A MODAL COMPARISON OF DOMESTIC FREIGHT TRANSPORTATION EFFECTS ON THE GENERAL PUBLIC: 2001–2014

January 2017

Prepared by

CENTER FOR PORTS AND WATERWAYS
TEXAS A&M TRANSPORTATION INSTITUTE
701 NORTH POST OAK, SUITE 430
HOUSTON, TEXAS 77024-3827

Prepared for

NATIONAL WATERWAYS FOUNDATION

www.nationalwaterwaysfoundation.org

A MODAL COMPARISON OF DOMESTIC FREIGHT TRANSPORTATION EFFECTS ON THE GENERAL PUBLIC: 2001–2014

FINAL REPORT

Prepared for
National Waterways Foundation

by

C. James Kruse, Director, Center for Ports & Waterways
Jeffery E. Warner, Assistant Research Scientist
Leslie E. Olson, Associate Research Scientist

Texas A&M Transportation Institute
The Texas A&M University System
College Station, Texas

January 2017

DISCLAIMER

This research was performed in cooperation with the National Waterways Foundation (NWF). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of NWF. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

This project was conducted in cooperation with NWF. The authors wish to acknowledge the involvement and direction of Mr. Matt Woodruff, a representative of NWF.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

EXECUTIVE SUMMARY

IMPORTANT NOTE REGARDING DATA

As noted at various points in this report, the common denominator for comparing statistics across the modes is ton-miles of freight traffic. In 2014, the Bureau of Transportation Statistics (BTS) changed its procedure for calculating ton-miles for trucks. Appendix B contains an abbreviated version of BTS' explanation of the change in methodology. This approximately doubled the ton-miles reported for trucks, which has a dramatic effect on the safety rates calculated for trucks. Because of this change, some of the statistics reported for trucks in this report cannot be compared to prior reports. Where comparative charts or tables are presented, the statistics for prior years have been restated where they are affected by the new ton-mile statistics.

BACKGROUND

This report updates the previous modal comparison study released by the Texas A&M Transportation Institute (TTI) in February 2012. That study used data from 2001–2009. This study includes data from 2001–2014 (2014 is the most recent year for which data are generally available for all three modes). Inland waterway traffic continues to compare favorably to the other two modes in each category of impacts.

The following topical areas were covered in this research:

- Cargo capacity.
- Congestion.
- Emissions.
- Energy efficiency.
- Safety impacts.
- Infrastructure impacts.

The analysis is predicated on the assumption that cargo will be diverted to rail or highway (truck) modes in the event of a major waterway closure. The analysis considered the possible impacts resulting from either a diversion of 100 percent of the current waterborne cargo to the highway mode *or* a diversion of 100 percent of the current waterborne cargo to the rail mode.

This report presents a snapshot in time in order to focus on several vital issues. The data used in this research are publicly available and can be independently verified and used to support various analyses.

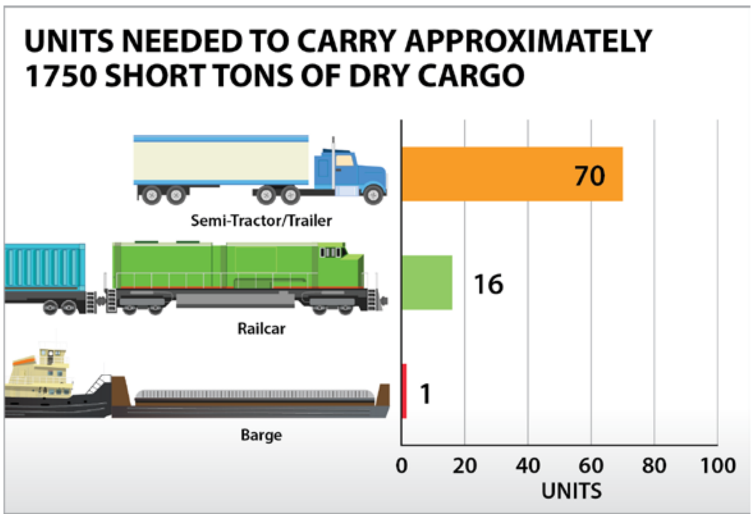
CARGO CAPACITY

Table ES-1 summarizes the standard capacities for the various freight units across all three modes used in this analysis.

Table ES-1. Standard Modal Freight Unit Capacities.

Modal Freight Unit	Standard Cargo Capacity
Highway – Truck Trailer	25 tons
Rail – Bulk Car	110 tons
Barge – Dry Bulk	1,750 tons
Barge – Liquid Bulk	27,500 bbl

Figure ES-1 illustrates the carrying capacities of dry and liquid cargo barges, railcars, and semi-tractor/trailers.



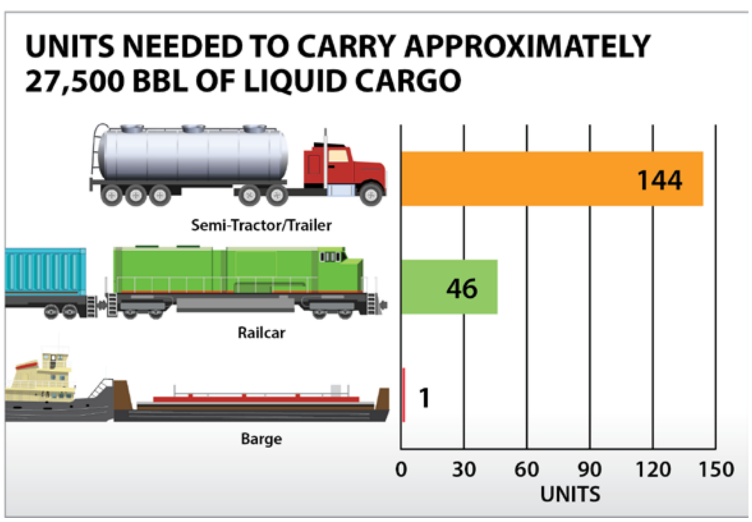
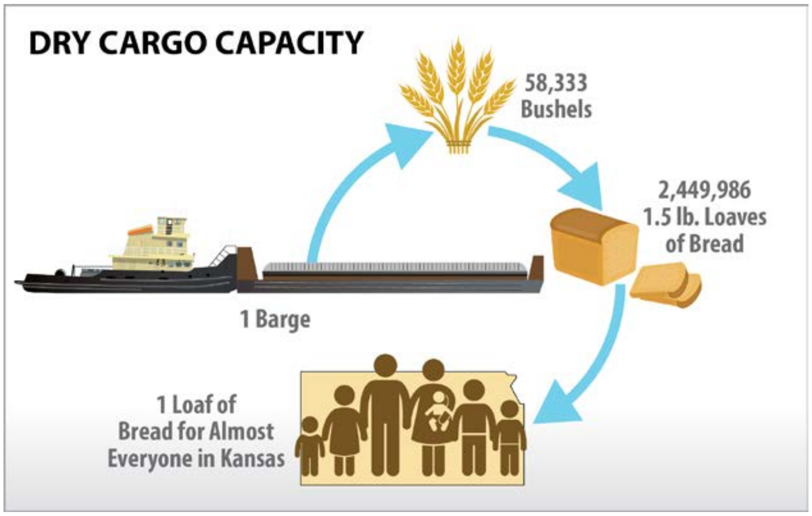


Figure ES-1. Modal Freight Unit Capacities.

It is difficult to appreciate the carrying capacity of a barge until one understands how much demand a single barge can meet. For example, a loaded covered hopper barge carrying wheat carries enough product to make almost 2.5 million loaves of bread, or the equivalent of one loaf of bread for almost every person in the state of Kansas. A loaded tank barge carrying gasoline carries enough product to satisfy the current annual gasoline demand of approximately 2,500 people. Figure ES-2 illustrates the capacities of dry and liquid cargo barges.[1]



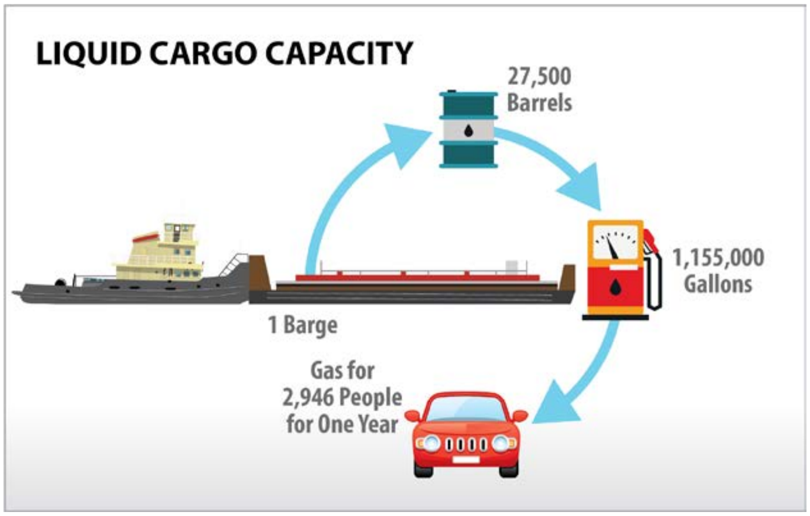


Figure ES-2. Cargo Capacity Examples.

CONGESTION ISSUES

Highway

Researchers obtained the latest national waterborne commerce data published by the U.S. Army Corps of Engineers Navigation Data Center (NDC) (calendar year 2014) (*1*). Researchers then extracted the tonnage and ton-mile data for the following major rivers:

- Mississippi River—Minneapolis to Mouth of Passes.
- Ohio River.

[1] Statistics regarding per capita consumption of gasoline are taken from Michael Sivak, *Has Motorization in the U.S. Peaked? Part 7: Update Through 2013*, The University of Michigan Transportation Research Institute, Ann Arbor, Michigan, March 2015.
https://deepblue.lib.umich.edu/bitstream/handle/2027.42/110979/103186.pdf?sequence=1&isAllowed=y

- Gulf Intracoastal Waterway (GIWW).
- Tennessee River.
- Cumberland River.
- Columbia River system—Columbia and Snake Rivers.

The amount of cargo currently transported on these rivers is equivalent to more than 49,000,000 truck trips annually that would have to travel on the nation's roadways in lieu of water transportation. The hypothetical diversion of current waterway freight traffic to the nation's highways would add 1,046 combination trucks to the current 875 trucks per day per lane on a typical rural interstate. The percentage of combination trucks in the average annual daily traffic on rural interstates would rise 14 percent from the current 17 percent to 31 percent. This increase in truck trips would cause the weighted average daily combination trucks per lane on segments of interstate between urban areas to rise by 118 percent on a nationwide basis. The impact near the waterways considered in this study would logically be much more severe than the national average, especially during the heavier truck travel periods of the year, month, week, or day.

Rail System

The tonnage moved on the inland river system would amount to an addition of nearly 16 percent more tonnage on the railroad system. This new burden would not be evenly distributed. The primary burden would be placed on the eastern U.S. railroads with little real opportunity to take advantage of excess capacity that may exist on the western U.S. railroads.

EMISSIONS ISSUES

Table ES-2 shows the emission comparison between the three modes.

Table ES-2. Summary of Emissions—Grams per Ton-Mile—2014.

Emissions (grams/ton-mile)					
	HC/VOC	**CO**	**NO_x**	**PM-10**	**CO_2**
Inland Towing	0.0094	0.0411	0.2087	0.0056	15.62
Railroad	0.0128	0.0558	0.2830	0.0075	21.19
Truck	0.08	0.27	0.94	0.05	154.08

Table ES-3 compares these factors with the factors calculated as of 2014. The truck factors for 2014 are restated to reflect the utilization of the latest Environmental Protection Agency (EPA) model (MOVES2014a), which is the model that was used to calculate the 2014 factors.

Table ES-3. Summary of Emissions—Grams per Ton-Mile—2005, 2009, and 2014.

	Emissions (grams/ton-mile)														
Mode	**HC/VOC**			**CO**			**NO_x**			**PM**			**CO_2**		
	2005	**2009**	**2014**	**2005**	**2009**	**2014**	**2005**	**2009**	**2014**	**2005**	**2009**	**2014**	**2005**	**2009**	**2014**
Inland Towing	0.01737	0.014123	0.0094	0.04621	0.0432	0.0411	0.46907	0.27435	0.2087	0.01164	0.007955	0.0056	17.48	16.41	15.62
Railroad	0.02421	0.018201	0.0128	0.06440	0.0556	0.0558	0.65368	0.35356	0.2830	0.01623	0.010251	0.0075	24.39	21.14	21.19
Truck	0.12	0.10	0.08	0.46	0.37	0.27	1.90	1.45	0.94	0.08	0.06	0.05	171.87	171.83	154.08

Figure ES-3 shows greenhouse gas (GHG) emissions expressed in metric tons of GHG produced per million ton-miles.

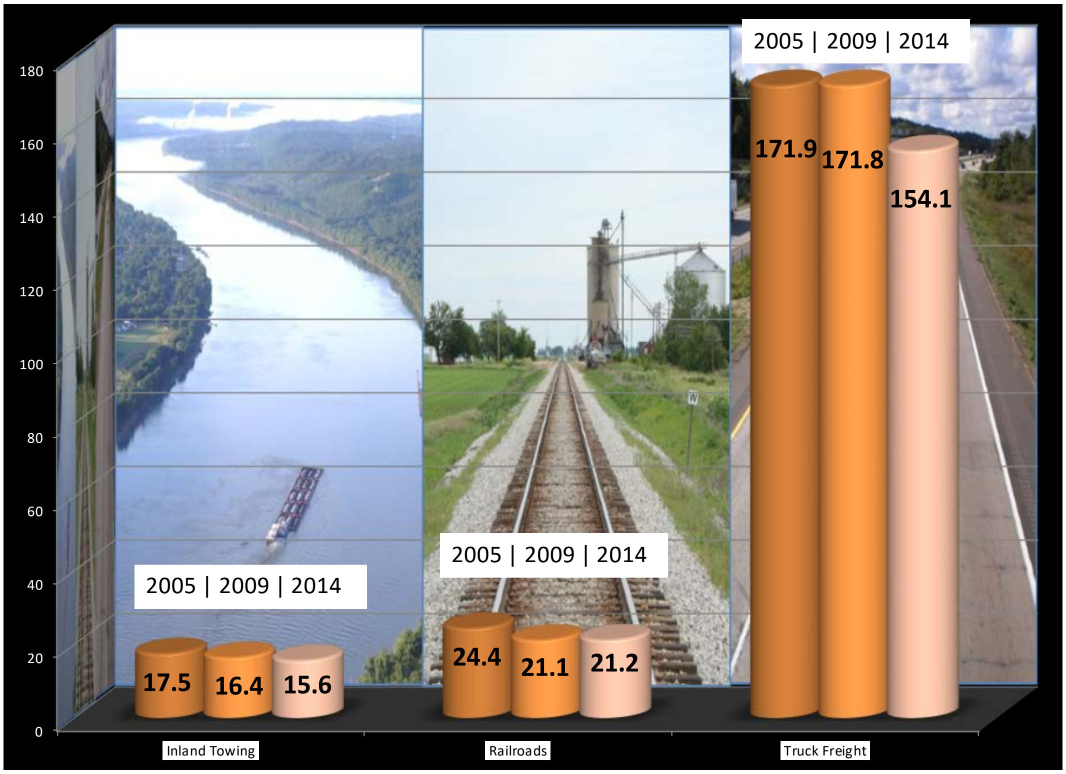


Figure ES-3. Metric Tons of GHG per Million Ton-Miles (2005, 2009, and 2014).

ENERGY EFFICIENCY

Figure ES-4 presents the average fuel efficiency in ton-miles per gallons for each of the modes on a national industry-wide basis.

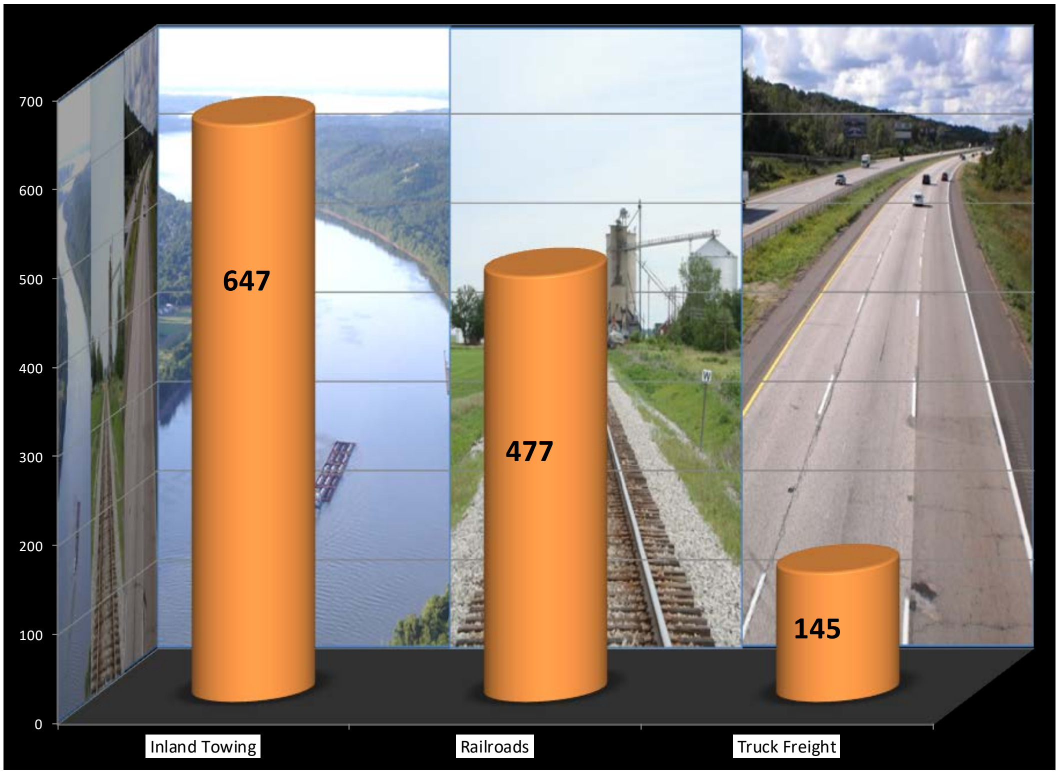


Figure ES-4. Comparison of Fuel Efficiency—2014.

Figure ES-5 shows how this statistic has varied by mode for three different periods: 2001–2005, 2001–2009, and 2001–2014.

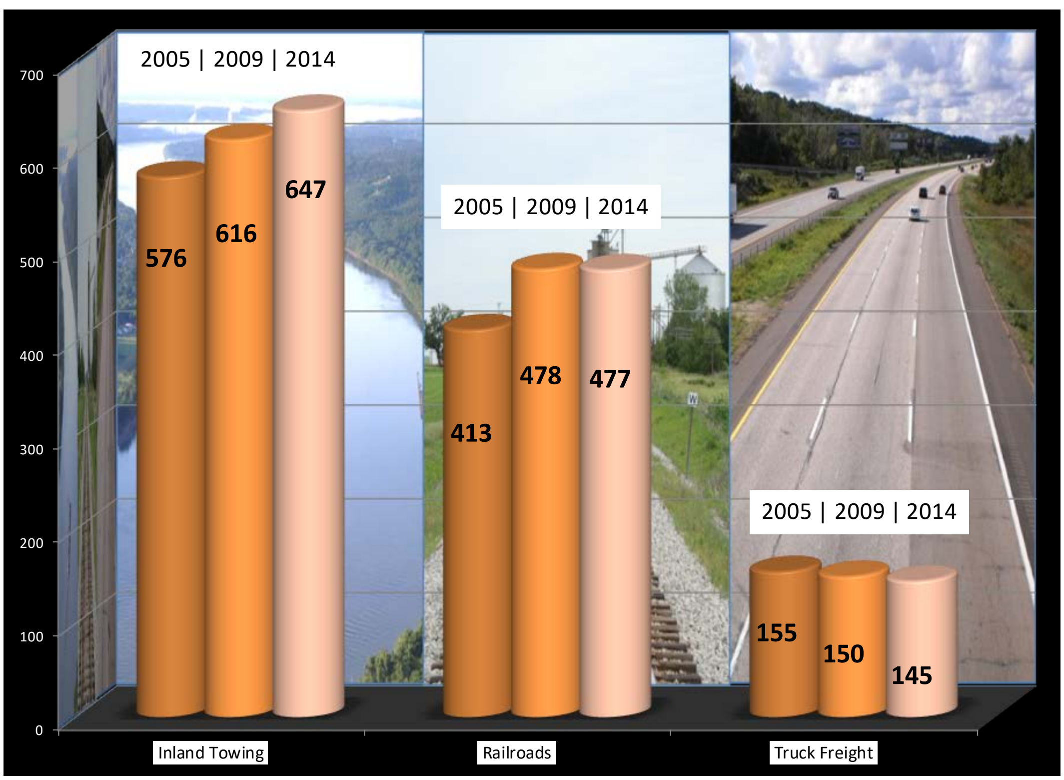


Figure ES-5. Comparison of Fuel Efficiency—2005, 2009, and 2014.

Inland waterway showed the most improvement for 2009 to 2014. This was due in part to the continual upgrading of the fleet and the high utilization rates that were achieved in the latter part of the study period. Rail and truck remained almost unchanged during this same period.

The marine fuel efficiency rates are based on energy consumption data calculated by the U.S. Army Corps of Engineers; the railroad efficiency rates are based on an analysis of data published by the railroad industry, Surface Transportation Board (STB), and Security and Exchange Commission (SEC); and truck efficiency rates are based on BTS reported data.

SAFETY IMPACTS

Fatalities and Injuries

Both rail and truck statistics include incidents involving only vehicular crashes or derailments. However, the waterborne database reports incidents resulting from various causes. In order to conduct a valid modal comparison for this study, a definition of incident analogous to the one used in the surface mode data was adopted. This modal comparison only uses data pertaining to waterborne incidents involving collisions, allisions (vessels striking a fixed object), groundings, or capsizings/sinkings.

The data for rail fatalities and injuries, respectively, were obtained from *Railroad Statistics: National Transportation Statistics—2016, Table 2-39: Railroad and Grade-Crossing Fatalities by Victim Class* and *Table 2-40: Railroad and Grade-Crossing Injured Persons by Victim Class*. Data for truck-related incidents were obtained from *Large Truck Crash Facts*, a publication of the Federal Motor Carrier Safety Administration. The data for waterborne incidents were taken from the Marine Casualty and Pollution Database, July 2015, a database that is maintained by the U.S. Coast Guard. (Incidents are added to this database only after the case has been fully investigated and closed by the U.S Coast Guard, which can take several years. Because of this delay, the more recent years in the analysis may not include all of the incidents that actually occurred.) Figure ES-6 and Figure ES-7 show the comparisons of fatality and injury rates, respectively.

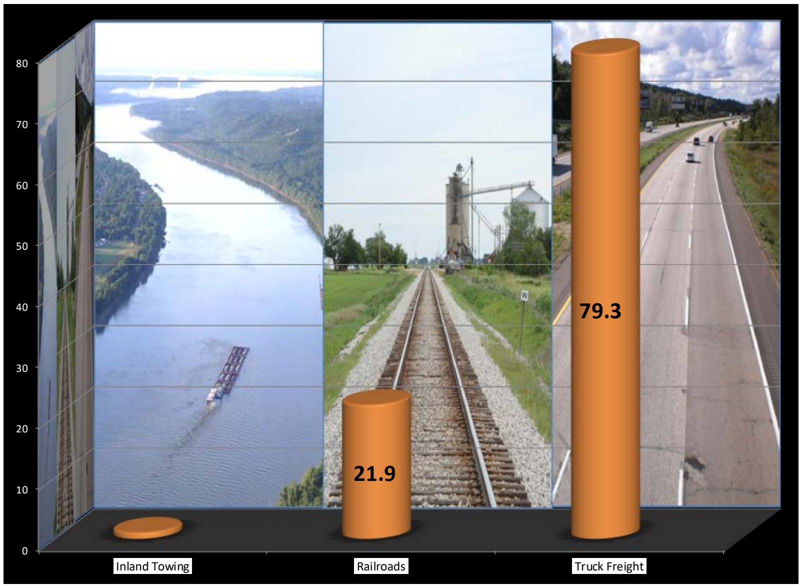


Figure ES-6. Ratio of Fatalities per Million Ton-Miles versus Inland Towing—2001–2014.

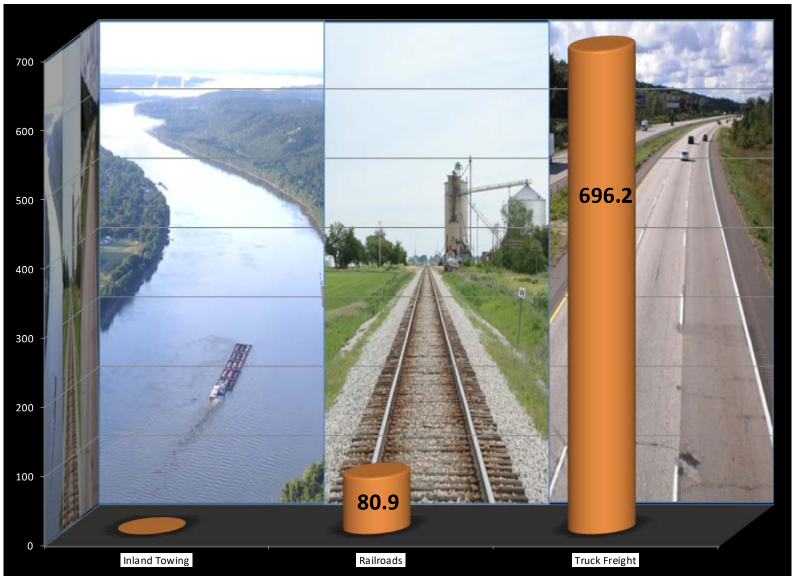


Figure ES-7. Ratio of Injuries per Million Ton-Miles versus Inland Marine—2001–2014.

Figure ES-8 and Figure ES–9 illustrate how these ratios have changed since the first study was conducted.

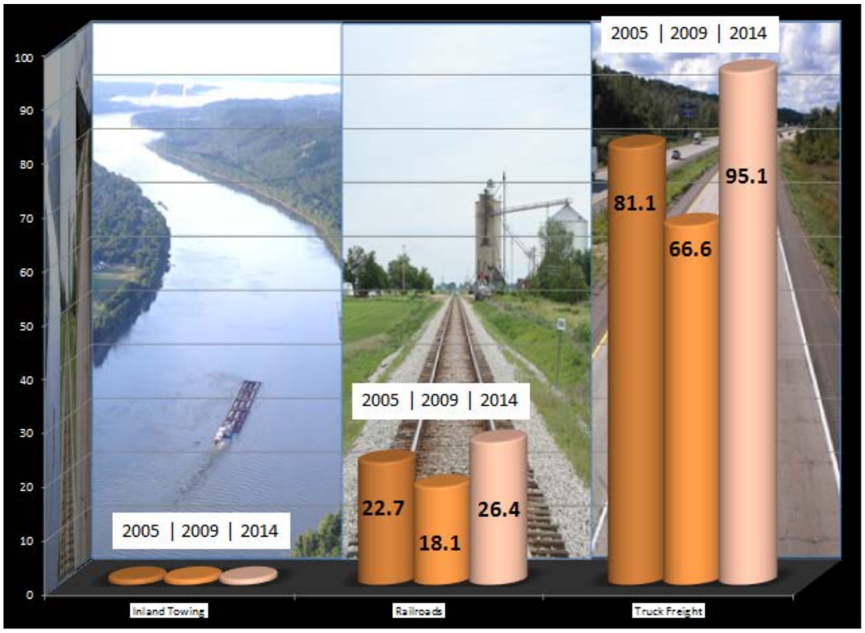


Figure ES-8. Ratio of Fatalities per Million Ton-Miles versus Inland Towing (2001–05, 2001–09, and 2001–14).

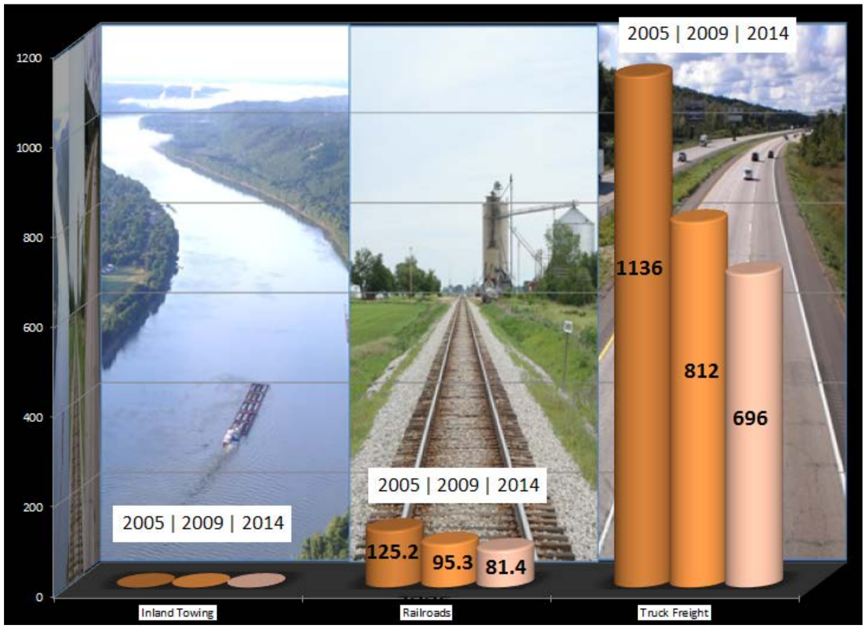


Figure ES–9. Ratio of Injuries per Million Ton-Miles versus Inland Towing (2001–05, 2001–09, and 2001–14.

Hazardous Materials Incidents

Data on hazardous materials incidents for rail and truck were taken from the Pipeline and Hazardous Materials Safety Administration's (PHMSA's) online Hazmat Incident Report database. Data for inland waterway incidents were extracted from the Coast Guard's Marine Information for Safety and Law Enforcement (MISLE) system. (As with fatalities and injuries, incidents are added to this database only after the case has been fully investigated and closed by the U.S Coast Guard, which can take several years. Because of this delay, the more recent years in the analysis may not include all of the incidents that actually occurred.)

Because all three reporting systems rely on self-reporting and the definitions of materials that require reporting are very complex, much of the spill data are suspect. However, for larger spills, it seems reasonable to assume that the accuracy of the data improves, due to the severity of the incident and public scrutiny, so the research team decided to analyze only large spills as a measure of the overall safety of the modes in the area of spills. The threshold quantity was set at 1,000 gallons. Table ES-4 provides a comparison of spills across the modes.

Table ES-4. Comparison of Large Spills across Modes—2001–2014.

Year	Mode								
	Water (Inland)			Railroad			Highway (Truck)		
	Number of Spills	Amount (gallons)	Ton-Miles (billion)	Number of Spills	Amount (gallons)	Ton-Miles (billion)	Number of Spills	Amount (gallons)	Ton-Miles (million)
2001	6	209,292	294.9	33	296,114	1,495	191	789,006	2,362,063
2002	7	32,459	278.4	29	245,183	1,507	153	633,534	2,427,693
2003	10	597,862	293.4	22	247,287	1,551	148	644,404	2,478,740
2004	11	237,155	284.1	33	379,992	1,663	170	731,919	2,427,170
2005	11	52,068	274.4	21	625,833	1,696	141	625,607	2,453,347
2006	9	246,900	279.8	38	671,544	1,772	144	551,273	2,405,811
2007	5	16,760	271.6	38	585,515	1,771	139	533,087	2,495,786
2008	3	285,508	261.0	19	216,248	1,777	119	505,043	2,752,658
2009	4	16,642	245.0	24	427,690	1,532	115	475,186	2,449,509
2010	3	6,598	263.2	21	306,181	1,691	135	696,420	2,512,429
2011	3	14,038	269.2	45	1,247,089	1,729	152	762,076	2,643,567
2012	7	16,030	268.4	39	532,595	1,713	163	680,848	2,676,970*
2013	5	16,270	251.5	60	1,128,002	1,741	143	594,278	2,772,406*
2014	1	30,240	281.3	24	245,398	1,851	146	590,450	2,872,613*
Total	85	1,777,822	3,816.2	446	7,154,671	23,489	2,059	8,813,130	35,730,762
Average	6	126,987	272.6	32	511,048	1,678	147	629,509	2,491,707
Average Annual Haz-Mat Ton-Miles (millions)			59,874			85,900*			104,200*
Rate**	0.0001014	2.1209087		0.0003709	5.949336		0.001402	6.041356	
Ratio to Water (Inland)				3.66	2.81		12.45	2.85	

Marine incidents are added to the database only after the case has been fully investigated and closed by the U.S Coast Guard, which can take several years. Because of this delay, the more recent years in the analysis may not include all of the incidents that actually occurred.

**Estimate. **Spills: Spills per Million Hazmat Ton-Miles. Amount: Gallons per Million Hazmat Ton-Miles.*

Inland waterway traffic continues to compare favorably, as shown in Figure ES-10 and Figure ES-11. Figure ES-11 highlights the fact that inland towing was the only mode to significantly improve its large spill record.

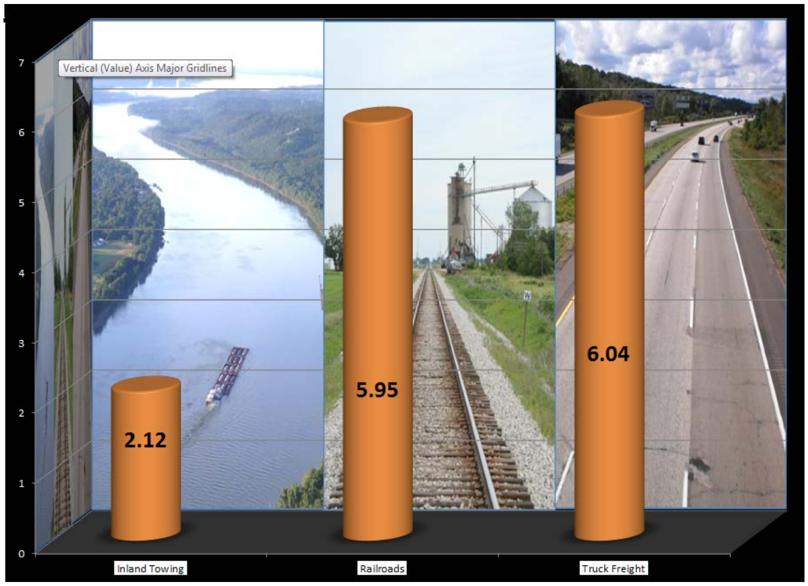


Figure ES-10. Gallons Spilled per Million Hazmat Ton-Miles (2001–2014).

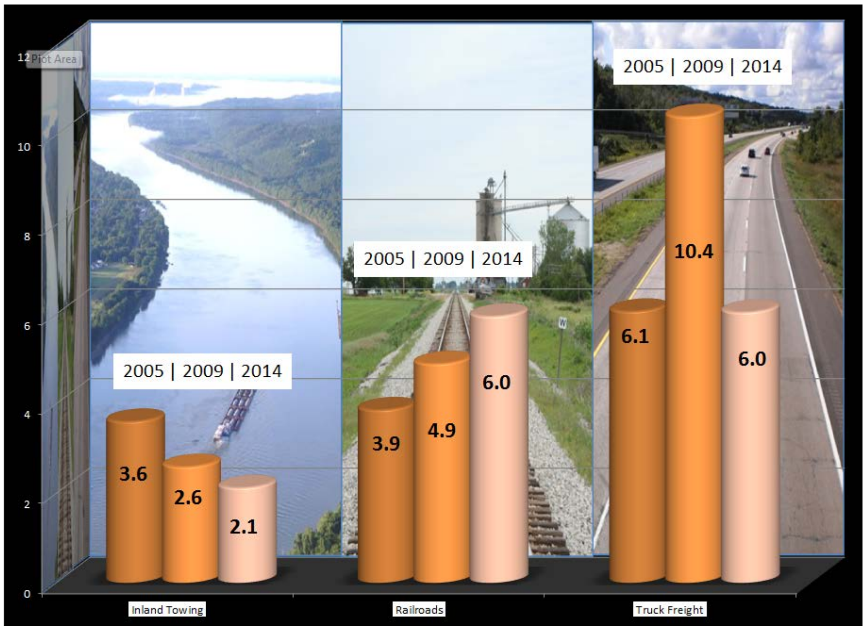


Figure ES-11. Gallons Spilled per Million Hazmat Ton-Miles (2001–05, 2001–09, and 2001–2014).

INFRASTRUCTURE IMPACTS

Pavement Deterioration

In the event of waterborne freight diversion to highway transport, approximately 2 inches of asphalt would have to be added to the pavement of 118,688 lane-miles of rural interstate given the higher levels of expected 20-year truck loadings, assuming an even truck traffic distribution over the national highway system. Corridors that are parallel to the major rivers would undoubtedly receive a higher concentration of the additional truck traffic and would be affected to a higher degree than the national average. Other improvements would be required, such as capital expenditures on new construction of infrastructure and facilities such as bridges, ramps, highway geometric features such as horizontal and vertical curves and shoulders, truck stops, service stations, rest areas, weigh stations, and traffic control. In addition, routine maintenance costs associated with the new infrastructure as well as with the existing, which would be used more heavily, would likely be significantly higher.

Railroad Infrastructure Impacts

With substantial diversion of inland waterway cargo traffic to railroads, one or more of the following effects could be expected in almost every case:

- Increased demand for rail cars and locomotives.
- Higher freight rates.
- Need to expand infrastructure (rail lines).
- Potentially slower and less reliable delivery time.

For example, the minimum cost to purchase railcars to handle just the diversion of Ohio River coal to the CSX Transportation Line (CSX) rail line is estimated at over $753 million at an estimated $91,000 per rail car. Furthermore, an additional 243 locomotives would have to be acquired at a cost of $486 million in order maintain efficiency and travel times at an acceptable level when adding so much traffic on this single route.

CHAPTER 1: BACKGROUND AND SIGNIFICANCE

IMPORTANT NOTE REGARDING DATA

As noted at various points in this report, the common denominator for comparing statistics across the modes is ton-miles of freight traffic. In 2014, the Bureau of Transportation Statistics (BTS) changed its procedure for calculating ton-miles for trucks. Appendix B contains an abbreviated version of BTS' explanation of the change in methodology. This approximately doubled the ton-miles reported for trucks, which has a dramatic effect on the safety rates calculated for trucks. Because of this change, some of the statistics reported for trucks in this report cannot be compared to prior reports. Where comparative charts or tables are presented, the statistics for prior years have been restated where they are affected by the new ton-mile statistics.

INTRODUCTION

The Inland Waterway System (IWWS) is a key element in the nation's transportation system. The IWWS includes approximately 12,000 miles of navigable waterways and 193 lock sites with 239 chambers that serve navigation (*2*). The system directly serves 38 states (*3*). It is part of a larger system referred to as "America's Marine Highways," which encompasses both deep draft and shallow draft shipping.

In 2014,[2] inland waterways maintained by the U.S. Army Corps of Engineers (Corps) handled over 599 million tons of freight (281 billion ton-miles) (*4*). This cargo was valued at more than $232 billion, resulting in an average transportation cost savings of more than $20/ton (as compared to other modes). This translates into more than $12 billion annually in transportation savings to America's economy. (*5*) Virtually all American consumers benefit from these lower transportation costs.

Various public, semi-public, and private entities are involved in the maintenance and operation of the waterway. The following list illustrates the types of enterprises that directly depend on the waterways:

- Ports.
- Ocean-going ships.
- Towboats and barges.
- Ship-handling tugs.
- Marine terminals.
- Shipyards.
- Offshore supply companies.
- Brokers and agents.
- Consultants, maritime attorneys.
- Cruise services.
- Suppliers and others.

[2] In order to maintain consistency across the modes, 2014 is the latest year this analysis uses for waterborne commerce.

The federal agencies most directly involved with the inland waterways are the Corps, the U.S. Coast Guard, and the Maritime Administration of the U.S. Department of Transportation.

IWWS is one modal network within the entire pool of domestic transportation systems networks that include truck and rail modal networks. The entire surface transportation system is becoming increasingly congested. The ability to expand this system in a timely fashion is constrained by both funding and environmental issues. Many proponents of the IWWS point out that it provides an effective and efficient means of expanding capacity with less funding, has virtually unlimited capacity, and impacts the environment much less than the other modes of transportation.

Figure 1 shows the composition by commodity of domestic waterborne freight tonnage, and Figure 2 shows the domestic freight tonnage carried by barge. These figures illustrate that a very high percentage of domestic freight traffic is composed of barges carrying bulk commodities—commodities that are low in value per ton and very sensitive to freight rates.

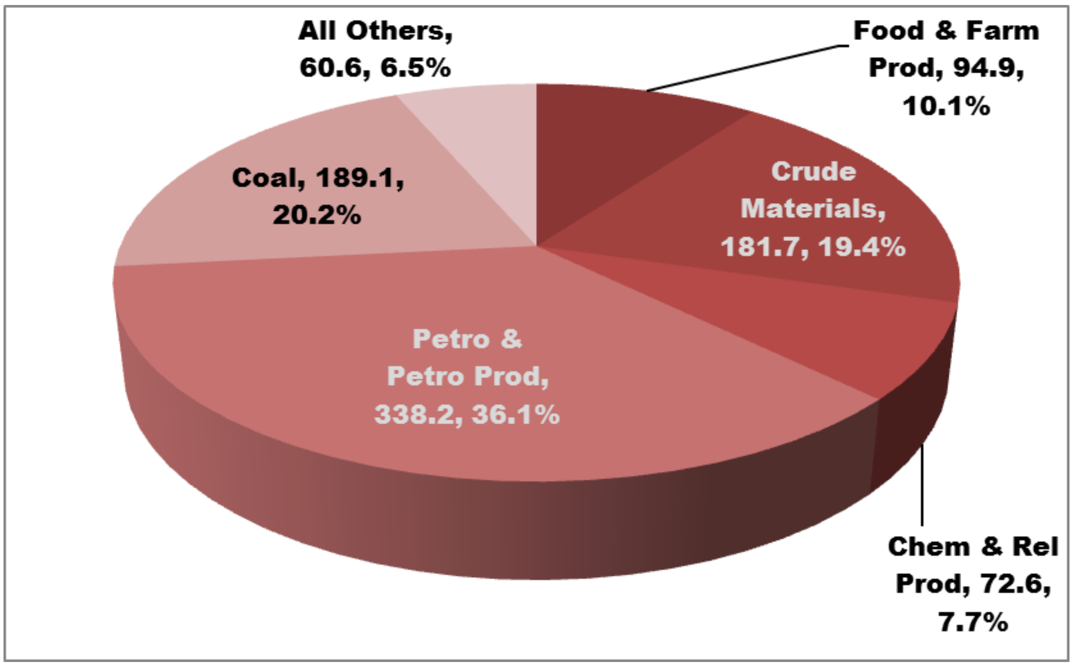


Figure 1. 2014 All Domestic Waterborne Traffic by Commodity Group (in Millions of Tons) (*4*).

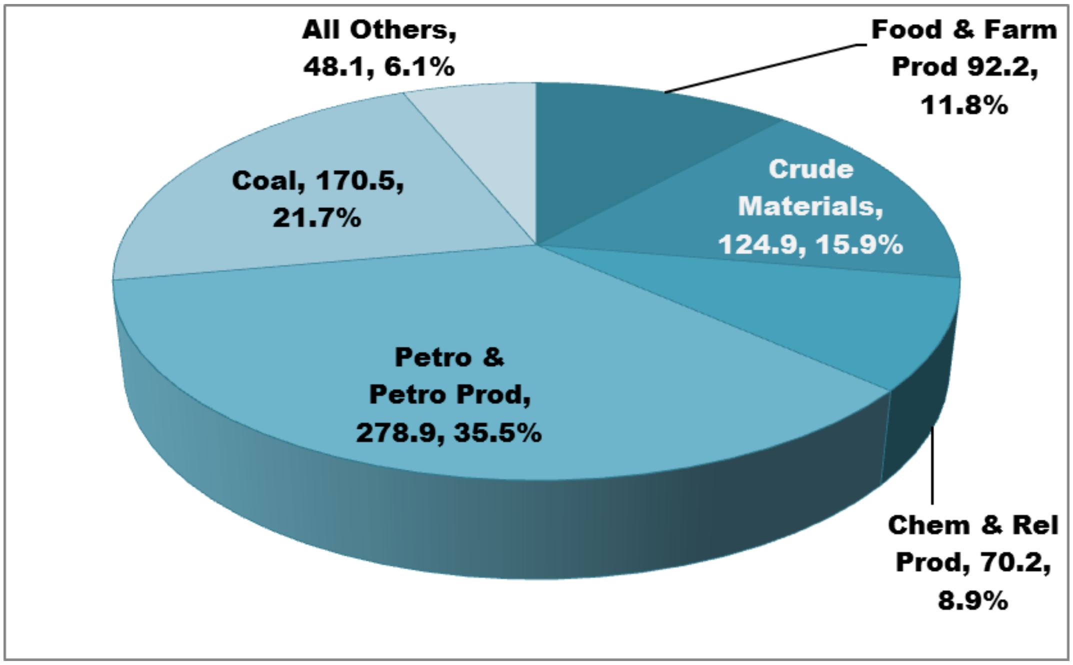


Figure 2. 2014 Domestic Barge Traffic by Commodity Group (in Millions of Tons) (*4*).

The economics of barge transportation are easily understood and well documented. This report updates environmental, selected societal, and safety impacts of using barge transportation as reported in *A Modal Comparison of Domestic Freight Transportation Effects on the General Public: 2001–2009*, published in February 2012.

IMPORTANT ASSUMPTIONS AND CONSTRAINTS

The hypothetical nature of this comparative study requires certain assumptions to enable valid comparisons across the modes.

The analysis is predicated on the assumption that cargo will be diverted to rail or highway (truck) modes in the event of a major waterway closure. The location of the closure and the alternative rail and highway routes available for bypass will determine any predominance in modal share. The geographical extent of the waterway system network does not allow any realistic predictions to be made for a closure location, the alternate modal routes available for bypass, or the modal split. As a result, this analysis adopts the all-or-nothing modal assignment principle. The analysis considered the possible impacts resulting from either a theoretical diversion of 100 percent of the current waterborne cargo to the highway mode *or* a theoretical diversion of 100 percent of the current waterborne cargo to the rail mode.

This analysis uses values of ton-miles of freight as the common denominator to enable a cross-modal comparison that takes into account both the shipment weight and the shipping distance. The following sources were used for ton-mile data:

- Waterborne Commerce Statistics, 2014, Part 5–National Summaries, Table 1-9 (*4*).
- Association of American Railroads (AAR) Class I Railroad Statistics (various editions).
- National Transportation Statistics—2016, Table 1-50: Special Tabulation (highway data) (*8*). The ton-mile statistics for trucking for 2012–2014 were estimated by applying the Transportation Services Index to the 2011 statistics.

Most of the issues related to a theoretical waterborne freight diversion are examined on a national or system-wide level. The level of detail of the available data does not permit any disaggregation, for example, to the state level. The system-wide level of analysis cannot support reasonable traffic assignment on specific highway links. It only permits a reasonable allocation of the truck traffic that would replace waterborne freight transportation to the highest class of long haul roadway, the rural segments of the interstate system.

Detailed data for train fuel consumption or composition are generally proprietary. Therefore, the research team developed methodologies for cross-referencing available train data with compiled statistics in order to support the comparative analysis among modes.

Barge transportation is characterized by the longest average haul operations, followed by rail, then by truck. This study is macroscopic in nature and focuses on the main stems of the major river systems. Considerable effort took place to investigate for possible differences in route lengths (circuity) among the three modes, in particular between the water and highway modes. Obviously, the water and rail modes have to follow fixed routes. The highway mode is highly flexible due to the expanse of the network, but it is known that truckers have their preferred routes, and aim to minimize the total trip length, especially in longer hauls. Geographic Information Systems, using data from the National Transportation Atlas Database (NTAD), were used to map and compare the lengths of the major river main stems with the most logical route that would most likely be chosen by trucks transporting barge commodities from an origin at one extreme of a river to a destination at the other extreme. Educated assumptions were made about which truck routes would likely be preferred, with assistance from the Federal Highway Administration's (FHWA) Estimated Average Annual Daily Truck Traffic, shown in Chapter 2.

Conventional wisdom prescribes circuity factors of 1.3:1 for water trip length and 1.1:1 for rail trip length, with respect to the highway trip length from the same origin to the same destination. These ratios, though, are based on microscopic evaluations of individual trips. The comparative analysis found that trip length differences are minimal between trips of length approximately equal to an entire river's length and the corresponding long haul highway route that would be followed. In some instances, the highway trip length is actually longer due to the absence of highway routes closely parallel to the adjacent river, simply because the presence of the latter makes the presence of the former redundant. For example, approximately 1,700 river miles have to be traveled by a barge along the Mississippi from Minneapolis to New Orleans. The corresponding southbound truck trip would most likely take place along Interstate 94, then Interstate 90, then Interstate 39, and finally Interstate 55, a total distance of about 1,900 miles (*6*), which is nominally longer than the Mississippi river route. Also according to NTAD, the GIWW, from Apalachee Bay, Florida, to the Louisiana-Texas border is 640 miles long. The stretch of Interstate 10 that runs parallel to this stretch of GIWW is more than 600 miles long, indicating that the two modal routes are very similar in length. The comparative analysis was also conducted for the remaining waterways under study and led to similar conclusions. Allowing for possible deviations from the assumed preferred highway route, the long haul routes on the river and respective highway would be very comparable in total length. Therefore, any attempt to compensate for possible differences in modal route circuity was deemed unnecessary for the purposes of this study.

Further, researchers assumed that in the event of a waterborne freight diversion to either truck or rail, the short haul, usually by truck, from the site to any mode's trunk line would still be present, at the same levels and on classes of roads similar to the current ones used for waterway access.

These roads would most likely be major, four lane arterials (for example, U.S. or state highway routes). A diversion of all waterway freight to either truck or rail would require a truck haul of similar length from the site to the respective mode's major artery. Existing short hauls associated with access to the waterways would be offset by similar ones to either the highway or the rail main line. Therefore, any compensation for differences relating to any aspect of short haul movements is considered unnecessary.

A logical consequence of a hypothetical waterborne freight diversion to either highway or rail would be a change in the transloading or intermodal facilities required. For example, in the absence of waterways, port facilities would become obsolete. At the same time, the need for transloading facilities between local truck and long haul truck, between local truck and rail, or between long haul and shorter haul rail would arise. However, investigation of the chain reaction effects of a hypothetical freight diversion on forecasting facility requirements is beyond the scope of this research study.

CHAPTER 2: CONGESTION ISSUES

BACKGROUND

In the event of a major waterway closure, cargo will have to be diverted to either the rail or highway (truck) mode. The location of the closure and the alternative rail and highway routes available for bypass will determine the predominance in modal share. The geographical extent of the waterway system network does not allow any realistic predictions to be made for a closure location, the alternate modal routes available for bypass, or the modal split. As a result, this analysis adopts the all-or-nothing modal assignment principle. The evaluation considered the possible impacts resulting from either a theoretical diversion of 100 percent of the current waterborne cargo to the highway mode *or* a theoretical diversion of 100 percent of the current waterborne cargo to the rail mode.

As mentioned earlier, cargoes moved on the inland waterways are typically bulk commodities with low unit values. This characteristic has a strong influence on the types of railcars and trucks that would be chosen to transport freight diverted from the waterways. Figure 2 shows the barge traffic distribution by commodity groups in 2014.

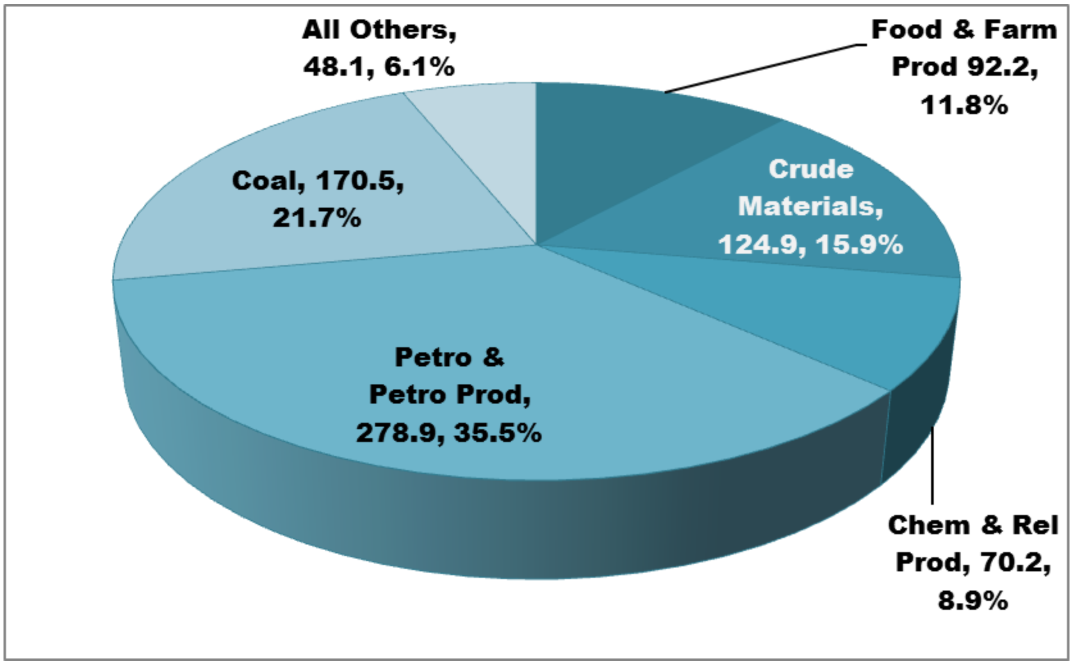


Figure 3. 2014 Domestic Barge Traffic by Commodity Group (in Millions of Tons) (*4*).

HIGHWAY

Data published by the U.S. Army Corps of Engineers NDC were obtained for calendar year 2014 (*7*). The domestic internal tonnage and ton-mile data for the following major rivers were extracted:

- Mississippi River—Minneapolis to Mouth of Passes (Internal).
- Ohio River.
- GIWW.

- Tennessee River.
- Cumberland River.
- Columbia River system—Columbia and Snake Rivers (Internal).

The tonnage and ton-mile data were then used to develop estimates of the equivalent truckloads, truck trips, and vehicle miles traveled (VMT) that would be required if all waterway freight transported on these major rivers were to be transported by truck. Table 1 shows all waterway data and estimated truck equivalent values. (The table assumes a cargo weight of 25 tons per truckload.) VMT is the typical unit of measure for highway travel and is simply the number of vehicles passing a point on the highway multiplied by the length of that segment of highway, measured in miles and usually on the order of one mile.

Table 1. Waterway and Truck Equivalents — 2014 Tonnage and Ton-Miles.

Waterway	Tonnage (x 000)	Ton-miles (x 000)	Avg Trip Lgth (miles)	Annual Truckloads	Annual Truck Trips	Annual Loaded Truck VMT	Total Annual Truck VMT
Mississippi System (Includes entire Ohio System)	475,032	243,849,890	513	19,001,280	38,002,560	9,747,656,640	19,495,313,280
GIWW	125,586	21,647,288	172	5,023,440	10,046,880	864,031,680	1,728,063,360
Columbia/Snake	12,049	591,155	49	481,960	963,920	23,616,040	47,232,080
Total	**612,667**	**266,088,333**	**—**	**24,506,680**	**49,013,360**	**10,635,304,360**	**21,270,608,720**
There are slight differences between these statistics and those reported at the national level because of differences in how intra-port tonnage is reported at the two levels.							

Waterway tonnage and ton-mile data were taken from NDC. Average trip length in miles on each waterway was then calculated by division of ton-miles by miles. In reality, though, the number would denote both the average barge and truck trip length, since highway miles have been assumed to be on a 1:1 basis with river miles. Annual truckloads were calculated by dividing the tonnage for each waterway by 25 tons/truck. They were then doubled to account for an equal number of empty return trips. The truck VMT can be calculated in either of two ways that result in the same figure. Ton-miles can be divided by 25 tons/truck and the result doubled—to account for the empty backhaul—or the trip length can be multiplied by the annual truck trips, which has already incorporated the loaded and the empty return trips.

Trucks that carry bulk commodities are limited in the backhauls they can attract. For example, a grain truck will not return with steel or any liquid product. Therefore, this hypothetical diversion scenario assumes that all trucks would return empty—a 100 percent empty backhaul. The exact percentage of empty backhaul for existing truck operations has rarely been precisely determined, but it is thought to be around 30–35 percent. Currently, however, trucks primarily haul break bulk cargo, which would make a non-empty return trip possible. On the other hand, tank trucks and certain commodity carriers tend to return empty. For example, a tank truck that had previously hauled anhydrous ammonia cannot carry anything but anhydrous ammonia on its return trip. Similarly, a tank truck that previously hauled gasoline is unlikely to haul industrial chemicals on the return the trip. Therefore, for this study, the annual truck trips are estimated at two times the annual truckloads.

Researchers obtained historical data for roadway congestion trends (rural interstate traffic) and intercity truck ton-miles to estimate and predict the possible roadway congestion effects due to a hypothetical diversion of river ton-miles to truck ton-miles. The rationale behind examining this particular relationship is that waterway movements are long distance ones, and the equivalent long distance truck movements would occur primarily on interstate highways that pass through rural settings located between urban areas.

The data range used in this analysis is from 1996 through 2014. Annual national historic data for intercity truck freight ton-miles through 2009 were obtained from BTS (*8*), at which time the BTS stopped calculating and reporting intercity truck freight ton-miles. The statistics for 2010–2011 were estimated using the regression equation developed in the 2001–2009 update. FHWA's Freight Analysis Framework version 4 (FAF4) data were used to calculate the interstate truck freight ton-miles for 2012–2014. The regression equation developed in the 2001–2009 update predicts values that are very close (within 3 percent) to the values taken from the FAF4 data, so the FAF4 data were used to carry the previous statistics forward. Table 2 tabulates the data used for this analysis.

Table 2. Intercity Truck Ton-Miles vs. Rural Interstate Vehicle Traffic.

Year	Intercity Truck Freight (Billion Ton-miles)	Weighted Average Daily Vehicles per Lane Rural Interstate (*9*)
1996	1,071	4,630
1997	1,119	4,788
1998	1,149	5,010
1999	1,186	5,147
2000	1,203	5,272
2001	1,224	5,381
2002	1,255	5,511
2003	1,264	5,465
2004	1,281	5,495
2005	1,291	5,439
2006	1,291	5,466
2007	1,317	5,470
2008	1,131	5,212
2009	1,206	5,243
2010	1,196[3]	5,198
2011	1,196[3]	5,198
2012	1,156 (*10*)	5,178
2013	1,197(*10*)	5,124
2014	1,225(*10*)	5,148

[3] Estimated using regression analysis from 2001–2009 update.

Linear regression techniques were applied to the historical BTS data (1996–2009) to develop an equation describing the relationship between these two variables. Figure 4 shows the line fitted, the equation developed using the BTS data. The adjusted R2 for this regression is 0.834. (R-squared, the coefficient of determination, is the proportion of variability in a data set that is accounted for by a statistical model.) The R^2 is close to 1, which indicates that the line is a very good fit to the data. In other words, there is a strong relationship between values of average daily vehicles per lane on rural interstates and intercity truck ton-miles, with the former historically dependent on the latter. The regression equation was used to determine the intercity truck freight ton-miles for 2010 and 2011. Figure 4 also shows the values of the FAF4 2012–2014 data, which closely align with the regression line. Considering this close relationship, the regression equation is used in the estimation and prediction of the possible roadway congestion effects due to a hypothetical diversion of river ton-miles to truck ton-miles.

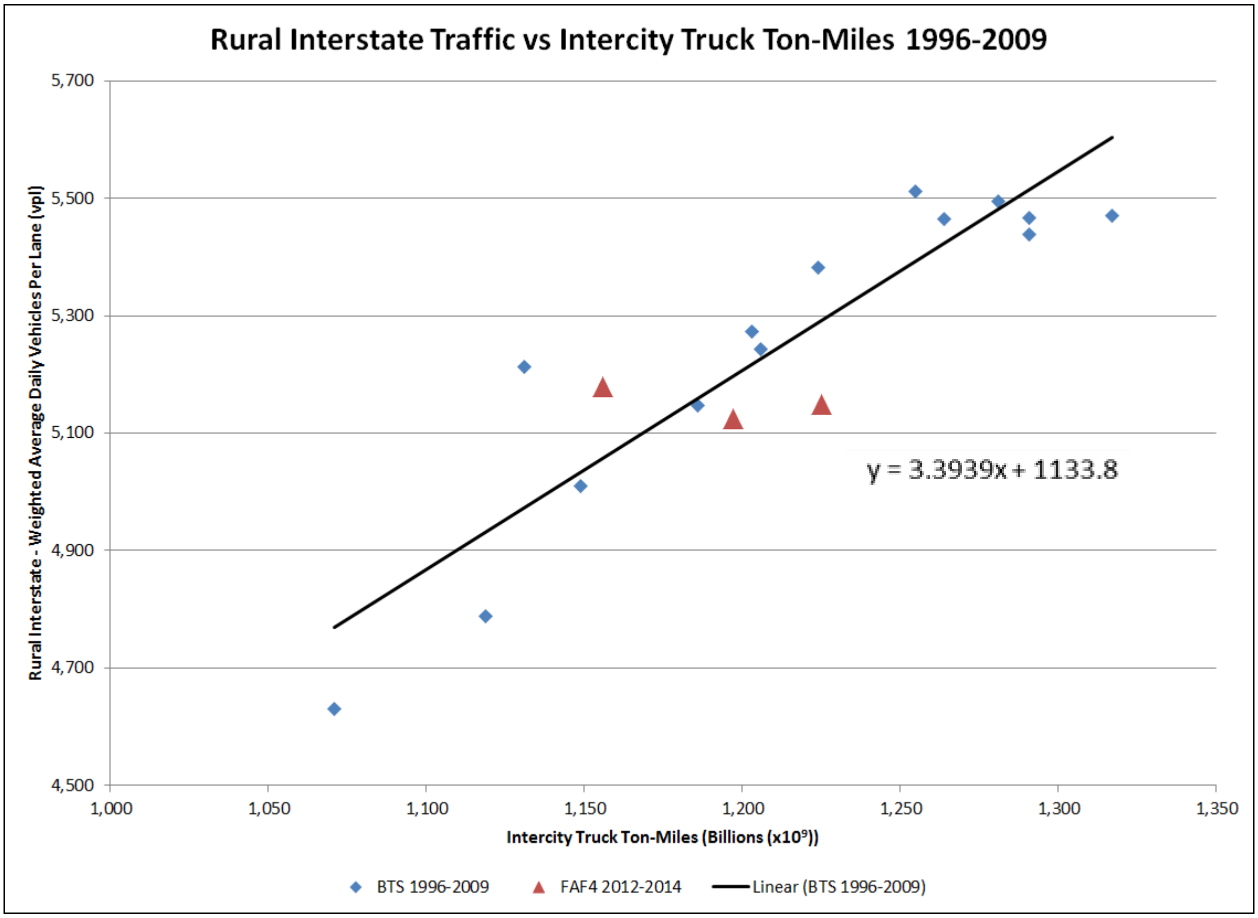


Figure 4. Average Daily Vehicles per Lane of Rural Interstate vs. Intercity Truck Ton-Miles.

In 2014, there were 5,148 average daily vehicles per lane on rural interstates, as shown in Table 2 above from Highway Statistics reports (*11*). On rural interstates, in the same year, 83 percent of daily traffic (4,273 vehicles) was composed of passenger cars, buses, and light and heavy single unit trucks. The remaining 17 percent of the traffic (or 875 vehicles) was combination trucks, the types of trucks that would carry diverted waterborne freight.

A total of 266.09 billion ton-miles was transported on the selected waterways in 2014. A total of 1,225 billion ton-miles were transported by interstate truck traffic in 2014. If the waterway ton-miles are diverted to trucks, the new total ton-miles attributed to intercity trucks add up to 1,491 billion. When this number is input to the developed regression equation, the weighted average daily vehicles per lane on rural interstates increases to 6,194. Since the number of passenger cars, buses, light trucks, and heavy single unit trucks are constant at 4,273 vehicles per lane, the remaining 1,921 vehicles would be combination trucks. Thus, the percentage of daily traffic that is combination trucks rises 14 percent from 17 percent to 31 percent. In other words, the hypothetical diversion of current waterway freight traffic would add 1,046 combination trucks to the current 875 per day per lane on a typical rural interstate.

In summary, the amount of cargo currently transported by the Mississippi and Ohio River Systems, GIWW, and Columbia/Snake River is the equivalent of 49 million truck trips annually that would have to travel on the nation's roadways if all the tonnage currently transported by barges on these waterways were to be forced onto highways. This increase in truck trips would cause the weighted average daily combination trucks per lane on segments of interstate between urban areas to rise by almost 120 percent on a nationwide basis.

This increase was derived from national level data and reflects an average nationwide increase. The absolute number and percent combination trucks per lane of rural interstate located near the waterways under study would likely be higher than average. Truck traffic due to the diverted waterborne freight would undoubtedly be concentrated in the corridors that are parallel to the major rivers, especially the outer lane, which tends to be used by trucks more heavily. Thus, the impact near the waterways considered in this study would logically be more severe than the national average, especially during the heavier truck travel periods of the year, month, week, or day.

Figure 5 shows truck traffic levels on the nation's major highways, while Figure 6 shows the locations of the major bottlenecks.

Major waterways help avoid the addition of 49 million truck trips to our highway system annually.

Figure 5. Average Daily Long-Haul Truck Traffic on the National Highway System (2011) (*12*).

Figure 6. Peak-Period Congestion on High-Volume Truck Portions of the National Highway System (2011) (*12*).

Data Limitations and Necessary Assumptions

The hypothetical and non-traditional nature of this study requires the adoption of several important assumptions in order to permit usage of existing data that could support a sound analysis.

First, the expanse of the roadway network in relation to the waterway or rail networks could not rationalize link assignment of the new truck traffic to a road class other than the interstate system. In addition, regional or corridor data are not readily available and analysis at an inter- or multistate geographical level could not be supported. The use of national data is considered the only appropriate basis given the scope of this study.

Second, it is necessary to assume that traffic delay is uniform along interstate segments regardless of whether they are classified as urban or rural. The rationale is that these long-haul combination trucks are likely to avoid urban cores that would lead to additional trip delay and travel on urban bypasses, which carry less passenger car traffic. The higher traffic volumes in urban areas and subsequent congestion are primarily attributed to a higher number and percentage of passenger cars in the traffic stream. The absolute number of trucks may be equal to the rural interstate segment downstream; however, their percentage of the traffic volume drops around urban areas due to the domination of passenger cars in the traffic stream.

Third, it was assumed that the shorter hauls to/from interstate truck routes are of similar length and other characteristics to the existing shorter hauls to/from river segments and take place on the same road classes, which are primarily major arterials other than the interstate system. Therefore, compensation due to this issue was considered unnecessary.

Finally, it was assumed that sufficient tractors, trailers, drivers, and other equipment would be available to move diverted cargo by truck. Availability of these items, particularly availability of truck drivers over the near and long term, continue to be among the top challenges identified for the trucking industry. As demand levels increase to expected robust levels and, when chain reaction effects are factored in, a serious disruption to the entire supply chain could occur. However, an analysis of this type and complexity is outside the scope of this study.

RAIL SYSTEM CONGESTION IMPACTS

This rail system congestion analysis provides an estimate of the impact that a closure of the inland river transportation system would have on the railroad industry and the potential impact to the transportation of commodities in particular.

Data on unit, grain train velocities, and available cars online were extracted from the published operating statistics as presented in the "railtimeindicators" report on the AAR website. The historical data for cars online and average train velocities were obtained from both U.S. Securities and Exchange Commission (SEC) Annual 10-K Forms and STB R-1 Report filings. The annual number of coal car loadings for years between 2010 and 2014 were obtained from the AAR's "railtimeindicators" tabular data.[4] Railroad train velocity by commodity for the Class I railroads is available on a 53-week history from the AAR website on a current basis—historical data are not maintained. The system velocity for all trains is reported by individual railroads in their annual reports on an inconsistent basis. Therefore, in order to establish a general train speed for commodity trains, the current 53-week (2016) individual railroad performance measures for CSX are used, which is the railroad that will be most affected in the hypothetical diversion scenario discussed below. (The CSX lines essentially parallel the Ohio River while the Norfolk Southern Railway lines are principally perpendicular to the river.)

Railroad Coal Traffic

Coal is the most important single commodity carried by U.S. freight railroads. In 2014, it accounted for 39 percent of tonnage, 20.2 percent of carloads, and 19.3 percent of gross revenue for U.S. Class I railroads. Coal is also an important commodity for many non-Class I railroads. According to the AAR, "69 percent of U.S. coal shipments were delivered to their final destinations by rail in 2014, followed by water (13 percent, mainly barges on inland waterways); truck (11 percent); and conveyor belts and tramways (7 percent, mainly at mine mouth plants)" (*13*). The market for coal transportation for the railroad industry has declined rapidly in recent years, down 29.4 percent since its high in 2008 (*13*).

The downturn in railroad coal transportation may primarily be attributable to increased electric utility utilization of cheap natural gas supplies. In 2014, railroads transported 20.8 percent fewer coal car loadings than in 2008. This analysis assumes that the market share for each

[4] Source: AAR communication to the authors on January 17, 2017

transportation sector has continued to remain relatively stable since the 2009 modal comparison study (*13*).

Coal's share of U.S. electricity generation has fallen sharply in recent years. Rail coal traffic has suffered accordingly. In 2008, the peak year for U.S. rail coal traffic, Class I railroads originated 7.71 million carloads of coal. In 2014, they originated 6.11 million carloads, down 20.8 percent from 2008's peak. Put another way, Class I railroads originated 1.6 million fewer carloads of coal in 2014 than in 2008. Using an assumed 115 carloads per coal train, there were nearly 14,000 fewer trainloads of coal in 2014 than in 2008.

Class I railroads originated 713.2 million tons of coal in 2014, down 165.4 million tons or 18.8 percent from 2008's peak of 878.6 million tons. Railroads have typically derived more revenue from coal than from any other single commodity, though the broad intermodal category accounted for more revenue than coal from 2003 to 2007.

Potential Rail System Congestion Impacts

For CSX—the railroad used in this hypothetical diversion of coal traffic—the weighted average coal train velocity for 2014 was estimated to be 17.5 miles per hour. The CSX Transportation system reported a decrease of the average velocity for all trains year after year from 2009, 2010, 2011, and then an increase in velocity for 2012 and 2013. However, in 2014 CSX again, reported a decrease in average velocity for all trains. In 2014, CSX reported a decrease in train velocities over 2013 of 13.4 percent because of increased traffic volume (*14*).

The tonnage moved on the inland river system would amount to an additional 15.8 percent more tonnage on the railroad system. This new burden would not be evenly distributed. The primary burden would be placed on the eastern U.S. railroads with little real opportunity to take advantage of excess capacity that may exist on the western U.S. railroads.

Diverting river traffic would add 16 percent more tonnage to the national rail system.

$$\% \text{ Railroad Coal Tonnage Increase} = \left(1 - \frac{RCT + OBCT}{RCT}\right) * 100$$

$$= \left(1 - \frac{713.200 + 112.877}{713.222}\right) * 100$$

$$= 15.83\%$$

RCT = Railroad Current Tonnage
OBCT = Ohio Barge Coal Tonnage

The coal traffic on the Ohio River provides a clear example of what the effect of a major diversion of traffic would be. The Ohio River main stem coal traffic was reported to be 112.877 million tons for the year 2014, which represents 18.8 percent of the total domestic barge tonnage (599.4 million short tons) and 73 percent of the coal tonnage for barges for the year (155.0 million short tons). The majority of the Ohio River coal traffic would have to be handled by the CSX railroad if the Ohio River transportation system ceased operations. CSX reported 1,262,000 coal car loadings for 2014. At 112 tons per carload, CSX transported 141.344 million tons of coal. The calculation for the percent Railroad Coal Tonnage Increase is performed using CSX Coal Tonnage and the Ohio Barge Coal Tonnage to determine the percent increase in coal tonnage the CSX would be burdened with should the river traffic require alternate transportation by railroad.

$$\% \text{ CSX Railroad Coal Tonnage Increase} = \left(1 - \frac{CSXCT + OBCT}{CSXCT}\right) * 100$$

$$= \left(1 - \frac{141.344 + 112.877}{141.344}\right) * 100$$

$$= 79.81\%$$

CSXCT = CSX Coal Tonnage
OBCT = Ohio Barge Coal Tonnage

If 112.877 million tons of Ohio River coal traffic were to be shifted to the CSX rail lines, the railroad would be faced with a nearly 80 percent increase in coal traffic, or an additional 1,007,830 car loadings of coal annually with 112 tons of coal in each car. If the trains were made up of 108 cars per train, there would be an annual addition of 9,332 train movements or 25.6 added train movements per day on the lines paralleling the Ohio River. Given the average round-trip time of a unit coal train of three days, one unit train can make 122 round trips per year. It would take 76.5 new unit trains (8,262 additional coal cars) to accomplish the additional 9,332 train movements—all on the CSX Railroad.

The CSX Railroad Annual Reports provide statistical data for average train velocity, average system dwell time, coal loadings in units, and annual total number of cars online for the period between 2009 and 2014. Table 3 show the data.[7] (The dwell time is the average amount of time between when a car arrives in a rail yard and when it departs the rail yard (*14*).

Table 3. CSX Railroad Performance Measures.

CSX Transportation															
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**With Diversion**
Velocity All Trains	21.7	22.5	21.1	20.3	19.2	19.8	20.8	20.5	21.8	21.0	20.6	22.7	23.2	20.1	18.9
Dwell	NA	23.2	25.3	28.7	29.7	25.6	23.2	23.3	24.1	25.0	25.9	23.7	22.2	26.3	NA
Coal Loadings (x 1,000)	1722	1574	1570	1659	1726	1798	1879	1553	1,487	1,573	1,533	1,290	1,195	1,262	2,270
Cars Online	NA	NA	NA	NA	NA	NA	NA	NA	216,010	210,984	206,432	189,994	182,266	203,699	205.,969

[7] All data are unaudited, and excerpted from http://investors.csx.com/phoenix.zhtml?c=92932&p=irol-reportsannual. Data in column, With Diversion, are calculated using other table data as reference.

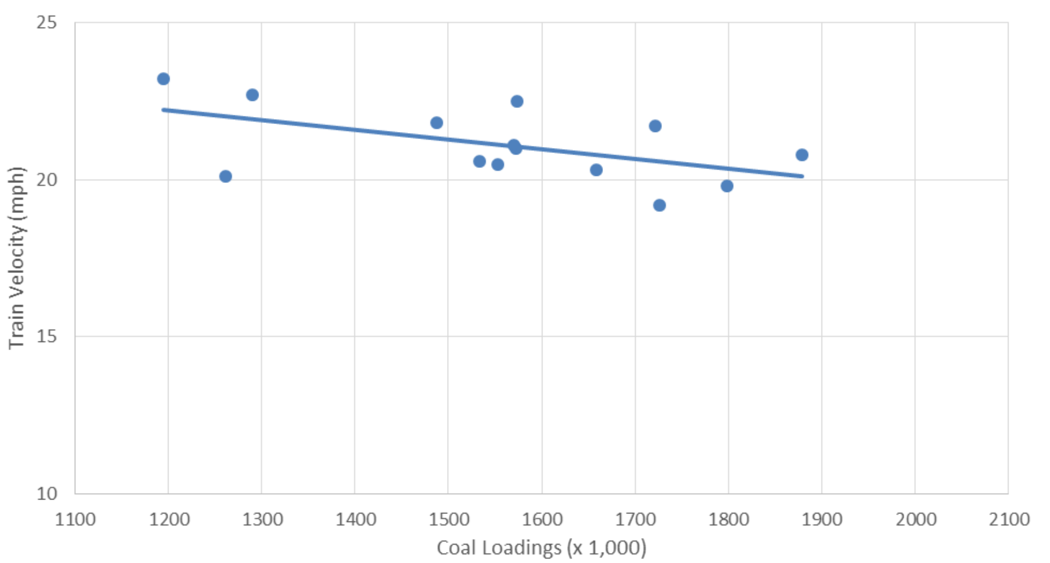


Figure 7. CSX Train Velocity as Function of Coal Loadings.

A regression analysis of these data yields the following equation:

$$y = -0.0031x + 25.911$$

The trend line fit analysis indicates a poor R^2 correlation coefficient of 0.287, which implies that only the direction is predictable given the assumptions applied to the regression. Evaluating the regression equation (produced in the previous 2009 study) for 2,269,830 coal car loadings provides a system average speed of 7.9 mph. Using the equation derived from the data above, the system average speed would be slightly more approximately 18.8 mph. Although the R^2 correlation coefficient is low, the speed predicted by the equation above is within the range of speed estimates derived using alternate methods of analysis and is shown here as the predicted value. The annual coal loading data and train velocities from the years 2001 to 2014 are for the entire CSX Railroad system. The actual CSX coal traffic train routes and route densities for the period between 2001 and 2014 is unknown.

For the projected increased coal loadings from closing the Ohio River barge traffic, it can reasonably be assumed that the 16 percent increase in the entire railroad system coal loadings will originate and terminate up or downstream near the Ohio River. Given that the added traffic would use only rail lines along the Ohio River, using the CSX System average train velocity is the best available metric to evaluate the impact on rail traffic. The increased coal traffic along the Ohio River diverted to only the CSX Railroad would increase CSX coal loadings by nearly 80 percent. The potential for increased coal rail traffic due to closing the Ohio River transportation system would affect the local rail lines much more severely than the rest of the system. The real possibility exists that the railroad system as currently developed could not respond by accommodating the shift of coal traffic and either it would end up in gridlock or very little additional coal traffic could be accommodated.

CHAPTER 3: EMISSIONS ISSUES

The first part of this chapter focuses on four primary pollutants that are tracked by EPA: hydrocarbons, carbon monoxide, nitrogen oxide, and particulate matter. An analysis of GHG emissions is included at the end of this chapter.

HIGHWAY

Emission models have been used by EPA to evaluate highway mobile source control strategies by states and local and regional planning agencies to develop emission inventories and control strategies for State Implementation Plans under the Clean Air Act; by metropolitan planning organizations and state transportation departments for transportation planning and conformity analysis; by academic and industry investigators conducting research; and in developing environmental impact statements.[5]

EPA's state-of-the-art emission modeling system MOVES (MOtor Vehicle Emission Simulator) estimates emissions from cars, trucks, and motorcycles incorporating new car and light truck energy and GHG rates and a number of other improvements. It covers a broad range of pollutants and allows multiple scale analysis (*15*). The current version is MOVES2014a, and in addition to the highway sources listed above, adds the capability to model non-highway mobile sources, including agriculture, airport support, commercial, construction, industrial, lawn/garden, logging, oil field, pleasure craft, railroad, recreational, and underground mining sectors.

MOVES is intended for official use in State Implementation Plan development and transportation conformity determinations as required by the Clean Air Act. EPA requires the use of MOVES in new regional emissions analyses for transportation conformity determinations.

Emission factor estimates depend on various conditions, such as ambient temperatures, altitude, travel speeds, operating modes, fuel volatility, mileage accrual rates, and others. Many of the variables affecting vehicle emissions can be specified by the user. The model allows modeling of specific, tailored situations via user-defined inputs that complement the basic emission factors (a specific vehicle category, roadway type, time of day, etc.).

MOVES2014a was used to model the emissions of long haul diesel fueled combination trucks nationally, based primarily on the model's built-in default values that were derived from national fleet and vehicle activity data.

The user-defined inputs used in MOVES include the following:

- Scale: national inventory.
- Time span: 2014; 12 months, 7 days, 24 hours.
- Geographic bounds: nation.
- Vehicles/equipment: diesel fuel combination long haul truck.
- Road type: all (rural and urban; restricted and unrestricted access; off-network).

[5] International measurement standards apply to emissions mass; therefore, the unit of mass measure is grams (i.e., kilograms, and metric tons.)

- Pollutants:
  - Volatile organic compounds (VOC).
  - Carbon monoxide (CO).
  - Nitrogen oxides (NO_x).
  - Carbon dioxide (CO_2).
  - Particulate matter of diameter 10 micrometers or less (PM-10).
- Processes:
  - Running/Start/extended idle emissions exhaust.
  - Brake wear/tire wear.
  - Crankcase running/start/extended idle exhaust.
  - Refueling displacement vapor/spillage loss.
- Output:
  - Mass units: grams.
  - Distance units: miles.
  - Activity: distance traveled.

Table 4 shows the output of MOVES (i.e., the emission factors of the above pollutants) in grams per VMT.

The output factors in grams per VMT, the total diversion truck VMT, and the diverted waterborne ton-miles were used to calculate emission rates in grams per ton-mile, which were then used to calculate the tons of additional annual emissions (Table 4). Every truck was assumed to return empty—or haul zero tons—so its return trip would have zero ton-miles. The conversion of vehicle-mile rates to ton-mile rates was necessary in order to enable a comparison with the water and rail modes on an equal basis. (Water and rail modes typically report and publish data using ton-miles, whereas highway data conventionally use vehicle-miles.)

Table 4. Emissions Analysis Results—2014.

Units	VOC	CO	NO_x	PM-10	CO_2
g/VMT	1.06	3.35	11.77	0.59	1,927.50
g/ton-mi (or tons/million ton-miles)	0.08	0.27	0.94	0.05	154.08
Tons (000s)	22.5	71.3	250.4	12.5	40,999.1
Total truck VMT = 21.3 billion Total truck ton-miles = 266.1 billion					

Although the range of increases in all pollutants may seem relatively modest, it must be borne in mind that the diversion truck fleet will operate primarily near the waterways under study. The impacts from truck emissions will be more severe in this geographical area than locations far away from these river bodies. The middle part of the U.S. already includes several areas designated by the EPA as non-attainment areas, most commonly for ozone. The only non-attainment area (for CO only) along the path of the Columbia/Snake Rivers is Portland, Oregon. Any emissions increase would only worsen existing problems. Figure 8 shows these non-attainment areas for ozone, CO, and PM-10 nationally.

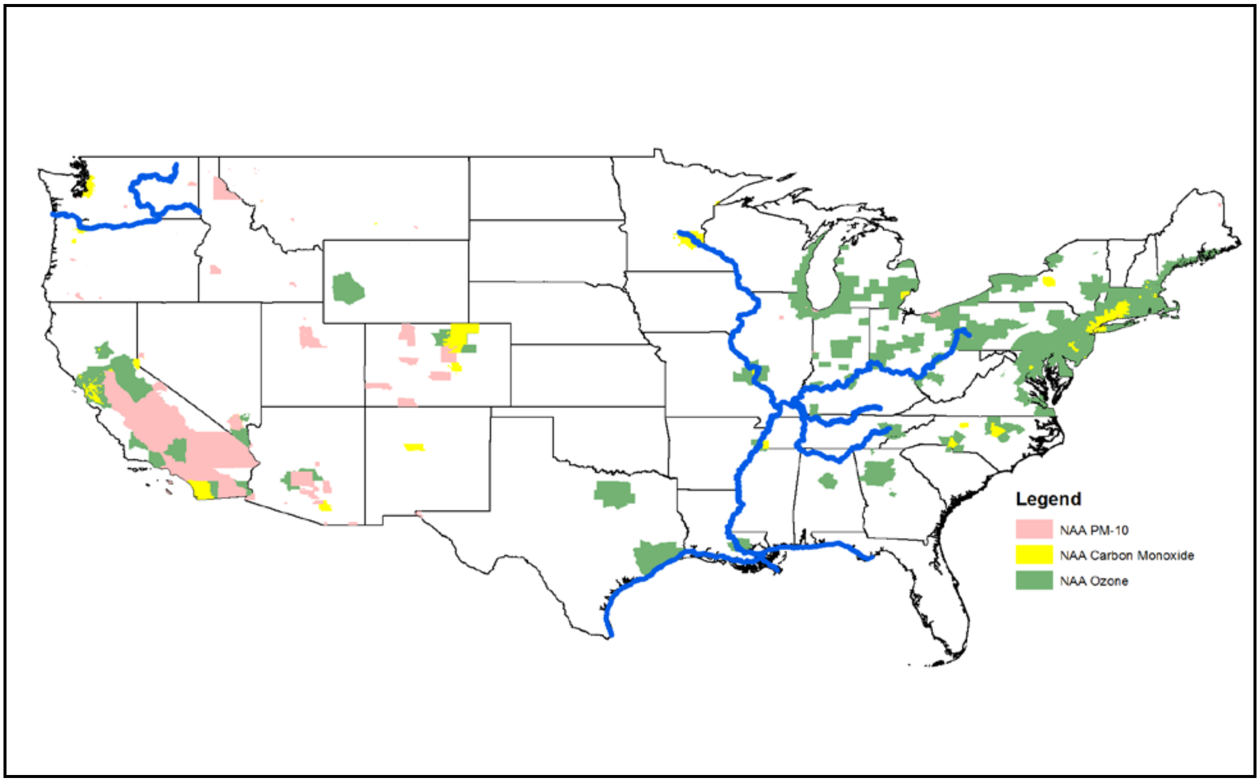


Figure 8. Nonattainment Areas in Study Area (*16*).

A theoretical waterborne freight diversion would have devastating effects on the entire spectrum of the trucking and fuel industries when new regulations and their implications are also considered. The demand for new trucks, drivers, and additional fuel supplies will increase dramatically. The potential air quality impact in future years is not quite as clear; however, air emission data indicate that NO_x is four times more sensitive to ozone creation than VOC. Every ton of NO_x emissions added because of a modal diversion offsets four tons of VOC reductions accomplished elsewhere (e.g., refineries and chemical plants).

For a complete discussion of pending federal regulations, please see the section titled "Future Federal Emissions & Energy Regulations — On-Road Vehicles" in Chapter 4.

RAILROAD LOCOMOTIVE AND MARINE EMISSIONS

EPA has regulated the emissions from railroad locomotives since January 1, 2001 (*17*). During the period of this study's snapshot in time of 2014, the railroads were subject to six regulated levels of emissions. The locomotive emission levels are designated as Tier 0, Tier 0+, Tier 1, Tier 1+, Tier 2, Tier 2+, and Tier 3 emissions (*18*). The regulations establish emission standards, methods, and procedures to calculate duty-cycle emissions from locomotives (*19*). EPA provides a conversion factor for the amount of pollutants locomotives would produce from each gallon of fuel used. For 2014, EPA also provides an estimated amount of emissions for each gallon of fuel consumed—135 grams of NO_x per gallon for line haul duty cycle locomotives (*20*).

It is often useful to express emission rates as grams of pollutant emitted per gallon of fuel consumed (g/gal). EPA has developed a conversion factor to convert grams per brake-horsepower-hour (g/bhp-hr) to g/gal, and provides Table 5 for use in estimating emissions when fuel gallons are known. The railroad switch emission values are included in the table for completeness, but are not used in reference to emissions from the railroads. The ton-miles due to rail yard switching are not included in EPA calculations or estimates. The railroads are required to provide kilowatt-hour production or fuel use in switchers for the estimate of emissions.

Table 5. 2014 Conversion Factors for Emissions in g/gal of Fuel Use.

Grams per Gallon Emission Factors (g/gal)				
	HC	**CO**	**NO_x**	**PM**
RR Line Haul	6.1	26.6	135	3.6
RR Switch	12.7	38.1	217	4.8

In 2004, EPA began to regulate commercial marine engines. The regulations are formulated for three categories of marine engines, Category 1, 2, and 3. Category 1 engines are those having less than 5.0 liters per cylinder, Category 2 engines are designated as those having a displacement of 5.0 liters per cylinder but less than 30 liters per cylinder, and Category 3 engines are those having a displacement of 30 or more liters per cylinder. Furthermore, the regulations introduced two tiers of emission levels, Tier 1 and Tier 2. EPA set a general life for marine engines of 10 years or 10,000 hours for Category 1 engines and 20,000 hours for Category 2 engines. Exceptions are allowed but, generally, engine manufacturers are required to petition EPA in order to obtain an exception. In 2008, EPA formalized Tier 3 marine regulations with implementation for Category 1 and 2 engines over 75 kw output per cylinder and between 7 and 15 liters displacement to begin implementation of the regulations in 2013.

The 2004 regulations governing the allowable emissions for marine engines in Category 1 required only new engines or newly rebuilt engines to comply at the regulated emission levels. There was a limit on the engine size and power level for the 2004 regulation, as well.

In 2007, EPA introduced new requirements on the deadline for new engines and newly rebuilt engines to comply with Tier 2 emission limits for Category 1 and 2 engines. Beginning in summer 2013, new or newly rebuilt engines were required to meet new Tier 3 lower emission standards applicable for their category. Some fleet owners have taken a proactive position on complying with the emission regulations and are repowering many of their vessels with newer, higher horsepower, and higher efficiency engines. However, the team determined that it is not possible to estimate the portion of the fleet that has become compliant with the Tier 3 emission regulations. Additionally, even if it were possible to determine the level of compliance, the impact to the overall marine fleet emission inventory through the end of 2014 would be minimal.

Beginning in 2007, EPA regulations limit commercial marine diesel engines in Category 1 to combined total hydrocarbon/oxides of nitrogen emissions output of no more than 7.2 grams/kilowatt hour limit and Category 2 engines of between 5 and 15 liters displacement per cylinder (comparable to locomotive engines) to a combined total hydrocarbon/oxides of nitrogen emissions output of no more than 7.8 grams/kilowatt hour and particulate matter output of no more than 0.27 grams per kilowatt-hour. The revised EPA locomotive and marine emissions regulations issued in June 2008 essentially require both industries to further reduce emissions and use ultra-low sulfur diesel (ULSD). The same emission factors are used in this analysis, following the EPA intent that both commercial marine diesel engines and locomotive diesel engines be governed by the same regulation.

The idle emissions for marine vessels are difficult to evaluate since every engine will idle at a different speed. Since the amount of fuel used per ton-mile of revenue is estimated based on reported fuel tax collected by the Internal Revenue Service (IRS) and the tonnage reported to the U.S. Army Corps of Engineers, the idle and running emissions are not at issue in this analysis. The same issue is present for railroad emissions with a comparable solution. Because this analysis does not attempt to develop a route specific emission profile, the idle and running emission profiles are not necessary for this study.

This emission analysis uses fuel consumption by mode to estimate the emissions for that mode. Regardless of emission output per kilowatt-hour for any mode, the total fuel consumption of the mode provides the total amount of emission output for that mode given that the emission per gallon of fuel consumed is equal for all modes. Table 8 presents the results of the analysis.

GREENHOUSE GAS EMISSIONS

Table 6 (reproduced as Table 12 in Chapter 4) provides a summary of fuel efficiency by mode.

Table 6. Summary of Fuel Efficiency.

Mode	Ton-Miles/Gallon
Inland Towing	647
Railroads	477
Truck	145

EPA has published data on fuel and the emissions that are created by burning the fuel (*20*). The GHG receiving the most focus around the world today is CO_2, so this GHG analysis focuses strictly on CO_2. Table 7 summarizes the relevant factors.

Table 7. 2014 EPA GHG Emissions Parameters—CO_2.

Diesel Fuel Carbon weight per US Gallon —	2,784 grams (average)/gal
% Carbon (C) oxidized into Carbon Dioxide (CO_2)	99
CO_2 molecular weight (Carbon 12, Oxygen (16x2) 32) 12+32=44, or CO_2 multiplier is =	44/12
CO_2 weight is (2,784 x 0.99 x (44/12)) =	10,106 g/US gal (or 10.106 kg/gal, or .010106 tons/gal, which = 98.97 gal/metric ton)
10,106 grams ÷ 453.59 grams per pound =	22.28 lb/US gal

A ton of GHG is defined here as a metric ton (2,205 lb), since that is the typical unit of measure employed in GHG analyses.

These calculations show that 2,784 grams of carbon/gal will oxide into 10,106 grams—or 22.28 lb—of carbon dioxide.

Using the factors shown in Table 7, one ton of GHG is produced per 98.97 gallons of fuel consumed.

2,205 lb/ton ÷ 22.28 lb GHG/gal = 98.97 gal/ton GHG

Therefore, the values for the number of ton-miles delivered per ton of GHG produced will be 98.97 times the number of ton-miles per gallon of fuel used. The simplest way of expressing the differences in the modes is to calculate the amount of ton-miles it takes for each mode to produce one ton of GHG. The following calculations take the ton-miles per gallon of fuel consumed by each mode and multiply by the gallons of fuel per ton of GHG. In other words, to produce a ton of GHG, a power unit must consume 98.97 gallons of fuel:

- **Railroad:** 477 ton-miles/gal × 98.97 gal/ton-GHG = 47,208.7 ton-miles/ton-GHG.
- **Inland Towing:** 647 ton-miles/gal × 98.97 gal/ton-GHG = 64,033.6 ton-miles/ton-GHG.
- **Truck:** For trucks, the inverse of the CO_2 factor shown in Table 4 yields ton-miles per ton-GHG: 1/0.00015408 = 6,490.

Figure 9 illustrates the results.

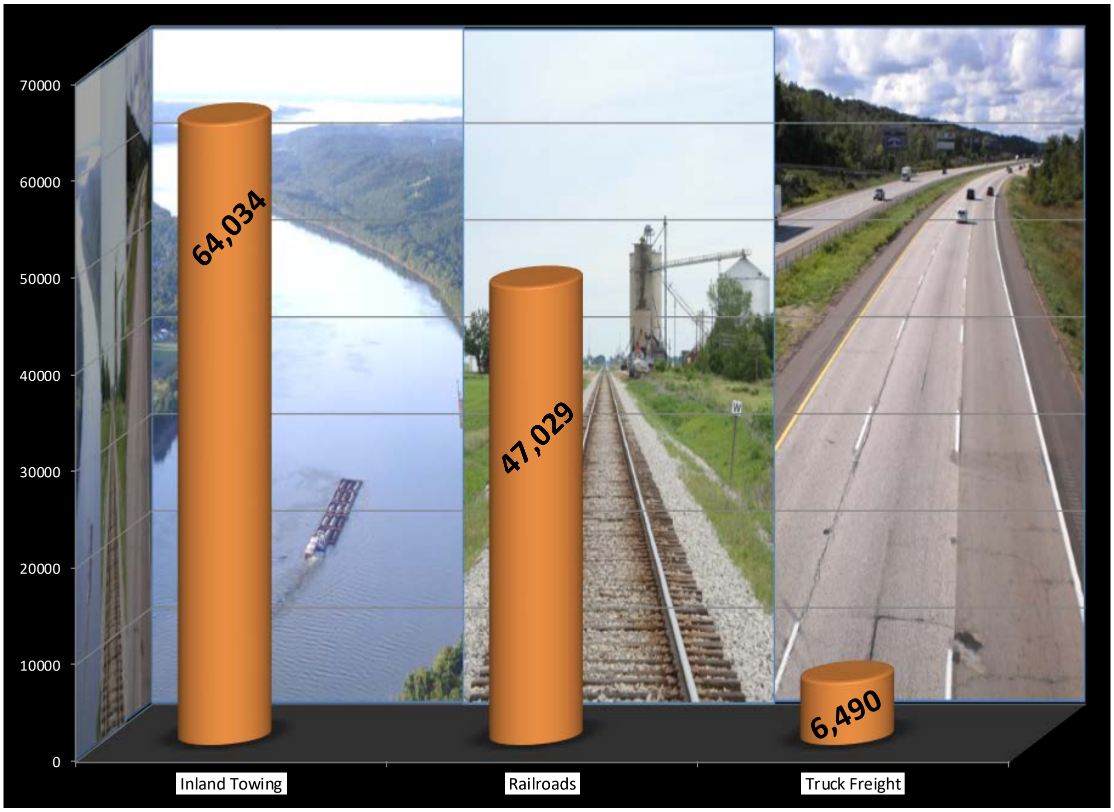


Figure 9. Ton-Miles per Metric Ton of GHG—2014.

Another way to evaluate the measure of the GHG between modes is to consider the tons of GHG per million ton-miles (tons-GHG/10^6 ton-miles).

- **For each mode:** 10^6 ton-Miles ÷ ton-miles/ton-GHG = ton-GHG/10^6 ton-Miles.
- **Railroad:** 10^6 ton-Miles ÷ 47,208.7 ton-miles/ton-GHG = 21.18 ton-GHG/10^6 ton-Miles.
- **Inland Towing:** 10^6 ton-Miles ÷ 64,033.6 ton-miles/ton-GHG = 15.62 ton-GHG/10^6 ton-Miles.

- **Truck:** Again, using the data provided in Table 4, the calculation for trucks is: 10^6 ton-Miles ÷ 6,490 ton-miles/ton-GHG=154.08 tons-GHG/10^6 ton-Miles.

Figure 10 illustrates these results.

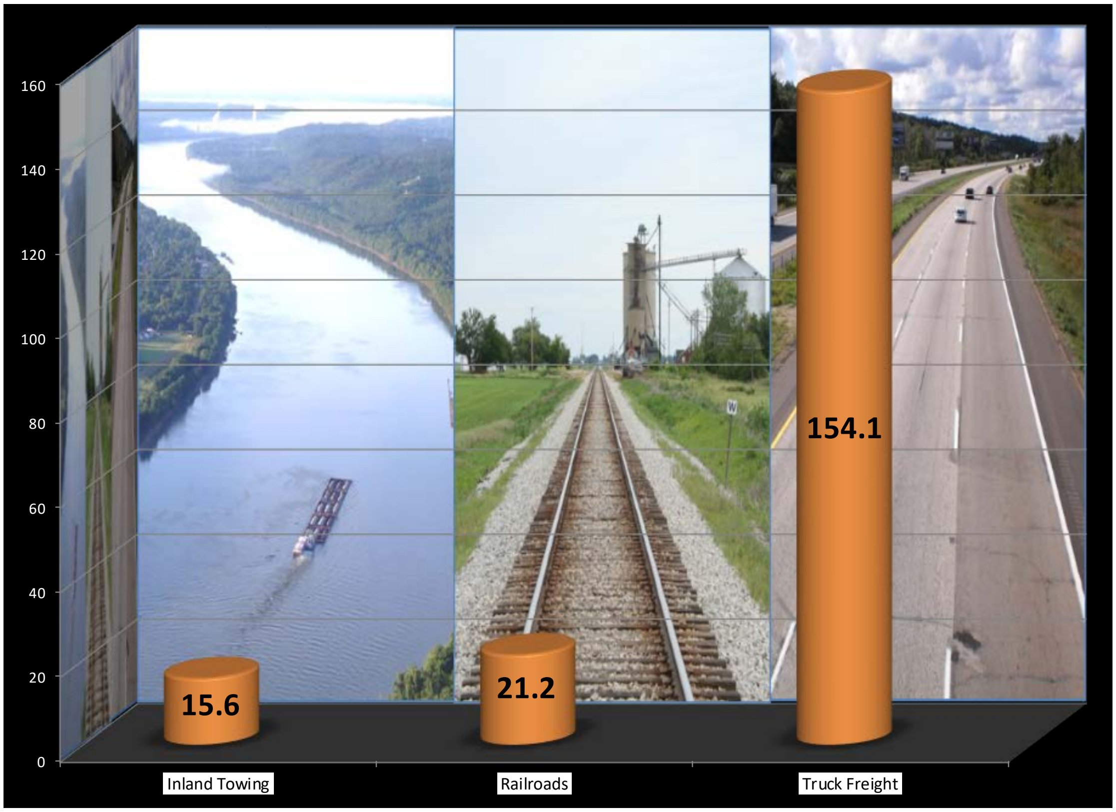


Figure 10. Metric Tons of GHG per Million Ton-Miles—2014.

According to statistics published by the U.S. Army Corps of Engineers, in 2014, the inland waterways logged 281 billion ton-miles of activity. Assuming that any modal change would result in the new mode operating at the average efficiency for the mode, the calculations above lead to the conclusion that had the inland waterway activity occurred on the railroads an additional 1.562 million metric tons of GHG would have been produced; on the highways, an additional 38.907 million tons would have been emitted. (The calculation consists of multiplying the difference in the rates of ton-GHG/ton-mile as shown above multiplied by (281billion ton-miles divided by 10^6).

SUMMARY MODAL COMPARISON

Table 8 shows the emissions comparison between the three modes. The 2014 value for inland towing ton-miles/gallon from Table 11 in the next chapter is used (647 ton-miles per gallon of fuel). The average ton-miles per gallon for all railroads (477 ton-miles per gallon of fuel) for 2014 from Table 9 (also in the next chapter) is used for the railroad emissions values.

Table 8. Summary of Emissions—Grams per Ton-Mile—2014.

Emissions (grams/ton-mile)					
	HC (VOC for truck)	**CO**	**NO_x**	**PM**	**CO_2[6]**
Inland Towing	0.0094	0.0411	0.2087	0.0056	15.62
Railroad	0.0128	0.0558	0.2830	0.0075	21.19
Truck	0.08	0.27	0.94	0.05	154.08

[6] CO_2 emissions for railroads were calculated on a system-wide basis.

CHAPTER 4: ENERGY EFFICIENCY

In the comparisons for the energy intensities of the freight modes evaluated in this study, energy used for moving the empty transportation equipment on return trips was taken into account. Researchers examined the data for each freight transportation mode to ensure that the empty movement portion was accounted for in the energy per revenue ton-mile calculations.

HIGHWAY

BTS indicates that the fuel economy rate for combination trucks in each of 2011, 2012, and 2013 was 5.8 miles per gallon (*21*), which agrees with the figure published in the U.S. Transportation Energy Data Book (*22*). Conventionally, VMT are used in reporting and publishing data for the highway mode, whereas ton-miles are used for the water and rail modes. For this reason, comparison of the highway mode to the other two modes in this study warranted conversion of vehicle-mile rates to ton-mile rates.

When the truck fuel efficiency rate of 5.8 miles per gallon is multiplied by the assumed truckload of 25 tons of cargo, a truck fuel efficiency of 145 ton-miles per gallon is generated. Each return trip is assumed to be empty—or haul zero cargo tons. The fuel efficiency of the return trip in ton-miles per gallon mathematically would equal zero, but the fuel efficiency in vehicle-miles per gallon would still equal 5.8. Since an across the board comparison of the three modes requires the use of a ton-miles per gallon rate, 145 ton-miles per gallon is the proper figure to use, which describes the fuel efficiency of a loaded truck.

A comparison of energy consumption for freight movement by the various surface transportation modes has previously been attempted. The researchers investigated the possible use of such a comparison contained in the U.S. Transportation Energy Data Book, but determined that the methodology used was not appropriate. For this report, the researchers calculated energy efficiencies using detailed data supplied by each transportation industry sector to government regulatory entities.

EPA has established a comprehensive national control program to regulate the heavy-duty vehicle and its fuel as a single system. In 2000, EPA moved forward on schedule with its rule to make heavy-duty trucks and buses run cleaner, particularly with respect to NOx and PM. Beginning with the 2007 model year, the harmful pollution from heavy-duty highway vehicles was reduced by more than 90 percent through the use of ULSD in combination with the use of high-efficiency diesel particulate filters, selective catalytic reduction, or exhaust gas recirculation. These devices are damaged by sulfur which is why the EPA also reduced the level of sulfur in highway diesel fuel by 97 percent in mid-2006—from 500 parts per million (ppm) in low sulfur diesel to 15 ppm in ULSD. The phase-in was set on a percent-of-sales basis: 50 percent from 2007 to 2009 and 100 percent in 2010.

EPA's PM emissions standards for new heavy-duty engines were set at 0.01 grams per brake-horsepower-hour (g/bhp-hr) and took full effect for diesels in the 2007 model year. The standards for NO_x and non-methane hydrocarbons are 0.20 g/bhp-hr and 0.14 g/bhp-hr, respectively, and took effect in January 2010.

EPA and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) announced in October 2010 a first-ever program to reduce GHG emissions and improve fuel efficiency of medium- and heavy-duty vehicles, such as the largest pickup trucks and vans, semi-trucks, and all types and sizes of work trucks and buses in between. These vehicles make up the transportation segment's second largest contributor to oil consumption and GHG emissions. Standards for combination trucks in Class 8 range from 118 ton-miles/gallon to 159 ton-miles/gallon. This Phase 1 final rule addressed model years 2014–2018. The program intends to create a strong and comprehensive heavy-duty national program (the HD National Program), designed to address the urgent and closely intertwined challenges of dependence on oil, energy security, and global climate change. The agencies estimate that the combined standards will reduce CO_2 emissions by about 270 million metric tons and save about 530 million barrels of oil over the life of vehicles built for the 2014 to 2018 model years, providing $49 billion in net program benefits. The reduced fuel use alone will enable $50 billion in fuel savings to accrue to vehicle owners, or $42 billion in net savings when considering technology costs.

A second phase of regulations is planned for model years beyond 2018. The Phase 2 program intends "to promote a new generation of cleaner, more fuel efficient trucks by encouraging the development of new and advanced cost-effective technologies through model year 2027" (*23*). EPA states that the program is expected to lower CO_2 emissions by approximately 1.1 billion metric tons, save vehicle owners fuel costs of about $170 billion, and reduce oil consumption by up to 2 billion barrels over the lifetime of the vehicles sold under the program. For Class 7 and 8 combination tractors and engines, the CO_2 and fuel consumption standards start in model year 2021, increase incrementally in model year 2024, and phase in completely by model year 2027. For the first time, GHG and fuel efficiency standards for trailers start in 2018 for EPA and 2021 for NHTSA. Trailer technologies that could be used to meet the standards include aerodynamic devices, lower rolling resistance tires, automatic tire inflation systems, and weight reduction.

RAIL

For freight modes, a significant portion of the energy expended is attributed to non-revenue purposes. For example, almost half of the energy consumed by freight rail is not used to move freight:

- More than 30 percent is used for empty backhaul.
- About 4 percent is reported lost or spilled each year.
- About 4 percent is consumed in idling.
- 10 percent is used by yard locomotives assembling and switching cars (*24*).

The energy consumption in the railroad industry was carefully evaluated in order to ensure that the full energy, the total equipment, and freight mileage movements were included. The data for the railroads were spread among four primary sources: AAR, STB, SEC, and the railroads' own annual reports to stockholders.

The AAR data were found on the AAR website in the RR Industry Info, Statistics, and Performance Measures sections. Both the SEC and the STB websites provide each railroad's required federal filings. The SEC data source is the 10-K annual report of financial status and operating data. The STB provides each railroad's R-1 report that includes operating data, particularly the railroad's locomotive fuel gallons on Schedule 750, line 4, and the revenue ton-miles of traffic reported on Schedule 755, line 108. The individual railroad's average annual cost per gallon of fuel is discretionarily available in their individual annual report. Additionally, individual railroads may include the actual gallons of locomotive fuel consumed in their annual report; however, this value is not consistently reported by any of the railroads except in their STB R-1 filings.

Table 9 lists the fuel efficiency calculated by the researchers using the available data from sources described above and the AAR reported value for gross ton-miles per gallon of fuel for the year 2014.

Table 9. Calculated Railroad Fuel Efficiency—2014.

	Gross Revenue Ton-Miles ($x10^6$) (*25*)	**Fuel Consumed ($x10^6$) (*26*)**	**Ton-Miles/Gallon[7]**
AAR (*27*)			479.0
BNSF	711,321	1,444.1	492.6
CN (US)	66,364	120.1	552.7
CPR (US)	39,856	71.1	560.6
CSX	245,212	507.3	483.4
KCS	33,826	72.0	469.9
NS	205,020	494.0	415.0
UP	549,629	1,169.3	470.0
Total/Average All Railroads	**1,851,228**	**3,877.9**	**477.4**

INLAND TOWING

It is more difficult to develop energy consumption data for the inland waterways (river and GIWWs) operators than for the railroad industry. The marine industry only reports tax information on fuel used to the federal government. Access to detailed information on individual moves is restricted and is generally available only to the Corps. The Corps has worked with the Tennessee Valley Authority and Oak Ridge National Laboratory to develop software to model the fuel consumption, reported tonnages, and traffic mileage of marine freight transportation for the waterways for which the Corps has jurisdictional responsibility.

The Corps provided the modeled data for the marine ton-miles per gallon of fuel for the years 1996–2014. The model relies heavily on statistics for fuel consumption to calculate ton-miles per gallon for inland waterway traffic. In order to test the validity of the model outputs, the fuel tax receipts reported by the IRS were compared to the fuel tax estimates produced by the model. The model uses these statistics to calculate fuel consumed and ton-miles per gallon. Table 10 shows the results of the validation tests on the fuel tax estimates.

[7] Calculated value, Gross Revenue Ton-Miles divided by Fuel Consumed.

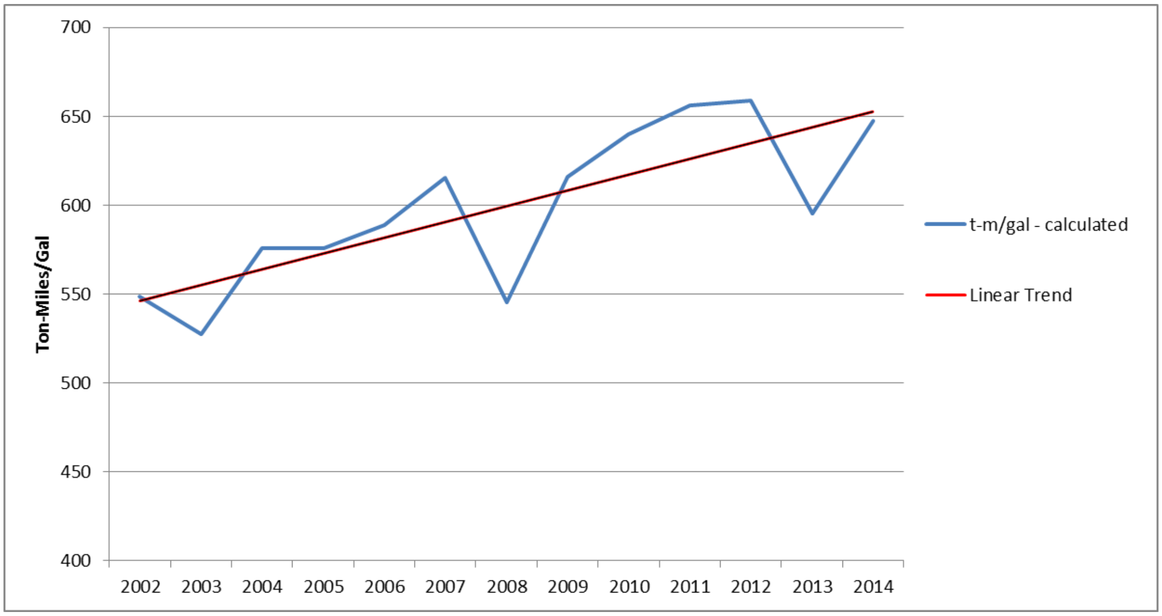
Table 10. Tax Receipts (Basis for Fuel Consumption).

Cal Year	Reported by IRS	Calculated	% Variation
1996	100,982,400	100,977,143	0.0%
1997	100,293,948	100,141,573	-0.2%
1998	97,159,316	99,219,614	2.1%
1999	106,082,016	106,901,160	0.8%
2000	104,386,000	107,949,756	3.4%
2001	97,786,000	98,427,308	0.7%
2002	95,356,000	98,472,571	3.3%
2003	90,601,000	91,892,127	1.4%
2004	91,058,000	90,069,659	-1.1%
2005	90,366,000	90,084,145	-0.3%
2006	77,844,000	86,633,431	11.3%
2007	93,566,000	80,516,238	-13.9%
2008	86,541,000	86,078,709	-0.5%
2009	73,175,000	73,058,323	-0.2%
2010	81,432,000	75,488,165	-7.3%
2011	85,754,000	75,766,838	-11.6%
2012	91,147,251	74,222,091	-18.6%
2013	73,495,321	76,125,506	3.6%
2014	81,519,513	100,083,527	22.8%

For the period of 1996–2005, annual variations of the estimated values from the actual values ranged between −0.3 percent and 3.4 percent—a very narrow range. However, in 2006 and 2007 the values deviated by 11.3 percent and −13.9 percent, respectively. The net of these two years, is a difference of 2.6 percent, which would seem to compare with the variations for the years shown above. It would appear that by 2008, the problems were being rectified. However, a closer examination shows that the estimated gallons of fuel consumed for 2008 were 6.9 percent greater than 2007 while, at the same time, ton-miles had actually decreased by 4.3 percent. (In fact, the model produced a figure of 545 ton-miles per gallon, which is markedly different from all other years in the 2004–2009 timeframe.) This indicates that the data for fuel tax collections and ton-miles were somehow out of sync for 2006–2008.

The problem with the variances appears to be due to timing and adjustment issues in the underlying data. (Neither the truck nor the rail data indicate any significant fluctuations in ton-miles per gallon during the same period.) The large variances occur again in the 2010–2014 period. However, taking the period as a whole, there was only a 2.8 percent variance between the calculated receipts and the actual receipts. Over the five-year period, the variance lies within the historical band. However, it took a major adjustment in 2014 to accomplish this. The model will have to be evaluated in the coming years to ensure that is producing accurate statistics for the purposes of modal comparison updates.

Figure 11 shows the trend line in the ton-miles per gallon calculated by the model for 2002–2014. The chart shows that while there are periodic fluctuations, over time the model seems to adhere to a predictable trend line.



The linear trend line equation for 2002–2014 is:

$$Y = 8.8309x + 537.52$$

where x is the ordinal number of the year (2002=1, 2003=2, etc.). This formula yields a ton-miles per gallon figure of 652.3 ton-miles per gallon for 2014 compared to 647.3 from the model—a variance of 0.8 percent).

Table 11. Marine Fuel Efficiency.

Year	Ton-Miles/Gallon
1996	531.5
1997	521.6
1998	543.0
1999	522.4
2000	513.3
2001	548.5
2002	548.6
2003	527.7
2004	575.7
2005	575.6
2006	589.0
2007	615.6
2008	545.4
2009	615.9
2010	639.9
2011	656.1
2012	658.9
2013	595.5
2014	647.3

Source: Tennessee Valley Authority and U.S. Army Corps of Engineers Fuel Efficiency Model

The railroads are 26.3 percent less fuel-efficient than the inland waterway freight transportation system based on revenue ton-miles per gallon. Improving the capacity of locks and avoiding the need to break up tows could make inland towing operations even more fuel efficient, but that analysis is outside the scope of this study. Both locomotive and marine engines are expected to progress toward greater fuel efficiency over the coming years.

Table 12 and Figure 12 present the results of the fuel efficiency calculations on a national industry-wide basis in summary form.

Table 12. Summary of Fuel Efficiency (2014).

Mode	Ton-Miles/Gallon
Inland Towing	647
Railroads	477
Truck	145

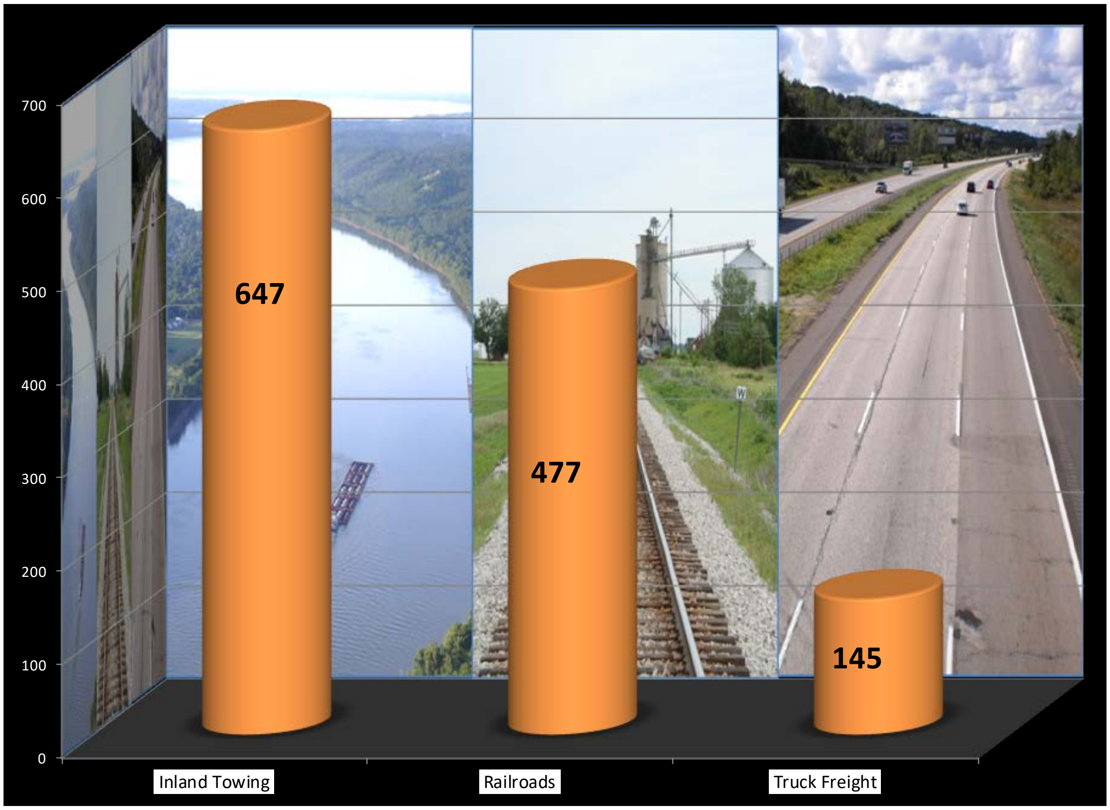


Figure 12. Comparison of Fuel Efficiency—2014.

CHAPTER 5: SAFETY IMPACTS

This study evaluates the impacts that could potentially result from diversion of barge freight to the highway or rail mode using three primary types of safety measures: fatalities, injuries, and hazardous materials spills.

FATALITIES AND INJURIES

The data for rail fatalities and injuries, respectively, were obtained from Railroad Statistics: *National Transportation Statistics—2016, Table 2-39: Railroad and Grade-Crossing Fatalities by Victim Class* and *Table 2-40: Railroad and Grade-Crossing Injured Persons by Victim Class.* Data for truck-related incidents were obtained from *Large Truck Crash Facts*, a publication of the Federal Motor Carrier Safety Administration. The data for waterborne incidents were taken from the Marine Casualty and Pollution Database, July 2015, a database that is maintained by the U.S. Coast Guard. The marine casualty database includes all incidents that occurred in water, whether deep-sea or inland; therefore, the dataset was reduced to only those incidents involving river barge traffic in order to facilitate further analysis. Incidents are added to this database only after the case has been fully investigated and closed by the U.S Coast Guard, which can take several years. Because of this delay, the more recent years in the analysis may not include all of the incidents that actually occurred.

Both rail and truck statistics include incidents involving only vehicular crashes or derailments. However, the waterborne database reports incidents resulting from various causes. In order to conduct a valid modal comparison for this study, a definition of incident analogous to the one used in the surface mode data was adopted. This modal comparison only uses data pertaining to waterborne incidents involving collisions, allisions (vessels striking a fixed object), groundings, or capsizings/sinkings.

The statistics for each mode were converted to a rate per million ton-miles to facilitate comparison. The following sources were used for ton-mile data:

- Waterborne Commerce Statistics, 2014, Part 5–National Summaries, Table 1-9 (*4*).
- AAR Class I Railroad Statistics (various editions).
- National Transportation Statistics—2016, Table 1-50: Special Tabulation (highway data) (*8*). The ton-mile statistics for trucking for 2012–2014 were estimated by applying the Transportation Services Index to the 2011 statistics.

Table 13 and Figure 13 show the comparison of fatality rates. Figure 13 shows the ratio of rail to water and truck to water; it is simply each mode's rate per million ton-miles divided by the inland waterway rate per million ton-miles.

Table 13. Fatality Statistics by Mode—2001–2014.

Mode	Annual Ton-miles* (million)	Total Fatalities	
		Annual Average*	Rate**
Highway	2,552,197	**4,452**	**0.001744** (7925%)
Railroad	1,677,800	**807**	**0.000481** (2185%)
Water	272,600	6	**0.000022**

**14-year average ** Per Million Ton-Miles*

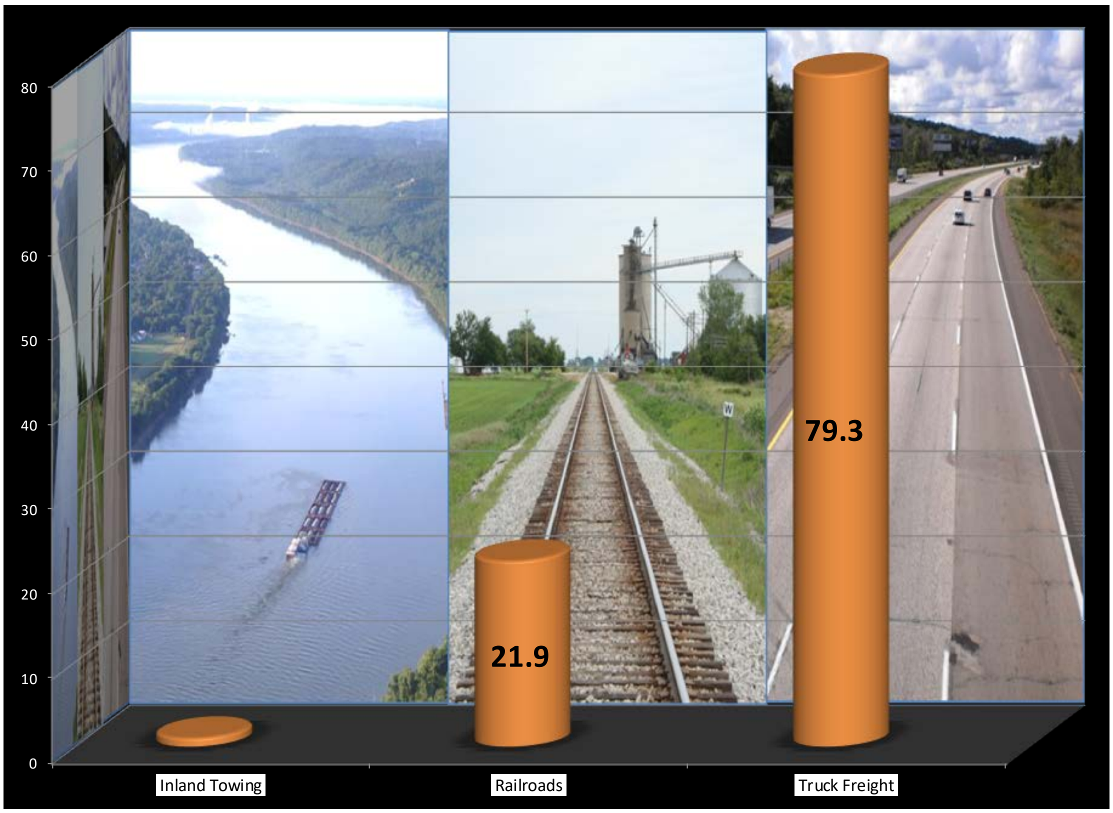


Figure 13. Ratio of Fatalities per Million Ton-Miles versus Inland Marine—2001–2014.

Figure 14 is similar to Figure 13. It shows the ratio of rail to water and truck to water; it is simply each mode's injury rate per million ton-miles divided by the inland waterway rate per million ton-miles.

Table 14. Comparison of Injuries by Mode—2001–2014.

Mode	Annual Ton-miles* (million)	Total Injuries	
		Total Annual*	Rate**
Highway	2,552,197	**104,286**	**0.040861 (69617%)**
Railroad	1,677,800	**7,962**	**0.004746 (8085%)**
Water	272,600	**16**	**0.000059**

** 14-year average ** Per Million Ton-Miles*

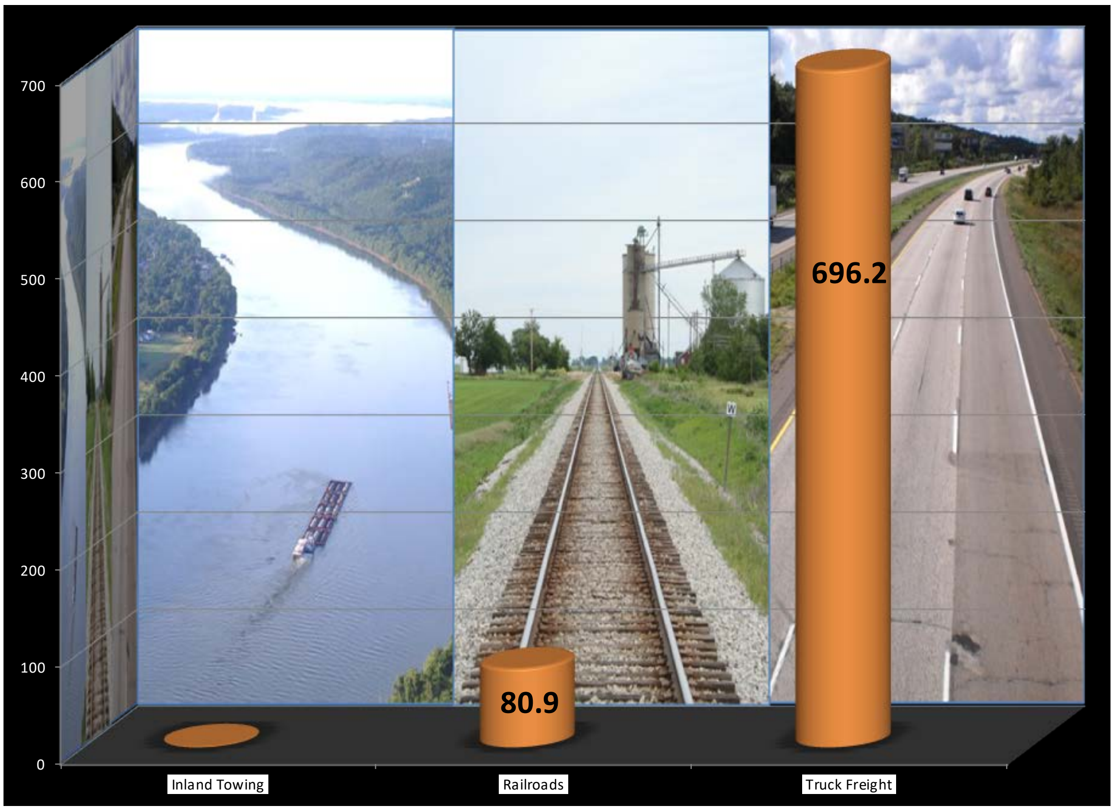


Figure 14. Ratio of Injuries per Million Ton-Miles versus Inland Marine—2001–2014.

HAZARDOUS MATERIALS INCIDENTS

Hazardous materials incidents are reported differently across the modes. Incidents for all three modes are contained in the PHMSA's online Hazmat Incident Report database. However, a close examination of the incidents for marine transportation revealed that only deep-sea incidents are being stored in the system; therefore, it was necessary to acquire data from the Coast Guard and from the Corps of Engineers on IWWS-related traffic.

The Coast Guard stores information on all incidents involving marine transportation while the Corps of Engineers reports tonnage and ton-mile statistics. The Corps reports the commodities according to Standard International Trade Classification code, a statistical classification system designed by the United Nations for commodities in international trade to provide the commodity aggregates needed for purposes of economic analysis and to facilitate the international comparison of trade-by-commodity data. The data reported by PHMSA use United Nations Identification Numbers for tracking commodities. Since the objective of this analysis is to develop an incident rate (as opposed to a comparison of how much of a given product is spilled), the PHMSA spill and ton-mile data are used for truck and rail statistics, while the Coast Guard and Corps data are used for the waterborne activity.

The Coast Guard transitioned to a new marine casualty tracking system in late 2001. Prior reviews have indicated that some of the data from 2001 were not picked up in the newer system. Since this report covers 2001–2014, it was necessary to review the data for both systems for 2001, while the newer system was used exclusively for 2002–2014. The earlier system was known as the Marine Safety Information System (MSIS). The current system is referred to as the Marine Information for Safety and Law Enforcement (MISLE) system. The Coast Guard data do not segregate deep-sea incidents from IWWS incidents, so the research team extracted the spills related to IWWS traffic.

As is the case with fatalities and injuries, incidents are added to this database only after the case has been fully investigated and closed by the U.S Coast Guard, which can take several years. Because of this delay, the more recent years in the analysis may not include all of the incidents that actually occurred.

Because all three reporting systems rely on self-reporting, and the definitions of materials that require reporting are very complex, much of the spill data are suspect. However, for larger spills, it seems reasonable to assume that the accuracy of the data improves, due to the severity of the incident and public scrutiny; therefore, the research team decided to analyze only large spills as a measure of the overall safety of the modes in the area of spills. The threshold quantity was set at 1,000 gallons.

Table 15 and Figure 15 provide a comparison of spills across the modes.

Table 15. Comparison of Large Spills across Modes—2001–2014.

Year	Mode								
	Water (Inland)			Railroad			Highway (Truck)		
	Number of Spills	Amount (gallons)	Ton-Miles (billion)	Number of Spills	Amount (gallons)	Ton-Miles (billion)	Number of Spills	Amount (gallons)	Ton-Miles (million)
2001	6	209,292	294.9	33	296,114	1,495	191	789,006	2,362,063
2002	7	32,459	278.4	29	245,183	1,507	153	633,534	2,427,693
2003	10	597,862	293.4	22	247,287	1,551	148	644,404	2,478,740
2004	11	237,155	284.1	33	379,992	1,663	170	731,919	2,427,170
2005	11	52,068	274.4	21	625,833	1,696	141	625,607	2,453,347
2006	9	246,900	279.8	38	671,544	1,772	144	551,273	2,405,811
2007	5	16,760	271.6	38	585,515	1,771	139	533,087	2,495,786
2008	3	285,508	261.0	19	216,248	1,777	119	505,043	2,752,658
2009	4	16,642	245.0	24	427,690	1,532	115	475,186	2,449,509
2010	3	6,598	263.2	21	306,181	1,691	135	696,420	2,512,429
2011	3	14,038	269.2	45	1,247,089	1,729	152	762,076	2,643,567
2012	7	16,030	268.4	39	532,595	1,713	163	680,848	2,676,970*
2013	5	16,270	251.5	60	1,128,002	1,741	143	594,278	2,772,406*
2014	1	30,240	281.3	24	245,398	1,851	146	590,450	2,872,613*
Total	85	1,777,822	3,816.2	446	7,154,671	23,489	2,059	8,813,130	35,730,762
Average	6	126,987	272.6	32	511,048	1,678	147	629,509	2,491,707
Average Annual Haz-Mat Ton-Miles (millions)			59,874			85,900*			104,200*
Rate**	0.0001014	2.1209087		0.0003709	5.949336		0.001402	6.041356	
Ratio to Water (Inland)				3.66	2.81		12.45	2.85	

Marine incidents are added to the database only after the case has been fully investigated and closed by the U.S Coast Guard, which can take several years. Because of this delay, the more recent years in the analysis may not include all of the incidents that actually occurred.

**Estimate* ***Spills: Spills per Million Hazmat Ton-Miles* *Amount: Gallons per Million Hazmat Ton-Miles*

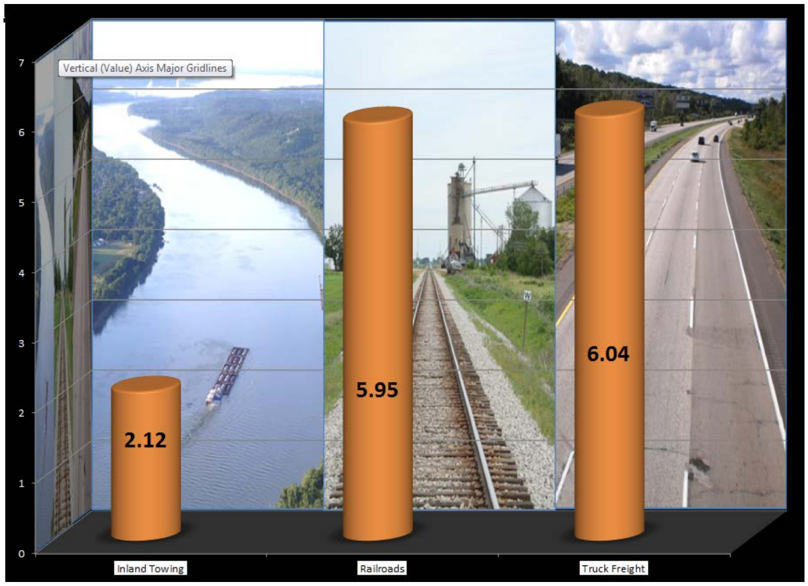


Figure 15. Gallons Spilled per Million Hazmat Ton-Miles (2001–2014).

What the statistics do not show (and this project does not attempt to analyze) is the effect such incidents have on the human population. Because they use infrastructure shared with the general public—infrastructure that has a high utilization rate by the general public or is in close proximity to large numbers of people—spills from truck and rail incidents are more likely to pose an immediate threat to the health of human beings than marine incidents. Waterborne transportation, by virtue of the fact that it occurs on a river, is less likely to pose an immediate threat to human beings, although it may have a detrimental effect on aquatic flora and fauna.

The project team attempted to compare the cost of property damages from hazardous materials incidents, but the data are extremely unreliable, so this analysis was not performed.

CHAPTER 6: INFRASTRUCTURE IMPACTS

The question addressed in this part of the analysis is, "What are the potential impacts to rail and highway infrastructure caused by a hypothetical diversion of waterborne traffic to either mode?"

In order to compare the impacts of a theoretical diversion of waterborne freight transportation to surface transportation with respect to land infrastructure, the effects of a situation where the waterways are closed and all cargo is forced to move either by rail or truck are evaluated. It is a highly unlikely event, but such an analysis helps evaluate the potential savings to the nation due to the utilization of waterborne transportation.

PAVEMENT DETERIORATION

Roadway pavements need to be designed at a level of structural capacity that can withstand the repeated loadings inflicted by heavy trucks. Passenger cars inflict minimal damage to the pavement by comparison. The structural number (SN) measures pavement structural capacity and new pavements, which are at full strength, have a SN of 4.5–5.0. The useful life of a new pavement is approximately 20 years, at which point the SN drops to about 2.5 and major rehabilitation is required. The total load expected over the pavement's lifetime due to heavy truck traffic is the primary input in calculating the thickness of a new pavement.

Previous chapters have defined the standard truck to be used in the event of a waterborne freight diversion as the combination tractor-semitrailer truck with GVWR of 80,000 lb. Figure 16 shows the axle configuration of this type of truck. There are five axles total, one steering axle, and four remaining axles in pairs, called tandem axles.

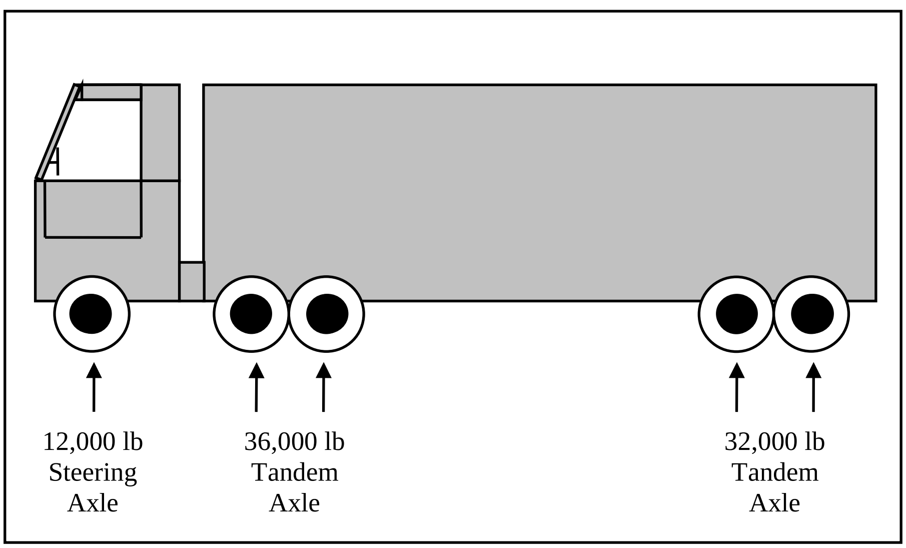


Figure 16. Semitrailer configuration 3-S2: the 18-wheeler.

A tandem axle involves two single axles close together and inflicts less pavement damage than two single axles further apart. The integrated load a truck exerts on a pavement is estimated by the number of equivalent 18,000-pound (or 18-kip) single axle loads (ESAL) using the Association of State Highway and Transportation Officials (AASHTO) fourth power equation.

The two equations for calculating the ESAL on a flexible (asphalt) pavement due to the weight on a single axle (W_{Single}) and due to the weight on a tandem axle (W_{Tandem}) respectively are:

$$ESAL_{Single} = \left(\frac{W_{Single}}{18{,}000 lbs} \right)^4 \qquad ESAL_{Tandem} = \left(\frac{W_{Tandem}}{33{,}200 lbs} \right)^4$$

The standard 18-wheeler has one 12,000 lb steering axle, a 36,000 lb tandem axle, and a 32,000 lb tandem axle, so the ESAL it exerts on the asphalt pavement is 2.44 ESAL, as shown below:

$$ESAL_{18-Wheeler} = \left(\frac{12{,}000}{18{,}000} \right)^4 + \left(\frac{36{,}000}{33{,}200} \right)^4 + \left(\frac{32{,}000}{33{,}200} \right)^4 = 2.44$$

In 2014, there were 5,148 average daily vehicles per lane on rural interstates. Inferred data from Highway Statistics (*11*) indicate that, in the same year on rural interstates, 17 percent of the traffic—or 875 vehicles—were combination trucks, or 18-wheelers. Assuming that no waterborne freight diversion will occur, the annual ESAL would be:

$$ESAL_{Annual} = 2.44 \times 875 \times 365 = 0.78 million$$

The analysis for congestion impacts estimates that a diversion of waterborne freight to the highway mode would result in 1,921 combination trucks per day per lane of a typical rural interstate, so the annual ESAL would increase:

$$ESAL_{Annual} = 2.44 \times 1{,}921 \times 365 = 1.71 million$$

Since the total loadings over the pavement lifetime are to be considered in designing a new pavement, the expected growth in truck traffic over the same period has to be included. At an annual constant percentage growth, *g*, of 2 percent and a pavement design lifetime, *N*, of 20 years, the ESAL expected assuming continuation of current conditions would be:

$$ESAL_{Expected} = ESAL_{Annual} \times \frac{(1+g)^N - 1}{g} = 0.78 million \times \frac{(1+.02)^{20} - 1}{0.02} = 19.0 million$$

Similarly, assuming a waterborne freight diversion occurs, the ESAL expected over a 20-year pavement life would be:

$$ESAL_{Expected} = ESAL_{Annual} \times \frac{(1+g)^N - 1}{g} = 1.71 million \times \frac{(1+.02)^{20} - 1}{0.02} = 41.5 million$$

A quick comparison of the two calculated values indicates that if a waterborne freight diversion occurs, the ESAL expected over the pavement throughout its 20-year lifetime is more than double (218 percent) the ESAL expected under current conditions.

The AASHTO guidelines for pavement design (*28*) were then followed to determine the pavement thickness required to accommodate the ESAL expected over the pavement's lifetime, first, assuming continuation of current conditions, and second, that a waterborne freight diversion will occur. Identical values for these remaining required parameters were used to ensure comparison on an equal basis:

- Reliability, R: 90 percent.
- Standard Deviation S_o: 0.35.
- Serviceability Loss, Δ PSI: 2.0.
- Subgrade Strength, M_R: 10,000 psi (10 ksi).
- Asphalt Concrete Elastic Modulus, E_{AC}: 380,000 psi.
- Asphalt Concrete Surface Course Structural Layer Coefficient, a: 0.41.

At the current level of ESAL expected over the pavement throughout the 20 years, the design SN was found to be 4.6, which is within the range of an SN of 4.5 to 5.0 for a new pavement or a pavement at full strength—one that has undergone major rehabilitation, typically 20 years after construction. In order for clearer comparison to take place, an all-asphalt pavement is assumed, whose required thickness, *d*, in inches, is:

$$d = \frac{SN}{a} \qquad \text{Here, } d = \frac{SN}{a} = \frac{4.6}{0.41} = 11.2\ inches$$

At the level of ESAL assuming freight diversion, the design SN was found to be 5.3, which is natural since a higher ESAL is expected over the pavement's lifetime. Similarly, in order for clearer comparison to take place, an all-asphalt pavement is assumed, whose required thickness, *d*, in inches, is:

$$d = \frac{SN}{a} \qquad \text{Here, } d = \frac{SN}{a} = \frac{5.3}{0.41} = 12.9\ inches$$

Comparison of the thickness results implies that in the event of a waterborne freight diversion, a flexible pavement on an average rural interstate would require an additional 1.7 inches of asphalt layer in order to adequately withstand the 20-year loadings of combination trucks without requiring premature major rehabilitation (before the 20 years expire). The asphalt thickness addition would occur at the construction stage of a new pavement or as an overlay to an existing pavement so that the pavement strength rises to the required SN of 5.3 and its longevity for the next 20 years is ensured, at which point major rehabilitation will have to be undertaken. Of course, if the existing pavement is already worn, the asphalt layer thickness will have to be first brought up to the 11.2 inches, and then up to the 12.9 inches so that it is strong enough to last for the next 20 years.

In the field, the additional 1.7 inches of asphalt layer calculated above would be rounded to 2 inches (assuming that this is the only reason for need of repaving and that the pavement is not already in need of repaving), which is also the minimum asphalt overlay thickness typically performed by departments of transportation. Assuming an even truck traffic distribution, a minimum 2 inches thickness of asphalt layer would have to be added to the pavement of 118,688 lane-miles of rural interstate (*29*) given the higher levels of expected 20-year truck loadings.

> Assuming an even truck traffic distribution, a minimum 2 inch thickness of asphalt layer would have to be added to the pavement of 118,688 lane-miles of rural interstate given the higher levels of expected 20-year truck loadings.

The system-wide impacts to infrastructure can be put into perspective when it is borne in mind that the rural segments of the interstate system consist of 118,688 lane-miles. In addition, there are over 8 million lane-miles classified under other functional highway systems nationally.

Corridors that are parallel to the major rivers considered would undoubtedly receive a higher concentration of the additional truck traffic and would be affected to a higher degree than the national average. This analysis assumed that truck traffic would be equally distributed over all lanes, but in reality, this may not always be true. In rural road segments with a low density of entry and exit ramps, the outer lane is used by trucks more heavily and the pavement in that lane sustains considerably higher levels of damage than the inner lane.

> Higher levels of heavy truck traffic typically require significant capital expenditure on bridges, ramps, highway geometric features such as horizontal and vertical curves and shoulders, truck stops, weigh stations, traffic control, etc., as well as higher routine maintenance costs.

It is beyond the scope of this analysis to accurately predict, analyze, or associate any monetary cost with other possible infrastructure impacts or improvements that would be required in the event of a waterborne freight diversion to heavy trucks. However, a transportation engineer can safely rely on past trends and experience to argue that these would include improvements in the form of capital expenditures on new construction of infrastructure and facilities such as bridges, ramps, highway geometric features such as horizontal and vertical curves and shoulders, truck stops, service stations, rest areas, weigh stations, and traffic control. In addition, routine maintenance costs associated with the new infrastructure and with the existing, which would be used more heavily, would likely be significantly higher.

RAILROAD INFRASTRUCTURE IMPACTS

The shift of the inland waterways freight to the existing railroads would affect the individual railroads at substantially different levels. Although a detailed economic analysis of costs to the railroads of the modal shift of all the inland waterway freight is beyond the scope of this analysis, a closer look at the previous rail impact example discussed in Chapter 2 can provide further indication of what the railroads could be expected to encounter with the possible closure of individual water transportation segments or entire routes.

CSX currently delivers coal to electric generating plants located along or in the near vicinity of the Ohio River. Consequently, the CSX Ohio River route track has some amount of dedicated coal train traffic (see Figure 17). If, in the example of the Ohio River closure, the CSX railroad were tasked with the transportation of the entire coal tonnage of the river, the probable initial outcome would be electric brownouts and interrupted manufacturing output.

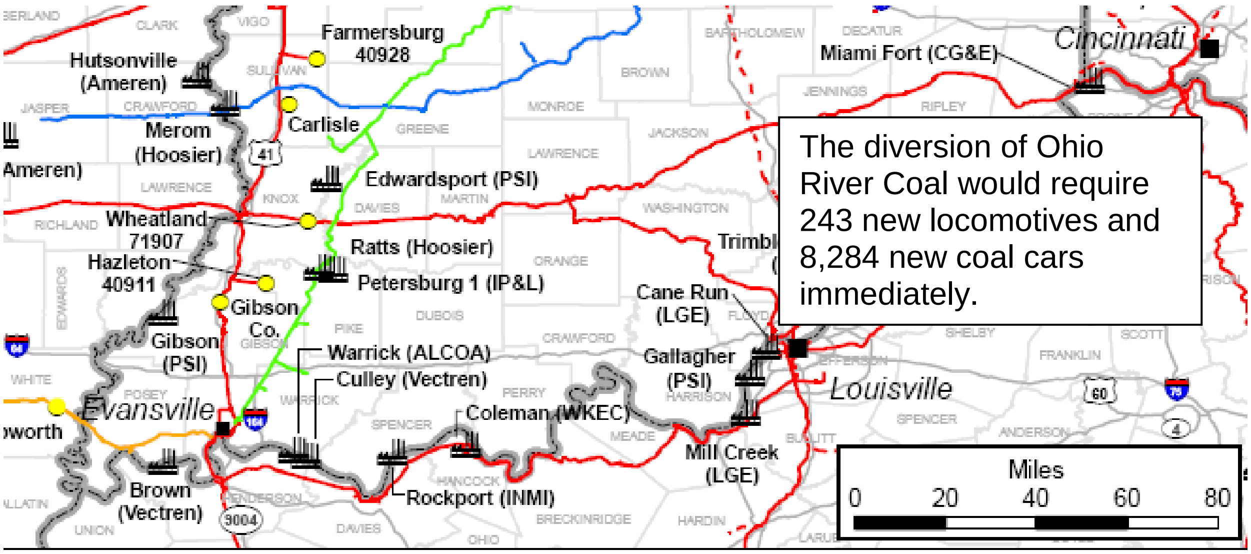


Figure 17. CSX IN-IL-Ohio River Regional Railroad Network. [8]

The Ohio River coal that is transported by barge is principally destined for the electric generation market along the river. The capacity requirements, in excess of one million railroad car loadings per year, could not be immediately met because there are not enough coal cars available to meet the initial demand for the increased transportation. The first impact would be the need to provide rail cars for the coal.

Since little is factually understood or known about the quantity or quality of stored coal cars compatible for use on the eastern railroads, this analysis assumes new coal cars would be ordered to satisfy the need to accommodate Ohio River barge transported coal.[9] Undoubtedly, large coal car orders would need to be negotiated. Potentially all the rail car manufacturing capacity would be required to meet the initial car demand requirement. An estimation of a typical unit coal car cost is approximately $91,000 each.[10]

The number of rail cars needed can be estimated by making a few assumptions. First, the cycle time for the typical river diverted traffic to a coal train might only be two days from the coalmine to the utility and returning to the mine. However, since all train traffic may be assumed to be much slower because of the large amount of new traffic, existing coal trains sharing the affected routes would also have their cycle times increased, or in other words, all coal trains using the

[8] CSX Railroad Coal Rate District map, Illinois and Indiana coal rate district.
[9] Freight Car America comment on eastern and western railroad coal car differences and unknown distribution of types in telephone call by TTI to Freight Car America, Jan. 5, 2017.
[10] Freight Car America Budget Estimate for New Al Coal Gon $91k provided by telephone call to TTI by Freight Car America, Jan. 5, 2017.

route would be slowed down to the three-day cycle time used elsewhere in this report. A requirement of 1,007,830 coal loadings using 108 car unit trains will require 9,332 unit train movements per year. Assuming that each train requires three days per trip and there are only 365 days in the year, each train can only make 121.7 trips per year. The number of additional required train sets is calculated by dividing the number of train initiations by the number of train trips per year, which yields 76.699 train sets. It is assumed any partial train set must be added as a whole train set, so there will need to be 77 train sets.

Typical coal trains of 100 or more loaded coal cars require three locomotives to operate safely and efficiently. A conservative estimate of 243 new locomotives would be needed to provide power for the new trains. The total number of new cars needed to meet the requirements for 77 new train sets is 8,284. The price tag for 243 new locomotives at a unit cost of $2,000,000 each is $486,000,000. At a unit cost of $91,000 each, the 8,284 new coal cars will cost $753,844,000. Together, the minimum equipment cost would be $1,239,844,000.

Many regulatory issues, operating concerns, and constraints are excluded from this example; for instance, the fact that every locomotive is required by regulation to have a substantial inspection four times each year is not considered in this example. The typical downtime for a scheduled 92-day locomotive inspection would be one day, where one day is the equivalent of one work shift. The inspection could easily take less time; however, if there were any unexpected events requiring extra shop time for minor repairs, the inspection event could exceed a 24-hour time period.

Because the current track capacity and train density along the CSX Ohio River route are unknown, it cannot be assumed that the addition of 77 additional train sets would introduce gridlock on the route. However, it can be assumed that the addition of 77 train sets would severely limit the operational efficiency of all trains on the route.

This is only one example of what might happen if any of the waterways were to be shut down. Regions outside the area discussed above might experience a more severe or less severe impact on rail operations, but the above illustration points out several effects that could be expected in almost every case:

- Increased demand for rail cars and locomotives.
- Higher freight rates.
- Need to expand infrastructure (rail lines).
- Potentially slower and less reliable delivery times.
- Increased motor vehicle congestion at rail crossings.
- Increased noise abatement issues.

REFERENCES

1 U.S. Army Corps of Engineers. Navigation Data Center. *Waterborne Commerce of the United States 2014*. http://www.navigationdatacenter.us/wcsc/wcsc.htm.

2 The U.S. Waterway System — Transportation Facts, Navigation Data Center, U.S. Army Corps of Engineers, December 2015. http://www.navigationdatacenter.us/factcard/factcard15.pdf.

3 Inland Waterway Navigation—Value to the Nation, U.S. Army Corps of Engineers, 2009. http://www.corpsresults.us/docs/navigation/VTNInlandNavBro_lores.pdf.

4 Waterborne Commerce of the United States, Calendar Year 2014, Part 5–National Summaries. http://www.navigationdatacenter.us/wcsc/pdf/wcusnatl14.pdf.

5 U.S. Army Corps of Engineers, Huntington District. Email communication, February 2016.

6 Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm. Accessed January 2017.

7 U.S. Army Corps of Engineers. Navigation Data Center. Waterborne Commerce of the United States 2014. http://www.navigationdatacenter.us/wcsc/wcsc.htm.

8 Bureau of Transportation Statistics. National Transportation Statistics 2016. U.S. Ton-Miles of Freight, Special Tabulation (Table 1-50). http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_50.html Accessed September 2016.

9 Federal Highway Administration, Office of Highway Policy Information. Highway Statistics 2014. Section 13: Performance Indicators, System travel density trends (weighted average AADT per lane) - Chart (Table TC-201C). Revised March 2016. http://www.fhwa.dot.gov/policyinformation/statistics/2014/tc201c.cfm Accessed January 2017.

10 Federal Highway Administration, Freight Office. Freight Analysis Framework version 4 (FAF4). http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/. Accessed January 2017.

11 Federal Highway Administration, Office of Highway Policy Information. Highway Statistics 2014. Section 13: Performance Indicators, Percentage Distribution of Traffic Volumes and Loadings on the Interstate System (Table TC-203). Revised November 2015. http://www.fhwa.dot.gov/policyinformation/statistics/2014/tc203.cfm Accessed January 2017.

12 Federal Highway Administration, Office of Freight Management and Operations, Freight Facts and Figures 2015. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/FF%26F_complete.pdf Accessed September 2016.

13 Association of American Railroads, *Railroads and Coal, July 2016*, Coal Transportation, p6, https://www.aar.org/BackgroundPapers/Railroads%20and%20Coal.pdf 12-09-2016.

14 CSX Annual Report, 2014. https://www.csx.com/index.cfm/investors/annual-materials/ Accessed January 2017.

15 U.S. Environmental Protection Agency, Office of Transportation and Air Quality. Motor Vehicle Emission Simulator (MOVES). https://www.epa.gov/moves. Accessed July 2016.

16 U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics. National Transportation Atlas Database 2015.

17 Title 40 CFR, 92, Subpart A, § 012.a, Tier 0 Standards.

18 Federal Register / Vol. 63, No. 73 / Thursday, April 16, 1998 / Rules and Regulations, p. 18978, Summary.

19 Title 40 CFR, 92, Subpart B, § 132, Calculations.

20 Technical Highlights, *Emission Factors for Locomotives*, Table 5, p7, EPA website, December 13, 2015, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100500B.PDF?Dockey=P100500B.PDF.

21 Bureau of Transportation Statistics. National Transportation Statistics 2016. Table 4-14: Combination Truck Fuel Consumption and Travel. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_14.html Accessed September 2016.

22 U.S. Department of Energy. Oak Ridge National Laboratory. Davis, S.C. and Diegel, S.W. Transportation Energy Data Book: Edition 34-2015, Table 5.2. http://cta.ornl.gov/data/download34.shtml Accessed September 2016.

23 U.S. Environmental Protection Agency, Office of Transportation and Air Quality. EPA and NHTSA Adopt Standards to Reduce Greenhouse Gas Emissions and Improve Fuel Efficiency of Medium- and Heavy-Duty Vehicles for Model Year 2018 and Beyond. EPA-420-F-16-044, August 2016. https://www3.epa.gov/otaq/climate/documents/420f16044.pdf. Accessed September 26, 2016.

24 A.B. Rose, Energy Intensity and Related Parameters of Selected Transportation Modes: Freight Movements, ORNL-5554 (Oak Ridge, TN: Oak Ridge National Laboratory, June 1979), pp. S-10 and 5-4.

25 STB R-1 Annual Report, Schedule 755, Line 110: Total gross revenue ton-miles all trains.

26 STB R-1 Annual Report, Schedule 750, Line 4: Total Fuel Consumed all trains except passenger.

27 Lisa A. Stabler, *Rail Safety in North America*, Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads, http://www.csgwest.org/policy/documents/CSGWestTEsessionJuly2015-final1.pdf.

28 American Association of State Highway Transportation Officials. *Guide for Design of Pavement Structures 1993 and 1998 Supplement*.

29 Federal Highway Administration, Office of Highway Policy Information. Highway Statistics 2014. Section 4: Highway Infrastructure, Public Road Lane-Miles by Functional System 1980–2014 (Table HM-260). January 2017. http://www.fhwa.dot.gov/policyinformation/statistics/2014/hm260.cfm Accessed January 2017.

APPENDIX A:
COMPARATIVE CHARTS

Note: The truck-related statistics that rely on overall truck ton-miles have been restated using the new ton-mile statistics published by BTS starting in 2014.

Table 16. Summary of Emissions—Grams per Ton-Mile—2005, 2009, and 2014.

Mode	HC/VOC			CO			NO_x			PM			CO_2		
	Emissions (grams/ton-mile)														
	2005	2009	2014	2005	2009	2014	2005	2009	2014	2005	2009	2014	2005	2009	2014
Inland Towing	0.01737	0.014123	0.0094	0.04621	0.0432	0.0411	0.46907	0.27435	0.2087	0.01164	0.007955	0.0056	17.48	16.41	15.62
Railroad	0.02421	0.018201	0.0128	0.06440	0.0556	0.0558	0.65368	0.35356	0.2830	0.01623	0.010251	0.0075	24.39	21.14	21.19
Truck	0.12	0.10	0.08	0.46	0.37	0.27	1.90	1.45	0.94	0.08	0.06	0.05	171.87	171.83	154.08

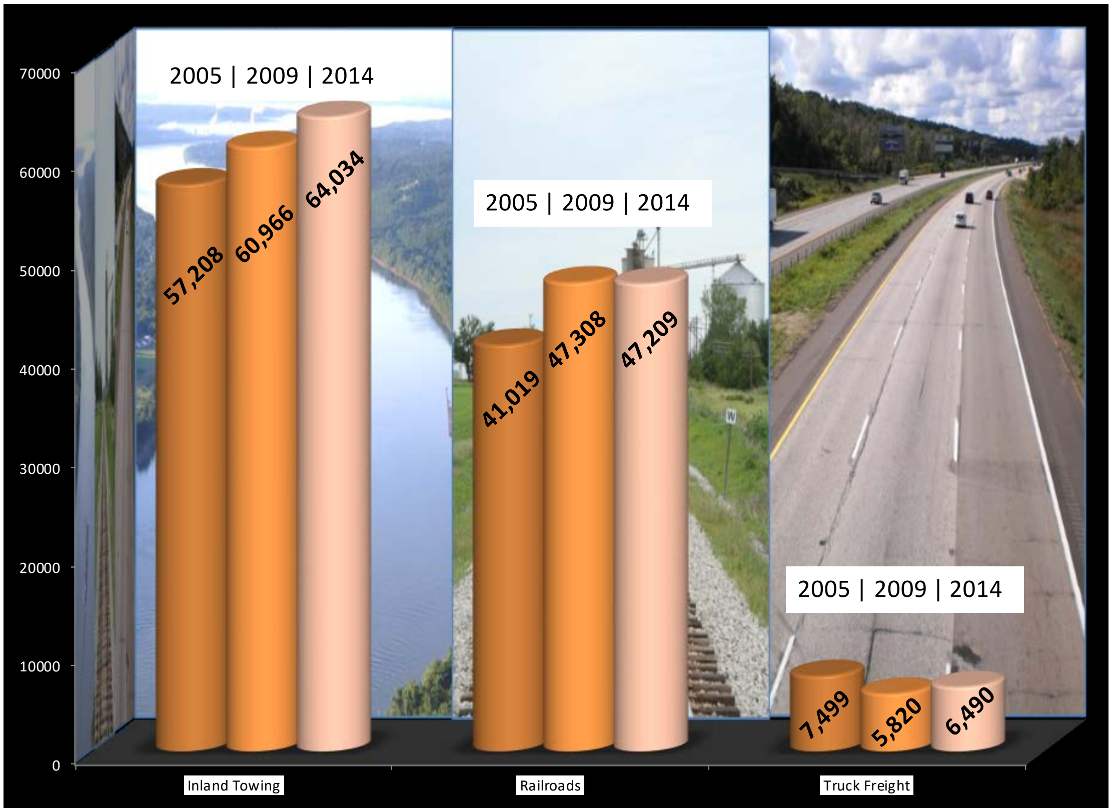


Figure 18. Ton-Miles per Ton of GHG (2001–05, 2001–09, and 2001–14).

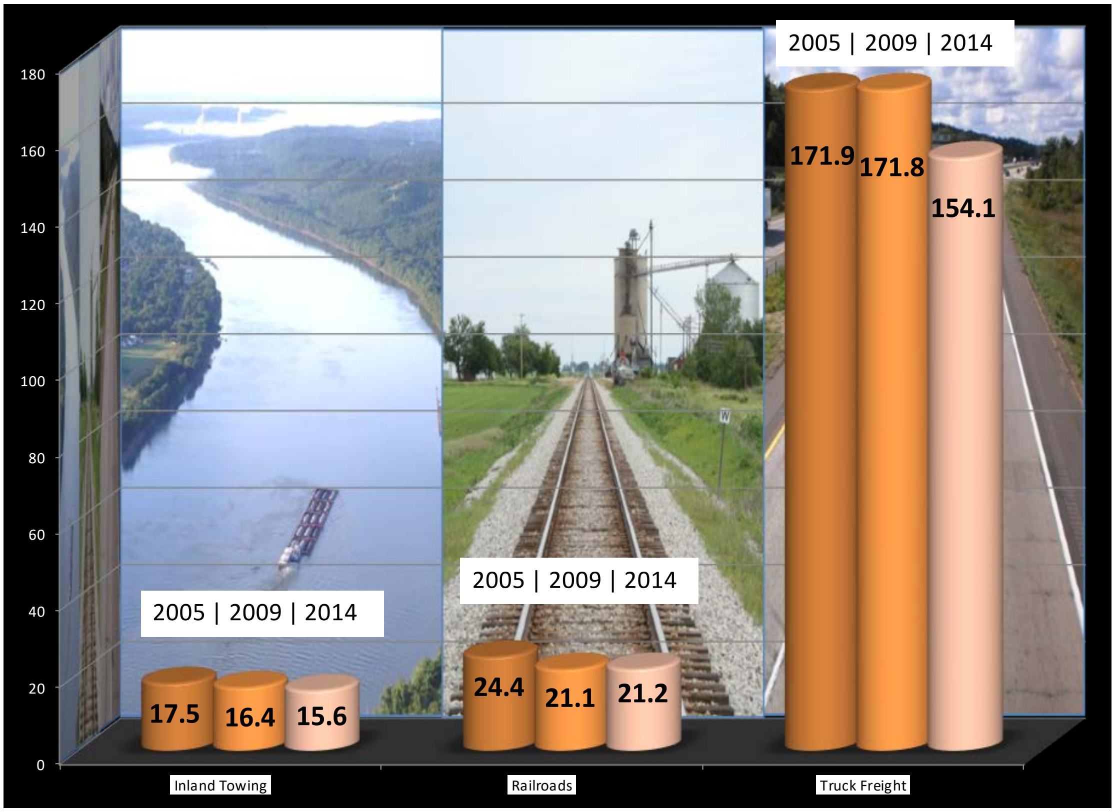


Figure 19. Tons of GHG per Million Ton-Miles (2001–05, 2001–09, and 2001–14).

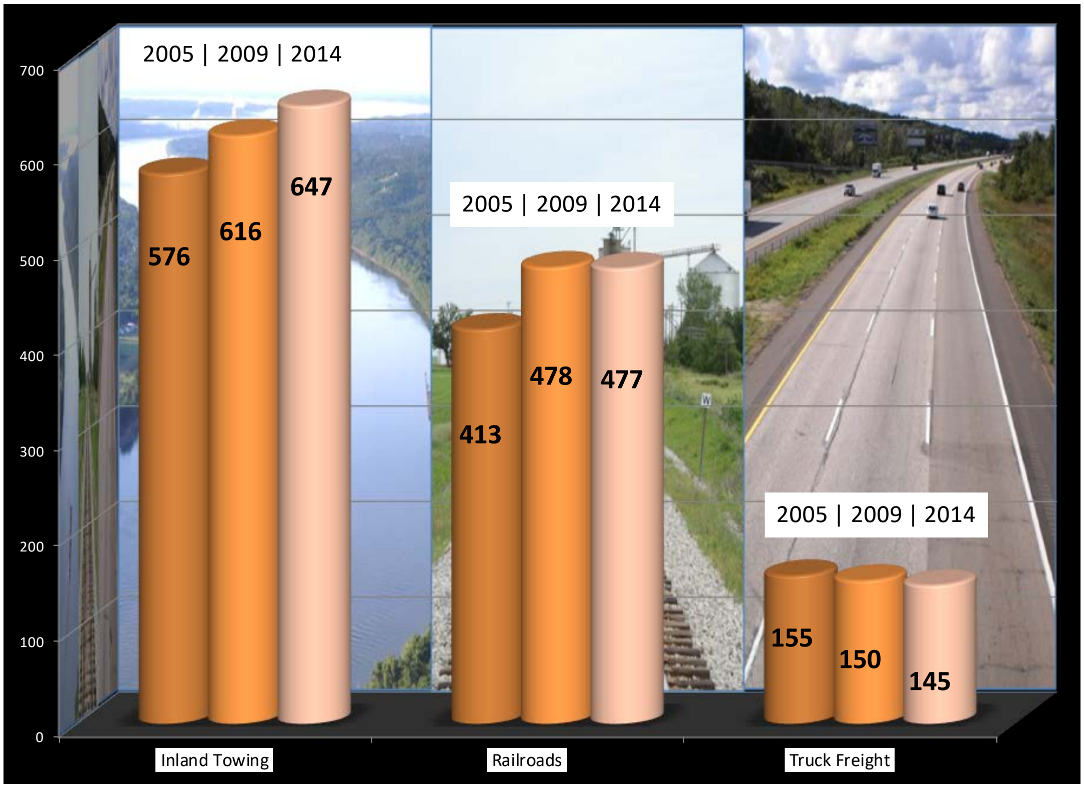


Figure 20. Comparison of Fuel Efficiency—2005, 2009, and 2014.

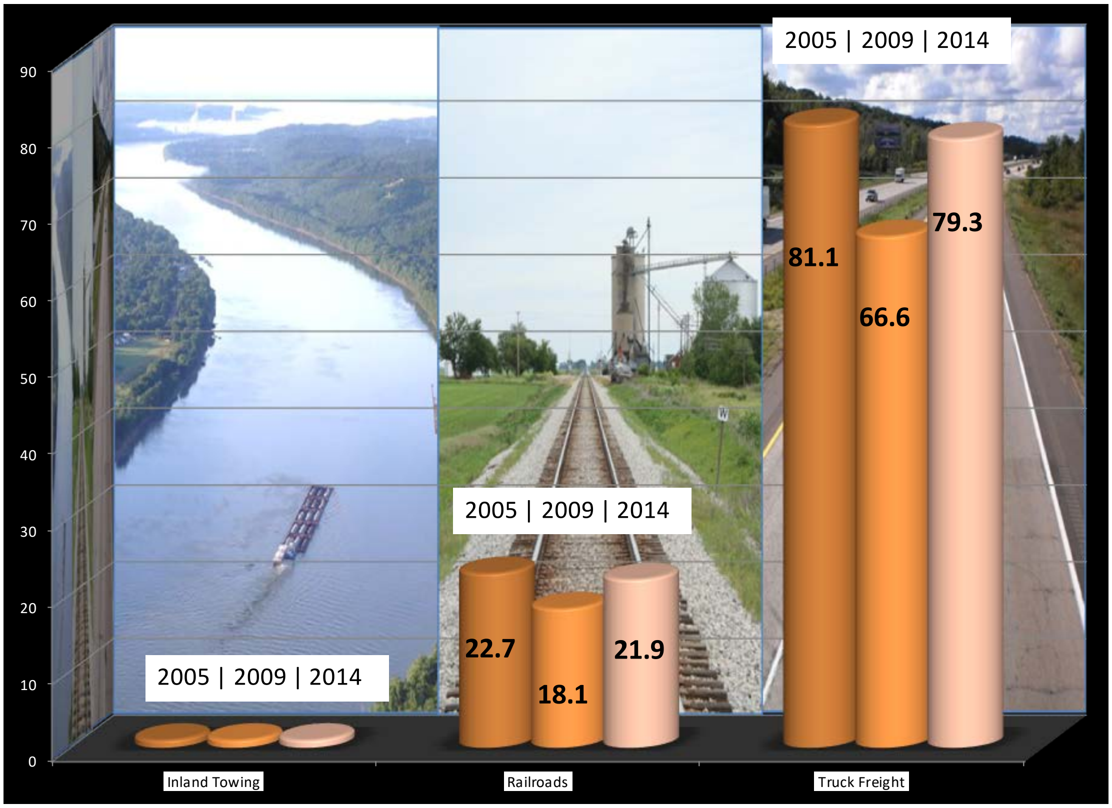


Figure 21. Ratio of Fatalities per Million Ton-Miles versus Inland Towing (2001–05, 2001–09, and 2001–14).

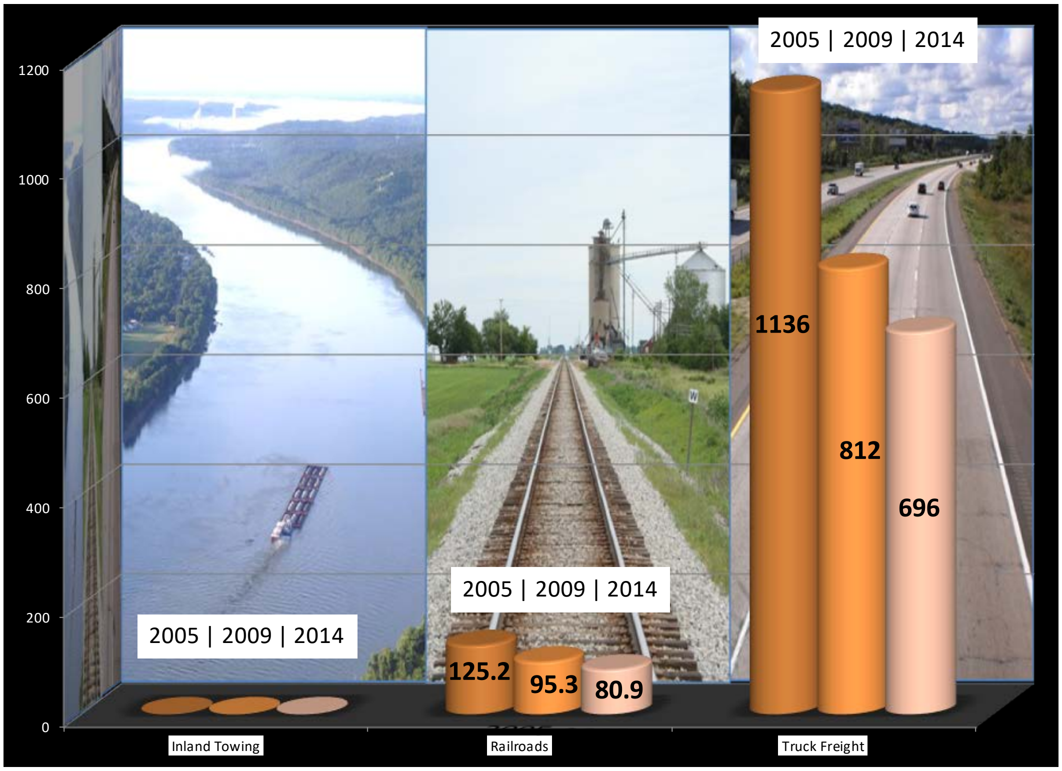


Figure 22. Ratio of Injuries per Million Ton-Miles versus Inland Towing (2001–05, 2001–09, and 2001–14.

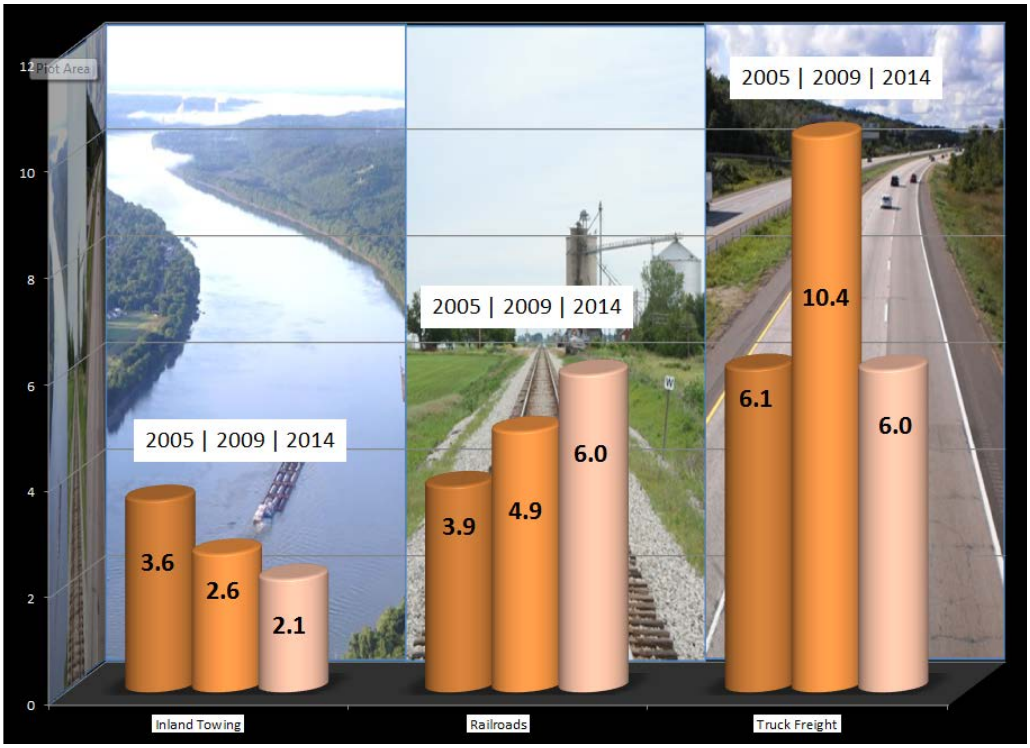


Figure 23. Gallons Spilled per Million Hazmat Ton-Miles (2001–05, 2001–09, and 2001–2014).

APPENDIX B: UPDATED FREIGHT TON-MILE ESTIMATES TECHNICAL SUMMARY (ABBREVIATED)

This appendix is an abbreviated version of a working paper published by BTS with the title *Updated Freight Ton-Mile Estimates Technical Summary*.

BTS has revised the methodology for calculating freight ton- miles across modes.[11] The objective is to make more comprehensive estimates by using the estimates of total freight ton-miles and pipeline ton-miles from the Federal Highway Administration's Freight Analysis Framework[12] (FAF). FAF uses the Commodity Flow Survey[13] (CFS) as the basis for estimating total freight ton-miles, and supplements those estimates with other data and modeling to estimate shipments outside the scope of the CFS, such as import movements from ports or border crossings to inland distribution centers, crude petroleum transport by pipeline, and product shipments from farms. We use the total freight ton-mile estimates and the pipeline ton-mile estimates from FAF3 as the basis for our revised estimates.

Estimating Total Ton-Miles

For the years covered by FAF estimates, 1997, 2002, 2007, and 2008 to 2011, the total ton-miles from FAF3 are used directly. For the years between 1997 and 2002, and between 2002 and 2007, linear interpolation is used to make those estimates. For years prior to 1997, truck ton-miles are estimated directly, and as a result, total ton-miles then become the summation of the modal estimates.

Estimating Truck Ton-Miles

Previous estimates of truck ton-miles (TM) were based upon miles traveled by trucks on intercity highways and average payloads of those trucks. New estimates are based upon FAF3, which provides a more direct and complete measure of ton-miles. The residual of total ton-miles less the sum of ton- miles by other modes is a more reliable estimate of truck ton-miles given uncertainties in estimates of truck ton-miles traveled and the lack of payload data since discontinuation of the Vehicle Inventory and Use Survey after 2002. In equation form:

Truck TM = Total TM – Air TM – Railroad TM – Waterway TM – Pipeline TM

For years before 1997, the trend in Truck Vehicle Miles Traveled (VMT) is used to make those estimates. For each previous year, the benchmark 1997 Truck TM is multiplied by the ratio of that year's truck VMT divided by the 1997 truck VMT value.

[11] The previous methodology is described in Dennis, Scott M., Improved Estimates of Ton-Miles, Journal of Transportation and Statistics, 8(1), 2005, pp. 23-30, U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics.

[12] Information on FAF3 can be found at: http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

[13] Information on the CFS can be found at: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/index.html

Comparison of Previous Ton-Miles Estimates with New Estimates

The estimates for total ton-miles and truck ton-miles using the previous methodology and the new methodology are shown in Figure 1.

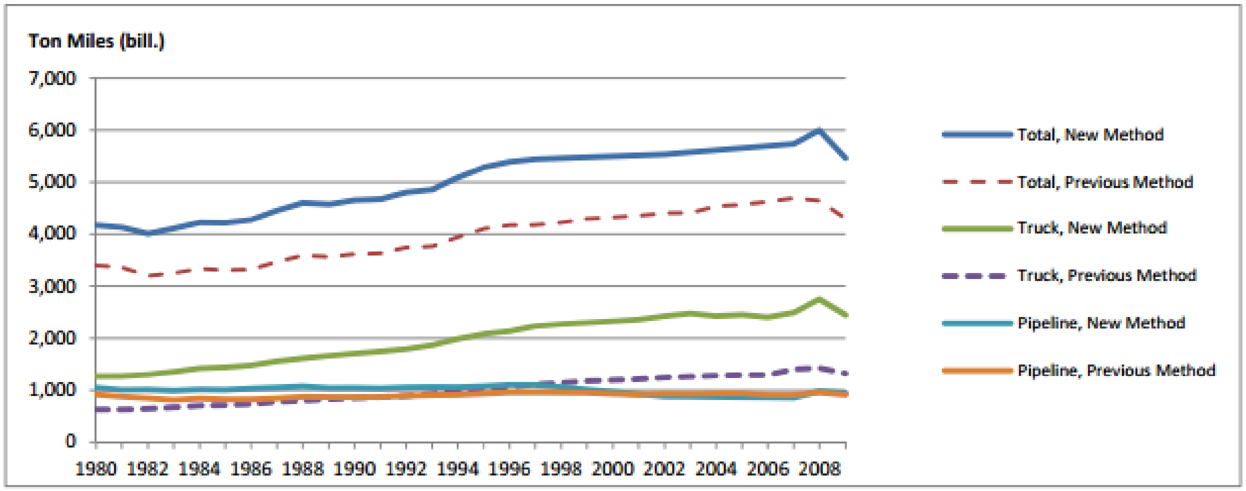


Figure 1. Total Ton-Miles and Truck Ton-Miles with Previous Methodology and New Methodology

The increase in both the total ton-miles and truck ton-miles is a result of using the higher, more comprehensive, estimates of total ton-miles from FAF3. The total pipeline ton-miles estimates are similar to those using the previous methodology.