MARITIME TRANSPORTATION RESEARCH AND EDUCATION CENTER
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U.S. DEPARTMENT OF TRANSPORTATION

A Modal Comparison of Domestic Freight Transportation Effects on The General Public: 2001–2019

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DISCLAIMER

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0. EXECUTIVE SUMMARY

0.1. 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. For years after 2011, the Bureau of Transportation Statistics (BTS) changed its procedure for calculating ton-miles for trucks. In the update for 2001–2014, the decision was made to use the original data and estimate the years that were affected by the change. In this report, all truck ton-mile statistics are based on the new approach. Truck statistics that are included from prior updates are restated using the new data. Appendix B contains an abbreviated version of BTS's explanation of the change in methodology.

At the time of this report, the government has only updated the data for ton-miles, injuries, and fatalities for trucks to 2018. Consequently, some of the statistics for the truck mode are only reported through 2018.

0.2. Background

This report updates the previous modal comparison study released by the Texas A&M Transportation Institute (TTI) in January 2017. That study used data from 2001–2014. This study includes data from 2001–2019 (2019 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.

0.3. 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—tractor-trailer	25 tons
Rail—bulk car	110 tons
Barge—dry bulk	1,750 tons
Barge—liquid bulk	27,500 barrels (bbl)

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

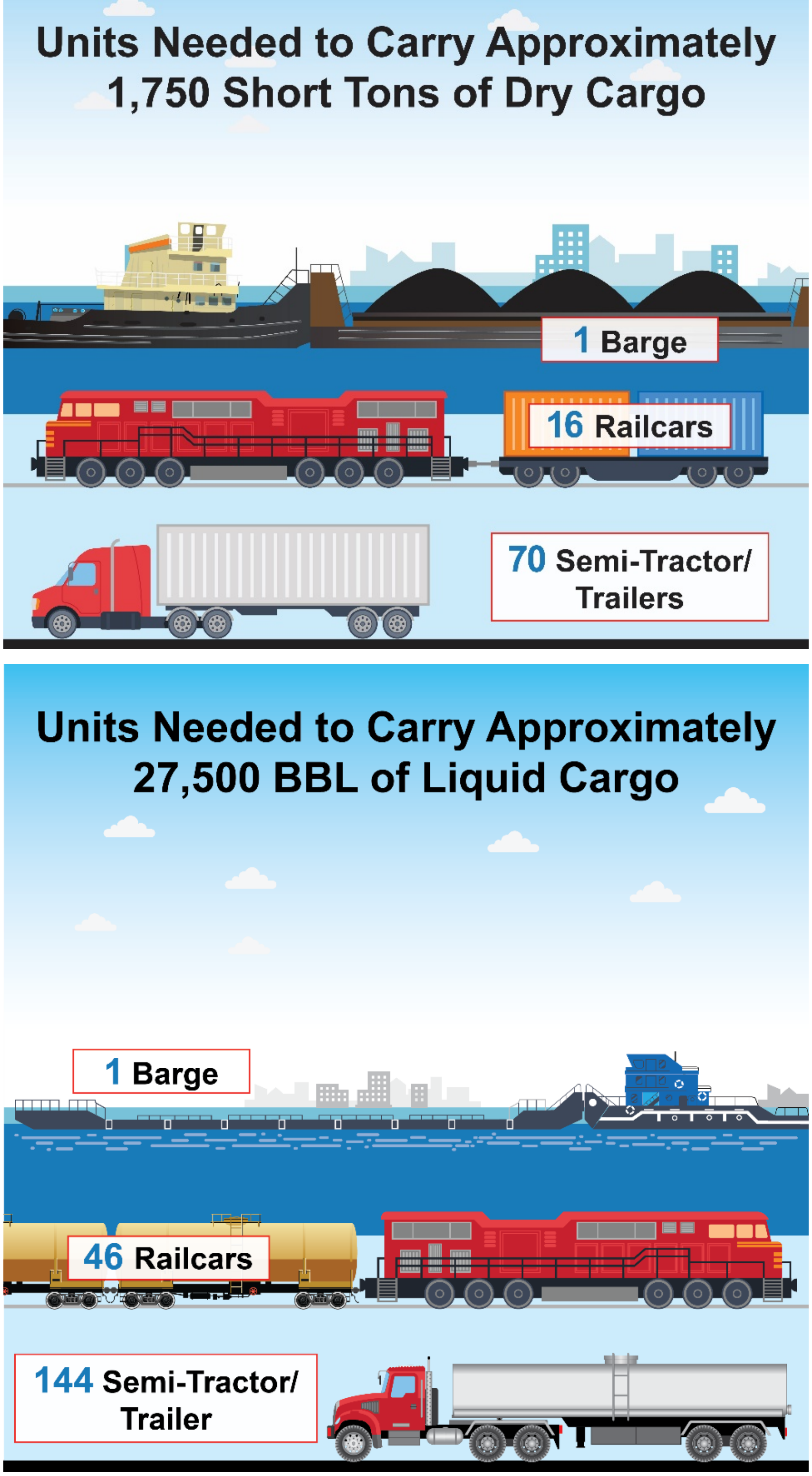

Figure ES-1. Modal Freight Unit Capacities.

It is difficult to appreciate the carrying capacity of a barge until one understands how much demand a single barge can meet. For example, one full barge load of wheat is more than enough to provide a 1-lb loaf of bread for every man, woman, and child living in Oklahoma in 2019.

A loaded tank barge with 27,500 bbl of gasoline carries enough product to satisfy the current annual gasoline demand of approximately 3,072 people (*1*, *2*).[1]Figure ES-2 illustrates the capacities of dry and liquid cargo barges.

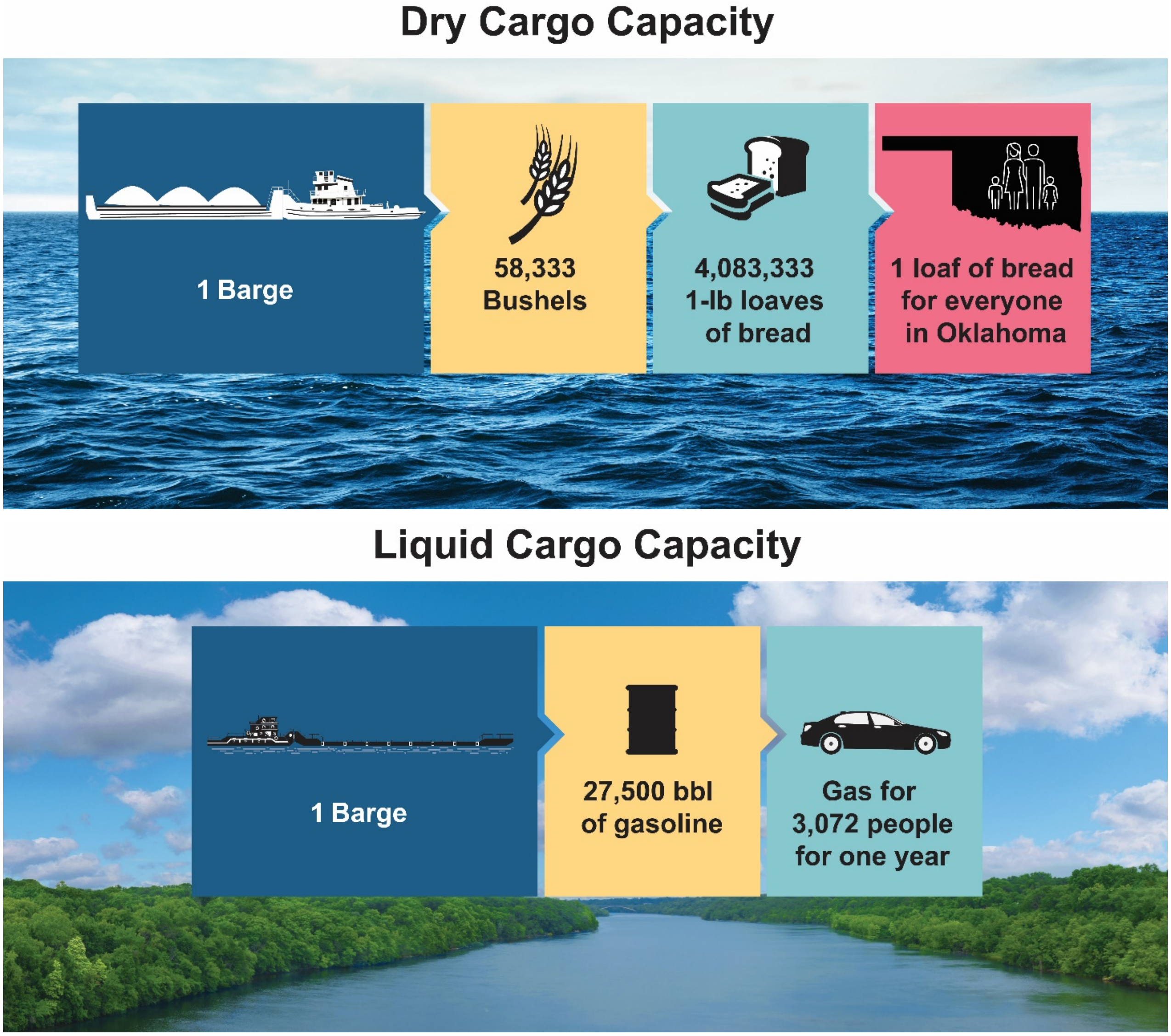

Figure ES-2. Cargo Capacity Examples.

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[1] Per capita use was calculated by taking the fuel consumed by light duty vehicles for 2019 as reported in the Transportation Energy Data Book ed. 39 and dividing it by the U.S. population on December 31, 2019, as reported by the Census Bureau.

0.4. Congestion Issues

0.4.1. Highway

Researchers obtained the latest national waterborne commerce data published by the U.S. Army Corps of Engineers Navigation Data Center (calendar years 2018 and 2019) (*3*, *4*, *5*). Because complete highway data are only available through 2018, researchers then extracted the 2018 tonnage and ton-mile data for the following major rivers:

- Mississippi River—Minneapolis, Minnesota, to Mouth of Passes.
- Ohio River.
- Gulf Intracoastal Waterway.
- Tennessee River.
- Cumberland River.
- Columbia River system—Columbia and Snake Rivers.

The amount of cargo transported on these rivers in 2018 is equivalent to more than 43,000,000 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 867 combination trucks to the current 960 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 11 percent from the current 17 percent to 28 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 to 138 percent of current levels 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.

0.4.2. Rail System

The grain traffic on the Mississippi River provides a clear example of what the effect of a major diversion of traffic from water to rail would be. The diversion of waterborne grain traffic from the Mississippi River would amount to an addition of nearly 38 percent more grain tonnage on the national railroad system, with the burden falling on the Union Pacific Railroad (UP) and Canadian National Railway (CN) rail networks. Prior updates reported that the diversion of Ohio River coal would add 16 percent to the railroad system, with the burden failing exclusively on the CSX rail system. Given that railroads are already experiencing capacity and system velocity issues, these findings illustrate the importance of maintaining the inland waterways system.

0.5. Emissions Issues

0.5.1. Emissions Profiles

Table ES-2 shows the emission comparison between the three modes for hydrocarbons (HC), nitrogen oxide (NO_x), particulate matter (PM) of a diameter of 10 micrometers or less (PM_{10}), carbon monoxide (CO), and carbon dioxide (CO_2).

Table ES-2. Emission Results by Mode in Analysis Year 2019.

Mode	Unit	HC	NO_x	PM_{10}	CO	CO_2
Truck	g/vehicle miles traveled	0.28	5.61	0.24	2.37	1758.78
	g/ton-mile (or MT/10^6 ton-mile)	0.0221	0.4487	0.0191	0.1898	140.7023
	metric tons avoided	3,978.9	72,254.7	3757.6	36,688.8	30.7×10^6
Railroad	g/ton-mile (or MT/10^6 ton-mile)	0.0083	0.2182	0.0053	0.0564	21.5678
	metric tons avoided	606.3	16,013.2	388.7	4,135.4	1.6×10^6
Inland towing	g/ton-mile (or MT/10^6 ton-mile)	0.0058	0.1526	0.0037	0.0394	15.0815

Table ES-3 shows how the emissions profiles for HC/volatile organic compounds (VOC), CO, NO_x, PM, and CO_2 have changed over the last two decades.

Table ES-3. Summary of Emissions—Grams per Ton-Mile (2005, 2009, 2014, and 2019).

Mode	Emissions (Grams/Ton-Mile)											
	HC/VOC				CO				NO_x			
	2005	2009	2014	2019	2005	2009	2014	2019	2005	2009	2014	2019
Inland towing	0.01737	0.014123	0.0094	0.0058	0.04621	0.0432	0.0411	0.0394	0.46907	0.27435	0.2087	0.1526
Railroad	0.02421	0.018201	0.0128	0.0083	0.06440	0.0556	0.0558	0.0564	0.65368	0.35356	0.2830	0.2182
Truck	0.12	0.10	0.08	0.02	0.46	0.37	0.27	0.19	1.90	1.45	0.94	0.45

Mode	Emissions (Grams/Ton-Mile)							
	PM				CO_2			
	2005	2009	2014	2019	2005	2009	2014	2019
Inland towing	0.01164	0.007955	0.0056	0.0037	17.48	16.41	15.62	15.08
Railroad	0.01623	0.010251	0.0075	0.0053	24.39	21.14	21.19	21.57
Truck	0.08	0.06	0.05	0.02	171.87	171.83	154.08	140.70

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

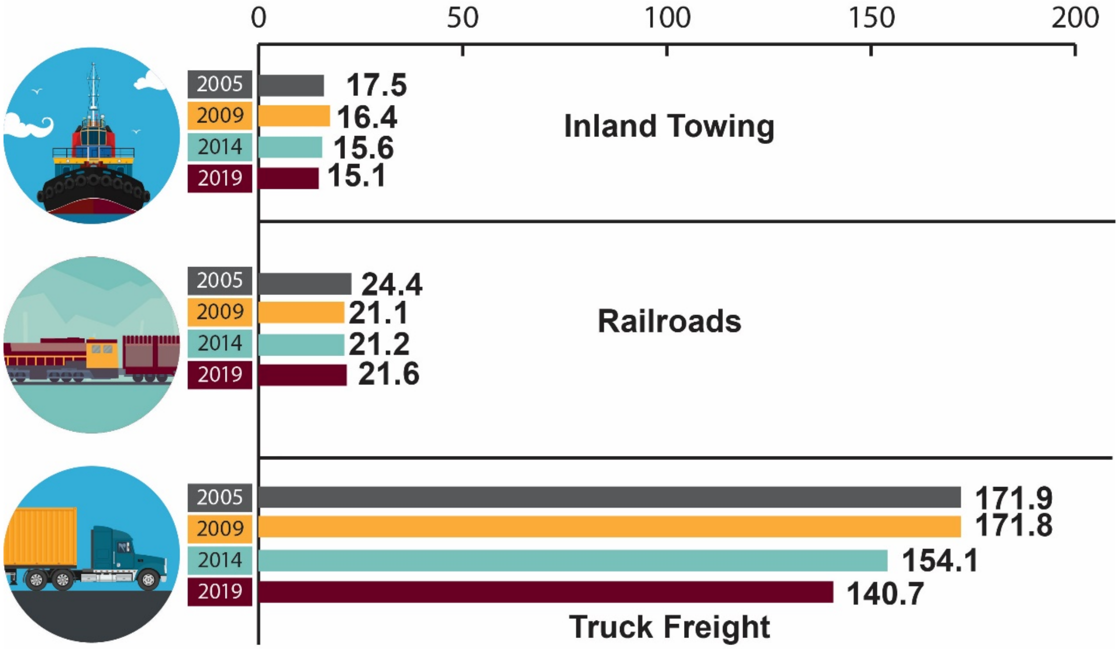

Figure ES-3. Metric Tons of GHG per Million Ton-Miles (2005, 2009, 2014, and 2019).

0.5.2. 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.

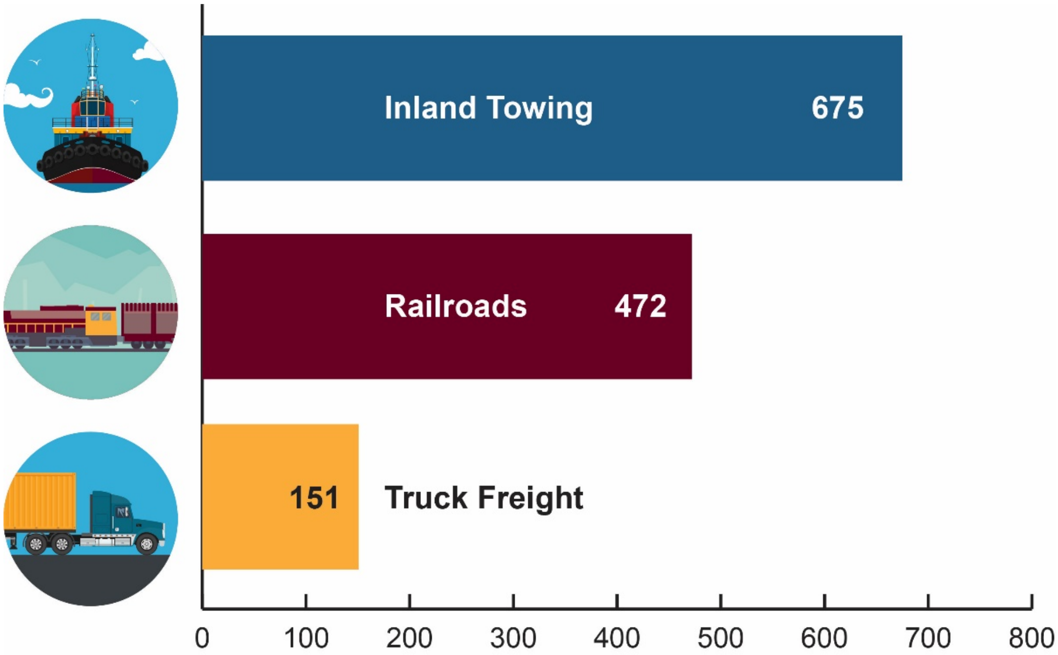

Figure ES-4. Comparison of Fuel Efficiency (2019).

Figure ES-5 shows how this statistic has varied by mode for the four modal comparisons TTI has published.

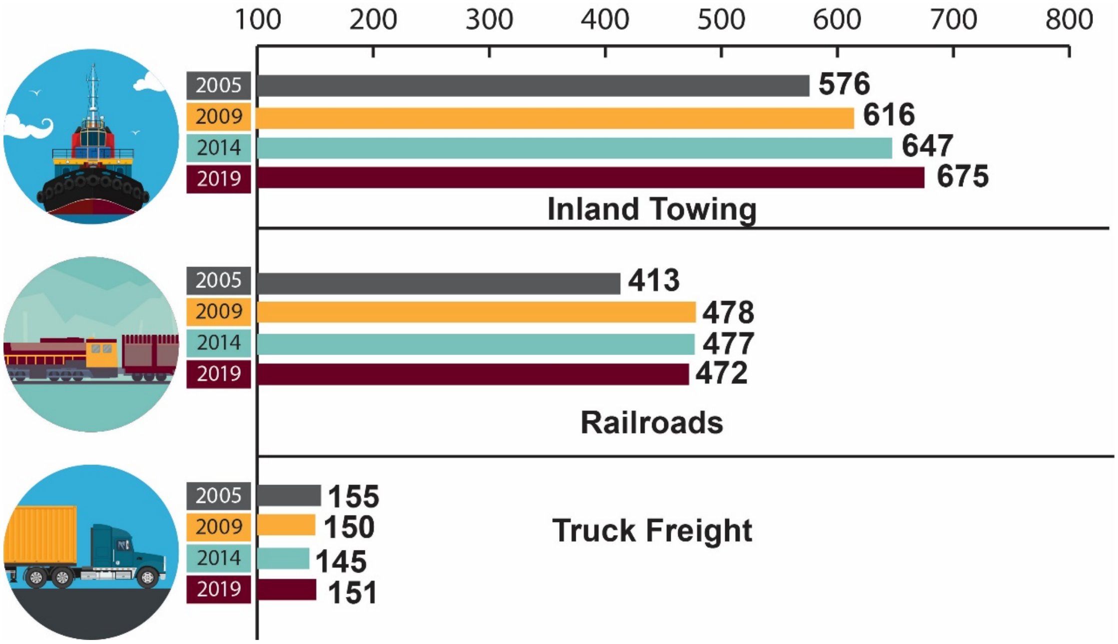

Figure ES-5. Comparison of Fuel Efficiency (2005, 2009, 2014, and 2019).

Inland waterway is the only mode to show continuous improvement. Rail and truck remained relatively unchanged during this same period.

The marine fuel efficiency rates are based on energy consumption data calculated by Oak Ridge National Laboratory; the railroad efficiency rates are based on an analysis of data published by the railroad industry, Surface Transportation Board, and Security and Exchange Commission; and truck efficiency rates are based on Bureau of Transportation Statistics (BTS)-reported data.

0.6. Safety Impacts

0.6.1. 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. 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 were obtained from *National Transportation Statistics* (update March 31, 2021), Table 2-39: Railroad and Grade-Crossing Fatalities by Victim Class and Table 2-40: Railroad and Grade-Crossing Injured Persons by Victim Class, respectively (*6*, *7*). Data for truck-related incidents were obtained from *Large Truck* *and Bus Crash Facts 2018*, a publication of the Federal Motor Carrier Safety Administration (*8*). The data for waterborne incidents were taken from the June 2020 version of the Marine Casualty and Pollution Database, 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 the incidents that actually occurred.) Figure ES-6 and Figure ES-7 show the comparisons of fatality and injury rates, respectively.

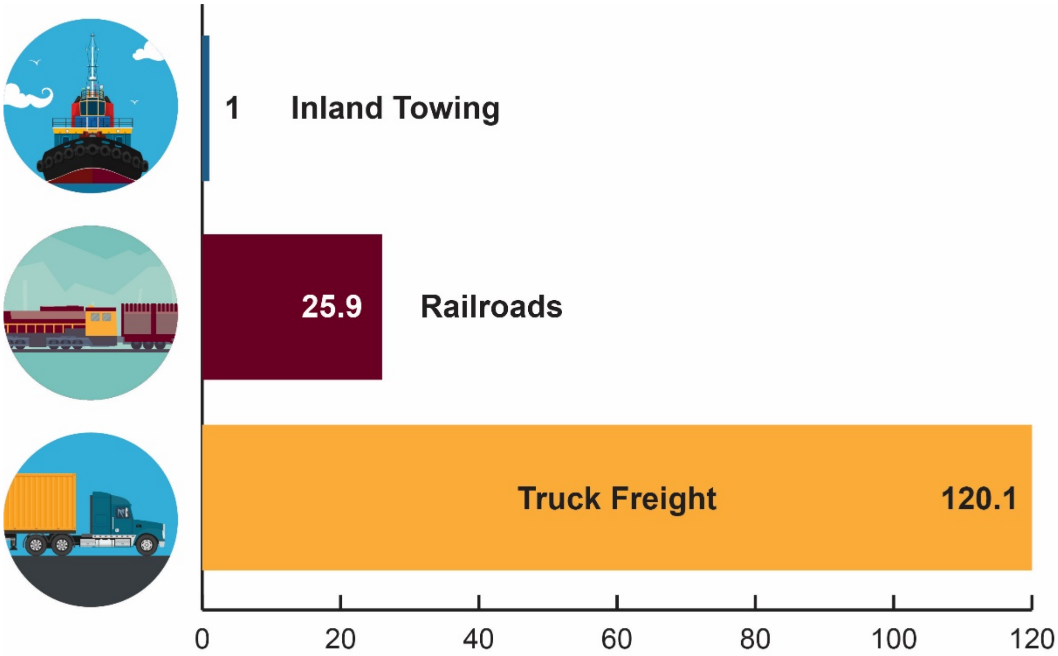

Figure ES-6. Ratio of Fatalities per Billion Ton-Miles versus Inland Towing (2001–2019).

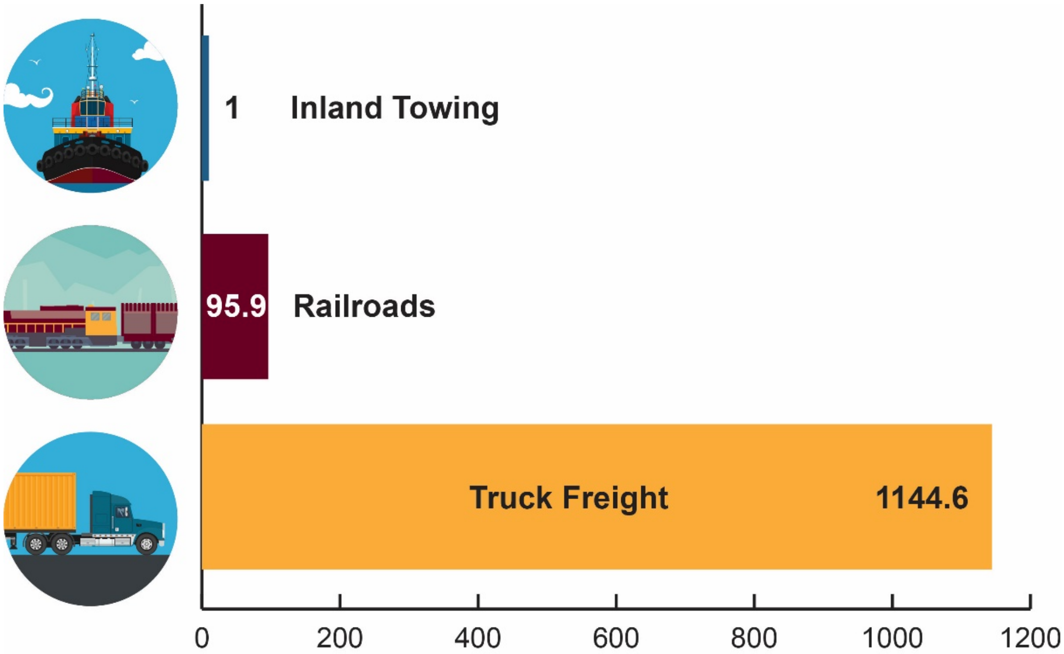

Figure ES-7. Ratio of Injuries per Billion Ton-Miles versus Inland Marine (2001–2019).

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

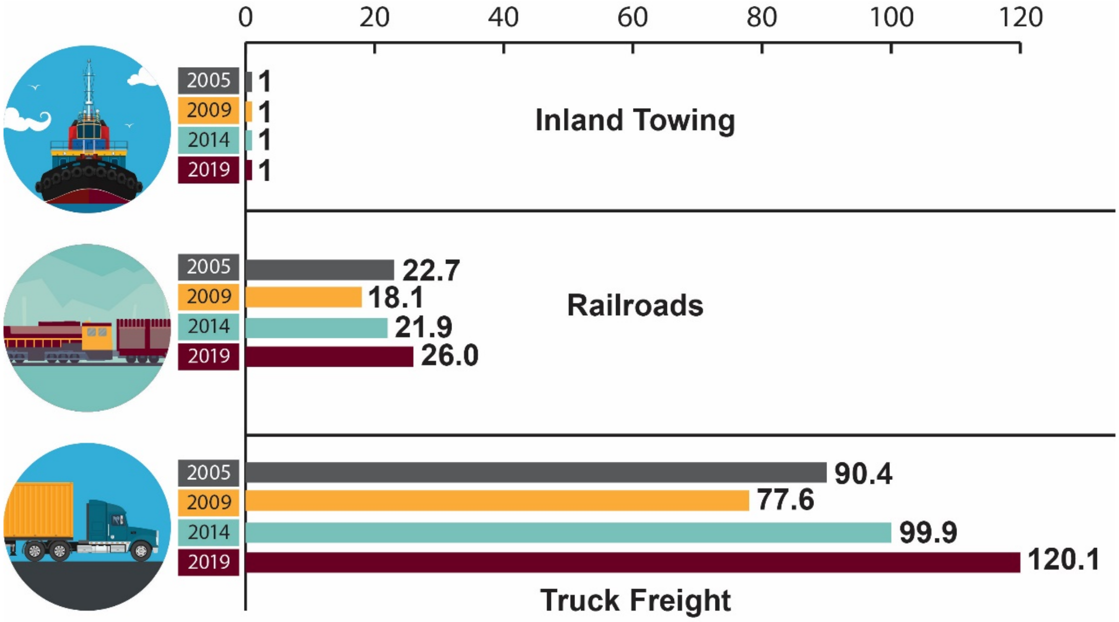

Figure ES-8. Ratio of Fatalities per Billion Ton-Miles versus Inland Towing (2001–2005, 2009, 2014, and 2019).

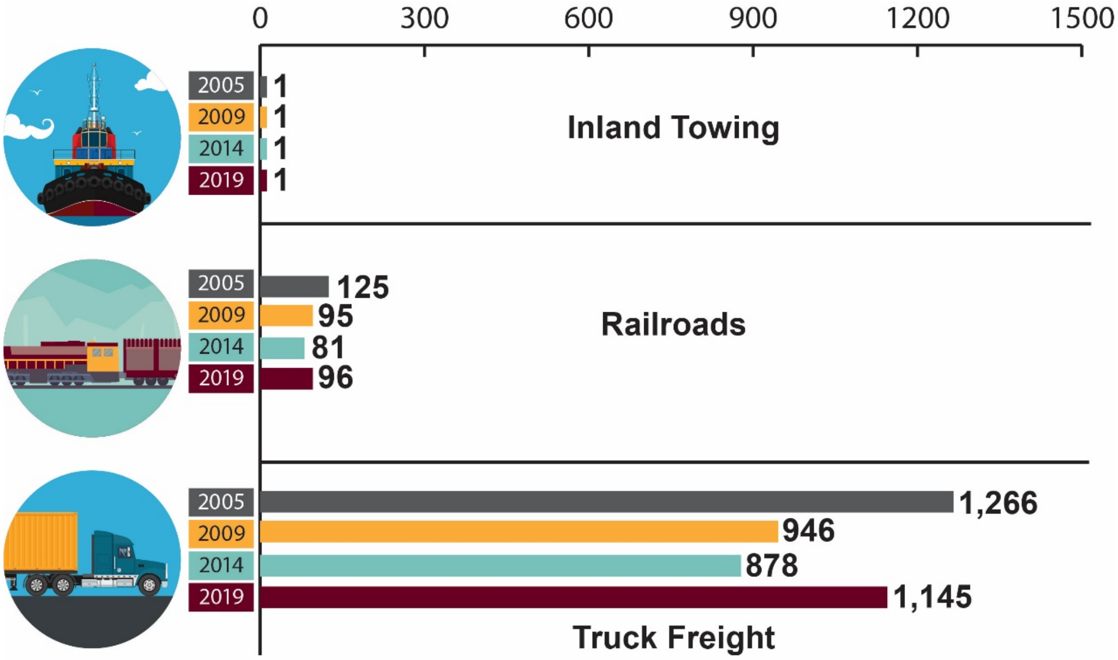

Figure ES-9. Ratio of Injuries per Billion Ton-Miles versus Inland Towing (2001–2005, 2009, 2014, and 2019).

0.6.2. Hazardous Materials Incidents

Data on hazardous materials incidents for rail and truck were taken from the Pipeline and Hazardous Materials Safety Administration's online Hazmat Incident Report database. Data for inland waterway incidents were extracted from the U.S. Coast Guard's Marine Information for Safety and Law Enforcement 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 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 gal. Table ES-4 compares spills across the modes.

Table ES-4. Comparison of Large Spills across Modes (2001–2019).

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	32	291,114	1,495	190	786,006	2,025,324
2002	7	32,459	293.6	29	245,183	1,507	152	623,534	2,189,937
2003	10	597,862	278.4	22	247,287	1,551	146	640,904	2,226,994
2004	11	237,155	284.2	33	379,992	1,663	169	729,419	2,249,260
2005	11	52,068	274.4	21	625,833	1,696	140	621,507	2,210,106
2006	8	236,700	279.9	38	671,544	1,772	144	551,273	2,154,885
2007	5	16,760	271.6	38	585,515	1,771	138	532,078	2,199,768
2008	4	289,757	260.9	19	216,248	1,777	119	505,043	1,843,146
2009	3	14,642	245.2	23	398,894	1,532	113	473,186	2,025,765
2010	6	439,985	263.3	21	306,181	1,691	134	693,163	1,806,337
2011	3	14,038	268.8	45	1,247,089	1,729	152	762,076	1,630,136
2012	7	16,030	268.5	39	532,595	1,713	163	680,848	1,822,154
2013	8	70,821	251.5	34	1,528,167	1,741	143	594,278	2,004,459
2014	5	50,340	281.1	24	245,398	1,851	146	590,450	1,956,805
2015	7	170,731	267.2	66	867,728	1,738	129	644,088	1,985,827
2016	5	48,154	261.4	14	155,724	1,585	118	434,824	2,060,780
2017	4	17,100	264.2	38	605,363	1,675	101	374,616	2,024,314
2018	5	40,089	270.2	25	311,598	1,730	115	431,062	2,033,921
2019	4	132,100	244.1	20	435,685	1,615			
Total	119	2,686,083	5,123.4	581	9,897,138	31,832	2,512	10,668,355	36,449,918
Average	6	141,373	269.7	31	520,902	1,675	140	592,686	2,024,995
Average annual hazmat ton-miles (millions)			60,486			78,700*			108,500*
Rate**	0.000099	2.337285		0.0003939	6.61883		0.001290	5.462544	
Ratio to water (inland)				3.98	2.83		13.03	2.34	

Note: 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 the incidents that actually occurred.

Truck ton-miles are not available for 2019, so 2019 hazmat statistics are not reported here.

**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.

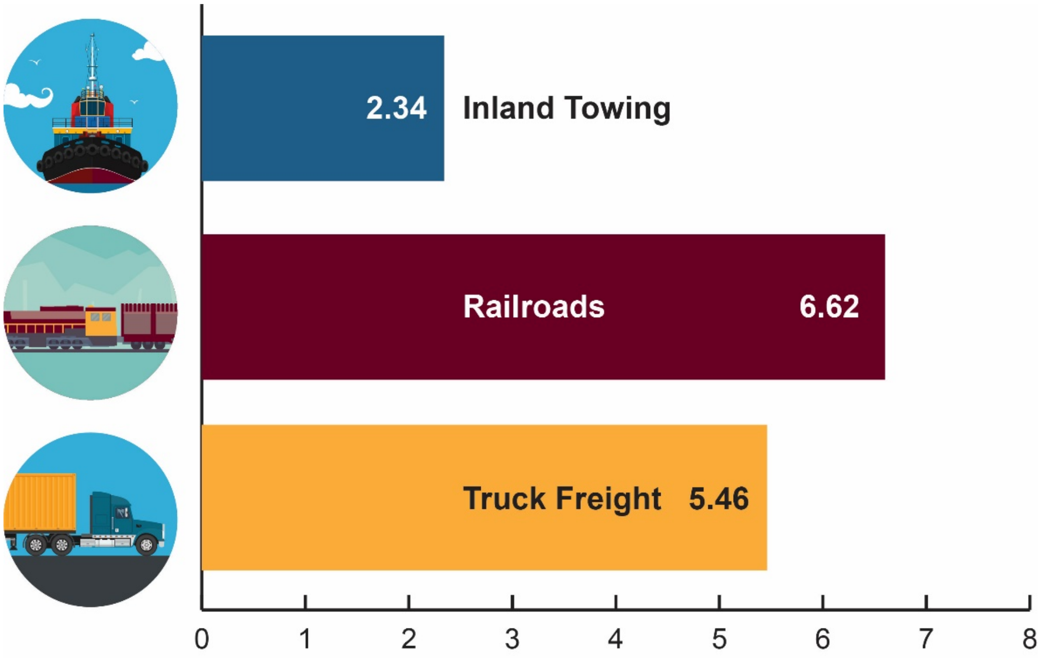

Figure ES-10. Gallons Spilled per Million Hazmat Ton-Miles (2001–2019).

Figure ES-11. Gallons Spilled per Million Hazmat Ton-Miles (2001–2005, 2009, 2014, and 2019).

0.7. Infrastructure Impacts

0.7.1. 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 119,885 lane-miles of rural interstate, given the higher levels of expected 20-year truck loadings and 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 infrastructure, which would be used more heavily, would likely be significantly higher.

0.7.2. Effect on Railroad and Roadway Systems

With substantial diversion of inland waterway cargo traffic to railroads, one or more of the following effects are to be expected:

- Increased demand for railcars, locomotives, and trucks.
- Higher freight rates.
- Need to expand infrastructure (rail lines, roadway network, and intermodal facilities).
- Potentially slower and less reliable delivery times.
- Increased motor vehicle congestion at rail crossings and along roadways both state and federally maintained.
- Increased noise abatement issues.
- Potential for unused and expired crops/commodities due to delay.

The diversion of grain off the Mississippi River provides an example of how important this artery is. The analysis of the effects of the diversion of grain shipments from water to rail indicates the real possibility exists that the railroad system as currently developed could not respond by accommodating the shift of grain traffic, which equates to 2.3 times the current number of grain carloads on both the UP system and the CN network in the United States. Prior updates have reported the same concerns with the diversion of coal traffic along the Ohio River.

1. BACKGROUND AND SIGNIFICANCE

1.1. 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. For years after 2011, BTS changed its procedure for calculating ton-miles for trucks. In the update for 2001–2014, the decision was made to use the original data and estimate the years that would have been affected by the change. In this report, all truck ton-mile statistics are based on the new approach. Truck statistics that are included from prior updates are restated using the new data. Appendix B contains an abbreviated version of BTS's explanation of the change in methodology.

At the time of this report, the government has only updated the data for ton-miles, injuries, and fatalities for trucks to 2018. Consequently, some of the statistics for the truck mode are only reported through 2018.

1.2. 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 192 lock sites with 237 chambers that serve navigation (*9*). The system directly serves 38 states (*10*). It is part of a larger system referred to as America's Marine Highways, which encompasses both deep-draft and shallow-draft shipping.

In 2019,[2] inland waterways maintained by the U.S. Army Corps of Engineers (USACE) handled over 502 million tons of freight (244 billion ton-miles) (*11*). This cargo was valued at more than $134.1 billion (*12*). Due to its efficiencies and lower costs, the IWWS saves between $7 billion and $9 billion annually over the cost of shipping by other modes (*13*). Virtually all American consumers benefit from these lower transportation costs.

The traffic on the IWWS was somewhat reduced in 2019 because of historic flooding; a decline in global oil prices, resulting in reduced domestic activity; and a dramatic drop in corn exports, resulting from several factors. On top of this, the pandemic hit in 2020, causing a slowdown in global economic activity, and several more weather events occurred. These factors will not persist. As shown in this report, the benefits of marine transportation are substantial at 2019 levels; they will grow as inland transportation rebounds and the world economy strengthens.

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[2] To maintain consistency across the modes, 2019 is the latest year this analysis uses for all three modes.

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:

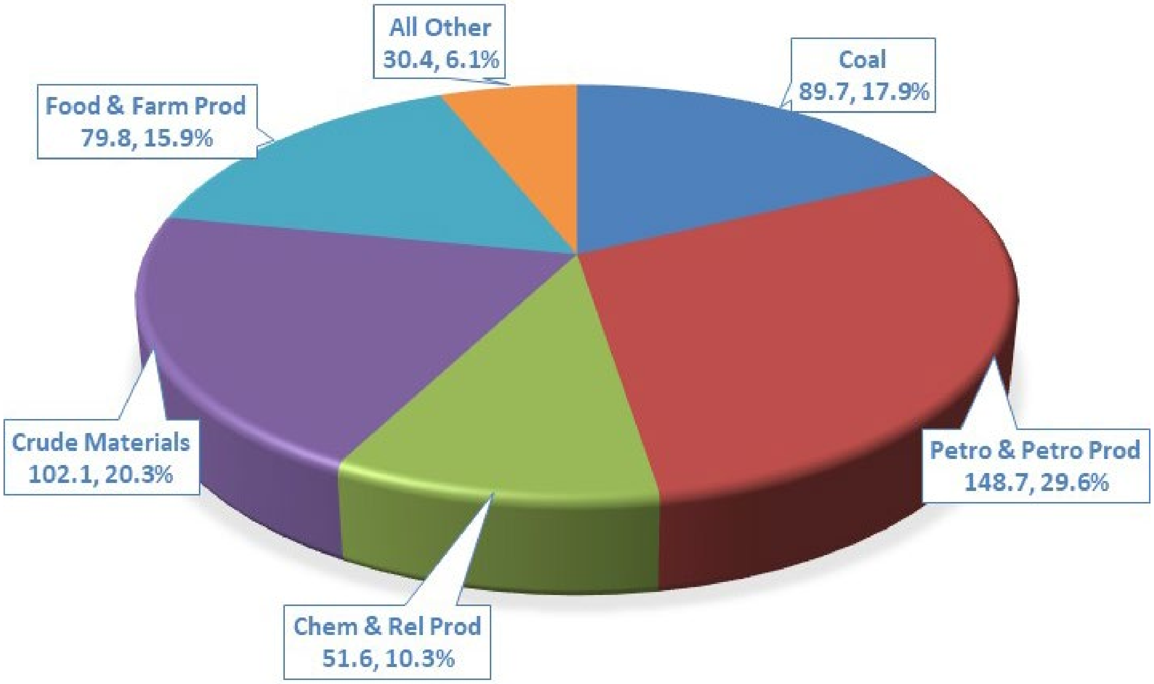
- Ports.
- Oceangoing ships.
- Towboats and barges.
- Ship-handling tugs.
- Marine terminals.
- Shipyards.
- Offshore supply companies.
- Brokers and agents.
- Consultants.
- Maritime attorneys.
- Cruise services.
- Suppliers and others.

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

The IWWS is one modal network within the entire pool of domestic transportation networks that includes 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 freight tonnage carried by barge on the inland waterways. The figure illustrates 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.

The economics of barge transportation are easily understood and well documented. This report updates environmental impacts, selected societal impacts, and safety impacts of using barge transportation as reported in *A Modal Comparison of Domestic Freight Transportation Effects on the General Public: 2001–2014*, published in January 2017.



Source: (11)

Figure 1. 2019 Inland Waterway Barge Traffic by Commodity Group (in Millions of Tons).

1.3. 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 ton-miles of freight as the common denominator to enable a cross-modal comparison that considers both the shipment weight and the shipping distance. The following sources were used for ton-mile data:

- *Waterborne Commerce Statistics of the United States 2019*: *Part 5 National Summaries*, Table 2-2 (*11*).
- *Association of American Railroads (AAR) Railroad Facts*, 2020 edition.
- *National Transportation Statistics*, 2019, Table 1-50: U.S. Ton-Miles of Freight, Special Tabulation (highway data), as of March 2021 (*14*).

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. The analysis 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 to support the comparative analysis among modes.

Barge transportation is characterized by the longest average haul operations, followed by rail and 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 possible differences in route lengths (circuity) among the three modes. Obviously, the water and rail modes must 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 on longer hauls.

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. For example, the Gulf Intracoastal Waterway (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.

For the Mississippi River between Minneapolis, Minnesota, and New Orleans, Louisiana, the water miles are slightly over 1,700 miles. Using the Illinois Soybean Association Transit Tool[3] to compare modal distances and transit times, the corresponding southbound truck trip calculates as 1,225 miles for a 1.4:1 water-to-highway ratio. The

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[3] The Illinois Soybean Association's Transit Tool is available at https://www.ilsoyadvisor.com/transit-tool/.

rail distance is reported as 1,646 miles for a 1.3:1 rail-to-highway ratio but is roughly equivalent to water miles. A different online truck routing tool[4] estimated the highway distance as 1,331 miles, which would result in a 1.3:1 water-to-highway ratio. These calculations indicate similar route lengths for the different modes between the expansive Minneapolis to New Orleans origin-destination pair.

The comparative analysis was also conducted for the remaining waterways under study and led to similar conclusions. The rail and water miles are very similar. 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 as well. 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 was 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.

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[4] The tool is available at http://truckmiles.com/.

2. CARGO CAPACITY

The dimensions of the units used to transport freight vary widely within each of the three modes (rail, truck, and inland waterway). To facilitate a meaningful cross-modal comparison, standard dimensions of the units used by each mode were defined. In comparing the modes, the capacity of the unit of transport was analyzed, not the average load. In this manner, all three modes were evaluated on the same scale.

The cargo weight is assumed to be roughly equal for liquid or dry bulk cargo. The densities of representative bulk commodities were investigated to ensure that the volume of a 50,000-lb (25-ton) net cargo weight is commensurate with the maximum tank truck volume of about 8,500 gal. For example, 50,000 lb of gasoline, at a density of 6.2 lb/gal, would occupy a volume of 8,065 gal. The process was repeated for several representative bulk commodities commonly transported by barge. The results confirmed that trucks carrying these heavy liquid or dry bulk commodities weigh out before cubing out (they hit weight limits before they are filled up). Therefore, this study assumes that the trucks that would transport this cargo in case of a waterway closure are constrained by weight limits; thus, the maximum allowable cargo weight is assigned.

The typical bulk commodity truck is a heavy-duty diesel vehicle with a gross vehicle weight rating (GVWR) of 80,000 lb, which includes between 44,000 and 50,000 lb of cargo weight. This project uses a typical tractor-trailer truck transporting 50,000 lb of cargo with an axle configuration of a steering axle and two tandem axles, or five total axles, that is, a typical 18-wheeler.

Following the same reasoning as the truck analysis, only railcars used for carrying bulk commodities are taken into consideration. Even among this type of railcar, there is significant variation in carload capacities depending on the specific commodity. Shipments of bulk commodities by rail, especially bulk grain commodities, are shipped as part of unit trains that shuttle between origins and destinations. The United Soybean Board reports unit trains consisting of 110 railcars with capacities of 110 tons per railcar (*15*). BNSF Railway shuttle train facility guidelines support the unit trains consisting of 110 railcars (*16*). Current rail industry operational strategies are trending toward longer trains. For unit grain trains, that could mean trains of 134 hopper railcars and eventually 147 hopper cars (*17*). Given these statistics, this study uses 110 tons as the loading capacity of a railcar.

Barge data were acquired from USACE's Navigation Data Center (NDC) Vessel Characteristics File for 2019 (*18*). The most common dimensions of barges carrying dry bulk (either covered or open) are 200 ft by 35 ft, followed by 195 ft by 35 ft. These two types represent 67 and 27 percent of the dry bulk barge population in the database, respectively. Given the large share represented by the 200-ft barge, the larger barges will be used as the standard barge in this report. The weighted average cargo capacity for these barges is 1,854 short tons. However, unlike the other modes, barges are often restricted to less than full carrying capacity by the infrastructure (rivers and locks) they use. Data acquired from the Institute for Water Resources and strapping tables available from several major barge lines indicate that the average system draft of loaded barges was close to 10 feet. The barge strapping tables indicate that at 10 feet, the average carrying capacity would be close to the 1,750 tons reported in the last modal comparison update released in 2017 (*19*); therefore, 1,750 is used as the carrying capacity in this update.

Although this comparison uses 1,750 tons as the standard barge capacity, several carriers report that they load significantly more (up to 1,900 tons) on certain segments, such as the lower Mississippi River, where draft restrictions are not in place for much of the year. Loads above 1,750 tons are also found on the Ohio River when water levels permit.

According to the same database, barges in the 195–200-ft length by 35-ft width category constitute 36 percent of the total tank barge fleet, while barges in the 297–300-ft length by 54-ft width category constitute 40 percent of the total barges carrying liquid bulk. Capacities are reported in tons, which can be converted to barrels by using the weight of each commodity per barrel (lb/bbl). Using a range of 6 lb/gal to 7.3 lb/gal, barrel weights may range from 252 lb/bbl to 306.6 lb/bbl, respectively. Table 1 shows the approximate carrying capacities for tank barges. Sales executives at Kirby Inland Marine indicated that due to infrastructure constraints and operational concerns, it is rare for a tank barge to exceed 27,500 barrels. Given this information, 27,500 barrels is used as the standard cargo capacity of a tank barge.

Table 1. Tank Barge Capacities.

Dimensions (Feet)	Average Cargo Capacity (Tons)	Number of Barrels Capacity (Theoretical)	
		Minimum	Maximum
195–200 × 35	1,709	11,148	13,563
297–300 × 54	4,116	26,849	32,667

Table 2 summarizes the standard capacities for the various freight units across all three modes that are used in this analysis.

Table 2. Standard Modal Freight Unit Capacities.

Modal Freight Unit	Standard Cargo Capacity
Highway—tractor-trailer	25 tons
Rail—bulk car	110 tons
Barge—dry bulk	1,750 tons
Barge—liquid bulk	27,500 bbl

Figure 2 illustrates the carrying capacity of a dry cargo barge in comparison to the rail and truck modes.

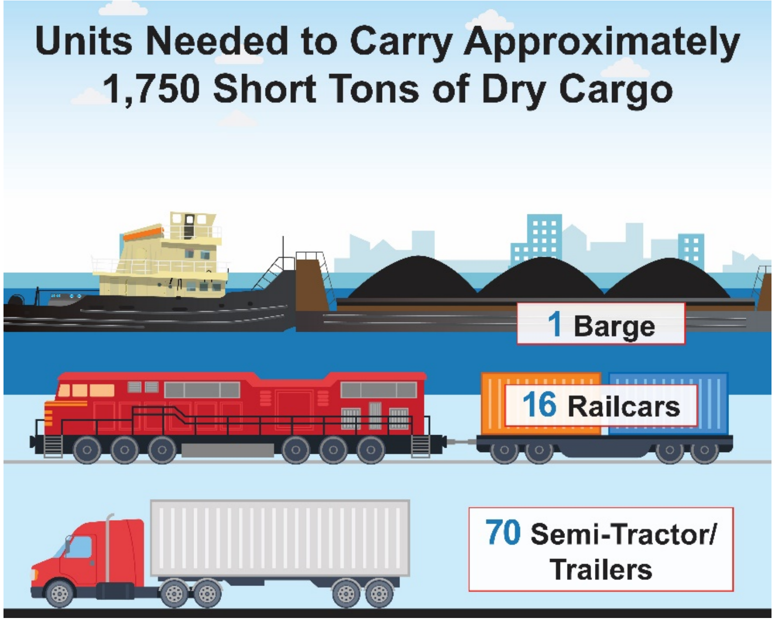

Figure 2. Dry Cargo Capacity Comparison.

Figure 3 illustrates the carrying capacity of a liquid cargo barge in comparison to the rail and truck modes.

Figure 3. Liquid Cargo Capacity Comparison.

It is difficult to appreciate the carrying capacity of a barge until one understands how much demand a single barge can meet. For example, as shown in Figure 4, one full barge load of wheat is more than enough to provide a 1-lb loaf of bread for every man, woman, and child living in Oklahoma in 2019.

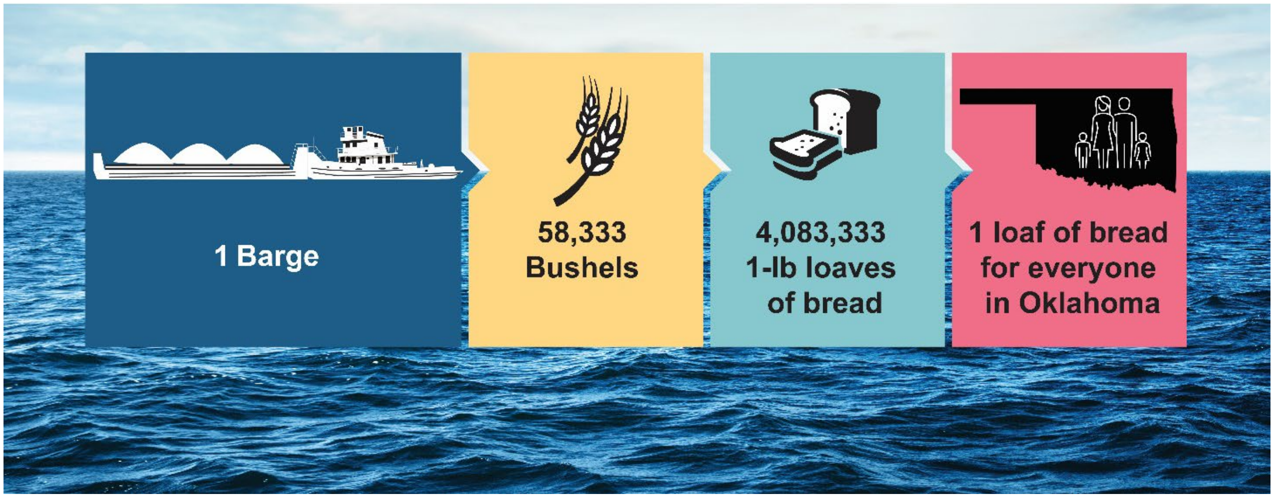

Figure 4. Wheat Illustration.

A loaded tank barge with 27,500 bbl of gasoline carries enough product to satisfy the current annual gasoline demand of approximately 3,072 people (*20*, *21*).[5] (See Figure 5.)

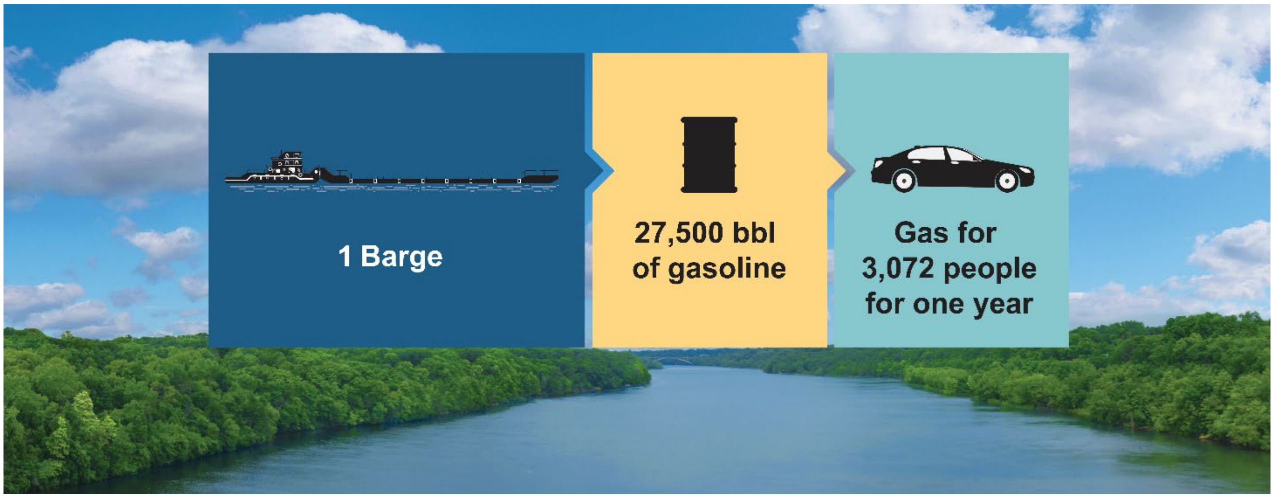

Figure 5. Gasoline Illustration.

Table 3 presents a tabulated comparison of the dimensions and capacities of the modal freight units involved in a typical trip to better understand the differences in the order of magnitude among the three modes.

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[5] Per capita use was calculated by taking the fuel consumed by light duty vehicles for 2019 as reported in the Transportation Energy Data Book ed. 39 and dividing it by the U.S. population on December 31, 2019, as reported by the Census Bureau.

Table 3. Modal Cargo Capacity Comparison.

Modal Freight Unit	Trip Configuration	Length (Feet)	Cargo Capacity (Tons)
Tow (dry cargo)	15-barge tow (5 × 3)	1,073	26,250
Unit train	110 cars, 3 locomotives	6,822*	12,100
Truck	1 tractor with a 53-ft trailer	70	25

**Assumes a railcar length of 60 ft.*

It is common to see tows of 15 barges or more on the major river systems. Figure 6 illustrates the carrying capacity of a 15-barge tow of dry cargo.

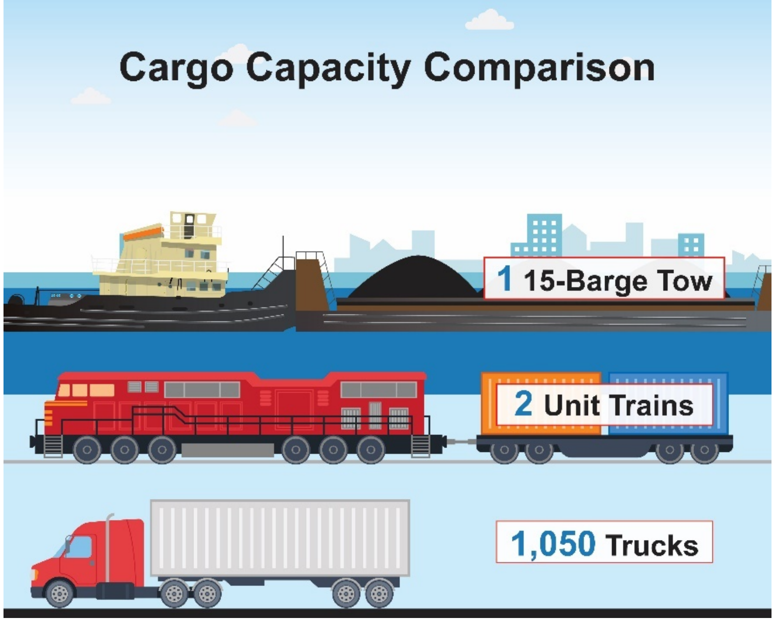


Figure 6. Capacity of 15-Barge Tow.

If the total domestic inland waterway tonnage (502 million tons) were loaded into the modal configurations indicated here at their maximum carrying capacity, and then the units were lined up end to end, the line of barges would extend almost 3,900 miles (the distance between Dallas, TX, and Anchorage, Alaska), while the line of trains would extend over 53,600 miles (over two times around the equator), and the line of trucks would extend almost 274,000 miles (11 times around the equator).

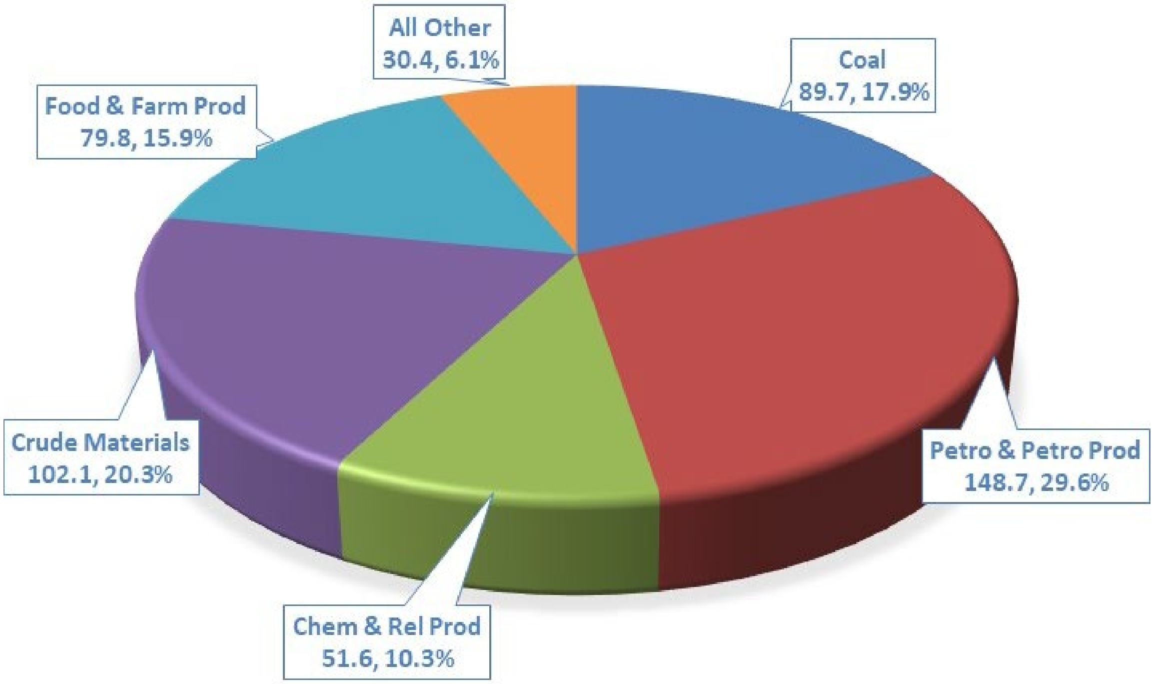
The fully loaded trucks required to transport the equivalent of waterborne cargo tonnage lined up end to end would circle the globe 11 times.

3. CONGESTION ISSUES

3.1. 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 previously, 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 7 shows the barge traffic distribution by commodity groups in 2019.



Source: (5)

Figure 7. 2019 Inland Waterway Barge Traffic by Commodity Group (in Millions of Tons).

3.2. Highway

3.2.1. Highway Statistical Analysis

Because highway data were only available through 2018, data published by the USACE NDC for calendar year 2018 were used (*3, 5*). The domestic internal tonnage and ton-mile data for the following major rivers were extracted:

- Mississippi River—Minneapolis, Minnesota, 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 waterborne freight transported on these major rivers were to be transported by truck. Table 4 shows the 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 transiting a segment on the highway multiplied by the length of that segment of highway, measured in miles.

Table 4. Waterway and Truck Equivalents—2018 Tonnage and Ton-Miles.

Waterway	Tonnage (× 000)	Ton-Miles (× 000)	Avg. Trip Length (Miles)	Annual Truckloads	Annual Truck Trips	Annual Loaded Truck VMT	Total Annual Truck VMT
Mississippi system (includes entire Ohio system)	419,753	235,979,199	562	16,790,120	33,580,240	9,436,047,440	18,872,094,880
GIWW	110,450	18,682,447	169	4,418,000	8,836,000	746,642,000	1,493,284,000
Columbia/ Snake	11,258	561,781	50	450,320	900,640	22,516,000	45,032,000
Total	**541,461**	**255,223,427**	—	**21,658,440**	**43,316,880**	**10,205,205,440**	**20,410,410,880**

Note: 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 the NDC. Average trip length in miles on each waterway was then calculated by division of ton-miles by tons. 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. Additionally, with the closure of a major waterway, trucks will be running new routes and servicing new facilities, making scheduling more difficult. 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 2018. Annual national historic data for intercity truck freight ton-miles through 2009 were obtained from BTS (*14*), at which time BTS stopped calculating and reporting intercity truck freight ton-miles. The statistics for 2010–2018 were estimated using the regression equation developed in the 2001–2009 update. Table 5 tabulates the data used for this analysis.

Table 5. Intercity Truck Ton-Miles versus Rural Interstate Vehicle Traffic.

Year	Intercity Truck Freight (Billion Ton-Miles)	Weighted Average Daily Vehicles per Lane Rural Interstate (*22*)
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*	5,198
2011	1,196*	5,198
2012	1,192*	5,178
2013	1,176*	5,124
2014	1,183*	5,148
2015	1,216*	5,260
2016	1,272*	5,452
2017	1,312*	5,586
2018	1,331*	5,650

**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 8 shows the line fitted, the equation developed using the BTS data, and the adjusted R^2 for this regression, which is 0.847. (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 for 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 2018. 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. The research team performed an extensive search to find a source of data that can substitute historical BTS data and extend to the most current data of intercity truck freight ton-miles. The Federal Highway Administration's Freight Analysis Framework version 4 (FAF4) provides truck freight ton-mile data from 2012 to 2018, and previous FAF versions provide historical freight ton-mile data. However, since each FAF version uses different methods and data sources, they cannot be compared to each other or used as a single source. Therefore, the research team continues to use the linear regression model derived from the historical BTS data for this study because it shows a strong relationship between intercity truck ton-miles and average daily vehicles per lane of the rural interstate.

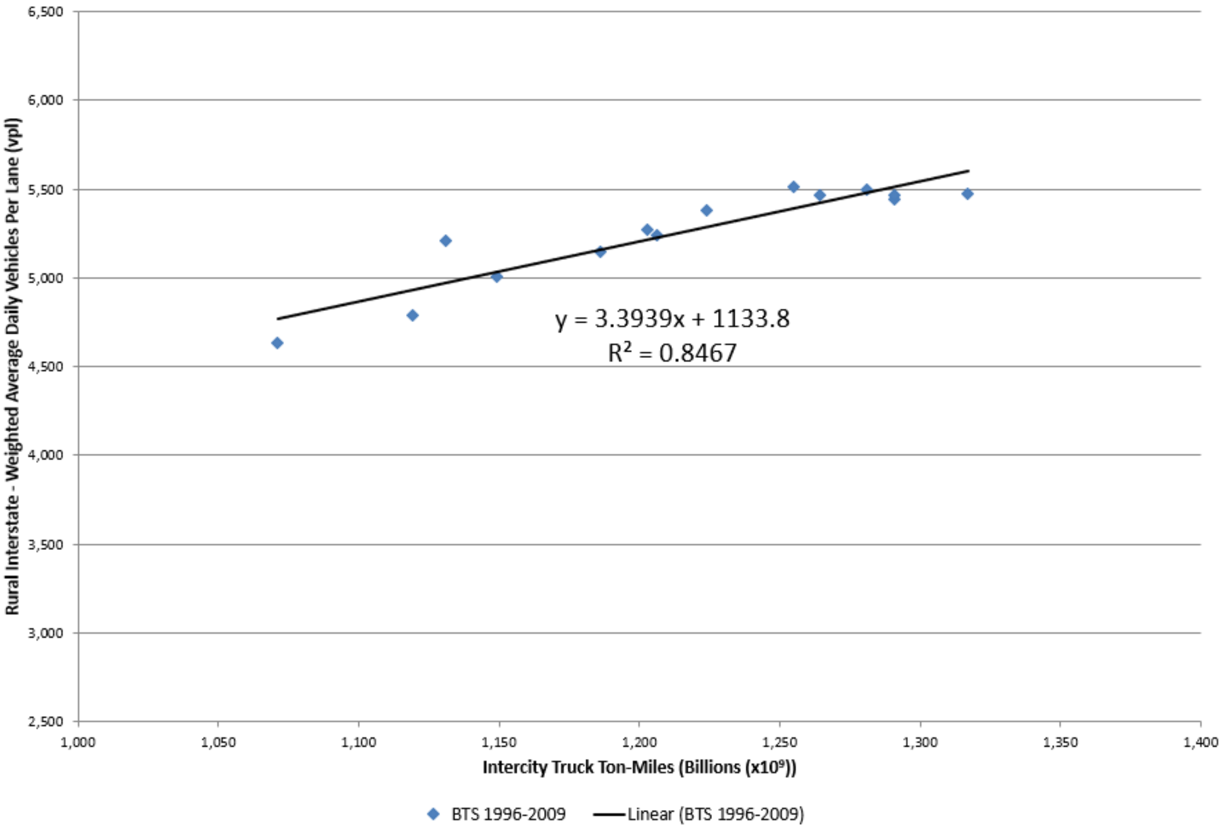


Figure 8. Average Daily Vehicles per Lane of Rural Interstate versus Intercity Truck Ton-Miles.

In 2018, 5,650 average daily vehicles per lane were on rural interstates, as shown in Table 5 from *Highway Statistics 2018* reports (*22*). After 2015, these reports no longer provide a percentage distribution of traffic volumes. Researchers assumed the 2018 percentage distribution of traffic volumes on rural interstates based on the historical data. On rural interstates, 83 percent of daily traffic (4,690 vehicles) was composed of passenger cars, buses, and light and heavy single-unit trucks. The remaining 17 percent of the traffic (or 960 vehicles) was combination trucks, the types of trucks that would carry diverted waterborne freight.

A total of 255.22 billion ton-miles was transported on the selected waterways in 2018. A total of 1,331 billion ton-miles were transported by interstate truck traffic in 2018. If the waterway ton-miles are diverted to trucks, the new total ton-miles attributed to intercity trucks add up to 1,586 billion. When this number is input into the developed regression equation, the weighted average daily vehicles per lane on rural interstates increases to

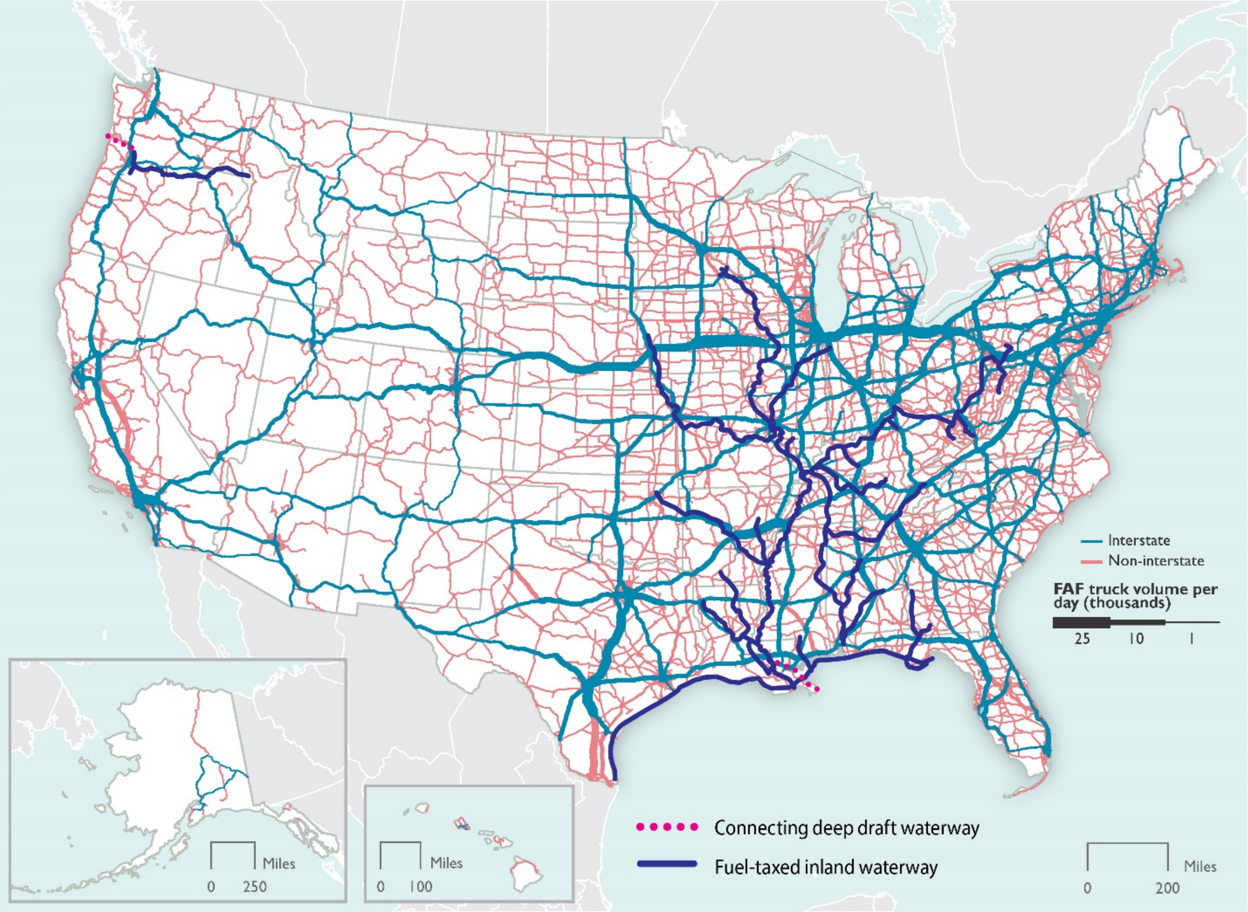
6,517. Since the number of passenger cars, buses, light trucks, and heavy single-unit trucks is constant at 4,690 vehicles per lane, the remaining 1,827 vehicles would be combination trucks. Thus, the percentage of daily traffic that is combination trucks rises 11 percent from 17 percent to 28 percent. In other words, the hypothetical diversion of current waterway freight traffic would add 867 combination trucks to the current 960 combination trucks 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 43 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 was 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 to 138 percent of current volumes on a nationwide basis.

This increase was derived from national-level data and reflects an average nationwide increase. The absolute number and percentage of 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.

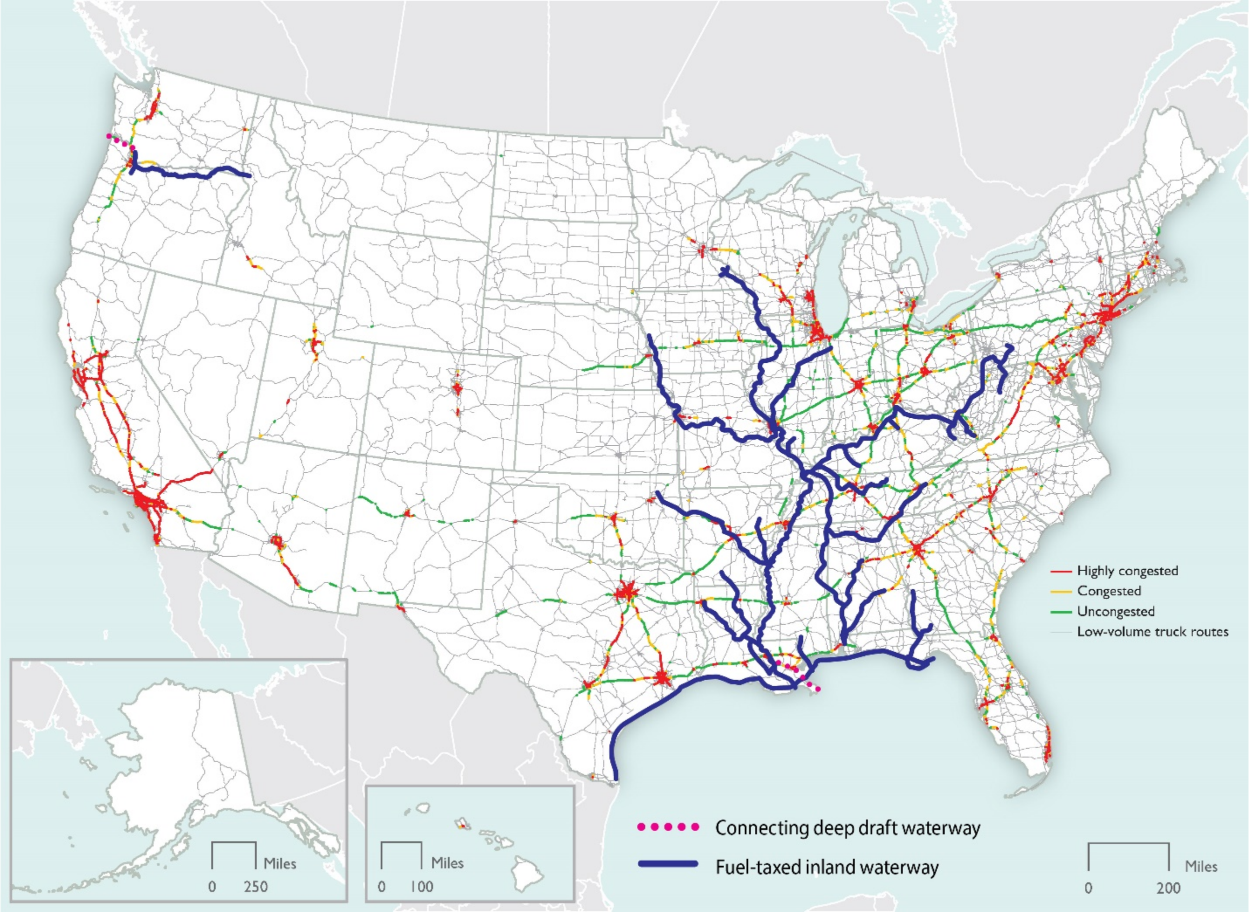
Major waterways help avoid the addition of more than 43 million truck trips to our highway system annually.

Figure 9 shows truck traffic levels on the nation's major highways, while Figure 10 shows the locations of the major bottlenecks.



Source: (23)

Figure 9. Average Daily Long-Haul Truck Traffic on the National Highway System (2015).



Source: (24)

Figure 10. Peak-Period Congestion on High-Volume Truck Portions of the National Highway System (2015).

3.2.2. Data Limitations and Necessary Assumptions

The hypothetical and nontraditional nature of this study requires the adoption of several important assumptions 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 dominance 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. It was also assumed that the shorter hauls 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. The availability of these items, particularly the availability of truck drivers over the near and long term, continues 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.

3.3. Rail System Congestion Impacts

This rail system congestion analysis estimates the impact that a closure of the inland river transportation system would have on the railroad industry and the potential impact on the transportation of commodities in particular. Grain traffic is used here as an example.

3.3.1. Data Sources

Data on annual grain carloads carried on U.S. railroads between 2008 and 2019 as revenue freight were extracted from the Freight Commodity Statistics on the Surface Transportation Board (STB) website (*25*). The recent train velocities for each railroad system from 2015 to 2019 were obtained from the U.S. Department of Agriculture (USDA) Agriculture Transportation Open Data Platform website (*26*), which catalogs rail service data reported by the railroads to STB. The recent years of railroad train velocity data by commodity for the Class I railroads are available on a weekly basis. Therefore, the system velocity for all trains used for this analysis is the average of weekly reported velocity by commodity per year. The historical data for average train velocities between 2008 and 2014 were retrieved from the investor fact books, annual reports, and monthly performance measures that each railroad provides on their individual websites.

3.3.2. Railroad Grain Traffic

The grain traffic on the Mississippi River provides a clear example of what the effect of a major diversion of traffic from water to rail would be. Grains produced in the United

States move to domestic and international markets through barges, railroads, and trucks, and two or more modes are often combined for efficient and low-cost grain movement (*27*). In 2019, grain movement accounted for 7.9 percent of tonnage and 4.5 percent of carloads for U.S. Class I railroads, which indicates 165.7 million tons and 1.7 million carloads of grain (*25*). According to USDA, 63 percent of U.S. grain shipments were delivered by truck in 2017, followed by rail and barge, representing 23 percent and 13 percent, respectively (*28*). The markets for grain transportation for the rail and barge industries have declined over the years, while the truck industry share has increased by 29 percent in the past three decades (*25*). However, rail and barge are still considered ideal modes for moving bulk grain commodities for long distances.

Although all the U.S. Class I railroads operate to some extent along or across the Mississippi River, two major U.S. rail carriers, the Union Pacific Railroad (UP) and the Canadian National Railway (CN), operate the entire length of the Mississippi River and locations along the river. UP and CN accounted for 22 percent and 5 percent of grain movement in the United States in 2019, respectively (*25*).

Barge movements along the Mississippi River originating from Minneapolis, Minnesota, to New Orleans, Louisiana, traverse five segments:

- Minneapolis to the mouth of the Missouri River.
- The mouth of the Missouri River to the mouth of the Ohio River.
- The mouth of the Ohio River to Baton Rouge, Louisiana.
- Baton Rouge to New Orleans.
- New Orleans to the mouth of Passes.

Assuming that origins in southern segments of the Mississippi River would not transport by rail if diverted, the research team chose the mouth of the Ohio River to Baton Rouge segment of the Mississippi River for the tons of grain transported by barge. The 2019 barge tons data were retrieved from the USACE Institute for Water Resources database (*3*).

According to the AAR carload traffic commodity groups, grain commodity includes grains (wheat, corn, oats, sorghum, etc.) and soybeans. For diversion, compatible grain commodities were also chosen from the barge tons data, including corn, oats, oilseeds, rice, sorghum grains, soybeans, and wheat. Outbound shipping and through traffic within the selected segment of the Mississippi River were considered to capture the downbound water traffic.

The grain tonnage moved on the inland river system would amount to an additional 38.2 percent more grain tonnage on the national railroad system. The selected segment of the Mississippi River grain traffic was 63.3 million tons for 2019, representing 57.3 percent of the total traffic on the segment.

Diverting river traffic would add 38 percent more grain tonnage to the national rail system.

$$\text{\% Railroad Grain Tonnage Increase} = (1 - \frac{RCT + MRGT}{RCT}) \times 100$$

$$= (1 - \frac{165.714 + 63.338}{165.714}) \times 100$$

$$= 38.2\%$$

Where:

- RCT = railroad current grain tonnage.
- MRGT = Mississippi River grain tonnage.

Assuming a diversion of Mississippi River grain traffic to both UP and CN in proportion to their combined grain carloads, UP would capture 80.9 percent, and CN would capture 19.1 percent of the river grain traffic. Table 6 shows these levels and the resulting additional grain car loadings by railroad.

Table 6. UP and CN Additional Grain Car Loadings.

Carrier	Grain Carloads	Percent Capture	Additional Car Loadings
UP	363,310	80.9%	465,994
CN	85,611	19.1%	109,808
Total	448,921	100.0%	575,801

For UP, the USDA Rail Dashboard reports the system train velocity between 2015 and 2019 on a weekly basis (*29*), and the UP monthly performance measures report the system train velocity from 2008 and 2014 (*30*).

In this scenario, the research team assumes almost 81 percent of the Mississippi River grain traffic would be handled by UP if the Mississippi River transportation system ceased operations. UP reported 35.1 million tons and 363,310 carloads of grain for 2019. The percentage of railroad grain tonnage increase is calculated using the UP grain tonnage and the Mississippi River grain tonnage to determine the percent increase in grain tonnage the UP would be burdened with should the river traffic require alternate transportation by railroad.

% UP Railroad Grain Tonnage Increase

$$= (1 - \frac{UPGT + MRGT}{UPGT}) \times 100$$

$$= (1 - \frac{35.054 + 51.259}{35.054}) \times 100$$

$$= 146.2\%$$

Where:

- UPGT = UP grain tonnage.
- MRGT = Mississippi River grain tonnage.

If 51.259 million tons of Mississippi River grain traffic were to be shifted to the UP rail lines, the railroad would face an approximately 146 percent increase in grain traffic, or an additional 465,994 car loadings annually with 110 tons of grain in each car. If the trains were made up of 110 cars per train, there would be an annual addition of 4,236 train movements or 11.6 added train movements per day on the existing UP rail lines.

The STB annual and quarterly freight commodity statistics and UP monthly performance measures provide statistical data for average train velocity and grain loadings in units between 2008 and 2019. Table 7 shows the performance measures of UP (*25, 29*).

Table 7. UP Railroad Performance Measures.

Measure	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	With Diver-sion
Velocity all trains	23.5	27.3	26.2	25.6	26.5	26.0	24.0	24.3	25.6	24.8	24.0	23.5	13.4
Grain loadings	397,287	345,002	360,237	353,110	312,367	299,983	375,516	339,703	383,438	373,309	356,017	363,310	829,304

Figure 11 illustrates the effect of the additional grain loadings on UP system train velocity.

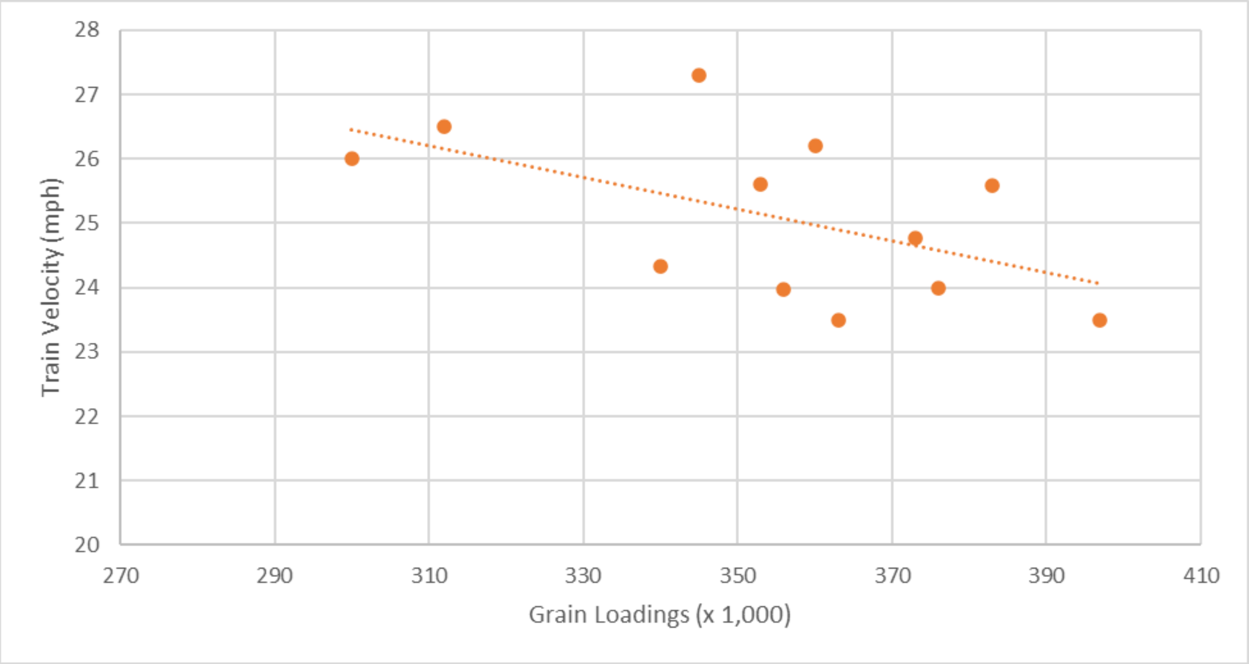


Figure 11. UP Train Velocity as a Function of Grain Loadings.

A regression analysis of these data yields the following equation:

$$y = -0.0247x + 33.853$$

The trend line fit analysis indicates a R^2 correlation coefficient of 0.2971, which implies that only the direction is predictable given the assumptions applied to the regression. Using the equation derived from the data, the average system speed for 829,304 grain car loadings would be 13.4 mph. The annual grain loading data and train velocities from 2008 to 2019 are for the entire UP railroad system. The actual UP grain traffic train routes and route densities for the analysis period are unknown.

For CN, the USDA Rail Dashboard reports the system train velocity between 2015 and 2019 on a weekly basis (*29*). The annual CN *Investor Fact Book* reports the system train velocity from 2008 and 2014 (*31*).

In this scenario, the research team assumed more than 19 percent of the Mississippi River grain traffic would be handled by CN if the Mississippi River transportation system ceased operations. CN reported 8.7 million tons and 85,611 carloads of grain for 2019. The percentage of railroad grain tonnage increase is calculated using CN grain tonnage and the Mississippi River grain tonnage to determine the percent increase in grain tonnage CN would be burdened with should the river traffic require alternate transportation by railroad.

% CN Railroad Grain Tonnage Increase $= (1 - \frac{CNGT + MRGT}{CNGT}) \times 100$

$$= (1 - \frac{8.688 + 12.079}{8.688}) \times 100$$

$$= 139.0\ \%$$

CNGT = CN grain tonnage
MRGT = Mississippi River grain tonnage

If 12.079 million tons of Mississippi River grain traffic were to be shifted to the CN rail lines, the railroad would face a 139 percent increase in grain traffic, or an additional 109,808 car loadings annually with 110 tons of grain each car. If the trains were made up of 110 cars per train, there would be an annual addition of 998 train movements or 2.7 added train movements per day on the existing CN rail lines.

Figure 12 illustrates the effect of the additional grain loadings on CN system train velocity.

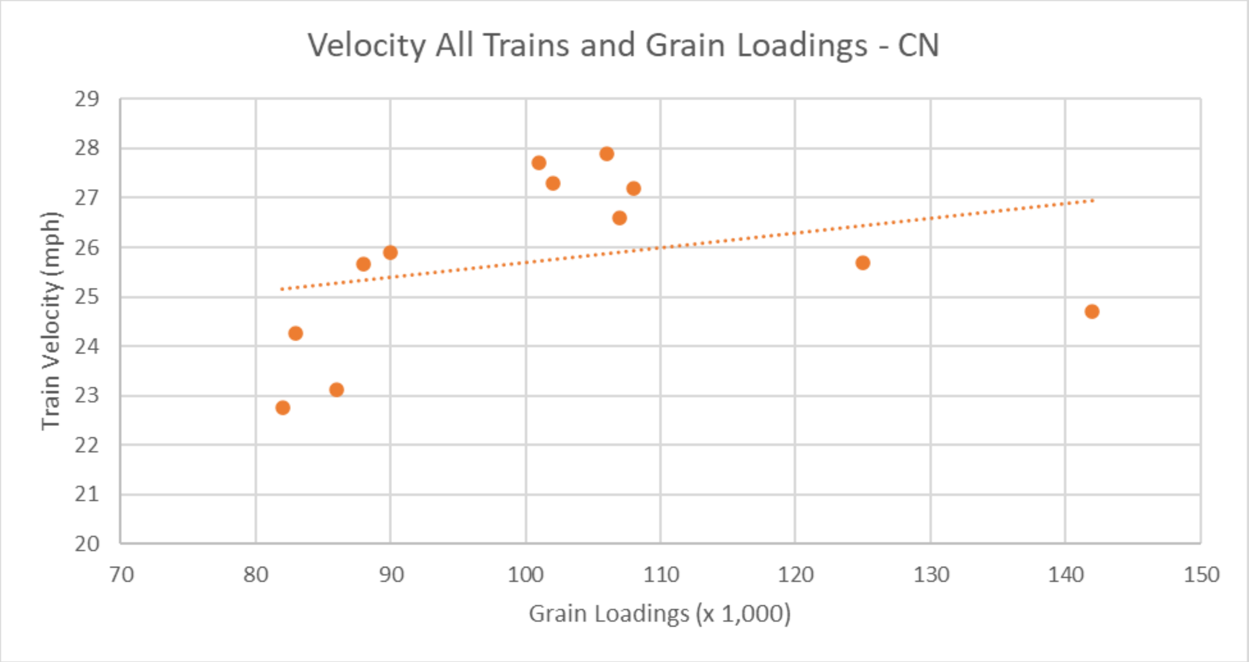


Figure 12. CN Train Velocity as a Function of Grain Loadings.

The trend line fit analysis indicates a poor R^2 correlation coefficient of 0.0964, a correlation too low to allow for a calculation of the impact on rail system velocity by the diversion of barge grain traffic.

The STB annual and quarterly freight commodity statistics and CN *Investor Fact Book* provide statistical data for average train velocity and grain loadings in units between 2008 and 2019. Table 8 shows the performance measures of CN (*25*, *31*).

Table 8. CN Railroad Performance Measures.

Measure	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	With Diversion
Velocity all trains	24.7	27.7	27.9	27.3	27.2	26.6	25.7	25.7	25.9	24.3	22.7	23.1	N/A
Grain loadings	142,194	101,257	105,506	101,970	108,311	107,229	124,755	88,334	89,514	82,990	81,641	85,611	195,419

The Mississippi River facilitates the movement of a significant level of grain commodities from the Midwest states to the Gulf Coast. Assuming a closing of the Mississippi River and diversion of barge traffic to rail, an appropriate metric is the rail system average train velocity for UP and CN. The diversion of grain traffic along the Mississippi River to the rail system would increase grain loadings by over 146 percent for UP and 139 percent for CN. The real possibility exists that the railroad system as currently developed could not respond by accommodating the shift of grain traffic, which equates to 2.3 times the current number of grain carloads on both the UP system and the CN network in the United States.

4. EMISSIONS ISSUES

This chapter contains an emissions impact analysis for four primary pollutants, including hydrocarbons (HC), carbon monoxide (CO), nitrogen oxide (NO_x), and particulate matter (PM) with a diameter of 10 microns or less (PM_{10}), as well as an analysis of carbon dioxide (CO_2) as the main greenhouse gas (GHG) emissions from freight operations. The chapter is divided into three broad sections covering emission estimation methodologies, results, and future emission regulations.

4.1. Emission Estimation Methodologies

This section describes the methodologies that the study team used to prepare the emission impact analysis of this task.

4.1.1. Commercial Freight Trucks

The U.S. Environmental Protection Agency (EPA) sets the emissions standards for motorized vehicles. The majority of freight trucks are heavy-duty diesel trucks and are subject to EPA's emissions standards for on-road heavy-duty diesel engines. This section provides a summary of the emissions standards applicable to on-road heavy-duty diesel trucks.

EPA introduced the first federal emission limits for diesel vehicles in 1974 and has gradually strengthened these limits through several updates. The current emissions standards for on-road heavy-duty engines were phased in from 2007 to 2010. These standards are the most stringent diesel emissions standards to date. The 2007 standards include very stringent limits for NO_x (0.20 g/bhp-hr, approximately 85 percent lower than the previous standard set in 2004) and PM (0.01 g/bhp-hr, 90 percent lower than the previous standard set in 1994). All the 2007 and newer heavy-duty diesel engines must comply with the PM emission limits, while the NO_x standard was implemented in phases between 2007 and 2010. All the new on-road heavy-duty diesel engines manufactured since 2010 must be certified to a NO_x emission level of 0.20 g/bhp-hr. This is commonly referred to as the 2010 NO_x standard for heavy-duty diesel engines, which is a full implementation of the 2007 standard. Table 9 summarizes the emissions standards for on-road heavy-duty diesel engines.

Table 9. On-Road Heavy-Duty Diesel Engine Emissions Standards.

Standard	Pollutant (Grams per Brake Horsepower-Hour)			
	CO	HC	NO_x	PM
U.S. 1991	15.5	1.3	5.0	0.25
U.S. 1998	15.5	1.3	4.0	0.10
U.S. 2004	15.5	HC + NO_x 2.4		0.10
U.S. 2007	15.5	0.14	0.2*	0.01
U.S. 2010	15.5	0.14	0.2	0.01

**Most diesel engine manufacturers certified their 2007–2009 engines to a fleet average NO_x limit of 1.2 g/bhp-hr.*

Source: (32)

EPA's Motor Vehicle Emission Simulator (MOVES) model is the official tool for developing emission inventories from mobile sources in all states other than California. MOVES is used extensively for various regulatory purposes such as State Implementation Plan development and transportation conformity analysis. MOVES3 is currently the latest official version of the MOVES model. Updates included in MOVES3 are:

- Inclusion of the latest data on vehicle populations, travel activity, and emission rates, as well as updated fuel supply information.
- Incorporation of the impacts of the heavy-duty GHG Phase 2 rule (*33*) and the Safer Affordable Fuel-Efficient vehicles rule (*34*).

The research team used MOVES3 to analyze the emissions impacts of long-haul diesel freight trucks. This analysis was done by primarily using the model's built-in default values derived from the national truck fleet and vehicle activity data. Similar modal comparison analyses previously conducted by the Texas A&M Transportation Institute (TTI) and EPA used previous versions of the MOVES model, that is, MOVES 2014a and MOVES 2014b, respectively (*19*, *35*).

As a starting point, the research team compared the differences between MOVES 2014a and MOVES3 by replicating the previous TTI study's methodology, assumptions, and input values with MOVES3 for the analysis year 2014. The user-defined inputs used in MOVES include the following:

- Scale: national inventory with default state and local allocation factors.
- Analysis year 2014: 12 months, 7 days, and 24 hours.
- Geographic bounds: nation.
- Vehicles: diesel fuel combination long-haul truck (source type 62).
- Road type: all (rural and urban, restricted and unrestricted access, and off-network).

- Pollutants:
    - Volatile organic compounds (VOC).
    - CO.
    - NO_x.
    - CO_2.
    - 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 unit: grams.
    - Distance unit: miles.
    - Activity: distance traveled and operating time.

Table 10 shows the emission factor results for the analysis year 2014 using MOVES3 compared to the results from the 2017 TTI report. As shown in the table, updates in MOVES3 have resulted in a substantial reduction of expected primary pollutant emissions and a slight decrease of CO_2 for the same analysis year. The updates in MOVES3 include an update of vehicle population and activity parameters (*36*, *37*). The research team observed that the resulting overall truck average speed in the 2017 TTI report is 41.7 mph, whereas the overall average speed from MOVES3 is 43.6 mph.

Table 10. MOVES 2014a and MOVES3 Result in Analysis Year 2014.

Source		CO_2	CO	NOx	PM_{10}	VOC
2017 TTI Report (*19**Error! Bookmark not defined.***) MOVES 2014a	g/VMT	1,927.50	3.35	11.77	0.59	1.06
MOVES3	g/VMT	1,860.64	2.96	9.54	0.45	0.49
	Difference from 2017 TTI	−3.5%	−11.7%	−18.9%	−24.4%	−53.4%

The results shown in Table 10 highlight the importance of using the latest MOVES model for the emissions impacts analysis of this study. The research team, therefore, selected MOVES3 for this study. All the user-defined input data are the same as those in the 2017 TTI report except for the analysis year that was set to the year 2019.

To facilitate the modal comparison of this study, the estimated emission rates from MOVES need to be converted into grams/ton-mile.[6] As described in the 2017 TTI report, the research team assumed an average cargo weight of 25 tons per truckload. Furthermore, all return trips were assumed to be empty (*19***Error! Bookmark not defined.**). The national average gross vehicle weight (GVW) for long-haul combination trucks (tractor and truckload combined) is 24.42 metric tons (26.92 short tons) in MOVES3's default database. With an assumption of an unladen Class 8 truck-tractor weight of 16.5 tons (33,000 lb), the assumed cargo weights of this study would result in an overall GVW of 29 tons, which is within a close range to the MOVES3 default value. Using the following equation, MOVES3's distance-based emissions results were converted to a weight-based emissions factor expressed as grams per ton-mile.

$$EFW_i = ER_i \div 12.5$$

Where:

- EFW_i = average weight-based emission factor for pollutant i (g/ton-mile).
- ER_i = average distance-based emission rate for pollutant i (g/VMT).
- 12.5 = average truck cargo weight for one round trip freight delivery (25 tons/truck for the laden leg and zero for the unladen leg).

The emissions impacts results based on these numbers are discussed in Section 4.2, along with results for other modes.

4.1.2. Railroad Locomotive

EPA's 1998 Locomotive Rule created an emission control program that subjected manufacturers and railroads to emissions standards, test procedures, and a full compliance program. This program also regulated the engine remanufacturing process. This part of the rule was deemed critical because locomotives are generally remanufactured four to eight times during their total service lives. The current engine emission regulation for locomotives was adopted by EPA in 2008 and includes five sets of emissions standards (also called tiers: Tier 0 through Tier 4) with applicability dependent on the date a locomotive is first manufactured. Locomotives originally manufactured in 2015 and later years are subject to the most stringent set of standards (i.e., Tier 4). Table 11 summarizes the emission limits for line-haul locomotives. Section 4.1.3 provides more details on the 2008 emissions standards, which cover both locomotives and marine engines' emissions.

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[6] Water and rail modes typically report and publish emissions data using ton-miles, whereas highway data conventionally use vehicle-miles.

Table 11. Standard Locomotive Exhaust Emission.

Line-Haul Emission Standard Tier	HC	NO_x	PM	CO
	(g/bhp-hr)			
Tier 0	1.00	9.50	0.22	5.00
Tier 1	0.55	7.40	0.22	2.20
Tier 2	0.30	5.50	0.10	1.50
Tier 3	0.30	5.50	0.10	1.50
Tier 4	0.14	1.30	0.03	1.50

Source: (38)

In a 2009 technical highlights document, EPA published a set of the "average typical in-use emission factors" for locomotives of different emission tiers. To account for the impact of remanufacturing of the locomotive on its emissions, EPA provided additional emission factors for three sub-tiers (i.e., Tier 0+, Tier 1+, and Tier 2+) representing remanufactured locomotives of Tiers 0, 1, and 2. Table 12 summarizes the average emission factors developed by EPA for each level. During the period of this study's snapshot in time of 2019, the railroads were subject to all eight levels of emission standard tiers. Tier 4 engines were not applicable to the 2017 TTI study, which estimated emissions for the analysis year 2014.

Table 12. Average Locomotive Exhaust Emission.

Tier	HC	NOx	PM	CO
	(g/bhp-hr)			
Tier 0: Originally manufactured from 1973 through 2001	0.48	8.60	0.32	1.28
Tier 0+: Originally Tier 0 but remanufactured	0.30	7.20	0.20	1.28
Tier 1: Originally manufactured from 2002 through 2004	0.47	6.70	0.32	1.28
Tier 1+: Originally Tier 1 but remanufactured	0.29	6.70	0.20	1.28
Tier 2: Originally manufactured from 2005 through 2011	0.26	4.95	0.18	1.28
Tier 2+: Originally Tier 2 but remanufactured	0.13	4.95	0.08	1.28
Tier 3: Originally manufactured from 2012 through 2014	0.13	4.95	0.08	1.28
Tier 4: Originally manufactured from 2015 or later	0.04	1.00	0.02	1.28

Source: (39)

The emission rates in grams per brake horsepower-hour illustrate the average amount of emission by each duty cycle and tier; however, it is often useful to express emission rates as grams of pollutant emitted per gallon of fuel consumed. In its 2009 technical highlight document, EPA also provides a set of fleet-average emission factors expressing the expected emissions from locomotives in grams per gallon for analysis years 2006 to 2040. Table 13 shows the fleet-average emission rates for the analysis year 2019, which are used in estimating emissions in this study. The railroad switch emission factors are included in the table for completeness but are not used in reference to emissions from the railroads.

Table 13. Fleet-Average Emission Factors for Locomotives in Analysis Year 2019.

Duty Cycle	HC	NO_x	PM_{10}	CO
	(g/gal)			
Linehaul	3.9	103	2.5	26.6
Switch	11.4	200	4.4	38.1

Source: (39)

4.1.3. Marine Engine

This section summarizes the regulations affecting the emissions from commercial marine engines. The emission regulations for marine diesel engines are formulated for three categories of marine engines:

- **Category 1 (C1):** engines over 37 kW with a per-cylinder displacement less than 5.0 L, with general engine life of 10 years or 10,000 hours.
- **Category 2 (C2):** engines with a per-cylinder displacement of 5.0 to 30 L, with general engine life of 20,000 hours.
- **Category 3 (C3):** engines with a per-cylinder displacement of 30 L or larger, which are typically used for propulsion on oceangoing vessels.

C1 and C2 marine engines are used to provide propulsion power on many commercial vessels involved in the domestic waterborne freight movement. Prior to 1998, marine diesel engines less than 37 kW were regulated under the provisions for the Tier 2 standards for nonroad compression ignition engines. EPA established the first marine engine-specific emissions standards in 1998 for C1 marine diesel engines, followed by emissions standards for C2 engines in 1999. These standards were based on the land-based Tier 2 standards for nonroad diesel engines. The start dates for the 1998 and 1999 standards' implementation were 2004 and 2007, respectively. These standards left C3 engines unregulated, which triggered a lawsuit against EPA by environmental organizations (*40*). As required by a court settlement resulting from this lawsuit, in 2003, EPA adopted a NO_x-only Tier 1 emission standard for commercial marine engines larger than 2.5 L per cylinder with an effective date of 2004.

EPA continued to strengthen the emissions standards for marine engines by introducing Tier 3 and Tier 4 emissions standards for marine diesel engines in 2008. The Tier 4 emissions standards were modeled after the 2007/2010 highway diesel engine standards and the Tier 4 nonroad rule. Tier 4 standards represent the most significant reduction of commercial marine engines to date and are applicable to commercial marine diesel engines above 600 kW.

While the Tier 3 standards cover engine-out emissions and rely on engine-based technologies, the Tier 4 standards focus on exhaust-out emission reductions by using exhaust after-treatment technologies, most importantly the selective catalytic reduction technology for NO_x reduction. The Tier 3 standards for commercial marine engines were phased in from 2009 to 2014, followed by the phase-in implementation of the after-treatment-centric Tier 4 standards for commercial marine engines at or above 600 kW between 2014 and 2017. To enable the use of catalytic exhaust after-treatment technologies, EPA also established a sulfur content limit for marine fuels (maximum 500 parts per million [ppm] effective June 2007 and 15 ppm effective June 2012).

In 2010, EPA adopted new engine emissions standards for C3 marine engines based on Tier 2 and Tier 3 NO_x limits and also restricted the production and sales of fuel oil with a sulfur content above 1,000 ppm for use within the U.S. emission control area and associated internal U.S. waters. In response to comments from the industry, in 2020, EPA adopted revisions to emission regulations for certain high-speed vessels and the associated engines with rated power between 600 and 1,400 kW to provide more time for engine manufacturers to certify additional engine models. The relief allowed under these revisions is implemented in two phases:

- **Phase 1:** engines that will be installed on vessels with a waterline length up to 65 ft and total power at or below 2,800 kW.
- **Phase 2:** engines that will be installed on vessels with fiberglass and other nonmetal hulls, a single propulsion engine with maximum power output up to 1,000 kW, and power density of at least 35.0 kW per liter displacement.

Because this study does not attempt to develop a route-specific emission profile, an industry-average emission profile would provide a sufficient level of accuracy. This updated analysis uses the same methodology that was used for the 2017 TTI report and was subsequently adopted by EPA for its 2020 SmartWay Shipper Company Partner Tool (*35*). The TTI methodology applies industry-average fuel-based emission factors for the target analysis year to the fuel consumption per ton-mile of waterborne freight movement to estimate the emissions impacts for the marine mode. The amount of fuel used per ton-mile is estimated based on the reported fuel tax collected by the Internal Revenue Service and the tonnage reported to USACE. Because marine engines and locomotive emissions are mainly regulated by the 2008 standards, the same fuel-based emission factors as shown in Table 13 are used in this analysis for both modes. Section 4.2 discusses the modal comparison results for the analysis year 2019.

4.1.4. Greenhouse Gas Impact

GHGs are gaseous compounds in the Earth's atmosphere that trap heat. GHGs resulting from human activities are considered the most significant driver of observed climate change. The primary human-made GHGs are CO_2, methane, nitrous oxide, and fluorinated gases. CO_2 comprises more than 97 percent of the GHGs released from transportation activities, and therefore the analysis of this study focuses on quantifying CO_2 (*41*).

EPA and USDOT have adopted a common conversion factor of 10,180 g of CO_2 per gallon of diesel consumed (*42*). This value is used for the analysis of marine and railroad GHG impacts in this study. In the 2017 TTI report, a slightly lower conversion factor of 10,106 g of CO_2 per gallon of diesel was used for the modal comparison.

4.2. Emissions and Greenhouse Gas Results

By applying the methodologies described in the previous section, the study team estimated the modal emissions impacts in the form of grams per ton-mile for the analysis year 2019. The estimation methods for the waterborne freight movement and railroads use fuel-based emission factors and would require fleet-average fuel efficiency numbers. Emissions of primary pollutants and CO_2 for trucks are obtained from the MOVES3 model. Table 14 shows the fuel efficiency of each mode as discussed in Chapter 5.

Table 14. Summary of Fuel Efficiency in Analysis Year 2019.

Mode	Fuel Efficiency (Ton-Miles per Gallon)
Inland towing	675
Railroad	472
Truck	151

Table 15 shows the emission results by mode in 2019. Based on the results, waterborne inland towing has the least emissions per ton-mile for all pollutants among all modes, followed by railroad locomotive. The grams per ton-mile results are numerically the same as metric tons per million ton-miles ($MT/10^6$ ton-mile). Appendix E provides a detailed explanation of the changes in truck emission rates from the 2017 TTI report.

Table 15. Emission Results by Mode in Analysis Year 2019.

Mode	Unit	HC	NO_x	PM_{10}	CO	CO_2
Inland towing	g/ton-mile (or $MT/10^6$ ton-mile)	0.0058	0.1526	0.0037	0.0394	15.0815
Truck	g/VMT	0.28	5.61	0.24	2.37	1758.78
	g/ton-mile (or $MT/10^6$ ton-mile)	0.0221	0.4487	0.0191	0.1898	140.7023
	metric tons avoided	3,978.9	72,254.7	3757.6	36,688.8	30.7×10^6
Railroad	g/ton-mile (or $MT/10^6$ ton-mile)	0.0083	0.2182	0.0053	0.0564	21.5678
	metric tons avoided	606.3	16,013.2	388.7	4,135.4	1.6×10^6

According to statistics published by USACE, in 2019, the inland waterways logged 244 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 show that moving the inland waterway activity to the railroads and trucks would result in the additional pollutant and GHG emissions as summarized in Table 15. The calculation consists of multiplying the difference in the rates of metric ton of emission per ton-mile multiplied by 244,000 million ton-miles.

Figure 13 and Figure 14 illustrate the differences in GHG emissions for the three modes.

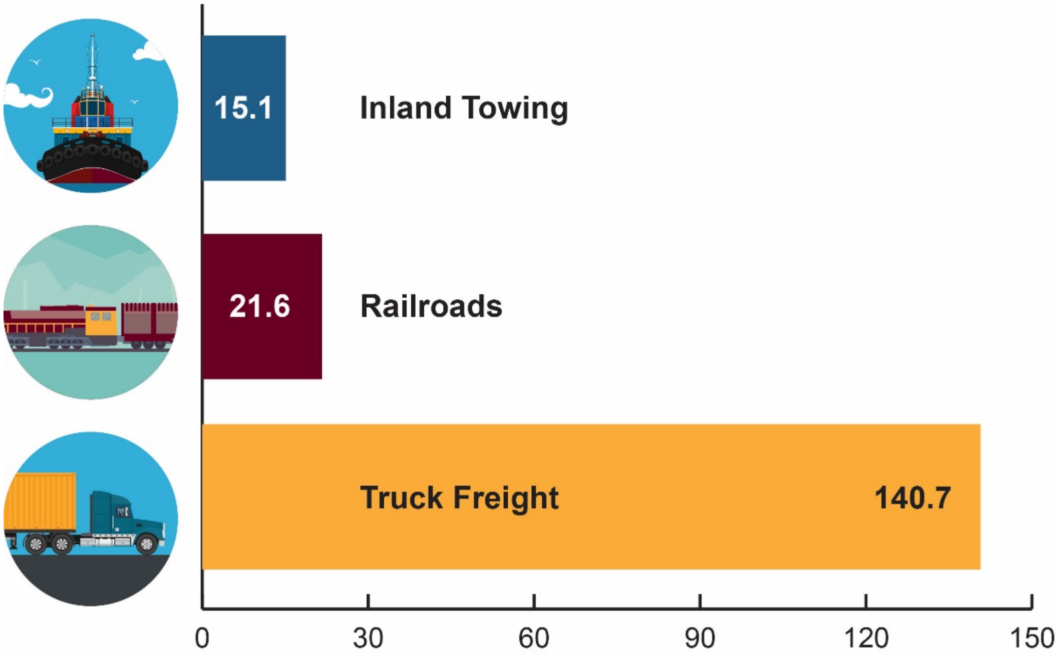


Figure 13. Metric Tons of GHG per Million Ton-Miles (2019).

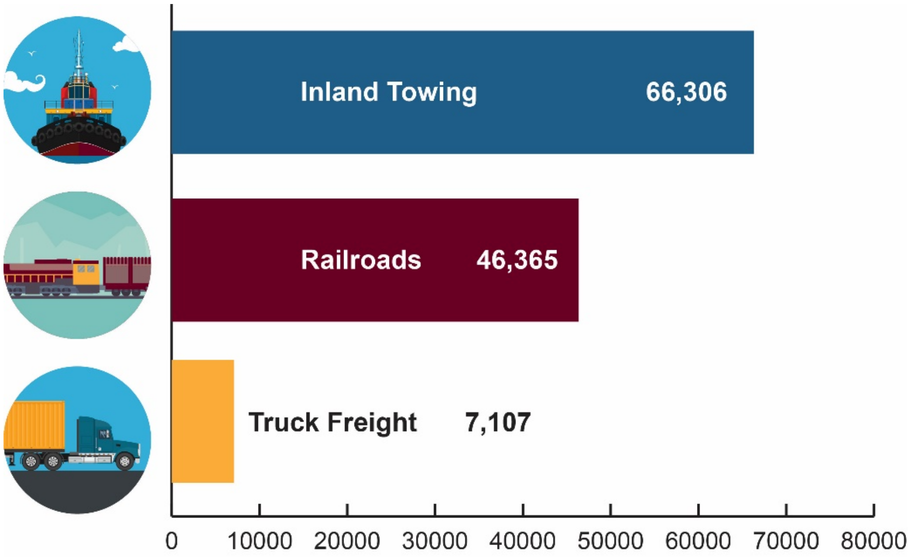
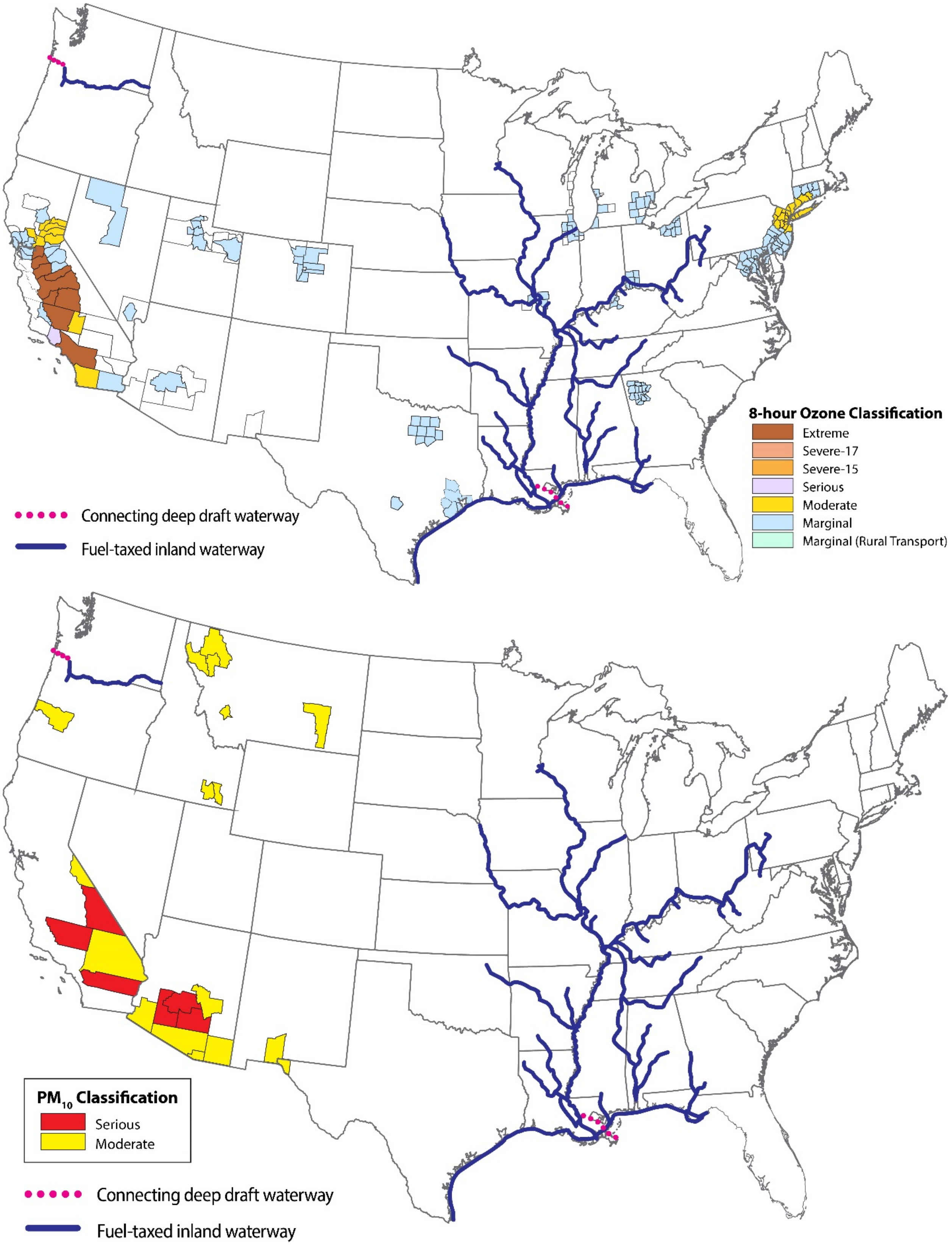


Figure 14. Ton-Miles per Metric Ton of GHG.

Although the range of increases in all pollutants may seem relatively modest, 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 Mississippi River, Ohio River, and Gulf Intracoastal

Waterway already run through several areas designated by EPA as nonattainment areas, most commonly for ground-level ozone. Any emissions increase would only worsen existing problems. Figure 15 shows these nonattainment areas for ozone and PM_{10} nationally.



Source: (43)

Figure 15. Ozone and PM$_{10}$ Nonattainment Areas as of June 2021.

4.3. Future Emission Regulations

The current federal emissions standards for highway heavy-duty diesel engines are phased in over the period of 2007 to 2010. In November 2018, EPA proposed its plan for the new Cleaner Trucks Initiative (*44*). This proposed initiative includes a stringent NO_x emission standard for heavy-duty trucks focusing on the reduction of NO_x emissions under real driving conditions. EPA intended to release the corresponding proposed rule in 2021; however, as of June 2021, EPA has not yet issued a proposed rule.

In 2020, the California Air Resources Board announced its new emission regulations titled *Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments* (*45*). This new regulation includes a future NO_x reduction requirement for diesel engines to reduce NO_x by approximately 75 percent below the current standards beginning in 2024 and 90 percent below the current standards in 2027.

The latest emissions standards for railroad locomotives and marine engines were issued in 2016 and 2020, respectively *(38*, *46*). EPA has not announced intent for a major revision for railroad locomotive and marine engine emissions standards in the near future.

5. ENERGY EFFICIENCY

5.1. Highway

BTS indicates that the fuel economy rate for combination trucks between 2014 and 2019 was 5.8, 5.9, 5.9, 6.0, 6.1, and 6.0[7] miles per gallon (mpg) (*47*), which is consistent with the data published in the *Transportation Energy Data Book* (*48*). Conventionally, VMT is 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 VMT rates to ton-mile rates.

When the truck fuel efficiency rate of 6.04 mpg for 2019 is multiplied by the assumed truckload of 25 tons of cargo, a truck fuel efficiency of 151 ton-miles/gal is generated. Each return trip is assumed to be empty—or hauling 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 6.0. Since an across-the-board comparison of the three modes requires the use of a ton-miles-per-gallon rate, 151 ton-miles/gal is the proper figure to use.

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 Transportation Energy Data Book and determined that is not appropriate for the modal comparison in this report. The energy data book combines heavy-duty (semi-tractor/trailer) trucks and medium-duty (single unit) trucks together, while the modal comparison concentrates solely on the heavy-duty trucks. Furthermore, the energy data book does not report on a ton-mile basis for trucks, which is what the modal comparison uses. Finally, the most recent version of the data book as of this report only goes through 2018. Therefore, 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 NO_x 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 ultra-low sulfur diesel 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 EPA also reduced the maximum allowed level of sulfur in highway diesel fuel by 97 percent in mid-2006—from 500 ppm in low-sulfur diesel to 15 ppm in

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[7] BTS reported these numbers rounded to one significant digit. When two significant digits are used, the calculated fuel economy for 2019 is 6.04.

ultra-low sulfur diesel. The phase-in was set on a percent-of-sales basis: 50 percent from 2007 to 2009 and 100 percent in 2010. Section 4.1.1 provides a more detailed overview of emissions standards for heavy-duty diesel trucks.

EPA and USDOT's National Highway Traffic Safety Administration (NHTSA) jointly announced in October 2010 the first-ever standards to reduce GHG emissions and improve fuel efficiency of medium- and heavy-duty highway vehicles rated at a GVW equal to or larger than 8,500 lb. These vehicles make up the transportation segment's second largest contributor to oil consumption and GHG emissions. These joint standards, commonly known as Phase 1 standards, cover vehicles of model years 2014 through 2018.

The joint fuel economy and GHG standards intend to create a strong and comprehensive heavy-duty national program, designed to address the urgent and closely intertwined challenges of dependence on oil, energy security, and global climate change. The Phase 1 standards for combination trucks in Class 8 range from 118 ton-miles/gal to 159 ton-miles/gal. EPA and NHTSA estimated 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 between 2014 and 2018, 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.

In October 2016, EPA and NHTSA published the second phase of GHG and fuel efficiency standards for medium- and heavy-duty vehicles and engines of model years beyond 2018. The Phase 2 standards intend "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" (*49*). These standards are designed to have GHG emissions from Class 8 trucks of model year 2027 and beyond to be approximately 40 percent lower than trucks of model year 2010. EPA states that these standards are 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 GHG and fuel consumption standards phase in between model year 2021 and model year 2027. In addition to vehicles and engines, Phase 2 standards cover trailers and gliders for the first time with a phase-in period between model year 2018 and model year 2027.[8] Trailer technologies that could

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[8] CO_2 standards set by EPA are mandatory starting with model year 2018. Fuel consumption standards set by NHTSA are voluntary for model years 2018–2020 and become mandatory for model years 2021 and beyond.

be used to meet the standards include aerodynamic devices, lower-rolling-resistance tires, automatic tire inflation systems, and weight reduction.

5.2. Rail

The energy consumption in the railroad industry was carefully evaluated to ensure that the full energy, total equipment, and freight mileage movements were included. The data for the railroads were taken primarily from the R-1 reports filed annually with STB.

The AAR data were found on the AAR website in the section on freight rail and preserving the environment. STB provides each railroad's R-1 report, which includes operating data, particularly the railroad's locomotive fuel gallons consumed on Schedule 750, line 4, and the revenue ton-miles of traffic reported on Schedule 755, line 108.

Table 16 lists the fuel efficiency calculated by researchers using the available data from the R-1 reports and the AAR reported value for gross ton-miles per gallon of fuel for the year 2019.

Table 16. Calculated Railroad Fuel Efficiency (2019).

Source	Gross Revenue Ton-Miles ($\times 10^6$) (*50*)	Fuel Consumed ($\times 10^6$) (*51*)	Ton-Miles per Gallon*
AAR (*52*)	—	—	472
BNSF Railway	665,033	1,365.9	486.9
CN (U.S.)/Grand Trunk	62,607	121.4	515.7
Canadian Pacific Railway (U.S.)/Soo Line	37,544	69.2	542.5
CSX	199,211	391.8	508.5
Kansas City Southern Railway Company	32,625	66.1	493.6
Norfolk Southern Railway	194,045	450.6	430.6
UP	423,433	954.6	443.6
Total/Average All Railroads	**1,614,498**	**3,419.6**	**472.1**

**Calculated value; gross revenue ton-miles divided by fuel consumed.*

5.3. Inland Towing

It is more difficult to develop energy consumption data for the inland waterway 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 USACE. USACE currently works with Oak Ridge National Laboratory (ORNL) to model the fuel consumption, reported tonnages, and traffic mileage of marine freight transportation for the waterways for which USACE has jurisdictional responsibility. For 2019, ORNL calculated the fuel efficiency for movements on fuel-taxed waterways (almost the entirety of cargo movements) to be 675 ton-miles/gal.

The railroads are 30 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 17 and Figure 16 summarize the results of the fuel efficiency calculations on a national industry-wide basis.

Table 17. Fuel Efficiency by Mode.

Mode	Ton-Miles per Gallon
Inland towing	675
Railroad	472
Truck	151

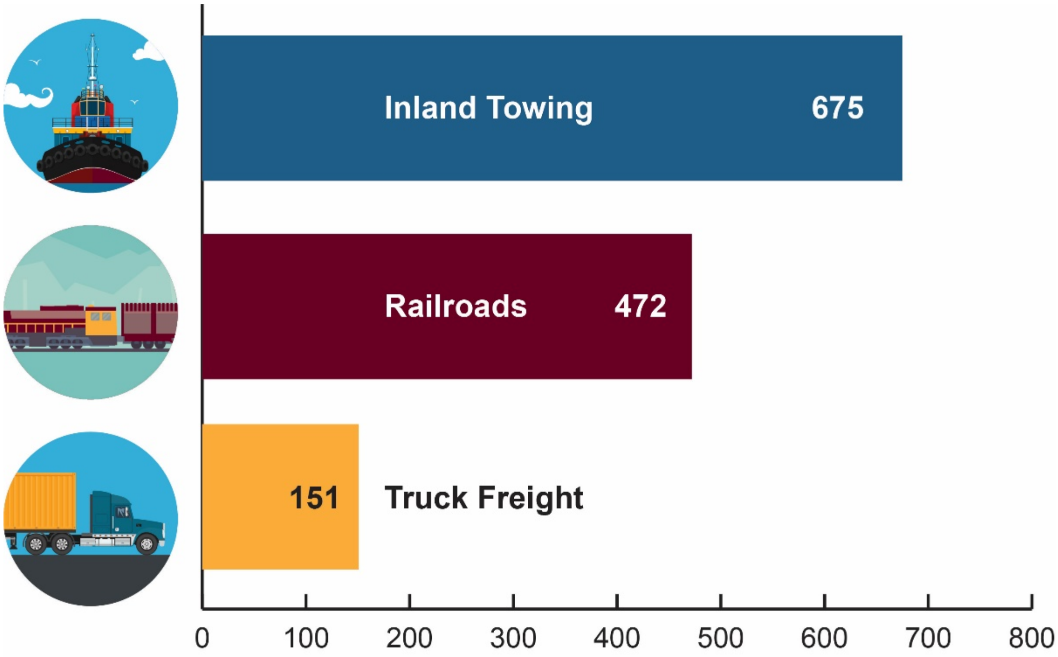

Figure 16. Comparison of Fuel Efficiency (2019).

6. 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.

Two elements of the highway mode analysis are only available through 2018: fatality/injury statistics and ton-miles of highway freight. The statistics presented in this chapter are for 2001–2019 for the inland waterway and rail modes, and through 2018 for the highway mode.

6.1. Fatalities and Injuries

Data for rail fatalities were obtained from Table 2-39: Railroad and Grade-Crossing Fatalities by Victim Class published in *National Transportation Statistics* (update March 31, 2021) (*6*). The data for injuries were obtained from Table 2-40: Railroad and Grade-Crossing Injured Persons by Victim Class published in *National Transportation Statistics* (*7*).

Data for truck-related incidents were obtained from *Large Truck and Bus Crash Facts 2018,* a publication of the Federal Motor Carrier Safety Administration (*8*).

Data for waterborne incidents were taken from the June 2020 version of the Marine Casualty and Pollution Database, 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 data set was reduced to only those incidents involving river barge traffic 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 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. 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 in the United States 2019: Part 5 National Summaries*, Table 2-2 (*11*).
- *AAR Railroad Facts*, 2020 edition (*52*).

- *National Transportation Statistics*, Table 1-50: U.S. Ton-Miles of Freight, Special Tabulation (highway data), as of March 2021 (*14*).

Table 18 and Figure 17 show the comparison of fatality rates. Figure 17 shows the ratio of rail to water and truck to water; it is simply each mode's rate per billion ton-miles divided by the inland waterway rate per billion ton-miles.

Table 18. Comparison of Fatalities by Mode.

Mode	Annual Ton-Miles* (Billion)	Total Fatalities	
		Annual Average*	Rate**
Highway	2,025.0	**4,498**	**2.2212** (12006%)
Railroad	1,675.3	**803**	**0.4793** (2591%)
Water	269.7	5	**0.0185**

**19-year average for railroad and water, and 18-year average for highway.*
***Per billion ton-miles.*

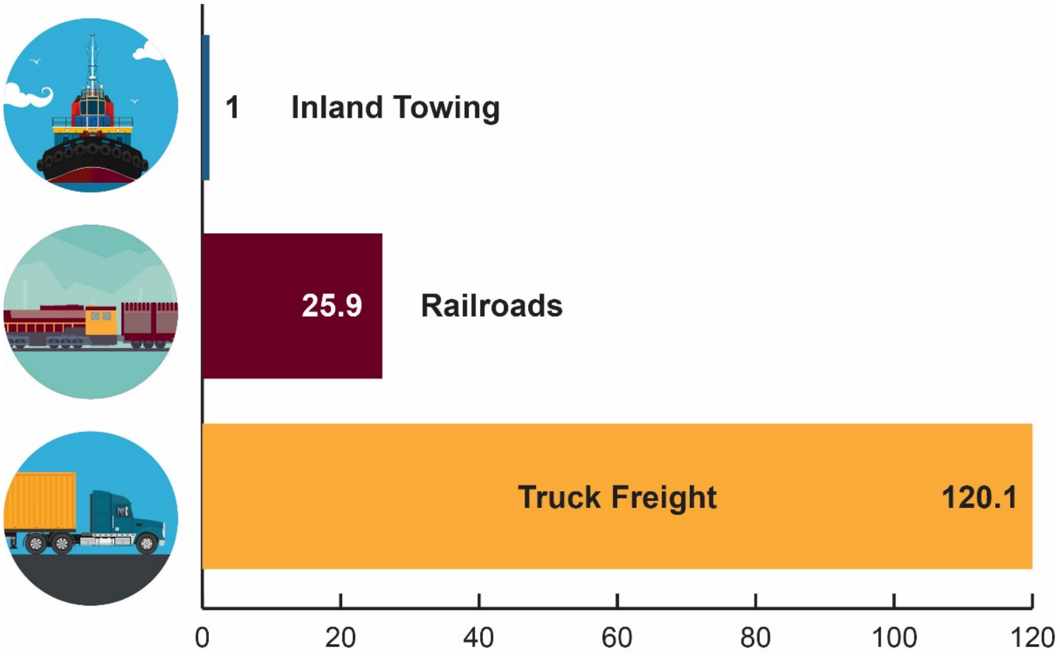

Figure 17. Ratio of Fatalities per Billion Ton-Miles versus Inland Marine (2001–2019).

Table 19 and Figure 18 show the ratio of rail to water and truck to water; it is simply each mode's injury rate per billion ton-miles divided by the inland waterway rate per billion ton-miles.

Table 19. Comparison of Injuries by Mode.

Mode	Annual Ton-Miles* (Billion)	Total Injuries	
		Total Annual*	Rate**
Highway	2,025.0	**111,722**	**55.1714** **(114463%)**
Railroad	1,675.3	**7,741**	**4.6207** **(9587%)**
Water	269.7	**13**	**0.0482**

**19-year average for railroad and water, and 18-year average for highway.*

***Per billion ton-miles.*

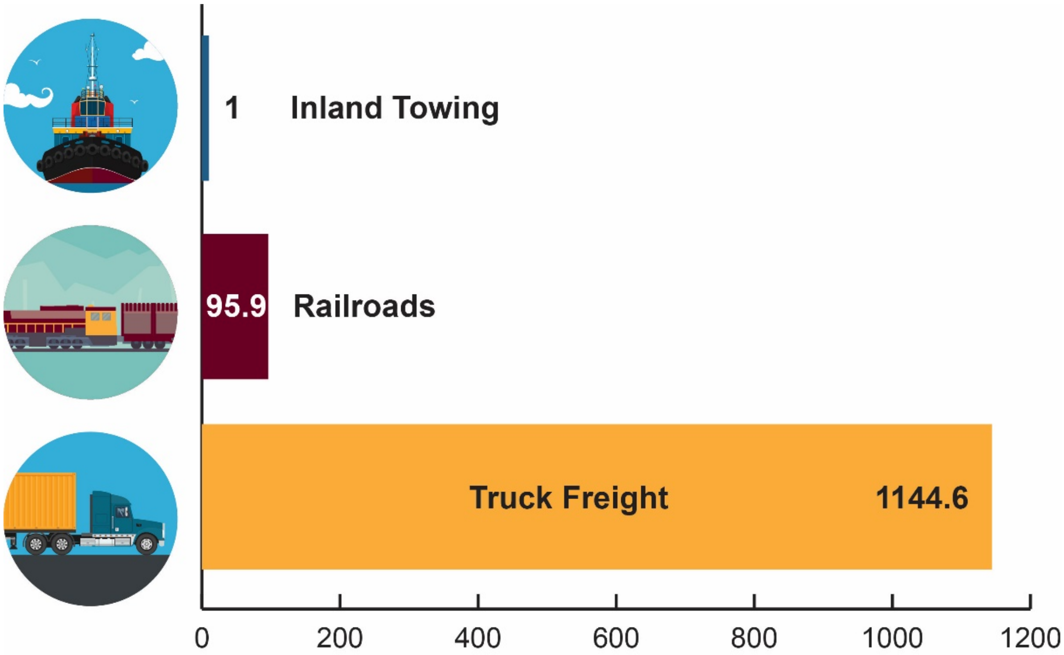

Figure 18. Ratio of Injuries per Billion Ton-Miles versus Inland Marine (2001–2019).

There are distinct differences in the trends for the modes. Figure 19 shows the trend in fatalities by mode. Figure 20 shows the trend in injuries by mode.

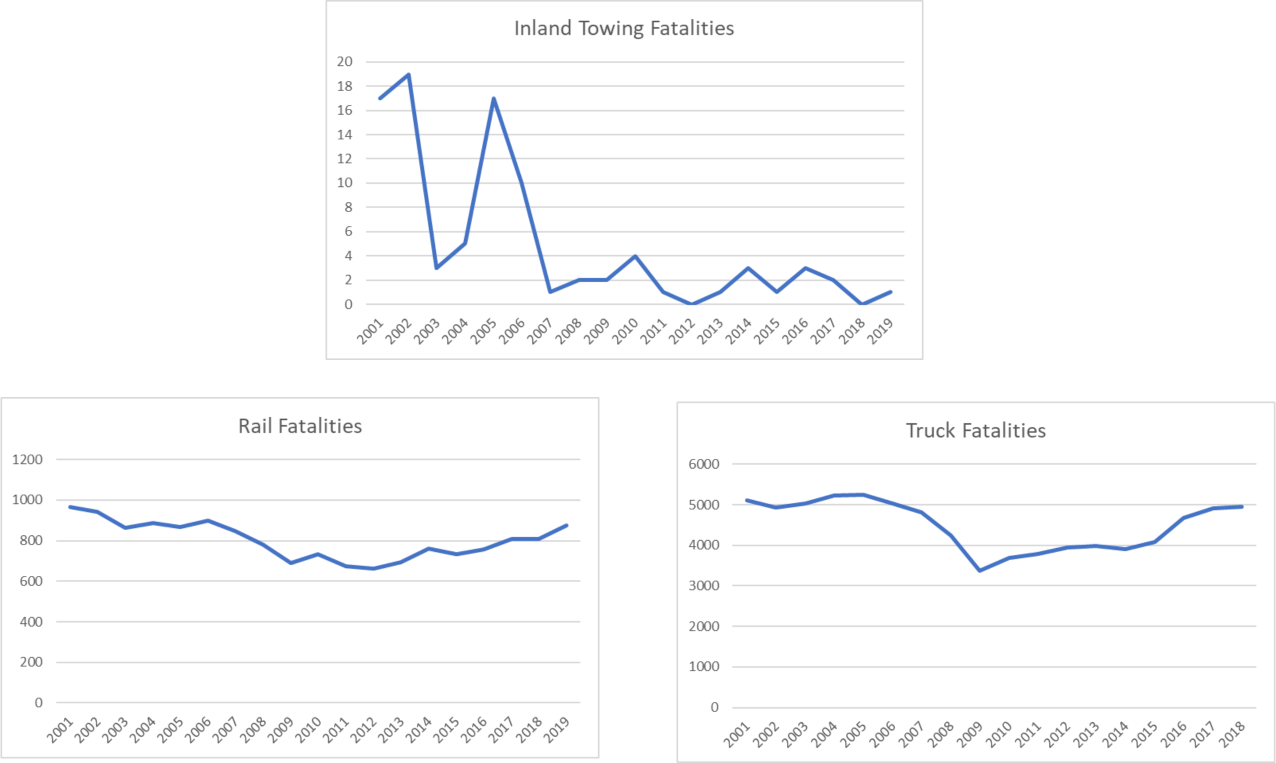

Figure 19. Trend in Fatalities by Mode.

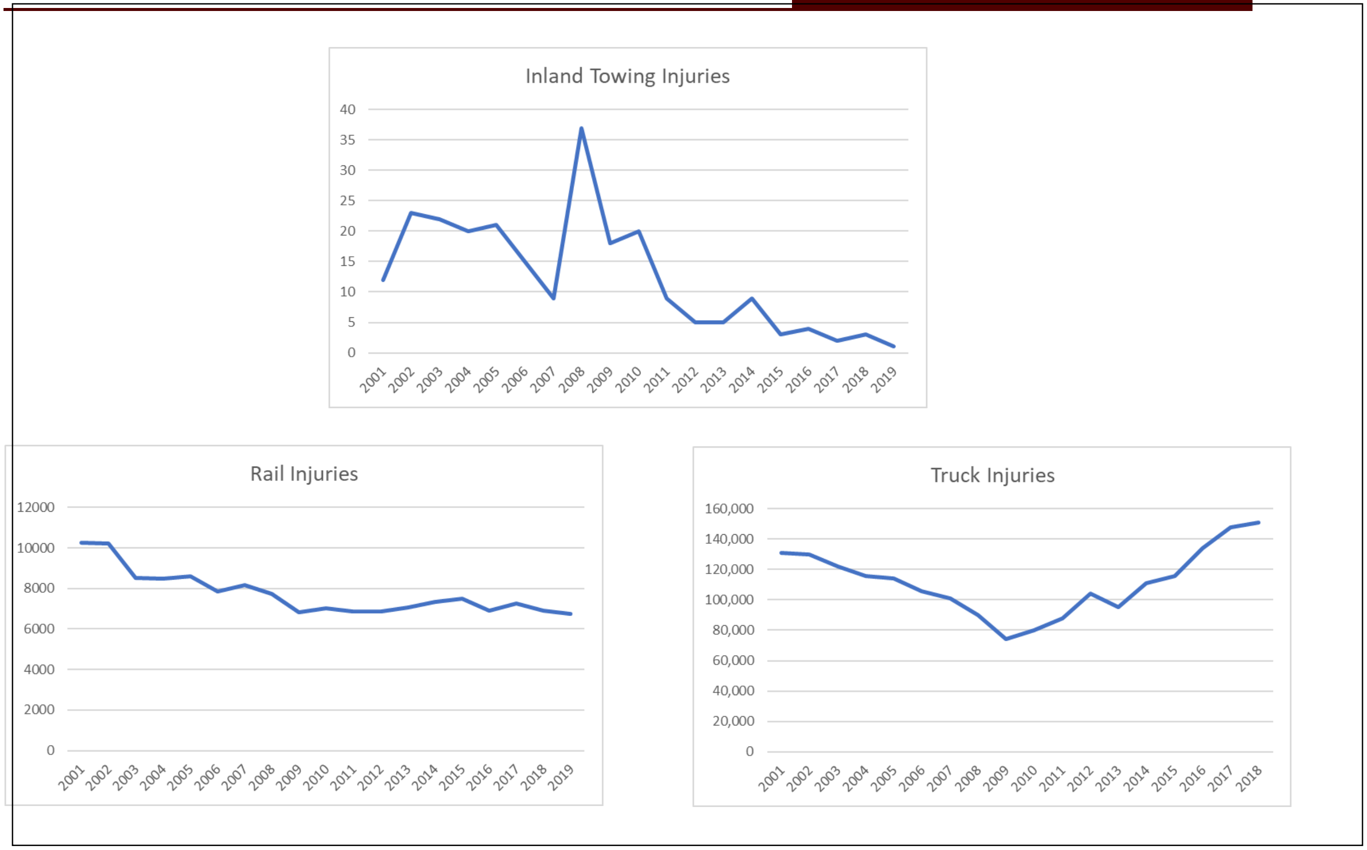

Figure 20. Trend in Injuries by Mode.

6.2. Hazardous Materials Incidents

Hazardous materials incidents are reported differently across the modes. Incidents for all three modes are contained in the Pipeline and Hazardous Materials Safety Administration's (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 on IWWS-related traffic from the U.S. Coast Guard.

The U.S. Coast Guard stores information on all incidents involving marine transportation, while USACE reports tonnage and ton-mile statistics. USACE 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 U.S. Coast Guard and USACE data are used for the waterborne activity.

The U.S. 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 2002–2019. The earlier system was known as the Marine Safety Information System. The current system is referred to as the Marine Information for Safety and Law Enforcement system. The U.S. 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 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 gal.

Table 20 and Figure 21 provide a comparison of spills across the modes.

Table 20. Comparison of Large Spills across Modes (2001–2019).

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	32	291,114	1,495	190	786,006	2,025,324
2002	7	32,459	293.6	29	245,183	1,507	152	623,534	2,189,937
2003	10	597,862	278.4	22	247,287	1,551	146	640,904	2,226,994
2004	11	237,155	284.2	33	379,992	1,663	169	729,419	2,249,260
2005	11	52,068	274.4	21	625,833	1,696	140	621,507	2,210,106
2006	8	236,700	279.9	38	671,544	1,772	144	551,273	2,154,885
2007	5	16,760	271.6	38	585,515	1,771	138	532,078	2,199,768
2008	4	289,757	260.9	19	216,248	1,777	119	505,043	1,843,146
2009	3	14,642	245.2	23	398,894	1,532	113	473,186	2,025,765
2010	6	439,985	263.3	21	306,181	1,691	134	693,163	1,806,337
2011	3	14,038	268.8	45	1,247,089	1,729	152	762,076	1,630,136
2012	7	16,030	268.5	39	532,595	1,713	163	680,848	1,822,154
2013	8	70,821	251.5	34	1,528,167	1,741	143	594,278	2,004,459
2014	5	50,340	281.1	24	245,398	1,851	146	590,450	1,956,805
2015	7	170,731	267.2	66	867,728	1,738	129	644,088	1,985,827
2016	5	48,154	261.4	14	155,724	1,585	118	434,824	2,060,780
2017	4	17,100	264.2	38	605,363	1,675	101	374,616	2,024,314
2018	5	40,089	270.2	25	311,598	1,730	115	431,062	2,033,921
2019	4	132,100	244.1	20	435,685	1,615			
Total	119	2,686,083	5,123.4	581	9,897,138	31,832	2,512	10,668,355	36,449,918
Average	6	141,373	269.7	31	520,902	1,675	140	592,686	2,024,995
Average annual hazmat ton-miles (millions)			60,486			78,700*			108,500*
Rate**	0.000099	2.337285		0.0003939	6.61883		0.001290	5.462544	
Ratio to water (inland)				3.98	2.83		13.03	2.34	

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 the incidents that actually occurred.

Truck ton-miles are not available for 2019, so 2019 hazmat statistics are not reported here.

**Estimate.*
***Spills: spills per million hazmat ton-miles. Amount: gallons per million hazmat ton-miles.*

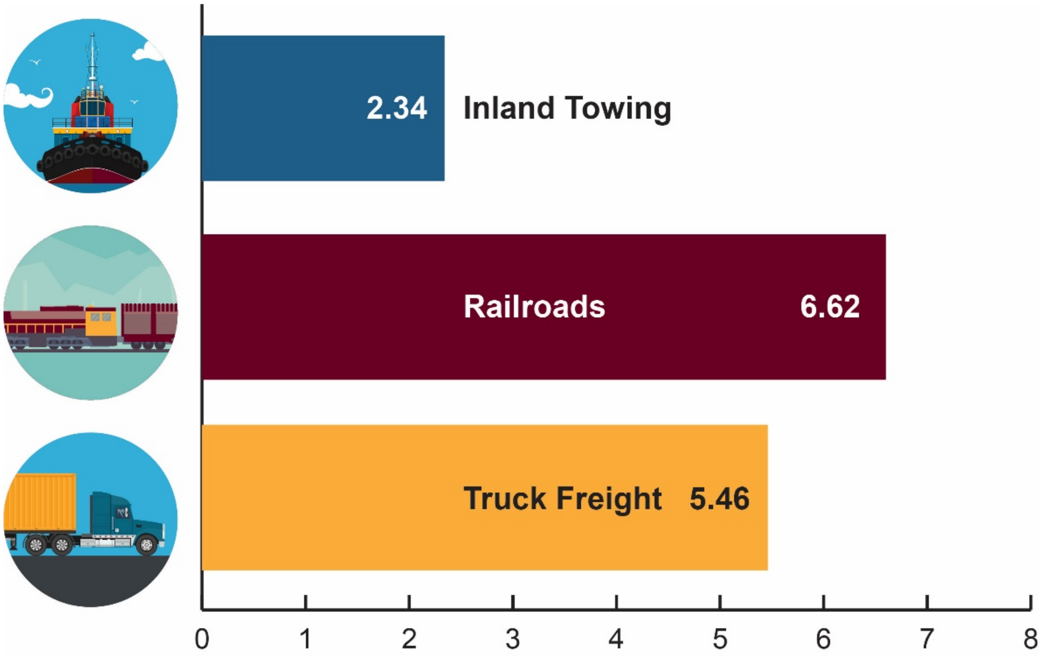

Figure 21. Gallons Spilled per Million Hazmat Ton-Miles (2001–2019).

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 truck and rail 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 or canal, is less likely to pose an immediate threat to human beings although it may have a detrimental effect on aquatic flora and fauna.

7. 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 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 use of waterborne transportation.

7.1. 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. New pavements, which are at full strength, have an 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 semi-tractor/trailer truck with a GVWR of 80,000 lb. Figure 22 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.

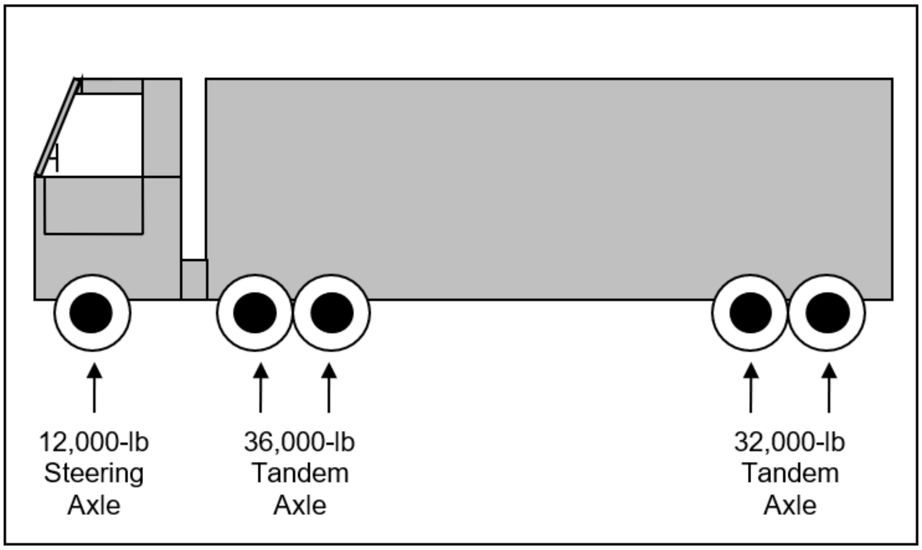

Figure 22. Semitrailer Configuration: The 18-Wheeler.

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:

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

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:

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

In 2018, there were 5,650 average daily vehicles per lane on rural interstates. Inferred data from *Highway Statistics 2018* (*22*) indicate that in that year on rural interstates, 17 percent of the traffic—or 960 vehicles—were combination trucks, or 18-wheelers. Assuming that no waterborne freight diversion will occur, the annual ESAL would be:

$$ESAL_{Annual} = 2.44 \times 960 \times 365 = 0.85\, million$$

The analysis for congestion impacts estimates that a diversion of waterborne freight to the highway mode would result in 1,827 combination trucks per day per lane of a typical rural interstate, so the annual ESAL would increase:

$$ESAL_{Annual} = 2.44 \times 1{,}827 \times 365 = 1.63\, million$$

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 must be included. The Federal Highway Administration's (FHWA) *Forecasts of Vehicle Miles Traveled (VMT): Spring 2021* (*53)*, projects that truck traffic will increase between 1.7 and 1.9 percent each year for 2019 to 2039. A two percent growth factor is widely used by traffic analysts. Given that the FHWA projections are so close to the 2 percent mark, the research team opted to use 2 percent as the growth factor for this analysis. 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:

$$\begin{aligned} ESAL_{Expected} &= ESAL_{Annual} \times \frac{(1+g)^N - 1}{g} = 0.85\, million \times \frac{(1+.02)^{20} - 1}{0.02} \\ &= 20.7\, million \end{aligned}$$

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

$$ESAL_{Expected} = ESAL_{Annual} \times \frac{(1+g)^N - 1}{g} = 1.63\, million \times \frac{(1+.02)^{20} - 1}{0.02}$$
$$= 39.5\, million$$

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 approximately 191 percent of the ESAL expected under current conditions.

The AASHTO guidelines for pavement design (*54*) were then followed to determine the pavement thickness required to accommodate the ESAL expected over the pavement's lifetime, assuming that current conditions continue and 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 a 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 5.1, 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:

$$d = \frac{SN}{a} \qquad \text{Here, } d = \frac{SN}{a} = \frac{5.1}{0.41} = 12.4\, inches$$

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

1.2 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 5.1 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 12.4 inches so that it is strong enough to last for the next 20 years.

Assuming an even truck traffic distribution, a minimum 2-inch thickness of asphalt layer would have to be added to the pavement of 119,885 lane-miles of rural interstate given the higher levels of expected 20-year truck loadings.

In the field, the additional 1.2 inches of asphalt layer calculated 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-inch thickness of asphalt layer would have to be added to the pavement of 119,885 lane-miles of rural interstate (*55*) 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 119,885 lane-miles. In addition, over 8 million lane-miles are classified under other functional highway systems nationally.

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.

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.

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 infrastructure, which would be used more heavily, would likely be significantly higher.

7.2. Effect on Railroad and Roadway Systems

The shift of the inland waterway 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 Chapters 2 and 3 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.

Agricultural shipments on the upper Mississippi River provide a good example of how important the waterways are to the nation’s economy. Agricultural grains including corn, oilseed, rice, soybeans, and wheat are currently moved on the Mississippi River by barge. If the Mississippi River were to be closed for any reason and the railroads were tasked with transporting the grain that would have moved by river, the initial outcome would be supply chain delays and interruptions, leading to possible crops deteriorating in the fields or silos, increased costs of transportation, increased costs due to expansion of facilities necessary for truck and rail transport, and increased final cost to consumers. The following analysis models the increased transportation costs that would occur if all tonnage were transferred to truck or rail.

The Mississippi River grain commodities that are transported by barge are principally destined for export through the Gulf of Mexico. Table 21 details the current baseline barge scenario for grain movements downriver along the Mississippi River.[9]

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[9] Appendix C provides assumptions and default values for each scenario. Appendix D provides a description of the estimate of towboat operating costs.

"Thru" traffic is traffic that originates outside the listed segment and travels the entire length of that segment. "Out" or outbound traffic is traffic that originates somewhere within the segment and travels downriver. Since the exact origin is not known, the analysis assumes that on average, the outbound traffic originates at the midpoint of the segment. "In" or inbound traffic is traffic that originates upriver from Baton Rouge, Louisiana, and terminates in New Orleans, Louisiana. For example, grain entering the Mississippi River just south of Minneapolis, Minnesota, would be counted as "out" traffic from Minneapolis to the mouth of the Missouri River, "Thru" traffic for the Mississippi River from the mouth of the Missouri River to mouth of the Ohio River and from the mouth of the Ohio River to Baton Rouge segments, and finally "in" traffic for the Baton Rouge to New Orleans segment. The Baton Rouge to New Orleans segment only has an inbound component because no grain is originating along that segment, and none is passing through New Orleans but rather terminating within the segment.

Table 21. Baseline Barge Scenario.

Type	Segment	Waterway Miles	Tons (*3*)	Trips
Thru	Minneapolis to Missouri River	677	10,174,143	388
Out	Minneapolis to Missouri River	339	12,265,844	467
Thru	Missouri River to Ohio River	176	22,894,513	654
Out	Missouri River to Ohio River	88	11,800,602	337
Thru	Ohio River to Baton Rouge	725	50,205,090	717
Out	Ohio River to Baton Rouge	363	13,117,280	187
In	Baton Rouge to New Orleans	134	63,349,548	905

In the event of a closure, the capacity requirements for railroad car loadings and long-haul trucking could not be immediately met due to the equipment that would be needed to meet the initial demand for the increased transportation. The first impact would be the need to provide railcars and trucks for the grain products. Table 22 and Table 23 detail the rail and roadway scenarios including the mileage, number of trips, and number of railcars and trucks that would be needed to shift all the grain commodities to either rail or truck.

Table 22. Rail Scenario.

Type	Segment	Rail Miles	Train Trips	Carloads
Thru	Minneapolis to Missouri River	600	841	92,492
Out	Minneapolis to Missouri River	300	1,014	111,508
Thru	Missouri River to Ohio River	182	1,892	208,132
Out	Missouri River to Ohio River	91	975	107,278
Thru	Ohio River to Baton Rouge	766	4,149	456,410
Out	Ohio River to Baton Rouge	383	1,084	119,248
In	Baton Rouge to New Orleans	98	5,235	575,905

Table 23. Roadway Scenario.

Type	Segment	Roadway Miles	Truck Trips/Trucks Needed
Thru	Minneapolis to Missouri River	547	406,966
Out	Minneapolis to Missouri River	274	490,634
Thru	Missouri River to Ohio River	118	915,781
Out	Missouri River to Ohio River	59	472,024
Thru	Ohio River to Baton Rouge	477	2,008,204
Out	Ohio River to Baton Rouge	239	524,691
In	Baton Rouge to New Orleans	83	2,533,982

To determine the difference in transportation costs between the three modes, the VMT and vehicle hours traveled (VHT) were first calculated for each segment. The VMT was determined based on the tonnage and trips calculated, while the VHT incorporated default speed values for each mode. For the baseline scenario, both barge and towboat miles and hours were calculated in Table 24. This scenario assumes 15 barges per flotilla north of the Missouri River, 20 barges per flotilla from the Missouri River to the Ohio River, and 40 barges per flotilla for the remainder along with 1 towboat per flotilla regardless of the river segment.

Table 24. Baseline Scenario VMT and VHT.

Type	Segment	Barge VMT	Towboat VMT	Barge VHT	Towboat VHT
Thru	Minneapolis to Missouri River	3,935,940	262,396	795,139	53,009
Out	Minneapolis to Missouri River	2,372,565	158,171	479,306	31,954
Thru	Missouri River to Ohio River	2,302,534	115,127	465,158	23,258
Out	Missouri River to Ohio River	593,402	29,670	119,879	5,994
Thru	Ohio River to Baton Rouge	20,799,252	519,981	4,201,869	105,047
Out	Ohio River to Baton Rouge	2,717,151	67,929	548,919	13,723
In	Baton Rouge to New Orleans	4,850,765	121,269	979,953	24,499
	Total	**37,571,608**	**1,274,543**	**7,590,224**	**257,483**

Table 25 provides the VMT and VHT for both rail and trucks. The rail scenario assumes 110 tons per railcar and unit trains of 110 cars. This results in the movement of 12,100 tons per unit train. The truck scenario assumes an average of 25 tons per truck. It takes 484 trucks to move the same tonnage as one unit train. Due to the large number of trucks needed, 1.8 billion miles of travel are needed to move the same commodities that move 5.3 million unit train miles, or 1.3 million flotilla miles.

Table 25. Rail and Truck VMT and VHT.

Type	Segment	Rail VMT	Truck VMT	Rail VHT	Truck VHT
Thru	Minneapolis to Missouri River	504,503	222,610,249	19,539	4,452,205
Out	Minneapolis to Missouri River	304,112	134,188,333	11,778	2,683,767
Thru	Missouri River to Ohio River	344,364	108,062,101	13,337	2,161,242
Out	Missouri River to Ohio River	88,748	27,849,421	3,437	556,988
Thru	Ohio River to Baton Rouge	3,178,273	957,913,117	123,093	19,158,262
Out	Ohio River to Baton Rouge	415,200	125,138,851	16,081	2,502,777
In	Baton Rouge to New Orleans	513,079	210,320,499	19,871	4,206,410
	Total	**5,348,278**	**1,786,082,572**	**207,137**	**35,721,651**

Using the VMT and VHT, the total transportation costs were determined in Table 26. Operating costs include crew time costs, fuel, and other vehicle operating costs. Safety costs vary greatly between the different modes. The fatality rate per 100 million VMT for trucks is 1.62 but only 0.01 for rail and 0.0005 for barges. This is further amplified by the greater number of miles traveled by trucks.

Table 26. Scenario Transportation Costs.

Cost Type	Barge Transportation Costs	Rail Transportation Costs	Truck Transportation Costs
Operating	$228,734,511	$2,174,317,500	$3,035,663,090
Safety	$69	$5,830	$315,386,461
Emissions	$192,714	$225,479,507	$391,985,461
Total	**$228,927,294**	**$2,399,802,836**	**$3,743,034,918**
Increased cost		**$2,170,875,542**	**$3,514,107,624**

Moving the grain commodity tonnage shown in Table 21 along the Mississippi River by barge costs $228 million. Moving the same tonnage of grain by rail would cost an additional $2.2 billion and an additional $3.5 billion by truck in transportation costs alone. <u>This does not account for the limited capacity of railroads or highways nor the additional costs resulting from increased congestion and delay that would result to other shippers and drivers</u>. An increase in rail or truck demand of this magnitude would also likely substantially increase the existing per-unit operating costs because <u>additional trucks, trains, and crew would need to be found.</u> Because of this, this model represents a conservative estimate of the costs because it does not account for price increases due to an increase in demand for truck and rail transportation.

Many regulatory issues, operating concerns, and constraints for both rail and trucks 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 24 hours. Additionally, truck drivers are limited in the number of continuous hours they can be on duty as well as the timing and scheduling of breaks required by law. There are multiple factors that are considered when calculating the hours of service requirements including speed of travel, number of hours on duty, and contiguous days of travel. Due to these constantly shifting variables, the truck scenario does not include these additional hours required to meet legal operating conditions. The exclusion of these elements makes for a more conservative estimate.

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

- Increased demand for railcars, locomotives, and trucks.
- Higher freight rates.
- The need to expand infrastructure (rail lines, roadway network, and intermodal facilities).
- Potentially slower and less reliable delivery times.
- Increased motor vehicle congestion at rail crossings and along roadways both state and federally maintained.
- Increased noise abatement issues.
- The potential for unused and expired crops/commodities due to delay.

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9. 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.

Table 27. Summary of Emissions—Grams per Ton-Mile (2005, 2009, 2014, and 2019).

Mode	Emissions (Grams/Ton-Mile)											
	HC/VOC				CO				NO$_x$			
	2005	2009	2014	2019	2005	2009	2014	2019	2005	2009	2014	2019
Inland towing	0.01737	0.014123	0.0094	0.0058	0.04621	0.0432	0.0411	0.0394	0.46907	0.27435	0.2087	0.1526
Railroad	0.02421	0.018201	0.0128	0.0083	0.06440	0.0556	0.0558	0.0564	0.65368	0.35356	0.2830	0.2182
Truck	0.12	0.10	0.08	0.02	0.46	0.37	0.27	0.19	1.90	1.45	0.94	0.45

Mode	Emissions (Grams/Ton-Mile)							
	PM				CO$_2$			
	2005	2009	2014	2019	2005	2009	2014	2019
Inland towing	0.01164	0.007955	0.0056	0.0037	17.48	16.41	15.62	15.08
Railroad	0.01623	0.010251	0.0075	0.0053	24.39	21.14	21.19	21.57
Truck	0.08	0.06	0.05	0.02	171.87	171.83	154.08	140.70

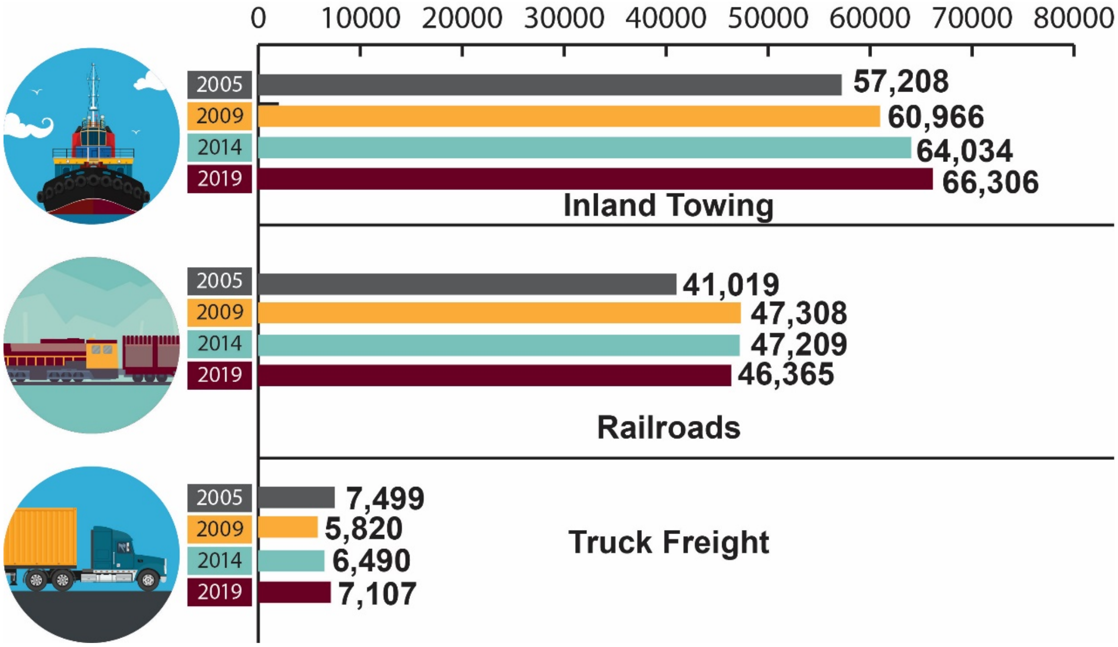

Figure 23. Ton-Miles per Ton of GHG (2001–2005, 2009, 2014, and 2019).

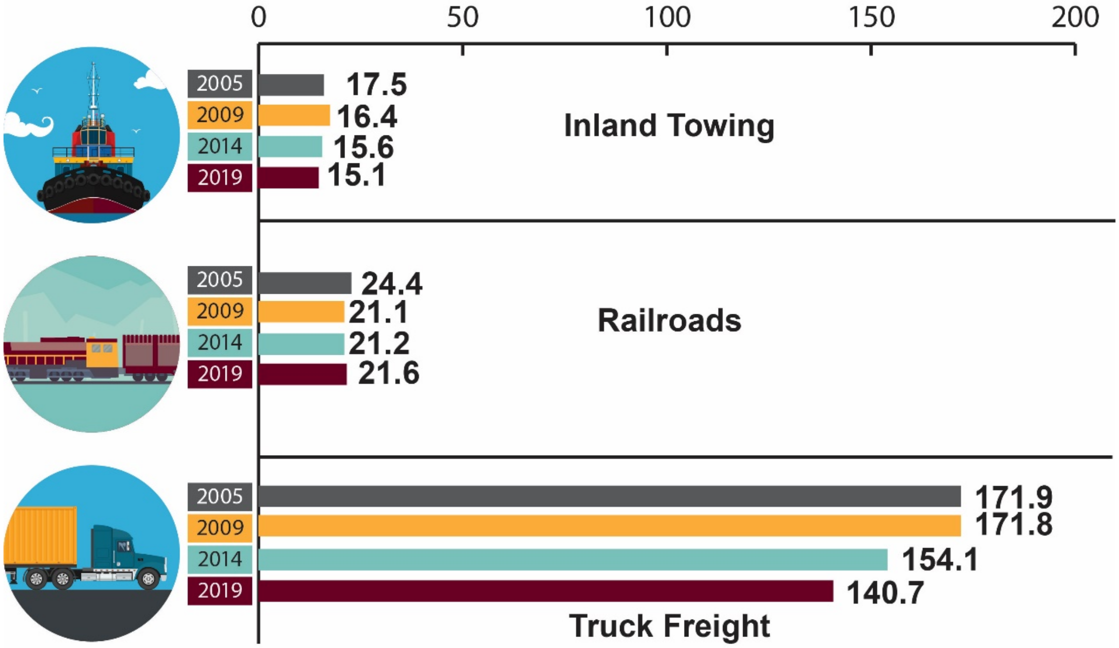

Figure 24. Tons of GHG per Million Ton-Miles (2001–2005, 2009, 2014, and 2019).

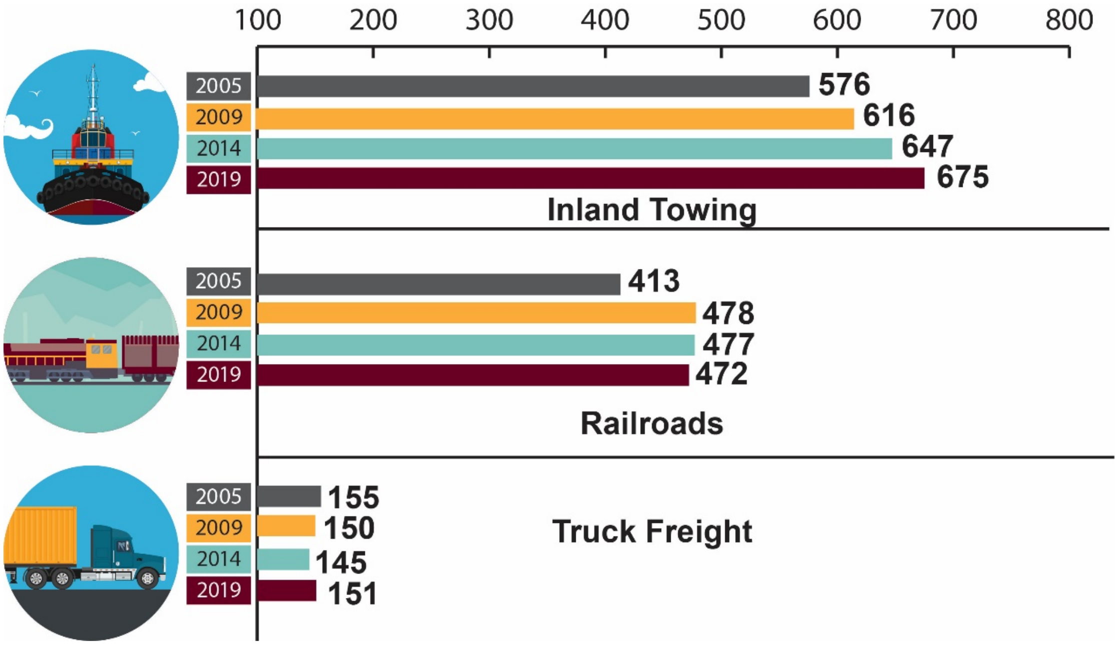

Figure 25. Comparison of Fuel Efficiency (2005, 2009, 2014, and 2019).

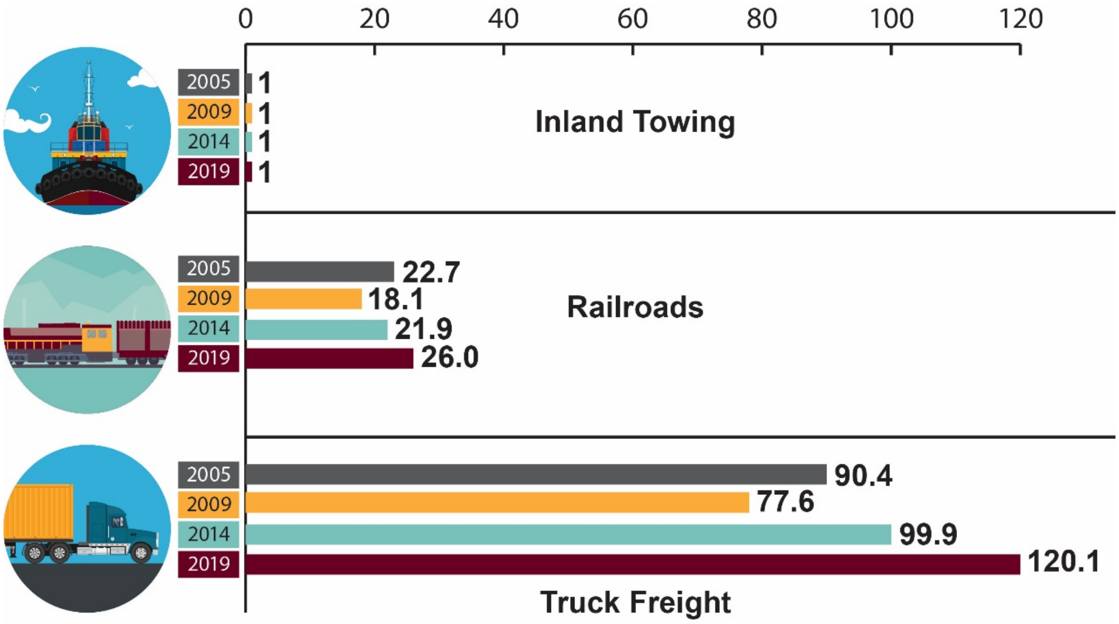

Figure 26. Ratio of Fatalities per Billion Ton-Miles versus Inland Towing (2001–2005, 2009, 2014, and 2019).

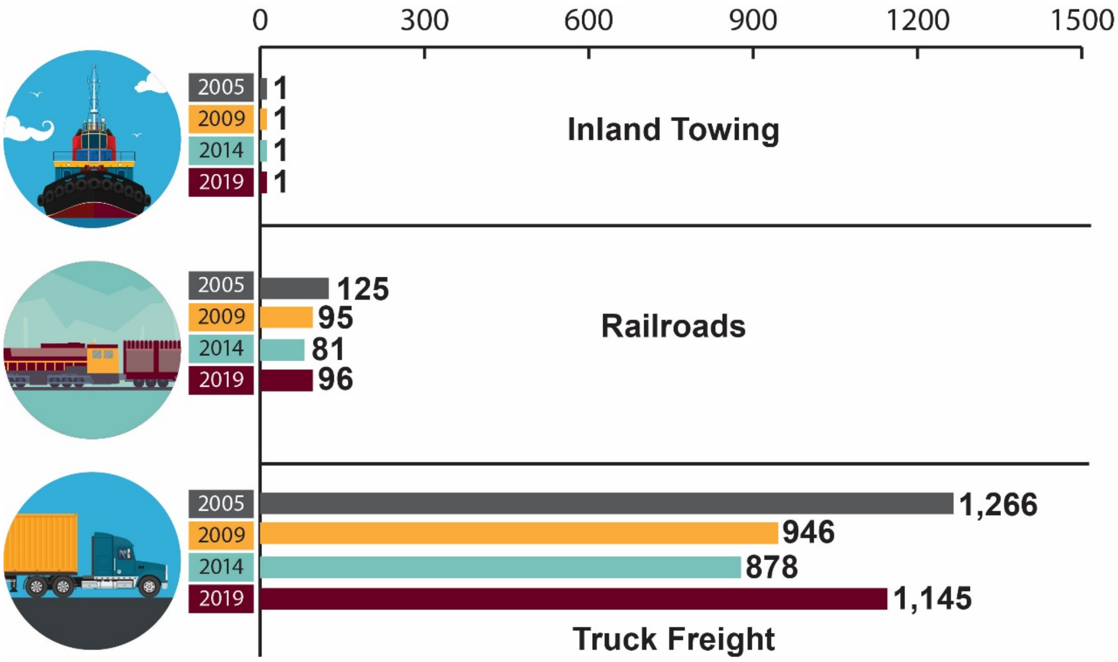

Figure 27. Ratio of Injuries per Million Ton-Miles versus Inland Towing (2001–2005, 2009, 2014, and 2019).

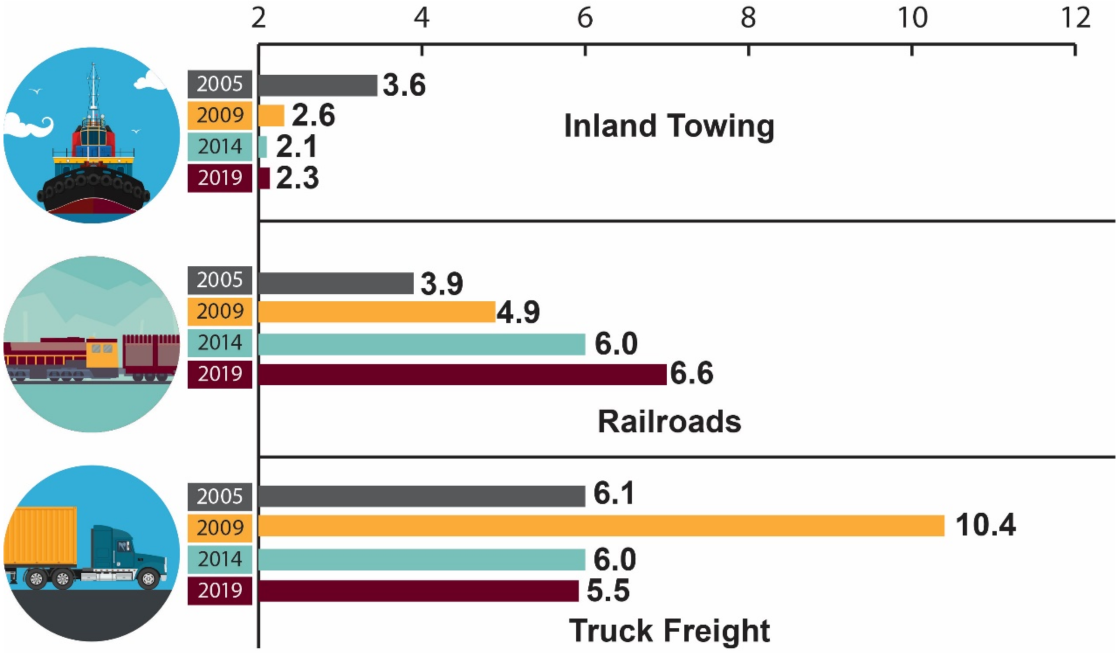

Figure 28. Gallons Spilled per Million Hazmat Ton-Miles (2001–2005, 2009, 2014, and 2019).

10. 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, July 26, 2017.*

BTS has revised the methodology for calculating freight ton-miles across modes.[10] 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 FAF.[11] FAF uses the Commodity Flow Survey (CFS)[12] as the basis for estimating total freight ton-miles. FAF 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. This study uses the total freight ton-mile estimates and the pipeline ton-mile estimates from FAF3 as the basis for the 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 were based on miles traveled by trucks on intercity highways and the average payloads of those trucks. New estimates are based on FAF3, which provides a more direct and complete measure of ton-miles. The residual of total ton-miles (TM) 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.

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[10] 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.

[11] Information on FAF3 is available at http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm.

[12] Information on the CFS is available at https://www.census.gov/programs-surveys/cfs.html .

In equation form:

$$\text{Truck TM} = \text{Total TM} - \text{Air TM} - \text{Railroad TM} - \text{Waterway TM} - \text{Pipeline TM}$$

For years before 1997, the trend in truck 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.

Comparison of Previous Ton-Miles Estimates with New Estimates

Figure 29 shows the estimates for total ton-miles and truck ton-miles using the previous methodology and the new methodology.

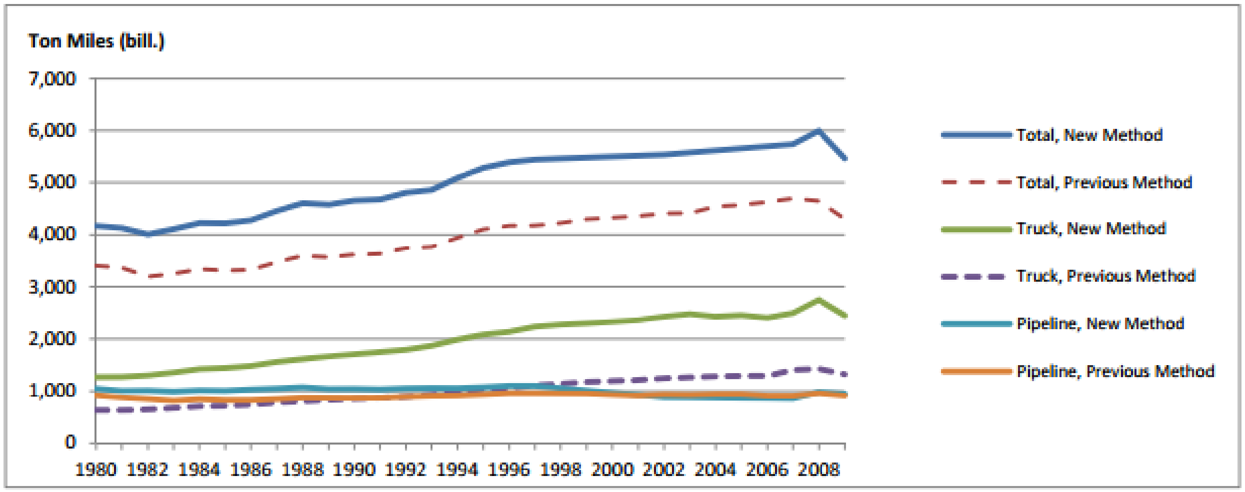

Figure 29. Total Ton-Miles and Truck Ton-Miles with Previous Methodology and New Methodology

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.

11. APPENDIX C: DEFAULT VALUES FOR CLOSURE SCENARIO

Table 28. Truck Default Values.

Factor/Assumption	Value	Source/Notes	Link
Crew cost factor ($/hr per crew member)	$30.80	USDOT benefit-cost analysis (BCA) guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf
Vehicle operating cost ($/hr)	$24.11	American Transportation Research Institute hourly cost value less fuel costs, driver wages, and driver benefits 2017 (2018 publication)	http://atri-online.org/wp-content/uploads/2017/10/ATRI-Operational-Costs-of-Trucking-2017-10-2017.pdf
Truck gallons per hour	9.84	Assumes average speed of 50 mph	
Truck $ per gallon	$3.056	U.S. Energy Information Administration, 2019	https://www.eia.gov/dnav/pet/pet_pri_gnd_a_epd2d_pte_dpgal_a.htm
$/hr fuel	$30.07	Calculated using listed assumptions	
Crew per vehicle	1.00	USDOT BCA guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf
Freight U.S. tons per vehicle	25.0	TREDIS Vehicle Inventory and Use System, 2002	
Fatality rate per 100 million annual VMT (large truck)	1.62	(Per 100 million VMT). National Highway Transportation Safety Administration, page 7	https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/2020-09/LTBCF%202018-v5_FINAL-09-15-2020.pdf
Fatal injury cost	$10,900,000	USDOT BCA guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf

Table 29. Emission Default Values.

Factor/Assumption	Value	Source/Notes	Link
Truck VOC rate (tons/VMT)	0.00000048	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Truck NO_x rate (tons/VMT)	0.00000584	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Truck sulfur oxide (SO_x) rate (tons/VMT)	0.00000002	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Truck PM rate (tons/VMT)	0.00000017	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Rail VOC rate (tons/VMT)	0.00005230	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Rail NO_x rate (tons/VMT)	0.00108515	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Rail SO_x rate (tons/VMT)	0.00000079	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Rail PM rate	0.00003425	TREDIS—Using MOVES3. Emission rates were aggregated, and the final rates represent a 5-year average.	
Marine VOC (tons/VHT)	—	EPA	https://archive.epa.gov/sectors/web/pdf/ports-emission-inv-april09.pdf
Marine NO_x (tons/VHT)	0.000014	EPA	https://archive.epa.gov/sectors/web/pdf/ports-emission-inv-april09.pdf
Marine SO_x (tons/VHT)	0.00000424	EPA	https://archive.epa.gov/sectors/web/pdf/ports-emission-inv-april09.pdf
Marine PM (tons/VHT)	0.00000049	EPA	https://archive.epa.gov/sectors/web/pdf/ports-emission-inv-april09.pdf
VOC	$2,138	USDOT BCA guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf

Factor/Assumption	Value	Source/Notes	Link
NO_x	$15,700	USDOT BCA guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf
SO_x	$40,400	USDOT BCA guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf
PM	$729,300	USDOT BCA guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf
CO_2	$50	USDOT BCA guidance, December 2021	https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf
Truck cost per mile	$0.22	Calculated using listed assumptions	
Rail cost per mile	$42.2	Calculated using listed assumptions	
Marine cost per hour	$0.75	Calculated using listed assumptions	

Table 30. Barge Default Values.

Factor/Assumption	Value	Source/Notes	Link
Barges per trip north of St. Louis	15	TTI	
Barges per trip St. Louis to Cairo Port	20	TTI	
Barges per Trip south of Cairo	40	TTI	
Towboat fuel cost per hour	$432.12	See Appendix D.	
Towboat other cost per hour	$247.34	See Appendix D.	
Tanker barge cost per hour	$39.21	See Appendix D.	
Dry barge cost per hour	$7.09	See Appendix D.	
Tons per barge	1,750	Soybean's Journey, p. 337	
Barge speed (mph)	4.95		
Cost per ton mile	$0.003		
Fatality rate per 100 million annual VMT (barge)	0.0005	TTI	
Marine—crew time cost ($/hr per crew member)	$41.76	TREDIS—based on Bureau of Labor Statistics National Occupational Employment and Wage Estimates, 2019	https://500.tredis.net/user_resources/TREDIS%20500%20Data%20Sources%20and%20Default%20Values.pdf
Tons per trip north of St. Louis	26,250	Calculated using listed assumptions	
Tons per trip St. Louis to Cairo	35,000	Calculated using listed assumptions	
Tons per trip Cairo to New Orleans	70,000	Calculated using listed assumptions	

Table 31. Rail Default Values.

Factor/Assumption	Value	Source/Notes	Link
Tons per railcar	110	Soy Transportation Coalition	https://www.soytransportation.org/Stats/Railroad_Capacity.pdf
Railcars per train	110	Soy Transportation Coalition	https://www.soytransportation.org/Stats/Railroad_Capacity.pdf
Average speed (mph)	25.82	USDA, Agriculture Marketing Services	https://www.ams.usda.gov/sites/default/files/media/RTIReportChapter9.pdf
Operating cost per hour < 500 miles	$37,672	Aggregated and calculated using STB waybill samples	
Operating cost per hour ≥ 500 miles	$10,497	Aggregated and calculated using STB waybill samples	
Fatality rate per 100 million annual VMT (rail)	0.01	USDOT BTS	https://www.bts.gov/archive/publications/transportation_statistics_annual_report/2001/chapter_06_figure_01_174

12. APPENDIX D: TOWBOAT OPERATING COST ESTIMATION

This estimation of towboat operating costs relies on information from federal agencies, including USACE, Bureau of Labor Statistics, and Energy Information Administration. Informal conversations with barge operators indicate that this estimate may be higher than actual operating costs. However, researchers do not have access to cost information from private carriers. Therefore, the research team decided to use the estimate developed in this appendix, given that it represents a conservative approach to the estimated benefits of waterborne transportation.

The operating costs that USACE reported in Economic Guidance Memorandum (EGM) 05-06 were inflated from 2003 costs, using the Inland Waterways Towing Transportation Producer Price Index to reflect 2017 dollars. This caused a 45.6 percent increase to the costs provided in the memorandum (or 1.456 times the stated costs). This was further updated to 2019 using the Producer Price Index for Inland Waterways Transportation of Freight because the Towing Index was discontinued after 2017. This resulted in an 8.2 percent increase in prices since 2017. Fuel prices were inflated from 2003 to 2019 using the EIA US Average No 2 Diesel price.[13] The Inland Waterways Fuel Tax of $0.29 was also included in the 2019 fuel price, bringing the 2019 price to $3.346 a gallon. This is an increase of 2.87 times the 2003 price of $1.166 used in the USACE economic guidance.

USACE contracted with the Tennessee Valley Authority and Chris Dager to analyze several aspects of fuel usage and towboat characteristics on inland waterways from as far back as 1997. Up through 2008, part of that analysis included a calculation of average towboat size per river segment, measured in horsepower (HP). For the Illinois River, the average ranged between 2410 HP and 2964 HP. The average over the entire time period was 2749 HP. The ranges included in the Economic Guidance Memorandum 05-06, Shallow Draft Vessels Operating Costs, Fiscal Year 2004[14] were 2200–2400 HP and 2800–3400 HP; therefore, the towboat horsepower used for this analysis is the 2800–3400 HP category.

For tank barges, the 297.5-ft by 54-ft barge without coils was used. For dry cargo barges, the 195-ft by 35-ft covered hopper barge was used.

Towboat costs in 2019 dollars were:

- Non-fuel daily cost: ($7,383.13 − $3,614.60) × 1.456 × 1.082 = $5,931.4.
- Daily fuel cost: $3,614.60 × 2.87 = $10,370.88.

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[13] https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm

[14] https://planning.erdc.dren.mil/TOOLBOX/library/EGMs/egm05-06.pdf

- Cost per day: $5,931.4 + $10,370.88 = $16302.28.
- Cost per hour = $679.26.

This hourly rate is consistent with costs reported by USACE for Ohio River towboats as of 2010. USACE calculated these costs for six locks downriver from Pennsylvania. The costs ranged from $554/hr to $602/hr.[15,16]

Tank barge costs in 2019 dollars were:

- EGM daily cost: $597.34.
- Adjusted daily cost: $597.34 × 1.456 × 1.082 = $941.04.
- Adjusted hourly cost: $39.21.

The dry barge costs in 2019 dollars were:

- EGM daily cost: $107.98.
- Adjusted daily cost: $107.98 × 1.456 × 1.082 = $170.11.
- Adjusted hourly cost: $7.088.

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[15] This was calculated from information presented in "Ohio River Navigation: Economic Impacts and Engineering Reliability" at the KSPE Annual Convention in Covington, Kentucky, April 29, 2011.

[16] Hammond, M., *Ohio River Navigation: Economic Impacts and Engineering Reliability,* PowerPoint slides, 2011, https://cdn.ymaws.com/www.kyengcenter.org/resource/resmgr/imported/OhioRiverFreightTraffic-EconomicImpactsandEngineeringReliability.pdf.

13. APPENDIX E: MOVES3 TRUCK EMISSIONS TRENDS

This appendix provides more details on truck emission information extracted from the MOVES model and used in this study. As the latest version of EPA's MOVES family, MOVES3, which was released in late 2020, contains the latest pollutant emission rates and vehicle activity information based on the latest available data and the existing emission regulations. It is therefore expected that the emission rates from MOVES3 will be different from the previous versions of the model. The remainder of this appendix provides more details about the changes in the heavy-duty trucks' emissions characteristics resulting from having a newer and cleaner long-haul truck fleet on the road.

The study team extracted national-level emission rates for long-haul trucks for a few years of interest from MOVES3 and MOVES2014a, using the same assumptions and methodology described in Chapter 4. All the input parameters are the same between the two versions of the model. The grams per VMT and grams per ton-mile results are summarized in Table 32 and Table 33. These results show that MOVES3 results for all the modeled pollutants are lower than MOVES2014a results.

Table 32. Result of MOVES3 for Heavy-Duty Long-Haul Trucks.

Unit	Year	HC	NO_x	PM_{10}	CO	CO_2
g/VMT	2005	1.0174	22.2057	1.0847	4.8699	1874.0201
	2009	0.8074	16.2790	0.7974	3.6737	1871.9445
	2014	0.4939	9.5433	0.4461	2.9586	1860.6377
	2015	0.4291	8.3937	0.3860	2.7843	1838.8989
	2016	0.3741	7.4246	0.3344	2.6561	1822.6834
	2017	0.3399	6.8207	0.3027	2.5579	1802.7673
	2018	0.3050	6.1682	0.2690	2.4551	1780.6380
	2019	0.2761	5.6090	0.2421	2.3721	1758.7787
g/ton-mile	2005	0.0814	1.7765	0.0868	0.3896	149.9216
	2009	0.0646	1.3023	0.0638	0.2939	149.7556
	2014	0.0395	0.7635	0.0357	0.2367	148.8510
	2015	0.0343	0.6715	0.0309	0.2227	147.1119
	2016	0.0299	0.5940	0.0267	0.2125	145.8147
	2017	0.0272	0.5457	0.0242	0.2046	144.2214
	2018	0.0244	0.4935	0.0215	0.1964	142.4510
	2019	0.0221	0.4487	0.0194	0.1898	140.7023

Table 33. Result of MOVES 2014a for Heavy-Duty Long-Haul Trucks.

Unit	Year	HC	NO_x	PM_{10}	CO	CO_2
g/VMT	2005	1.7187	21.4379	1.1439	5.4035	1959.2665
	2009	1.3814	16.0042	0.8156	4.2817	1961.2579
	2014	1.0572	11.7662	0.5915	3.3532	1933.6106
	2015	0.9933	10.9704	0.5517	3.1587	1920.0921
	2016	0.9330	10.2179	0.5142	2.9773	1906.5771
	2017	0.8748	9.4889	0.4778	2.8047	1889.2247
	2018	0.8177	8.7704	0.4417	2.6369	1871.6778
	2019	0.7648	8.1109	0.4088	2.4833	1854.7332
g/ton-mile	2005	0.1375	1.7150	0.0915	0.4323	156.7413
	2009	0.1105	1.2803	0.0652	0.3425	156.9006
	2014	0.0846	0.9413	0.0473	0.2683	154.6888
	2015	0.0795	0.8776	0.0441	0.2527	153.6074
	2016	0.0746	0.8174	0.0411	0.2382	152.5262
	2017	0.0700	0.7591	0.0382	0.2244	151.1380
	2018	0.0654	0.7016	0.0353	0.2110	149.7342
	2019	0.0612	0.6489	0.0327	0.1987	148.3787

As shown in Figure 30, the average emission rate results from both versions of the model show a decreasing trend over time; however, the rate of decrease for NO_x, HC, and PM_{10} from MOVES3 is higher than those from MOVES2014a. This decreasing trend can be explained by two factors:

- Stringent emissions standards for trucks that are of model year 2010 and later.
- The retirement of old trucks and increasing share of the new trucks in the long-haul truck population.

As described in Chapter 4, the full implementation of the 2007 emissions standards (also referred to as 2010 standards) for on-road heavy-duty trucks means that the newer trucks have substantially lower NO_x, PM, and HC emissions than their predecessors. Figure 31 demonstrates this significant reduction in trucks' emissions by showing an example of model-year-specific emission rates extracted from MOVES3. Furthermore, the long-haul trucking industry has continued to replace older trucks with new trucks that comply with the current emissions standards. Figure 32 depicts the national-level model year distribution of long-haul trucks for the analysis years 2014 and 2019, which were extracted from the MOVES3 database. As summarized in Table 34, more than half of the trucks in the long-haul fleet in 2019 were complying with the 2010 standards.

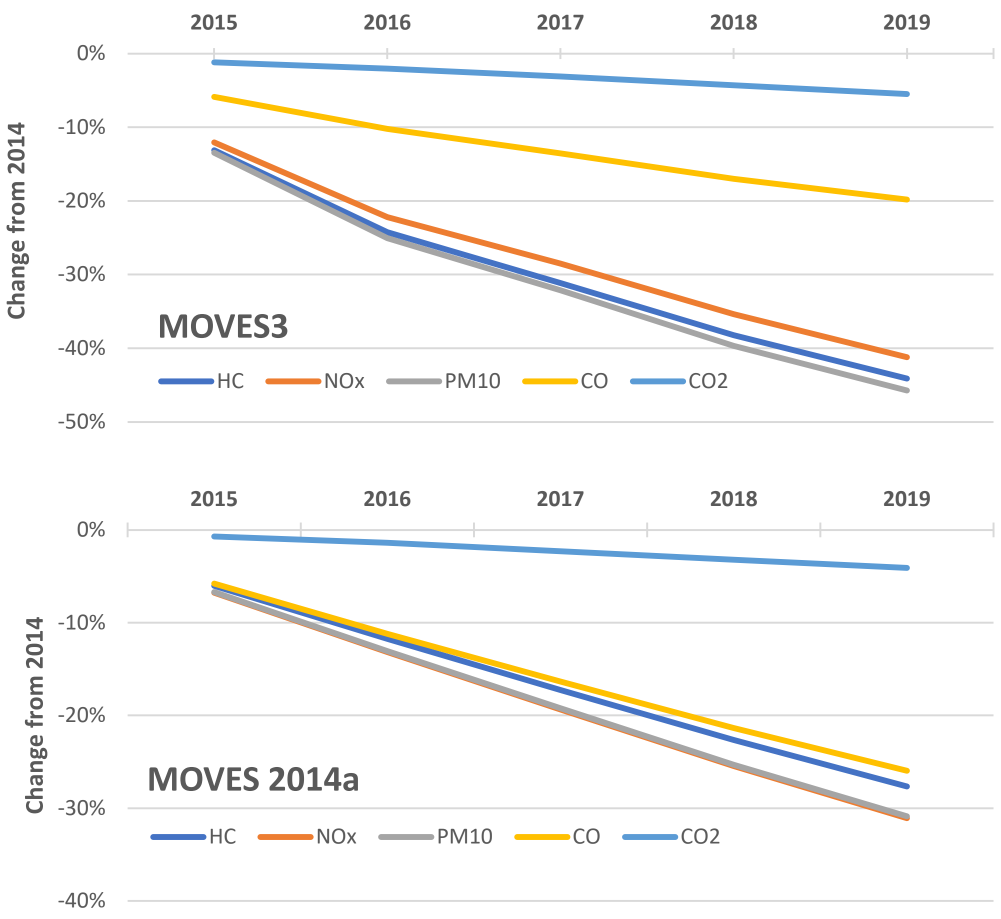

Figure 30. Change of Fleet Emission Rates for Heavy-Duty Trucks.

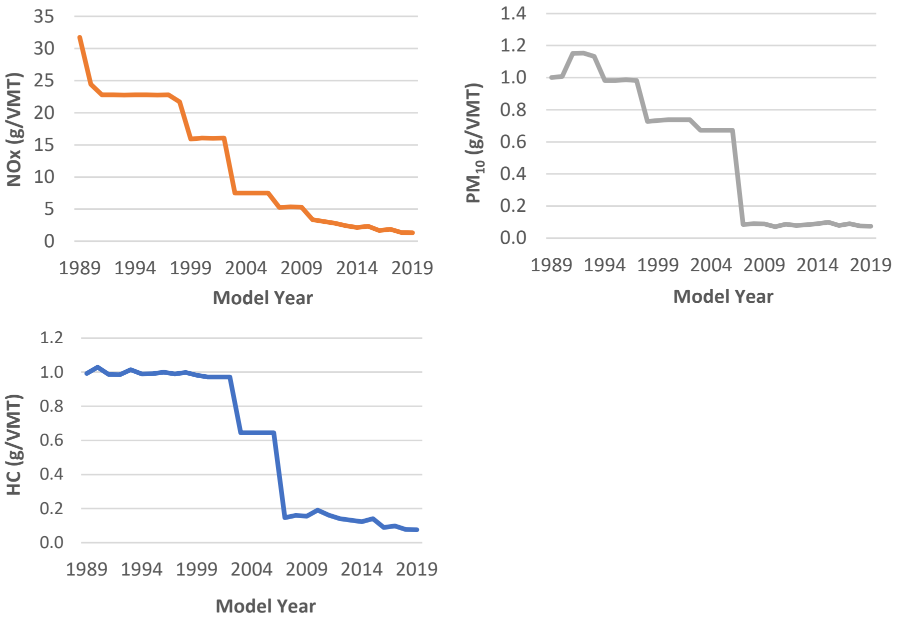

Figure 31. Long-Haul Trucks' Emission Rates (Average Speed 50 mph on a Rural Freeway).

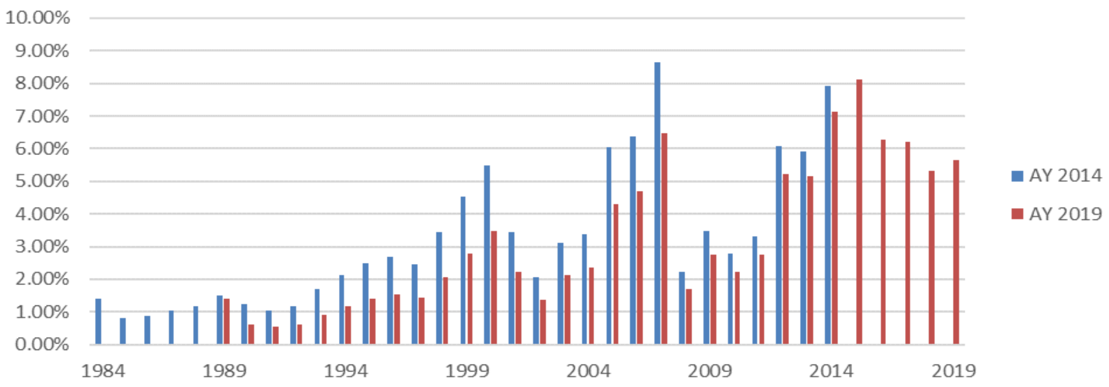

Figure 32. Long-Haul Combination Diesel Truck Model Year Distribution.

Table 34. Long-Haul Combination Diesel Truck Model Year Distribution.

Vehicle Model Year	Analysis Year 2014	Analysis Year 2019
Older than 2004	43.8%	23.7%
Older than 2007	59.6%	35.1%
Younger than 2010	26.1%	54.0%