Modal Investment Comparison: The Impact of Upper Mississippi River Lock and Dam Shutdowns on State Highway Infrastructure

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16. Abstract This project reviews southbound agricultural shipments from the Upper Mississippi River originating from the states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin to understand the potential impacts of shifting barge shipments to the parallel highway infrastructure. The project examines impacts to congestion on parallel highways, highway maintenance costs, trucking industry costs and environmental impacts of two diversion scenarios. Through evaluation of the two scenarios, the individual and cumulative impacts of shutdowns of each of the lock and dams on the Upper Mississippi River are modeled as highway loads with estimated costs and delays.		
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Executive Summary

The Mississippi River is a critical corridor for transportation of agricultural products and, in turn, is critical to the economies of the states that utilize the river to transport these trade goods. In the MAASTO/MAFC region, five of the region's states are dependent on the Upper Mississippi River to move the majority of their agricultural products. The navigable portion of the Upper Mississippi River region is defined as that portion of the river from St. Paul/Minneapolis to St. Louis at the last lock system. This is considered the area that is navigable for freight movement on barges, and movement is facilitated through the locking chamber at the facilities. All of these structures were constructed between the 1930's and late 1950's. The USACE estimates that there are over $1 billion in backlogged maintenance costs for these structures. Given the age and maintenance backlog, a failure at any of these facilities, especially the southernmost, would divert agricultural products to truck or rail. USACE categorizes most of the facilities as "fix as fail."

As all practitioners are aware, funding and budgeting problems fall across the modes evenly. According to the 2015 Highway Conditions and Performance report, there is an $836 billion backlog in bridge and highway investment. Given the lack of investment and, in many cases, deteriorating pavement conditions, a potential shutdown of the Mississippi River due to lock and dam failure and forcing the agricultural tonnage onto the highways in five key agriculture-producing states could wreak havoc on highways. Those highways would likely absorb additional pavement and structural damage from increased traffic of fully loaded trucks.

The purpose of this report is to demonstrate the impact of lock and dam closures on the Upper Mississippi River would have on the parallel highways based on the increased truck numbers required to move the displaced agricultural products. Our approach is similar to other studies and focuses on identifying:

1. What is the tonnage of agricultural commodities moving downstream on the Upper Mississippi River? At what locations are the tonnages sourced into the river system?
2. How many truckloads would be required to move an equivalent tonnage on parallel road routes?
3. Which routes would these trucks take to reach St. Louis to get back on the river?
4. What impact (average annual daily truck traffic, congestion, increased maintenance, etc.) would these additional trucks have on the road infrastructure of Minnesota, Wisconsin, Iowa, Illinois, and Missouri?
5. How does the cost of these impacts, or cost of the improvements designed to mitigate these impacts, compare with the cost of improving Upper Mississippi River control structures?

In Chapter One, the introduction and purpose section, the magnitude of the freight movement on the Upper Mississippi River today and the in future is addressed. This section also discusses the current trend in transportation agencies to pursue multimodal solutions to freight congestion. From here, the idea that investments in marine infrastructure could offset the need for more rapid or extensive investment in the highway mode is identified as the underlying theme for this project.

Chapter Two provides the literature and data review to address marine freight and commodity shipments on the Mississippi and the state of the lock and dam system. It also includes previous research on the impacts of marine freight corridor shutdowns. Chapter Two also addresses literature on the concerns of the public regarding freight movement, cost to agriculture, and impact to roads from marine-diverted freight. This chapter provides context to the Upper Mississippi River and its role in big logistics and brings the importance of the system to light.

Chapter Three presents the methodology that was used to examine the “what if” scenarios. The two scenarios included in this analysis are: 1) 100% of all the agricultural products are diverted to the highways, and 2) 25% of the diverted tonnage is assigned to railroads and 75% to highways. This chapter also defines how freight loads were attributed geographically to ports, the equivalent number of truck loads required, as well as the parallel highway routes most likely to host the agricultural and commodity moves.

Chapter Four provides the analysis. Under the extreme closure of the entire system north of lock 25, and with 100% of the tonnage going to trucks, there would be an additional 12,337,400 tons of goods moved on 489,496 truckloads. Pavement damage costs are estimated at $28,841,353 and additional costs to the trucking industry would be approximately $283,072,536. Further, there would be an additional 212,464 tons of CO_2 with an approximate social cost of $7,720,704.

This analysis can also be considered a starting point for understanding the impacts of container markets along the entire Mississippi River, entering at the gulf or at rail intermodal centers and reaching its final urban destination via the water. Similarly, for OSOW loads, marine movements could offer the ultimate solution of harmonization, congestion-free travel (mostly), and tremendous reductions in pavement damage and maintenance costs. Containers and OSOW can be planned for delivery with precision on the riverfront.

The Upper Mississippi River is a crucial marine transportation asset for the Upper Midwest. Delayed investment and maintenance of the Lock and Dam infrastructure that supports the Upper Mississippi is a major threat to the region’s economic security.

Increased investment in marine infrastructure on the Upper Mississippi River system can mitigate highway maintenance and pavement costs, provide safer travel on both marine and highway systems, and provide environmental benefits. Developing polices and funding programs to support our entire system as a system, will support logistics and system reliability and prevent the treadmill of short-term funding and emergency infrastructure solutions to patch the transportation infrastructure and our economy. It is time to take a systems approach with our freight infrastructure to avoid the unnecessary drag on the nation’s economy.

1. Introduction

Increasingly, progressive state departments of transportation are emerging from their historic role as highway agencies to agencies that support a total system of transportation that includes all modes. This multimodal approach is especially important in freight transportation given the range of loads moved, the quantities moved, and the impacts to the environment and general public from the freight movement. All modes must be leveraged to move the current tonnage in the United States of 55 million tons per day valued at $49.3 billion dollars (USDOT, 2015, Chapter 2). And, current estimates suggest freight tonnages to increase nearly 30% between 2013 and 2040 (USDOT, 2015, Table 2-1).

This move to managing a multimodal system is exemplified in the MAASTO region. The move towards a multimodal systems approach is not only due to strong leadership at the agency level, but also to the region's role as a crossroads for rail, waterways and highways. The region is where eastern railroads meet western railroads and, as a result, the three largest rail hubs in the U.S. are found in Chicago, St. Louis and Kansas City. Further, the multimodal approach in the region is driven by natural resources and raw products produced in the area, as well as the geographic blessings of the Mississippi River and Great Lakes marine freight systems. However, freight and multimodal investment needs face the same challenges as investment needs in all transportation areas. There has been underinvestment in the system across the board and a continued reduction in available funds. As a result, new construction programs are being reduced as agencies work to overcome a backlog of maintenance needs in every mode. According to the recently released 2015 USDOT Conditions and Performance Report, there is a $836 billion backlog in highway and bridge investments alone. [2015 Conditions and Performance - Policy | Federal Highway Administration]

Assuming cargoes, markets, and market timing can adapt to freight movement on a variety of modes, there is rationale for supporting modes with available capacity and fewer environmental impacts. There is also rationale for assuming that investments in these modes with capacity available, could reduce the damage, maintenance and investment needs on the dominant modes with little or no capacity remaining. The case explored here examines the impacts to the parallel highway facilities based on failure of each of the locks and dams on the Upper Mississippi River. The area of analysis ranges from the upper limits of navigation at St. Paul, Minnesota to the lower point in St. Louis, Missouri, where the lock and dam system ends. Barring additional investment in marine infrastructure resulting in the eventual failure of the marine infrastructure, how many additional tons of cargo, number quantities of trucks, and marginal costs will the highway system be required to absorb? Further, how do these impacts compare to the needed investment in marine infrastructure? These questions drive the analysis in this project.

Purpose

The navigable portion of Upper Mississippi River is defined as a portion of the Mississippi River from Minneapolis and St. Paul to St. Louis. This section of the river is a critical transportation asset for the states of Minnesota, Wisconsin, Iowa, Illinois, and Missouri. The river's barge transportation system provides low-cost movement of bulk commodities like agricultural products. These barges also play an important role in limiting road and rail congestion due to these commodities; one 15-barge tow carries as much cargo as 216 rail cars or 1,050 semitrucks (Iowa Department of Transportation, 2016).

Barge navigation on the Upper Mississippi is made possible by a series of locks and dams, many of which were built in the 1930s and have reached the end of their service lives. As the locks continue to age, the probability of their failure increases. Lock shutdowns for maintenance and reconstruction threaten the river's viability as a transportation corridor, pose a risk to the industries that rely on the river for marine shipping, and could contribute to congestion of other modes like road and rail.

The goal of this project is to determine the potential individual and cumulative highway infrastructure and trucking impacts of shutdowns of each of the locks and dams on the Upper Mississippi River. This project focuses on downbound agricultural shipments and asks what impact that volume of freight would have on the region's roads if it were diverted from barge to truck. By determining the potential impacts of this modal shift, we hope to better understand: 1). the feasibility, benefits, and the cost of failure of the dominant agricultural export mode (marine), and 2) how the value of multimodal, freight-specific investments may be compared across modes. This approach expands the understanding of corridor resilience by integrating agricultural commodity and logistics models to refine the understanding of the consequences and benefits of a multimodal systems approach to freight movement.

Previous research on the economic importance of the Upper Mississippi River and the impacts of its shutdown on agricultural shipments has often assumed that railroads would absorb most of the displaced shipments. Instead of assuming that rail service would accommodate displaced barge shipments, this report focuses on two scenarios. The first scenario assumes that only trucks carry the displaced shipments. The second scenario assumes 25% of displaced tonnage goes to rail and 75% goes to trucking, as estimated in a recent Illinois study (Meyer et al, 2007). This decision to focus predominantly on trucks reflects: 1) the increasingly limited available capacity of railroads as crude oil shipments increase, and 2) a primary interest in how such a large volume of agricultural goods would affect the road system.

Research Questions

1. What is the tonnage of agricultural commodities moving downstream on the Upper Mississippi River?
2. How many truckloads would be required to move an equivalent tonnage on parallel road routes?
3. Which routes would these trucks take to reach St. Louis to get back on the river?
4. What impact (average annual daily truck traffic, congestion, increased maintenance, etc.) would these additional trucks have on the road infrastructure of Minnesota, Wisconsin, Iowa, Illinois, and Missouri?
5. How the cost of these impacts, or improvements designed to mitigate these impacts on the highway side, compare with the cost of improving Upper Mississippi River control structures?

2. Background

Current State of Commodity Shipments / Agricultural Shipments

While this analysis is based on 2015-2016 commodity data, historically, the tonnages and values of river shipments have always been significant. Between 2008 and 2011 barges on the Upper Mississippi River between St. Paul and the confluence of the Missouri River carried an average of 61.3 million tons of cargo. (Institute for Water Resources, 2011). From 2000 and 2010, the total value of freight moving on river was $876.4 billion, or an average of $87.6 billion each year. Of that value, 62% was from downbound shipments, and 38% was from upbound shipments (Kruse et al, 2011). And, according to a 2013 Iowa DOT modernization study for the upper Mississippi, it is estimated that 126 million tons of freight move on the upper section of the river, more than 36 times 1930's tonnage. This tonnage includes both the Illinois and Missouri portions of the river tonnages (HDR Engineering, Inc. 2013).

Agricultural commodities make up a very large portion of the downstream freight on the Upper Mississippi River. At Lock and Dam 25, the lock immediately upstream of the confluence of the Illinois and Mississippi rivers, agricultural commodities make up 92% of the downbound tonnage (US Army Corps of Engineers, 2016). Of these agricultural commodities, corn and soybeans comprised nearly 90% of food and farm products moving on the Mississippi and Ohio rivers, and were primarily destined for Lower Mississippi River ports (Yu et al, 2011). Between 2000 and 2010, the average monthly value of corn and soybeans handled at each lock on the Upper Mississippi was $59.6 million and $40.3 million (Kruse et al, 2011).

In addition to the value of goods moved, the system, as a whole, yields large benefits. The US Army Corps of Engineers estimates that each year, maintaining the control structures of the Upper Mississippi and Illinois rivers costs $115 million, and yields $1 billion in transportation cost savings (US Army Corps of Engineers, 2016). Looking toward the future, inland waterway tonnages are expected to increase by 23% from 2010 to 2050 (HDR Engineering, Inc., 2013). Additional investment in the Upper Mississippi's infrastructure will be needed to maintain the system and accommodate future growth.

State of Lock and Dam Infrastructure

In 2013, the American Society of Civil Engineers gave the United States' inland waterway system a grade of "D-" for its poor condition and frequent delays. The Society noted that the Ohio and Mississippi river systems had a disproportionate number of delays relative to the rest of the nation's rivers. These problems are reflected in the US Army Corps of Engineers' estimates that the backlog of maintenance for the Upper Mississippi River's locks and dams is over $1.0 billion (US Army Corps of Engineers, 2016). Much of the system was constructed in the 1930s, and as maintenance costs exceed funding, the Corps has pursued a "fix-as-fail" approach, rather than preventative maintenance. This approach means that unplanned repairs can take days, weeks, or months, during which traffic through affected structures may be delayed, or blocked completely. Ultimately, industries and communities that rely on the river for freight shipment are assuming more risk as infrastructure continues to age and becomes more likely to fail. A 2011 study identified Locks and Dams 20 and 25 as the two most critical structures on the Upper Mississippi, based on their age, need for maintenance, and the economic consequences of their failure (Kruse et al, 2011). Information on the age and condition of each of the Corp's district's locks and dams can be found here: Upper Mississippi River Locks and Dams Fact Sheets.

Research on the Impacts of Shutdowns

Given the importance of the Mississippi River to the economic health of both the Midwest and the nation as a whole, multiple studies on the impact of river shutdowns have been conducted. Table 2.1 lists studies that were identified for this project.

Table 2.1 - Previous Studies on the Impact of Lock Shutdowns

Name/Year	Title
Meyer et al, 2007	Impact of a Lock Failure on Commodity Transportation on the Mississippi or Illinois Waterway
Kruse et al, 2007	A Modal Comparison of Domestic Freight Transportation Effects on the General Public
Kruse et al, 2011	America's Locks and Dams: A Ticking Time Bomb for Agriculture?
HDR Engineering, 2013	U.S. Inland Waterway Modernization: A Reconnaissance Study; prepared for Iowa Department of Transportation
Gossardt et al, 2014	Inland Navigation in the United States: An Evaluation of Economic Impacts and the Potential Effects of Infrastructure Investment
Yu et al, 2016	Economic Impacts Analysis of Inland Waterways Disruptions on the Transport of Corn and Soybeans

The first study, by Meyer et al, utilized the International Grain Transportation Model (IGTM) to simulate a closure of Lock and Dam 25 from October through December. They found this closure reduced corn and soybean producer revenue between $219 and $505 million, depending on how railroad shipping rates reacted to the closure. The authors hypothesized that a longer-term closure would have less of a negative impact on agricultural producers, as rail capacity would expand to meet new demand (Meyer et al, 2007).

Another 2007 study translated shutdown impacts into measures relevant to the general public. Using the Highway Economic Requirements System-State Version (HERS-ST) highway investment model, Kruse et al calculated the impacts of a shutdown of the Upper Mississippi and Illinois rivers on highways near St. Louis. The authors assumed a 100% diversion from barges to trucks, and focused on the highway impacts for four counties in Missouri (Franklin, Jefferson, St. Charles, and St. Louis), and 5 counties in Illinois (Jersey, Madison, Monroe, Randolph, and St. Clair). In the ten years after a shutdown of the river, truck traffic would almost triple and highway improvement costs to accommodate increased truck traffic would range from $345 million to $722 million. Maintenance costs would increase by 80-93%, traffic delays would increase by almost 500%, and injuries and fatalities would increase by 36-45%. Table 2.2 lists the impacts of a river shutdown on various factors relevant to the general public.

Table 2.2 - Impact of River Shutdown on Factors Relevant to the General Public

Category	Current (2005)	10 Years After Waterway Closure			
		Without Improvements	% Change	With Improvements	% Change
Semi Trucks per Lane-Mile Per Day	1218	3736	207%	3781	210%
Average Speed – Peak (mph)	69.9	62.0	-11%	65.5	-6%
Average Speed – Off Peak (mph)	70.8	66.1	-7%	70.6	0%
Delay – Total (hrs per 1000 VMT)	0.07	0.46	466%	0.44	495%
Crashes (annual)	3448	4688	36%	4999	45%
Injuries (annual)	1692	2310	36%	2454	45%
Fatalities (annual)	13	18	36%	19	45%
Maintenance Costs ($ million per 1000 miles)	0.79	1.53	93%	1.42	80%
Emissions Costs ($ per 1000 VMT)	12.28	16.86	37%	18.68	52%
Source: Kruse et al, 2007.					

A 2011 study by Kruse et al using an updated version of the IGTM found that closures of Locks 20 and 25 produced economic impacts similar to those found by Meyer et al. A short-term, two-week shutdown would cost agricultural producers about $2.8 million, and a yearlong shutdown would cost producers between $44.0 and $44.7 million. Barge operators would lose between $5 million and $150 million, depending on the duration of the shutdown, and how rail rates reacted.

This study also attempted to further determine whether or not railroads could accommodate agricultural traffic displaced by lock shutdowns, and determined that rail capacity overall was not constrained and could accommodate a large portion of diverted agricultural commodities, with some shipments being diverted to trucks. The study also noted that, while trucking is essential to agricultural operations, long-haul movements in lieu of barge shipments would severely tax already underperforming infrastructure.

Table 2.3 - Cost to Agricultural Producers of Lock Closures

Cost to Agricultural Producers of Lock Closures ($1,000s)				
	Two Weeks	One Month	Three Months	One Year
Lock 20 - Upper Mississippi	2,821	4,884	15,444	44,030
Lock 25 - Upper Mississippi	2,821	4,884	15,445	44,706
Source: Kruse et al, 2011.				

In 2014, the universities of Kentucky and Tennessee prepared a report on the economic impacts and potential effects of inland waterway investment. The study used REMI simulations to model the effect of “all-or-nothing” losses of navigation in a variety of watersheds. In this study, the Upper Mississippi watershed included the Illinois and Missouri rivers, as well. The study estimated that a loss of service on the Upper Mississippi would result in the loss of 82,000 jobs in the first year, and a total of 83,000 jobs over 10 years, as industries adapted to a closed river system. A closure was also estimated to reduce earnings in the Upper Mississippi region by $3.976 billion per year.

The study also investigated the benefits of upgrading Locks 22, 24, 25, and the Mel Price Lock on the Upper Mississippi, as well as the O’Brien and LaGrange locks on the Illinois River. The annual cost of these upgrades over a ten-year time horizon was estimated to be $182.3 million, while the average annual benefits over the life of the projects was estimated to be $235 million. The authors estimated that over the long term, 20 years after the projects were completed, 3,810 jobs would be created thanks to improved navigation. In the shorter term, between 3,000 and 3,900 new jobs would be attributed to the construction of navigational improvements, although these job benefits would dissipate after construction was completed.

The most recent study, completed in 2016, Yu et al applied the IGTM once more to the Upper Mississippi. This study examines closures for three months (September – November), and one year (September – August) in 2024–2025. This study estimated that corn and soybean exports would be reduced by up to 5 million tons (9% of total) over a three-month closure, and 8 million tons (13% of total) over a yearlong closure. In turn, Pacific Northwest and Atlantic Coast ports emerge as key export points. Closure for three months would reduce total economic activity related to grain transportation by $933 million, while a yearlong closure would reduce activity by $2 billion. However, the authors estimate that the positive grain shipment economic activity associated with rail shipment increases would surpass the economic losses in barges and trucks. The decline in corn and soybean economic surplus (irrespective of transportation mode) caused by a shutdown of Lock and Dam 25 for a year or more would result in a decrease of more than 7,000 jobs, $1.3 billion labor income, and $2.4 billion of economic activity, annually. Ultimately, closing Lock and Dam 25 would have negative impacts on jobs, labor income, and total industry output. Table 2.4 displays the potential economic impacts associated with different durations of closure and rail shipping rate responses.

Table 2.4 - Potential Economic Impacts Associated with Different Durations of Lock Closures and Rail Shipping Rate Responses

Closure Length	Rail Rate Change	Employment (number)	Labor Income	Total Value Added	Total Industry Output
3 Months	0	-2,711	-284.5	-396.1	-837.0
	5	-2,333	-345.5	-453.8	-791.9
	15	-2,172	-443.0	-576.3	-852.9
One Year	0	-1,872	-228.8	-248.0	-699.8
	5	-813	-400.7	-447.0	-788.2
	15	845	-548.7	-553.2	-537.3
Note: Labor Income, Total Value Added, and Total Industry Output are expressed in millions of dollars.					

These six studies paint varying pictures of the economic impacts rendered by a shutdown of the Upper Mississippi River, but what they all share in common is the conclusion that a loss of service on the Upper Mississippi will have negative economic impacts on the region and nation. All of the studies above also assumed that railroads could assume much of the load of displaced agricultural shipments. This project will add to this body of knowledge by investigating the potential infrastructure impacts of shifting such large volumes of traffic to the region's roads.

Research on the Impact of Trucks on Roads

To understand the impact of trucks on infrastructure, the physical impacts to the roadway, monetized damage, and delay are examined. A 2014 MAFC report estimated that the pavement damage of an average-weight, five-axle truck is equivalent to 4,000 cars on flexible pavements, and 6,200 cars on rigid pavements. However, relative impacts vary widely based on a variety of factors including weight distribution, pavement age, and temperature. The table below lists the relative impact of trucks to cars from a variety of state research projects.

Table 2.5 - Impact of Trucks Compared to Cars on Rigid and Flexible Pavements

Pavement	AL	AZ	CO	IN	MN	NV	OH	VA	WI
Rigid	5,100	7,300	5,800	7,300	6,200	6,200	6,500	5,800	5,500
Flexible	3,600	3,900	4,300	5,200	4,300	2,700	4,700	4,200	3,400
Source: "Understanding Freight Vehicle Pavement Impacts: How do Passenger Vehicles and Trucks Compare?" http://midamericafreight.org/wp-content/uploads/ESALs.pdf									

Monetizing this heavy truck damage is also difficult, since damage is a function of many different factors. One paper from 2001 provides two cost estimates for a five-axle semitruck carrying 80,000 pounds. It notes that an earlier version of the Comprehensive Truck Size and Weight Study assigned 9 cents of damage per mile on rural interstate highways, and $5.90 per mile on rural local roads. A second estimate was 48.9 cents for state highways, 16.2 cents for U.S. highways, and 2.7 cents for interstate highways (Luskin and Walton, 2001).

A more recent Canadian study from 2014 provides an even finer look at pavement costs based on type of road. Cost estimates are in 2014 U.S. Dollars per mile. The trends found in this study also show that trucks have a greater impact on smaller local roads relative to highways.

Table 2.6 - Marginal Pavement Cost Per Average 5-Axle Truck Per Mile in Southern Ontario

	New Pavements	In-Service Pavements
Urban Freeway	0.006	0.002897
Major Arterial	0.020	0.010139
Minor Arterial	0.035	0.017381
Collector	0.087	0.044901
Local	1.296	0.667715
Source: Hajek et al, 2014.		

The analysis below will demonstrate that the cost associated with damage from thousands of additional trucks can exceed $20 million. However, additional costs from trucks also come from congestion and delay, health impacts, and safety impacts. Further additional infrastructure investments to the highways will then be needed to accommodate displaced river traffic. And, given state of repair and current construction cycles, these costs can be assumed to aggregate over 2–10 years to accommodate construction and replacement cycles of failed infrastructure.

3. Methodology

This project is driven by the following eight assumptions and approaches to analyze the displacement of tonnages to trucks.

1. To provide a “what if” comparison of what an equivalent volume of river traffic would look like on the regions highways, this project examines two scenarios: 1) all agricultural loads shifted to trucks, and 2) 75% of agricultural loads shifted to trucks and 25% shifted to rail.
2. Adequate trucking labor and equipment are available to meet demand created by modal shift.
3. For this analysis, it is assumed that if the river were to shut down, producers will continue shipping their products to the same river terminals that they would use when the river was operating. From these same terminals, trucks will carry loads to grain terminals in St. Louis downstream of the lock and dam infrastructure.
4. That barge loading facilities in St. Louis have the capacity to accommodate all of the truck-borne agricultural tonnage generated by a shutdown.
5. Thirty percent of the downbound agricultural tonnage passing through Pool 21 is unloaded in Quincy, IL. Based on this rate, it is assumed that 30% of the agricultural products loaded in each pool are destined for Quincy, and the remaining 70% are destined for St. Louis and then New Orleans.
6. This analysis assumes the average five-axle semitruck can carry 25 tons of agricultural products. For trucking costs, it uses $1.593 per mile, ATRI’s estimate of marginal cost of truck operation for 2016.
7. This analysis uses a marginal cost of pavement damage per truck per mile of $0.162. The estimated cost of damage from an 80,000 lb., five-axle truck varies widely, from less than 1 cent per mile on interstates, to $5.90 per mile on rural roads (Luskin and Walton, 2001). Pavement damage varies based on a number of factors, including pavement age, temperature, and distribution of weight. The 16.2 cents-per-mile estimate used is an estimate for damage on U.S. Highways from a 2001 paper by Walton and Luskin. Newer papers, from 2014, put the marginal cost of pavement damage from trucks at much smaller amounts, between $0.006 and $0.66, depending on the type of road, and damage costs may be adjusted in the final report (Hajek et al, 2014).
8. The average shipping season is nine months.
9. The social cost of CO_2 from emissions was calculated at $36/ton of CO_2 based on the estimate used by federal regulator agencies (Interagency Working Group on Social Cost of Greenhouse Gases, 2016)

The following discussion identifies data sources used to estimate tonnages displace, and the impacts to highway operations and infrastructure.

Commodity data for the locks was obtained from the US Army Corps of Engineers’ Lock Performance Monitoring System. The system provides upbound and downbound tonnage estimates for each lock in the Upper Mississippi system and is broken into nine different commodity groups. The data obtained from the Lock Performance Monitoring System was collected between August 2015 and July 2016. The system only provides data through the previous calendar year, so additional years of commodity data were not available.

Truck volume data was obtained by the Minnesota, Wisconsin, Iowa, Illinois, and Missouri state DOTs using their online mapping tools or traffic count maps. All data is from 2013 to 2015, depending on the region of each state.

Table 3.1 - Truck Volume Data Sources and Dates

State	Link to Data	Notes
Illinois	link	The majority of Illinois' data is from 2015, with some segments from 2013
Iowa	link	Data from 2013 to 2015. (2013 in NE, 2014 in SE)
Minnesota	link	Data from 2013 to 2015
Missouri	link	Data from 2015
Wisconsin		Current GIS data provided by WisDOT staff

Truck Load / Capacity data was provided by materials from the Iowa Department of Transportation, and confirmed by MAASTO Motor Carrier Committee members, SCOHT members and from industry working in the Upper Mississippi River area.

Analysis Process

Combining Pools

To identify the most likely origins for the agricultural tonnages and to facilitate estimation of individual and cumulative impacts, tonnages were assigned to an originating pool. Army Corps' navigational charts, state DOT listings of barge terminals, and google satellite images were used to identify pools that did not have agricultural terminals. These pools were merged with adjacent downstream pools that did have terminals. This merging process was done to simplify analysis without excluding some pools of the river. The table below lists which pools were merged.

Table 3.2 - Pools Merged to Simplify Analysis

Empty Pool	Merged with pool
1	2 – St. Paul, MN
3	4 – Red Wing, MN
5	6 – Winona, MN
7	8 – La Crosse, WI
11	12 – Dubuque, IA
23	24 – Louisiana, MO
25	26 – Alton, IL

Calculating Each Pool's Tonnage

Next, each pool's impact on upbound or downbound commodity flows was calculated. Commodity shipment data for the locks was obtained from the US Army Corps of Engineers' Lock Performance Monitoring System. The system provides upbound and downbound tonnage estimates for nine commodity groups for each lock in the Upper Mississippi system. The data obtained from the Lock Performance Monitoring System was collected between August 2015 and July 2016. The System only provides data through the previous calendar year, so additional years of commodity data were not available. Therefore, this report does not examine or control for long-term trends in marine commodity shipment.

The changes in upbound and downbound tonnage in each pool were calculated by finding the difference in tonnage values between locks. For example, facilities in a pool could be loading 10 tons, and unloading 5 tons, and this calculation method results in an outcome of 5 tons "loaded." For the purpose of this paper, loaded and unloaded refers to the total changes to a stream's tonnage in each pool. In order to determine the true amounts loaded and unloaded, the amount flowing through each lock and dam was compared against the amount flowing through the next lock in the sequence.

For example, the following table shows the agricultural commodity calculations for Pool 14, which includes Clinton, Iowa.

Table 3.3 - Agricultural Commodity Calculations for Pool 14

	Downbound (ktons)	Upbound (ktons)
Lock and Dam 13:	10,991.2	131.35
Lock and Dam 14:	12,235.18	160.59
Change in Pool 14:	1,243.98 loaded	29.24 unloaded

Assigning Pool Tonnages to Specific Locations

These changes in tonnage were then assigned to a specific city on each pool of the river. While each pool may have multiple locations where commodities are being transferred from water to other modes, only one location was selected per pool. For pools where multiple agricultural commodity facilities were present, cities with the highest concentration of facilities, or largest facilities were chosen. Pathfinding tests using Google Maps showed that choice of city for each pool had little impact on the overall route commodities took to their endpoint. Table 3.4 lists the origin point used for each section of the river.

Table 3.4 - Origin Point Used for River Section Pools

Pools	Point of Origin	Tonnage Change (ktons)
1, 2	St. Paul, MN	+ 4,224.6
3, 4	Red Wing, MN	+ 1,561.6
5, 6	Winona, MN	+ 1,388.0
7, 8	La Crosse, WI	+ 480.4
9	Lansing, IA	- 79.2
10	McGregor, IA	+ 2,083.7
11, 12	Dubuque, IA	+ 1,046.3
13	Savannah, IL	+ 285.8
14	Clinton, IA	+ 1,243.9
15	Bettendorf, IA	+ 174.1
16	Davenport, IA	+ 1,074.2
17	Muscatine, IA	+ 379.3
18	Keithsburg, IL	+ 1,138.6
19	Burlington, IA	+ 1,519.9
20	Keokuk, IA	+ 900
21	Quincy, IL	- 5,247.1
22	Hannibal, MO	+ 166.0
23, 24	Louisiana, MO	+ 0.5
25, 26	Alton, IL	+ 19,007.3

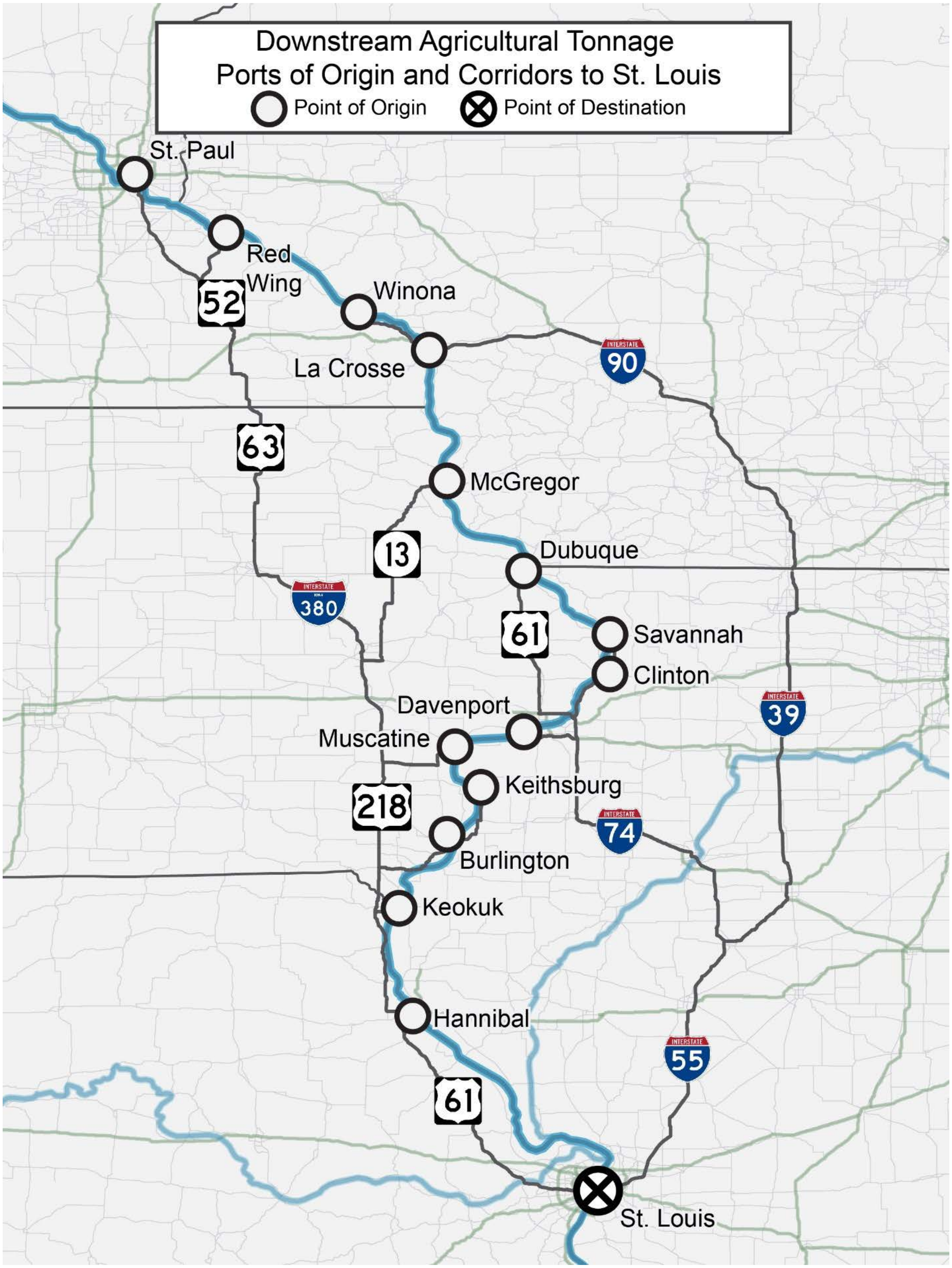
Excluding Certain Cities from Analysis

At Quincy, Illinois, about 30% of the downbound agricultural tonnage is unloaded. Origin/destination data was not available, and whether or not that 30% of tonnage would travel to Quincy by barge or truck would depend on which lock shut down, so 30% of each city's loaded agricultural tonnage was excluded from the analysis.

Further, Lansing, Iowa was excluded, as less than 1% of downbound agricultural tonnage was unloaded there. Louisiana, Missouri was excluded because less than 1% of downbound agricultural tonnage was loaded there.

Calculating Routes from Cities to St. Louis

This report assumes that if a lock on the Upper Mississippi River were to shut down, two scenarios would follow: 1) all of the tonnage upstream of that lock would be carried by truck, or 2) 75% would travel by truck, and 25% would travel by rail. In both scenarios, the truck tonnage would go to St. Louis, where it would be transloaded to barge and carried on to the Gulf of Mexico. Consideration of potential rail routes and impacts is not included in this analysis. To determine what routes newly generated truck traffic would take from points of origin to St. Louis, two applications were used: ArcGIS' Network Analyst tool, and Google Maps' navigation tool. Google consistently found routes that were shorter in both time and mileage than ArcGIS, so Google's results were used. Map 3.1 shows the overall three corridors laid out by Google Maps. Not all cities are displayed on the map, but all cities follow one of the corridors indicated on the map to reach St. Louis.



Map 3.1 - Google Maps Corridors Used

Route Descriptions

As shown in the preceding map, portions of U.S. and state highways from Minnesota to Missouri would be impacted. These facilities are listed below.

Minnesota:

The main corridor from St. Paul to the Iowa border follows US-52 from the Twin Cities to Rochester, where the southbound route follows US-63.

Trucks from Red Wing follow MN-58 to its junction with US-52.

Traffic from Winona follows US-14 to I-90, where it crosses into Wisconsin

Iowa:

US-63, I-380, and US-218 make up the main route through the state. Traffic from Minnesota follows US-63 to Waterloo, where it joins I-380. The corridor continues past Iowa City, where I-380 turns into US-218, which makes up the rest of the corridor to shortly before the Missouri border. IA-27 makes up the remainder of the route to the Missouri border.

Iowa Branch Routes:

McGregor: IA-13 to Cedar Rapids, where it joins the main corridor on I-380.

Dubuque: US-61 south to I-80, where it then crosses into Illinois.

Clinton: Immediately crosses the river to Illinois.

Davenport: I-280 to enter Illinois.

Muscatine: US-61 to IA-92, then it joins US-218.

Burlington: US-61 to IA-2, then it joins US-218.

Keokuk: US-61 into Missouri.

Wisconsin:

Traffic from Winona, MN and La Crosse follow I-90 from the Minnesota border to the Illinois border.

Illinois:

Traffic from Winona and LaCrosse follows I-39 to I-55 to St. Louis.

Traffic from Clinton, Savanna and the Quad Cities uses I-74 and I-155 to reach I-55

Traffic from Keithsburg uses local roads to reach IL-164, which runs to US-34 and into Burlington, IA.

Missouri:

US-61 and I-64 make up the remainder of the corridor on the western bank of the Mississippi.

Calculating Impacts: Inputs and assumptions

In order to calculate displace tonnage and truck loads, and impacts to operations and pavements, the following data were used. Table 3.5 lists the inputs used in the analysis.

Table 3.5 - Inputs Used in Analysis

		Source
Truck Weight (cargo only)	25 tons	Iowa DOT Report, Motor Carrier input
Marginal trucking cost per mile	$1.593	ATRI
Marginal Cost of Damage	$0.162	Luskin and Walton, 2001, Hajek et al, 2014

Calculating Impacts:

The tonnage and impacts associated with moving commodities from each pool by road were calculated individually. The table below shows the truckloads, damage costs, and trucking costs associated with moving each pool's tonnage by road. As mentioned above, 30% of each pool's tonnage was excluded from the analysis, as 30% of downbound agricultural shipments are unloaded at Quincy, Illinois.

Calculating Impacts of Truck Traffic:

Truck traffic data for the routes described above was obtained from state DOTs. Total truck counts were used, for states that provided combination and single unit truck counts, these counts were summed. This was done because not all states had counts broken down into specific types of trucks. For states with many truck observations, every 1-5 miles, some sampling methods were used to simplify the analysis. These methods included:

1. Sampling traffic counts before and after the convergence of truck routes from upstream cities.
2. Sampling traffic counts before and after intersection/convergence/divergence of truck routes, and Interstate highways.
3. Sampling traffic counts on both side of state borders
4. Sampling traffic counts before and after cities with a population greater than 20,000.
5. Averaging truck count for segments between major cities.

The Upper Mississippi's navigation season generally runs from March through November, with ice closing most of the northern portions from December through February. Closure occurs in late November and early December, and the average start date for navigation is March 22 (Duchschere, 2015).

Since this analysis models the effects of river shutdown on roads, and the river is operational for 9 of 12 months of the year, calculation of truck counts and impacts was modified to reflect the fact that shipping occurs for roughly 75% of the year. Average Annual Daily Truck Traffic counts were multiplied by 75% to create Average Seasonal Daily Truck Traffic (ASDTT) counts. The total truckloads generated in each city were divided by 274 to yield the additional ASDTT for each day of the shipping season.

Downbound agricultural commodity barge shipments are not equally distributed across the shipping season, there are tonnage "peaks" in early summer, and in fall. Therefore, the daily truck counts calculated and presented below may be higher or lower, depending on month.

Three truck-related phenomena were investigated and mapped:

1. The accumulation of truckborne tonnage across the system
2. The change in ASDTT before and after the shutdown of the river system.
3. The change in trucks as a share of total traffic before and after shutdown of the river system.

These scenarios were calculated and mapped for Scenario 1, 100% diversion of river traffic to trucks. Data for scenario 2 was also calculated, and presented in tables with data from Scenario 1.

4. Results

For a north-south tow, if Lock and Dam 25 (the last control structure before the confluence of the Mississippi and Illinois rivers) were to fail, regional impacts for Minnesota, Wisconsin, Iowa, Illinois, and Missouri would be significant assuming that all agricultural products would be trucked to St. Louis. In Table 4.1, with 100% diversion to trucks, over 12 million truck tons, or 489,496 truckloads would be driven to the highways. For the assumed nine-month navigation season, that is equivalent to an additional 54,388 trucks per month. Or, based on a 274 day shipping season, it is equal to 1,786 trucks per day traveling north to south between St. Paul and St. Louis. Pavement damage is estimated at nearly $29 million and trucking industry costs are valued at over $283 million with an additional 212,464 tons of CO_2 added to the atmosphere.

With 75% of the tonnage diverted to the road, over 9 million tons requiring, 367,122 truckloads would be on the roads. This equates to over $21 million in pavement costs, over $212 million in trucking industry costs and an additional 159,348 tons of CO_2 in the atmosphere.

Table 4.1 - Results of Lock and Dam 25 shutdown

Scenario	Truck Tons	Truck Loads	Damage Cost	Trucking Cost	Additional CO_2 Tons
1. 100% to truck	12,237,400	489,496	$28,841,353	$283,072,536	212,464
2. 75% to truck	9,178,050	367,122	$21,631,015	$212,304,402	159,348

The table below shows the individual impacts of shutdowns in tonnage, truck load, pavement damage, and cost of trucking. Based on Scenario 1, with 100% displacement to trucks, the impacts are shown below and are calculated over a nine-month shipping season. The column of "Total Tons" represents all tonnage on the river including the 30% that leaves the river at Quincy. The "Tons to Truck" column represents the total tonnage without the 30% that departs in Quincy.

Table 4.2 - Impacts by City: Scenario 1 (100% Diversion to Truck)

City	Total Tons	Tons to Trucks	Truck Loads	Trucks Per Day	Pavement Damage Cost	Trucking Cost
St. Paul	4,224,600	2,957,220	118,289	432	$8,680,742	$85,199,874
Red Wing	1,561,600	1,093,120	43,725	160	$3,520,459	$34,552,649
Winona	1,388,020	971,614	38,865	142	$3,261,358	$32,009,629
La Crosse	480,000	336,000	13,440	49	$1,075,576	$10,556,582
McGregor	2,083,700	1,458,590	58,344	213	$3,582,180	$35,158,437
Dubuque	1,046,300	732,410	29,296	107	$1,589,916	$15,604,727
Savannah	285,000	199,500	7,980	29	$394,292	$3,869,901
Clinton	1,234,980	864,486	34,579	126	$1,585,329	$15,559,711
Davenport	1,074,220	751,954	30,078	110	$1,291,255	$12,673,433
Muscatine	379,000	265,300	10,612	39	$457,292	$4,488,239
Keithsburg	1,138,630	797,041	31,882	116	$1,136,262	$11,152,198
Burlington	1,519,950	1,063,965	42,559	155	$1,447,844	$14,210,317
Keokuk	900,000	630,000	25,200	92	$730,750	$7,172,172
Hannibal	166,000	116,200	4,648	17	$88,098	$864,667

Based on Scenario 2, with 75% displacement to truck, the impacts are shown below, and are calculated over a nine-month shipping season.

Table 4.3 - Impacts by City: Scenario 2 (75% Diversion to Truck, 25% Diversion to Rail)

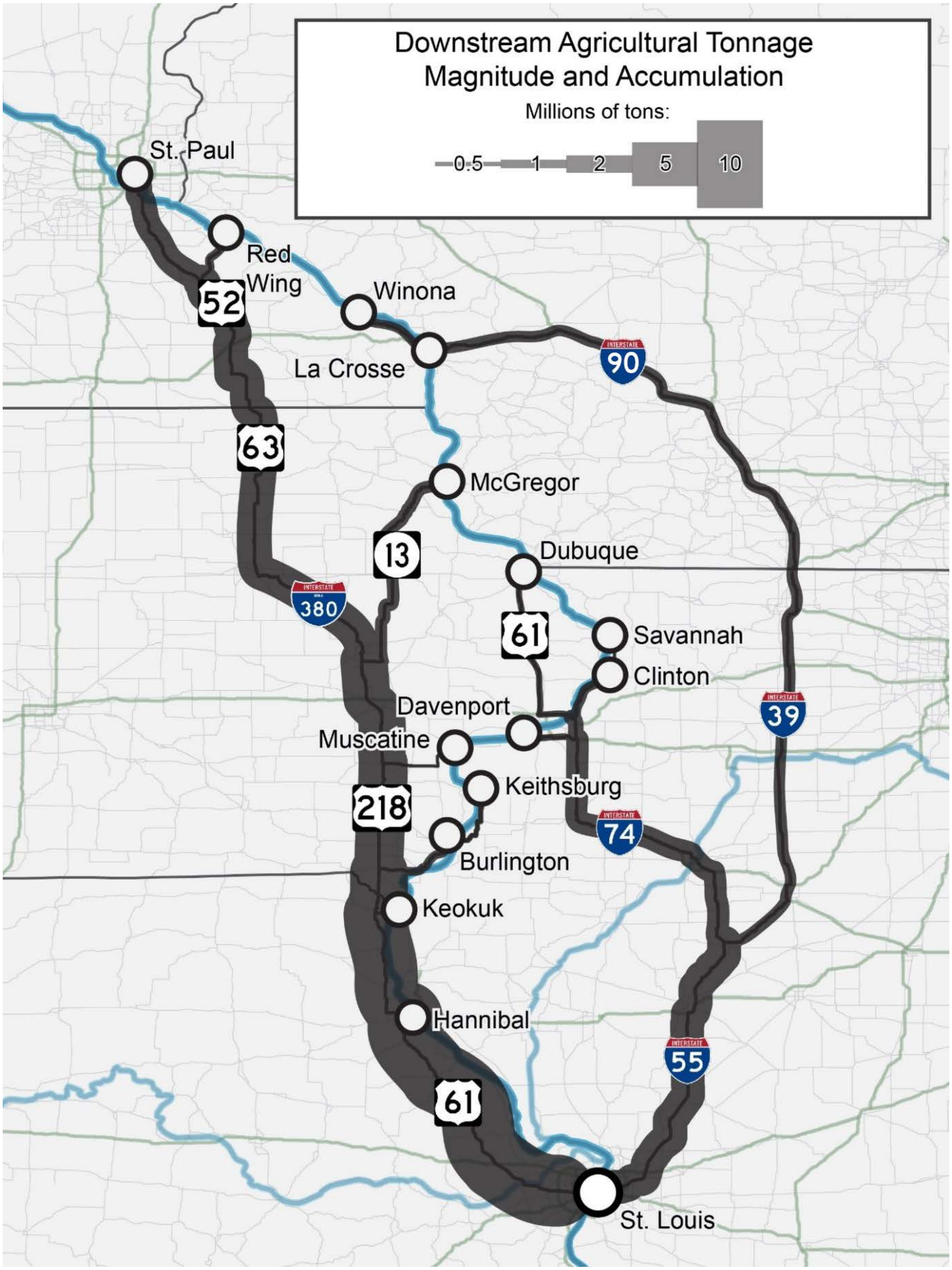
City	Total Tons	Tons to Trucks	Truck Loads	Trucks Per Day	Pavement Damage Cost	Trucking Cost
St. Paul	4,224,600	2,217,915	88,717	324	$6,510,556	$63,899,905
Red Wing	1,561,600	819,840	32,794	120	$2,640,344	$25,914,487
Winona	1,388,020	728,711	29,149	106	$2,446,019	$24,007,222
La Crosse	480,000	252,000	10,080	37	$806,682	$7,917,437
McGregor	2,083,700	1,093,943	43,758	160	$2,686,635	26,368,828
Dubuque	1,046,300	549,308	21,972	80	$1,192,437	$11,703,546

Savannah	285,000	149,625	5,985	22	$295,719	$2,902,426
Clinton	1,234,980	648,365	25,934	95	$1,188,997	$11,669,783
Davenport	1,074,220	563,966	22,559	82	$968,442	$9,505,075
Muscatine	379,000	198,975	7,959	29	$342,969	$3,366,179
Keithsburg	1,138,630	597,781	23,912	87	$852,196	$8,364,148
Burlington	1,519,950	797,974	31,919	116	$1,085,883	$10,657,737
Keokuk	900,000	472,500	18,900	69	$548,062	$5,379,129
Hannibal	166,000	87,150	3,486	13	$66,074	$648,501

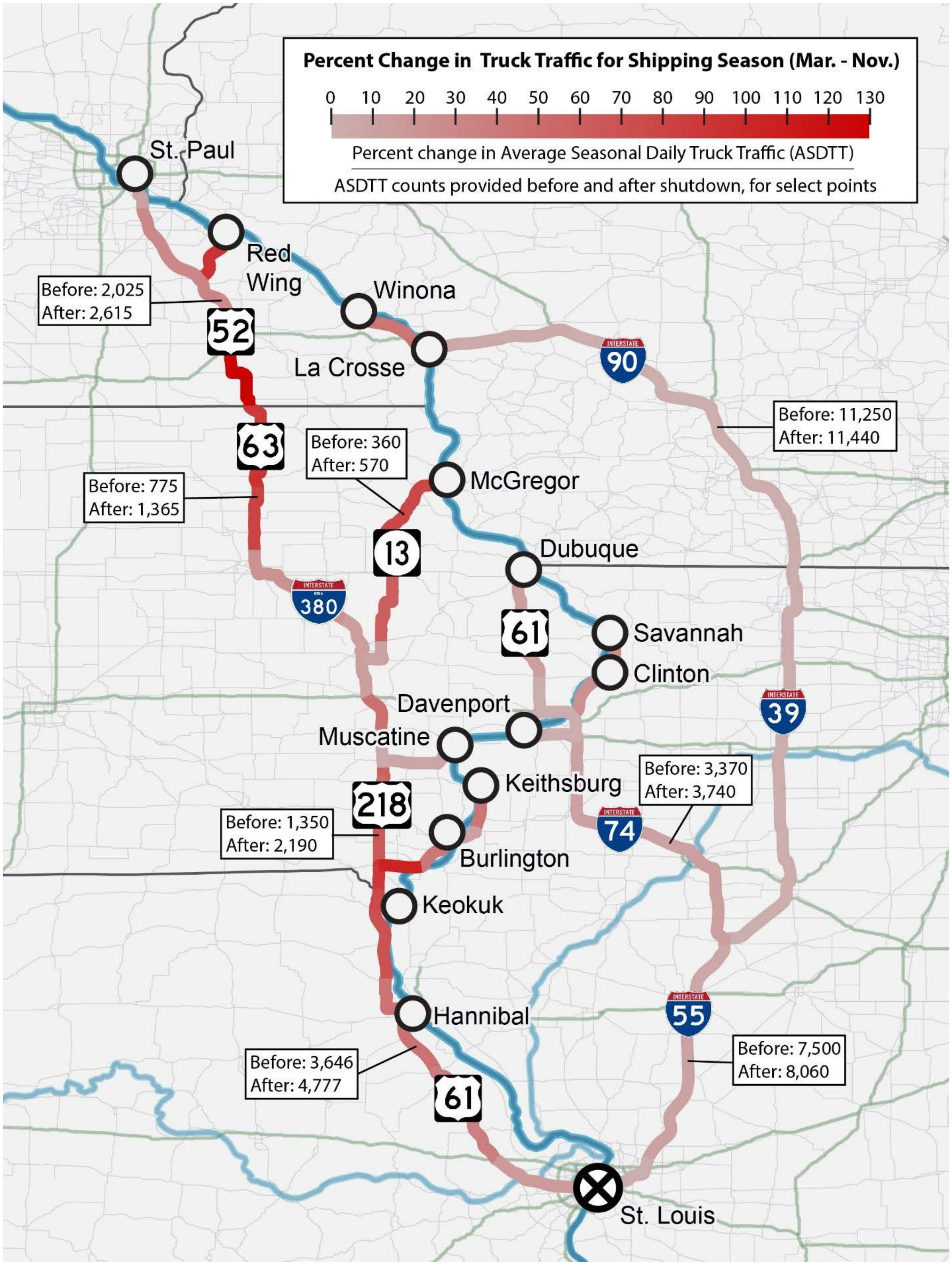
Next, the cumulative impacts of shutdown were calculated. These impacts demonstrate that that the consequences of a lock failure compound as increased areas of the river are impacted. Further, a failure on the lower portion of this system would likely impact all upstream loading as assumed costs go to load a barge, move downstream and then unload and load onto trucks would prove prohibitive.

Table 4.4 – North-South Cumulative Impacts of Lock and Dam Failure

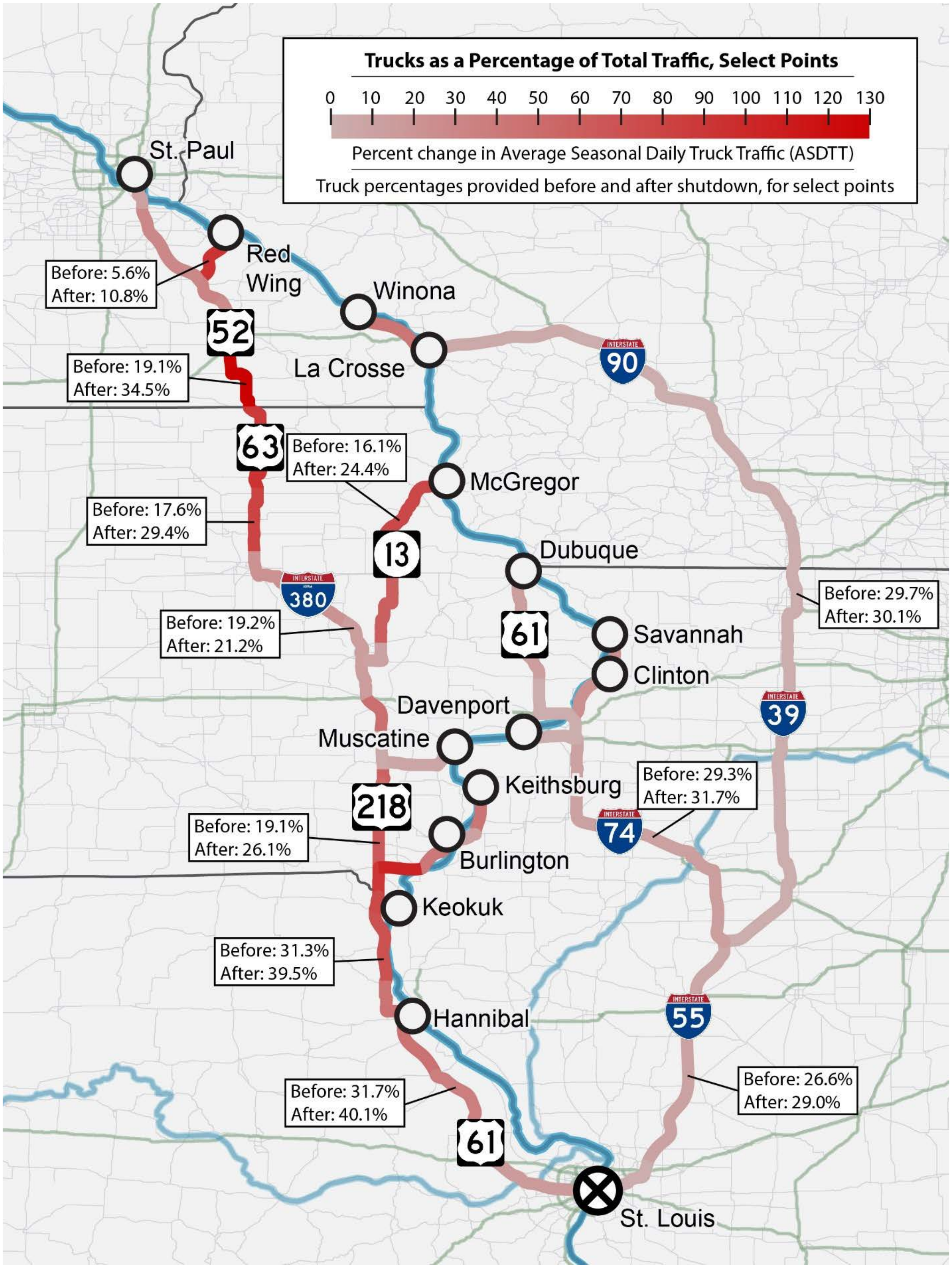
	Truck Tons		Truck Loads		Damage Cost		Trucking Cost	
Scenario	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
St. Paul	2,957,220	2,217,915	118,289	88,717	$8,680,742	$6,510,556	$85,199,874	$63,899,905
Red Wing	4,050,340	3,037,755	162,014	121,510	$12,201,200	$9,150,900	$119,752,523	$89,814,392
Winona	5,021,954	3,766,466	200,878	150,659	$15,462,559	$11,596,919	$151,762,152	$113,821,614
La Crosse	5,357,954	4,018,466	214,318	160,739	$16,538,135	$12,403,601	$162,318,734	$121,739,050
McGregor	6,816,544	5,112,408	272,662	204,496	$20,120,316	$15,090,237	$197,477,171	$148,107,878
Dubuque	7,548,954	5,661,716	301,958	226,469	$21,710,231	$16,282,673	$213,081,898	$159,811,424
Savannah	7,748,454	5,811,341	309,938	232,454	$22,104,523	$16,578,392	$216,951,799	$162,713,849
Clinton	8,612,940	6,459,705	344,518	258,388	$23,689,852	$17,767,389	$232,511,510	$174,383,632
Davenport	9,364,894	7,023,671	374,596	280,947	$24,981,107	$18,735,831	$245,184,943	$183,888,707
Muscatine	9,630,194	7,222,646	385,208	288,906	$25,438,400	$19,078,800	$249,673,182	$187,254,886
Keithsburg	10,427,235	7,820,426	417,089	312,817	$26,574,661	$19,930,996	$260,825,380	$195,619,035
Burlington	11,491,200	8,618,400	459,648	344,736	$28,022,505	$21,016,879	$275,035,696	$206,276,772
Keokuk	12,121,200	9,090,900	484,848	363,636	$28,753,254	$21,564,941	$282,207,868	$211,655,901
Hannibal	12,237,400	9,178,050	489,496	367,122	$28,841,353	$21,631,015	$283,072,536	$212,304,402



Map 4.1 - Downstream Agricultural Tonnage Magnitude and Accumulation



Map 4.2 - Changes in Truck Traffic by Origin



Map 4.3 - Changes in Truck Percentage of Total Traffic by Origin

Impacts of a Shift to Trucking

With the help of maps, trends for the region emerge. The largest percent increases occur in rural Minnesota and Iowa, where relatively less-traveled U.S. and State Highways could see a large increase in truck traffic. Highways between Rochester, Minnesota, and Waterloo, Iowa will see some of the greatest percent increases, as will Iowa highway 13 from McGregor to Cedar Rapids, and Minnesota highway 58 from Red Wing to Zumbrota. By contrast, roads on the eastern bank of the Mississippi will see less impact. This is due to a relatively lower amount of tonnage shipped from ports that would use these routes, and relatively higher preexisting truck traffic counts, especially on the interstate corridors of I-74, I-39, and I-55.

A similar trend emerges when examining truck traffic as a percentage of total traffic. The greatest increases in truck share occurred between Rochester, Minnesota and Waterloo, Iowa. Large increases also occurred on US-61 in Missouri, where the combined tonnage of eight ports put an additional 335,259 trucks on the road.

Across the region, based on the calculated one-season shutdown of Lock and Dam 25, between 9.1 and 12.4 million tons of agricultural goods would be displaced. The equivalent is between 367,000 and 489,000 truckloads. It would cost between $212.3 and $283 million to move these loads by truck, and damage from these movements could cost states between $21.6 and $28.8 million. This analysis only examined the impacts of downbound agricultural commodities. As shown in previous studies, the true cost of a river shutdown would be much greater, as it would raise the cost of shipping for multiple commodities and reduce the economic competitiveness of the Upper Midwest.

Comparing the Value of Investments

These diversion, truck load and cost numbers serve as a potential base when comparing the value of dissimilar infrastructure investments. The $21.6-$28.8 million damage cost estimate found using a marginal damage cost of $0.16 per truck per mile could serve as a starting point. By comparison, the backlog of maintenance for the Mississippi and Illinois rivers is $1 billion. To examine the value or cost of one shipping season of a total shut down with trucks carrying 100% of the load, total damage estimates, trucking costs and social costs are estimated at $319,562,593. The maintenance backlog for the Upper Mississippi River is estimated at $1,000,000,000. Table 4.5 below also includes the social cost of carbon.

Table 4.5 - Total Costs of Closure for Scenario 1

Scenario	100% to Truck
Truck Tons	12,237,400
Truck Loads	489,496
Pavement Damage Estimate ($)	$28,841,353
Increased Cost to Trucking ($)	$283,072,536
Additional Tons (CO_2)	212,464
Social Cost of CO_2 ($ at $36/ton)	$7,648,704
Total Estimated Cost to 100% Truck Displacement ($)	**$319,562,593**
Maintenance Backlog Upper Mississippi River	**$1,000,000,000**

Under the 100% truck scenario with a Hannibal closure, it would take under 4 shipping seasons to account for the maintenance backlog. If two, or three facilities were to fail in the following years, then the entire $1,000,000,000 maintenance backlog for the Upper Mississippi River could be accounted for in two shipping seasons or earlier. The point being that investment is necessary in all of our modes to avoid the lumpy and costly logistics mistakes of rebalancing where and how freight moves.

What do we want to say about comparing investments?

In the future, applying the Highway Economic Requirements System-State Version (HERS-ST), as demonstrated in Kruse et al, 2007, to multiple cities along the river could provide more in-depth cost estimates of specific lock and dam failures. Further, developing simple but regionally-specific models, Matrix decision models, and spreadsheet that can be used in agencies to support decision in a multimodal environment.

As an addendum to this effort, national probe performance data could provide a baseline on truck and corridor performance, and be compared to truck and corridor performance with the additional trucks.

The Army Corps of Engineers estimates that maintaining the control structures of the Upper Mississippi and Illinois rivers costs $115 million, annually, and yields $1 billion in transportation cost savings (US Army Corps of Engineers, 2016). Looking toward the future, inland waterway tonnages are expected to increase by 23% from 2010 to 2050 (HDR, 2013). Additional investment in the Upper Mississippi's infrastructure will be needed to maintain the system and accommodate future growth.

Currently, 54% of the infrastructure on the Upper Mississippi River is more than 50 years old and 36% are more than 70 years old. Fix as fail is not a viable long-term solution given the importance of agricultural exports to the five Upper Mississippi states.

Table 4.6 - Age and Condition of Lock and Dams

Lock and Dam	Year Completed	Last Rehab Work	20 Year Capital Investment Plan			
			Facilities	New or Rehab	Cost ($M 2010)	Investment Phase
2	1948	1995	L&D	Rehab	60	3
3	1938	1991	L&D	Rehab	60	3
4	1935	1994	L&D	Rehab	60	3
5	1935	1998	L&D	Rehab	60	3
6	1936	1999	L&D	Rehab	60	3
7	1937	2002	L&D	Rehab	60	3
8	1937	2003	L&D	Rehab	60	3
9	1937	2006	L&D	Rehab	60	3
10	1937	1969	L&D	Rehab	60	3
11	1934	2009	Not listed in plan			
12	1938	2009	L&D	Rehab	60	3
13	1939	1996	L&D	Rehab	60	3
14	1939	2011	L&D	Rehab	70	3
15	1932	1996	L&D	Rehab	70	3
16	1937	N/A	L&D	Rehab	70	3
17	1937	N/A	L&D	Rehab	70	3
18	1935	N/A	L&D	Rehab	70	3
19	1957	2008	L&D	Rehab	70	3
20	1933	1991	L	New	269.5	2
21	1935	N/A	L	New	394.5	2
22	1935	N/A	L	New	304.5	2
24	1940	2005	L	New	379	2
25	1939	1999	L&D	New	436	2
26	1989	N/A	L&D	Rehab	60	3
27	1953	N/A	Not listed in plan			
			Investment Plan Cost:		$2,923.5 million	

*Lock and Dam 23 was never built.

20-year capital investment plan numbers are from this USACE report: http://www.iwr.usace.army.mil/Portals/70/docs/Wood_doc/IMTS_Final_Report_13_April_2010_Rev_1.pdf

Map 4.4 - Upper Mississippi Locks and Dams (US Army Corps of Engineers, n.d.)

5. Conclusion:

The Upper Mississippi River is a crucial marine transportation asset for the Upper Midwest. Delayed investment and maintenance of the Lock and Dam infrastructure that supports the Upper Mississippi is a major threat to the region's economic security. Previous research has focused on how a shutdown of the river may affect the economy of the region, and how shipments might shift to rail and coastal ports. This study expanded this body of knowledge by asking what the impact to the region's roads would be if 100% or 75% of the Upper Mississippi's downbound agricultural commodities shifted to truck, and traveled to St. Louis. Between 367 and 489 thousand truckloads would be generated, and, if enough trucks and drivers were available, shipping costs for trucking would range between $21 and $28 million. Rural highways on the western side of the river would experience the greatest increases in truck traffic, and greatest increases in trucks as a share of total traffic.

Increased investment in marine infrastructure can mitigate increased highway maintenance costs through increased modal share and reduced pavement damage and safety issues. If we are unable to develop polices and funding programs to support our entire system as a system, then logistics costs, system reliability and a treadmill of short term funding and infrastructure solutions will be needed to patch the transportation infrastructure and our economy. This drag on the Nation's economy will prove difficult given the overall lack of infrastructure investment in all critical public freight areas – the marine mode, highway mode, aviation, and rail.

Appendix A - References

Duchschere, Kevin. “First Tows of Year Reach Hastings, Opening River Navigation Season.” *Star Tribune*, March 25, 2015. Accessed October 25, 2017. http://www.startribune.com/first-tows-of-year-reach-hastings-opening-river-navigation-season/297527601/

Gossardt, Ted, Larry Bray, and Mark Burton. “Inland Navigation in the United States: An Evaluation of Economic Impacts and the Potential Effects of Infrastructure Investment.” University of Kentucky. December 2014. Accessed October 25, 2017. http://www.nationalwaterwaysfoundation.org/documents/INLANDNAVIGATIONINTHEUSDECEMBER2014.pdf.

Hajek, Jerry, Susan Tighe, and Bruce Hutchinson. “Allocation of Pavement Damage Due to Trucks Using a Marginal Cost Method.” *Transportation Research Record,* Vol. 1613. Washington D.C. Transportation Research Board, 2014. Accessed October 25, 2017. http://trrjournalonline.trb.org/doi/abs/10.3141/1613-07

HDR Engineering, Inc. “U.S. Inland Waterway Modernization Reconnaissance Study.” *Iowa Department of Transportation*. April 2013. Accessed August 29, 2017. https://iowadot.gov/systems_planning/freight/TIGER_docs/IowaDOT_UMR_Waterway%20Modernization%20Study.pdf

Institute for Water Resources. *Waterborne Commerce of the United States, Part 2–Waterways and Harbors Gulf Coast, Mississippi River System and Antilles*. U.S. Army Corps of Engineers, IWR-WCUS-11-2. 2011. Accessed August 30, 2017. http://www.navigationdatacenter.us/wcsc/pdf/wcusmvgc11.pdf

Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866*. August 2016. Accessed October 25, 2017. https://19january2017snapshot.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf

Iowa Department of Transportation. “Compare…” May 12, 2016. Accessed August 29, 2017. https://iowadot.gov/compare.pdf

Kruse, James, Zafarbek Ahmedov, Bruce McCarl, Ximing Wu, and James Mjelde. *America’s Locks & Dams: “A Ticking Time Bomb for Agriculture?”* College Station, Texas. Texas Transportation Institute, December 2011. Accessed October 25, 2017. http://unitedsoybean.org/wp-content/uploads/Americas_Locks_And_Dams.pdf

Kruse, James, Annie Protopapas, and Leslie Olson. *A Modal Comparison of Domestic Freight Transportation Effects on the General Public*. College Station, Texas. Texas Transportation Institute, December 2007. Accessed October 25, 2017. https://www.marad.dot.gov/wp-content/uploads/pdf/Phase_II_Report_Final_121907.pdf

Luskin, David, and C. Michael Walton. “Effects of Truck Size and Weights on Highway Infrastructure and Operations: A Synthesis Report.” Austin: Center for Transportation Research, 2001. http://ctr.utexas.edu/wp-content/uploads/pubs/2122_1.pdf

Meyer, Seth, Luis Fellin, and Peter Stone. *Impact of a Lock Failure on Commodity Transportation on the Mississippi or Illinois Waterway*. University of Missouri - Columbia: Food and Agricultural Policy Research Institute, September 2007.

Mid-America Freight Coalition. *Understanding Freight Vehicle Pavement Impacts: How Do Passenger Vehicles and Trucks Compare*. Madison, Wisconsin. National Center for Freight and Infrastructure Research and Education, 2014. Accessed September 5, 2017. http://midamericafreight.org/wp-content/uploads/ESALs.pdf

Russell, Eugene R., Sr., Michael W. Babcock, and Curtis Mauler. "A Methodology for Determining Road Damage Due to Railroad Branchline Abandonment*." Semisequicentennial Transportation Conference Proceedings.* Ames, Iowa. Iowa State University, May 1996. Accessed October 25, 2017. http://www.ctre.iastate.edu/pubs/semisesq/session4/russell/index.htm

US Army Corps of Engineers. *Backlog of Maintenance*. Rock Island: US Army Corps of Engineers, August 30, 2016. http://www2.mvr.usace.army.mil/projects/pubFactsheet/BacklogofMaintenance-MajorRehabilitationandMajorMaintenance-MississippiRiverIllinoisWaterwayLocksAndDams.pdf

US Army Corps of Engineers. [Map of Upper Mississippi River-Illinois Waterway] *US Army Corps of Engineers, Rock Island District*. Accessed October 23, 2017. http://www.mvr.usace.army.mil/Portals/48/docs/CC/2013_Flood/UMR-IWWSystemMap.jpg

U.S. Department of Transportation, Bureau of Transportation Statistics. "Chapter 2 Freight Moved in Domestic and International Trade." *Freight Facts and Figures 2015*. Washington, DC. 2015. Accessed August 30, 2017. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/data_and_statistics/by_subject/freight/freight_facts_2015/chapter2

U.S. Department of Transportation, Bureau of Transportation Statistics. Table 2-1 Weight of Shipments by Transportation Mode: 2007, 2013, and 2040". *Freight Facts and Figures 2015*. Washington, DC. 2015. Accessed August 30, 2017. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/data_and_statistics/by_subject/freight/freight_facts_2015/chapter2/table2_1

Yu, Edward, Burton English, and R. Jamey Menard. *Economic Impacts Analysis of Inland Waterways Disruptions on the Transport of Corn and Soybeans*. Staff Report #AE16-08. Department of Agricultural and Resource Economics, University of Tennessee. September 2016. Accessed October 25, 2017. https://ag.tennessee.edu/arec/Documents/publications/EconomicImpactsInlandWaterwaysDisruptions092016.pdf

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