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ECONOMIC EVALUATION OF ARKANSAS INLAND WATERWAYS AND POTENTIAL DISRUPTION IMPACTS

MBTC DOT 3029

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1. Project Abstract

Arkansas is one of thirty-eight states with an inland waterway transportation system. Over one thousand miles of Arkansas navigable waterways have the potential to attract industries by offering low-cost transportation in a strategic location with links to domestic markets, including Chicago, Houston, and Pittsburgh and coastal ports in the Gulf of Mexico. A decade ago, prior research indicated that Arkansas ports directly and indirectly contribute to the economic growth of this state, including economic value, earnings, and employment. There is a need for current information on the economic impacts of Arkansas' inland waterway transportation system, and what impact disruptions to this system may have. This information may spur investment in port development, which can in turn increase Arkansas' competitive advantage over neighboring states while continuing to offer social and environmental transportation benefits.

2. Introduction

The project is structured into four sections. First, background information about inland waterways in the U.S. and Arkansas and their benefits are presented. Second, a literature review of input-output models and economic and disruption impacts is provided. Third, the economic impact of Arkansas inland waterways is evaluated in terms of direct, indirect and induced impacts. Lastly, potential disruption impacts are assessed.

3. Background on Water Transportation

The following sections give an overview of the waterway system in the U.S., emphasize the inland waterways system in Arkansas, and provide benefits of water transportation.

3.1 The Navigable Inland Waterways System of the United States

The inland waterways system of the U.S. has a total of 12,000 miles of navigable inland waterways. In total, thirty-eight states are connected via navigable inland waterways (U.S. Army Corps of Engineers, 2005).

In 2007, over 622 million tons of cargo were shipped via the inland waterways system, and on the total U.S. waterway system over 1 billion tons valued at more than $380 billion were shipped (U.S. Army Corps of Engineers, 2009).

In 2006, the commodities that were primarily shipped on inland waterways were coal and petroleum and petroleum products, which were 29% and 25% of the total value in tons, respectively. Other commodities include crude materials (19%), food and farm products (19%), and chemicals, with 8% of the total volume in tons shipped via inland waterways (U.S. Army Corps of Engineers, 2009).

3.2 Arkansas Inland Waterways System

The State of Arkansas has more than 1,000 miles of navigable waterways, including the following five rivers (Arkansas Waterway Commission, 2011):

- Arkansas River
- Mississippi River
- Ouachita River
- Red River
- White River

Each river is accessible within 65 miles of each county in the State of Arkansas. Figure 1 gives an overview of the navigable waterways in the State of Arkansas.

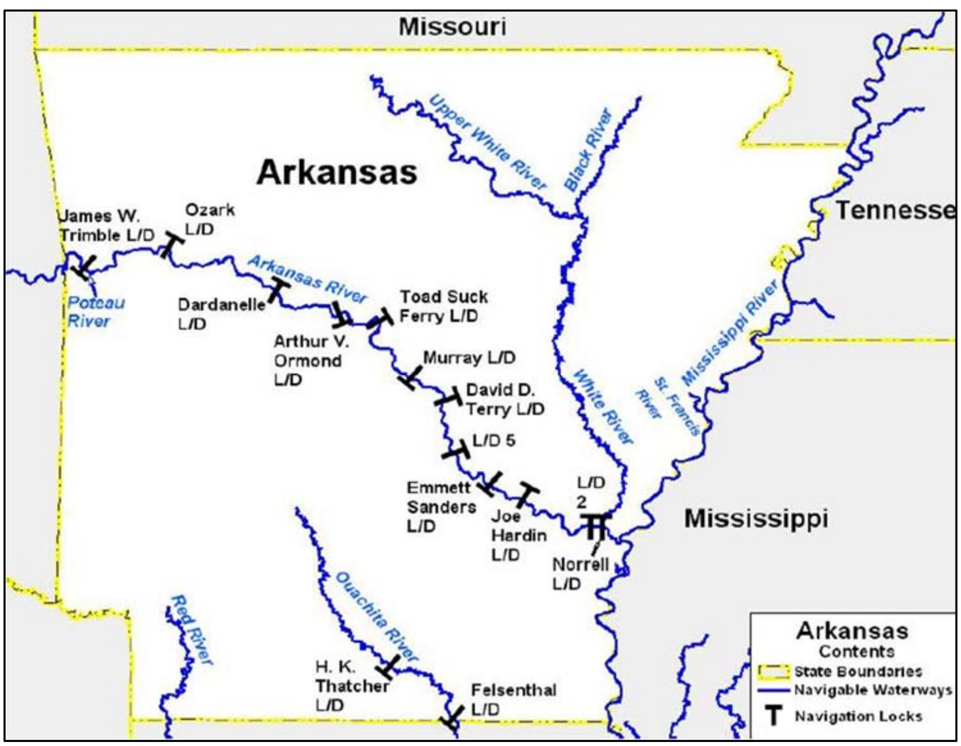

Figure 1: Navigable Waterways in Arkansas Source: Waterways Council, Inc.

In addition, the following nine public ports are located in Arkansas (Arkansas Waterway Commission, 2011):

- Arkansas River: Fort Smith, Pine Bluff, Little Rock
- Mississippi River: Helena-West Helena-Phillips County, Osceola, West Memphis, Yellow Bend
- Ouachita River: Camden, Crossett

In 2009, 10.4 million of short-tons (1 short-ton=2000 pounds) of waterborne commodities were shipped to, from or within the State of Arkansas (U.S. Army Corps of Engineers, 2010).
Figure 2 and Table 1 present the waterway shipments in tons with Arkansas as origin. The State of Arkansas commodity flow data from the U.S. Army Corps of Engineers was used to create the Figure 2 and Table 1 (U.S. Army Corps of Engineers, n.d.). The main commodity shipped from Arkansas to other destinations was food and food products with more than 4.6 million tons per year, followed by sand, gravel, shells, clay, salt and slag with over 2.5 million tons per year. Petroleum products are the third most shipped commodity from Arkansas, with over 1.2 million tons per year.

Figure 3 and Table 2 present the waterway shipments in tons with Arkansas as destination. The State of Arkansas commodity flow data from the U.S. Army Corps of Engineers was used to create Figure 3 and Table 2 (U.S. Army Corps of Engineers, n.d.). The main commodity shipped to Arkansas from other destinations is sand, gravel, shells, clay, salt, and slag with more than 2.9 million tons per year, followed by unknown commodities with over 1.0 million tons per year. Primary metal products are the third most shipped commodity to Arkansas with almost 1.0 million tons per year.

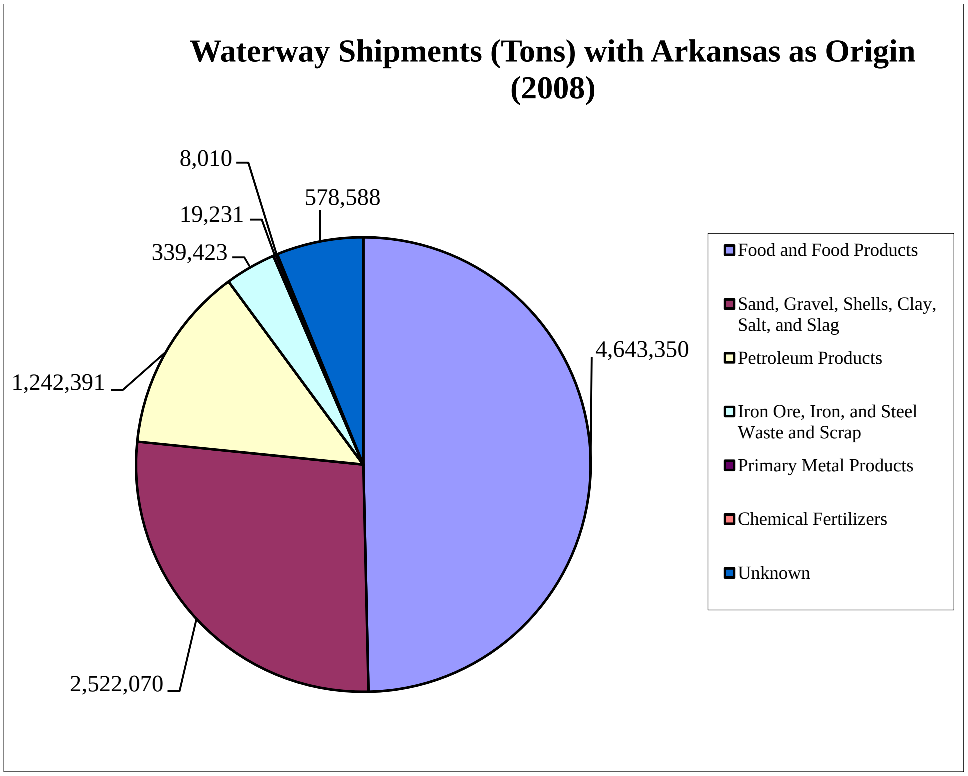

Figure 2: Waterway Shipments (Tons) with Arkansas as Origin

Table 1: Waterway Shipments (Tons) with Arkansas as Origin

Commodity	**Tonnage**
Food and Food Products	4,643,350
Sand, Gravel, Shells, Clay, Salt, and Slag	2,522,070
Petroleum Products	1,242,391
Iron Ore, Iron, and Steel Waste and Scrap	339,423
Primary Metal Products	19,231
Chemical Fertilizers	8,010
Unknown	578,588
Total	9,353,063

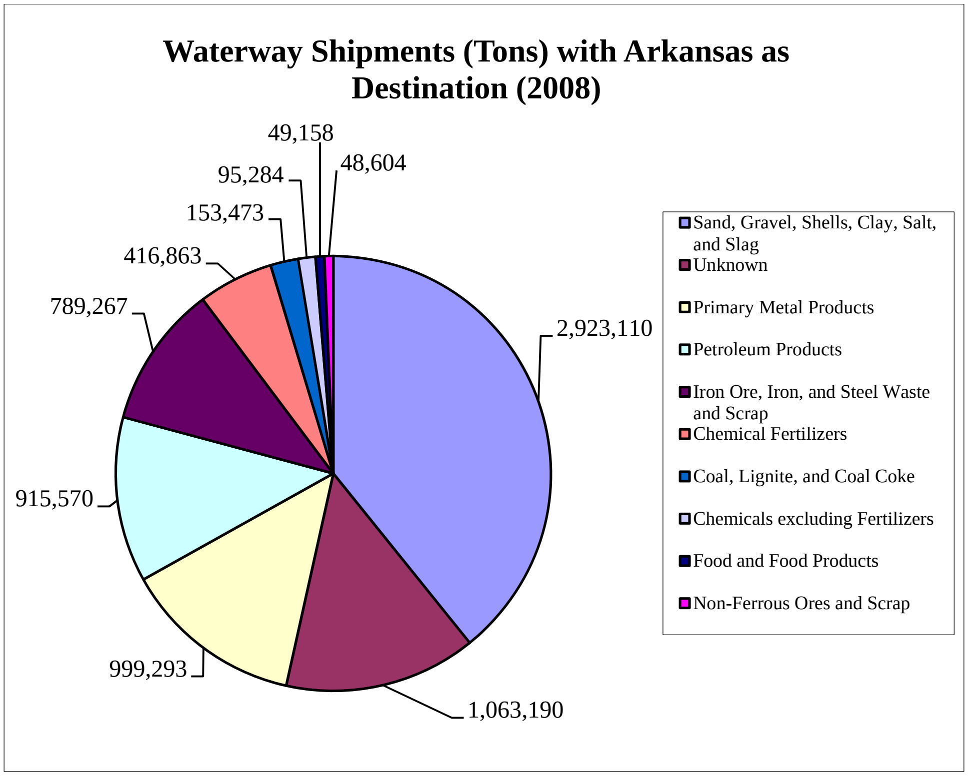

Figure 3: Waterway Shipments (Tons) with Arkansas as Destination

Table 2: Waterway Shipments (Tons) with Arkansas as Destination

Commodity	**Tonnage**
Sand, Gravel, Shells, Clay, Salt, and Slag	2,923,110
Unknown	1,063,190
Primary Metal Products	999,293
Petroleum Products	915,570
Iron Ore, Iron, and Steel Waste and Scrap	789,267
Chemical Fertilizers	416,863
Coal, Lignite, and Coal Coke	153,473
Chemicals excluding Fertilizers	95,284
Food and Food Products	49,158
Non-Ferrous Ores and Scrap	48,604
Total	7,453,812

3.3 Benefits of Water Transportation

Waterway transportation is clearly categorized as the mode of transportation with the cheapest bulk, but also as the slowest mode and the mode with most limited connections, since these are predetermined by the natural flow of waterways. **Error! Reference source not found.** categorizes different transportation modes according to three categories: faster delivery, better connections and cheaper bulk.

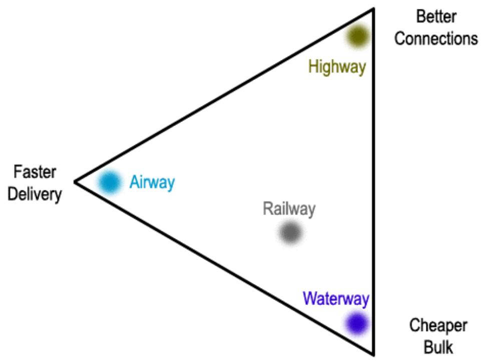

Figure 4: Comparison of Different Modes of Transportation

Source: Missouri Department of Transportation, 2006

The following list contains more benefits of water transportation:

- Using water transportation leads to an annual transportation savings of $7 billion in the U.S. (U.S. Army Corps of Engineers, 2009).
- Transportation cost for barges is lower than for rail or trucks. As can be seen in Figure 5, the cost of one ton-mile (moving one ton of freight for a mile) is 0.72 cents with a barge, 2.24 cents with rail, and 26.62 cents with a large semi truck.

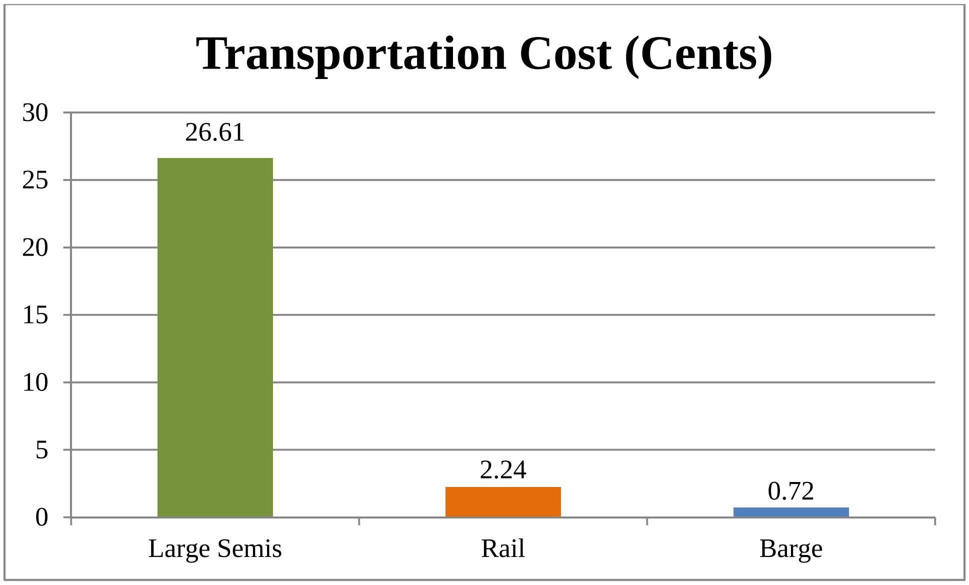

Figure 4: Transportation Cost per ton mile in cents; Source: Guler, Johnson, & Cooper, 2012

- Water transportation is more fuel efficient than other modes of transportation and decreases air emissions (U.S. Army Corps of Engineers, 2009). As is presented in Figure 6, one gallon of fuel can move one ton of freight 155 miles by truck, 436 miles by rail, and 576 miles by barge.

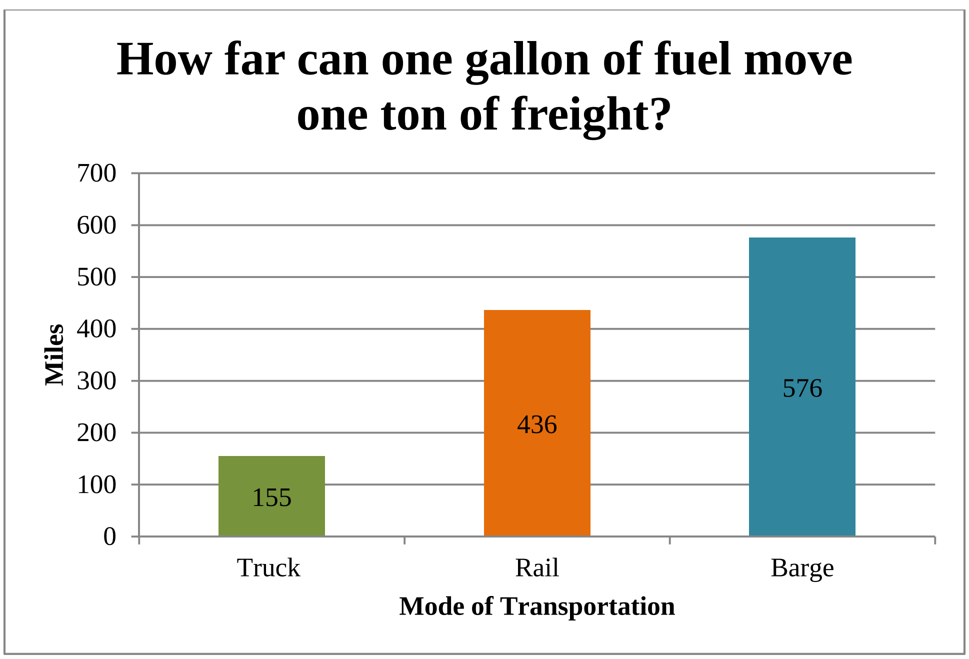

Figure 5: Fuel-Efficiency of Different Modes of Transportation

Source: Center for Ports and Waterways Texas Transportation Institute, 2007

- The cargo capacity for barges is higher than for rail or trucks. One barge can carry 1,500 tons, which is equivalent to the capacity of 15 railcars or 58 large semi-trucks, as shown in Figure 6.

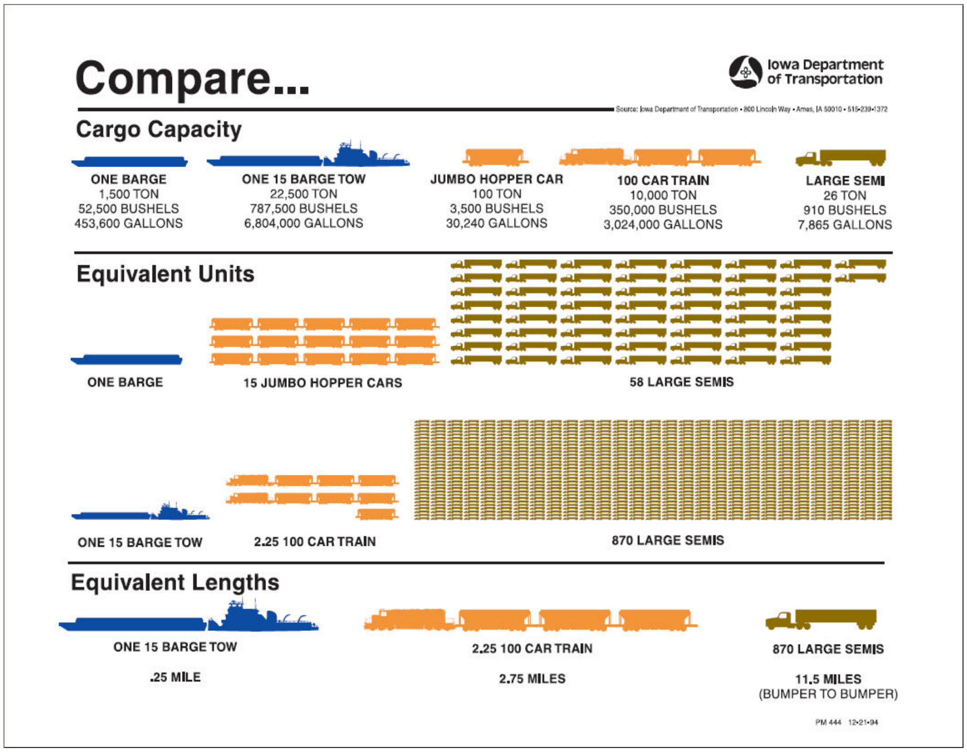

Figure 6: Comparison of Cargo Capacity; Source: Iowa Department of Transportation (2008)

- Shipping freight via inland waterways causes fewer fatalities than shipping via railroads or trucks. Figure 7 shows the ratio of fatalities to inland waterways per billion ton miles. One fatality occurring on inland waterways is equivalent to 22.7 fatalities on railroads and as many as 155 fatalities on truck freight. In Figure 8, the ratios of injuries to inland waterways are presented. One injury occurring in inland waterways is equivalent to 125 injuries occurring on railroads and as many as 2171 injuries occurring on truck freight.

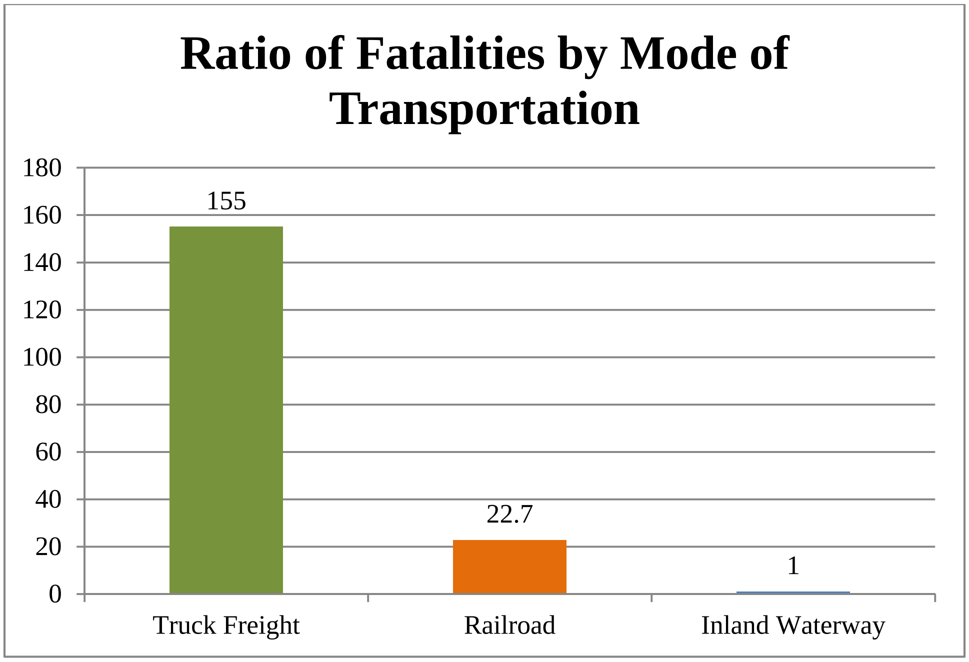

Figure 7: Ratio of Fatalities to Inland Waterways per Billion Ton-Miles

Source: Center for Ports and Waterways Texas Transportation Institute, 2007

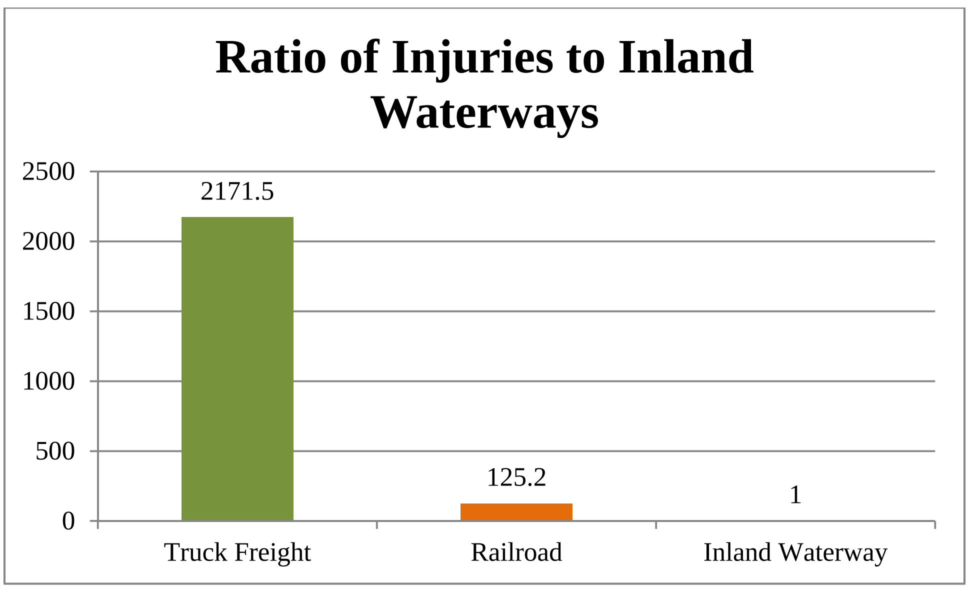

Figure 8: Ratio of Injuries to Inland Waterways per Billion Ton-Miles

Source: Center for Ports and Waterways Texas Transportation Institute, 2007

- Using waterways as mode of transportation relieves already congested roads and railroads. For example, the usage of waterways avoids over 58 million truck trips per year (Center for Ports and Waterways Texas Transportation Institute, 2007).

4. Literature Review

4.1 Introduction

To develop a methodology for the "Economic Evaluation of Arkansas Inland Waterways and Potential Disruption Impacts" project, a thorough literature review was conducted. The main fields of interest for this review were inland waterways, economic analysis, input-output models and disruptive events. The literature review allowed a better understanding of the variety of methodologies and data used to conduct an economic impact analysis.

An important extension of economic impact studies is the research concerning about disruptive events in transportation and their economic impacts. Disruptive events can be "natural disasters, accidents, terrorism, war, political and economic instability, supply unavailability, transportation delays, and labor strikes or conflicts" (Figliozzi & Zhang, 2009, p.3). The following review provides an oversight of various models and research approaches in the field of economic impact analysis. It also includes research about economic impacts of disruptive events in the field of transportation.

4.2 Economic Analysis Methodology Used

As shown in Table 3, the most commonly used economic models are Impact Analysis for Planning (IMPLAN), Inoperability Input-output Models, and the Regional Input-output Modeling System (RIMS II). Our review of the relevant literature reveals that there is little agreement among scholars regarding which method to use for economic analysis of maritime transportation and associated disruptions.

To measure economic impacts, Leontief developed an input-output model in 1941 (Leontief, 1986). His approach was and is today still widely used (A. Strauss-Wieder, Inc., 2011). The main idea of Leontief's model is that there exists a strong relationship between one industry's input and its output (Jung, Santos, & Haimes, 2009). In addition, the input-output model is a "static equilibrium model" (U.S. Department of Commerce, 1997) and provides only a "snapshot" of "technical requirements and industry relationships" at a specific point in time (A. Strauss-Wieder, Inc., 2011). Leontief's economic impact matrix is the foundation of several new models developed by different researchers. Over time, researchers developed and extended the original idea of Leontief's input-output model. Thus, today a broad variety of economic input-output models exists and is implemented in studying economic impacts in maritime transportation as shown in Table 3.

Table 3: Economic Analysis Methodology Used

	Model	Description	Author(s)
Input-output (IO) Models	IMPLAN Based Models	Impact Analysis for Planning	Folga et al. (2009)
		National Interstate Economic Model (NIEMO)	Gordon et al. (2005)
			Gordon et al. (2008)
			Park et al. (2008)
		TransNIEMO	Gordon et al. (2008)
	Inoperability IO Models	Dynamic Multiregional Inoperability IO Model	MacKenzie et al. (2011)
		Inoperability IO Model	Jung et al. (2009)
		Risk-based Multi-Regional Inoperability IO Model	Pant et al. (2011)
	RECON	The Rutgers Economic Advisory Service IO Model	A. Strauss-Wieder, Inc. (2011)
	REIMs	Multi-Regional Commodity Flow Model	Okuyama et al. (1999)
	REMI	Regional Economic Models, Inc.	Economic Research Associates (2007)
	RIMS II	Regional IO Modeling System	Loren C. Scott & Associates (2008)
			Martin Associates (2006)
			Nachtmann (2001)
			Richardson & Scott (2004)
	Rural Inland Waterways Kit	The extension of MARAD Model	Hamilton et al. (2000)
	SCPM	Southern California Planning Model	Gordon et al. (2005)
			Gordon et al. (2008)
			Rosoff & Winterfeldt (2007)
	Other IO Models	Canada IO Tables	InterVIDTAS Consulting Inc. (2008)
		IO Multipliers	Colegrave et al. (2008)
		Singapore IO Tables	Toh et al. (1995)
		Taiwan IO and Linear Programming Model	Wang & Miller (1995)
		Welsh IO Tables	Bryan et al. (2006)
Other Models	DEA	Date Envelopment Analysis	Xuemei (2011)
	Discrete Choice Model	Decision Tree Model Combining Discrete Choices	Qu & Meng (n.d.)
	Logit Model	Based on Consumer Behavior Theory	Figliozzi & Zhang (2009)
	MOBILE Model	By United States Environmental Protection Agency	Chatterjee et al. (2001)
	SIERRA	System for Import/Export Routing and Recovery Analysis	Jones et al. (2011)
	Spatial equilibrium model	Integrated Grain Transportation Model (IGTM)	Kruse et al. (2011)

4.3 Affected Region Studied

When conducting an economic impact analysis, the affected region must be clearly defined (U.S. Department of Commerce, 1997). Based on the purpose of the study, scholars may define the affected region from regional to global. A listing of study regions found in our literature review is presented in Table 4. As shown in Table 4, the regional studies can be conducted at the city, county, economic region, state, or multi-state levels (MacKenzie, Barker, and Grant, 2011). Some scholars conduct economic analyses at the national level. Other scholars define their affected region on an international level or as combination of regional, national, and global levels.

Table 4: Affected Regions Studied

Level	Affected Region Detail	Author(s)
Regional	2 cities and 5 counties in California	Gordon et al. (2005)
	27 highway sections	Chatterjee et al. (2001)
	31 counties in New York, New Jersey, and Pennsylvania	A. Strauss-Wieder, Inc. (2011)
	Auckland	Colegrave et al. (2008)
	Congressional districts	Kruse et al. (2011)
	Arkansas	Nachtmann (2001)
	Los Angeles Metropolitan Area	Rosoff & Winterfeldt (2007)
	Multiple states	MacKenzie (2011)
		Pant et al. (2011)
	San Diego county and California	Economic Research Associates (2007)
	Shanghai	Xuemei (2011)
	South Wales	Bryan et al. (2006)
	Illinois	Folga et al. (2009)
	Vancouver, Oregon and Washington	Martin Associates (2006)
National	Republic of Singapore	Toh et al. (1995)
	United States	Park et al. (2008)
International	International Supply Chain	Lewis et al. (2006)
	International Trade in the United States	Jung et al. (2009)
	United States and 46 other countries	Jones et al. (2011)
Combination	British Columbia and Canada	InterVIDTAS Consulting Inc. (2008)
	Houma Metropolitan Statistical Area and United States	Loren C. Scott & Associates (2008)
	Regional, National, and Global	Gordon et al. (2008)
	Louisiana and the United States	Richardson & Scott (2004)

4.4 Source of Economic Impact

The sources of the economic impact analysis studied in the maritime transportation literature are shown in Table 5. A single port, multiple ports, a single lock, multiple straits, and inland waterway infrastructure are the classification levels for the source of economic impact for maritime transportation in the reviewed literature.

Table 5: Source of Economic Impact

Source of Economic Impact	Author(s)
Single Port	A. Strauss-Wieder, Inc. (2011)
	Economic Research Associates (2007)
	Gordon et al. (2008)
	Lewis et al. (2006)
	Loren C. Scott & Associates (2008)
	MacKenzie (2011)
	Martin Associates (2006)
	Pant et al. (2011)
	Toh et al. (1995)
	Xuemei (2011)
Multiple Ports	Bryan et al. (2006)
	Colegrave et al. (2008)
	Gordon et al. (2005)
	Gordon et al. (2008)
	InterVIDTAS Consulting Inc. (2008)
	Park et al. (2008)
	Rosoff & Winterfeldt (2007)
Single Lock	Chatterjee et al. (2001)
	Kruse et al. (2011)
Multiple Straits	Qu & Meng (n.d.)
Inland Waterway Infrastructure	Folga et al. (2009)

4.5 Economic Indicators Used

According to the reviewed literature, five major economic indicators with synonyms/components are found and identified in Table 6. These are Gross Domestic Product (by State), Gross Output, Employee Earnings, Employment, and Tax Revenue.

Table 6: Economic Indicators

Economic Indicator	Synonyms/ Components	Author(s)
Gross Domestic Product (by State)	GDP ($)	Colegrave et al. (2008)
		Gordon et al. (2008)
		Xuemei (2011)
	GDP ($)/Value-added ($)	InterVIDTAS Consulting Inc. (2008)
	GDP ($)/Value-added ($)/National Income ($)	Wang & Miller (1995)
	Gross Regional Product ($)/Output ($)	Gordon et al. (2005)
	Gross State Product (GSP) ($)	Nachtmann (2001)
	Value Added Gross Regional Product (GRP) ($)	Economic Research Associates (2007)
Gross Output	Economic Output ($)/Output ($)/Gross Revenue ($)	InterVIDTAS Consulting Inc. (2008)
	Economic Value ($)	Martin Associates (2006)
	Gross Output ($)	Wang & Miller (1995)
	Industry Output ($)	Pant et al. (2011)
	Output ($)	Colegrave et al. (2008)
		Economic Research Associates (2007)
		Gordon et al. (2008)
		Hamilton et al. (2000)
		Toh et al. (1995)
	Sales ($)	Loren C. Scott & Associates (2008)
		Richardson & Scott, 2004
	Spending ($)/Output ($)	Bryan et al. (2006)
	Total Business Income/Revenue	A. Strauss-Wieder, Inc. (2011)
Employee Earnings	Earnings ($)	Richardson & Scott (2004)
	Employee Earnings ($)	Nachtmann (2001)
		Loren C. Scott & Associates (2008)
	Household Incomes ($)	Colegrave et al. (2008)
	Income ($)	Hamilton et al. (2000)
		Toh et al. (1995)
	Personal Income ($)	Economic Research Associates (2007)
		Martin Associates (2006)
	Total Earnings ($)/Personal Income ($)	A. Strauss-Wieder, Inc. (2011)
	Wage ($)	Wang & Miller (1995)
	Wages ($)/Payroll ($)	InterVIDTAS Consulting Inc. (2008)

Table 6: Economic Indicators (Continued)

Economic Indicator	Synonyms/ Components	Author(s)
Employment	Employment	A. Strauss-Wieder, Inc. (2011)
		Economic Research Associates (2007)
		Hamilton et al. (2000)
		Loren C. Scott & Associates (2008)
		Nachtmann (2001)
		Richardson & Scott (2004)
		Toh et al. (1995)
	Employment (Full-time-equivalents jobs)	Colegrave et al. (2008)
		Bryan et al. (2006)
	Jobs	Gordon et al. (2008)
		Martin Associates (2006)
	Jobs (person-years)	Gordon et al. (2005)
		InterVIDTAS Consulting Inc. (2008)
Tax Revenues	Indirect Business Taxes ($)	Hamilton et al. (2000)
	Payroll Tax, Property Tax, Sales Tax, Transient Occupancy Tax, and Business License Tax	Economic Research Associates (2007)
	Sales Taxes ($)	Loren C. Scott & Associates (2008)
	State and Local Taxes ($), Federal Taxes ($)	Martin Associates (2006)
	Taxes Paid by Employers and Employees, Taxes Paid by the Port Authority, Taxes Paid by Cruise Passengers, Crew, and Cruise Lines	InterVIDTAS Consulting Inc. (2008)
	Total Local Tax ($), Total State Tax($), Total Federal Tax ($)	A. Strauss-Wieder, Inc. (2011)

4.6 Disruption Case Scenario

Because of the uncertain nature of disruptions, it is necessary to make assumptions to conduct an economic assessment of future disruptions. Thus, many scholars study hypothetical case scenarios. Table 7 indicates which scholars conduct a hypothetical scenario analysis and which scholars conduct a disruption analysis on a real world incident.

Table 7: Economic Analysis of Disruptions

Disruption Case Scenario	Author(s)
Hypothetical	Chatterjee et al. (2001)
	Figliozzi & Zhang (2009)
	Folga et al. (2009)
	Gordon et al. (2005)
	Gordon et al. (2008)
	Jones et al. (2011)
	Kruse et al. (2011)
	Lewis et al. (2006)
	MacKenzie et al. (2011)
	Okuyama et al. (1999)
	Pant et al. (2011)
	Park et al. (2008)
	Qu & Meng (n.d.)
	Richardson & Scott (2004)
	Rosoff & Winterfeldt (2007)
	Wang & Miller (1995)
Real	Jung et al. (2009)
	Loren C. Scott & Associates (2008)

4.7 Type of Disruption Studied

Based on the scope, scholars conducted a disruption economic impact analysis for either a specific type of disruptive event or for a disruption in general. Specific types of disruption analysis can focus on natural or man-made disruptions. These classifications are presented in Table 8.

Table 8: Types of Disruption Studied

Type of Disruption Studied	Detail (if any)	Author(s)
Natural Disaster	Earthquake	Okuyama (1999)
	Erosion	Richardson & Scott (2004)
Man-made	Labor Strike	Jung et al. (2009)
	Lockout	Park et al. (2008)
	Terrorist Attacks	Gordon et al. (2005)
		Gordon et al. (2008)
		Rosoff & Winterfeldt (2007)
General		Chatterjee et al. (2011)
		Figliozzi & Zhang, (2009)
		Folga et al. (2009)
		Jones, et al. (2011)
		Kruse et al. (2011)
		Lewis et al. (2006)
		Loren C. Scott & Associates (2008)
		Qu & Meng (n.d.)
		Wang & Miller (1995)
Other	Sudden Port Closures	MacKenzie et al. (2011)
	Process Disruptions of Ports	Pant et al. (2011)

4.8 Alternative Modes of Transportation and Rerouting

During a maritime transportation disruption, decision makers have the option of rerouting to an alternative mode of transportation. Some of the papers consider an alternative mode of transportation and/or rerouting opportunities, while others do not as shown in Table 9.

Table 9: Alternative Mode of Transportation/Rerouting

Alternative Mode of Transportation/Rerouting	Author(s)
Yes	Chatterjee et al. (2001)
	Figliozzi & Zhang, (2009)
	Folga et al. (2009)
	Gordon et al. (2008)
	Jones et al. (2011)
	Kruse et al. (2011)
	MacKenzie et al. (2011)
	Okuyama et al. (1999)
	Park et al. (2008)
	Qu & Meng (n.d.)
No	Gordon et al. (2005)
	Jung et al. (2009)
	Lewis et al. (2006)
	Loren C. Scott & Associates (2008)
	Pant et al. (2011)
	Richardson & Scott (2004)

5. Economic Impact of Inland Waterway Transportation

5.1 Introduction

To efficiently assess the economic impacts of the navigable waterway transportation system, an economic impact model is developed, and an associated analysis is conducted. Our model assesses economic impacts under both normal and disruption scenarios. The results of the model provide information which can spur investment in port development. This can increase the competitive advantage of the associated region, while maintaining the current environmental and social benefits. A case study on the navigable waterways of the State of Arkansas is conducted. Since only publicly available data sources are utilized, the method can be used for different economic regions and is not only limited to Arkansas.

5.2 Economic Impact Model without Disruption

The total economic impact is calculated from the sum of direct, indirect and induced economic impacts. Each economic impact can be represented by four distinct indicators, which are GDP by State, Employment, and Employee Earnings, and Gross Output. Figure 10 shows the overall steps of our preliminary research. First, all necessary data is collected. Then, the direct impacts of the four different economic indicators are calculated utilizing dependency rates and Gross Output Rates. Next, the indirect and induced impacts are estimated using RIMS II multipliers. Lastly, the total impacts are found by totaling direct, indirect, and induced impacts for each indicator.

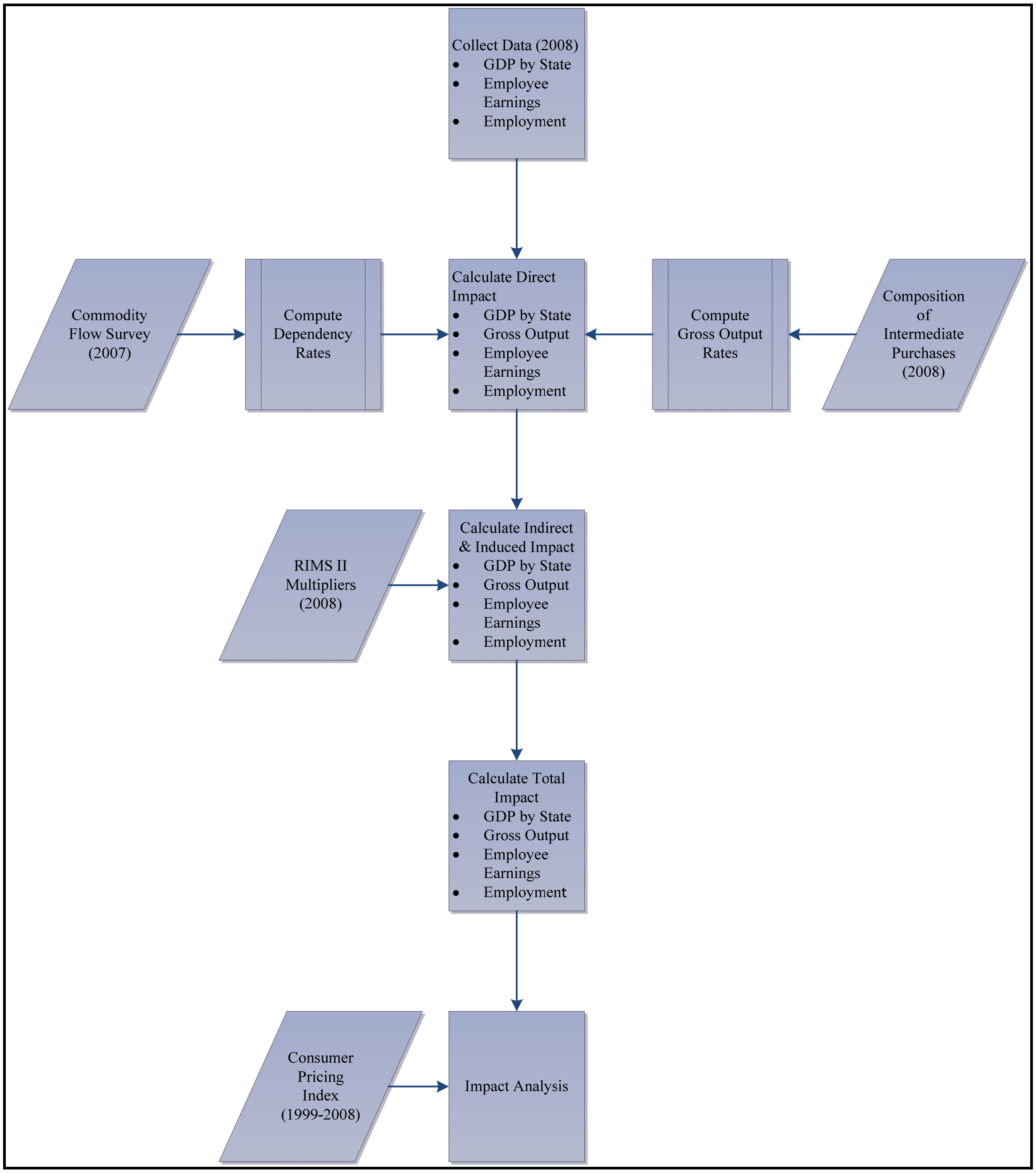

Figure 10: Economic Impact Methodology

Direct impacts are defined by Hamilton, Rasmussen and Zeng (2000) as the dollar value of ports' and terminals' main processes. These processes include, according to Cowan and Brooks (1995): stevedoring, cargo-passenger handling expenses, vessel port-call expenses, crew expenditures, and services relating to freight forwarding, banking, and insurance.

The indirect impacts are created by direct impacts because directly dependent industries request some supply outputs from other industries. For instance, directly dependent industries in the State of Arkansas might need supplies from other industries located in Arkansas. Thus, the directly dependent industries spend a part of their generated revenues on the local economy of Arkansas (Economic Research Associates, 2007).

Cowan and Brooks (1995, p. 401) explain that induced impacts "include the economic activities arising from household purchases of goods and services made possible because of the wages generated by the direct and indirect activities." The authors also mention that it is hard to distinguish indirect and induced impacts from each other. The problem can be overcome by using RIMS II multipliers. By multiplying the direct impacts with the RIMS II multipliers, the total impacts can be calculated. Then, subtracting the direct impacts from the total impacts leads to the sum of indirect and induced impacts.

5.2.1 Data Collection

The first step is to determine which data will be valuable to conduct the Economic Evaluation of Arkansas Inland Waterways analysis. The following Table 10 shows the data sources that contribute to the success of the project.

Table 10: Data Sources

Data Type	Data Source
2007 Arkansas Origin and Destination Commodity Flow Survey in value and in tons	Bureau of Transportation Statistics, 2010
2008 Arkansas Gross Domestic Product by State ($)	Bureau of Economic Analysis, 2012
2008 Compensation of Employees by NAICS Industry Employee Earnings Data	Bureau of Economic Analysis, n.d., Regional Data
2008 Arkansas Total Full-Time and Part-Time Employment Data (# of jobs)	Bureau of Economic Analysis, n.d., Regional Data
2008 Arkansas RIMS II Multipliers	Bureau of Economic Analysis, n.d., RIMS II Online Order and Delivery System
1999–2008 Consumer Pricing Index	U.S. Bureau of Labor Statistics, 2012
2008 U.S. Composition of Intermediate Purchases	Bureau of Economic Analysis, n.d., RIMS II Online Order and Delivery System

5.2.2 Direct Impact

In this section, the calculation of the direct impacts is discussed. To measure direct impacts, first the dependency rates for each industry are calculated using Commodity Flow Survey data (Bureau of Transportation Statistics, 2010), and then Gross Output Rates are computed by using the composition of intermediate purchase data (Bureau of Economic Analysis, n.d.a). Lastly, the three economic indicators of GDP by State, Employee Earnings, and Employment are multiplied by the dependency rate for each industry to calculate the initial change in final demand. However, to find "each additional dollar of output delivered to final demand" (Bureau of Economic Analysis, n.d.b) for each industry, the Gross Output Rate is utilized. The reason for converting the direct GDP by State impact to direct Gross Output impact is that final demand RIMS II multipliers are based on Direct Gross Output impact.

5.2.2.1 Compute the Dependency Rates

The dependency rate of each industry is identified by using the 2007 Commodity Flow Survey Data (Bureau of Transportation Statistics, 2010). These rates are used to calculate the direct impacts of the water transportation subsector and the dependent industries. The dependent industries are the industries that their outputs carried on the Arkansas navigable water transportation system. Dependency rates are calculated for the sector levels of manufacturing and wholesale trade, because subsector level values are not available for the water transportation industry in the State of Arkansas in the 2007 Commodity Flow Survey Data (Bureau of Transportation Statistics, 2010). For information purposes, the subsectors of the manufacturing sector are wood, product manufacturing, petroleum and coal products, manufacturing, chemical manufacturing, primary metal manufacturing, fabricated metal product manufacturing, and miscellaneous manufacturing. The subsectors of the wholesale trade sector are merchant wholesalers; durable goods, which consist of hardware and plumbing merchant wholesalers and merchant wholesalers; and nondurable goods, which includes an industry group of farm product raw material merchant wholesalers. To calculate the dependency rate of each industry deemed to depend on water transportation, Equation 1 is utilized.

$$D_i = \frac{W_i}{T_i}$$ **Equation 1**

D_i : Dependency rate of industry *i*

W_i : Total tonnage shipped via water transportation by industry *i*

T_i : Total tonnage shipped via all modes of transportation by industry *i*

Example:

W_i and T_i are found to be 1,179,000 tons and 117,995,000 tons in the 2007 Commodity Flow Survey, respectively for the manufacturing sector in the State of Arkansas. Utilizing Equation 1, D_i where i=Manufacturing is calculated as:

$$D_{Manufacturing} = \frac{1{,}179{,}000\ tons}{117{,}995{,}000\ tons} = 0.0100$$

Table 11 shows the dependency rates of the industries that depend on inland waterways in the State of Arkansas. It is assumed that the dependency rate of the water transportation subsector is fully dependent and therefore, equal to 1.0000.

Table 11: Dependency Rates

NAICS Code	NAICS Description	Transportation Type	Destination: AR (tons)	Origin: AR (tons)	Total (tons)	Dependency Rate
31-33	**Manufacturing**	All Modes	55,864,000	62,131,000	117,995,000	0.0100
		Water	880,000	299,000	1,179,000	
42	**Wholesale trade**	All Modes	37,679,000	35,842,000	73,521,000	0.0832
		Water	2,329,000	3,789,000	6,118,000	
483	**Water transportation**	N/A	N/A	N/A	N/A	1.0000

5.2.2.2 Compute the Gross Output Rates

The Gross Output Rate is calculated and utilized to convert direct GDP by State impacts into direct Gross Output impacts. In this section, the step by step calculation of the Gross Output Rate is illustrated. The first step is to calculate the Total Value Added of the water transportation subsector and the dependent industries, which is gathered from U.S. Department of Commerce Bureau of Economic Analysis (Bureau of Economic Analysis, n.d.b). The values in the Total Value Added column in Table 12 are the summation of employee compensation, taxes on production and imports, less subsidies, and gross operating surplus columns. The Total Value

Added of the manufacturing sector is the summation of the Total Value Added of all the subsectors that are dependent on the water transportation subsector in the State of Arkansas.

Table 12: Total Value Added of sectors and subsectors of the U.S.

		Composition of Intermediate Purchases (U.S. Producer Value)			
NAICS Code	**NAICS Description**	**Compensation of employees**	**Taxes on production and imports, less subsidies**	**Gross operating surplus**	**Total Value Added**
483	**Water Transportation**	$5,871,000,000	$710,000,000	$7,537,000,000	$14,118,000,000
31- 33	**Manufacturing**	$294,707,000,000	$16,568,000,000	$350,961,000,000	$662,236,000,000
321	**Wood Product Manufacturing**	$21,425,000,000	$839,000,000	$4,504,000,000	$26,768,000,000
324	**Petroleum and Coal Products Manufacturing**	$16,657,000,000	$2,899,000,000	$129,691,000,000	$149,247,000,000
325	**Chemical Manufacturing**	$87,498,000,000	$6,369,000,000	$118,938,000,000	$212,805,000,000
331	**Primary Metal Manufacturing**	$33,232,000,000	$2,338,000,000	$22,940,000,000	$58,510,000,000
332	**Fabricated Metal Product Manufacturing**	$91,067,000,000	$2,841,000,000	$41,757,000,000	$135,665,000,000
339	**Miscellaneous Manufacturing**	$44,828,000,000	$1,282,000,000	$33,131,000,000	$79,241,000,000
42	**Wholesale trade**	$437,510,000,000	$176,024,000,000	$207,495,000,000	$821,029,000,000

Table 12 shows the U.S. values of the Total Value Added of the water transportation subsector as $14,118,000,000, of the manufacturing sector as $662,236,000,000, and of the wholesale trade sector as $821,029,000,000.

After calculating the Total Value Added, the Gross Output of the water transportation subsector and the two dependent industries are calculated. The Gross Output is calculated as the summation of the U.S. producer values of all aggregate industries (Bureau of Economic Analysis, n.d.b).

Next, the Total Value Added rate is calculated using Equation 2:

$$VAR_i = \frac{TVA_i}{GO_i} \qquad \textbf{Equation 2}$$

VAR_i : Value Added rate of industry *i*

TVA_i: Total Value Added of industry *i*

GO_i : Gross Output of industry *i*

Last, the value-added rates are converted into Gross Output Rates Equation 3:

$$GOR_i = \frac{1}{VAR_i} \qquad \textbf{Equation 3}$$

GOR_i *: Gross Output Rate of industry i*

Example:

$TVA_{Manufacturing}$ *is calculated from Table 12 as $662,236,000,000, and* $GO_{Manufacturing}$ *is given as $2,201,013,000,000 in Table 13* (Bureau of Economic Analysis, n.d.a).

$$VAR_{Manufacturing} = \frac{\$662,236,000,000}{\$2,201,013,000,000} = 0.3009$$

$$GOR_{Manufacturing} = \frac{1}{0.3009} = 3.3236$$

The result in the example can be interpreted as every dollar of Gross Output of the manufacturing sector in the U.S. generates approximately 30 cents of value-added output, or one dollar of value added is generated approximately from three dollars and thirty-two cents of Gross Output. Since there is no state-level data available for the State of Arkansas, these national rates are used as approximates for the dependent industries of the State of Arkansas.

The latter calculation is repeated for water transportation and the two dependent industries, and the results are shown in Table 13. The shaded cells represent the Gross Output rates that are utilized to calculate the direct impacts.

Table 13: Gross Output Rate Results

		Composition of Intermediate Purchases (U.S. Producer Value)			
NAICS Code	**NAICS Description**	**Total Value Added**	**Gross Output**	**Value-added Rate**	**Gross Output Rate**
483	**Water Transportation**	$14,118,000,000	$38,172,000,000	0.3699	2.7038
31- 33	**Manufacturing**	$662,236,000,000	$2,201,013,000,000	0.3009	3.3236
321	**Wood Product Manufacturing**	$26,768,000,000	$96,354,000,000	0.2778	3.5996
324	**Petroleum and Coal Products Manufacturing**	$149,247,000,000	$726,001,000,000	0.2056	4.8644
325	**Chemical Manufacturing**	$212,805,000,000	$638,372,000,000	0.3334	2.9998
331	**Primary Metal Manufacturing**	$58,510,000,000	$249,136,000,000	0.2349	4.2580
332	**Fabricated Metal Product Manufacturing**	$135,665,000,000	$338,701,000,000	0.4005	2.4966
339	**Miscellaneous Manufacturing**	$79,241,000,000	$152,449,000,000	0.5198	1.9239
42	**Wholesale trade**	$821,029,000,000	$1,267,191,000,000	0.6479	1.5434

In this section the direct impacts are computed by utilizing the dependency rates and Gross Output rates for the four economic indicators.

$$Direct_{GDP_i} = GDP_i * D_i$$ **Equation 4**

$Direct_{GDP_i}$: GDP by State ($) of directly impacted portion of industry *i*

GDP_i : GDP by State ($) of industry *i*

$$Direct_{GO_i} = Direct_{GDP_i} * GOR_i$$ **Equation 5**

$Direct_{GO_i}$: Gross Output value ($) of directly impacted portion of industry *i*

$$Direct_{EmpEarn_i} = EmpEarn_i * D_i$$ **Equation 6**

$Direct_{EmpEarn_i}$: Employee earnings ($) of directly impacted portion of industry *i*

$EmpEarn_i$: Employee earnings ($) of industry *i*

$$Direct_{Emp_i} = Emp_i * D_i$$ **Equation 7**

$Direct_{Emp_i}$: Employment of directly impacted portion of industry *i*

Emp_i : Employment of industry *i*

Example:

It is important to note that all of the numbers are rounded. $D_{Manufacturing}$ is calculated as 0.0100 in Table 11 and $GOR_{Manufacturing}$ is computed as 3.3236 in Table 13. $GDP_{Manufacturing}$ for the State of Arkansas is $14,693,000,000 in year 2008 (Bureau of Economic Analysis, 2012) . Thus, the direct Gross Output impact of the manufacturing sector in the State of Arkansas is calculated as follows:

$$Direct_{GDP_{Manufacturing}} = \$14{,}693{,}000{,}000 * 0.0100 = \$146{,}811{,}704$$

$$Direct_{GO_{Manufacturing}} = \$146{,}811{,}704 * 3.3236 = \$487{,}944{,}583$$

5.2.2.3 Direct Impact Results

In Table 14, the direct impact results for the water transportation subsector and the dependent industries are given for each economic indicator. The total values are calculated as the summation of water transportation and dependent industries for each economic indicator. These direct impact values were used for the calculation of indirect and induced impacts.

Table 14: Direct Impact of Water Transportation Subsector and Dependent Industries (2008)

Industry	Economic Indicator	Direct Impact
Water Transportation	**GDP by State ($)**	$18,000,000
	Gross Output ($)	$48,668,083
	Employee Earnings ($)	$7,420,000
	Employment (# of jobs)	268
Dependent Industries	**GDP by State ($)**	$720,241,581
	Gross Output ($)	$1,372,986,621
	Employee Earnings ($)	$345,187,467

	Employment (# of jobs)	6,248
Total	**GDP by State ($)**	$738,241,581
	Gross Output ($)	$1,421,654,704
	Employee Earnings ($)	$352,607,467
	Employment (# of jobs)	6,516

5.2.3 Total Impact

5.2.3.1 Methodology

In this section, the direct impact of each dependent industry is multiplied by its corresponding RIMS II multipliers (Bureau of Economic Analysis, n.d.b). For indirect and induced GDP by State (value-added) impact final demand value-added multipliers are used, and for Gross Output impact, final demand output multipliers are used. However, direct-effect multipliers are used for calculating the Employment and Employee Earnings indirect and induced economic impacts. Finally, to find the total impact, direct, indirect, and induced impacts are totaled. The RIMS II multipliers are illustrated in Table 15.

Table 15: RIMS II Multipliers

	Final Demand Multipliers		**Direct Effect Multipliers**	
Industry	**Output (dollars)**	**Value-added (dollars)**	**Earnings (dollars)**	**Employment (jobs)**
Water Transportation	1.5400	0.6602	2.0959	2.9475
Manufacturing	1.8333	0.7499	2.3444	2.8012
Wholesale Trade	1.6822	1.0381	1.6088	2.0292

$$Indirect_{GDP_i} = Direct_{GO_i} * RIMS_{VA_i} - Direct_{GDP_i}$$ **Equation 8**

$Indirect_{GDP_i}$: Indirect and induced GDP by State impact ($) of industry *i*

$RIMS_{VA_i}$: Final demand value-added multiplier of industry *i*

$$Indirect_{TGO_i} = Direct_{GO_i} * RIMS_{O_i} - Direct_{GO_i}$$ **Equation 9**

$Indirect_{GO_i}$: Indirect and induced Gross Output ($) impact of industry *i*

$RIMS_{O_i}$: Final demand output multiplier of industry *i*

$$Indirect_{EmpEarn_i} = Direct_{EmpEarn_i} * RIMS_{Earn_i} - Direct_{EmpEarn_i}$$ **Equation 10**

$Indirect_{EmpEarn_i}$: Indirect and induced Employee Earnings ($) impact of industry *i*

$RIMS_{Earn_i}$: Direct- effect earnings multipliers of industry *i*

$$Indirect_{Emp_i} = Direct_{Emp_i} * RIMS_{Emp_i} - Direct_{Emp_i}$$ **Equation 11**

$Indirect_{Emp_i}$: Indirect and induced Employment impact of industry *i*

$RIMS_{Emp_i}$: Direct- effect Employment multipliers of industry *i*

Example:

$Direct_{GO_{Manufacturing}}$ is calculated as \$487,944,583 in section 2.4.3 and $RIMS_{O_{Manufacturing}}$ is given as 1.8333.

$$Indirect_{GO_{Manufacturing}} \$487,944,583 * 1.8333 - \$487,944,583 = \$406,620,486$$

5.2.3.2 Total Impact Results

In Table 16, the direct impact values are given for water transportation and dependent industries in the Direct Impact Column. In the fourth Column, the indirect and induced impacts, which are calculated by multiplying direct impact with the corresponding RIMS multipliers, are shown. The total impact Column is calculated as the summation of the direct, indirect, and induced impact values. The shaded numbers give the total impacts of the water transportation subsector in the State of Arkansas.

Table 16: Total Economic Impacts

Industry	Economic Indicator	Direct Impact	Indirect & Induced Impact	Total Impact
Water Transportation	GDP by State ($)	$18,000,000	$14,130,669	$32,130,669
	Gross Output ($)	$48,668,083	$26,280,765	$74,948,848
	Employee Earnings ($)	$7,420,000	$8,131,578	$15,551,578
	Employment (# of jobs)	268	522	790
Dependent Industries	GDP by State ($)	$720,241,581	$564,413,937	$1,284,655,518
	Gross Output ($)	$1,372,986,621	$1,010,396,164	$2,383,382,785
	Employee Earnings ($)	$345,187,467	$275,327,972	$620,515,439
	Employment (# of jobs)	6,248	7,865	14,114
Total	GDP by State ($)	$738,241,581	$578,544,605	$1,316,786,186
	Gross Output ($)	$1,421,654,704	$1,036,676,929	$2,458,331,633
	Employee Earnings ($)	$352,607,467	$283,459,550	$636,067,017
	Employment (# of jobs)	6,516	8,387	14,904

5.2.4 Summary

The results of the economic impact analysis are presented according to four indicators: GDP by State (value-added) impacts, Gross Output impacts, Employee Earnings impacts, and Employment impacts.

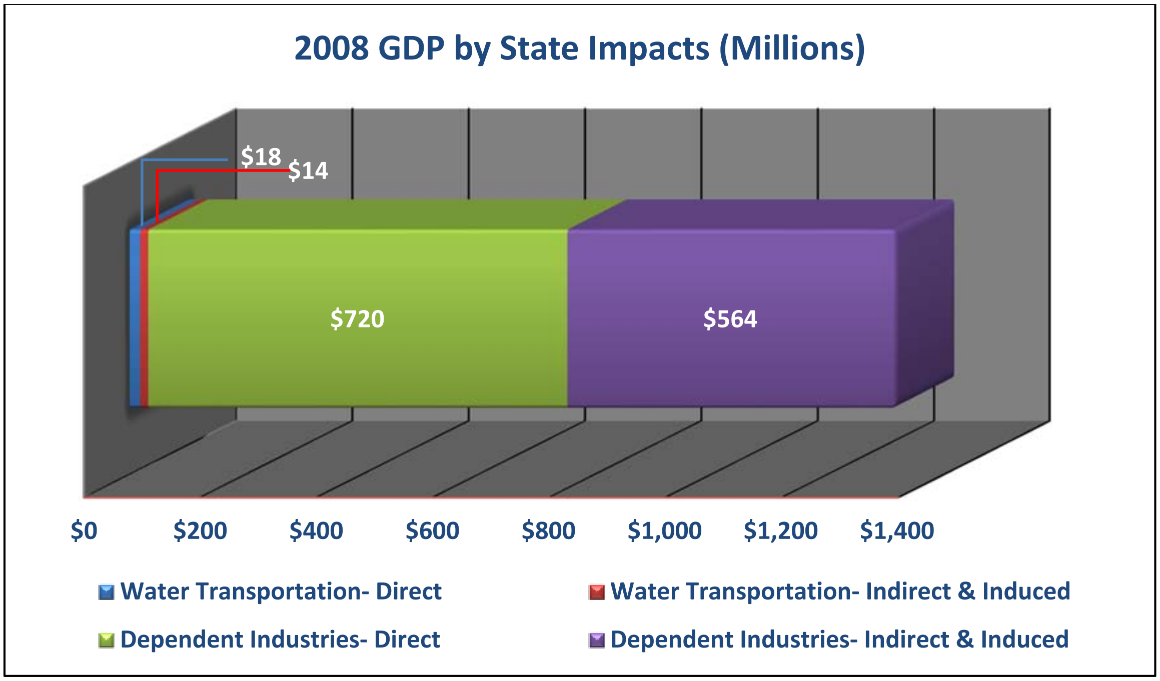

Figure 11: GDP by State Impacts

Figure 11 indicates the GDP by State (value-added) impacts of inland waterways in the State of Arkansas. The main findings are:

- The direct GDP by State impact of the water transportation subsector is $18 million.
- The direct GDP by State impact of the dependent sectors, manufacturing and wholesale trade, is $720 million.
- The indirect and induced GDP by State impact of the water transportation subsector is $14 million.
- The indirect and induced GDP by State impact of the dependent sectors is $564 million.

- As a result, the total GDP by State impact of inland waterways in the State of Arkansas is $1,317 million which is 1.32% of total GDP by State of the State of Arkansas in 2008.

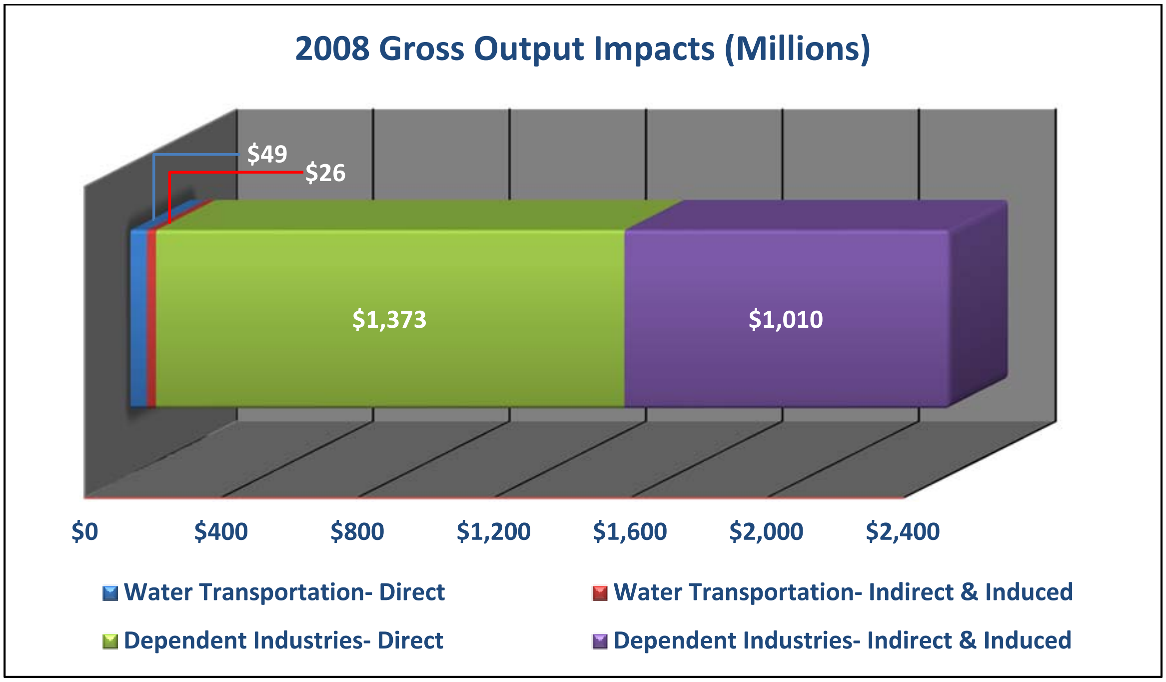

Figure 12: Gross Output Impacts

Figure 12 indicates the Gross Output impacts of inland waterway transportation in the State of Arkansas. The main findings are:

- The direct Gross Output impact of the water transportation subsector is $49 million.
- The direct Gross Output impact of the dependent sectors, manufacturing and wholesale trade is $1,373 million.
- The indirect and induced Gross Output impact of the water transportation subsector is $26 million.
- The indirect and induced Gross Output impact of the dependent sectors is $1,010 million.
- As a result, the total Gross Output impact of inland waterways in the State of Arkansas is $2,458 million.

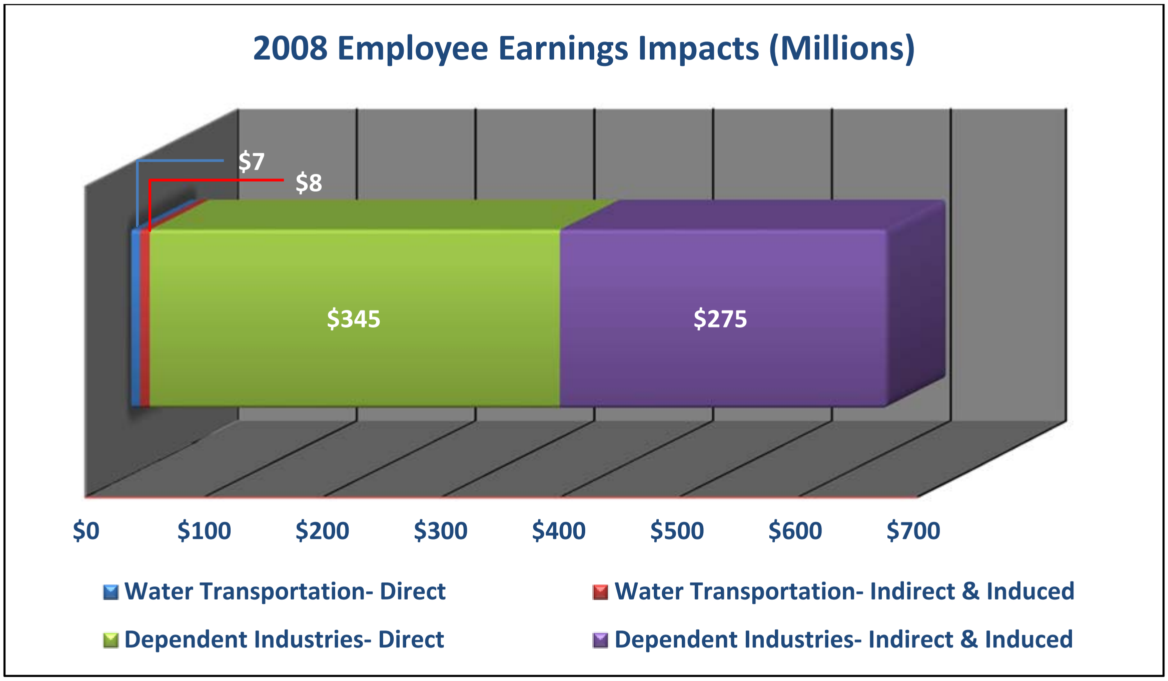

Figure 13: Employee Earnings Impacts

Figure 13 indicates the Employee Earnings impacts of inland waterways in the State of Arkansas. The 2008 Employee Earnings data are used to calculate the impacts. The main findings are:

- The direct Employee Earnings impact of the water transportation subsector is $7 million.
- The direct Employee Earnings impact of the dependent sectors, manufacturing and wholesale trade, is $345 million.
- The indirect and induced Employee Earnings impact of the water transportation subsector is $8 million.
- The indirect and induced Employee Earnings impact of the dependent sectors is $275 million.
- As a result, the total Employee Earnings impact of water transportation in the State of Arkansas is $636 million which is 1.14% of total Employee Earnings of the State of Arkansas in 2008.

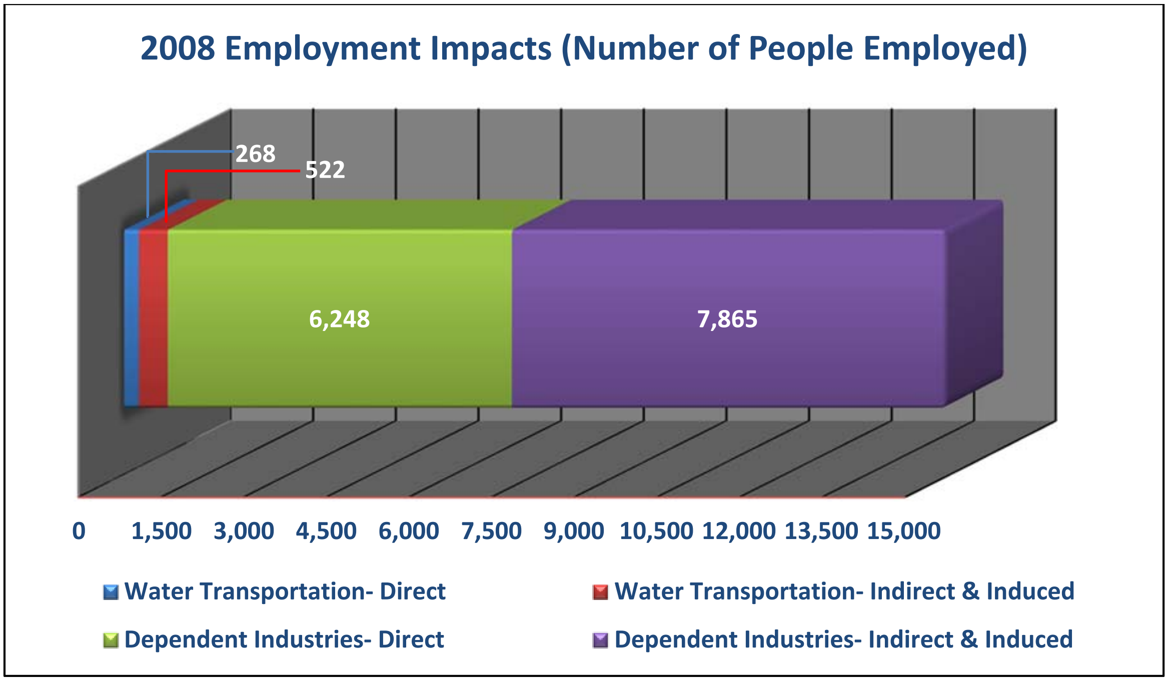

Figure 14: Employment Impacts

Figure 14 indicates the total Employment impacts of water transportation in the State of Arkansas. The 2008 Employment data are used to calculate the impacts. The main findings are:

- The direct Employment impact of the water transportation subsector is 268 people.
- The direct Employment impact of the dependent sectors, manufacturing and wholesale trade, is 6,248 people.
- The indirect and induced Employment impact of the water transportation subsector is 522 people.
- The indirect and induced Employment impact of the dependent sectors is 7,865 people.
- As a result, the total Employment impact of water transportation in the State of Arkansas is 14,904 people which is 0.94% of total Employment of the State of Arkansas in 2008.

5.2.5 Comparison

The following tables compare the results from the project "Economic Evaluation of the Impact of Waterways on the State of Arkansas" conducted in 2001 by Dr. Heather Nachtmann (Nachtmann, 2001) and this project. Nachtmann (2001) used data from 1998, and in the current project, data from 2008 is used.

To compare the results from the previous project (Nachtmann, 2001) and the current project, the GDP by state (value- added) impact found in 2001 needs to be adjusted for time value of money. Therefore, the consumer pricing index is used to adjust the 1998 total GDP by state impact to the year 2008.

$$Total_{GDP_{2008\,(adj.)}} = Total_{GDP_{1998}} * \prod_{t=1999}^{2008} \left(1 + \frac{CPI_t}{100}\right)$$ **Equation 12**

$Total_{GDP_{2008\,(adj.)}}$: 1998 total (direct+indirect+induced) GDP by state ($) of all industries adjusted for time value of money until the year 2008

$Total_{GDP_{1998}}$: Total (direct+indirect+induced) GDP by state ($) impact of all industries for the year 1998

$\mathrm{CPI_t}$: Consumer pricing index percentage for the year t

$$Total_{EmpEarn_{2008\,(adj.)}} = Total_{EmpEarn_{1998}} * \prod_{t=1999}^{2008} \left(1 + \frac{CPI_t}{100}\right)$$ **Equation 13**

$Total_{EmpEarn_{2008\,(adj.)}}$: 1998 total (direct+indirect+induced) employee earnings ($) of all industries adjusted for time value of money to the year 2008

$Total_{EmpEarn_{1998}}$: Total (direct+indirect+induced) employee earnings ($) of all industries for the year 1998

Example:

The total GDP by state impact was measured as $811 million in the previous analysis (Nachtmann, 2001).

$$Total_{GDP_{2008\,(adj.)}} = Total_{GDP_{1998}} * \left(1 + \frac{CPI_{1999}}{100}\right) * \left(1 + \frac{CPI_{2000}}{100}\right) * \ldots * \left(1 + \frac{CPI_{2008}}{100}\right)$$

$$Total_{GDP_{2008\,(adj.)}} = \$811{,}392{,}531 * \left(1 + \frac{2.2}{100}\right) * \left(1 + \frac{3.4}{100}\right) * \ldots * \left(1 + \frac{3.8}{100}\right) = \$1{,}071{,}336{,}852$$

In the previous analysis in 2001, the total GDP by state impact was measured as $811 million. Adjusted for inflation this shows a 22.91% increase.

Table 17: Comparison of Total GDP by State Impacts

Year	Consumer Pricing Index (%)	Total GDP by State (1998)	Total GDP by State Impact (2008)	Change (%)
1998	1.6	$811,392,531		
1999	2.2	$829,243,167		
2000	3.4	$857,437,434		
2001	2.8	$881,445,682		
2002	1.6	$895,548,813		
2003	2.3	$916,146,436		
2004	2.7	$940,882,390		
2005	3.4	$972,872,391		
2006	3.2	$1,004,004,308		
2007	2.8	$1,032,116,428		
2008	3.8	$1,071,336,852	$1,316,786,186	22.91%

In the previous 2001 analysis, the total employee earnings impacts were measured as $561 million. Adjusted for inflation, this shows a 14.11% decrease.

Table 18: Comparison of Total Employee Earnings

Year	Consumer Pricing Index (%)	Total Employee Earnings (1998)	Total Employee Earnings (2008)	Change (%)
1998	-	$560,876,401		
1999	2.2	$573,215,682		
2000	3.4	$592,705,015		
2001	2.8	$609,300,755		
2002	1.6	$619,049,568		
2003	2.3	$633,287,708		
2004	2.7	$650,386,476		
2005	3.4	$672,499,616		
2006	3.2	$694,019,604		
2007	2.8	$713,452,152		
2008	3.8	$740,563,334	$636,067,017	-14.11%

In the previous 2001 analysis, the total employment impact was measured with 17,418 people. This shows a 14.43% decrease.

Table 19: Comparison of Total Employment

Total Employment (1998)	Total Employment (2008)	Change (%)
17,418	14,904	-14.43%

5.2.6 Conclusion

Conducting an economic impact study can be costly in terms of money and time (Hamilton, 2001) if primary data are gathered with surveys and interviews. Although a primary data collection approach may lead to more accurate results, the accuracy of a survey based approach depends on the response rate and response quality of the respondents. Companies might not be willing to share confidential information related to sales, proportion of the products shipped via water transportation, customers, suppliers, employment and employee earnings, and capital. In this project a systematic economic analysis study of inland waterways in Arkansas is conducted. Since publicly available data sources are utilized, the method can be used for different economic regions and is not only limited to Arkansas. Especially for relatively big regions, such as cities, states, or countries, our approach can be applied by using readily available governmental data sources related to economic indicators and commodity flow survey.

5.3 Potential Disruption Impacts

5.3.1 Introduction

After assessing the economic impact of inland waterway transportation in Arkansas, this section will now shift the focus to assessing potential economic disruption impacts. The purpose of this section is to measure the economic impacts of potential disruptions on the inland waterways navigation system in the State of Arkansas. The nature of disruptions is multifaceted, but it is likely that some disruptions of inland waterway transportation to occur.

The most important factor of disruptive events is that they cannot be precisely predicted. Hence, uncertainty plays a major role when evaluating the economic impact of such events. To address the uncertainty of disruptive event, a scenario analysis, including Monte Carlo simulation and sensitivity analysis, are conducted in this study. The magnitude of the economic impact of a disruption depends on disruption duration estimation accuracy and on the decision making process of decision makers. Therefore, a decision tree analysis is also utilized to better understand the behavior of individual decision makers under different disruption scenarios.

Figure 15 provides an overview of our methodology for assessing the economic impact of disruptive events on navigable waterways. First, some underlying calculations are presented upon which the main assessment of the disruption impact is based on. Then, transportation, penalty, and holding cost are assessed. Next, the decision making process is outlined to better understand under which condition on alternative will be chosen. Furthermore, in a scenario analysis, the disruption impact on the dependent industries is calculated. Lastly, the disruption impact on the water transportation subsector is presented.

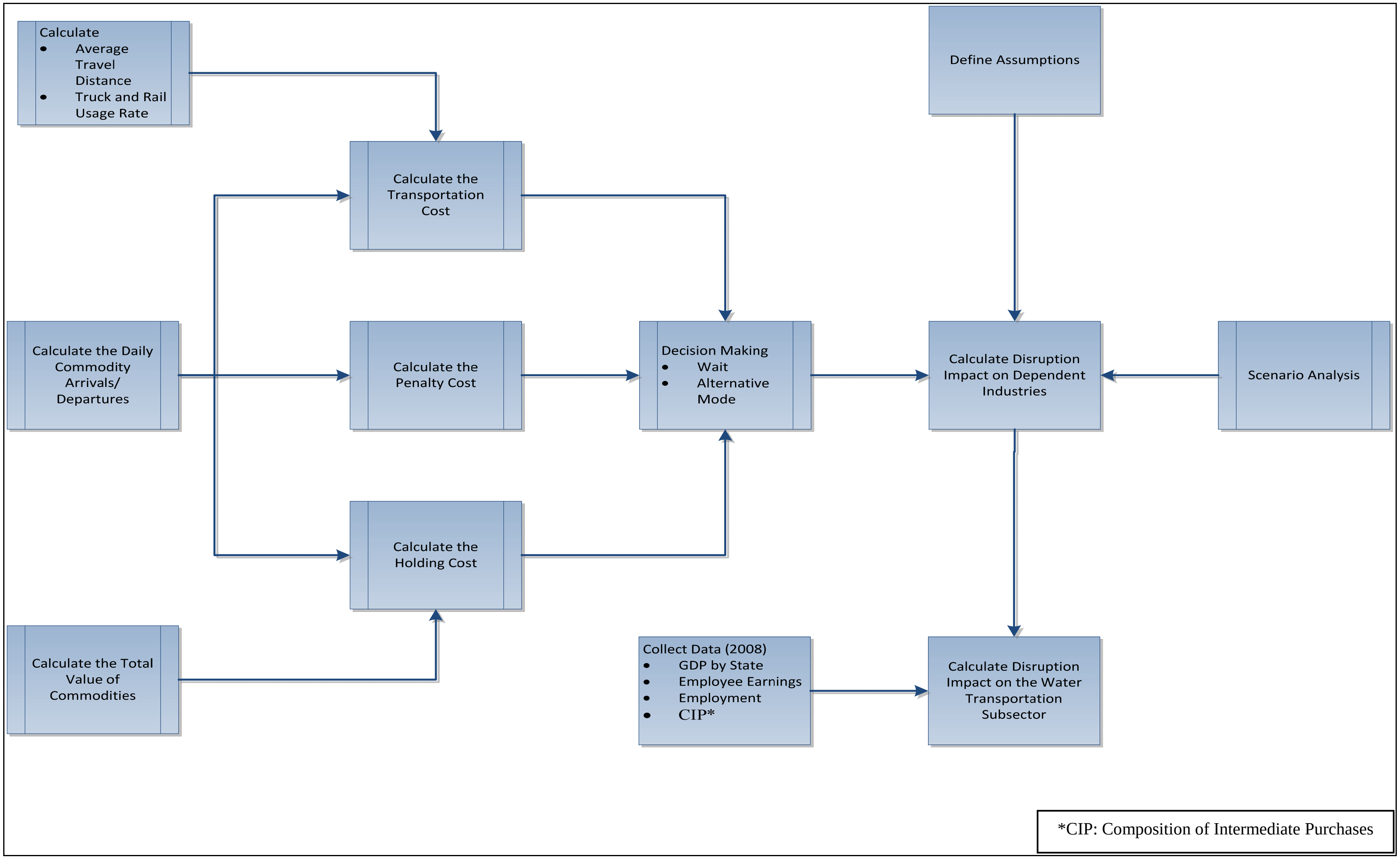

Figure 15: Economic Impact of Navigable Waterway Disruptions Assessment Methodology

5.3.2 Assumptions

Several assumptions were made to conduct this disruption assessment. The list of assumptions and corresponding sources is given in Table 20.

Table 20: Assumptions

Assumptions	Reference
There is no capacity constraint on alternative mode of transportation.	MacKenzie, Barker, & Grant, 2011
Commodity flow only on the inland waterways of the State of Arkansas is disrupted.	Pant, Barker, Grant, & Landers, 2011
The inland waterways system works 5 days a week.	Pant, Barker, Grant, & Landers, 2011
The 2008 yearly commodity flow is converted to a daily flow by dividing it into 260 working days.	Pant, Barker, Grant, & Landers, 2011
As soon as the disruption is over, all barges that queued up will be able to move immediately from/to the inland waterway system in Arkansas.	Pant, Barker, Grant, & Landers, 2011
Commodity price and final demand do not change.	Rose & Liao, 2005
A daily holding cost of h = $100/day represents a 24.33% annual holding cost rate, a reasonable rate for many supply chains	Lewis, Erera, & White III, 2006
The cost per ton mile is 0.72 cents for barge, 2.24 cents for rail, and 26.61 cents for truck.	Guler, Johnson, & Cooper, 2012
The market behaves monopolistically, so there are no substitutes for commodities.	Thissen, 2004
For the first week the shipment is late a 3% penalty cost is charged. For each additional week the shipment is late, an additional 7% penalty cost is charged on top of the initial 3%.	Anjoran, 2009

5.3.3 Disruption Impact on the Dependent Industries

First, this section illustrates some underlining calculations for the total cost estimation. Second, transportation cost, penalty cost, and holding cost are calculated. Third, an overview of the decision making process is presented.

5.3.3.1 Calculating the Daily Commodity Arrivals and Departures

In Table 21, 2008 commodity flow values (Qu & Meng, Transportataion Research Board, n.d.) are given for three categories: from Arkansas to other states, from other states to Arkansas, and from Arkansas to Arkansas.

Table 21: Daily Arrivals of Shipments

	2008 Commodity Flow (tons)	# of Shipments per Year	# of Working days in a Year	# of Shipments per Day
From Arkansas to Other States	9,353,063	1,039	260	4.00
From Other States to Arkansas	7,453,812	828	260	3.19
From Arkansas to Arkansas	2,592,531	288	260	1.11
			Total	**6.07**

The capacity for one barge is estimated as 1,500 tons (Iowa Department of Transportation, 2008). In addition, it is estimated that one shipment equals to six barges (May, 2002), so the capacity of one shipment is calculated as the following:

$$w_{shipment} = 6 * w_b \qquad \textbf{Equation 14}$$

$w_{shipment}$: Weight capacity of a shipment which includes 6 barges in tons

w_b: Weight capacity of a barge in tons

The number of shipments needed to accommodate the commodities of the year 2008 can be found with Equation 15:

$$n_{shipment,i} = \frac{CF_{2008,i}}{w_{shipment}}$$ **Equation 15**

$CF_{2008,i}$: 2008 commodity flow in tons (i=1, 2, 3; for 1= from Arkansas to other states; 2= from other states to Arkansas; 3= from Arkansas to Arkansas)

$n_{shipment,i}$: Number of shipments for year 2008 (i=1, 2, 3; for 1= from Arkansas to other states; 2= from other states to Arkansas; 3= from Arkansas to Arkansas)

Example: $CF_{2008,1}$ is given as 9,353,063 tons from Arkansas to other states (U.S. Army Corps of Engineers, n.d.).

$$w_{shipment} = 6 * 1{,}500 = 9{,}000\ tons$$

$$n_{shipment,1} = \frac{9{,}353{,}063}{9{,}000} = 1{,}039 \text{ shipments}$$

As it can be seen in Table 21, the number of working days is calculated as 5 days per week for 52 weeks which equals to 260 days working days per year (Pant, Barker, Grant, and Landers, 2011). As a result, there are 4 outgoing, 3.19 incoming, and 1.11 intra-regional shipments on average per working day on the State of Arkansas inland waterway system. To account for the stochastic behavior of shipment arrivals and departures, it is assumed that the total arrival and departure number of shipments in the State of Arkansas inland waterway system is Poisson distributed with a mean 6. The mean is calculated as the summation of incoming and outgoing commodity flow (in terms of number of shipments) minus the intra- regional flow (in terms of number of shipments). The mean is calculated as 6.07 as shown in Table 21, and is rounded to 6 shipments.

5.3.3.2 Calculating the Average Travel Distance

According to the 2007 Commodity Flow Survey (Bureau of Transportation Statistics, 2010), the distance of commodities travelled is between 250 and 499 miles. For further calculations it is assumed that the average travel distance for a ton of commodity (d_{av}) is uniformly distributed between 250 and 499 miles which is illustrated in Table 22.

Table 22: Average Travel Distance (miles) for Inland Waterways Transportation

	Mile
Average Distance 2007 per ton	250- 499

5.3.3.3 Calculating Truck and Rail Usage Rates

When a disruption of the waterway system occurs, carriers can chose to either wait until the water system reopens or go with an alternative mode of transportation. The following truck and rail usage rates are only relevant for carriers who decide to switch to an alternative mode of transportation.

Table 23: Usage Ratios for Various Transportation Modes

Truck Usage Rate (ton based)	Rail Usage Rate (ton based)	Normalized Truck Usage Rate	Normalized Rail Usage Rate
0.797	0.106	0.883	0.117

In Table 23, the State of Arkansas truck and rail usage rates are taken from the 2007 Commodity Flow Survey Table 1a (Bureau of Transportation Statistics, 2010). The reason for calculating the truck and rail usage rates is that the shipments that are disrupted on the navigable inland waterway transportation are assumed to use truck or rail as an alternative mode of transportation based on the calculated normalized usage rates. Then, the ratios are normalized as follows:

$$NU_{tr} = \frac{U_{tr}}{U_{tr} + U_r}$$ **Equation 16**

$$NU_r = \frac{U_r}{U_{tr} + U_r}$$ **Equation 17**

NU_{tr}: Normalized truck usage rate

U_{tr}: Truck usage rate

NU_r: Normalized rail usage rate

U_r: Rail usage rate

Example: U_{tr} and U_r are given as 0.797 and 0.106 respectively in the Commodity Flow Survey 2007.

$$NU_{tr} = \frac{0.797}{0.797 + 0.106} = 0.883$$

As a result of normalization, approximately 88.3% of the alternative mode commodities will be carried by trucks and 11.7% of the alternative mode commodities will be carried by rail during the disruption period.

5.3.3.4 Calculating the Total Value of Commodities per Shipment

The reason for calculating the total commodity value per shipment is that these values are used to calculate penalty cost due to late delivery. The total value per shipment is calculated in Table 24.

Table 24: Commodity Value ($)

Average Value per Ton	Total Value (6 barges)
$975.15	$8,776,358.11

The average value per ton is calculated from the 2007 Commodity Flow Survey utilizing Equation 18:

$$V_{ton} = \frac{V_{or} + V_{des}}{f_{or} + f_{des}} \qquad \textbf{Equation 18}$$

V_{ton}: The average value in dollars per ton for commodities that flow on inland waterways in the State of Arkansas

V_{or}: The total value in dollars of commodities that are originated in the State of Arkansas and delivered to other states on the inland waterways

V_{des}: The total value in dollars of commodities that are originated in other states and delivered to the State of Arkansas on the inland waterways

f_{or}: The total flow in tons of commodities that are originated in the State of Arkansas and delivered to other states on the inland waterways

f_{des}: The total flow in tons of commodities that are originated in other states and delivered to the State of Arkansas on the inland waterways

$$V_{shipment} = w_{shipment} * V_{ton} \qquad \textbf{Equation 19}$$

$V_{shipment}$: Total dollar value of the commodities of a shipment (6 barges)

Example: V_{or}, $V_{des,}$ f_{or}, f_{des} are given by the 2007 Commodity Flow Survey with $92,865,000,000, $93,892,000,000, $97,973,000, and $93,543,000 respectively. $w_{shipment}$ is calculated as 9,000 tons on page 31.

$$V_{ton} = \frac{\$92{,}865{,}000{,}000 + \$93{,}892{,}000{,}000}{97{,}973{,}000 + 93{,}543{,}000} = \$975.15$$

$$V_{shipment} = 9{,}000 * \$975.15 = \$8{,}776{,}358$$

For future calculations, it is assumed that the average value per ton is normally distributed with a mean of $975.15 and a standard deviation of $61.61. The standard deviation of average value per ton is calculated by using the coefficient of variation for value for the manufacturing and wholesale trade sectors of the 2007 Commodity Flow Survey data for the State of Arkansas.

5.3.3.5 Calculating the Cost

5.3.3.5.1 Transportation Cost

The transportation cost per ton mile is $0.0072 for one barge, $0.0224 for one railcar, and $0.2661 for one large semi- truck (Guler, Johnson, and Cooper, 2012).

Table 25: Transportation Costs per Ton Mile for Various Transportation Modes

	Barge	Railcars	Large Semi-truck	Transportation Cost
Transportation Cost per Ton Mile (dollars)	$0.007	$0.022	$0.266	$0.044

To measure the cost for alternative transportation modes, Equation 20 is used:

$$c_{alt} = NU_r * c_r + NU_{tr} * c_{tr} \qquad \textbf{Equation 20}$$

c_{alt}: Cost of alternative mode of transportation per ton mile

c_r: Cost of railcar per ton mile

c_{tr}: Cost of truck per ton mile

Transportation cost is the cost that incurs because of using an alternative mode of transportation rather than water transportation. Transportation cost per ton mile in dollars can be calculated as:

$$c_{add} = c_{alt} - c_b \qquad \textbf{Equation 21}$$

c_{add}: Transportation cost per ton mile that incur because of alternative mode of transportation usage

c_b: Cost of barge per ton mile

Example:

$$c_{alt} = 0.117 * 0.022 + 0.883 * 0.266 = \$0.051$$

$$c_{add} = 0.051 - 0.007 = \$0.044$$

Transportation cost is calculated with the following formula:

$$c_{Tadd}^{n} = c_{add} * d_{av} * w_{shipment}$$

c_{Tadd}^{n} = Total transportation cost for decision n (if decision 1 (wait) is selected, then n=1, if decision 2 is selected (using alternative mode of transportation), then n=2)

5.3.3.5.2 Penalty Cost

Penalty cost is taken as 3% of the total value of commodities for the first week of delay. A 7% charge is applied to any additional week of delay. A similar penalty system is used by Walmart (Painter and Whalen, 2010). Since a substantial amount of the commodity flow on the waterways of Arkansas consists of wholesales trade, this penalty cost system is applied. Penalty cost is calculated with the following formulas:

$$p_1 = t_{dweek} * 0.03 * V_{shipment} \qquad \textbf{Equation 22}$$

$$p_2 = \begin{cases} (t_{dweek} - 1) * 0.07 * V_{shipment} & , t_{dweek} > 1 \\ 0 & , otherwise \end{cases} \qquad \textbf{Equation 23}$$

p_1 : 3% penalty cost that applies every week that delivery is late

p_2 : 7% penalty cost that applies every week after the first week that delivery is late

t_{dweek} = Number of weeks that commodities are delivered late

5.3.3.5.3 Holding Cost

To calculate the holding cost per day per ton, the holding cost per 40 ft. container is converted to per ton values. The daily holding cost for a 40 ft. container is given as h = $100/day (Lewis, Erera, and White III, 2006). According to Lewis et al. (2006) this is "a reasonable rate for many supply chains."

Table 26: Holding Cost

	1 Container (40ft)	1 Ton
Holding cost per day	$100	$3.77

The calculation is given in Equation 24:

$$h_{ton} = \frac{h_{40ft}}{w_{40ft}} \qquad \textbf{Equation 24}$$

h_{ton}: Daily holding cost per ton

h_{40ft}: Daily holding cost per 40ft container

w_{40ft}: 40ft container weight capacity in tons which is 26.5 ton (Shipping Containers, n.d.)

Example:

$$h_{ton} = \frac{\$100/container}{26.5\ ton/container} = \$3.77\ per\ ton$$

The holding cost per shipment is calculated with Equation 25:

$$h_{shipment} = w_{shipment} * h_{ton} * 1.4 * t_{dday} \qquad \textbf{Equation 25}$$

$h_{shipment}$ = Holding cost per shipment that is caused by delay in delivery

t_{dday} = Number of working days that commodities are delivered late

It is multiplied by 1.4 because a normal week has 7 days. Thus, being 5 working days late means being late one whole week. Therefore daily holding cost is multiplied by seven to find the weekly cost, and then the calculated weekly cost is divided by 5 to find average cost per working day.

5.3.3.6 Decision Tree and Decision Making

Three different disruption scenarios are generated based on the literature. It is important to note that the duration of the scenarios can be adapted to different time frames. In our model, the total cost is calculated for short term (2 weeks), midterm (8 weeks), and long term (24 weeks) disruptions. Figure 16 presents the three scenarios. For each scenario, the decision makers have two alternatives, either to wait until the waterway reopen or to select a different mode of transportation. Also, each alternative contains three possible disruption duration outcomes, i.e. accurate estimation (A.E.), overestimation (O.E.), and underestimation (U.E.). Accurate estimation means the duration of disruption is correctly estimated whereas for the under and over estimation scenarios, the duration of disruption is not estimated precisely so that the decision makers must decide to either wait or use an alternative mode of transportation based on the incorrect estimation.

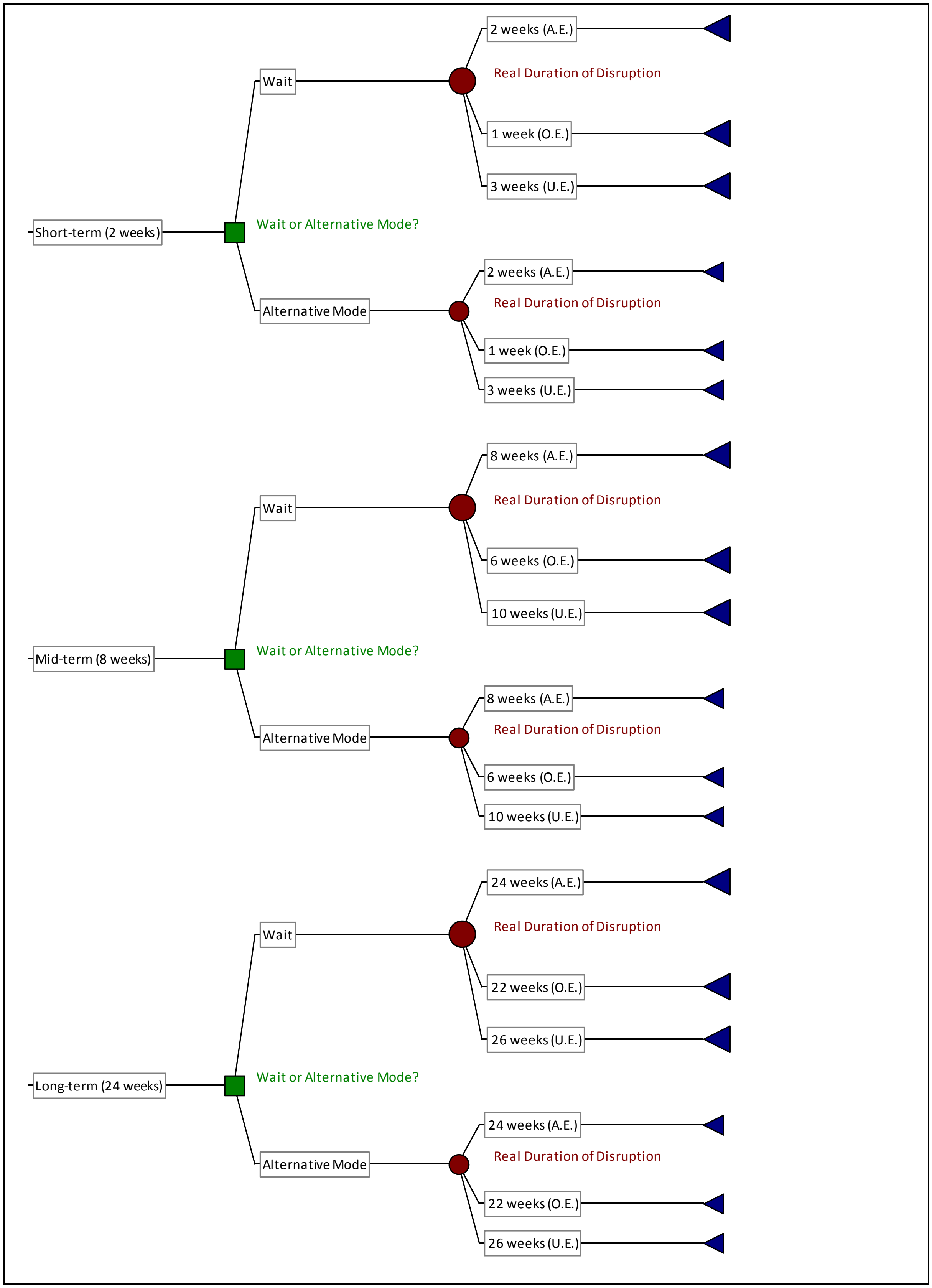

Figure16: Decision Tree

Total cost are compared for two decision alternatives in Table 27 to better understand which decision will be made under various disruption scenarios. The first decision is waiting until the disruption is over and the waterway reopens. The second decision is defined as choosing an alternative mode of transportation. As informed by the 2007 commodity survey, truck and rail are taken into consideration as alternative modes of transportation.

Table 27: Decision Scenarios

		Working Days (expected disruption period)			
Decision	**Cost Component**	**4**	**5**	**6**	**7**
Decision 1- Wait	**Transportation Cost**	$0	$0	$0	$0
	Penalty Cost 3%	$210,633	$263,291	$315,949	$368,607
	Penalty Cost 7%	$0	$0	$119,431	$238,862
	Holding Cost	$190,189	$237,736	$285,283	$332,830
	Total Cost	$400,821	$501,027	$720,663	$940,299
Decision 2- Alternative Mode	**Transportation Cost**	$147,652	$147,652	$147,652	$147,652
	Penalty Cost 3%	$255,923	$255,923	$255,923	$255,923
	Penalty Cost 7%	$0	$0	$0	$0
	Holding Cost	$237,736	$237,736	$237,736	$237,736
	Total Cost	$641,311	$641,311	$641,311	$641,311

In the first row of Table 27, the expected disruption periods in working days is given. According to these expectations, the companies make a decision to either wait or use an alternative mode of transportation. It is assumed that the expected disruption period is not changing at any point of time. Also, companies cannot change their decision according to subjective feelings. These assumptions are made because each disruption case may have its unique feature which can impact the costs drastically. This approach is a generic approach for any kind of disruption.

In the second column of Table 27, three different types of cost are identified. These costs are transportation cost, penalty cost, and holding cost. The penalty cost is defined with 3% for the first week of delay and 7% for any additional week of delay. All three types of costs are calculated as additional expense that occurs in addition to regularly incurred (no disruption) expenses.

It is shown in Table 27 that the transportation cost for Decision 1 is always $0 because transportation cost only occurs if the decision maker decides to choose a different mode of transportation. On the other hand, for Decision 2, the transportation cost is calculated as $147,651.79. The reason for the higher transportation cost is that choosing an alternative mode of transportation (truck and rail) is more expensive per ton-mile than using water transportation. In Table 27, all of the 7% penalty cost cells are calculated as $0 for a disruption period of less than a week. Only after 5 working days of disruption, the 7% penalty cost applies. Another important point is that independent from the real disruption duration, decision makers who chose to use an alternative mode of transportation do not need to pay the 7% penalty cost because it is assumed that they will reach their destination within one week. The time period of one week includes analyzing the situation, making the decision to use an alternative mode of transportation, finding the appropriate truck or railcar, and incurring the travel time for selected alternative mode of transportation to reach the commodity pickup location, loading time, and additional travel time to destination if it is longer than the barge transportation time.

Lastly, total cost is calculated from the summation of transportation cost, penalty cost, and holding cost. As a result, if the expected disruption length is longer than 5 working days (1 week), then it will be better for a decision maker to choose an alternative mode of transportation. However, if the expected disruption length is one week or less, it is better for a decision maker to wait until the inland waterway navigation system in Arkansas reopens. In Table 27, the preferred decisions are colored in green to indicate which decision is chosen.

5.3.4 Disruption Impact on the Water Transportation Subsector

Based on the results of the decision making section and proposed scenarios, the impact of disruption on the water transportation subsector is calculated in this section. The disruption impact of water transportation in the State of Arkansas is measured for the four economic indicators: GDP by State, Gross Output, Employee Earnings, and Employment. The measurement is based on the 2008 GDP by State data, the Gross Output Rate, the 2008 compensation of employees by NAICS industry data, the 2008 total full-time and part-time Employment by NAICS industry data, the number of shipments that chose an alternative mode of transportation because of disruption, and the total shipments in 2008 that travel via inland waterways in the State of Arkansas.

The 2008 GDP by State value of the water transportation industry in Arkansas is $18 million. (Bureau of Economic Analysis, 2012). The direct GDP by State loss is calculated with Equation 26:

$$Direct_{GDP_{Water}} = GDP_{Water} * \frac{n_{alt}}{\sum_{i=1}^{3} n_{shipment,i}}$$ **Equation 26**

n_{alt}: Number of shipments that choose an alternative mode of transportation because of disruption

$\sum_{i=1}^{3} n_{shipment,i}$: Total shipments in 2008 that travel via inland waterways in the State of Arkansas (i=1, 2, 3; for 1= from Arkansas to other states; 2= from other states to Arkansas; 3= from Arkansas to Arkansas)

The Gross Output Rate is calculated using Equation 3.

$$Direct_{GO_i} = Direct_{GDP_i} * GOR_i$$ **Equation 27**

$Direct_{GO_i}$: Gross Output value ($) of directly impacted portion of industry *i*

GOR_i: Gross Output Rate of industry *i*

$$Direct_{EmpEarn_{Water}} = EmpEarn_{Water} * \frac{n_{alt}}{\sum_{i=1}^{3} n_{shipment,i}}$$ **Equation 28**

$$Direct_{Emp_{Water}} = Emp_{Water} * \frac{n_{alt}}{\sum_{i=1}^{3} n_{shipment,i}}$$ **Equation 29**

Note: In Equations 27-29, it is assumed that all four economic indicators for the water transportation subsector in the State of Arkansas can be written as a linear function of the number of shipments. n_{alt} is randomly generated according to Poisson distribution with a mean of 6 shipments arrival per day. $\sum_{i=1}^{3} n_{shipment,i}$ is calculated as subtracting intra-regional shipments from the summation of Arkansas origin and destination flows (see Table 21). $\sum_{i=1}^{3} n_{shipment,i}$ can be calculated as:

$$\sum_{i=1}^{3} n_{shipment,i} = Origin\ Flows + Destiantion\ Flows - Intraregional\ Flows$$ **Equation 30**

$$\sum_{i=1}^{3} n_{shipment,i} = 1{,}039 + 828 - 288 = 1{,}579 \text{ shipments}$$

Example: For short- term and accurate duration estimation of the disruption scenario, direct GDP by State loss of water transportation is calculated using Equation 26 as shown below. n_{alt} is generated as 35 shipments for a disruption period of 2 weeks. GDP by State value corresponding to water transportation in the State of Arkansas is illustrated in Table 16 as $18,000,000. The total flow on the navigable inland waterway transportation calculated by using Equation 30 as 1,579 shipments

$$Direct_{GDP_{Water}} = \$18{,}000{,}000 * \frac{35}{1579} = \$398{,}987$$

5.3.5 Summary

5.3.5.1 Water Transportation Subsector

Table 28: Summary of Disruption Impacts on the Water Transportation Subsector

	Short- term (2 weeks)		Mid- term (2 months)		Long- term (6 months)	
	Mean	**95% Confidence Interval**	**Mean**	**95% Confidence Interval**	**Mean**	**95% Confidence Interval**
Direct GDP by State Loss ($)	$341,989	($227,992,$467,384)	$2,393,920	($2,063,331,$2,724,509)	$7,865,738	($7,272,958,$8,447,118)
Direct Gross Output Loss ($)	$924,663	($616,442,$1,294,528)	$6,472,639	($5,578,799,$7,366,480)	$21,267,243	($19,664,495,$22,839,170)
Direct Employee Earnings Loss ($)	$140,975	($93,984,$192,666)	$986,827	($850,551,$1,123,103)	$3,242,432	($3,012,172,$3,486,789)
Direct Employment Loss (# of jobs)	5	(3,7)	36	(31,41)	117	(109,126)

After running the Monte Carlo Simulation for 1,000 iterations, the results for the water transportation subsector are illustrated in Table 28. For each of the four economic indicators and each of the three disruption scenarios, the corresponding means and 95% confidence intervals are calculated. Since the impact on the water transportation subsector only depends on the estimation of the disruption duration, the actual disruption duration does not impact the water transportation subsector. Hence, the three scenarios of accurate estimation, overestimation and underestimation are studied under the short-term, mid-term, and long-term scenarios.

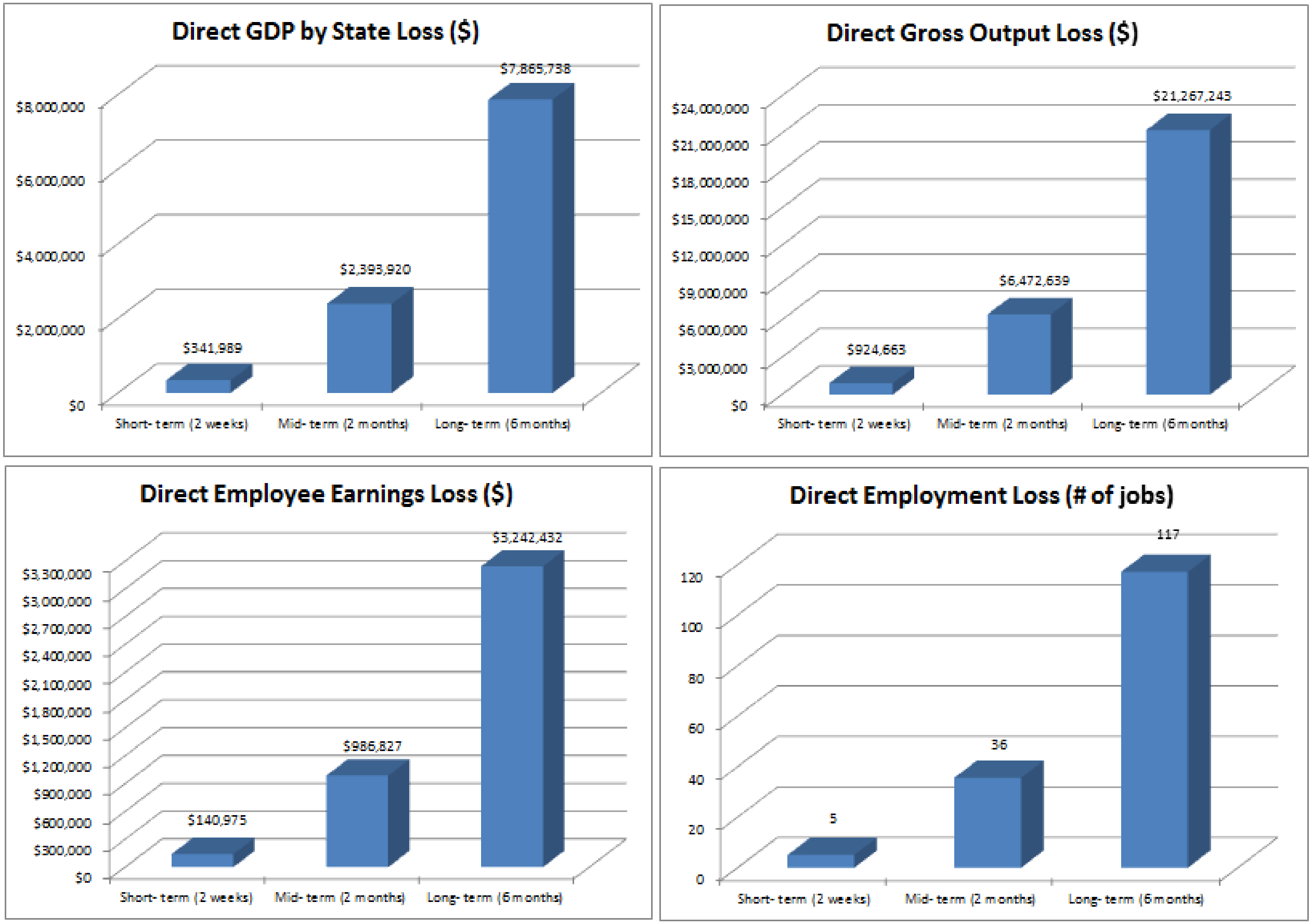

Figure 17: Summary of Disruption Analysis Results

As shown in Figure 17, the relationship of disruption duration estimation and the economic indicators is non-linear. For example, as the disruption duration estimation increases from 2 weeks to 2 months, the direct GDP by State loss increases approximately seven times. Also, as the disruption duration estimation increases from 2 weeks to 6 months, the direct GDP by State loss increases approximately 23 times. Since each of the four economic indicators is a linear function of shipments choosing an alternative mode of transportation, these ratios hold for all four economic indicators.

5.3.5.2 Dependent Industries

In Table 29, the first row presents the expected number of shipment arrivals according to Poisson distribution for the given disruption scenario. The row highlighted in blue illustrates the total cost incurred by shipments which decided to wait for the waterway system to reopen. Similarly, the row highlighted in purple presents the total cost incurred by shipments which chose to switch to a different mode of transportation. Additionally, Table 29 provides the total cost which is the summation of total cost for Decision 1 and total cost for Decision 2. Decision 1 refers to waiting the navigable inland waterway system to reopen and Decision 2 refers to choosing alternative mode of transportation. The Monte Carlo simulation is run for 1,000 iterations, and the lower and upper limits of the 95% confidence intervals are presented in Table 29. Additionally, the total best cost is included in Table 29. The total best cost is defined as the cost that can be achieved by knowing the exact disruption duration when a disruption occurs. Hence, it represents the minimum additional cost that can occur if the disruption duration can be accurately predicted.

Table 29: Summary of Disruption Impact Results on Dependent Industries

	Short- term (Expectation is 2 weeks)			**Mid- term (Expectation is 2 months)**			**Long- term (Expectation is 6 months)**		
	A.E.* (2 weeks of disruption)	**O.E.** (1 week of disruption)**	**U.E.*** (3 weeks of disruption)**	**A.E.* (2 months of disruption)**	**O.E.** (6 weeks of disruption)**	**U.E.*** (10 weeks of disruption)**	**A.E.* (6 months of disruption)**	**O.E.** (22 weeks of disruption)**	**U.E.*** (26 weeks of disruption)**
Shipment (6 barges) Arrival	60	30	90	240	180	300	720	660	780
Additional Penalty Cost (3%)	$4,606,615	$0	$16,890,922	$4,606,615	$0	$36,852,921	$4,739,233	$0	$37,913,867
Additional Penalty Cost (7%)	$0	$0	$10,748,769	$0	$0	$39,412,151	$0	$0	$40,546,774
Additional Holding Cost	$4,279,245	$0	$15,690,566	$4,279,245	$0	$34,233,962	$4,279,245	$0	$34,233,962
Decision 1 Total Cost	$8,885,860	$0	$43,330,257	$8,885,860	$0	$110,499,034	$9,018,479	$0	$112,694,604
Additional Transportation Cost	$4,429,554	$4,429,554	$4,429,554	$31,006,876	$26,577,322	$31,006,876	$101,879,734	$97,450,180	$101,879,734
Additional Penalty Cost (3%)	$7,677,692	$7,677,692	$7,677,692	$53,743,843	$46,066,151	$53,743,843	$176,586,912	$168,909,220	$176,586,912
Additional Holding Cost	$7,132,075	$7,132,075	$7,132,075	$49,924,528	$42,792,453	$49,924,528	$164,037,736	$156,905,660	$164,037,736
Decision 2 Total Cost	$19,239,321	$19,239,321	$19,239,321	$134,675,247	$115,435,926	$134,675,247	$442,504,382	$423,265,061	$442,504,382
Total Cost	$28,125,181	$19,239,321	$62,569,578	$143,561,107	$115,435,926	$245,174,281	$451,522,860	$423,265,061	$555,198,985
TC Lower Confidence Limit (LCL)	$20,855,662	$12,501,691	$48,574,823	$70,964,038	$51,732,422	$208,225,770	$405,985,668	$376,349,119	$496,970,317
TC Upper Confidence Limit (UCL)	$36,767,925	$26,567,099	$79,118,306	$225,626,416	$184,196,145	$281,054,487	$499,020,281	$474,332,751	$614,438,872
Total (best) Cost	$28,125,181	$8,885,860	$47,364,502	$143,561,107	$105,082,465	$182,039,749	$451,522,860	$412,911,600	$490,001,502
TC (best) LCL	$20,074,659	$5,825,175	$37,011,547	$69,733,351	$50,936,079	$156,133,021	$405,985,668	$368,424,785	$436,878,829
TC (best) UCL	$35,974,595	$12,538,936	$57,705,777	$228,968,881	$168,231,309	$208,459,981	$499,020,281	$462,898,410	$542,700,739

*A.E. stands for accurate estimation, **O.E. stands for overestimation, ***U.E stands for underestimation

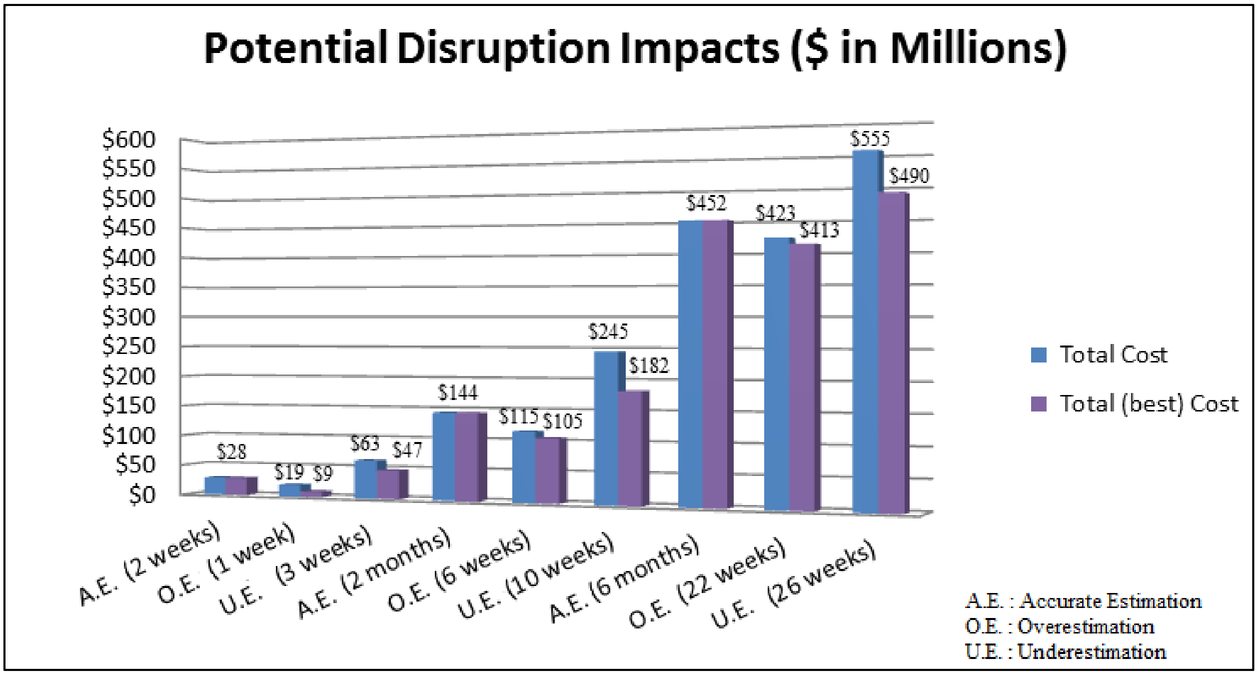

Figure 18: Potential Disruption Impacts ($ in Millions)

*A.E. stands for accurate estimation, **O.E. stands for overestimation, ***U.E stands for underestimation

In Figure 18, the total cost and the total best cost are presented. As mentioned before, when the disruption duration is accurately predicted, the total cost and total best cost are equal. Additionally, underestimating the disruption duration causes a greater impact than overestimating the disruption duration. For example, the difference between total cost and total best cost for the scenario of underestimation (26 weeks) equals to $65 million whereas overestimation (22 weeks) leads to a difference of only $10 million.

5.3.5.3 Total Cost Incurred by Arkansas Sensitivity Analysis

It is unknown what portion of the total cost is actually incurred by the dependent industries in the State of Arkansas. Thus, a sensitivity analysis is conducted, and the results are presented in Table 30. The buyer is defined as the destination of the shipped commodities based on the 2007 Commodity Flow Survey. The seller is defined as the origin of the shipped commodities based on the 2007 Commodity Flow Survey. The data from Table 30 are visualized in Figure 19.

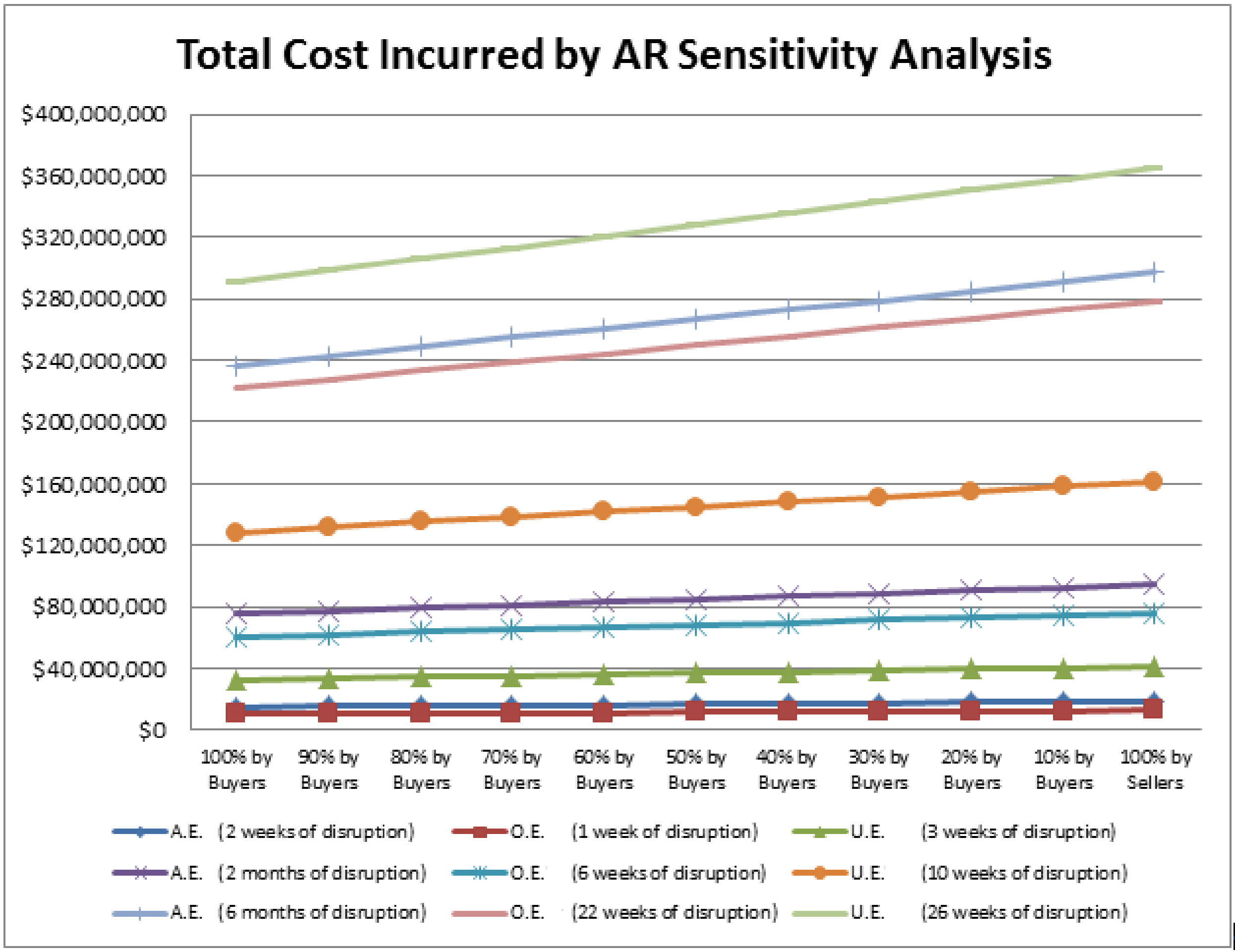

Figure 199: Total Cost Incurred by AR Sensitivity Analysis

Figure 19 shows that the lower the portion of the total cost for buyers, the higher the incurred total cost for the seller, and thus, for Arkansas.

Table 30: Sensitivity Analysis

	Cost Distribution	Short- term (Expectation is 2 weeks) A.E. (2 weeks)	Short- term O.E. (1 week)	Short- term U.E. (3 weeks)	Mid- term (Expectation is 2 months) A.E. (2 months)	Mid- term O.E. (6 weeks)	Mid- term U.E. (10 weeks)	Long- term (Expectation is 6 months) A.E. (6 months)	Long- term O.E. (22 weeks)	Long- term U.E. (26 weeks)
Total Cost Incurred by AR	**100% by Buyers**	$14,748,469	$10,088,843	$32,810,650	$75,281,526	$60,533,056	$128,566,116	$236,772,553	$221,954,540	$291,138,927
	90% by Buyers	$15,124,264	$10,345,909	$33,646,674	$77,199,719	$62,075,455	$131,842,014	$242,805,580	$227,610,001	$298,557,224
	80% by Buyers	$15,500,059	$10,602,975	$34,482,698	$79,117,912	$63,617,853	$135,117,913	$248,838,607	$233,265,461	$305,975,521
	70% by Buyers	$15,875,854	$10,860,042	$35,318,722	$81,036,105	$65,160,251	$138,393,812	$254,871,634	$238,920,921	$313,393,817
	60% by Buyers	$16,251,649	$11,117,108	$36,154,746	$82,954,298	$66,702,650	$141,669,710	$260,904,662	$244,576,382	$320,812,114
	50% by Buyers	$16,627,444	$11,374,175	$36,990,770	$84,872,491	$68,245,048	$144,945,609	$266,937,689	$250,231,842	$328,230,411
	40% by Buyers	$17,003,239	$11,631,241	$37,826,794	$86,790,685	$69,787,446	$148,221,507	$272,970,716	$255,887,302	$335,648,708
	30% by Buyers	$17,379,033	$11,888,307	$38,662,818	$88,708,878	$71,329,844	$151,497,406	$279,003,743	$261,542,763	$343,067,005
	20% by Buyers	$17,754,828	$12,145,374	$39,498,842	$90,627,071	$72,872,243	$154,773,305	$285,036,771	$267,198,223	$350,485,301
	10% by Buyers	$18,130,623	$12,402,440	$40,334,866	$92,545,264	$74,414,641	$158,049,203	$291,069,798	$272,853,683	$357,903,598
	100% by Sellers	$18,506,418	$12,659,507	$41,170,890	$94,463,457	$75,957,039	$161,325,102	$297,102,825	$278,509,144	$365,321,895

A.E. stands for accurate estimation, O.E. stands for overestimation, U.E stands for underestimation

6. Conclusions

Conducting an economic impact study can be costly in terms of money and time (Hamilton, 2001) if primary data are gathered with surveys and interviews. Although a primary data collection approach may lead to more accurate results, the accuracy of a survey based approach depends on the response rate and response quality of the respondents. Companies might not be willing to share confidential information related to sales, proportion of the products shipped via water transportation, customers, suppliers, Employment and Employee Earnings, and capital. In this project, a systematic economic analysis study of inland navigable waterways in Arkansas is conducted. Since publicly available data sources are utilized, the method can be used for different economic regions and is not only limited to Arkansas. Generally for relatively large regions such as cities, states, or countries, our methodological approach can be applied by using readily available governmental data sources related to economic indicators and Commodity Flow Survey.

In this study, the economic impact of disruptive events on the inland navigable waterway system of Arkansas is investigated. A scenario analysis is conducted where the waterway transportation system in Arkansas is closed down due to a disruptive event. The scenario analysis includes three different levels of expected disruption duration (short-term, mid-term, and long-term). The cost estimation techniques are used to predict the additional incurred cost for the water transportation subsector and dependent industries. Additionally, a Monte Carlo simulation and sensitivity analysis are included.

The findings of the study show that the expected duration of a disruption determines whether decision makers are better off waiting for the waterway system to reopen or to switch to a different mode of transportation. Furthermore, estimation accuracy of disruption duration can help the involved stakeholders to reduce total cost caused by the disruptive event. In addition, the relationship between estimated disruption duration and economic loss for the water transportation subsector, and the total cost for the dependent industries is found to be non-linear.

Future research will focus on evaluating the economic impact of an actual disruptive event, i.e. closure of the waterway system due to drought or port closure due to maintenance. Additionally, it can be examined how decision makers actually behave when a disruptive event occurs through surveys or interviews. Finally, the model proposed in this study could be applied to different study regions.

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