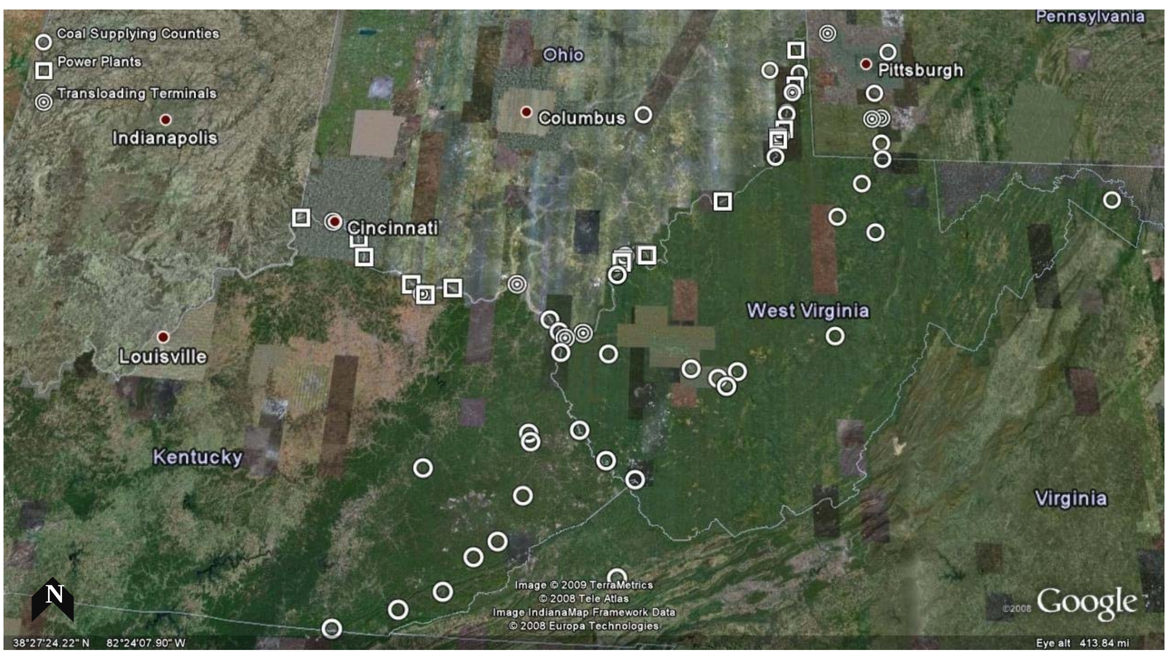


Figure 10. A screenshot from Google Earth displaying the locations of coal supplying counties, power plants, and transloading terminals

To locate these centroids, we first considered waterway, then rail, and finally truck modes. If waterway and rail modes were both available and if a coal stack was noted along the waterway, then the county centroid was assigned as the stack's location. If waterway access was not available, then we selected the intersection of railway and road points closest to the county's geographic center as the centroid. We made some exceptions to the above rule to be consistent with historical data, and thus defined 7 county centroids at points 5 to 15 miles outside of their respective borders.

We then manually measured every alternative water and rail transportation route distance via Google Earth's Ruler Path® tool and recorded the shortest alternative to a spreadsheet supply-demand matrix. Road distances were calculated using Google Earth's Directions function. We then checked the measured distances with EIA's available historical data for consistency. We repeated this process for all 3074 feasible water, rail, and road routes between the supply centroids, transshipment points, and power plants. These possible routes represent the decision variables in our model described in Section 3.2. Transportation choices are thus road, rail, or water modes, or combinations of these modes via transshipment points. We call these modal combinations *multimode* routes.

We acquired the annual power plant coal demand data from 2006 USACE data (U.S. Army Corps of Engineers, 2006); the annual coal supply of counties from 2007 EIA data (Energy Information Administration, 2008); and the historical traffic flows through the locks of concern from 2003 Lock Performance Monitoring System data (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004). We determined the cost rates for each transportation mode from the 2007 Indiana Logistics Summit data given in Figure 11 (American Commercial Lines, 2007). Because the coal prices have remained stable over recent years (United States. National Energy Policy Development Group., 2001) and we don't have the actual cost of coal on each coal mine, we therefore used average transportation cost in our optimization modeling.

	Barge	Rail	Truck
Equivalent Units	1 Barge	15 Railcars	58 Large Semis
Cost per ton mile (cents)	0.72¢	2.24¢	26.61¢

Figure 11. Cost Rates for Transportation Modes

Modeling Approach

We formulated our problem as a minimum cost flow model, and used Microsoft Excel® with the Premium Solver™ plug-in to optimize it.

We modeled power plants as demand nodes, the coal supplying county centroids as supply nodes, and the intermodal terminals and L/Ds as transshipment nodes. We considered three types of transportation modes: water, rail and truck, each as a separate arc between connecting nodes, where such modal choices exist. We ignored conveyor transport because of the lack of cost rate data and its uncommon use. Our decision variables are the transportation arc volumes between these nodes, in units of annual metric tons of coal shipped through those arcs.

We added side constraints to the basic minimum cost network flow model to promote reasonable and realistic solutions. First, a maximum quota constraint (an upper bound) was set for each county's supply amount to promote reasonable and realistic solutions. In particular, the Ohio River Basin supplies various other coal-consuming industries, so, a model recommendation to consume a particular coal mine's entire annual production capacity is not reasonable. Instead, our quota constraints preserve some mine capacity for sharing among related coal-consuming industries. We computed this quota as the county's percent share in the total system supply, multiplied by the aggregate power plant demand.

We added a second constraint set to account for the transloading terminal capabilities given in Table 2. The terminals' annual coal handling capacities are set as their respective upper bounds. No lower bounds are set for the terminals as we also seek the optimal allocation of multimodal transportation terminal uses.

Table 2. Transloading Terminal Capabilities

Transloading Terminals	**Rail-to-truck**	**Rail-to-barge**	**Truck-to-barge**	**Truck-to-rail**	**Barge-to-rail**	**Barge-to-truck**
Terminal 1	+	+	+	-	-	-
Terminal 2	+	+	+	+	+	+
Terminal 3	-	+	-	-	-	-
Terminal 4	-	+	+	-	-	-
Terminal 5	+	-	-	+	-	-
Terminal 6	+	+	+	+	-	-
Terminal 7	+	+	+	+	+	+
Terminal 8	-	+	-	-	-	-
Terminal 9	-	+	-	-	+	-

Our last side constraint set represents the historical upstream and downstream coal flow through the respective L/Ds. The annual traffic through each lock is set as an upper bound on the inflow. We include the following modeling assumptions:

- The Guyandotte, Gauley, North Fork, and Levisa Rivers are navigable for short distances to connect the respective counties to the Ohio River. This is consistent with historical data.
- Every supply/demand/transshipment node situated along a river has access for all three transportation modes except terminal #5 and the L/D structures. Terminal #5 only enables a switch between road and rail transportation modes, and locks only have water transportation access. We assume other overland nodes have road and rail transportation access in consistent with the historical data.
- We ignore truck usage for transferring coal from trains into barges, and vice versa, if such usage is for short (1-2 mile) distances.
- Power plants can't share each other's coal stock piles.
- Handling costs including transshipment costs are ignored as the required cost rates are either not open-source or unknown.

Our model notation is as follows:

K the set of all system nodes (counties, power plants, locks, dams and terminals)
I the set of candidate origin nodes (counties and terminals)
J the set of candidate destination nodes (power plants and terminals)
S the set of candidate supply nodes (counties)
T the set of transloading terminals
L the set of lock and dam structures
X_{ij_barge} the annual amount of coal shipped from node i to node j by barge, tons
X_{ij_rail} the annual amount of coal shipped from node i to node j by rail, tons
X_{ij_truck} the annual amount of coal shipped from node i to node j by truck, tons
C_{ij_barge} the cost per ton mile of coal shipped from node i to node j by barge, cents
C_{ij_rail} the cost per ton mile of coal shipped from node i to node j by rail, cents
C_{ij_truck} the cost per ton mile of coal shipped from node i to node j by truck, cents
b_k the annual supply or demand amount of node k, tons
q_s the annual quota that a county can supply of node s, tons
h_t the annual capacity of coal that a transloading terminal t can handle, tons
u_l the annual upstream traffic passing through lock, l, tons

d_l the annual downstream traffic passing through lock, l, tons

d_i the distance of node i from the zero milepoint of the Ohio River

U_l $\{i \in I \mid d_i \leq d_l \,;\, \forall l \in L\}$ is the set of origin nodes, i, to points upstream of the lock or dam l

M_l $\{i \in I \mid d_i \geq d_l \,;\, \forall l \in L\}$ is the set of origin nodes i to points downstream of the lock or dam l

Our network flow model formulation is:

Minimize

$$\sum_{i \in I}\sum_{j \in J} C_{ij\_barge} X_{ij\_barge} + \sum_{i \in I}\sum_{j \in J} C_{ij\_rail} X_{ij\_rail} + \sum_{i \in I}\sum_{j \in J} C_{ij\_truck} X_{ij\_truck} \qquad (1)$$

Subject to

$$\sum_{i \in I}(X_{ik\_barge} + X_{ik\_rail} + X_{ik\_truck}) - \sum_{j \in J}(X_{kj\_barge} + X_{kj\_rail} + X_{kj\_truck}) \geq b_k \qquad \forall k \in K \qquad (2)$$

$$\sum_{j \in J}(X_{sj\_barge} + X_{sj\_rail} + X_{sj\_truck}) \leq q_s \qquad \forall s \in S \qquad (3)$$

$$\sum_{i \in I}(X_{it\_barge} + X_{it\_rail} + X_{it\_truck}) \leq h_t \qquad \forall t \in T \qquad (4)$$

$$\sum_{i \in U_l} X_{il\_barge} \leq d_l \qquad \forall l \in L \qquad (5)$$

$$\sum_{i \in M_l} X_{il\_barge} \leq u_l \qquad \forall l \in L \qquad (6)$$

$$X_{ij\_barge} \geq 0 \qquad \forall i \in I,\ \forall j \in J \qquad (7)$$

$$X_{ij\_rail} \geq 0 \qquad \forall i \in I,\ \forall j \in J \qquad (8)$$

$$X_{ij\_truck} \geq 0 \qquad \forall i \in I,\ \forall j \in J \qquad (9)$$

Our objective function (1) minimizes the total system transportation cost. Constraint (2) enforces the balance-of-flow rule at each node. Constraint (3) states that no county can exceed its assigned production quota. In the same way, constraint (4) indicates that no transshipment terminal can exceed its annual coal handling capacity. Constraints (5, 6) enforce that the annual amount of coal volume transiting a lock cannot exceed that dock's annual capacity. Constraints (7-9) enforce arc volume non-negativity.

Scenarios Considered

After running the model with the basic constraints and identifying the L/D structures that contain the most flow volume, the water transportation mode was gradually disrupted in consecutive scenarios by eliminating those locks that carry the heaviest annual traffic. To do that, both u_l *and* d_l, the annual capacities of those locks, were set to zero.

We considered 9 particular scenarios depicted in Table 3. Scenario 1 is the base case, with no disruptions. The second scenario disrupts the single lock with the most volume, as identified in Scenario 1. Scenario 3 disrupts the top 3 locks, scenario 4 the top 6, scenario 5 the top 9, and scenario 6 disrupts the entire Ohio River as a transportation mode. Scenarios 7 – 9 remove the maximum quota constraints (3) on county coal production. In particular, scenario 7 models no county maximum quotas and no mode disruptions; scenario 8 combines no county production quotas with Ohio River transportation mode denial, and scenario 9 combines no quotas with the disruption of the single lock with the highest volume.

Table 3. The list of the Scenarios Investigated

Scenarios	**Quota Application**	**Disruption Points**
Scenario 1 (Base Case)	+	No disruption
Scenario 2	+	L/D #11
Scenario 3	+	L/D #10, #11, #12
Scenario 4	+	L/D #1, #2, #3, #10, #11, #12
Scenario 5	+	L/D #1, #2, #3, #4, #5, #6, #10, #11, #12
Scenario 6	+	The entire Ohio River
Scenario 7	-	No disruption
Scenario 8	-	The entire Ohio River
Scenario 9	-	L/D #11

Results.

We examine the results in terms of total system transportation cost, cost per power plant, transportation modes used, the amount shipped by each transportation mode, the share of the coal-supplying counties in the system, the traffic flow through the lock and dam structures, and the use of transshipment terminals. We investigate total system transportation costs both with, and without maximum quotas for the supplying counties.

The optimal establishment of a coal distribution network to minimize coal transportation costs

We found that an optimized coal transportation strategy could save approximately $65 million each year (in 2007 dollars) simply by removing the quota condition. While a maximum quota condition ensures that almost all 43 counties are used to supply coal, without the quota only 14 of the 43 counties are needed to supply all 18 coal-fired power plants for less than half the total transportation cost, as shown in Figure 12.

Figure 13 shows the coal transportation costs that each power plant experiences under four different scenarios. For each scenario, this is the distribution of the total coal transportation cost to the power plants. For the scenarios with water transportation available and no maximum county production quota, the annual transportation cost is less than $10M for every power plant, while only two plants (PP11 and PP16) exceed the $10M mark when a quota is applied. Conversely, when the Ohio River and its tributaries are denied for both the quota and no quota scenarios, there is a significant cost increase for at least 11 plants. We also found that, in the event of a river usage denial, power plants #14, #16 and #17 will suffer the biggest impact in terms of transportation costs, accounting for 65% of the cost increase for the scenarios having production quotas and 69% of the cost difference for the scenarios having no quotas.

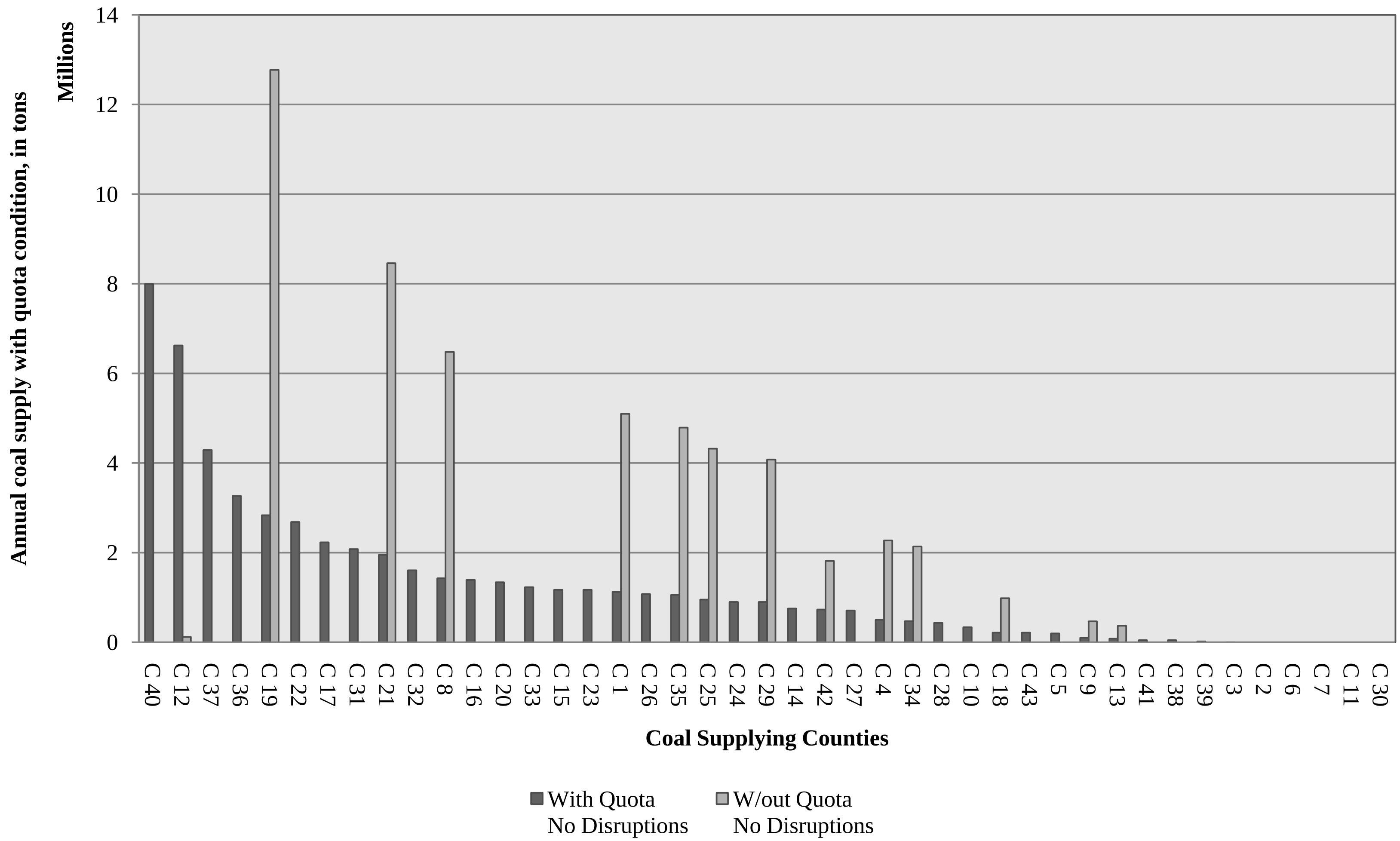
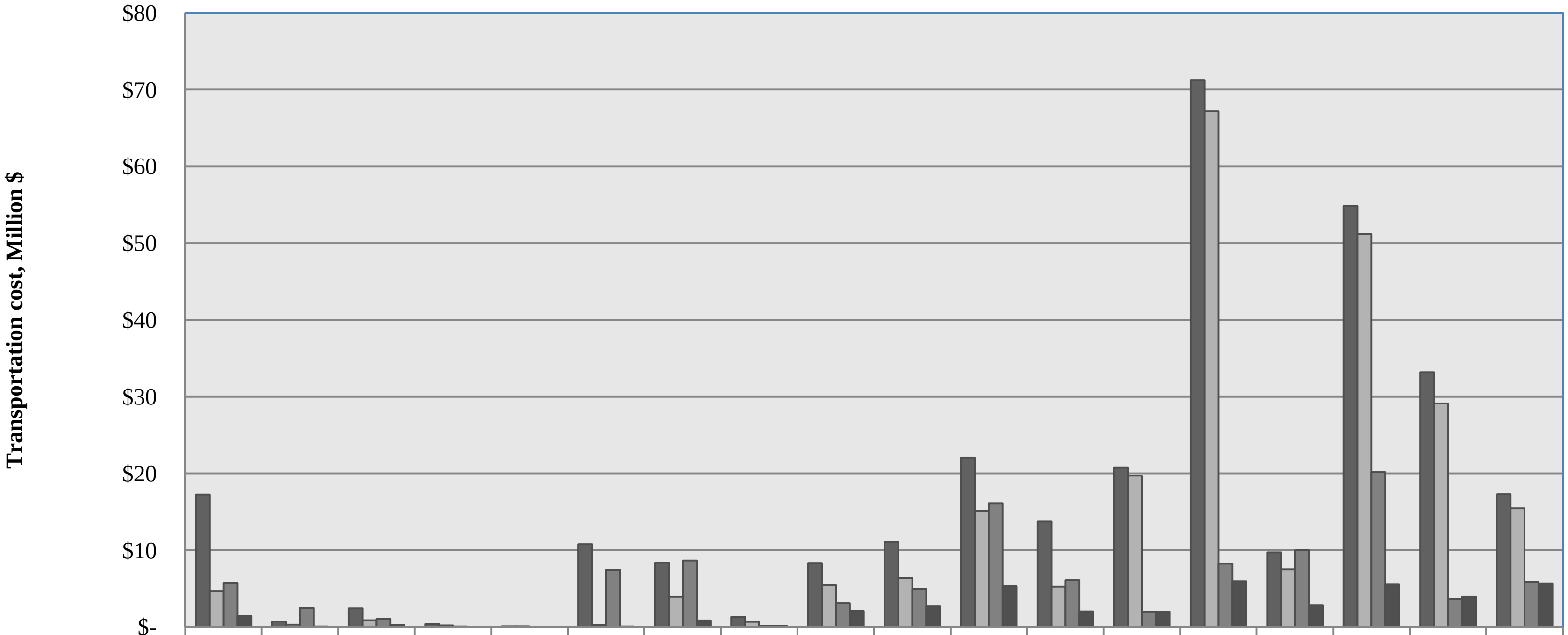


Figure 12. The comparison of annual coal supply of coal supplying counties with or without a quota condition



Million $	PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8	PP9	PP10	PP11	PP12	PP13	PP14	PP15	PP16	PP17	PP18
With Quota Disrupted	$17.2	$0.71	$2.39	$0.39	$0.07	$10.7	$8.36	$1.33	$8.32	$11.0	$22.0	$13.7	$20.7	$71.2	$9.69	$54.8	$33.1	$17.2
W/out Quota Disrupted	$4.66	$0.29	$0.86	$0.18	$0.07	$0.22	$3.94	$0.66	$5.48	$6.36	$15.0	$5.25	$19.7	$67.1	$7.50	$51.1	$29.1	$15.4
With Quota No Disruptions	$5.72	$2.47	$1.08	$0.05	$0.02	$7.45	$8.67	$0.13	$3.11	$4.95	$16.1	$6.08	$1.99	$8.26	$9.99	$20.1	$3.69	$5.88
W/out Quota No Disruptions	$1.48	$0.07	$0.26	$0.05	$0.02	$0.07	$0.87	$0.13	$2.08	$2.73	$5.33	$2.01	$1.99	$5.95	$2.85	$5.56	$3.94	$5.66

Power plants

Figure 13. The disruption effects on the power plants' annual transportation costs with or without a quota condition

The best alternative coal supplies and transportation modes if water transportation is denied

We progressively denied key lock and dam structures and recorded annual county coal production with and without quota conditions. We observed that under a quota condition, the same counties supply the same total amount of coal for all scenarios, although the particular plants supplied changes. However in the non-quota scenarios, not only the particular power plants supplied changes, but also some counties emerged as suppliers while other counties are eliminated as suppliers. Figure 14 illustrates our results for the disruption scenarios.

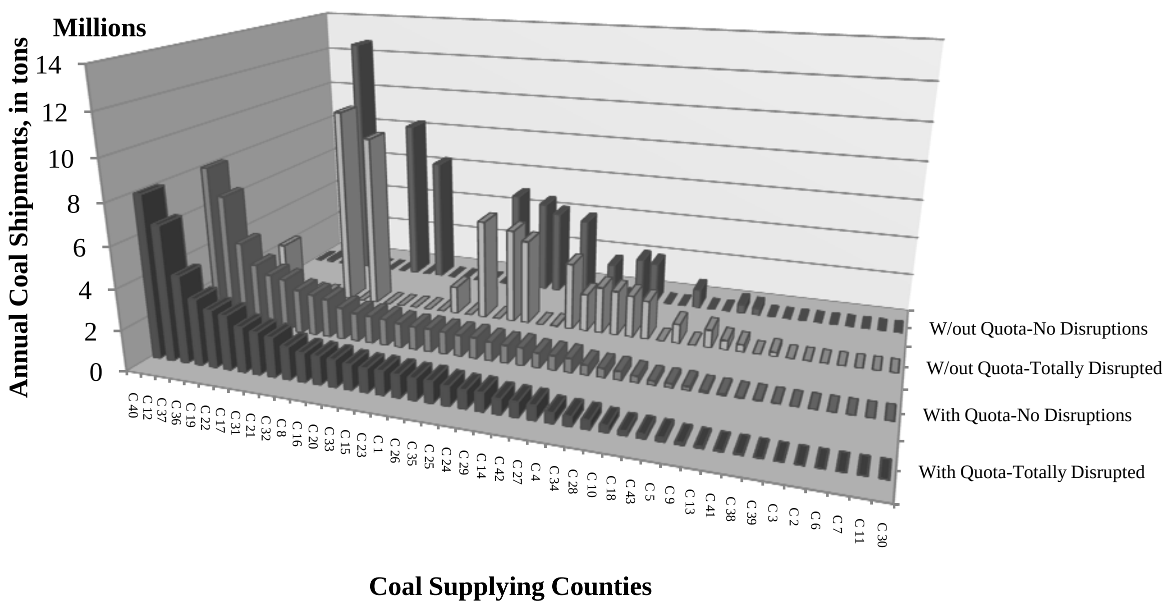
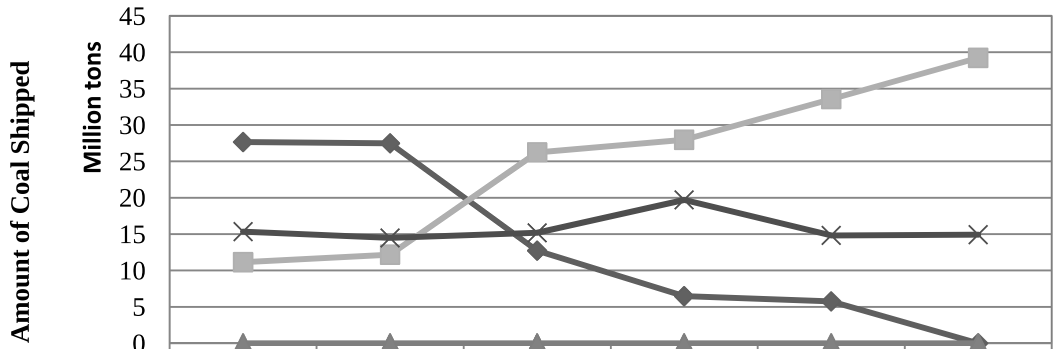


Figure 14. The shippers’ preferences on coal supplying county selection

When water transportation is completely denied, the changes in transportation mode selection leads to a remarkable increase in total transportation cost. Without disruption, water transportation volume is almost twice that of every other mode used, as illustrated in Figure 15. We found that rail transportation emerges as the preferred mode when barge transportation becomes unavailable.



Million tons	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Barge Only	28	27	13	6	6	0
Rail Only	11	12	26	28	34	39
Truck Only	0	0	0	0	0	0
Multimode	15	14	15	20	15	15

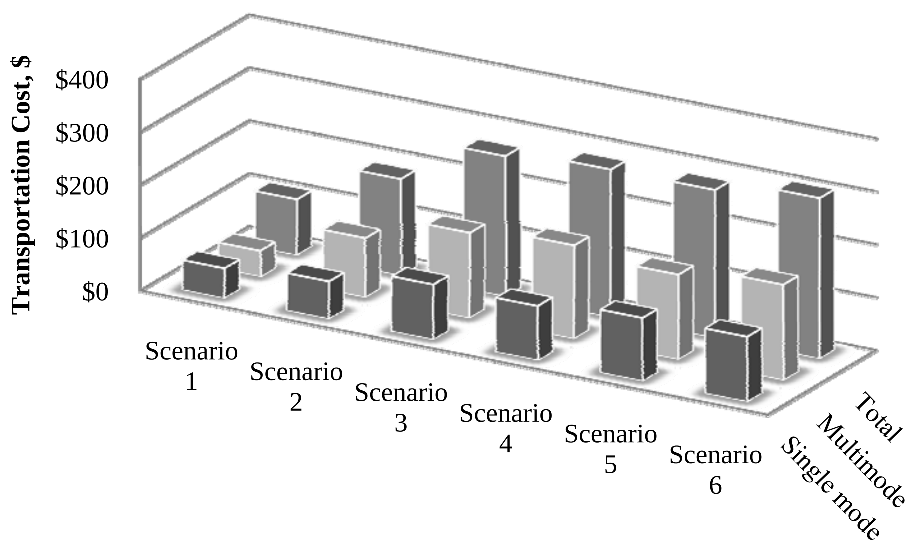
Scenarios

Figure 15. The impacts of L/D disruptions on the coal shipment distribution by transportation mode based on a maximum quota condition

Note that although trucks were not preferred, they may be embedded in multimode transportation choices. Moreover, despite the observation that a disruption of the single highest volume lock doesn't seem to affect total transportation cost, Figure 16 reveals that the portion of truck and rail use imbedded in multimode choices increases, because their related cost increases by almost $63 Million. Nevertheless, our results suggest that trucks are the least preferred transportation mode.

The most critical lock or locks with the potential to make the biggest economic impact

Figure 16 shows that the total system cost tends to increase as the number of L/D disruptions increases. Note that while the cost share of single mode decreases, its complementary use of multiple mode increases, and *vice-versa*, assuring an overall increment in the total cost. It is remarkable that total denial of water transportation almost triples the overall system transportation cost. Another point is that approximately three fourths of this increment are caused from disruptions of the 3 L/Ds (#10, #11, and #12, denoted in Figure 18) that handle the most coal volume.



Million $	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Single mode	$56.66	$71.06	$104.17	$102.72	$119.26	$122.89
Multimode	$49.22	$112.30	$161.37	$176.62	$160.49	$180.48
Total	$105.88	$183.35	$265.55	$279.34	$279.75	$303.38

Figure 16. The impacts of L/D disruptions on total system costs based on a maximum quota condition

When one of these locks fails, shippers would look for alternative routes or transportation modes. Figures 17 and 18 show the impacts of L/D #11 failure to the traffic passing through other locks, with and without quota conditions. As seen in both figures, the biggest traffic impact occurs to the two adjacent L/Ds. Furthermore, most of the coal traffic that passed through L/D #11 before the denial, now switches to overland transportation modes, as the shipping amounts switched to the adjacent L/Ds don't satisfy all disrupted traffic and the traffic passing through the other L/Ds is not significantly affected.

What if the Ohio River and its tributaries become unavailable for transportation?

Figure 19 illustrates the cost effects of water transportation denial. This denial makes the non-quota total transportation cost jump from $41M to $233M, but this increase is still less than the quota-based disruption scenario.

Figure 20 shows that multimodal transportation is always used, covering at least 35% of all coal flow regardless of the disruption scenario modeled. Figure 21 indicates that transloading terminals 5 and 6 are used for all disruption scenarios, while terminals 3 and 4 become redundant as disruptions occur. Note that while Terminal 1 is lightly used, Terminal 8 is never used in any disruption scenario.

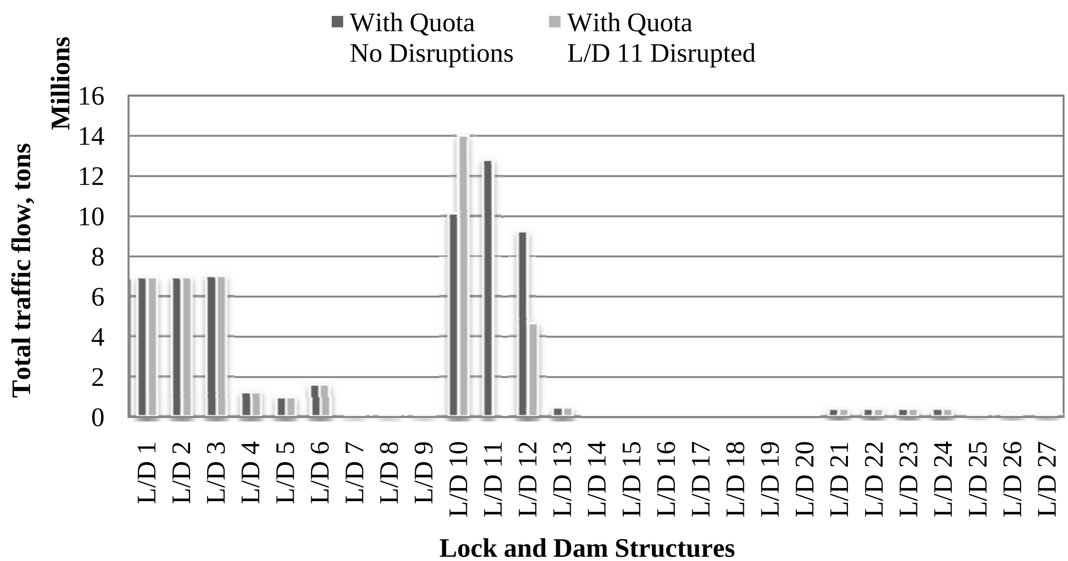


Figure 17. The impacts of the disruption of L/D #11 on the coal traffic with quota condition

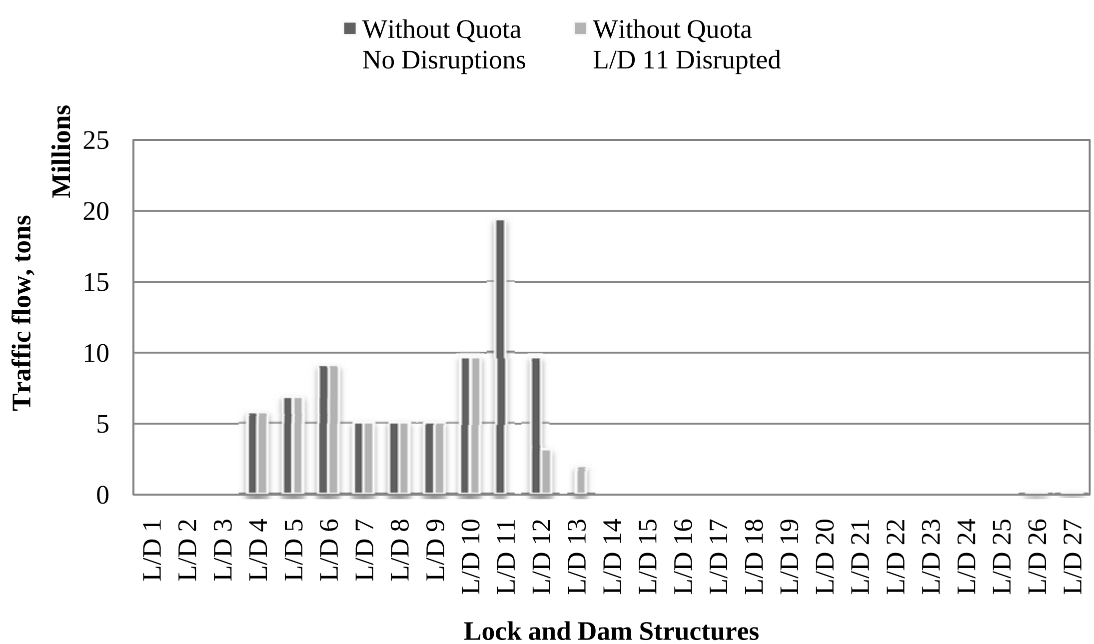


Figure 18. The impacts of the disruption of L/D #11 on the coal traffic without quota condition

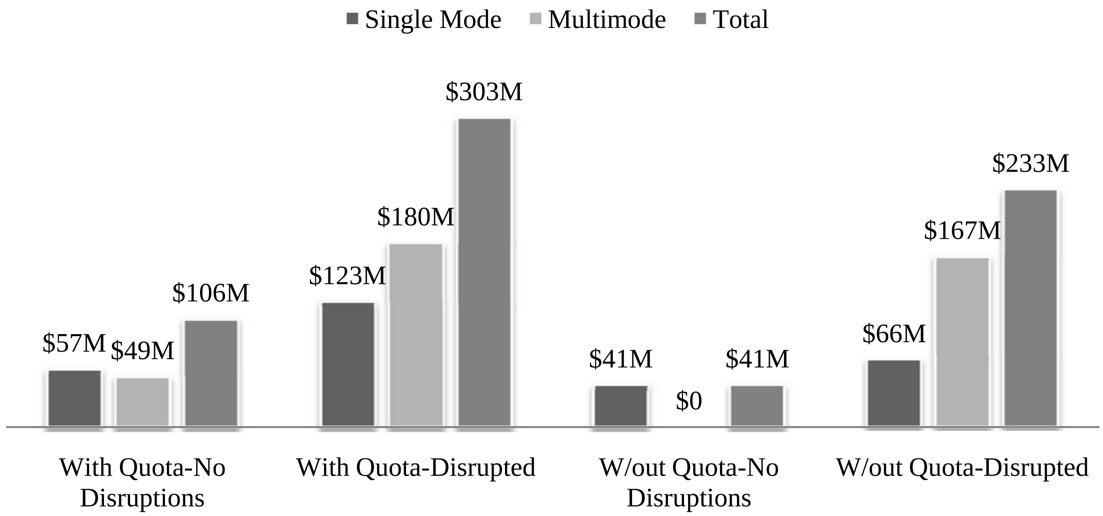
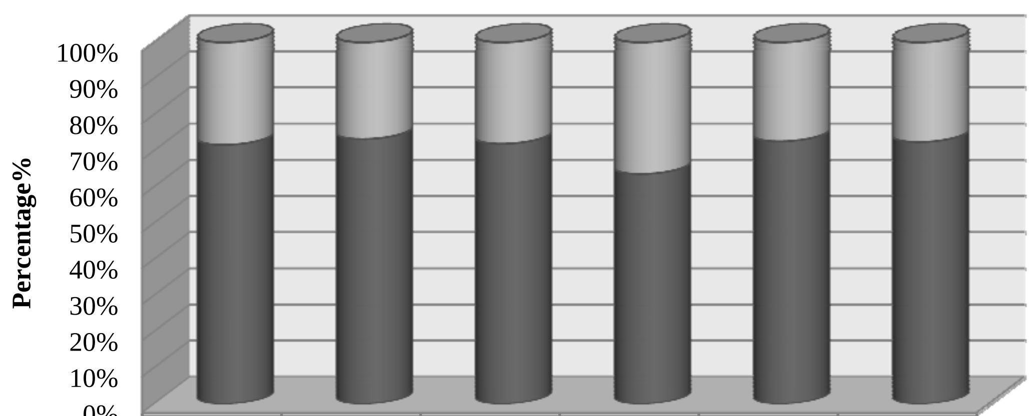


Figure 19. Comparison of transportation costs with or without a quota condition



Million tons	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Multimode	15	14	15	20	15	15
Single Mode	39	40	39	34	39	39

Figure 20. The percentage of coal which handled in transloading terminals for the disruption scenarios having a quota

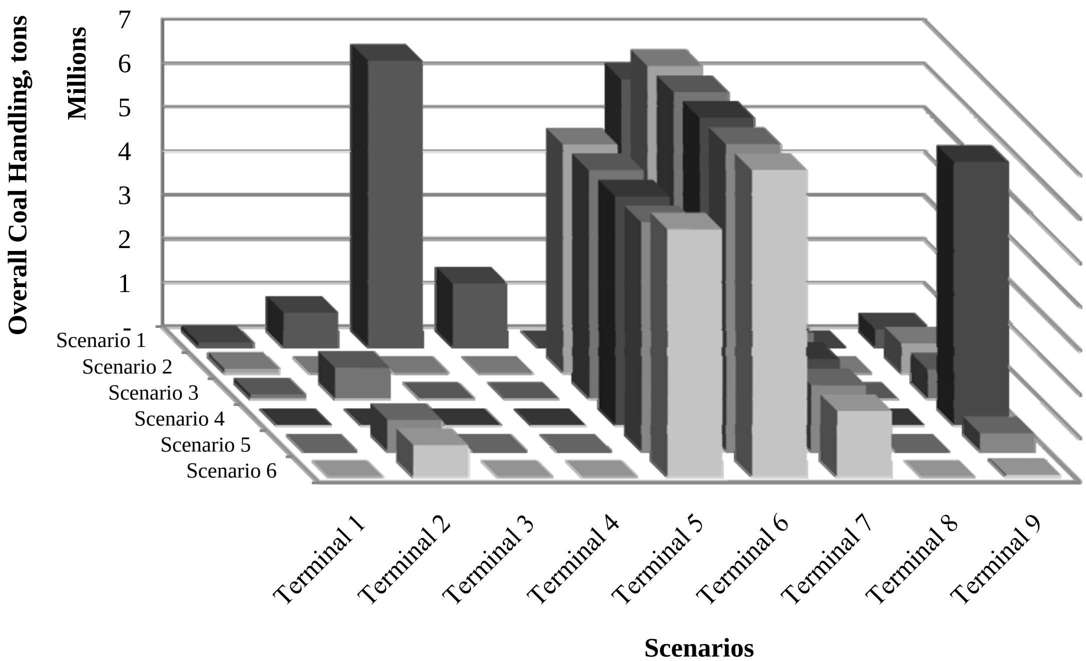


Figure 21. The percentage of coal which handled in transloading terminals for the disruption scenarios having a quota

Discussion.

If we consider that the cost amounts in this model reflect a portion of the basin's economy that benefits from the L/Ds, the increments in millions of dollars indicate the importance of maintenance operations for these structures. The President's Fiscal Year 2007 budget amount ($4.733 Billion) transmitted to Congress in new federal funding for the Civil Works program of the U.S. Army Corps of Engineers (US Army Corps of Engineers, 2006), validates the importance of these L/Ds.

Our model also shows the substitution impacts between water and rail transportation modes. Truck transportation may be used for short distances in multimodal transportation, but it is not cost effective for single mode uses, having a cost rate 12 times larger than rail transport.

Our research also shows that the cost assigned to multimodal transportation is higher than single mode usage when river disruptions occur. This comparison reveals the importance of transloading terminals and the need to optimize their locations. Although 6 existing terminals are adequate to handle coal demand without river disruption, our model indicates that after disruption, terminal #3 and #4 usage is discontinued in a minimum cost modal rearrangement. Moreover, terminal #8 is not used in any scenario. A location analysis for transloading terminals that considers emergency scenarios may identify more cost effective results and foster multimodal transportation.

A logical, but incorrect conclusion is that the three power plants which suffer the highest transportation cost growth from river disruptions are those with the largest annual coal demand. Instead, their cost growth stems from either their lack of alternative transportation mode access or their overland distance to the supplier counties. Those three power plants should consider options to overcome the likely negative impacts of extended river disruptions.

It is remarkable that if there is no maximum county production quota, then only 14 of the 43 counties' mines are needed to supply all the power plants for a significantly lower transportation cost. Hence, if all power plants work together and agree to share the coal supply of those 14 counties, then total annual transportation cost may be far less than it is today--indicating the need for a delivered-coal cost optimization effort among all 38 power plants situated in the Ohio River basin.

Conclusions.

Significant transportation-centric insights can be derived by using only commonly available spreadsheet-based analysis tools, open-source information systems, and web-based geographic tools. Using them, we found that Ohio River Basin electrical rates can be reduced if the utility companies can (1) support an optimization effort that considers supply point selection, modes used, and transshipment point locations, (2) work together to reduce the cost of delivered coal, and (3) prepare for possible natural or man-made river transportation disruptions.

A limitation of our research is our aggregation of individual mines into county centroids, which could affect our transportation cost estimates. A second limitation is that our data sources were populated in different years, ranging from 2003 for L/D volume data to 2007 for county coal production. A third limitation is that our model assumes that river outages would last for a year or more. Future research will investigate outages that span shorter timeframes. Future research can also extend our model by considering coal handling costs, by using both coal production costs (which were not available for us) and transportation rates, and by expanding our optimization to include all power plants in the Ohio River basin.

Disclaimer

The views expressed are those of the authors, and do not reflect the official policy or positions of the United States Air Force, Department of Defense, or the U.S. Government.

IV. Conclusions and Recommendations

Chapter Overview

So far, the research purpose, the problem areas, the methodology to solve those problems, the results and the conclusions are put forward. This chapter will basically provide an overall summary and evaluation of the results and will clarify the parts that are not implied in details. Specifically, it will mention some additional outputs and discussions in addition to the conclusions presented in the previous chapter.

Conclusions and Significance of Research

The results and the conclusions are briefly presented in the previous chapter along with the submitted journal article. Basically, the model that we used seeks to answer 'what if' type questions. First and the most important of all, the scale of the monetary amount is large enough to provide an insight for the consideration of an optimization's significance. Recall that the President's Fiscal Year 2007 (FY07) budget amount transmitted to Congress in new federal funding for the Civil Works program of the U.S. Army Corps of Engineers is $4.733 Billion (US Army Corps of Engineers, 2006).

Our research shows that the cost assigned to multimodal transportation is higher than single mode usage in case of disruptions, although, for all disruption scenarios, the share of multimodal transportation remains almost the same. This interesting output reveals two important aspects: The first one is the urgent need for an optimization of the locations of transloading terminals. Because, as it is mentioned before, one terminal is never used in any optimization scenarios, and two other terminals don't have any benefits in case of water transportation disruptions. However, the second aspect implies a gap of the research. Because, the utilization of multimodal transportation might decrease if handling costs were taken into consideration. Note that the model is based on the transportation costs in units of $ per ton-mile.

This research also indicates that the water and rail transportations are substitutes. Therefore, the hypothesis that the road transportation is still not cost effective for single mode utilizations is emphasized. According to the model, even the shipper prefers rail as the second best alternative transportation mode; such a decision most assuredly increases the transportation costs in tens of million Dollars.

Furthermore, one of the other remarkable conclusions of our research is the bullwhip effect that the power plants experience in case of not having an agreement between each other. If we consider that the power plants and coal supplying counties are members of a bad-mapped supply chain, the necessity of a good mapping emerges due to the high transportation costs. Thereafter, the power plants can look for precautionary moves to overcome the likely negative effects of the lack of appropriate transportation mode access and the length of overland distance to the coal supplying counties.

Finally, from the military standpoint, our research supports the required maintenance and restoration activities of the U.S. Army Corps of Engineers on the lock and dam structures. It may provide an insight to the decision makers who release money for those activities. On the other hand, the research's methodology can easily be adapted to the military applications that include a network flow such as operational planning. It provides the main aspects of a network flow problem and exemplifies those aspects with an application in transportation field.

Validation Efforts

In order to validate our model, a draft report had been e-mailed to the experts in the field upon the completion of the first analysis. In that draft report, the purpose of the research, the modeling approach, the data that is used in the model, results and likely conclusions were provided and their thoughts were asked. Unfortunately, no response has received so far but however, the model validated itself in two different ways.

The first validation was provided with the harmony of the cost amounts in comparison with the historical disruption events which were mentioned in the literature review. It shows that the costing aspect of the model reflects the reality. And the second validation was that the resemblance of the coal distribution network of the model with EIA’s 2001 data. Recall that the application of a quota constraint for the coal supplying counties is used to catch the status-quo of the coal distribution network. In this case, the assignments of the coal mines to the power plants of the model were close enough to the EIA’s historical data of coal distribution network.

Recommendations for Action

As it is previously mentioned in the submitted journal article, electricity generating costs in the basin are among the lowest in the nation and they can be even lower (U.S. Department of Energy, Energy Information Administration, 2007). For such better rates, this research provides the following recommendations to the power plants using a cost minimization perspective:

1. To optimize the overall coal distribution process in terms of transportation costs,

2. To make an agreement or to offer a new law that enforces the utility companies to work together,

3. To be ready for future's possible natural or man-made disruptions with alternative cost-effective responses.

Recommendations for Future Research

Future research can take this study one step further by taking the handling costs into consideration, by using total coal delivery costs instead of using transportation rates, or by making an optimization for all the power plants in the basin. An optimization among all 38 coal-fired power plants situated in the Ohio River Basin in terms of coal delivery costs may conclude with enormous cost savings and therefore with the ability to produce electricity for lower expenses.

Summary

In this chapter, following a brief summary of the research, the conclusions that is not previously mentioned in text, the significance of the research, the validation efforts, the recommended actions and future research areas are discussed. In the Appendices, the data tables, which are either produced or utilized through the study, are provided with their sources for the researchers who want to reproduce or improve this research.

Appendix A: The Milepoint Index of Nodes with Water Transportation Access

No	State	County	Milepoint on the Ohio River	Milepoint on the Tributary from the Ohio River
1	OH	County 1	91	
2	OH	County 2	264.2	
3	OH	County 3	168.2	79.5
4	OH	County 4	78	
5	OH	County 6	315.3	
6	OH	County 7	254.2	
7	OH	County 8	122	
8	OH	County 9	264.2	
9	WV	County 12	263.1	68.5
10	WV	County 13	65	
11	WV	County 14	263.1	89.2
12	WV	County 15	263.1	89.2
13	WV	County 16	0	159
14	WV	County 17	263.1	83.6
15	WV	County 18	302	25
16	WV	County 19	314.2	90
17	WV	County 20	0	122.4
18	WV	County 21	107.5	
19	WV	County 22	314.2	90
20	WV	County 23	0	92
21	WV	County 24	263.1	101.58
22	WV	County 25	314.2	8.6
23	KY	County 28	535.5	275
24	KY	County 29	314.2	72
25	KY	County 30	322.4	
26	KY	County 32	314.2	116
27	KY	County 34	314.2	65.4
28	KY	County 35	314.2	60
29	KY	County 37	314.2	117.34
30	PA	County 39	0	15.89
31	PA	County 40	0	81
32	PA	County 41	0	30.5
33	PA	County 42	92	
34	PA	Terminal 1	28.28	
35	OH	Terminal 2	78	
36	WV	Terminal 3	303.2	
37	WV	Terminal 4	311.2	
38	OH	Terminal 5	349.85	
39	KY	Terminal 6	397.5	

No	State	County	Milepoint on the Ohio River	Milepoint on the Tributary from the Ohio River
40	KY	Terminal 7	463	
41	PA	Terminal 8	0	57
42	PA	Terminal 9	0	63
43	OH	Power Plant 1	53	
44	OH	Power Plant 2	73	
45	OH	Power Plant 3	73	
46	OH	Power Plant 4	100	
47	WV	Power Plant 5	109	
48	WV	Power Plant 6	111	
49	WV	Power Plant 7	157	
50	WV	Power Plant 8	157	
51	WV	Power Plant 9	245	
52	WV	Power Plant 10	246	
53	OH	Power Plant 11	256	
54	OH	Power Plant 12	257	
55	OH	Power Plant 13	382	
56	OH	Power Plant 14	397	
57	KY	Power Plant 15	406	
58	OH	Power Plant 16	435	
59	OH	Power Plant 17	444	
60	OH	Power Plant 18	482	

Notes:

1. The milepoints are measured via the ruler path tool of the Google Earth Freeware Ver. 4.3.7284.3916 (beta).
2. The existence of a milepoint on the tributary column indicates that the milepoint on the Ohio River shows the respective tributary's mouth milepoint on the Ohio River.
3. The counties that are not listed in the above table have no water transportation access.

Appendix B: The Distance Matrix between the Origin Nodes and the Transloading Terminals by Transportation Mode

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
1	**OH**	**County 1**									
		Barge	62.72	13.00	212.20	220.20	258.85	306.50	372.00	148.00	154.00
		Truck	67.10	13.20	228.00	236.00	213.00	241.00	236.00	56.90	52.70
		Rail	67.15	11.90	212.38	220.21	230.55	306.87	256.47	125.72	131.45
2	**OH**	**County 2**									
		Barge	235.92	186.20	39.00	47.00	85.65	133.30	198.80	321.20	327.20
		Truck	222.00	175.00	41.00	53.30	56.80	112.00	170.00	218.00	214.00
		Rail	241.35	186.10	136.31	125.20	163.23	212.67	235.25	272.42	266.69
3	**OH**	**County 3**									
		Barge	219.42	169.70	214.50	222.50	261.15	308.80	374.30	304.70	310.70
		Truck	132.00	84.20	206.00	213.00	127.00	171.00	165.00	128.00	123.00
		Rail	142.44	87.19	287.67	171.27	155.26	231.58	181.18	201.01	206.74
4	**OH**	**County 4**									
		Barge	49.72	0.00	225.20	233.20	271.85	319.50	385.00	135.00	141.00
		Truck	55.10	0.00	235.00	243.00	221.00	249.00	243.00	65.70	61.50
		Rail	55.25	0.00	224.28	232.11	242.45	318.77	268.37	113.82	119.55
5	**OH**	**County 5**									
		Truck	58.70	35.00	231.00	239.00	217.00	245.00	239.00	77.70	73.50
		Rail	61.43	25.89	249.86	257.69	222.31	344.35	248.23	120.00	125.73
6	**OH**	**County 6**									
		Barge	287.02	237.30	12.10	4.10	34.55	82.20	147.70	372.30	378.30
		Truck	308.00	250.00	13.60	13.00	36.00	91.50	151.00	254.00	260.00
		Rail	290.90	235.65	14.25	5.56	33.68	91.82	157.81	360.93	355.20
7	**OH**	**County 7**									
		Barge	225.92	176.20	49.00	57.00	95.65	143.30	208.80	311.20	317.20
		Truck	208.00	161.00	50.00	62.30	64.30	120.00	177.00	204.00	200.00
		Rail	231.74	176.49	146.31	135.20	173.23	222.67	245.25	282.42	276.69

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
8	**OH**	**County 8**									
		Barge	93.72	44.00	181.20	189.20	227.85	275.50	341.00	179.00	185.00
		Truck	97.20	43.30	177.00	184.00	223.00	271.00	266.00	87.10	82.90
		Rail	97.00	41.75	317.19	325.02	289.64	419.94	315.56	150.80	158.44
9	**OH**	**County 9**									
		Barge	235.92	186.20	39.00	47.00	85.65	133.30	198.80	321.20	327.20
		Truck	222.00	175.00	41.00	53.30	56.80	112.00	170.00	218.00	214.00
		Rail	241.35	186.10	136.31	125.20	163.23	212.67	235.25	272.42	266.69
10	**WV**	**County 10**									
		Truck	137.00	131.00	184.00	192.00	231.00	271.00	303.00	75.60	81.70
		Rail	183.19	140.81	273.79	262.68	314.26	363.70	429.69	103.51	95.87
11	**WV**	**County 11**									
		Truck	221.00	245.00	353.00	361.00	399.00	439.00	468.00	156.00	162.00
		Rail	262.54	294.77	373.78	362.67	401.91	450.14	516.13	184.77	188.59
12	**WV**	**County 12**									
		Barge	303.32	253.60	108.60	116.60	155.25	202.90	268.40	388.60	394.60
		Truck	258.00	200.00	60.80	68.70	107.00	148.00	263.00	204.00	210.00
		Rail	363.12	307.87	61.79	66.29	110.79	152.59	223.84	365.29	357.65
13	**WV**	**County 13**									
		Barge	36.72	13.00	238.20	246.20	284.85	332.50	398.00	122.00	128.00
		Truck	41.20	15.60	249.00	256.00	234.00	262.00	257.00	52.60	48.50
		Rail	42.86	23.52	235.64	243.86	256.23	330.23	282.15	99.52	107.16
14	**WV**	**County 14**									
		Barge	324.02	274.30	129.30	137.30	175.95	223.60	289.10	409.30	415.30
		Truck	253.00	219.00	80.10	87.90	127.00	167.00	282.00	199.00	205.00
		Rail	329.30	274.63	86.17	90.67	135.17	176.97	248.22	304.27	296.63

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
15	**WV**	**County 15**									
		Barge	324.02	274.30	129.30	137.30	175.95	223.60	289.10	409.30	415.30
		Truck	254.00	220.00	81.20	89.00	128.00	168.00	283.00	200.00	206.00
		Rail	329.30	274.63	86.17	90.67	135.17	176.97	248.22	304.27	296.63
16	**WV**	**County 16**									
		Barge	187.28	237.00	462.20	470.20	508.85	556.50	622.00	102.00	96.00
		Truck	130.00	124.00	173.00	181.00	219.00	260.00	275.00	76.10	82.30
		Rail	160.86	105.61	238.68	227.57	279.06	328.50	394.49	95.83	90.10
17	**WV**	**County 17**									
		Barge	318.42	268.70	123.70	131.70	170.35	218.00	283.50	403.70	409.70
		Truck	272.00	213.00	74.50	82.40	121.00	161.00	276.00	218.00	224.00
		Rail	323.51	268.84	80.38	84.88	129.38	171.18	242.43	298.48	290.84
18	**WV**	**County 18**									
		Barge	298.72	249.00	26.20	34.20	72.85	120.50	186.00	384.00	390.00
		Truck	297.00	238.00	19.00	24.90	63.50	104.00	219.00	243.00	249.00
		Rail	329.45	274.20	28.12	32.62	77.12	118.92	190.17	331.62	323.98
19	**WV**	**County 19**									
		Barge	375.92	326.20	101.00	93.00	125.65	173.30	238.80	461.20	467.20
		Truck	338.00	279.00	89.90	81.70	119.00	158.00	252.00	284.00	290.00
		Rail	376.05	317.82	95.63	86.52	119.25	168.69	234.68	405.98	398.34
20	**WV**	**County 20**									
		Barge	150.68	200.40	425.60	433.60	472.25	519.90	585.40	65.40	59.40
		Truck	105.00	99.30	191.00	199.00	237.00	278.00	322.00	58.70	49.50
		Rail	144.88	118.81	247.11	255.33	292.26	341.70	407.69	63.29	57.56
21	**WV**	**County 21**									
		Barge	79.22	29.50	195.70	203.70	242.35	290.00	355.50	164.50	170.50
		Truck	83.20	29.30	190.00	198.00	230.00	257.00	252.00	71.30	67.10
		Rail	83.06	28.74	195.44	203.66	240.59	290.03	269.79	139.72	147.36

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
22	**WV**	**County 22**									
		Barge	375.92	326.20	101.00	93.00	125.65	173.30	238.80	461.20	467.20
		Truck	338.00	279.00	89.90	81.70	119.00	158.00	252.00	284.00	290.00
		Rail	376.05	317.82	95.63	86.52	119.25	168.69	234.68	405.98	398.34
23	**WV**	**County 23**									
		Barge	120.28	170.00	395.20	403.20	441.85	489.50	555.00	35.00	29.00
		Truck	94.70	89.00	217.00	225.00	264.00	304.00	312.00	33.40	29.60
		Rail	115.15	148.54	276.84	285.06	321.99	371.43	437.42	33.56	27.83
24	**WV**	**County 24**									
		Barge	336.40	286.68	141.68	149.68	188.33	235.98	301.48	421.68	427.68
		Truck	240.00	231.00	92.40	100.00	139.00	179.00	294.00	186.00	192.00
		Rail	341.54	286.87	98.41	102.91	147.41	189.21	260.46	316.51	308.87
25	**WV**	**County 25**									
		Barge	294.52	244.80	19.60	11.60	44.25	91.90	157.40	379.80	385.80
		Truck	311.00	252.00	17.60	9.40	46.50	85.50	201.00	256.00	263.00
		Rail	302.73	244.50	22.31	13.20	45.93	95.37	161.36	332.66	325.02
26	**WV**	**County 26**									
		Truck	205.00	199.00	150.00	158.00	196.00	237.00	352.00	151.00	157.00
		Rail	297.19	254.81	387.79	376.68	428.26	477.70	543.69	217.51	209.87
27	**KY**	**County 27**									
		Truck	491.00	443.00	198.00	190.00	255.00	184.00	203.00	413.00	419.00
		Rail	540.71	485.46	373.66	362.55	351.34	190.07	217.09	599.28	605.01
28	**KY**	**County 28**									
		Barge	782.22	732.50	507.30	499.30	460.65	413.00	347.50	867.50	873.50
		Truck	420.00	361.00	127.00	119.00	132.00	128.00	162.00	366.00	372.00
		Rail	480.29	425.04	261.65	253.04	290.92	129.65	156.67	538.86	544.59

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
29	**KY**	**County 29**									
		Barge	357.92	308.20	83.00	75.00	107.65	155.30	220.80	443.20	449.20
		Truck	367.00	308.00	73.70	65.40	100.00	138.00	201.00	313.00	319.00
		Rail	385.92	327.69	106.15	97.54	135.42	153.40	217.94	441.51	447.24
30	**KY**	**County 30**									
		Barge	294.12	244.40	19.20	11.20	27.45	75.10	140.60	379.40	385.40
		Truck	315.00	256.00	20.40	12.70	29.00	82.70	142.00	261.00	267.00
		Rail	297.85	242.60	21.04	12.45	49.48	76.17	142.16	356.42	362.15
31	**KY**	**County 31**									
		Truck	443.00	384.00	174.00	166.00	200.00	211.00	229.00	389.00	395.00
		Rail	574.89	519.64	407.84	396.73	385.52	224.25	251.27	633.46	639.19
32	**KY**	**County 32**									
		Barge	401.92	352.20	127.00	119.00	151.65	199.30	264.80	487.20	493.20
		Truck	391.00	332.00	97.60	89.40	124.00	135.00	215.00	336.00	343.00
		Rail	425.09	366.86	145.32	136.71	174.59	192.57	257.11	480.68	486.41
33	**KY**	**County 33**									
		Truck	422.00	363.00	129.00	121.00	155.00	181.00	216.00	368.00	374.00
		Rail	460.73	402.50	180.96	172.35	210.23	210.04	237.36	516.32	522.05
34	**KY**	**County 34**									
		Barge	351.32	301.60	76.40	68.40	101.05	148.70	214.20	436.60	442.60
		Truck	361.00	303.00	68.30	60.00	94.80	132.00	196.00	307.00	313.00
		Rail	380.18	321.95	100.41	91.80	129.68	147.66	212.20	435.77	441.50
35	**KY**	**County 35**									
		Barge	345.92	296.20	71.00	63.00	95.65	143.30	208.80	431.20	437.20
		Truck	333.00	274.00	61.60	53.40	90.60	130.00	245.00	278.00	285.00
		Rail	349.53	291.30	69.11	60.00	92.73	142.17	208.16	379.46	371.82
36	**KY**	**County 36**									
		Truck	439.00	380.00	146.00	138.00	172.00	207.00	225.00	385.00	391.00
		Rail	477.14	418.91	197.37	188.76	226.64	207.21	234.53	532.73	538.46

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
37	**KY**	**County 37**									
		Barge	403.26	353.54	128.34	120.34	152.99	200.64	266.14	488.54	494.54
		Truck	331.00	272.00	111.00	103.00	140.00	179.00	274.00	277.00	283.00
		Rail	398.53	340.30	118.11	109.00	141.73	191.17	257.16	428.46	420.82
38	**KY**	**County 38**									
		Truck	484.00	436.00	235.00	227.00	248.00	178.00	196.00	474.00	480.00
		Rail	534.78	479.53	367.73	356.62	345.41	184.14	211.16	593.35	599.08
39	**PA**	**County 39**									
		Barge	44.17	93.89	319.09	327.09	365.74	413.39	478.89	41.11	47.11
		Truck	55.70	68.90	287.00	294.00	286.00	314.00	308.00	60.30	66.50
		Rail	42.83	93.09	317.06	324.89	335.23	411.55	361.15	80.30	74.57
40	**PA**	**County 40**									
		Barge	109.28	159.00	384.20	392.20	430.85	478.50	544.00	24.00	18.00
		Truck	87.30	81.60	223.00	230.00	269.00	309.00	305.00	21.60	22.70
		Rail	104.88	159.36	287.11	295.33	332.26	381.70	427.73	23.29	17.56
41	**PA**	**County 41**									
		Barge	58.78	108.50	333.70	341.70	380.35	428.00	493.50	26.50	32.50
		Truck	51.80	66.60	266.00	274.00	268.00	295.00	290.00	18.30	24.40
		Rail	56.32	110.80	335.08	342.91	353.25	429.57	379.17	36.73	31.00
42	**PA**	**County 42**									
		Barge	63.72	14.00	211.20	219.20	257.85	305.50	371.00	149.00	155.00
		Truck	79.70	15.20	231.00	239.00	216.00	244.00	238.00	56.40	52.20
		Rail	67.60	16.34	210.90	219.12	231.47	305.49	257.39	124.26	131.90
43	**VA**	**County 43**									
		Truck	369.00	354.00	166.00	158.00	193.00	203.00	283.00	315.00	321.00
		Rail	492.80	434.57	212.38	203.27	236.00	285.44	351.43	522.73	515.09

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
44	**PA**	**Terminal 1**									
		Barge	0.00	49.72	274.92	282.92	321.57	369.22	434.72	85.28	91.28
		Truck	0.00	57.40	295.00	302.00	273.00	300.00	295.00	76.50	69.90
		Rail	0.00	55.25	282.81	290.64	283.74	378.11	309.66	79.68	87.32
45	**OH**	**Terminal 2**									
		Barge	49.72	0.00	225.20	233.20	271.85	319.50	385.00	135.00	141.00
		Truck	55.10	0.00	235.00	243.00	221.00	249.00	243.00	65.70	61.50
		Rail	55.25	0.00	224.28	232.11	242.45	318.77	268.37	113.82	119.55
46	**WV**	**Terminal 3**									
		Barge	274.92	225.20	0.00	8.00	46.65	94.30	159.80	360.20	366.20
		Truck	296.00	237.00	0.00	8.40	46.80	102.00	207.00	241.00	248.00
		Rail	282.81	224.28	0.00	11.11	50.35	98.58	164.57	312.31	304.67
47	**WV**	**Terminal 4**									
		Barge	282.92	233.20	8.00	0.00	38.65	86.30	151.80	368.20	374.20
		Truck	303.00	244.00	8.40	0.00	40.20	80.60	196.00	249.00	255.00
		Rail	290.64	232.11	11.11	0.00	39.24	87.47	153.46	320.53	312.89
48	**OH**	**Terminal 5**									
		Barge	321.57	271.85	46.65	38.65	0.00	47.65	113.15	406.85	412.85
		Truck	270.00	222.00	46.90	40.40	0.00	56.30	116.00	287.00	294.00
		Rail	283.74	242.45	50.35	39.24	0.00	125.50	191.64	394.61	388.88
49	**KY**	**Terminal 6**									
		Barge	369.22	319.50	94.30	86.30	47.65	0.00	65.50	454.50	460.50
		Truck	296.00	248.00	103.00	81.00	56.40	0.00	65.70	292.00	287.00
		Rail	378.11	318.77	98.58	87.47	125.50	0.00	66.70	408.00	400.36
50	**KY**	**Terminal 7**									
		Barge	434.72	385.00	159.80	151.80	113.15	65.50	0.00	520.00	526.00
		Truck	290.00	243.00	205.00	196.00	115.00	65.30	0.00	286.00	282.00
		Rail	309.66	268.37	164.57	153.46	191.64	66.70	0.00	382.19	387.92

in miles			TRANSLOADING TERMINALS								
No	**State**	**Origin / Destination**	**Terminal 1**	**Terminal 2**	**Terminal 3**	**Terminal 4**	**Terminal 5**	**Terminal 6**	**Terminal 7**	**Terminal 8**	**Terminal 9**
51	**PA**	**Terminal 8**									
		Barge	85.28	135.00	360.20	368.20	406.85	454.50	520.00	0.00	6.00
		Truck	74.20	65.80	241.00	249.00	287.00	295.00	289.00	0.00	6.20
		Rail	79.68	113.82	312.31	320.53	394.61	408.00	382.19	0.00	7.64
52	**PA**	**Terminal 9**									
		Barge	91.28	141.00	366.20	374.20	412.85	460.50	526.00	6.00	0.00
		Truck	70.00	61.60	240.00	248.00	286.00	290.00	285.00	6.20	0.00
		Rail	87.32	119.55	304.67	312.89	388.88	400.36	387.92	7.64	0.00

Note: The milepoints are measured via the ruler path and directions tools of the Google Earth Freeware Ver. 4.3.7284.3916 (beta).

Appendix C: The Distance Matrix between the Origin Nodes and the Power Plants by Transportation Mode

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
1	**OH**	**County 1**									
		Barge	38.00	18.00	18.00	9.00	18.00	19.50	66.00	66.00	154.00
		Truck	39.90	17.80	17.80	9.90	19.20	20.30	67.70	67.70	157.00
		Rail	38.14	16.42	16.42	9.35	18.53	19.88	67.70	67.70	147.44
2	**OH**	**County 2**									
		Barge	211.20	191.20	191.20	164.20	155.20	153.70	107.20	107.20	19.20
		Truck	193.00	179.00	179.00	135.00	126.00	125.00	77.20	77.20	23.60
		Rail	212.71	190.99	190.99	231.33	191.34	192.69	242.74	242.74	197.16
3	**OH**	**County 3**									
		Barge	194.70	174.70	174.70	147.70	138.70	137.20	90.70	90.70	156.30
		Truck	102.00	88.90	88.90	83.30	92.50	93.50	84.50	84.50	90.10
		Rail	113.43	91.71	91.71	84.64	93.82	95.17	142.99	142.99	222.73
4	**OH**	**County 4**									
		Barge	25.00	5.00	5.00	22.00	31.00	32.50	79.00	79.00	167.00
		Truck	27.90	5.80	5.80	22.10	31.50	32.50	80.00	80.00	164.00
		Rail	26.24	4.52	4.52	21.25	30.43	31.78	79.60	79.60	159.34
5	**OH**	**County 5**									
		Truck	29.00	29.50	29.50	47.20	56.50	57.50	110.00	110.00	160.00
		Rail	32.42	21.06	21.06	46.83	56.01	57.36	105.18	105.18	184.92
6	**OH**	**County 6**									
		Barge	262.30	242.30	242.30	215.30	206.30	204.80	158.30	158.30	70.30
		Truck	267.00	254.00	254.00	210.00	201.00	200.00	152.00	152.00	79.40
		Rail	261.89	240.17	240.17	307.47	205.22	203.87	156.05	156.05	76.31
7	**OH**	**County 7**									
		Barge	201.20	181.20	181.20	154.20	145.20	143.70	97.20	97.20	9.20
		Truck	178.00	165.00	165.00	117.00	108.00	107.00	58.80	58.80	13.60
		Rail	202.71	180.99	180.99	221.33	181.34	182.69	232.74	232.74	207.16

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
8	**OH**	**County 8**									
		Barge	69.00	49.00	49.00	22.00	13.00	11.50	35.00	35.00	123.00
		Truck	70.10	48.00	48.00	22.20	20.50	19.30	38.20	38.20	106.00
		Rail	67.99	46.27	46.27	20.50	114.38	115.73	163.55	163.55	243.29
9	**OH**	**County 9**									
		Barge	211.20	191.20	191.20	164.20	155.20	153.70	107.20	107.20	19.20
		Truck	193.00	179.00	179.00	135.00	126.00	125.00	77.20	77.20	23.60
		Rail	212.71	190.99	190.99	231.33	191.34	192.69	242.74	242.74	197.16
10	**WV**	**County 10**									
		Truck	136.00	136.00	136.00	96.50	105.00	94.40	90.80	90.80	151.00
		Rail	167.05	145.33	145.33	204.26	110.38	109.03	124.53	124.53	204.27
11	**WV**	**County 11**									
		Truck	237.00	235.00	235.00	245.00	255.00	256.00	249.00	249.00	309.00
		Rail	302.54	290.25	290.25	316.02	325.20	326.55	374.37	374.37	434.63
12	**WV**	**County 12**									
		Barge	278.60	258.60	258.60	231.60	222.60	221.10	174.60	174.60	86.60
		Truck	217.00	204.00	204.00	160.00	151.00	150.00	102.00	102.00	71.30
		Rail	334.11	312.39	312.39	371.32	277.44	276.09	228.27	228.27	148.53
13	**WV**	**County 13**									
		Barge	12.00	8.00	8.00	35.00	44.00	45.50	92.00	92.00	180.00
		Truck	15.60	10.10	10.10	36.40	45.80	46.80	94.30	94.30	178.00
		Rail	67.34	18.69	18.69	44.46	41.89	43.24	91.06	91.06	170.80
14	**WV**	**County 14**									
		Barge	299.30	279.30	279.30	252.30	243.30	241.80	195.30	195.30	107.30
		Truck	237.00	224.00	224.00	179.00	170.00	169.00	121.00	121.00	90.60
		Rail	300.87	279.15	279.15	338.08	239.06	237.71	189.89	189.89	110.15

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
15	**WV**	**County 15**									
		Barge	299.30	279.30	279.30	252.30	243.30	241.80	195.30	195.30	107.30
		Truck	238.00	225.00	225.00	180.00	172.00	170.00	122.00	122.00	91.70
		Rail	300.87	279.15	279.15	338.08	239.06	237.71	189.89	189.89	110.15
16	**WV**	**County 16**									
		Barge	212.00	232.00	232.00	259.00	268.00	269.50	316.00	316.00	404.00
		Truck	129.00	129.00	129.00	77.70	69.30	68.10	62.70	62.70	123.00
		Rail	131.85	110.13	110.13	169.06	75.18	73.83	89.33	89.33	169.07
17	**WV**	**County 17**									
		Barge	293.70	273.70	273.70	246.70	237.70	236.20	189.70	189.70	101.70
		Truck	231.00	218.00	218.00	174.00	165.00	164.00	116.00	116.00	85.00
		Rail	295.08	273.36	273.36	332.29	233.27	231.92	184.10	184.10	104.36
18	**WV**	**County 18**									
		Barge	274.00	254.00	254.00	227.00	218.00	216.50	170.00	170.00	82.00
		Truck	256.00	243.00	243.00	199.00	190.00	189.00	141.00	141.00	73.80
		Rail	300.44	278.72	278.72	337.65	243.77	242.42	194.60	194.60	114.86
19	**WV**	**County 19**									
		Barge	351.20	331.20	331.20	304.20	295.20	293.70	247.20	247.20	159.20
		Truck	297.00	284.00	284.00	240.00	231.00	230.00	182.00	182.00	151.00
		Rail	276.36	254.64	254.64	395.42	219.69	218.34	238.22	238.22	158.48
20	**WV**	**County 20**									
		Barge	175.40	195.40	195.40	222.40	231.40	232.90	279.40	279.40	367.40
		Truck	104.00	104.00	104.00	70.50	78.60	68.30	87.30	87.30	147.00
		Rail	145.05	123.33	123.33	182.26	88.38	87.03	102.53	102.53	182.27
21	**WV**	**County 21**									
		Barge	54.50	34.50	34.50	7.50	1.50	3.00	49.50	49.50	137.50
		Truck	56.00	33.90	33.90	7.90	2.00	3.10	51.40	51.40	119.00
		Rail	54.98	33.26	33.26	92.19	1.69	3.04	50.86	50.86	130.60

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
22	**WV**	**County 22**									
		Barge	351.20	331.20	331.20	304.20	295.20	293.70	247.20	247.20	159.20
		Truck	297.00	284.00	284.00	240.00	231.00	230.00	182.00	182.00	151.00
		Rail	276.36	254.64	254.64	395.42	219.69	218.34	238.22	238.22	158.48
23	**WV**	**County 23**									
		Barge	145.00	165.00	165.00	192.00	201.00	202.50	249.00	249.00	337.00
		Truck	93.40	93.70	93.70	89.60	98.90	100.00	114.00	114.00	173.00
		Rail	143.39	140.00	140.00	165.77	118.11	116.76	132.26	132.26	212.00
24	**WV**	**County 24**									
		Barge	311.68	291.68	291.68	264.68	255.68	254.18	207.68	207.68	119.68
		Truck	249.00	236.00	236.00	192.00	183.00	182.00	134.00	134.00	103.00
		Rail	313.11	291.39	291.39	350.32	251.30	249.95	202.13	202.13	122.39
25	**WV**	**County 25**									
		Barge	269.80	249.80	249.80	222.80	213.80	212.30	165.80	165.80	77.80
		Truck	270.00	257.00	257.00	212.00	204.00	202.00	154.00	154.00	81.80
		Rail	203.04	181.32	181.32	322.10	146.37	145.02	164.90	164.90	85.16
26	**WV**	**County 26**									
		Truck	204.00	204.00	204.00	164.00	172.00	162.00	145.00	145.00	157.00
		Rail	281.05	259.33	259.33	318.26	224.38	223.03	238.53	238.53	318.27
27	**KY**	**County 27**									
		Truck	461.00	448.00	448.00	442.00	360.00	358.00	311.00	311.00	280.00
		Rail	511.70	489.98	489.98	548.91	558.09	559.44	464.01	464.01	384.27
28	**KY**	**County 28**									
		Barge	757.50	737.50	737.50	710.50	701.50	700.00	653.50	653.50	565.50
		Truck	379.00	366.00	366.00	322.00	313.00	312.00	264.00	264.00	191.00
		Rail	451.28	429.56	429.56	488.49	497.67	499.02	403.59	403.59	323.85

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
29	**KY**	**County 29**									
		Barge	333.20	313.20	313.20	286.20	277.20	275.70	229.20	229.20	141.20
		Truck	326.00	313.00	313.00	268.00	260.00	258.00	210.00	210.00	138.00
		Rail	353.93	332.21	332.21	375.32	384.50	385.85	248.09	248.09	168.35
30	**KY**	**County 30**									
		Barge	269.40	249.40	249.40	222.40	213.40	211.90	165.40	165.40	77.40
		Truck	274.00	261.00	261.00	217.00	208.00	207.00	159.00	159.00	81.80
		Rail	268.84	247.12	247.12	323.27	212.17	212.17	163.00	163.00	83.26
31	**KY**	**County 31**									
		Truck	402.00	389.00	389.00	345.00	336.00	335.00	287.00	287.00	256.00
		Rail	545.88	524.16	524.16	583.09	592.27	593.62	498.19	498.19	418.45
32	**KY**	**County 32**									
		Barge	377.20	357.20	357.20	330.20	321.20	319.70	273.20	273.20	185.20
		Truck	350.00	337.00	337.00	292.00	284.00	282.00	234.00	234.00	162.00
		Rail	393.10	371.38	371.38	414.49	423.67	425.02	287.26	287.26	207.52
33	**KY**	**County 33**									
		Truck	381.00	368.00	368.00	324.00	315.00	314.00	266.00	266.00	193.00
		Rail	428.74	407.02	407.02	450.13	459.31	460.66	322.90	322.90	243.16
34	**KY**	**County 34**									
		Barge	326.60	306.60	306.60	279.60	270.60	269.10	222.60	222.60	134.60
		Truck	320.00	307.00	307.00	263.00	254.00	253.00	205.00	205.00	132.00
		Rail	348.19	326.47	326.47	369.58	378.76	380.11	242.35	242.35	162.61
35	**KY**	**County 35**									
		Barge	321.20	301.20	301.20	274.20	265.20	263.70	217.20	217.20	129.20
		Truck	292.00	279.00	279.00	234.00	226.00	224.00	176.00	176.00	146.00
		Rail	249.84	228.12	228.12	368.90	193.17	191.82	211.70	211.70	131.96
36	**KY**	**County 36**									
		Truck	398.00	385.00	385.00	341.00	332.00	331.00	283.00	283.00	210.00
		Rail	445.15	423.43	423.43	466.54	475.72	477.07	339.31	339.31	259.57

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
37	**KY**	**County 37**									
		Barge	378.54	358.54	358.54	331.54	322.54	321.04	274.54	274.54	186.54
		Truck	290.00	277.00	277.00	233.00	224.00	223.00	175.00	175.00	144.00
		Rail	298.84	277.12	277.12	417.90	242.17	240.82	260.70	260.70	180.96
38	**KY**	**County 38**									
		Truck	454.00	441.00	441.00	435.00	421.00	420.00	372.00	372.00	299.00
		Rail	505.77	484.05	484.05	542.98	552.16	553.51	458.08	458.08	378.34
39	**PA**	**County 39**									
		Barge	68.89	88.89	88.89	115.89	124.89	126.39	172.89	172.89	260.89
		Truck	65.30	63.40	63.40	85.60	94.90	96.00	143.00	143.00	230.00
		Rail	69.34	88.26	88.26	114.03	123.21	124.56	172.38	172.38	252.12
40	**PA**	**County 40**									
		Barge	134.00	154.00	154.00	181.00	190.00	191.50	238.00	238.00	326.00
		Truck	86.00	86.30	86.30	82.20	91.50	92.60	119.00	119.00	179.00
		Rail	133.12	129.73	129.73	176.04	128.38	127.03	142.53	142.53	222.27
41	**PA**	**County 41**									
		Barge	83.50	103.50	103.50	130.50	139.50	141.00	187.50	187.50	275.50
		Truck	67.80	71.20	71.20	62.20	76.50	77.60	125.00	125.00	211.00
		Rail	84.56	81.17	81.17	106.94	141.23	142.58	190.40	190.40	270.14
42	**PA**	**County 42**									
		Barge	39.00	19.00	19.00	8.00	17.00	18.50	65.00	65.00	153.00
		Truck	41.90	19.90	19.90	8.90	17.00	18.00	66.40	66.40	160.00
		Rail	42.58	20.86	20.86	69.20	17.15	18.50	66.32	66.32	146.06
43	**VA**	**County 43**									
		Truck	372.00	359.00	359.00	314.00	306.00	304.00	256.00	256.00	226.00
		Rail	393.11	371.39	371.39	512.17	336.44	335.09	354.97	354.97	275.23

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
44	**PA**	**Terminal 1**									
		Barge	24.72	44.72	44.72	71.72	80.72	82.22	128.72	128.72	216.72
		Truck	30.90	51.80	51.80	78.20	98.20	99.30	136.00	136.00	216.00
		Rail	110.20	50.73	50.73	76.50	84.75	86.10	134.85	134.85	214.59
45	**OH**	**Terminal 2**									
		Barge	25.00	5.00	5.00	22.00	31.00	32.50	79.00	79.00	167.00
		Truck	27.90	5.80	5.80	22.10	31.50	32.50	80.00	80.00	164.00
		Rail	26.24	4.52	4.52	21.25	30.43	31.78	79.60	79.60	159.34
46	**WV**	**Terminal 3**									
		Barge	250.20	230.20	230.20	203.20	194.20	192.70	146.20	146.20	58.20
		Truck	255.00	242.00	242.00	197.00	189.00	187.00	139.00	139.00	62.00
		Rail	250.52	228.80	228.80	296.69	193.75	192.40	144.58	144.58	64.84
47	**WV**	**Terminal 4**									
		Barge	258.20	238.20	238.20	211.20	202.20	200.70	154.20	154.20	66.20
		Truck	262.00	249.00	249.00	205.00	196.00	195.00	147.00	147.00	69.50
		Rail	258.35	236.63	236.63	304.52	203.86	202.51	152.80	152.80	71.96
48	**OH**	**Terminal 5**									
		Barge	296.85	276.85	276.85	249.85	240.85	239.35	192.85	192.85	104.85
		Truck	240.00	227.00	227.00	221.00	230.00	231.00	185.00	185.00	78.20
		Rail	254.73	243.37	243.37	269.14	243.10	241.75	189.73	189.73	111.20
49	**KY**	**Terminal 6**									
		Barge	344.50	324.50	324.50	297.50	288.50	287.00	240.50	240.50	152.50
		Truck	266.00	253.00	253.00	247.00	256.00	257.00	196.00	196.00	134.00
		Rail	345.01	323.29	323.29	399.44	288.34	288.34	239.17	239.17	159.43
50	**KY**	**Terminal 7**									
		Barge	410.00	390.00	390.00	363.00	354.00	352.50	306.00	306.00	218.00
		Truck	261.00	247.00	247.00	242.00	251.00	252.00	243.00	243.00	200.00
		Rail	294.61	272.89	272.89	295.06	271.48	272.83	305.16	305.16	225.42

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 1**	**Power Plant 2**	**Power Plant 3**	**Power Plant 4**	**Power Plant 5**	**Power Plant 6**	**Power Plant 7**	**Power Plant 8**	**Power Plant 9**
51	**PA**	**Terminal 8**									
		Barge	110.00	130.00	130.00	157.00	166.00	167.50	214.00	214.00	302.00
		Truck	70.90	70.50	70.50	66.40	75.70	76.80	137.00	137.00	210.00
		Rail	107.92	104.53	104.53	130.30	153.58	152.23	167.73	167.73	247.47
52	**PA**	**Terminal 9**									
		Barge	116.00	136.00	136.00	163.00	172.00	173.50	220.00	220.00	308.00
		Truck	66.70	66.20	66.20	62.20	71.50	72.50	120.00	120.00	206.00
		Rail	115.56	112.17	112.17	137.94	145.94	144.59	160.09	160.09	239.83

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 10**	**Power Plant 11**	**Power Plant 12**	**Power Plant 13**	**Power Plant 14**	**Power Plant 15**	**Power Plant 16**	**Power Plant 17**	**Power Plant 18**
1	**OH**	**County 1**									
		Barge	155.00	165.00	166.20	291.00	305.50	315.00	344.00	353.30	391.00
		Truck	157.00	154.00	156.00	245.00	242.00	239.00	252.00	242.00	253.00
		Rail	148.80	166.87	168.47	-	-	314.32	-	-	274.48
2	**OH**	**County 2**									
		Barge	18.20	8.20	7.00	117.80	132.30	141.80	170.80	180.10	217.80
		Truck	23.60	8.00	6.50	91.10	105.00	128.00	146.00	177.00	187.00
		Rail	195.80	7.20	6.10	-	-	220.12	-	-	253.79
3	**OH**	**County 3**									
		Barge	157.30	167.30	168.50	293.30	307.80	317.30	346.30	355.60	393.30
		Truck	90.10	87.80	89.40	159.00	172.00	168.00	182.00	172.00	182.00
		Rail	224.09	91.58	93.18	-	-	239.03	-	-	199.72
4	**OH**	**County 4**									
		Barge	168.00	178.00	179.20	304.00	318.50	328.00	357.00	366.30	404.00
		Truck	164.00	161.00	163.00	252.00	249.00	246.00	259.00	250.00	260.00
		Rail	160.70	178.77	180.37	-	-	326.22	-	-	286.91
5	**OH**	**County 5**									
		Truck	160.00	157.00	159.00	249.00	246.00	242.00	256.00	246.00	256.00
		Rail	186.28	176.80	178.40	-	-	351.80	-	-	266.77
6	**OH**	**County 6**									
		Barge	69.30	59.30	58.10	66.70	81.20	90.70	119.70	129.00	166.70
		Truck	79.40	65.60	64.10	70.30	84.40	94.00	123.00	132.00	177.00
		Rail	74.95	137.47	136.41	-	-	99.27	-	-	176.35
7	**OH**	**County 7**									
		Barge	8.20	1.80	3.00	127.80	142.30	151.80	180.80	190.10	227.80
		Truck	13.60	2.10	3.60	98.60	113.00	136.00	153.00	184.00	195.00
		Rail	205.80	2.28	4.38	-	-	230.12	-	-	263.79

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 10**	**Power Plant 11**	**Power Plant 12**	**Power Plant 13**	**Power Plant 14**	**Power Plant 15**	**Power Plant 16**	**Power Plant 17**	**Power Plant 18**
8	**OH**	**County 8**									
		Barge	124.00	134.00	135.20	260.00	274.50	284.00	313.00	322.30	360.00
		Truck	106.00	98.00	99.50	257.00	271.00	269.00	282.00	273.00	283.00
		Rail	244.65	262.72	264.32	-	-	410.17	-	-	334.10
9	**OH**	**County 9**									
		Barge	18.20	8.20	7.00	117.80	132.30	141.80	170.80	180.10	217.80
		Truck	23.60	8.00	6.50	91.10	105.00	128.00	146.00	177.00	187.00
		Rail	195.80	7.20	6.10	-	-	220.12	-	-	253.79
10	**WV**	**County 10**									
		Truck	151.00	148.00	149.00	265.00	279.00	289.00	318.00	327.00	320.00
		Rail	205.63	292.26	293.86	-	-	371.15	-	-	448.23
11	**WV**	**County 11**									
		Truck	309.00	306.00	308.00	433.00	447.00	447.00	484.00	475.00	485.00
		Rail	433.27	473.54	475.14	-	-	457.59	-	-	534.67
12	**WV**	**County 12**									
		Barge	85.60	75.60	74.40	187.40	201.90	211.40	240.40	249.70	287.40
		Truck	71.30	74.60	73.10	142.00	156.00	165.00	194.00	203.00	279.00
		Rail	147.17	211.25	210.19	-	-	161.04	-	-	242.38
13	**WV**	**County 13**									
		Barge	181.00	191.00	192.20	317.00	331.50	341.00	370.00	379.30	417.00
		Truck	178.00	175.00	176.00	266.00	263.00	260.00	273.00	263.00	274.00
		Rail	172.16	192.55	194.15	-	-	337.68	-	-	300.69
14	**WV**	**County 14**									
		Barge	106.30	96.30	95.10	208.10	222.60	232.10	261.10	270.40	308.10
		Truck	90.60	93.90	92.40	161.00	175.00	184.00	213.00	223.00	298.00
		Rail	108.79	95.28	94.26	-	-	185.42	-	-	266.76

in miles			POWER PLANTS								
No	State	Origin / Destination	Power Plant 10	Power Plant 11	Power Plant 12	Power Plant 13	Power Plant 14	Power Plant 15	Power Plant 16	Power Plant 17	Power Plant 18
15	**WV**	**County 15**									
		Barge	106.30	96.30	95.10	208.10	222.60	232.10	261.10	270.40	308.10
		Truck	91.70	95.00	93.40	162.00	176.00	186.00	214.00	224.00	299.00
		Rail	108.79	95.28	94.26	-	-	185.42	-	-	266.76
16	**WV**	**County 16**									
		Barge	405.00	415.00	416.20	541.00	555.50	565.00	594.00	603.30	641.00
		Truck	123.00	120.00	121.00	254.00	268.00	277.00	306.00	282.00	292.00
		Rail	170.43	257.06	258.66	-	-	335.95	-	-	413.03
17	**WV**	**County 17**									
		Barge	100.70	90.70	89.50	202.50	217.00	226.50	255.50	264.80	302.50
		Truck	85.00	88.30	86.80	155.00	169.00	179.00	208.00	217.00	293.00
		Rail	103.00	89.49	88.47	-	-	179.63	-	-	260.97
18	**WV**	**County 18**									
		Barge	81.00	71.00	69.80	105.00	119.50	129.00	158.00	167.30	205.00
		Truck	73.80	60.00	58.50	97.80	112.00	121.00	150.00	160.00	235.00
		Rail	113.50	177.58	176.52	-	-	127.37	-	-	208.71
19	**WV**	**County 19**									
		Barge	158.20	148.20	147.00	157.80	172.30	181.80	210.80	220.10	257.80
		Truck	151.00	140.00	139.00	153.00	167.00	177.00	206.00	215.00	268.00
		Rail	157.12	225.42	224.36	-	-	177.14	-	-	253.22
20	**WV**	**County 20**									
		Barge	368.40	378.40	379.60	504.40	518.90	528.40	557.40	566.70	604.40
		Truck	147.00	144.00	146.00	272.00	286.00	295.00	324.00	329.00	340.00
		Rail	183.63	270.26	271.86	-	-	349.15	-	-	426.23
21	**WV**	**County 21**									
		Barge	138.50	148.50	149.70	274.50	289.00	298.50	327.50	336.80	374.50
		Truck	119.00	111.00	113.00	261.00	258.00	255.00	268.00	259.00	269.00
		Rail	131.96	180.19	181.79	-	-	297.48	-	-	288.33

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 10**	**Power Plant 11**	**Power Plant 12**	**Power Plant 13**	**Power Plant 14**	**Power Plant 15**	**Power Plant 16**	**Power Plant 17**	**Power Plant 18**
22	**WV**	**County 22**									
		Barge	158.20	148.20	147.00	157.80	172.30	181.80	210.80	220.10	257.80
		Truck	151.00	140.00	139.00	153.00	167.00	177.00	206.00	215.00	268.00
		Rail	157.12	225.42	224.36	-	-	177.14	-	-	253.22
23	**WV**	**County 23**									
		Barge	338.00	348.00	349.20	474.00	488.50	498.00	527.00	536.30	574.00
		Truck	173.00	170.00	172.00	298.00	312.00	322.00	329.00	319.00	329.00
		Rail	213.36	299.99	301.59	-	-	378.88	-	-	455.96
24	**WV**	**County 24**									
		Barge	118.68	108.68	107.48	220.48	234.98	244.48	273.48	282.78	320.48
		Truck	103.00	106.00	105.00	173.00	187.00	197.00	226.00	235.00	310.00
		Rail	121.03	107.52	106.50	-	-	197.66	-	-	279.00
25	**WV**	**County 25**									
		Barge	76.80	66.80	65.60	76.40	90.90	100.40	129.40	138.70	176.40
		Truck	81.80	68.00	66.50	80.90	94.90	105.00	133.00	143.00	217.00
		Rail	83.80	152.10	151.04	-	-	103.82	-	-	179.90
26	**WV**	**County 26**									
		Truck	157.00	164.00	162.00	231.00	245.00	254.00	283.00	293.00	368.00
		Rail	319.63	406.26	407.86	-	-	485.15	-	-	562.23
27	**KY**	**County 27**									
		Truck	280.00	248.00	247.00	201.00	187.00	186.00	224.00	214.00	219.00
		Rail	382.91	412.49	411.43	-	-	195.77	-	-	235.63
28	**KY**	**County 28**									
		Barge	564.50	554.50	553.30	428.50	414.00	404.50	375.50	366.20	328.50
		Truck	191.00	178.00	176.00	144.00	130.00	129.00	184.00	174.00	179.00
		Rail	322.49	352.07	351.01	-	-	135.35	-	-	175.21

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 10**	**Power Plant 11**	**Power Plant 12**	**Power Plant 13**	**Power Plant 14**	**Power Plant 15**	**Power Plant 16**	**Power Plant 17**	**Power Plant 18**
29	**KY**	**County 29**									
		Barge	140.20	130.20	129.00	139.80	154.30	163.80	192.80	202.10	239.80
		Truck	138.00	124.00	123.00	134.00	149.00	125.00	223.00	213.00	217.00
		Rail	166.99	196.57	195.51	-	-	159.40	-	-	236.48
30	**KY**	**County 30**									
		Barge	76.40	66.40	65.20	59.60	74.10	83.60	112.60	121.90	159.60
		Truck	81.80	65.60	64.10	61.50	75.60	85.20	114.00	123.00	168.00
		Rail	81.90	153.27	152.21	-	-	83.62	-	-	160.70
31	**KY**	**County 31**									
		Truck	256.00	224.00	223.00	228.00	214.00	212.00	251.00	241.00	246.00
		Rail	417.09	446.67	445.61	-	-	229.95	-	-	269.81
32	**KY**	**County 32**									
		Barge	184.20	174.20	173.00	183.80	198.30	207.80	236.80	246.10	283.80
		Truck	162.00	148.00	147.00	158.00	173.00	138.00	236.00	226.00	231.00
		Rail	206.16	235.74	234.68	-	-	198.57	-	-	275.65
33	**KY**	**County 33**									
		Truck	193.00	179.00	178.00	190.00	204.00	182.00	237.00	227.00	232.00
		Rail	241.80	271.38	270.32	-	-	216.04	-	-	255.90
34	**KY**	**County 34**									
		Barge	133.60	123.60	122.40	133.20	147.70	157.20	186.20	195.50	233.20
		Truck	132.00	119.00	117.00	129.00	143.00	119.00	217.00	208.00	212.00
		Rail	161.25	190.83	189.77	-	-	153.66	-	-	230.74
35	**KY**	**County 35**									
		Barge	128.20	118.20	117.00	127.80	142.30	151.80	180.80	190.10	227.80
		Truck	146.00	112.00	111.00	125.00	139.00	149.00	177.00	187.00	261.00
		Rail	130.60	198.90	197.84	-	-	150.62	-	-	226.70
36	**KY**	**County 36**									
		Truck	210.00	196.00	195.00	207.00	210.00	208.00	246.00	237.00	241.00
		Rail	258.21	287.79	286.73	-	-	213.21	-	-	253.07

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 10**	**Power Plant 11**	**Power Plant 12**	**Power Plant 13**	**Power Plant 14**	**Power Plant 15**	**Power Plant 16**	**Power Plant 17**	**Power Plant 18**
37	**KY**	**County 37**									
		Barge	185.54	175.54	174.34	185.14	199.64	209.14	238.14	247.44	285.14
		Truck	144.00	140.00	138.00	175.00	189.00	198.00	227.00	237.00	290.00
		Rail	179.60	247.90	246.84	-	-	199.62	-	-	275.70
38	**KY**	**County 38**									
		Truck	299.00	285.00	284.00	194.00	180.00	179.00	217.00	207.00	212.00
		Rail	376.98	406.56	405.50	-	-	189.84	-	-	229.70
39	**PA**	**County 39**									
		Barge	261.89	271.89	273.09	397.89	412.39	421.89	450.89	460.19	497.89
		Truck	230.00	227.00	228.00	318.00	315.00	311.00	325.00	315.00	325.00
		Rail	253.48	271.55	273.15	-	-	432.72	-	-	379.69
40	**PA**	**County 40**									
		Barge	327.00	337.00	338.20	463.00	477.50	487.00	516.00	525.30	563.00
		Truck	179.00	176.00	177.00	303.00	317.00	308.00	321.00	312.00	322.00
		Rail	223.63	310.26	311.86	-	-	389.15	-	-	446.27
41	**PA**	**County 41**									
		Barge	276.50	286.50	287.70	412.50	427.00	436.50	465.50	474.80	512.50
		Truck	211.00	208.00	210.00	299.00	296.00	293.00	306.00	297.00	307.00
		Rail	271.50	289.57	291.17	-	-	437.71	-	-	397.71
42	**PA**	**County 42**									
		Barge	154.00	164.00	165.20	290.00	304.50	314.00	343.00	352.30	390.00
		Truck	160.00	157.00	159.00	248.00	245.00	242.00	255.00	245.00	256.00
		Rail	147.42	167.79	169.39	-	-	312.94	-	-	275.93
43	**VA**	**County 43**									
		Truck	226.00	229.00	227.00	227.00	241.00	207.00	305.00	295.00	300.00
		Rail	273.87	342.17	341.11	-	-	293.89	-	-	369.97

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 10**	**Power Plant 11**	**Power Plant 12**	**Power Plant 13**	**Power Plant 14**	**Power Plant 15**	**Power Plant 16**	**Power Plant 17**	**Power Plant 18**
44	**PA**	**Terminal 1**									
		Barge	217.72	227.72	228.92	353.72	368.22	377.72	406.72	416.02	453.72
		Truck	216.00	213.00	215.00	304.00	301.00	298.00	311.00	302.00	312.00
		Rail	215.95	235.41	237.01	-	-	380.54	-	-	328.20
45	**OH**	**Terminal 2**									
		Barge	168.00	178.00	179.20	304.00	318.50	328.00	357.00	366.30	404.00
		Truck	164.00	161.00	163.00	252.00	249.00	246.00	259.00	250.00	260.00
		Rail	160.70	178.77	180.37	-	-	326.22	-	-	286.91
46	**WV**	**Terminal 3**									
		Barge	57.20	47.20	46.00	78.80	93.30	102.80	131.80	141.10	178.80
		Truck	62.00	48.20	46.70	81.10	95.20	105.00	134.00	143.00	223.00
		Rail	63.48	143.23	142.17	-	-	104.36	-	-	183.11
47	**WV**	**Terminal 4**									
		Barge	65.20	55.20	54.00	70.80	85.30	94.80	123.80	133.10	170.80
		Truck	69.50	55.70	54.20	74.50	88.60	98.20	127.00	136.00	212.00
		Rail	70.60	133.12	132.06	-	-	95.92	-	-	172.00
48	**OH**	**Terminal 5**									
		Barge	103.85	93.85	92.65	32.15	46.65	56.15	85.15	94.45	132.15
		Truck	78.20	62.10	60.60	35.10	49.20	58.80	87.50	96.90	142.00
		Rail	109.84	171.15	170.09	-	-	132.95	-	-	210.18
49	**KY**	**Terminal 6**									
		Barge	151.50	141.50	140.30	15.50	1.00	8.50	37.50	46.80	84.50
		Truck	134.00	118.00	116.00	21.40	7.40	7.70	37.50	47.00	91.50
		Rail	157.36	229.44	228.38	-	-	7.45	-	-	85.24
50	**KY**	**Terminal 7**									
		Barge	217.00	207.00	205.80	81.00	66.50	57.00	28.00	18.70	19.00
		Truck	200.00	184.00	182.00	80.10	66.10	62.80	28.20	18.60	19.40
		Rail	223.35	295.28	294.22	-	-	59.13	-	-	18.54

in miles			POWER PLANTS								
No	**State**	**Origin / Destination**	**Power Plant 10**	**Power Plant 11**	**Power Plant 12**	**Power Plant 13**	**Power Plant 14**	**Power Plant 15**	**Power Plant 16**	**Power Plant 17**	**Power Plant 18**
51	**PA**	**Terminal 8**									
		Barge	303.00	313.00	314.20	439.00	453.50	463.00	492.00	501.30	539.00
		Truck	210.00	207.00	209.00	322.00	295.00	292.00	305.00	296.00	306.00
		Rail	248.83	312.93	314.53	-	-	412.44	-	-	400.73
52	**PA**	**Terminal 9**									
		Barge	309.00	319.00	320.20	445.00	459.50	469.00	498.00	507.30	545.00
		Truck	206.00	203.00	205.00	294.00	291.00	288.00	301.00	292.00	302.00
		Rail	241.19	320.57	322.17	-	-	406.71	-	-	406.46

Notes:

1. The empty red boxes indicate the inexistence of access to the respective transportation mode in the power plant site.
2. The milepoints are measured via the ruler path and directions tools of the Google Earth Freeware Ver. 4.3.7284.3916 (beta).

Appendix D: The Traffic Passing Through the Lock and Dam Structures in 2003

Milepoint from the Ohio River	Milepoint on the Ohio River	Lock and Dam (L/D) Structures	Direction	Historical Traffic Flow (tons)
Ohio River				
	6.2	L/D 1	Up	7,555,000.00
			Down	6,952,000.00
	13.3	L/D 2	Up	7,515,000.00
			Down	6,977,000.00
	31.7	L/D 3	Up	8,017,000.00
			Down	7,050,000.00
	53	L/D 4	Up	16,692,000.00
			Down	6,117,000.00
	81	L/D 5	Up	20,418,000.00
			Down	6,122,000.00
	125	L/D 6	Up	16,679,000.00
			Down	18,151,000.00
	158	L/D 7	Up	16,930,000.00
			Down	15,226,000.00
	208	L/D 8	Up	17,511,000.00
			Down	15,488,000.00
	241	L/D 9	Up	17,549,000.00
			Down	15,701,000.00
	277	L/D 10	Up	16,850,000.00
			Down	15,355,000.00
	337.34	L/D 11	Up	4,732,000.00
			Down	30,523,000.00
	428	L/D 12	Up	2,330,000.00
			Down	24,392,000.00
	521.5	L/D 13	Up	2,354,000.00
			Down	12,475,000.00
Allegheny River				
6.7	0	L/D 14	Up	1,448,000.00
14.5	0	L/D 15	Up	1,445,000.00
Monongahela River				
115.4	0	L/D 16	Up	32,000.00
108	0	L/D 17	Up	32,000.00
102	0	L/D 18	Up	32,000.00
90.8	0	L/D 19	Up	2,360,000.00
82	0	L/D 20	Up	2,310,000.00
61.2	0	L/D 21	Up	4,792,000.00
41.5	0	L/D 22	Up	401,000.00
23.8	0	L/D 23	Up	1,213,000.00
11.2	0	L/D 24	Up	6,401,000.00

Milepoint from the Ohio River	Milepoint on the Ohio River	Lock and Dam (L/D) Structures	Direction	Historical Traffic Flow (tons)
Kanawha River				
82.8	263.1	L/D 25	Up	23,000.00
67.7	263.1	L/D 26	Up	121,000.00
31	263.1	L/D 27	Up	162,000.00

Source: 2003 Lock Performance Monitoring System (LPMS) data (U.S. Army Corps of Engineers Great Lakes and Ohio River Division, 2004)

Notes:

1. The milepoints are measured via the ruler path tool of the Google Earth Freeware Ver. 4.3.7284.3916 (beta).
2. The existence of a milepoint on the tributary column indicates that the milepoint on the Ohio River shows the respective tributary's mouth milepoint on the Ohio River.

Appendix E: The Annual Supply of the Coal Supplying Counties

No	State	Counties	Supply Amount (tons)
1	OH	County 1	5,096,563.64
2	OH	County 2	0.00
3	OH	County 3	3,628.74
4	OH	County 4	2,273,404.86
5	OH	County 5	899,020.04
6	OH	County 6	0.00
7	OH	County 7	0.00
8	OH	County 8	6,479,113.13
9	OH	County 9	468,107.31
10	WV	County 10	1,518,627.19
11	WV	County 11	0.00
12	WV	County 12	30,009,669.88
13	WV	County 13	368,316.99
14	WV	County 14	3,405,571.36
15	WV	County 15	5,301,587.39
16	WV	County 16	6,313,098.33
17	WV	County 17	10,099,687.27
18	WV	County 18	983,388.21
19	WV	County 19	12,843,013.80
20	WV	County 20	6,072,694.38
21	WV	County 21	8,841,422.09
22	WV	County 22	12,164,439.64
23	WV	County 23	5,300,680.20
24	WV	County 24	4,075,980.86
25	WV	County 25	4,320,920.73
26	WV	County 26	4,875,210.58
27	KY	County 27	3,212,341.02
28	KY	County 28	1,968,590.80
29	KY	County 29	4,075,980.86
30	KY	County 30	0.00
31	KY	County 31	9,425,649.03
32	KY	County 32	7,282,878.77
33	KY	County 33	5,571,021.24
34	KY	County 34	2,135,512.78
35	KY	County 35	4,789,935.22
36	KY	County 36	14,788,017.79
37	KY	County 37	19,437,339.38
38	KY	County 38	208,652.48
39	PA	County 39	88,904.10
40	PA	County 40	36,237,492.84
41	PA	County 41	211,845.77
42	PA	County 42	3,318,917.08
43	VA	County 43	973,409.18

Source: 2007 Data of Energy Information Administration (Energy Information Administration, 2008)

Appendix F: The Annual Demand of the Power Plants

No	State	Power Plants	Demand Amount (tons)
1	OH	Power Plant 1	5,800,340.00
2	OH	Power Plant 2	1,875,730.00
3	OH	Power Plant 3	1,875,730.00
4	OH	Power Plant 4	852,970.00
5	WV	Power Plant 5	1,786,550.00
6	WV	Power Plant 6	3,213,290.00
7	WV	Power Plant 7	3,454,050.00
8	WV	Power Plant 8	531,610.23
9	WV	Power Plant 9	2,343,480.00
10	WV	Power Plant 10	2,756,070.00
11	OH	Power Plant 11	7,367,770.00
12	OH	Power Plant 12	2,924,820.00
13	OH	Power Plant 13	1,750,610.00
14	OH	Power Plant 14	5,770,660.00
15	KY	Power Plant 15	2,177,980.00
16	OH	Power Plant 16	4,042,930.00
17	OH	Power Plant 17	2,581,650.00
18	OH	Power Plant 18	3,049,960.00

Source: The United States Army Corps of Engineers 2006 data
(U.S. Army Corps of Engineers, 2006)

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Vita

1st Lieutenant Çağlar Utku GÜLER graduated from Maltepe Military High School in Izmir, Turkey. He entered undergraduate studies at the Turkish Air Force Academy in Istanbul where he graduated as a Lieutenant with a Bachelor of Science degree in Aeronautics Engineering in August 2003.

His first assignment was at Cigli, Izmir as a student in basic pilot training in 2003. In 2004, he was assigned to the Logistics and Supply School in Izmir and upon completion his education there, he was assigned to the GES Command, Ankara, in 2005 where he served as a Logistics Planning Officer for 2 years. In August 2007, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to a logistics post in the Turkish Air Force.

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14. ABSTRACT

What if the Ohio River is disrupted or denied partially or completely as a transportation corridor? A disruption may be either a natural or man-made disaster or a planned outage on the river's lock and dam structures. Recent history is full of water transport disruption events having significant economic effects on the waterside industries. To assess coal-based economic impacts, we developed a network flow model to represent waterside coal-fired power plants situated along the Ohio River, their respective coal supplying mines, and the various transportation modes that connect them. We show that significant transportation-centric insights can be derived by using only commonly available spreadsheet-based analysis tools, open-source information systems, and web-based geographic tools.

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