AMERICA'S LOCKS & DAMS: "A TICKING TIME BOMB FOR AGRICULTURE?"

FINAL REPORT

December 2011

Prepared by

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for
UNITED SOYBEAN BOARD

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EXECUTIVE SUMMARY

Background

Agriculture accounted for 22% of all transported tonnage and 31% of all ton-miles in the United States in 2007.[1] The surface transportation system in the U.S. is central to agriculture's ability to compete in domestic and world markets. The rapidly deteriorating condition of the nation's lock and dam infrastructure imperils the ability of the waterborne transportation system to provide a service that will enable U.S. agricultural producers to continue to compete. Should a catastrophic failure of lock and dam infrastructure occur, agricultural producers—and consequently the American consumer—will suffer severe economic distress. This research analyzed and evaluated data and information that will illustrate this vulnerability at a micro level rather than the traditional macro level.

The task of transporting agricultural commodities from the farm to first handlers and processors and ultimately to domestic and international retail markets and ports requires a highly developed, integrated transportation network, of which marine transportation is a vital component. A high percentage of these commodities pass through one or more locks on their way to market. Should a waterway be closed due to one or more lock failures, the resultant increase in costs that would be incurred in utilizing truck or rail transportation would decrease or even eliminate the cost advantage of U.S. Midwestern producers. This would be especially detrimental to export shipments. From 2005 through 2009, 87–91% of corn exported through lower Mississippi ports arrived at the ports via barge; for soybeans, the percentage was 87–89%.[2]

This research examined the condition of locks on key segments of the nation's waterways, analyzed their usage, determined which are most likely to suffer catastrophic failure, and estimated the impact at the local level based on projected freight flows. The geographical scope of the research included:

- Upper Mississippi River: Locks 1-27, Upper and Lower St. Anthony Falls, Melvin Price, and Chain of Rocks Locks.
- Illinois River: Peoria Lock, LaGrange Lock.
- Ohio River: entire lock system from Pittsburgh, PA, to Cairo, Illinois.

[1] Denicoff, M., E. Jessup, A. Taylor, and D. Nibarger. 2010. Chapter 2: The Importance of Freight Transportation to Agriculture. In Study of Rural Transportation Issues, ed. M. Smith. United States Department of Agriculture and United States Department of Transportation, 18–114.
[2] Marathon, N., and M. R. Denicoff. 2011. Transportation of U.S. Grains: A Modal Share Analysis 1978–2007. U.S. Transportation Services Division, USDA Agricultural Marketing Service. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5090455 (accessed May 1, 2011), and USDA-AMS. Grains Inspected and/or Weighted for Export by Region and Port Area Reported in Calendar Years 2005–2009.

Based on analytical work reported in Chapter 3, six locks were chosen for detailed analysis. They were chosen based on their economic importance and physical condition. The six locks are:

- Illinois River LaGrange Lock and Dam.
- Ohio River Emsworth Lock and Dam.
- Ohio River Markland Lock and Dam.
- Ohio River Olmsted Lock and Dam (replacement for L&D 52 and 53).
- Upper Mississippi River Lock and Dam 20.
- Upper Mississippi River Lock and Dam 25.

Chapter 1: Lock Volumes/Values and Modal Splits for Future Flows

Chapter 1 documents the following waterway-specific information:

- Current freight flows, in terms of volume and value (2008–2010).
- Future estimates of freight flows, in terms of volume and value.
- Modal split estimates for future freight flows.

The Ohio River has the highest total commodity flow, followed by the Upper Mississippi and Illinois Rivers. The share of each commodity group of the total freight flow varies across rivers and time of year. For instance, coal is the major commodity transported on the Ohio River in terms of volume; it represents 59% of total freight volume and approximately 55% of that volume is upbound. Grain flows become more prevalent in the lower reaches of the river. However, in terms of value, the petroleum products category dominates, with coal being the second largest value group.

Grain, particularly corn and soybeans, is the dominant freight movement on the Upper Mississippi River in terms of both volume and value throughout all reaches of the river. The transportation volume of petroleum products is relatively insignificant compared to grain and other commodity groups except in the lower reaches of the Upper Mississippi River—in the St. Louis area—where it increases.

Coal and petroleum product movements make up almost the entire freight flow at the upstream end of the Illinois River, within the Chicago suburbs; grain flows in this segment of the river are almost nonexistent. Once the river exits the Chicago area, corn and soybeans begin to appear in the traffic statistics. In terms of values, the petroleum products group shows the highest value on the upper river and grain shows the highest value on the lower reaches.

Grain is mainly transported downstream on all rivers. Coal is primarily shipped upstream on the Upper Mississippi River, it is primarily downbound on the Illinois River (60%), and it is slightly more upbound than downbound (55% vs. 45%) on the Ohio River. The flow of petroleum products seems to be fairly balanced between upbound and downbound movements on all three rivers.

The variability in the volumes of individual commodity groups on each river throughout the year reflects seasonality patterns in their primary consumption. The Ohio River exhibits a steady stream of commodity flows throughout the year due to the sizeable share of energy commodities. The Upper Mississippi River exhibits the highest fluctuations in the total volume of commodity flows due to corn and soybeans being the principal commodities transported. The volume of grain shipments rises significantly during the summer months and the second half of the fall season. The variability in the volume of commodity flows on the Illinois River is not as pronounced as in the case of the Upper Mississippi River.

The models employed in the research indicate an expected persistent increase in the values of freight for the coming decade. The predicted growth is particularly strong for the Upper Mississippi and Ohio Rivers, for which the total values are shown to overtake historical highs by 2015 and continue increasing beyond that point. For the Illinois River, model results indicate that the total values will overpass their historical high at the end of this decade.

By 2050, nation-wide transportation of grain is projected to increase by 5.5 million and 9.6 million tons by truck and rail, respectively, whereas barge transportation is projected to decrease by nearly 15 million tons. The total share of truck changes from 22% in the base year to 24% in 2050, from 53% to 58% for rail, and from 25% to 18% for barge. These changes in modal transportation shares are primarily because of potential climate change effects and will affect various regions of the country differently over time.

Chapter 2: Lock Operational Statistics and Wait Times

Chapter 2 provides the following lock- and commodity- specific information:

- Statistics for 10 years for total freight transiting locks.
- Statistics for 10 years for agricultural freight transiting locks.
- Statistics on average wait times at six focus locks:
    - Emsworth, Markland, and Lock 52 (Ohio River).
    - Lock 20 and Lock 25 (Upper Mississippi River).
    - LaGrange Lock (Illinois River).

Over the 11-year period 2000–2010, the highest volume of monthly freight transit occurred on the Ohio River with the Upper Mississippi River being second. On average, a lock on the Ohio River accommodated a total freight volume of 4.1 million tons per month. The average freight volumes on the Illinois and Upper Mississippi Rivers were 1.6 million and 1.7 million tons, respectively. In terms of consistency of freight transit, Illinois River locks had more stable freight flows than locks on the Upper Mississippi and Ohio Rivers, as indicated by their lower variability around their respective average monthly volumes. Downbound freight movements accounted for 44%, 63%, and 42% of total freight volumes on the Illinois, Upper Mississippi, and Ohio Rivers respectively.

During the 2000–2010 period, corn and soybean movements combined accounted for over 92%, 94%, and 82% of the total volume of grain movements by barge on the Illinois, Upper

Mississippi, and Ohio Rivers, respectively. The highest volume of total monthly corn and soybeans flows was recorded on the Upper Mississippi River with the Illinois River coming in second. On average, a lock handled 641,000 tons and 176,000 tons of corn and soybeans, respectively, each month on the Upper Mississippi River (both directions); 219,000 tons and 54,000 tons of corn and soybeans on the Illinois River (both directions); and 87,000 tons and 54,000 tons of corn and soybeans on the Ohio River (both directions). The average monthly volumes of downbound corn and soybeans at locks on all rivers are multiple times the corresponding volumes in the opposite direction.

The average monthly value of corn and soybeans handled at each lock during the 2000–2010 period was $59.6 million and $40.3 million for the Upper Mississippi River, $20 million and $11.7 million for the Illinois River, and $8.9 million and $13.1 million for the Ohio River.

All rivers showed a high level of variability in the monthly flow of corn and soybeans. This can be attributed to the seasonal nature of grain production and freezing during the winter season at the upstream end of the rivers.

The researchers analyzed congestion at the six focus locks for the past 10 years. There was wide dispersion in terms of waiting time at various locks. The proportion of zero waiting time ranged from 22% to as high as 70%. Average waiting times ranged between 63 minutes and 190 minutes, with an overall average of 132 minutes. The standard deviations are several magnitudes larger than the average waiting times, indicating considerable variability at the six focus locks. The maximum waiting time exceeded ten days, probably due to some unannounced lock closures.

The overall average waiting time in 2000 was around 150 minutes and declined to around 50 minutes in 2004, then increased in the following years, peaking in 2010 at more than 200 minutes. In both the annual and monthly average waiting times, Ohio River Lock 52 is a bottleneck lock for the following reasons: (1) it averages the highest waiting time; (2) it exhibits the most volatile seasonal variations; and (3) waiting times have increased substantially during the last few years.

Chapter 3: Lock Condition Information and Potential Modal Diversion Impacts

Chapter 3 provides the following information:

- Lock-specific assessments of the following:
    - Current operational condition of the lock.
    - Cost of maintaining or upgrading the lock and dam to a proper condition.
    - Locks most likely to experience catastrophic failure or severe impairment and with most significant level of potential impact on barge shipments.
- Potential ramifications of a theoretical modal shift resulting from waterway closures, including changes in volumes and costs, by mode, by lock, and in total.
- Assessment of the condition and capacity of the rail and highway systems to effectively accommodate potential increases in volume.

Currently, 54% of the Inland Marine Transportation System's (IMTS) structures are more than 50 years old and 36% are more than 70 years old. The age and increase in hours of outage are a concern. On the Ohio River, for example, navigation outages have increased more than 3-fold since 2000, going from approximately 25,000 hours to 80,000 hours.[3] There have been two recent failures: Markland Lock in 2009 (5 months) and Greenup Lock in 2010 (1 month). Delays and budget overruns have become so severe that they are causing other projects to lose funding or be delayed by a number of years (e.g., the Olmsted Locks and Dam Project on the Ohio River).

Much of the evaluation and prioritization work for maintenance and rehabilitation has already been done in a collaborative effort between navigation industry representatives and the U.S. Army Corps of Engineers (Corps) inland navigation experts. Six projects within the geographic study area were selected for detailed analysis as part of this research project. Combined cost estimates were roughly $4 billion, of which approximately less than half—$1.8 billion—has been funded to date. These projects are in various stages of completion.

Changes in modal splits and associated transportation costs by type of transportation mode were estimated under four different lock closure time horizons—two weeks, one month, whole quarter, and one year—for each of the six focus locks. In all scenarios, lock closures reduce the total volume (all modes combined) of domestic transportation of grain.

Though alternative transport modes will haul more grain in some of the regions to partially offset the reduced barge transport due to lock closures, the net effect is negative under any scenario. In all but one of the 24 scenarios, lock closure of any duration decreased the volume of domestic grain transported by barge, as well as the total volume transported by all three modes. The effect of lock closures on modal splits in grain transportation was not equal across the locks. However, the volume of domestic grain transportation by rail was projected to increase and the volume of truck transportation to decrease under most scenarios.

The overall cost of transportation for domestic-bound grain at a national level decreased under all scenarios due to the decreased volume of total shipments. However, substantial tonnage diversion to rail combined with the higher-than-barge rail rates increased the overall cost per unit. For instance, under a three-month lock closure scenario, the volume of rail transportation increases by nearly the same amount as the decrease in volume by barge (5.5 million tons). In this case, the cost of transporting 5.5 million tons of grain amounts to $137.5 million—a $71.6 million net increase in transportation cost over the base scenario.

Currently, rail capacity cannot be considered constrained. However, general demand for rail transportation (all commodities) is projected to grow at a fast rate through 2035. The resulting

[3] Background Memorandum, Hearing on "the Economic Importance and Financial Challenges of Recapitalizing the Nation's Inland Waterways Transportation System", U.S. House of Representatives Committee on Transportation and Infrastructure, September 16, 2011.

level of congestion would affect nearly every region of the country and would likely cause severe price adjustments and congestion delays without significant investment in railroad infrastructure or changes in modal allocations by shippers.

Federal government data in 2004 reported that over half of federal-aid highways are in less-than-good condition and more than one quarter of the nation's bridges are structurally deficient or functionally obsolete. Great deficiencies exist in funds to maintain and improve our nation's roads. A potential diversion of barge traffic to rail or long haul truck would further add to current or forecasted demand resulting in detrimental effects on our infrastructure and increasing costs to our economy.

Chapter 4: Economic Impact at Congressional District/Regional Level

Chapter 4 provides the following information:

- Impacts by Crop Reporting District (CRD) and Congressional District (CD) including:
    - Effect on agricultural commodity prices.
    - Effect on agricultural inputs.
    - Effect on energy prices.
- Profiles of mode use and costs for farmers, grain elevators, and soybean processors.

Four closure durations were modeled at five of the six focus locks (those with agricultural movements): two weeks, one month, one quarter, and one year.[4] A failure at any one of the focus locks would cost agricultural producers anywhere between $900,000 and $45 million, and result in lost revenues to barge companies between $2.2 million and $162.9 million, depending on duration.

The 10 most-affected CRDs were identified and the maximum drop in price to producers plus the maximum rise in price to grain consumers were also estimated. These included not only CRDs close to the river where the effects are primarily on producers, but also CRDs elsewhere that have substantial consumption by processing and feeding industries which would be affected by higher grain prices.

A closer examination of just one of the focus locks—LaGrange Lock on the Illinois River—reveals the wide-ranging nature of the economic impacts. The most vulnerable CRD to a failure of the LaGrange Lock on the Illinois River is Illinois CRD 20. Illinois CRD 20 is principally composed of Illinois CD 11; however, CDs 1, 2, 3, 6, 8, 9, 10, 13, 14, and 16 contain small parts of CRD 20. This CRD would lose $4.3 million and the price of corn would be reduced $0.70 per ton and the price for soybeans by $2.45 per ton. The second most vulnerable CRD would be Illinois CRD 10 with $3.1 million lost from a failure of the LaGrange Lock. Illinois CRD 10 is principally composed of CD 16 but CDs 11, 14, 17, and 18 also have parts of their area in this CRD. The third to the sixth most vulnerable CRDs were shown by the model to be consumption areas in

[4] Emsworth Lock is not included in the grain flow simulation model because no grain is transported through this lock.

North Carolina, Texas, California, and Georgia. All CRDs affected by all lock closures were mapped to the corresponding CDs in a similar fashion.

The model also allowed insights into incidence of the costs and effects on welfare distribution, costs, flows etc. that can be summarized as:

- International consumers have the most to lose.
- Barge companies lose significant revenue.
- Barge use is reduced and replaced by rail and small ship.
- The U.S. loses a small amount of export share.
- Cost of closure is about $1.50 per ton that traverses a lock.

The review of previous studies of lock closures and coal price percentage changes indicated that short-term closure of the Ohio River increases costs for coal shipments, but not dramatically. The energy sector has the ability to withstand short-term closures. Although there are general options for responses that are specific to each utility company and electricity generating plant, any combination of these responses will increase costs to the utility plants. Over a six-month closure, potential increases in wholesale costs were modeled to be a total of $129.9 million for New Jersey, Pennsylvania, and Massachusetts.

Annual figures for the production, storage, and demand for grain for a representative farmer, country grain elevator, and biofuels (biodiesel and ethanol) producer, respectively, were developed. The three CRDs most vulnerable to a lock closure and their associated CDs are identified for each of the focus locks. As an example, the table on the next page shows the three most vulnerable CRDs at Mississippi River Lock and Dam 25. For each CRD, the corresponding CDs are reported, with CDs that make up more than 25% of the land area of a CRD shown in red font.

Table ES.1. Profile of representative farmer, country grain elevator, and biofuels producer.

				SUPPLY		DEMAND	
Lock	CRD	Congressional District	Country Elevator Capacity (1000 T)	Average Farmer's Corn Production (1000 T)	Average Farmer's Soybean Production (1000 T)	Soybean for Biodiesel Production (1000 T)	Corn for Ethanol Production (1000 T)
Lock 25	IA CRD 20	01,04	116,878	1,099	209		852,426
Lock 25	IA CRD 90	02,03	116,878	964	233	64,206	604,762
Lock 25	IA CRD 60	01,02,03	116,878	1,118	212		1,687,360

CHAPTER 1
LOCK VOLUMES/VALUES AND MODAL SPLITS FOR FUTURE FLOWS

Current Volumes and Values

The freight data used for this analysis contain flow information on 37 commodity types. To facilitate the analysis, all commodities were grouped into four different categories in order of relevance to the study. The first group—grains—contains agricultural products such as wheat, corn, rye, barley, rice, sorghum, soybeans, flaxseed, and others. In addition, the volumes and values of corn and soybeans are also presented separately since they are the major commodities in the grains category. The second group—coal—contains commodities such as coal, lignite, and coke. The third group—petroleum—contains all petroleum products. The last group—Other—contains all other commodities and products. Each observation in the data shows the amount of freight by direction that transited each lock of the river during the month.

In Calendar Year 2010, the Ohio River had the largest amount of total commodity flows followed by the Upper Mississippi and Illinois Rivers. The total combined volume of freight flows in both directions through all locks on the Ohio River amounted to 1.04 billion tons. The Upper Mississippi and Illinois Rivers accounted for 486 million and 116 million tons, respectively. However, the share of each commodity group of the total freight flow varies across rivers and time of year. For instance, referring to Table 1.1, we can see that coal is the major commodity transported on the Ohio River; it represents 59% of total freight volume and approximately 55% of that volume is upbound. The share of coal sharply diminishes on the Illinois and Upper Mississippi Rivers. Grain, particularly corn and soybeans, is the major freight commodity on these two rivers, constituting almost half of the freight volume on the Upper Mississippi River and one-fifth of the freight volume on the Illinois River.

Table 1.1. Total Volume of Commodity Flows and Their Share by Group (Million Tons).

Year	River	Grain	Grain (%)	Coal	Coal (%)	Petroleum	Petroleum (%)	Other	Other (%)	Total
2010	IL	24	20%	13	11%	19	16%	60	52%	116
2010	MISS	236	48%	51	10%	19	4%	180	37%	486
2010	OH	49	5%	614	59%	58	6%	315	30%	1036
2008–10	IL	65	18%	42	11%	59	16%	197	54%	362
2008–10	MISS	668	47%	189	13%	56	4%	521	36%	1435
2008–10	OH	130	4%	1747	59%	185	6%	914	31%	2976

The variability in the volumes of individual commodity groups throughout the year reflects seasonality patterns. The Ohio River exhibits a steady stream of commodity flows throughout the year due to the sizeable share of energy commodities. The Upper Mississippi River exhibits the highest fluctuations in the total volume of commodity flows due to corn and soybeans being the principal commodities transported on the river (see Figure 1.2). The volume of grain flow rises significantly during the summer months and the second half of the fall season. The variability in the volume of commodity flows on the Illinois River is not as pronounced as in the case of the Upper Mississippi River (see Figure 1.3). The observed relative shares of individual commodity groups in the total volume of commodity flows on all rivers are very similar for the year 2010 and the 2008–2010 time horizon under consideration. Therefore, the figures show the average values for each month over the three-year period (2008–2010) to simplify their presentation.[5]

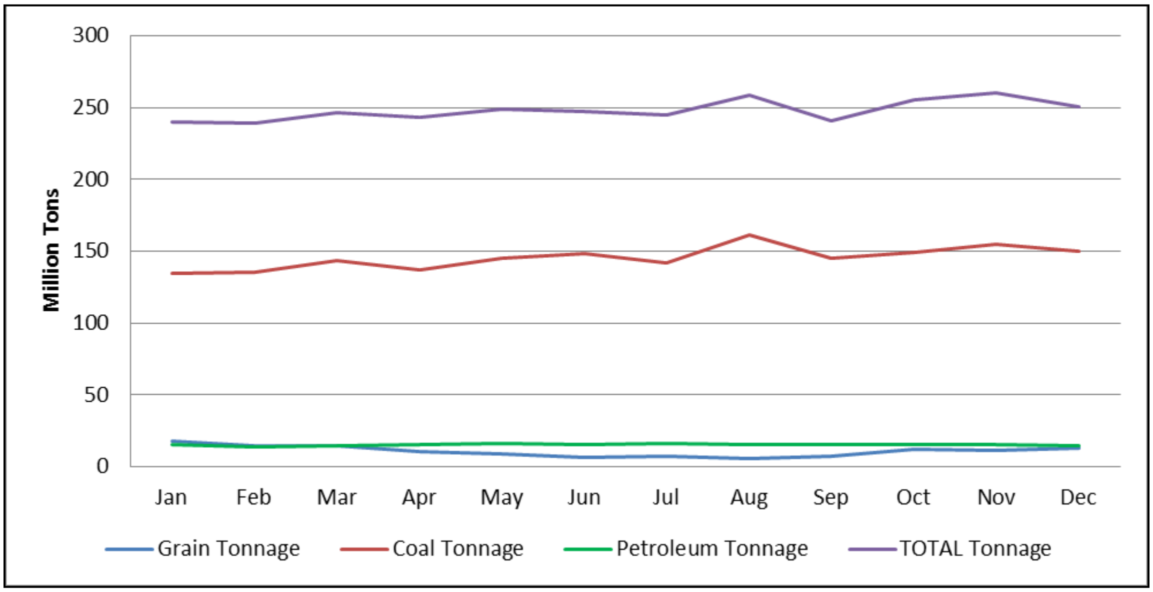

Figure 1.1. Total Volume of Commodity Flows in Both Directions on Ohio River during 2008–10.

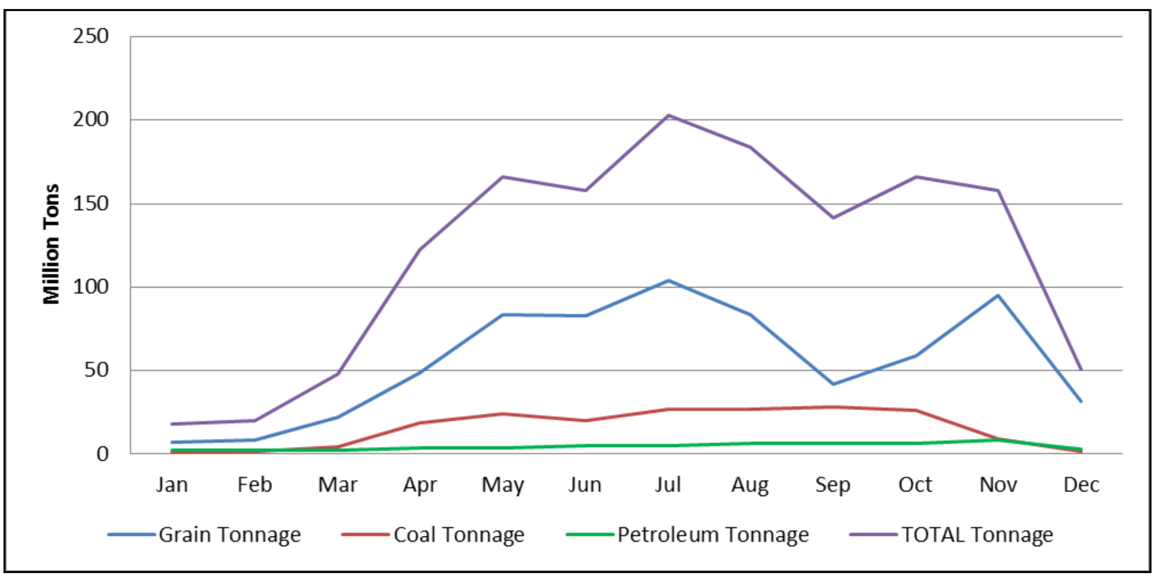

Figure 1.2. Total Volume of Commodity Flows in Both Directions on Upper Mississippi River during 2008–10.

[5] Throughout the four memos, unless noted otherwise, data depicted in tables and figures are based on the researchers' calculation from the lock traffic and tonnage data obtained from the Corps and other governmental and public sources specified in the text.

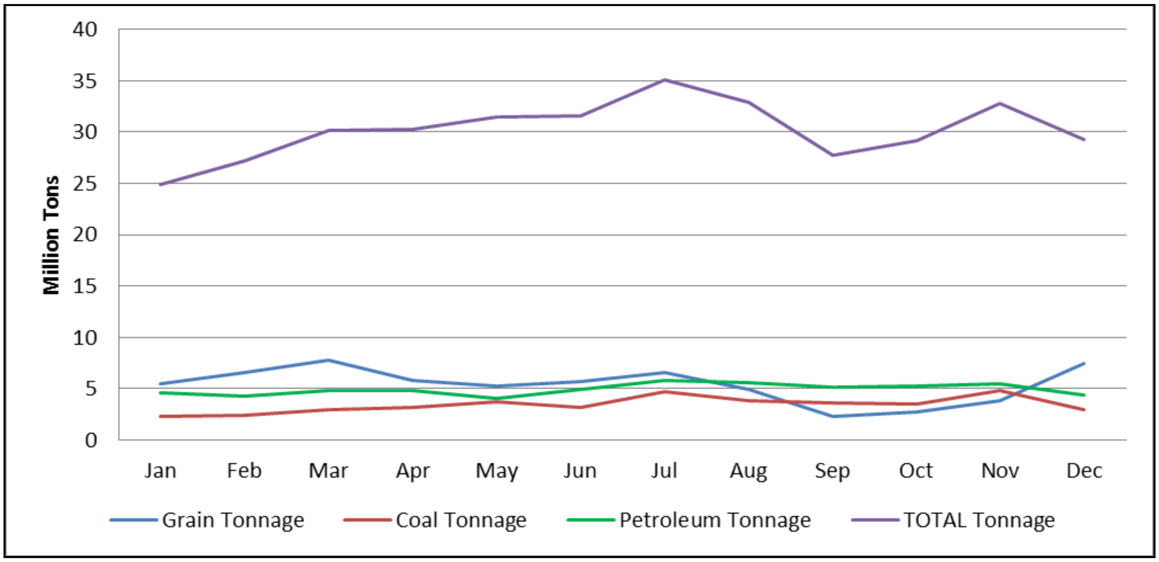

Figure 1.3. Total Volume of Commodity Flows in Both Directions on Illinois River during 2008–10.

Figure 1.4 through Figure 1.9 present the flow of commodity volumes and their corresponding values (both directions combined) at individual locks on the Illinois, Upper Mississippi, and Ohio Rivers for the period 2008 to 2010. The left-most lock on the graph represents the lock highest upstream on the river and the right-most lock represents the most downstream lock.

Figure 1.4 and Figure 1.5 present commodity flows and their values by commodity group passing through the locks on the Illinois River for the three-year period 2008 to 2010. At the upstream end of the Illinois River, within the Chicago suburbs, coal and petroleum product movements made up almost the entire freight flow, with the highest volume (over 10 million tons) at Dresden Island Lock (Grundy County, IL). Grain flows in this segment of the river are almost nonexistent. Once the river exits the Chicago area, corn and soybeans start entering the river in Grundy County. During the study period, grain flows dominated the traffic on the lower river, reaching over 26 million tons of corn and soybeans passing through LaGrange Lock, the last lock on the Illinois River. In terms of values, the petroleum products group shows the highest value on the upper river and grain shows the highest value on the lower reaches. The highest value of petroleum products was recorded at more than $1 billion at Dresden Island Lock and the combined value of corn and soybeans was estimated at $4.7 billion. Because coal is a low value bulk commodity, it does not play a major role in terms of cargo value on the Illinois River.

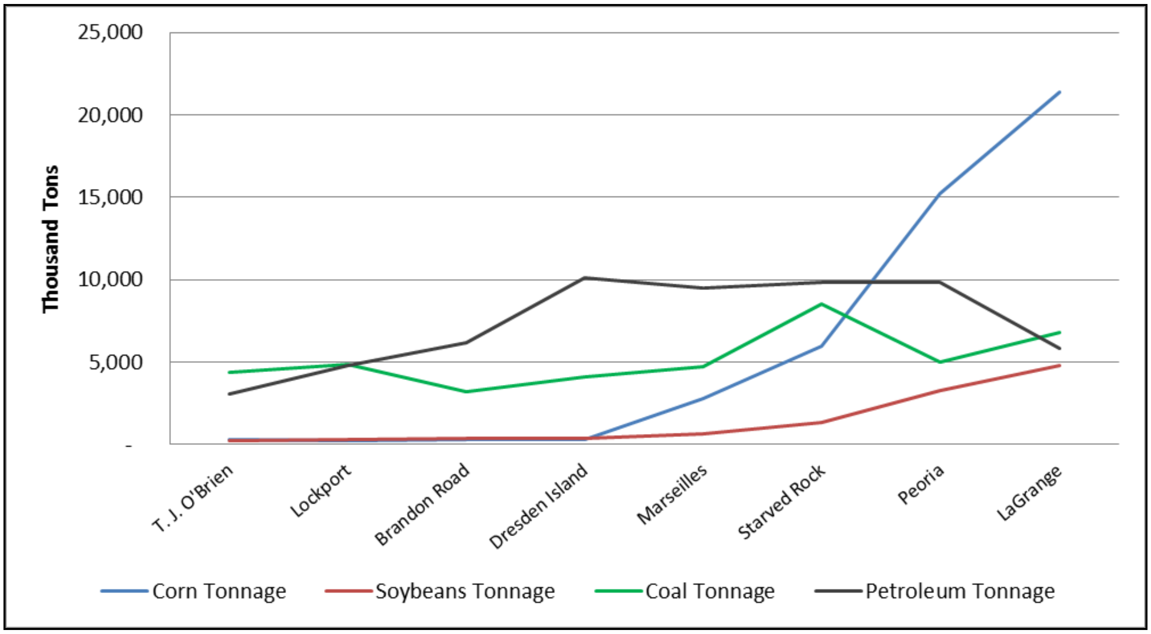

Figure 1.4. Commodity Volumes (Both Directions) at Illinois River Locks for 2008–2010.

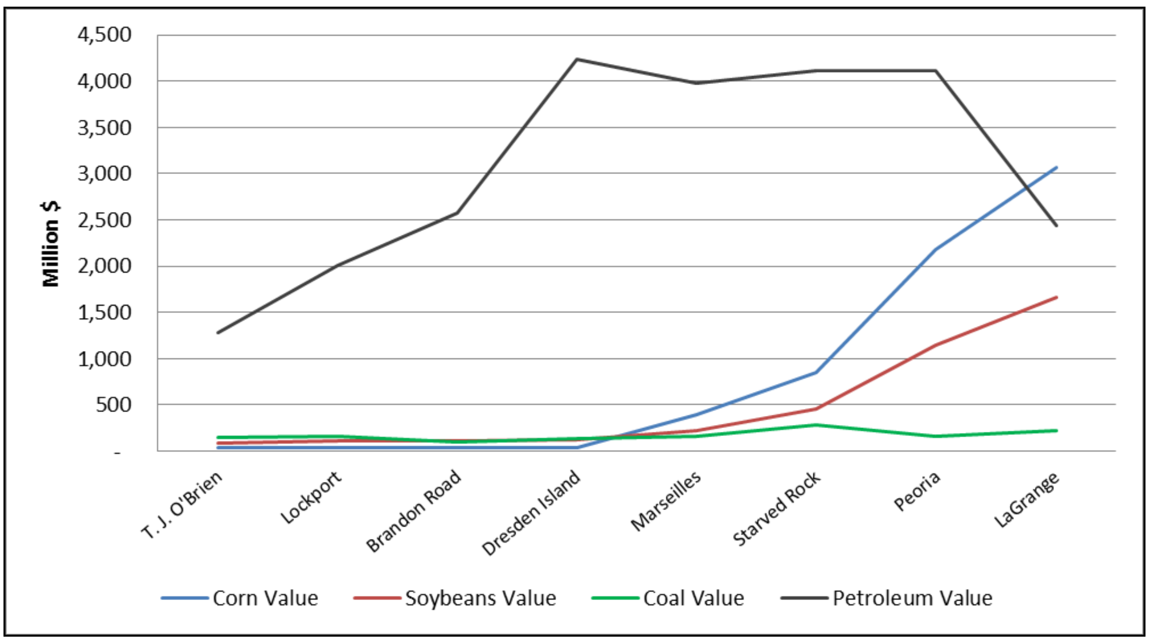

Figure 1.5. Commodity Values (Both Directions) at Illinois River Locks for 2008–2010.

Unlike the Illinois River, grain transportation on the Upper Mississippi River is the dominant freight movement in terms of both volume and value throughout all reaches of the river (see Figure 1.6 and Figure 1.7). For the three-year period 2008 to 2010, the volume of corn and soybeans passing through Melvin Price Lock amounted to 52.8 and 17.2 million tons, respectively, with corresponding values of $7.6 billion and $6.1 billion, respectively. Coal transportation is the second largest group by volume; however, it is the lowest in terms of value. The transportation volume of petroleum products is relatively insignificant compared to other groups until the lower reaches of the Upper Mississippi River, in the St. Louis area, where it increases. Despite its relatively low volume, the total value of petroleum products at Melvin Price Lock was estimated at $7.4 billion.

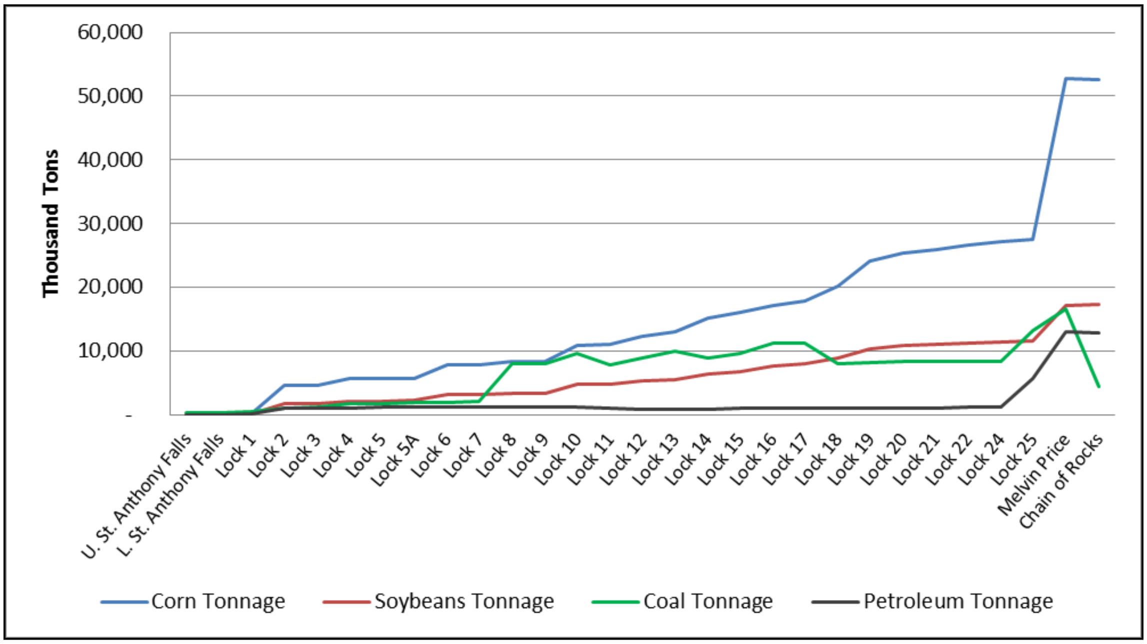

Figure 1.6. Commodity Volumes (Both Directions) at Upper Mississippi River Locks for 2008–2010.

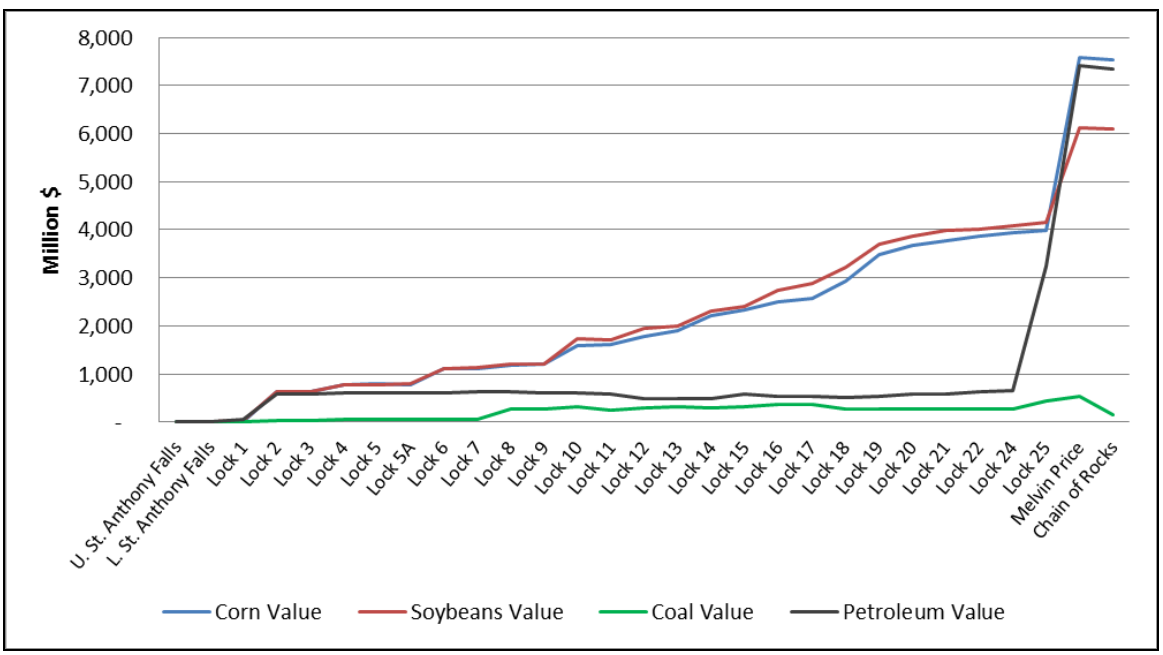

Figure 1.7. Commodity Values (Both Directions) at Upper Mississippi River Locks for 2008–2010.

Coal constitutes the dominant freight flow on the Ohio River. During 2008–2010, the volume of coal movements was a high percentage of tonnage at all locks on the river (see Figure 1.8). Its three-year volume of 131.6 million tons reached its highest point at Cannelton Lock. Petroleum products account for the second largest movement until the lower reaches of the river where grain flows become dominant. However, in terms of value, the petroleum products category dominates over all other categories, with coal being the second largest value group (see Figure 1.9). For example, $11.2 billion worth of petroleum products passed through Greenup Lock during this period.

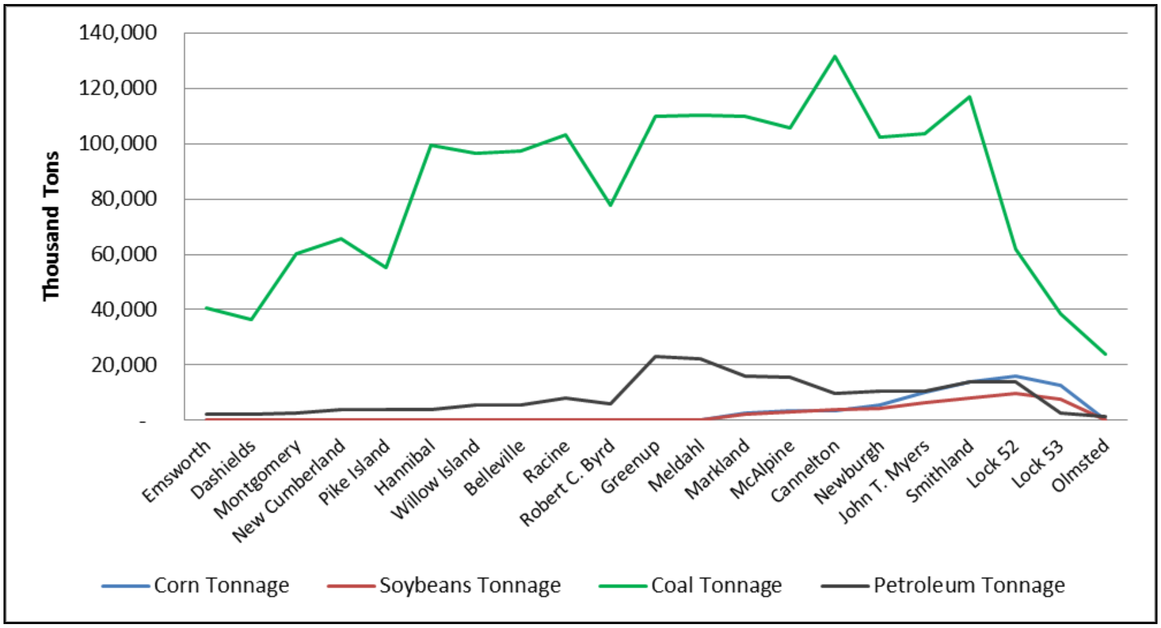

Figure 1.8. Commodity Volumes (Both Directions) at Ohio River Locks for 2008–2010.

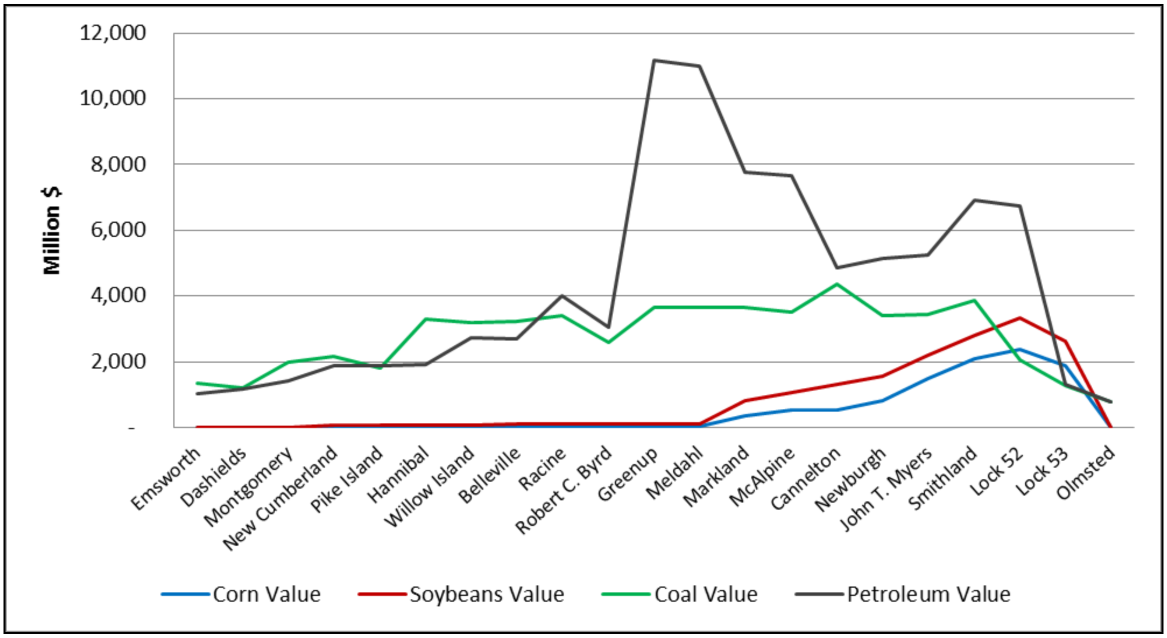

Figure 1.9. Commodity Values (Both Directions) at Ohio River Locks for 2008–2010.

Observed commodity flows by direction at the locks vary substantially among the rivers. Table 1.2 shows the volume of freight flows by direction (upbound or downbound) for each river for 2008–2010. Grain is mainly transported downstream on all rivers and coal is primarily shipped upstream with the exception of the Illinois River. The flow of petroleum products seems to be fairly balanced between upbound and downbound movements on all three rivers.

Table 1.2. Freight Movements by Direction for Each River, 2008–2010 (Million Tons).

River	Grain		Coal		Petroleum	
	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound
IL	59	5	25	17	35	24
MISS	658	11	24	165	39	27
OH	113	18	789	958	88	97

Because the values in Table 1.2 represent total upbound and downbound freight flows for the entire river, they do not fully describe the dynamics of freight flows by direction at individual locks. Figure 1.10 through Figure 1.12 below provide this flow dynamic by commodity group and lock for 2008–2010. Solid lines in the graphs represent downbound flows; dotted lines represent upbound flows. On the Illinois River, grain shipments are almost entirely downbound; other groups do not have such disproportionate freight flows. The same pattern of grain shipments is observed on the Upper Mississippi River with a significant upbound movement (compared to downbound) of coal up to Lock 8 (Houston County, MN). The volume of coal shipments was high in both directions on the Ohio River; most of these shipments seem to be unloaded at Meldahl, Markland, McAlpine, Cannelton, Newburgh, and John T. Myers locks. This is an area between Cincinnati, OH, and Louisville, KY. Downbound grain shipments on the Ohio River predominate, just as they do on the other rivers.

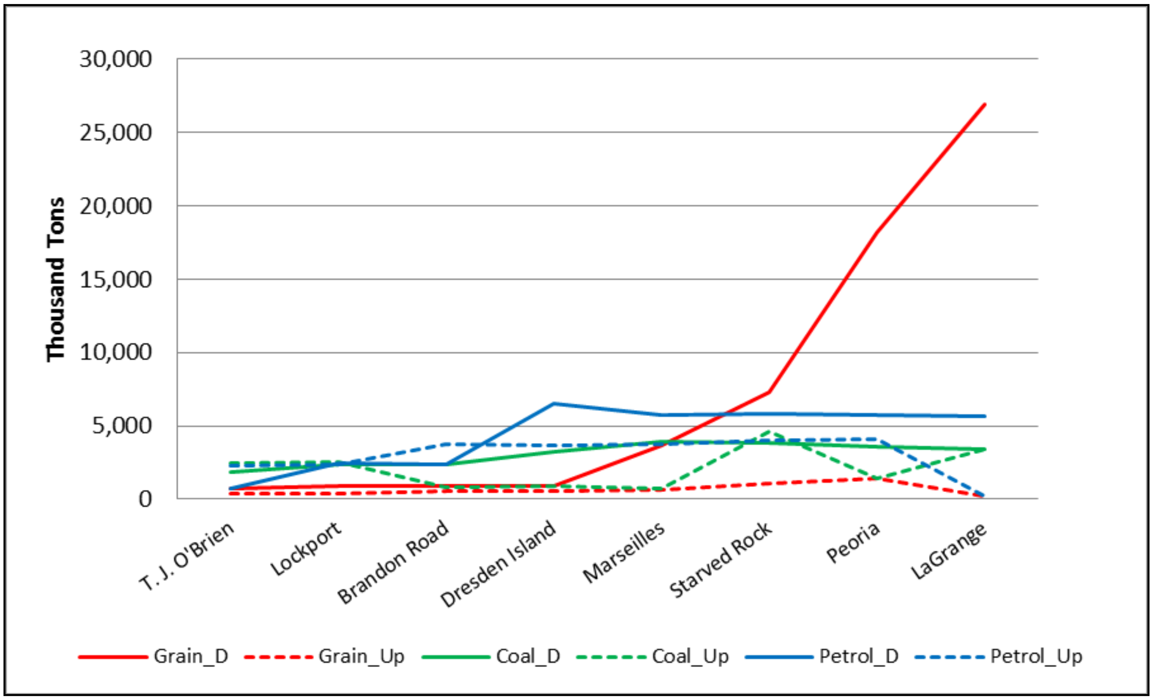

Figure 1.10. Commodity Movements through Illinois River Locks during 2008–2010.

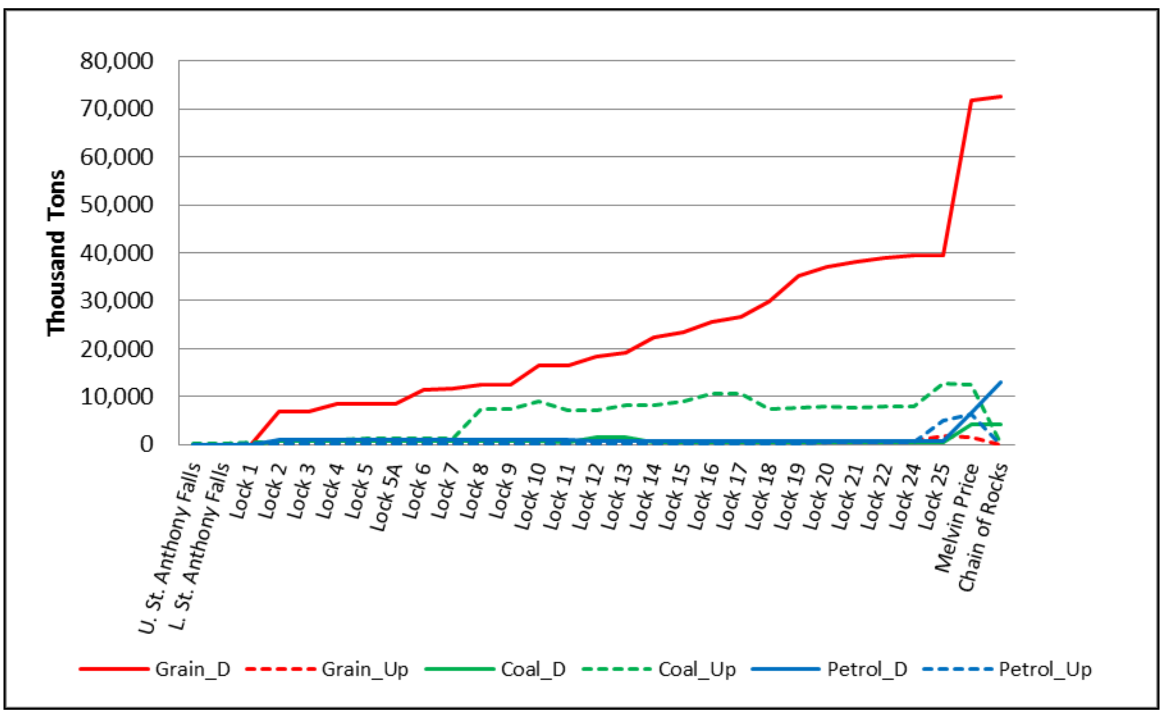

Figure 1.11. Commodity Movements through Upper Mississippi River Locks during 2008–2010.

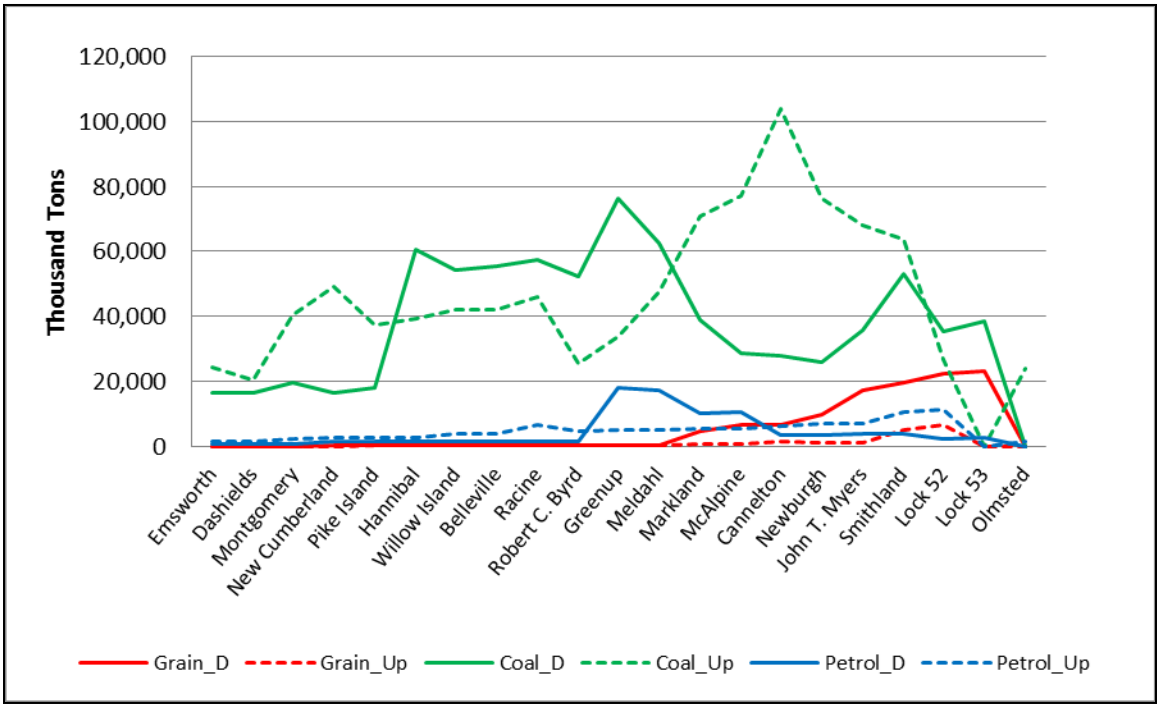

Figure 1.12. Commodity Movements through Ohio River Locks during 2008–2010.

Estimated Future Volumes and Values

Reliable estimates of future freight volumes and values cannot be obtained without careful analysis of historical data. We use structural analysis and time series models for this task. In particular, structural analysis with explanatory variables models the relationship between the outcome of interest (freight volumes in our case) and some possible contributing factors. The insight obtained from structural analysis then facilitates our forecasting based on the estimated models and our projection of the development of identified contributing factors in our model. In contrast, time series techniques, such as the flexible ARIMA (Auto-Regressive Integrated Moving Average) models, contend that the impacts of contributing factors are best encapsulated by the realized time series. Thus, careful modeling of deterministic and stochastic trends and seasonal behaviors of the time series data might offer a more complete picture, especially given the fact that many possible contributing factors cannot be easily measured or are simply not known to the researchers.

Either method has its own share of pros and cons. As far as forecasting is concerned, a key distinction between these methods is that unless there are leading indicators, forecasting into the future with structural analysis requires projection of contributing factors. On the other hand, time series models project the future based on the history of the series, and no explicit use of explanatory variables is required. (In principle, we can include explanatory variables into time series models. This inclusion, however, is oftentimes redundant since the impacts of these factors are captured by the history of the series in question).

Historical Freight Volumes at Six Priority Locks

In Figure 1.13, we plot the historical monthly volumes (total tonnage) of freight through the six locks of interest.

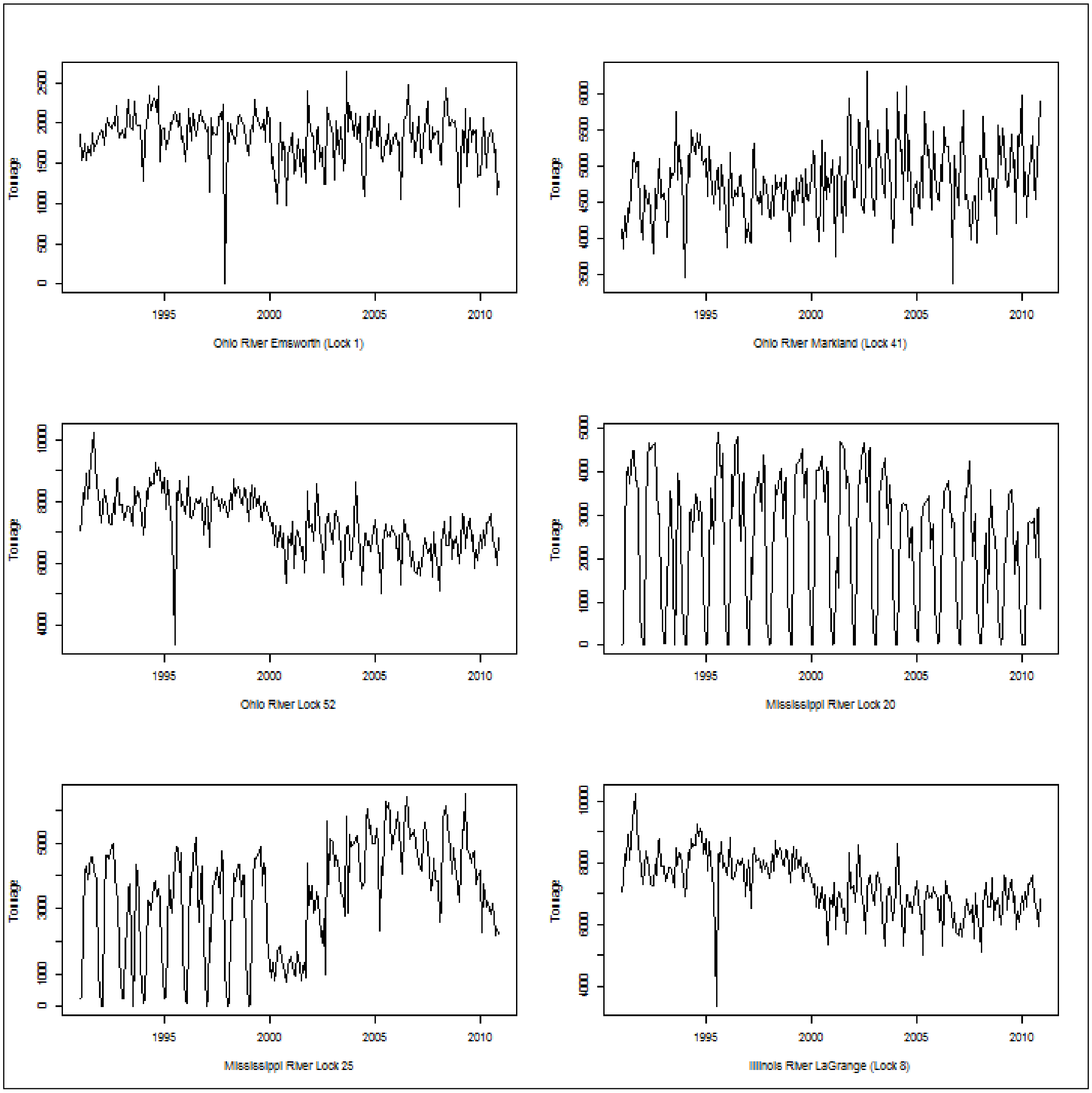

Figure 1.13. Freight Volumes in Thousands of Tons, 1991 to 2010.

Some explanatory remarks are in order. Seasonal patterns are evident in these plots; however, the seasonal fluctuations, magnitudes, and trends of freight volumes vary considerably across the locks. The plots do not appear to reveal any discernible trend. Lock 20 on the Upper Mississippi River is closed during the winter months, as was Lock 25 before year 2000. However, some structural changes appear to exist for this lock. There was a period of low traffic between 2000 and 2002, followed by elevated levels of traffic for the rest of the decade, with the lock remaining open during the winter months. The other four locks are shown to stay open throughout the course of the year, except for periodic lock closures possibly caused by extreme weather or river conditions, maintenance, and unscheduled disruptions.

Structural Analysis

In our structural analysis, we pooled data from these six locks to form a longitudinal data set to avoid unduly large influences from individual events and to exploit the underlying common regularity of the observed freight volumes. Since the freight includes both agricultural and nonagricultural products, we used the gross domestic product and total grain production as a proxy for the induced demand of waterborne transportation. In addition, because the traffic conditions are heavily affected by weather conditions, especially temperature, we also included average monthly temperatures for each lock in question. We note that weather conditions certainly affect grain production; however, this effect is partially reflected by grain production. In this study, we used average monthly temperature to capture the contemporary effect of weather conditions on waterway transportation.

The explanatory variables are:

- Quarterly GDP—source: US Bureau of Labor Statistics.
- Annual US grain production—source: U.S. Department of Agriculture (USDA)-Economic Research Service (ERS).
- Average monthly temperature—the historical temperature records from weather stations at the shortest distance to the locks in question (source: National Oceanic and Atmospheric Administration national climatic data center).
- Year variable for time trend.
- Monthly dummy variables—February through December (January is left out as the baseline case).

Given that the waterway traffic levels are mainly affected by extremely low winter temperatures, we further interacted the monthly average temperatures with a dummy variable for the winter (from November through March of the following year).

Defining $Y_{i,t}$ as the tonnage for the *i*th lock at time *t*, our longitudinal model is given by:

$$Y_{i,t} = a_0+a_1GDP_t + a_2Grain\_Productions_t + a_3Winter\_Temperature_{i,t} + a_4Nonwinter\_Temperature_{i,t} +$$
$$a_5Year+b_2Month\_2 + \ldots + b_{12}Month\_12 + u_i + e_{i,t},$$

where u_i is a time-invariant lock-specific individual effect, and $e_{i,t}$ is an independently and identically distributed error term with mean zero and finite variance. The individual effects were modeled using the random effect estimator. We also estimated the model with a fixed effect estimator, whose results are quantitatively similar to those of the random effect estimator and hence not reported.

We used the maximum likelihood method in our estimation. Table 1.3 gives the estimation results.

Table 1.3. Estimation Results of Regression Model.

Variables	Coefficients	Standard Errors
Intercept	1616.26	1377.83
Year	−22.23	31.58
Winter Temperature	25.99 *	8.75
Non-winter Temperature	−7.08	11.28
GDP	0.01	0.08
Grain Production	0.54	0.44
February	−193.53	128.97
March	38.46	168.25
April	1774.62 *	642.4
May	2030.43 *	736.24
June	2031.73 *	828.71
July	2194.00 *	866.17
August	2162.38 *	856.36
September	1951.05 *	776.02
October	1977.31 *	662.61
November	443.59 *	176.31
December	25.99 *	8.75
Cross-sectional Standard Error	2108.98	
Residual Standard Error	929.50	

**: statistically significant at the 5% confidence level.*

The estimation results confirmed our visual examination of the time series—there was not a significant trend in freight traffic during the observation period, but seasonal effects were present. The impacts of overall GDP and grain production were suggested to be positive, albeit not statistically significant. The average winter temperature had a statistically positive impact on freight volumes. Should the average winter temperature continue to rise, as projected by the Intergovernmental Panel on Climate Change (IPCC), waterway traffic during the winter months will continue to grow. On the other hand, the average non-winter temperature appears to have little impact on the freight.

The pronounced seasonal effects were estimated precisely in this model. We left out January as the baseline case. Most of the monthly dummies were statistically significant, except for December, February, and March. The obvious reason for the low volume of freight during the winter months is that some segments of the rivers are frozen during these months. The freight volume is highest from May through October and peaks in July and August.

Last, we note that the estimated cross-sectional (among locks) standard error is more than twice that of the residuals, indicating substantial lock-specific variations. By pooling data from multiple representative locks, we are able to encapsulate a common structure underlying the waterway transportation system, which varies considerably across rivers and locks.

Time Series Models

We next proceeded to use time series techniques to model traffic for individual locks. As was discussed earlier, many possible contributing factors exist that are not observed or are unknown to the researchers. Thus, our structural analysis should be viewed as an approximation to the underlying determination mechanism of waterway traffic, capturing the impacts of some major contributing factors. In contrast, time series methods that rely on the history of the events to project future developments do not require explicit modeling of the determination of the quantities in question, reasoning that all contributing factors are reflected in the realized outcomes. Consequently, forecasting based on time series techniques may be sometimes more reliable and less dependent on the explicit projections of the future development of contributing factors.

We use the auto-regressive integration and ARIMA model in our analysis. To reduce the impacts of idiosyncratic fluctuations in waterway traffic at individual locks, we first took the average freight volumes across the six locks in question, resulting in a time series of average monthly freight volumes for 240 periods from 1991 through 2010. The top plot of Figure 1.14 reports the average monthly freight volumes. As is seen in the freight volumes for individual locks, there is a pronounced seasonal pattern; however, there is no indication of a long-run trend. Even after we aggregate across the six locks, the impact of the unusually low volumes for Mississippi Lock 25 is still quite evident from the plot.

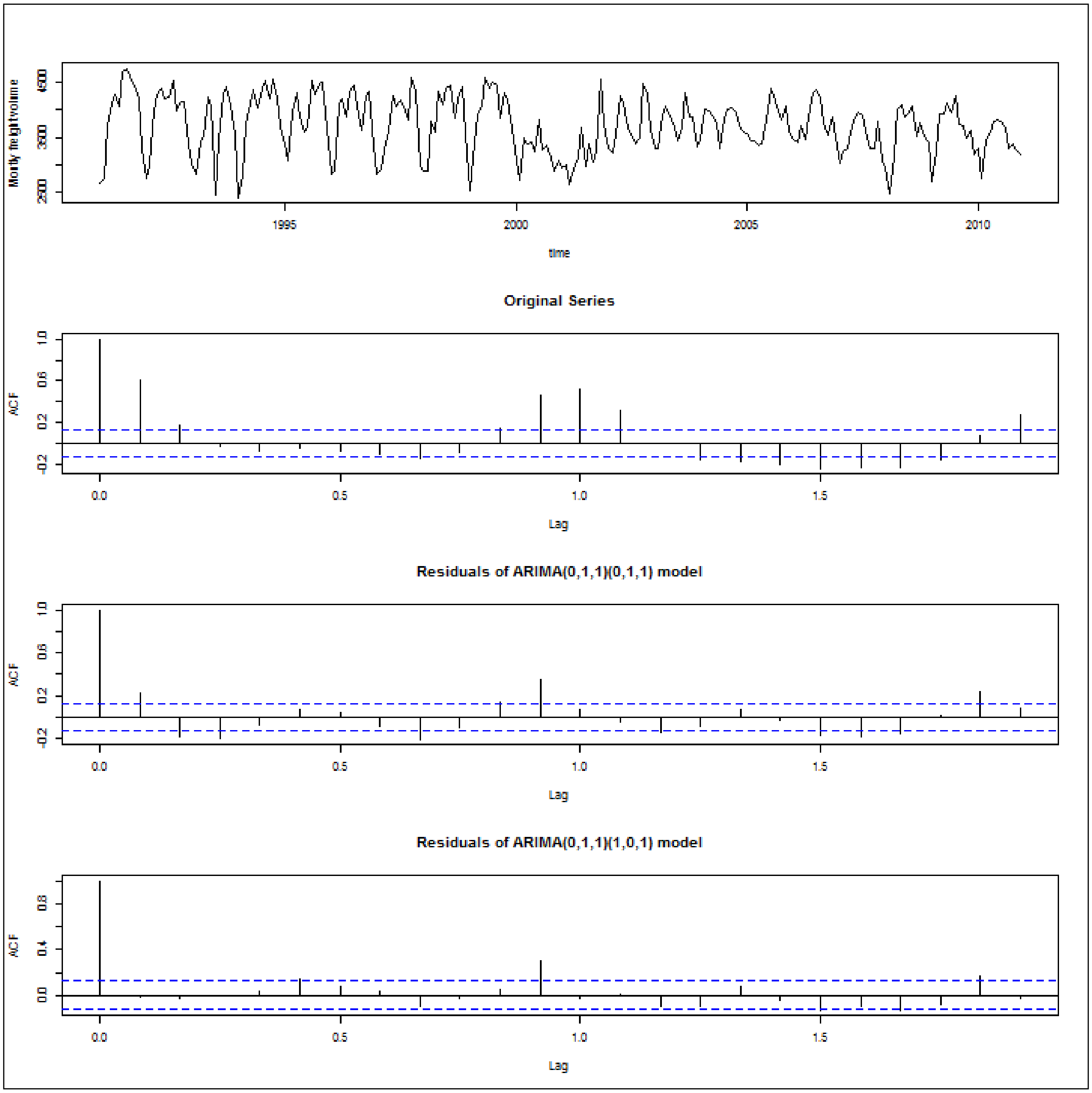

Figure 1.14. Time Series Analysis of Freight Volumes.

One of the most powerful tools in time series analysis is the auto-correlation coefficient of a time series at various spacings of time lag. For instance, the auto-correlation between two random variables at time t and t+s is defined as $\rho s = cor\ (yt, yt+s)$. An auto-correlation coefficient, restricted between −1 and 1, indicates the degree of correlation between random variables at different points in time. A zero auto-correlation indicates two variables are linearly independent; the larger the coefficient is (in terms of absolute values), the stronger the degree of linear correlation.

An order one auto-regressive process can be characterized by $yt = \rho yt\text{-}1 + et$, where et is an inter-temporally independent error term. When $\rho=1$, the time series has the so-called unit root problem. This process is non-stationary because the variance of the process keeps increasing as it progresses. Consequently, differencing of the time series is required to restore stationarity. When the error term of a time series follows an auto-regressive process, the time series is said to follow a moving average process. In practice, different combinations of these issues are possible.

The second plot of Figure 1.14 reports the correlogram of the average monthly freight volumes. The correlogram reports the coefficient of auto-correlation at different levels of lags. When a time series is inter-temporally independent, all auto-correlation coefficients equal zero. The results indicate two possible sources of auto-correlation. A significant auto-correlation happens at lag 1, indicating a slow change of freight volumes during the course of a year. A second source of auto-correlation is evident around lag 12. (In the plot, the unit of time is a year; thus, the 12-month lag is marked as lag 1). This captures the seasonal pattern of waterway traffic. The combination of lag 12 and lag 1 auto-correlation explains the cluster of significant auto-correlation coefficients around lag 12.

Three techniques are commonly used in time series analysis to transform a time series such that the resultant series are close to white noises (roughly speaking, uncorrelated time series): auto-regression, moving average, and differencing. These techniques can be applied to both the non-seasonal and seasonal components of time series, if called for. The seasonal ARIMA model is a flexible family of models that accommodate all these possibilities. In particular, a seasonal ARIMA model is parameterized as ARIMA(p,d,q)x(P,D,Q), where p, d, q refer to the order of auto-regression, differencing, and moving average for the non-seasonal component of the series, and P, D, and Q are their seasonal counterparts.

In practice, we usually tackle the seasonable components first, especially when pronounced seasonal patterns exist, as in our case. Thus, we first transformed the original series with a seasonal differencing at lag 12. Differencing a time series is usually undertaken to render a non-stationary time series stationary. However, when the original series are only "partially" non-stationary in the sense that the auto-correlation coefficient is significantly less than 1 (hence not a unit root process), differencing may lead to substantial negative auto-correlation. This "over-differencing" can be mitigated by using a first order moving average term following the differencing.

As for the non-seasonal auto-correlation, we can choose from two options. One possibility, the same as our adjustment to the seasonal auto-correlation, is to first difference the series (at lag 1) and then impose a moving average term to mitigate possible over-differencing. This leads to the popular ARIMA(0,1,1)x(0,1,1) model. Alternatively, one can avoid the first differencing by employing adjustment with respect to the observed auto-correlation. That is, we employ an auto-regression model without first differencing the series, giving rise to an ARIMA(1,0,0)x(0,1,1) model.

In this study, we employed both models. The adequacy of the proposed models can then be gauged by examining the correlogram of residuals of these models to see if there are significant intertemporal patterns remaining. Since the two models entail the same number of coefficients, they are directly comparable in terms of their residual correlograms or goodness-of-fit measures.

The third and fourth plots of Figure 1.14 report the auto-correlation coefficients of the ARIMA(0,1,1)x(0,1,1) and ARIMA(1,0,0)x(0,1,1) models, respectively. The results from these two models are quite similar: the lag 1 auto-correlation has been satisfactorily removed and so has the lag 12 auto-correlation, although there are some hints of auto-correlation at lag 11, which is plausibly due to the joint force of lag 1 and lag 12 auto-correlations that are not completely removed by our transformation. In principle, we can remove the remaining auto-correlations by including additional autoregressive (AR) and/or moving average (MA) terms to the ARIMA model in question. However, the cost of this over parameterization of the ARIMA model oftentimes outweighs its benefit. In particular, it may undermine the stability of its forecasting. Given that only a minor trace of auto-correlation remains in the residuals, we opted not to add additional terms to our models.

Of the two models considered, the ARIMA(1,0,0)x(0,1,1) model seems to perform slightly better in the sense that the lag 1 autocorrelation has been satisfactorily removed. To save space, below we only report results from this model. The equation of this model can be written as follows:

$$Y_t = a_0 + Y_{t-12} + a_1(Y_{t-1}-Y_{t-13}) - a_2 e_{t-12}$$

where a_0 is an intercept, a_1 is the lag 1 auto-correlation coefficient, a_2 is the seasonal moving average coefficient, and e_t is the residual at period t. The estimated results for this model are given in Table 1.4. (We have also estimated an ARIMA(1,0,1)x(0,1,1) model, where the coefficient for the non-seasonal moving average is not statistically significant.)

Table 1.4. Estimation Results of ARIMA(1,0,0)x(0,1,1) Models.

	Coefficient	Standard Error
Intercept (a_0)	−17.95	10.31
Auto-correlation (a_1)	0.52*	0.06
Seasonal moving average (a_2)	−0.84*	0.05
Log-likelihood	−1656.59	
AIC	3321.18	

The estimated results are consistent with our visual examination of the correlogram of the original series. There is a significant auto-correlation at lag 1. The lag 12 seasonal auto-correlation has been removed by seasonal differencing. Because the magnitude of seasonal auto-correlation is less than unity, a seasonal moving auto-correlation term is called for to adjust for this over-differencing. This is evidenced by the high statistical significance of the seasonal moving average term.

In Figure 1.15 we report the estimated freight volumes (dotted) together with the observed volumes (solid). The estimates track the actual data closely, including the unusually low freight volumes around year 2001.

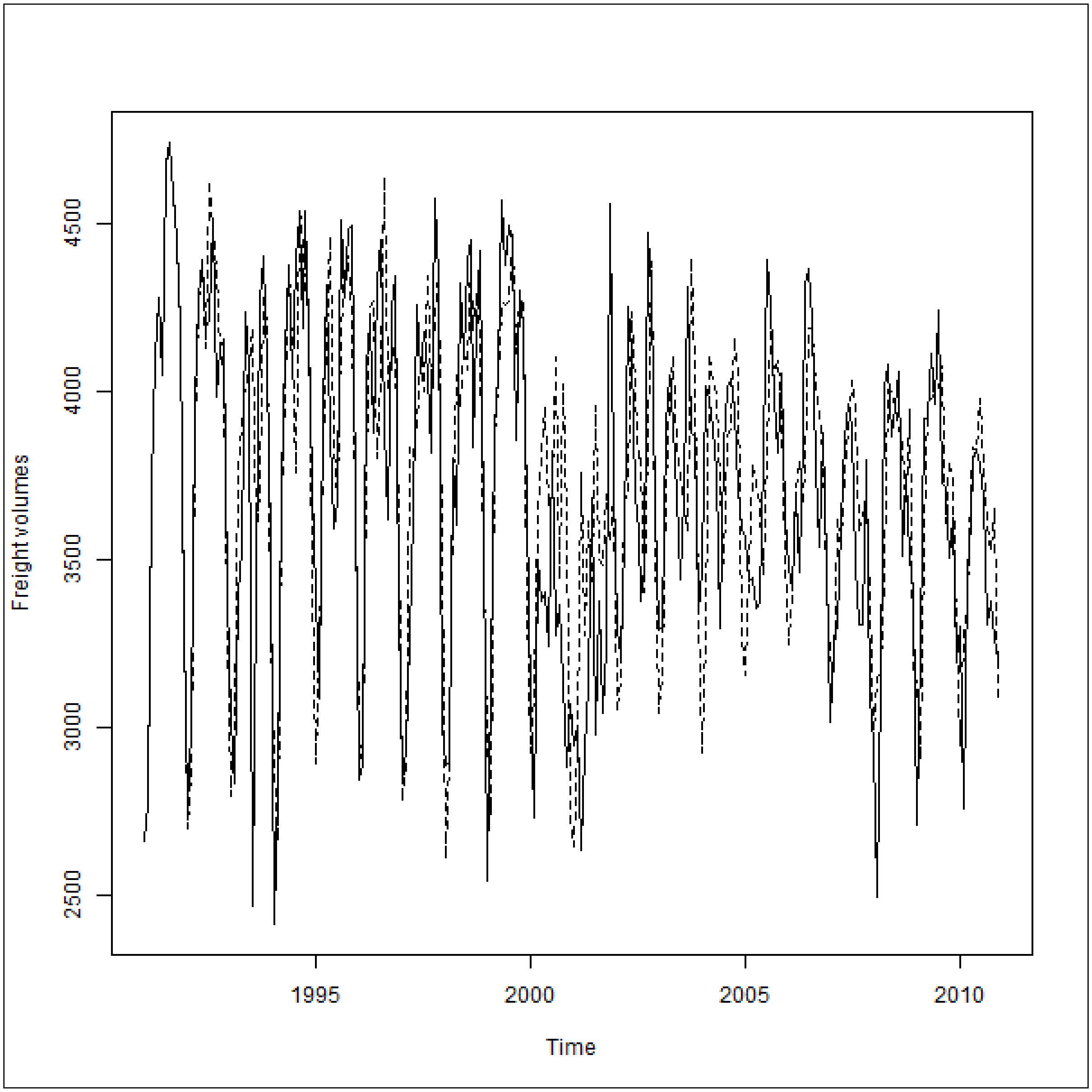

Figure 1.15. Estimated Freight Volumes (Dotted) vs. Observed Volumes (Solid).

Forecasting

As indicated above, the regression analysis and time series models have different strengths. The time series models do not model the determination of the process explicitly and thus any forecasting is based on the assumption that the current trend will prevail in the future, an assumption that is probably valid for short-run forecasting. In contrast, regression analyses strive to model the underlying process of the observed series explicitly based on some possibly contributing factors. We can then project the future development of the quantity in question using the estimated coefficients and our best projections of the contributing factors as parameters. A key advantage of this approach is that it facilitates forecasting under many hypothetical scenarios of interest. The quality of the forecasting then depends on how well the models approximate the underlying true data generating process.

In this section, we report forecasts using both approaches. We first report 10-year forecasting based on our ARIMA(1,0,0)x(0,1,1) model. The results are reported in Figure 1.16, where the predicted freight volumes (in dotted lines) are appended after the historical data. The forecasting volumes closely follow the seasonal patterns of the observed data. Since the ARIMA models assume the current trends will prevail in the future, the gradual decline of freight traffic is largely driven by the reduction in freight volumes near the end of the observation periods. The validity of the forecasting results thus depends crucially on the implicitly maintained assumption that the current trends carry into the future. In the absence of abrupt changes in the underlying process, the forecasts should be relatively reliable.

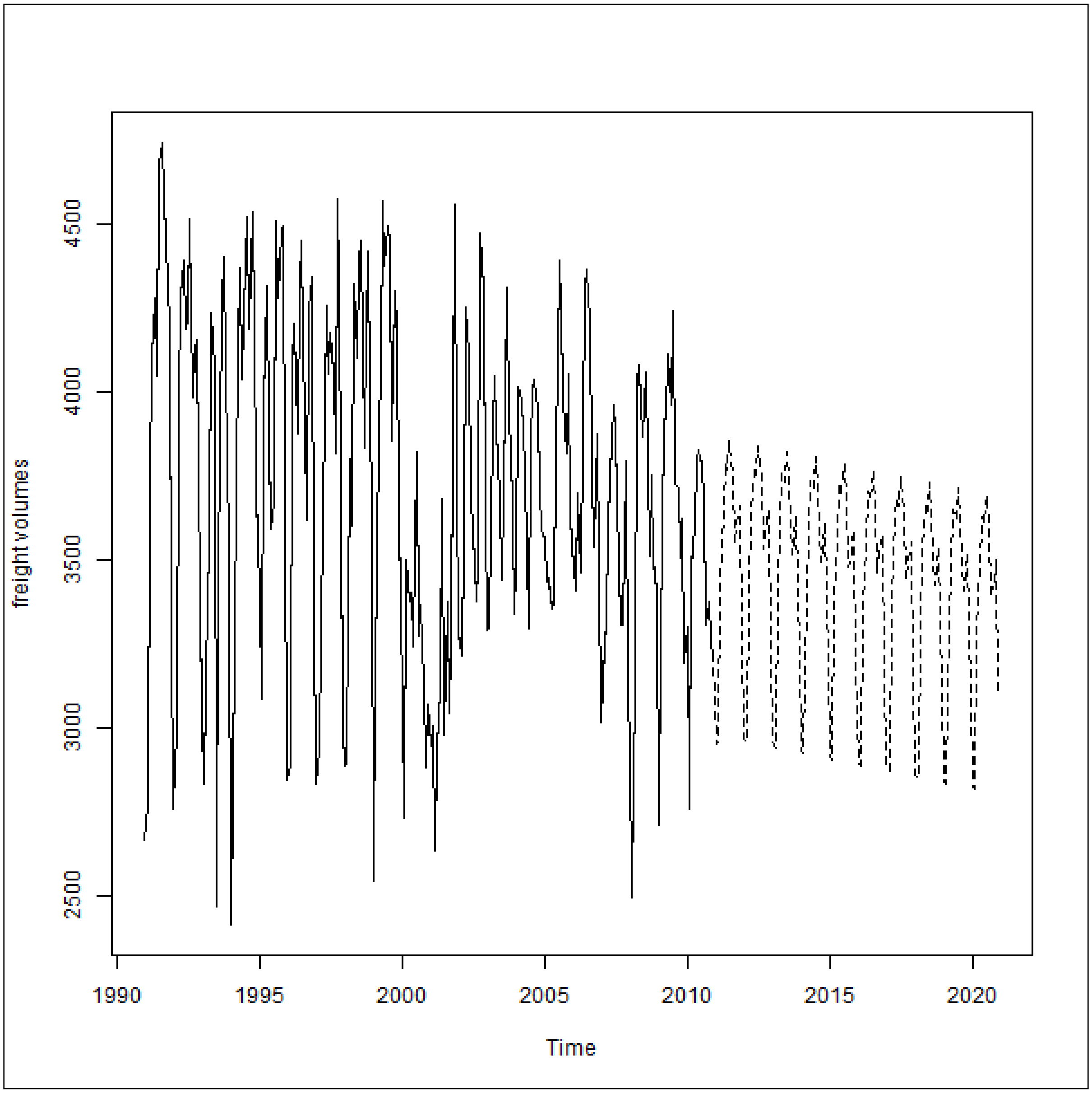

Figure 1.16. Ten-Year Forecasting Based on ARIMA Model.

We next undertook forecasting based on the regression analysis presented in the previous section. This task requires the projection of the future development of explanatory variables used in our model. For grain production, we used the long-term projection provided by the USDA. For the GDP, we used the average economic growth rate for the last eight quarters and extrapolated the current quarterly GDP to year 2010.[6] For the average temperature, the IPCC 2007 report offers projections under different scenarios for the surface temperature from year 1990 through 2100. We used a conservative estimate—the average surface temperature will

[6] The long run economic growth may be higher than the scenario used in our forecast, given that the economy is currently in recession.

rise by 3°C, a number that is close to the median of projections offered by a large number of climate models.[7] The annualized rate was then used in our projection of future temperatures.

Figure 1.17 reports the forecasts for years 2011 through 2020. The forecasting based on two different approaches is remarkably similar. In fact, our calculation indicates that the two sets of forecasts have a correlation coefficient of 0.96.

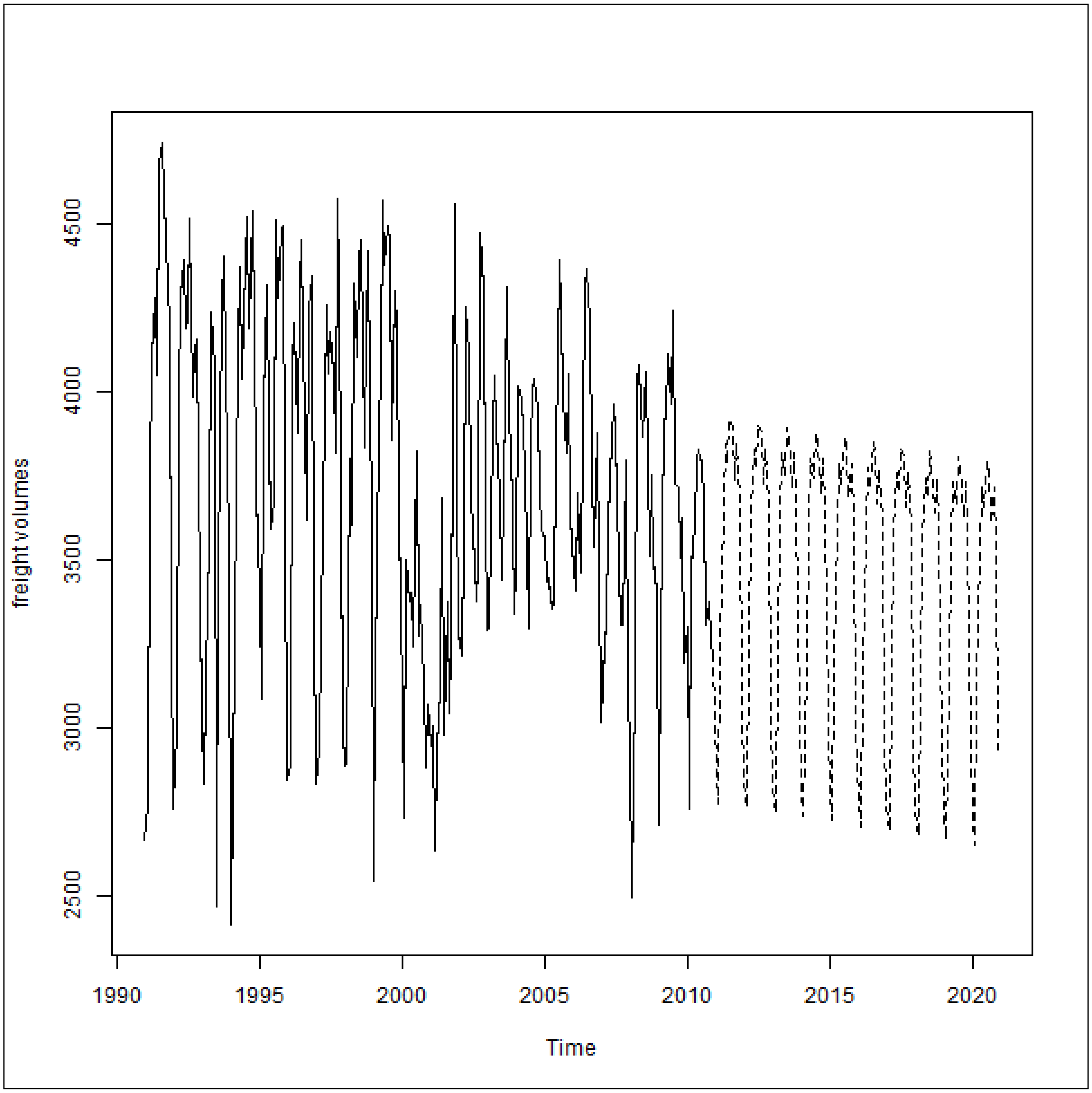

Figure 1.17. Forecasts Based on Regression Model.

[7] The distribution of projected temperature growth from various models is skewed to the right, giving rise to a larger average than the median. Thus, the median is a conservative estimate of future global warming.

Forecasting of Future Values

The total values of freights in the inland waterway system are determined by not only the volumes of traffic but also factors such as the composition of the freight and their representative values, which in turn are influenced by the underlying overall domestic and international economic environment.

The value of freight depends on not only its volumes, but also its unit prices, which are determined by the complicated interplay of supply and demand of all the commodities in the domestic and international markets. A comprehensive structural analysis is beyond the scope of this study. In this section, we focus on the time series analysis of freight values. In particular, we look at the monthly total values of freight on the three rivers from year 2000 through year 2010. For each river for a given month, the total values are calculated as weighted averages for a number of major commodity groups, including grains, petroleum products, coals, chemicals, crude materials, and other products.

We first report the historical data during our sample period in Figure 1.18. Unlike the freight volumes, the total values follow an increasing trend during the last decade. There is a visible decline in 2009, followed by a relatively swift recovery. The impacts of the recent economic downturn are more significant for the Illinois and Ohio Rivers, but less so for the Upper Mississippi River. On the other hand, the Upper Mississippi River demonstrates the most pronounced seasonable variations. These phenomena can be attributed to the fact that the Upper Mississippi River has the largest share of agricultural products in its freight composition. Therefore, compared to the other two rivers, the volume and values of its freight are less sensitive to business cycles and track the agricultural production and harvest season closely.

We modeled the historical series of total values for the three rivers separately. We used the ARIMA(0,1,1)X(0,1,1) models in our estimations to account for both seasonal and non-seasonal correlations. Examinations of the residuals of these fitted models suggested that these models had satisfactorily removed the observed inter-temporal correlations. We then used the fitted models to forecast future values. Figure 1.19 reports the forecasting results.

For all three series, our results indicate persistent increase in the values of freight for the coming decade.[8] The predicted growth is particular strong for the Upper Mississippi and Ohio Rivers, for which the total values are shown to overtake historical highs by 2015 and continue increasing beyond that point. For the Illinois River, our results indicate that the total values will overpass its historical high at the end of this decade.

[8] Despite the relatively stable freight volumes observed during the past few years, the rising freight values are driven by the change in the compositions of commodities transported through the system and their increasing weighted average unit prices.

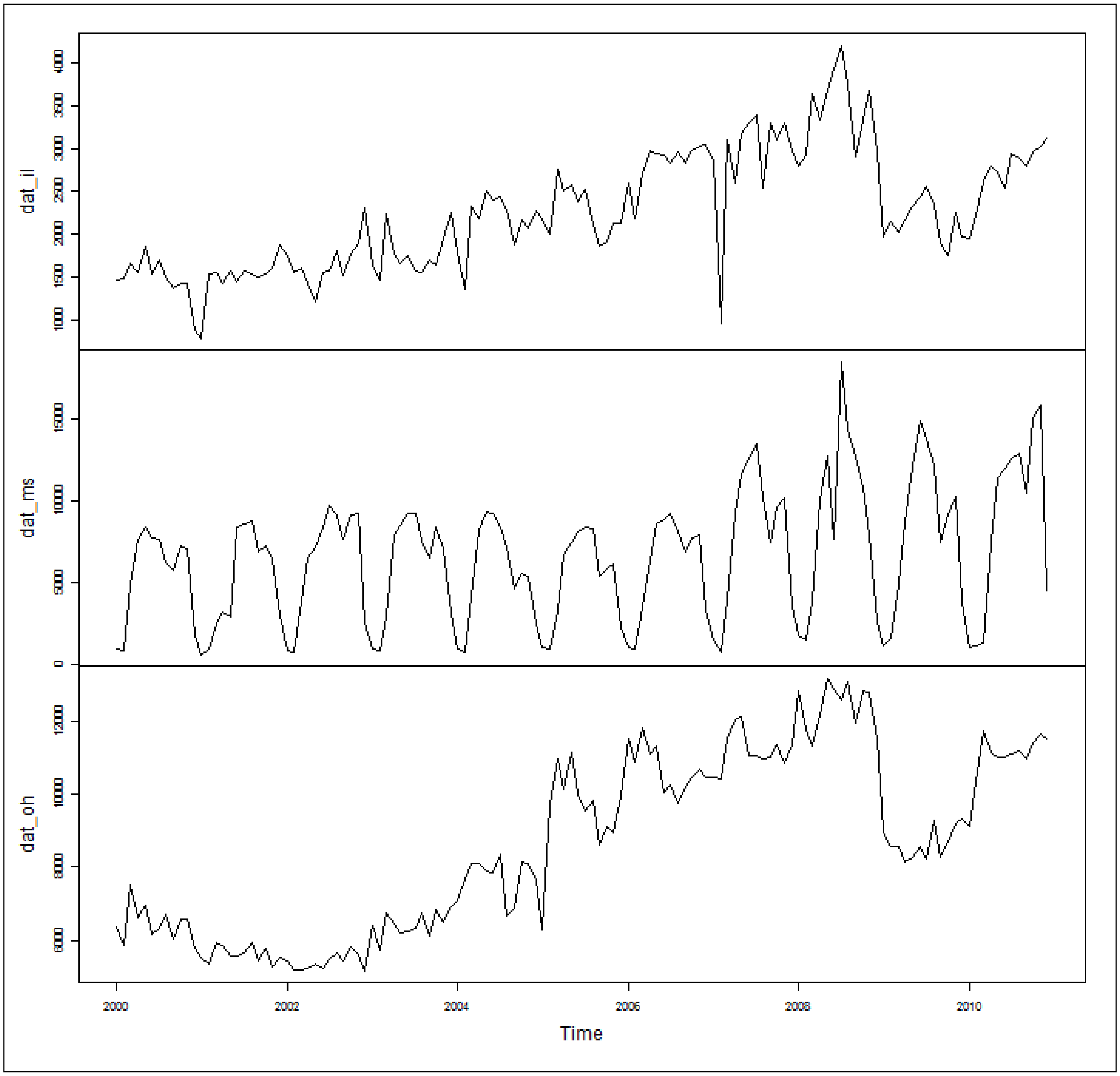

Figure 1.18. Historical Values of Freight Movements.

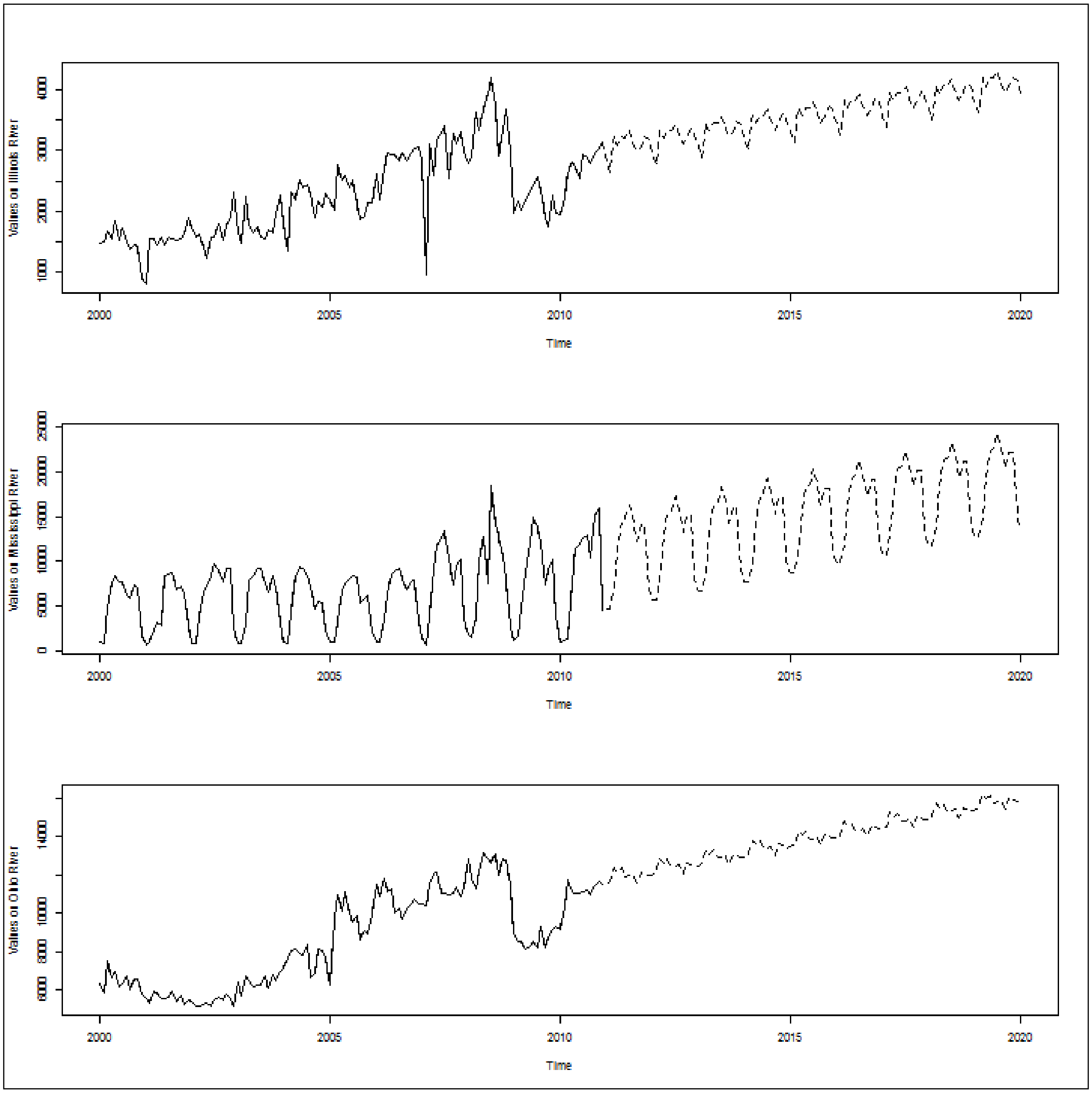

Figure 1.19. Forecasting of Freight Values.

Analysis of Modal Splits for Future Flows

Attavanich et al.[9] simulate changes in the crop mix and planted acreage across U.S. geographic regions due to climate-induced shifts for 2050 using the Agricultural Sector Model (ASM) and the projections of Global Circulation Models (GCMs). GCMs simulate spatial distributions of future temperature and precipitation levels around the world based on assumed future emissions and atmospheric concentrations of greenhouse gases. Then projected climate scenarios are used as inputs to the ASM to simulate the future production levels and their geographic locations. Results include projected levels of corn and soybean production and their flows by mode of transportation and geographic area and are compared with those of the model base year, the 2007–08 crop year.

Transportation volumes of corn and soybeans for domestic use and for exports by each transportation mode are given for the base year and 2050 in Table 1.5. Table 1.6 shows corresponding changes between the base year and 2050. By 2050, the volume in truck hauls in export and domestic grain transportation is projected to increase by 400,000 tons for exports and 2 million tons for domestic consumption for corn, and 760,000 tons for exports and 2.4 million tons for domestic consumption for soybeans. The volume of corn transportation by rail for export and domestic use is projected to increase by 7.5 million tons for exports and 700,000 tons for domestic consumption. The volume by rail will increase by 2.1 million tons for exported soybeans while it will decrease by 800,000 tons for soybeans for domestic consumption. However, the total projected barge flow for corn decreases by 14.8 million tons, a high percentage (98.8%) of which is export-bound barge hauls.

Transportation of grain is projected to increase by 5.5 and 9.6 million tons by truck and rail, respectively, whereas barge transportation is projected to decrease by nearly 15 million tons. The total share of truck changes from 22% in the base year to 24% in 2050, from 53% to 58% for rail, and from 25% to 18% for barge.

[9] Attavanich, W., B.A. McCarl, S.W. Fuller, D.V. Vedenov, and Z. Ahmedov, "The Effect of Climate Change on Transportation Flows and Inland Waterways Due to Climate-Induced Shifts in Crop Production Patterns", Selected paper presented at the 2011 Annual Meetings of the Agricultural and Applied Economics Association, Pittsburgh, July, June, 2011.

Table 1.5. Transportation Volumes of Domestic and Export Grain Shipments in Base Year and in 2050 (Thousand Tons).

Grain	Mode	Base			2050		
		Domestic	Export	Total	Domestic	Export	Total
Corn	Truck	23,938	5,639	29,577	25,915	6,038	31,953
	Rail	62,985	21,454	84,439	63,683	29,005	92,688
	Barge	1,365	34,409	35,774	1,195	19,786	20,981
Soybeans	Truck	12,473	2,019	14,492	14,864	2,776	17,640
	Rail	7,731	13,282	21,013	6,910	15,431	22,341
	Barge	1,034	13,395	14,429	856	13,390	14,246
Total grain	Truck	36,411	7,658	44,069	40,779	8,814	49,593
	Rail	70,717	34,735	105,452	70,593	44,435	115,028
	Barge	2,399	47,804	50,203	2,052	33,176	35,228
SHARE							
Corn	Truck	81%	19%	100%	81%	19%	100%
	Rail	75%	25%	100%	69%	31%	100%
	Barge	4%	96%	100%	6%	94%	100%
Soybeans	Truck	86%	14%	100%	84%	16%	100%
	Rail	37%	63%	100%	31%	69%	100%
	Barge	7%	93%	100%	6%	94%	100%
Total grain	Truck	33%	8%	22%	36%	10%	24%
	Rail	65%	40%	53%	62%	52%	58%
	Barge	2%	53%	25%	2%	38%	18%
TOTAL	ALL	100%	100%	100%	100%	100%	100%

Table 1.6. Changes in the Transportation Volume of Domestic and Export Grain Shipment from Base Year to 2050 (Thousand Tons).

Grain	Mode	Domestic	Export	Total
Corn	Truck	1,977	400	2,377
	Rail	698	7,551	8,249
	Barge	−170	−14,622	−14,792
Soybeans	Truck	2,391	756	3,147
	Rail	-821	2,149	1,328
	Barge	−177	−6	−183
Total grain	Truck	4,369	1,156	5,525
	Rail	−124	9,700	9,576
	Barge	−348	−14,628	−14,976

The projected climate change scenarios will affect individual regions of the country differently. Table 1.7 shows the volume of grain transportation originated from each geographic region to all destinations (including exports) by each mode of transportation. Table 1.8 shows the changes in modal volumes between the base year and 2050. Table 1.9 shows the description of regions and sub-regions used in Table 1.7 and Table 1.8. Truck shipments originating from the Corn Belt region are projected to increase by 3.1 million tons and 1.4 million tons for corn and soybeans, respectively. On the other hand, the volume of rail shipments from this region will decrease by 7.6 million tons and the volume of barge shipments will decrease by 14 million tons for corn while the reductions in truck hauls by both modes are insignificant. The volume of truck shipments of corn from the Great Plains is projected to decrease by 2 million tons while rail shipments are projected to increase by 1.3 million tons. Reduction in soybean barge shipments in the amount of 556,000 tons is projected, which will offset truck and rail volume increases of 477,000 tons and 110,000 tons, respectively. Generally, it is projected that barge shipments will decrease in all regions (except for soybeans originating in the South-Central region). Significant increases in corn shipment via rail are projected for the Lake States (4.5 million tons), Northeast (6.6 million tons), and the South-Central region (2.3 million tons). Rocky Mountains and the Northeast region are also projected to have additional corn transportation via truck in the amount of 1.1 million tons and 1.9 million tons, respectively.

Table 1.7. Grain Shipments by Region and by Mode of Transportation in Base Year and in 2050 (Thousand Tons).

Region	Mode	Base			2050		
		Corn	Soybeans	Total	Corn	Soybeans	Total
Corn Belt	Truck	14,168	8,644	22,812	17,310	10,090	27,400
	Rail	41,714	3,398	45,112	34,124	3,349	37,473
	Barge	29,495	9,985	39,480	15,501	9,979	25,480
Great Plains	Truck	3,622	686	4,308	1,578	1,163	2,741
	Rail	25,716	10,763	36,479	27,043	10,873	37,916
	Barge	0	990	990	0	434	434
Lake States	Truck	2,372	2,470	4,842	2,421	2,757	5,178
	Rail	9,715	3,732	13,447	14,260	4,391	18,651
	Barge	4,922	2,122	7,044	4,478	1,715	6,193
Rocky Mountains	Truck	89	0	89	1,220	0	1,220
	Rail	1,805	0	1,805	2,145	0	2,145
Pacific	Truck	623	0	623	443	0	443
	Rail	0	0	0	346	0	346
Northeast	Truck	839	76	915	2,787	333	3,120
	Rail	764	928	1,692	7,326	1,216	8,542
Southeast	Truck	988	709	1,697	440	892	1,332
	Rail	69	87	156	115	135	250
South Central	Truck	5,186	1,879	7,065	5,010	2,135	7,145
	Rail	4,326	1,983	6,309	6,637	1,886	8,523
	Barge	1,357	1,257	2,614	1,002	2,082	3,084
Southwest	Truck	1,690	28	1,718	747	272	1,019
	Rail	330	122	452	694	491	1,185
	Barge	0	75	75	0	37	37

Table 1.8. Changes in the Grain Shipment from Regions by Modes of Transportation in Base Year and in 2050 (Thousand Tons).

REGION	Corn			Soybean		
	Truck	Rail	Barge	Truck	Rail	Barge
Corn Belt	3,142	−7,591	−13,994	1,446	−49	−7
Great Plains	−2,045	1,327		477	110	−556
Lake States	49	4,545	−444	287	659	−407
Rocky Mountains	1,131	340	0	0	0	0
Pacific	−180	346	0	0	0	0
Northeast	1,948	6,562	0	257	288	0
Southeast	−549	46	0	183	48	0
South Central	−176	2,311	−355	256	−98	825
Southwest	-943	364	0	244	369	−39
TOTAL	2,377	8,250	−14,793	3,150	1,327	−184

Table 1.9. ASM Regions and Subregions.

Market Region	Production Region (States/Subregions)
Northeast (NE)	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
Lake States (LS)	Michigan, Minnesota, Wisconsin
Corn Belt (CB)	All regions in Illinois, Indiana, Iowa, Missouri, Ohio (Illinois North, Illinois South, Indiana North, Indiana South, Iowa West, Iowa Central, Iowa Northeast, Iowa South, Ohio Northwest, Ohio South, Ohio Northeast)
Great Plains (GP)	Kansas, Nebraska, North Dakota, South Dakota
Southeast (SE)	Virginia, North Carolina, South Carolina, Georgia, Florida
South Central (SC)	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, Eastern Texas
Southwest (SW)	Oklahoma, All of Texas but the Eastern Part (Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, Texas Trans Pecos)
Rocky Mountains (RM)	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
Pacific Southwest (PSW)	All regions in California (California North, California South)
Pacific Northwest (PNW)	Oregon, Washington, and the Cascade mountain range

CHAPTER 2
LOCK OPERATIONAL STATISTICS AND WAIT TIMES

Statistics on Total Freight Transiting Locks

Table 2.1 to Table 2.3 below provide information and descriptive statistics on the total volume and values of freight (all commodities combined) transiting each lock of the Illinois, Upper Mississippi, and Ohio Rivers for the 10-year period 2000–2010. In particular, Table 2.1 shows descriptive statistics for total freight flows transiting each lock of the rivers by direction. The columns show the minimum or the maximum amount of freight that transited a specific lock on the river in a month during this period.

For instance, the maximum amount of total monthly freight that transited any one lock of the Illinois, Upper Mississippi, and Ohio Rivers was 4.1, 8.5, and 9.1 million tons, respectively. The third column from the left ("Std. Dev.") shows the variability (standard deviation) in monthly freight volumes among the locks of a particular river. It can be observed that some of the locks on each river did not have any flows in the winter months and this may be attributed to the winter freeze on the northern segments of the rivers. The highest volume of monthly freight transit occurred on the Ohio River with the Upper Mississippi River being second. On average, a lock on the Ohio River accommodated total freight volume of 4,165,869 tons per month. The average freight volumes on the Illinois and Upper Mississippi Rivers were 1,610,842 and 1,708,541 tons, respectively. In terms of consistency of freight transit, Illinois locks had more stable freight flows than locks on the Upper Mississippi and Ohio Rivers as indicated by their lower variability (548,873 tons versus 1,604,727 tons and 1,682,969 tons, respectively) around their respective average monthly volumes. Historical data indicate that there is higher variability in freight flows on the Upper Mississippi and Ohio Rivers and relatively lower variability on the Illinois River around each river's 10-year average freight flows.

Table 2.1. Total Commodity Flows by Direction (Short Tons).

Direction	Mean	Std. Dev.	Min	Max
ILLINOIS				
Down	712,651	488,760	34,500	3,040,168
Up	898,191	338,965	0	1,728,502
TOTAL	**1,610,842**	**548,873**	**246,936**	**4,132,061**
UPPER MISSISSIPPI				
Down	1,073,123	1,149,939	0	6,043,736
Up	635,417	634,294	0	3,626,230
TOTAL	**1,708,541**	**1,604,727**	**0**	**8,522,598**
OHIO				
Down	1,757,463	972,906	0	4,592,853
Up	2,409,275	1,139,878	0	6,004,800
TOTAL	**4,165,869**	**1,682,969**	**0**	**9,125,324**

The lock names and numbers in the Lock column are arranged to reflect the order of locks along the rivers. Moving from top to bottom in the table reflects the downstream flow and the opposite is true for upstream movement. A total of 1.7 billion tons of freight (all locks combined) transited the Illinois River between January 2000 and December 2010. The combined freight volume amounted to 6.5 and 11.5 billion tons on the Upper Mississippi and Ohio Rivers, respectively. Downbound freight movements accounted for 44%, 63%, and 42% of total freight volumes on the Illinois, Upper Mississippi, and Ohio Rivers, respectively.

Total upbound freight transiting each lock was generally consistent along the entire Illinois River whereas the largest portion of downbound freight entered the river mostly at the Peoria and LaGrange locks. The share of downbound freight movements on the Illinois River reached as high as 80% of the total flow at the lower reaches of the river. Similarly, the share of upbound freight reached nearly 80% of the total volume at the upstream end of the river.

In terms of freight values, downbound freight movements had much higher values than upbound movements at the downstream end of the river and vice versa at the upstream end of the river. For instance, the total value of downbound and upbound freight movement between 2000 and 2010 constituted nearly $36.1 billion and $9 billion, respectively, at LaGrange Lock. On the other hand, the total value of commodities moving upstream was valued at $19.1 billion and the downbound freight valued at $5.5 billion at T.J. O'Brien Lock during this period.

Table 2.2. Total Volume of Freight Transiting Locks on Illinois River, 2000–2010 (Million Tons).

Lock Name	Down	Down (%)	Up	Up (%)	TOTAL
T. J. O'Brien	30	21%	112	79%	142
Lockport	51	31%	115	69%	166
Brandon Road	51	29%	125	71%	176
Dresden Island	68	36%	123	64%	191
Marseilles	82	39%	128	61%	210
Starved Rock	99	40%	151	60%	250
Peoria	166	54%	143	46%	309
LaGrange	205	80%	52	20%	257
TOTAL	**753**	**44%**	**948**	**56%**	**1,701**

Table 2.3. Total Value of Freight Transiting Locks on Illinois River, 2000–2010 (Million USD).

Lock Name	Down	Down (%)	Up	Up (%)	TOTAL
T. J. O'Brien	5,488	22%	19,094	78%	24,583
Lockport	9,244	32%	19,586	68%	28,829
Brandon Road	9,326	30%	21,400	70%	30,726
Dresden Island	12,583	37%	21,189	63%	33,772
Marseilles	14,806	40%	22,159	60%	36,965
Starved Rock	17,742	40%	26,349	60%	44,091
Peoria	29,115	54%	24,945	46%	54,060
LaGrange	36,113	80%	8,983	20%	45,095
TOTAL	**134,417**	**45%**	**163,705**	**55%**	**298,121**

A significant amount of downbound freight tended to enter the Upper Mississippi River starting at Lock 2 and additional freight entered at each subsequent downstream lock. However, an increase in downbound freight is observed at the last two locks—Melvin Price and Chain of Rocks—above the confluence of the Illinois River and Upper Mississippi River. Upbound freight, on the other hand, entered the river at Melvin Price Lock in large amounts (283 million tons) and about 60% of this cargo unloaded after transiting Lock 25 at barge locations around St. Louis, MO. The rest of the upbound freight gradually diverted off the river before reaching the most upstream locks.

The commodity values at each lock of the Upper Mississippi River exhibited patterns similar to corresponding physical commodity movements. At the upstream end of the Upper Mississippi River, Lock 2 facilitated \$6.9 billion and \$4.8 billion of downbound and upbound freight, respectively. The total value of all downbound commodities transiting Melvin Price Lock amounted to \$62.7 billion and the value of upbound commodities amounted to \$38 billion.

Table 2.4. Total Volume of Freight Transiting Locks on Upper Mississippi River, 2000–2010 (Million Tons).

Lock Name	Down	Down (%)	Up	Up (%)	TOTAL
Upper St. Anthony Falls	3	17%	13	83%	16
Lower St. Anthony Falls	3	17%	13	83%	16
Lock 1	3	7%	35	93%	38
Lock 2	53	60%	35	40%	87
Lock 3	53	59%	36	41%	89
Lock 4	60	60%	40	40%	100
Lock 5	60	60%	40	40%	100
Lock 5A	60	57%	45	43%	105
Lock 6	77	63%	45	37%	122
Lock 7	78	61%	50	39%	128
Lock 8	81	53%	72	47%	153
Lock 9	81	52%	75	48%	156
Lock 10	103	56%	81	44%	184
Lock 11	103	56%	82	44%	185
Lock 12	117	59%	82	41%	199
Lock 13	121	56%	94	44%	215
Lock 14	146	60%	99	40%	245
Lock 15	145	59%	99	41%	244
Lock 16	155	60%	105	40%	260
Lock 17	161	61%	105	39%	266
Lock 18	174	64%	96	36%	270
Lock 19	197	67%	98	33%	295
Lock 20	206	66%	104	34%	310
Lock 21	217	68%	103	32%	320
Lock 22	222	68%	106	32%	328
Lock 24	232	68%	107	32%	339
Lock 25	232	46%	275	54%	507
Melvin Price	466	62%	283	38%	749
Chain of Rocks	501	97%	14	3%	515
TOTAL	**4,108**	**63%**	**2,432**	**37%**	**6,540**

Table 2.5. Total Value of Freight Transiting Locks on Upper Mississippi River, 2000–2010 (Million USD).

Lock Name	Down	Down (%)	Up	Up (%)	TOTAL
Upper St. Anthony Falls	299	16%	1,608	84%	1,907
Lower St. Anthony Falls	293	15%	1,609	85%	1,903
Lock 1	312	6%	4,775	94%	5,087
Lock 2	6,812	59%	4,762	41%	11,574
Lock 3	6,822	58%	4,956	42%	11,778
Lock 4	7,836	59%	5,498	41%	13,335
Lock 5	7,831	59%	5,482	41%	13,313
Lock 5A	7,848	56%	6,240	44%	14,088
Lock 6	10,066	62%	6,234	38%	16,300
Lock 7	10,101	59%	6,923	41%	17,024
Lock 8	10,553	51%	10,049	49%	20,602
Lock 9	10,564	50%	10,385	50%	20,949
Lock 10	13,496	54%	11,284	46%	24,780
Lock 11	13,485	54%	11,371	46%	24,856
Lock 12	15,401	58%	11,382	42%	26,783
Lock 13	15,935	55%	12,930	45%	28,865
Lock 14	19,134	59%	13,512	41%	32,646
Lock 15	18,964	58%	13,529	42%	32,493
Lock 16	20,349	59%	14,392	41%	34,741
Lock 17	21,171	59%	14,434	41%	35,605
Lock 18	22,994	64%	13,113	36%	36,107
Lock 19	26,122	66%	13,358	34%	39,480
Lock 20	27,229	66%	14,215	34%	41,443
Lock 21	28,940	67%	14,026	33%	42,966
Lock 22	29,609	67%	14,471	33%	44,080
Lock 24	30,854	68%	14,598	32%	45,451
Lock 25	30,880	45%	37,255	55%	68,135
Melvin Price	62,692	62%	38,038	38%	100,730
Chain of Rocks	67,663	98%	1,692	2%	69,355
TOTAL	**544,255**	**62%**	**332,121**	**38%**	**876,376**

On the Ohio River, the total volume of upbound freight had a higher share than downbound freight at nearly all the locks. The highest recorded volume of upbound freight (589 million tons) was at Smithland Lock; volumes then gradually diminished to 136 million tons at Emsworth Lock. The highest total downbound transit occurred at Greenup Lock and farther downstream at Locks 52 and 53. Increased freight transit at the latter two locks may be attributable to downbound freight coming from the Cumberland and Tennessee Rivers en route to the Mississippi River.

The values of commodity flows on the Ohio River also exhibited patterns similar to physical flows. Greenup and Smithland Locks handled the largest volumes of downbound and upbound freight transit in terms of total value. For instance, the value of downbound freight at Greenup Lock constituted $43.2 billion and the value of upbound freight constituted $57.8 billion at Smithland Lock during the 10-year period.

Table 2.6. Total Volume of Freight Transiting Locks on Ohio River, 2000–2010 (Million Tons).

Lock Name	Down	Down (%)	Up	Up (%)	TOTAL
Emsworth	96	41%	136	59%	232
Dashields	93	40%	137	60%	230
Montgomery	101	29%	250	71%	351
New Cumberland	90	23%	308	77%	398
Pike Island	101	27%	279	73%	380
Hannibal	244	46%	285	54%	529
Willow Island	214	41%	315	59%	529
Belleville	215	41%	316	59%	531
Racine	227	38%	369	62%	596
Robert C. Byrd	234	47%	261	53%	495
Greenup	444	64%	250	36%	694
Meldahl	380	55%	312	45%	692
Markland	256	40%	391	60%	647
McAlpine	216	35%	394	65%	610
Cannelton	237	32%	516	68%	753
Newburgh	228	32%	497	68%	725
John T. Myers	264	35%	481	65%	745
Smithland	375	39%	589	61%	964
Lock 52	421	47%	468	53%	889
Lock 53	435	100%	0	0%	435
Olmsted	0	0%	123	100%	123
TOTAL	**4,872**	**42%**	**6,676**	**58%**	**11,548**

Table 2.7. Total Value of Freight Transiting Locks on Ohio River, 2000–2010 (Million USD).

Lock Name	Down	Down (%)	Up	Up (%)	TOTAL
Emsworth	9,106	40%	13,604	60%	22,710
Dashields	8,821	40%	13,287	60%	22,108
Montgomery	9,697	29%	24,295	71%	33,992
New Cumberland	8,761	23%	29,879	77%	38,640
Pike Island	9,750	27%	26,902	73%	36,652
Hannibal	24,528	47%	27,498	53%	52,027
Willow Island	21,640	42%	30,440	58%	52,080
Belleville	21,802	42%	30,606	58%	52,409
Racine	23,083	39%	36,100	61%	59,184
Robert C. Byrd	23,352	47%	25,924	53%	49,277
Greenup	43,226	63%	25,220	37%	68,445
Meldahl	36,879	54%	31,608	46%	68,487
Markland	24,904	38%	39,886	62%	64,790
McAlpine	21,086	34%	40,053	66%	61,139
Cannelton	23,320	31%	52,388	69%	75,708
Newburgh	22,614	31%	49,346	69%	71,960
John T. Myers	26,125	35%	47,618	65%	73,742
Smithland	37,063	39%	57,783	61%	94,846
Lock 52	42,173	48%	45,572	52%	87,744
Lock 53	43,333	100%	0	0%	43,333
Olmsted	0	0%	12,376	100%	12,376
TOTAL	**481,263**	**42%**	**660,385**	**58%**	**1,141,649**

Statistics on Agricultural Freight Transiting Locks

Table 2.8 to Table 2.11 provide freight information specifically on corn and soybeans (agricultural products) similar to that presented in the preceding section for the same period (2000–2010). During this period, combined corn and soybean movements accounted for over 92%, 94%, and 82% of total grain movements by barge on the Illinois, Upper Mississippi, and Ohio Rivers, respectively. For this reason and in order to present more detailed information, this section provides flow statistics on corn and soybeans only.

The highest volume of total monthly corn and soybeans flows—in the amount of 3.7 million tons and 1.8 million tons, respectively—was recorded on the Upper Mississippi River. The second highest monthly total flows of corn and soybeans occurred on the Illinois River. On average, a lock handled 641,000 tons and 176,000 tons of corn and soybeans on the Upper Mississippi River (both directions); 219,000 tons and 54,000 tons of corn and soybeans on the Illinois River (both directions); and 87,000 tons and 54,000 tons of corn and soybeans on the Ohio River (both directions) on a monthly basis. The average monthly volumes of downbound corn and soybeans at locks on all rivers are multiple times the corresponding volumes in the opposite direction. All rivers showed a high level of variability in the monthly flow of corn and soybeans. This can be attributed to the seasonal nature of grain production and freezing during the winter season at the upstream end of the rivers.

Table 2.8. Total Commodity Flows by Direction (Short Tons).

Variable	Mean	Std. Dev.	Min	Max
ILLINOIS				
Corn - downbound	211,571	312,557	0	1,848,294
Corn - upbound	7,241	11,754	0	82,384
Corn - total	**218,812**	**314,739**	**0**	**1,848,294**
Soybean - downbound	50,134	85,413	0	705,393
Soybean - upbound	4,201	5,505	0	35,680
Soybean - total	**54,335**	**86,310**	**0**	**705,393**
UPPER MISSISSIPPI				
Corn - downbound	636,640	719,215	0	3,715,804
Corn - upbound	4,318	9,629	0	94,627
Corn - total	**640,958**	**723,043**	**0**	**3,724,118**
Soybean - downbound	171,496	217,637	0	1,740,440
Soybean - upbound	4,442	6,451	0	57,632
Soybean - total	**175,938**	**220,994**	**0**	**1,798,072**
OHIO				
Corn - downbound	74,233	138,023	0	910,115
Corn - upbound	12,456	37,663	0	304,605
Corn - total	**86,684**	**155,504**	**0**	**938,065**
Soybean - downbound	45,198	84,855	0	667,549
Soybean - upbound	8,795	20,203	0	158,307
Soybean - total	**53,990**	**92,007**	**0**	**667,649**

Table 2.9 to Table 2.11 show the upbound and downbound summary of corn and soybean movements and their corresponding values by lock on the Illinois, Upper Mississippi, and Ohio Rivers. Initial downbound corn first entered the Illinois River in large amounts (14.2 million tons) at Marseilles Lock and the freight volume increased even more between Peoria and LaGrange locks (see Table 2.9).

The values corresponding to commodity flows in Table 2.9 are given in Table 2.10. During 2000–2010, the total values of corn and soybeans shipped downstream were $1.3 billion and $642 million at Marseilles Lock. On the other hand, the values of downbound corn and soybeans transiting LaGrange Lock reached $9.4 billion and $5 billion during this period.

Table 2.9. Total Volume of Corn and Soybeans Transiting Locks on Illinois River, 2000–2010 (Thousand Tons).

Lock Name	Corn (down)	Corn (up)	Corn Total	Soybean (down)	Soybean (up)	Soybean Total
T. J. O'Brien	1,950	455	2,405	822	362	1,184
Lockport	2,405	455	2,860	1,309	363	1,672
Brandon Road	2,402	523	2,925	1,310	398	1,708
Dresden Island	2,404	549	2,953	1,358	422	1,780
Marseilles	14,251	710	14,961	3,150	612	3,762
Starved Rock	27,155	2,027	29,182	6,031	919	6,950
Peoria	72,475	2,726	75,201	15,932	1,124	17,056
LaGrange	100,377	202	100,579	23,029	238	23,267
TOTAL	**223,419**	**7,647**	**231,066**	**52,942**	**4,436**	**57,378**

Table 2.10. Total Value of Corn and Soybeans Transiting Locks on Illinois River, 2000–2010 (Million USD).

Lock Name	Corn (down)	Corn (up)	Corn Total	Soybean (down)	Soybean (up)	Soybean Total
T. J. O'Brien	167	41	208	181	82	263
Lockport	196	41	237	273	83	356
Brandon Road	195	49	244	273	91	364
Dresden Island	196	51	247	284	97	381
Marseilles	1,283	68	1,351	642	143	785
Starved Rock	2,516	193	2,709	1,272	205	1,477
Peoria	6,762	268	7,030	3,392	262	3,654
LaGrange	9,437	20	9,457	4,993	55	5,048
TOTAL	**20,752**	**731**	**21,483**	**11,310**	**1,018**	**12,328**

The first lock at the upstream end of the Upper Mississippi River that facilitated a significant volume of grain was Lock 2 where 26.6 million tons and 6.6 million tons of downbound corn and soybeans, respectively, passed through during this period (Table 2.11). This lock is located in a region where a high volume of corn and soybeans is produced (see Figure 2.1 and Figure 2.2). Downbound corn and soybeans are valued at $2.4 billion and $1.5 billion, respectively (see Table 2.12.) More grain entered the river at the downstream locks. The amount of downbound corn and soybeans that transited Lock 25 amounted to 140 million tons and 40.4 million tons, respectively. The values were $13.2 billion for corn and $9.3 billion for soybeans. Melvin Price Lock facilitated a significantly higher volume of downbound freight (258.6 million tons of corn and 68 million tons of soybeans); however, this volume includes all downbound grain shipments coming from the Illinois River.

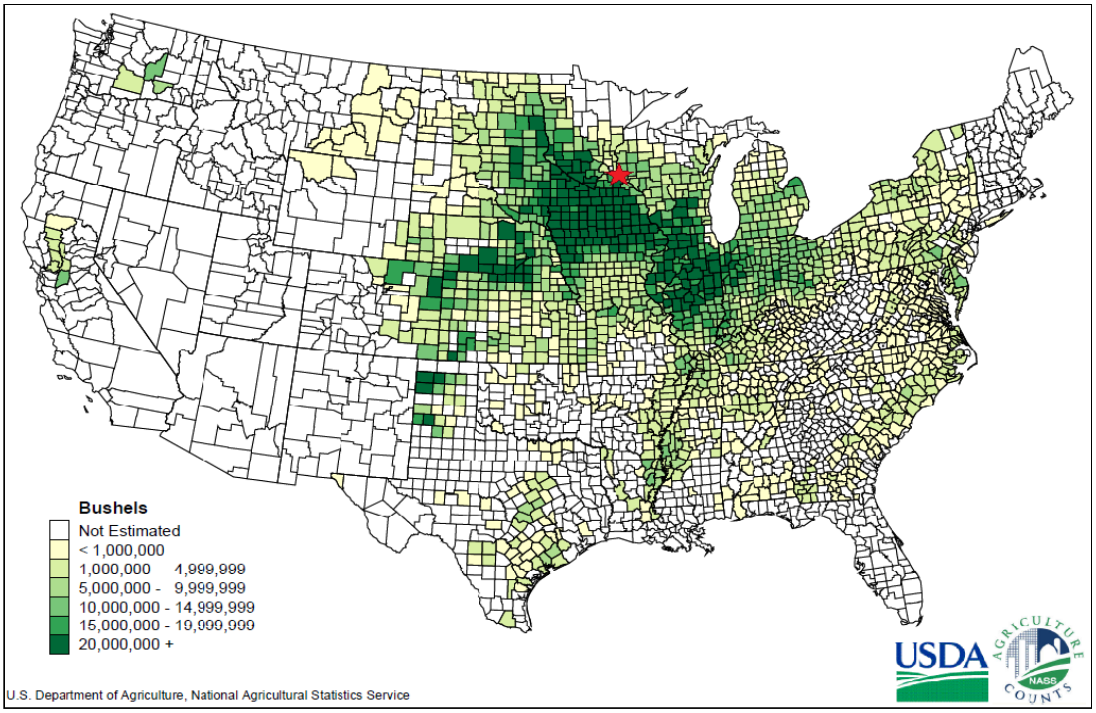

Figure 2.1. 2010 Corn Production by County for Selected States.
Source: http://www.nass.usda.gov/Charts_and_Maps/Crops_County/pdf/CR-PR10-RGBChor.pdf

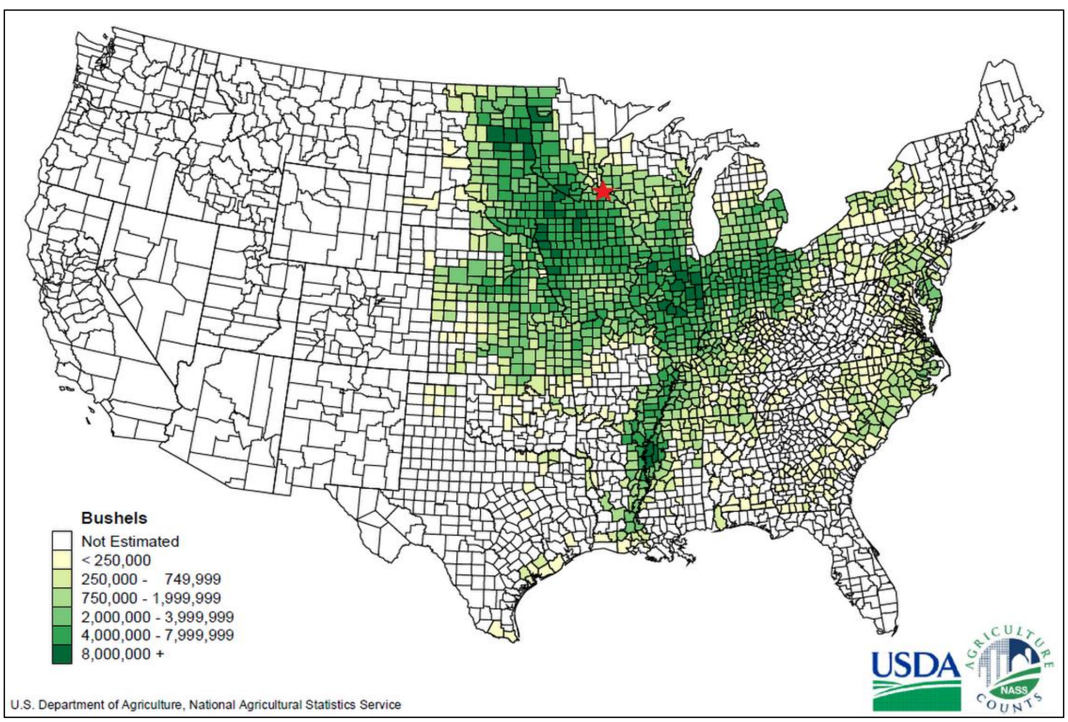

Figure 2.2. 2010 Soybean Production by County for Selected States.
Source: http://www.nass.usda.gov/Charts_and_Maps/Crops_County/pdf/SB-PR10-RGBChor.pdf

Table 2.11. Total Volume of Corn and Soybeans Transiting Locks on Upper Mississippi River, 2000–2010 (Thousand Tons).

Lock Name	Corn (down)	Corn (up)	Corn Total	Soybean (down)	Soybean (up)	Soybean Total
Upper St. Anthony Falls	743	6	749	345	5	350
Lower St. Anthony Falls	759	30	789	338	12	350
Lock 1	744	305	1,049	336	246	582
Lock 2	26,615	228	26,843	6,553	239	6,792
Lock 3	26,600	226	26,826	6,550	238	6,788
Lock 4	32,132	240	32,372	7,871	259	8,130
Lock 5	32,111	264	32,375	7,844	241	8,085
Lock 5A	32,178	220	32,398	7,899	310	8,209
Lock 6	44,997	218	45,215	11,447	299	11,746
Lock 7	45,265	278	45,543	11,491	426	11,917
Lock 8	47,460	350	47,810	12,119	431	12,550
Lock 9	47,530	438	47,968	12,066	514	12,580
Lock 10	63,967	321	64,288	15,930	494	16,424
Lock 11	64,343	378	64,721	16,018	517	16,535
Lock 12	72,414	403	72,817	18,423	541	18,964
Lock 13	75,308	509	75,817	19,049	583	19,632
Lock 14	88,822	479	89,301	22,285	576	22,861
Lock 15	92,323	518	92,841	22,994	656	23,650
Lock 16	98,403	454	98,857	26,454	632	27,086
Lock 17	101,772	436	102,208	28,402	617	29,019
Lock 18	111,303	414	111,717	31,220	645	31,865
Lock 19	127,369	854	128,223	36,454	719	37,173
Lock 20	132,876	870	133,746	38,232	961	39,193
Lock 21	135,505	763	136,268	39,407	942	40,349
Lock 22	137,990	826	138,816	39,745	961	40,706
Lock 24	140,323	908	141,231	40,401	1,022	41,423
Lock 25	140,085	2,767	142,852	40,454	1,936	42,390
Melvin Price	258,564	2,822	261,386	67,934	1,981	69,915
Chain of Rocks	258,559	9	258,568	68,228	3	68,231
TOTAL	**2,437,059**	**16,529**	**2,453,588**	**656,488**	**17,004**	**673,492**

Table 2.12. Total Value of Corn and Soybeans Transiting Locks on Upper Mississippi River, 2000–2010 (Million USD).

Lock Name	Corn (down)	Corn (up)	Corn Total	Soybean (down)	Soybean (up)	Soybean Total
Upper St. Anthony Falls	55	0.3	55	56	0.7	57
Lower St. Anthony Falls	56	2.2	58	54	2.1	56
Lock 1	56	27	83	54	57	111
Lock 2	2,402	19	2,421	1,458	55	1,513
Lock 3	2,402	19	2,421	1,458	55	1,513
Lock 4	2,925	20	2,945	1,775	58	1,833
Lock 5	2,924	23	2,947	1,772	56	1,828
Lock 5A	2,929	19	2,948	1,781	76	1,857
Lock 6	4,110	20	4,130	2,572	71	2,643
Lock 7	4,137	24	4,161	2,582	101	2,683
Lock 8	4,349	32	4,381	2,744	102	2,846
Lock 9	4,356	41	4,397	2,732	120	2,852
Lock 10	5,880	31	5,911	3,710	115	3,825
Lock 11	5,922	36	5,958	3,725	118	3,843
Lock 12	6,673	38	6,711	4,270	123	4,393
Lock 13	6,953	49	7,002	4,416	132	4,548
Lock 14	8,176	46	8,222	5,151	132	5,283
Lock 15	8,508	50	8,558	5,325	146	5,471
Lock 16	9,083	44	9,127	6,134	141	6,275
Lock 17	9,399	41	9,440	6,574	137	6,711
Lock 18	10,344	39	10,383	7,260	146	7,406
Lock 19	11,920	84	12,004	8,457	162	8,619
Lock 20	12,453	79	12,532	8,856	224	9,080
Lock 21	12,716	68	12,784	9,111	223	9,334
Lock 22	12,953	74	13,027	9,192	226	9,418
Lock 24	13,175	85	13,260	9,337	237	9,574
Lock 25	13,151	256	13,407	9,339	453	9,792
Melvin Price	24,353	252	24,605	15,172	455	15,627
Chain of Rocks	24,335	0.7	24,336	15,284	0.0	15,284
TOTAL	**226,695**	**1,519**	**228,214**	**150,351**	**3,924**	**154,275**

The Ohio River did not have much grain movement in either direction at the upstream locks between Emsworth and Meldahl. Most grain flows occurred between Markland Lock and Lock 52, the largest portion being downbound. During this period, 39.9 million tons and 22.8 million tons of downbound corn and soybeans, respectively, and 16.9 million tons and 7.7 million tons of upbound corn and soybeans, respectively, transited Lock 52. At Lock 52, downbound corn and soybeans were valued at $4.1 billion and $5.5 billion, respectively; the corresponding upbound values were $1.78 billion and $1.9 billion (see Table 2.14).

Table 2.13. Total Volume of Corn and Soybeans Transiting Locks on Ohio River, 2000-2010 (Thousand Tons).

Lock Name	Corn (down)	Corn (up)	Corn Total	Soybean (down)	Soybean (up)	Soybean Total
Emsworth	0	9	9	0	66	66
Dashields	0	13	13	1	68	69
Montgomery	0	68	68	2	128	130
New Cumberland	26	78	104	385	128	513
Pike Island	21	100	121	374	142	516
Hannibal	27	114	141	375	159	534
Willow Island	24	115	139	387	167	554
Belleville	25	114	139	394	180	574
Racine	25	162	187	399	238	637
Robert C. Byrd	42	237	279	411	357	768
Greenup	65	248	313	420	330	750
Meldahl	99	377	476	423	576	999
Markland	9,805	466	10,271	7,098	715	7,813
McAlpine	13,262	493	13,755	9,452	758	10,210
Cannelton	13,427	703	14,130	9,579	2,853	12,432
Newburgh	17,323	523	17,846	12,409	1,564	13,973
John T. Myers	32,399	591	32,990	17,651	1,542	19,193
Smithland	36,784	13,277	50,061	19,277	6,643	25,920
Lock 52	39,857	16,819	56,676	22,722	7,699	30,421
Lock 53	42,562	0	42,562	23,531	0	23,531
Olmsted	0	9	9	0	57	57
TOTAL	**205,773**	**34,516**	**240,289**	**125,290**	**24,370**	**149,660**

Table 2.14. Total Value of Corn and Soybeans Transiting Locks on Ohio River, 2000–2010 (Million USD).

Lock Name	Corn (down)	Corn (up)	Corn Total	Soybean (down)	Soybean (up)	Soybean Total
Emsworth	0.0	0.7	1	0.0	16	16
Dashields	0.0	1.1	1	0.2	16	16
Montgomery	0.0	6.7	7	0.6	30	31
New Cumberland	3.7	8	12	111	30	141
Pike Island	2.9	10	13	109	33	142
Hannibal	3.7	11	15	109	38	147
Willow Island	3.2	11	14	112	40	152
Belleville	3.2	11	14	114	45	159
Racine	3.3	18	21	116	57	173
Robert C. Byrd	5.1	24	29	118	85	203
Greenup	7.9	26	34	117	76	193
Meldahl	11	38	49	117	134	251
Markland	967	48	1,015	1,700	169	1,869
McAlpine	1,328	52	1,380	2,246	183	2,429
Cannelton	1,343	74	1,417	2,277	699	2,976
Newburgh	1,794	56	1,850	2,987	411	3,398
John T. Myers	3,345	66	3,411	4,278	407	4,685
Smithland	3,810	1,305	5,115	4,678	1,624	6,302
Lock 52	4,115	1,679	5,794	5,506	1,897	7,403
Lock 53	4,380	0.0	4,380	5,681	0.0	5,681
Olmsted	0.0	0.8	1	0.0	14	14
TOTAL	**21,126**	**3,446**	**24,572**	**30,377**	**6,004**	**36,381**

Statistics on Lock Waiting Times

Due to the increased traffic and deteriorating lock conditions along the rivers, congestion at various locks sometimes leads to extended waiting times at locks. In this section, we document the congestion situation at the six priority locks for the past 10 years.

During periods when the locks were operating under normal conditions and there was light traffic, barges did not need to wait for lockage; however, there was wide dispersion in terms of waiting time at various locks. Table 2.15 displays key waiting time summary statistics for the period 2000 to 2010.

Table 2.15. Summary statistics of waiting times.

Lock	Zero Wait Time (%)	Average Waiting Time (minutes)	Standard Deviation	Maximum Waiting Time (minutes)
Ohio Emsworth	61	63	237	4761
Ohio Markland	52	83	228	3307
Ohio Lock 52	70	190	582	10,462
Miss. Lock 20	25	120	228	14,490
Miss. Lock 25	22	160	351	14,368
Illinois LaGrange	44	155	366	11,033

The proportion of zero waiting time ranges from 22% to as high as 70%. Average waiting times range between 63 minutes and 190 minutes, with an overall average of 132 minutes. The standard deviations are several magnitudes larger than the average waiting times, indicating considerable dispersion at all six locks in question. The maximum waiting time exceeds 10 days, probably due to some unannounced lock closures.

Next, we examine the waiting time of barges with waiting times greater than zero (i.e., barges that had to wait for passage at the lock). The average waiting times and their standard deviations are reported below. The average waiting times increase considerably, as do their standard deviations. The overall average time for barges that experienced a wait is 265 minutes. Table 2.16 shows these statistics for each of the six locks.

Table 2.16. Summary statistics of non-zero waiting times.

Lock	Average Waiting Time (minutes)	Standard Deviation
Ohio Emsworth	160	357
Ohio Markland	175	306
Ohio Lock 52	634	923
Miss. Lock 20	160	251
Miss. Lock 25	206	386
Illinois LaGrange	276	454

To better illustrate the distribution of waiting times, Figure 2.3 plots the histograms of waiting times for the six priority locks. The six distributions share a common profile of extended right tails, caused by infrequent unusually long waiting times associated with extreme lock conditions. At the same time, considerable differences exist across the locks. Several locks exhibit bi-modal distributions with a second significant mode, whereas others are only associated with near zero waiting times.[10] Interestingly, for all distributions with significant second modes, the locations of the second modes cluster around the 90 minute mark.

[10] Roughly speaking, a point on a density curve is called a mode if it is the highest point of the density function within a given neighbor. A distribution can have zero, one, or multiple modes. For example, the normal distribution with mean zero, whose density peaks at zero, has a mode at zero. Distributions with one single mode

We next look at the evolution of average waiting time during the sample period of 2000 to 2010, which is reported in the top plot of Figure 2.4 . The overall average waiting time started in 2000 around 150 minutes and declined sharply to around 50 minutes in 2004, and then increased in the following years, peaking in 2010 at the level of more than 200 minutes. We conjecture that the overall increasing trend of waiting time is associated with both planned and unplanned closures necessitated by aging lock conditions.

The lower plot of Figure 2.4 reports the 10-year average waiting times by month across all locks. A seasonable pattern is evident from the plot. The average time peaks during the summer and fall, corresponding to the agricultural production cycle. On the other hand, the early spring months report the least waiting time.

Last, we examine the differences of the annual and monthly average waiting times across the locks. Figure 2.5 reports the corresponding results, in which the following legends are used:

1. Ohio River Emsworth Lock.
2. Illinois River LaGrange Lock.
3. Mississippi River Lock 20.
4. Mississippi River Lock 25.
5. Ohio River Markland Lock.
6. Ohio River Lock 52.

In both the annual and monthly average waiting times, Ohio River Lock 52 is probably a bottleneck lock for the following reasons: (1) it averages the highest waiting time; (2) it exhibits the most volatile seasonal variations; and (3) waiting times have increased substantially during the last few years.

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are called uni-modal distributions, while those with multiple modes are called multi-modal distributions. In particular, distributions with two modes are called bi-modal distributions.

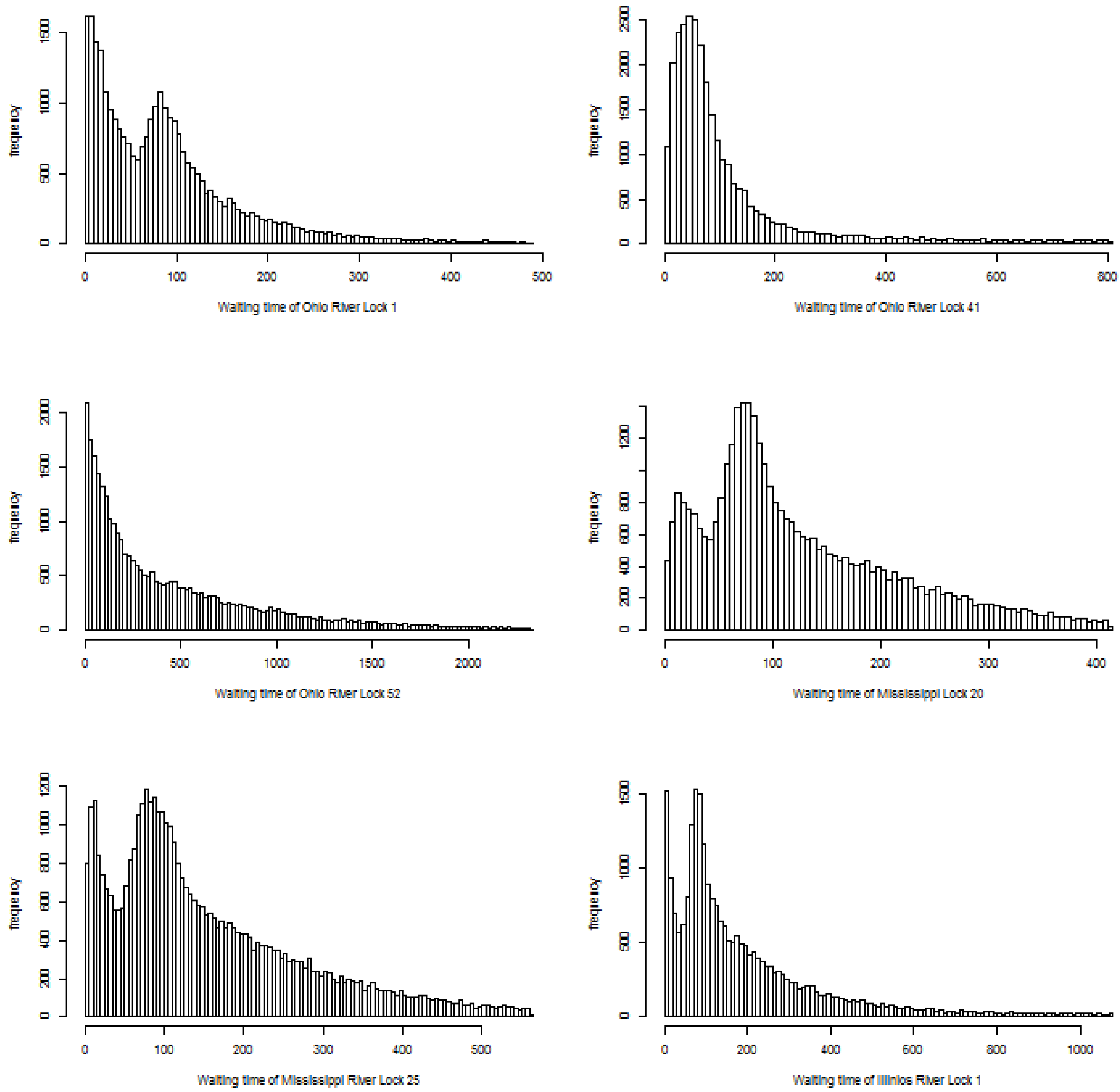
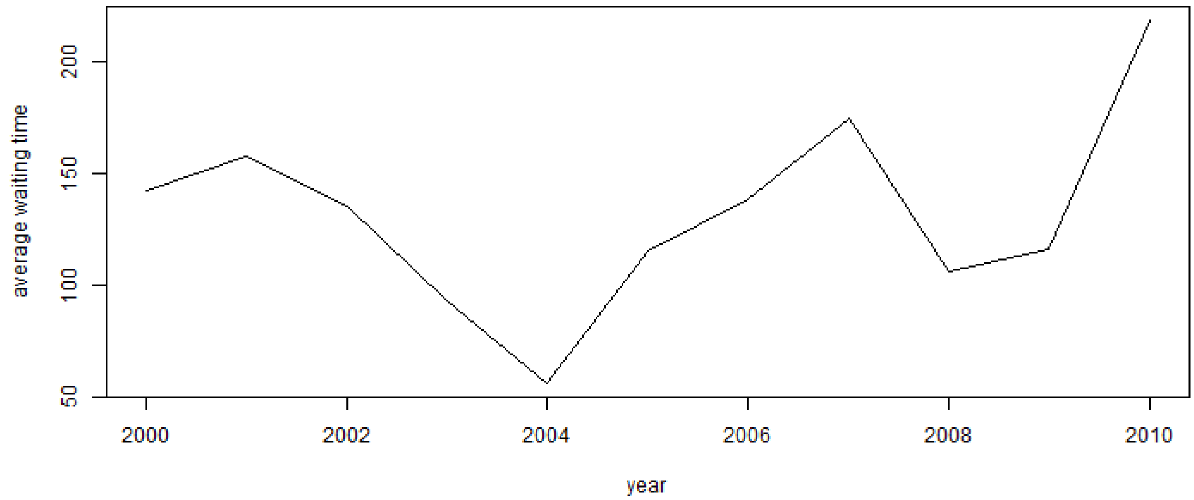


Figure 2.3. Histograms of Waiting Times.



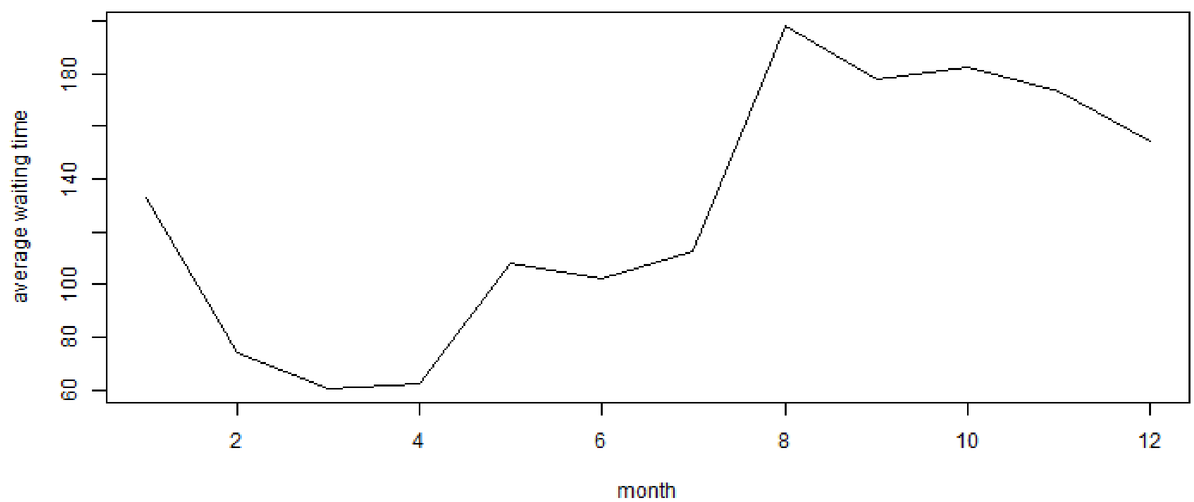
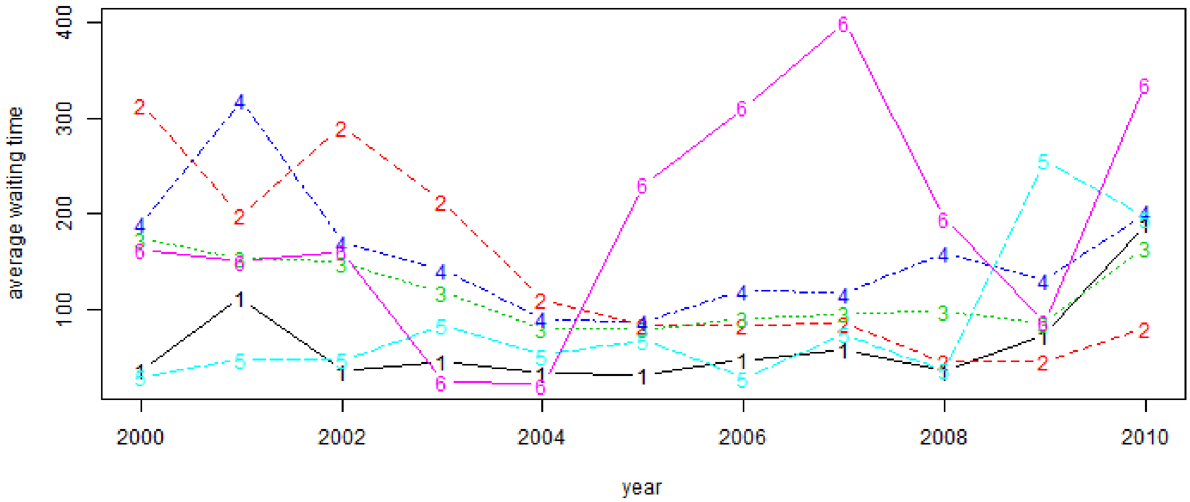


Figure 2.4. Average Waiting Times by Year and Month across Six Focus Locks



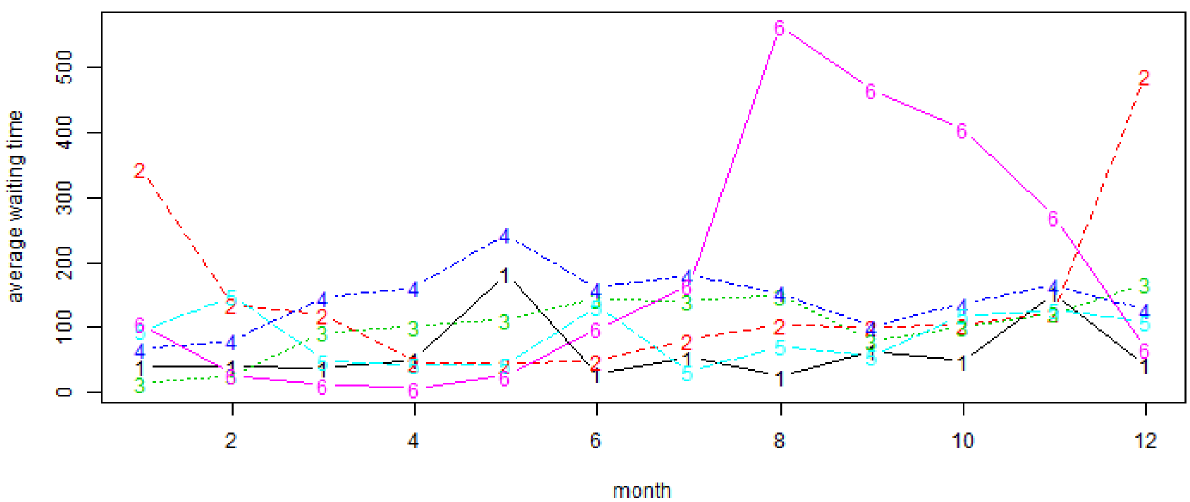


Figure 2.5. Annual and Monthly Waiting Times across Six Focus Locks

Legend: 1. Ohio River Emsworth Lock; 2. Illinois River LaGrange Lock; 3. Mississippi River Lock 25; 4. Mississippi River 25; 5. Ohio River Markland Lock; 6. Ohio River Lock 52

CHAPTER 3 LOCK CONDITION INFORMATION AND POTENTIAL MODAL DIVERSION IMPACTS

Lock Condition, Maintenance/Replacement Costs, and Prioritization

Introduction

The Corps operates and maintains approximately $232 billion worth of water resources infrastructure assets, including a network of 11,000 miles of the "fuel-taxed" Inland Waterway System (FTWS).[11] The FTWS includes 207 lock chambers (at 171 sites) on 27 inland rivers and intracoastal waterways system segments. Of the 207 locks on fuel-taxed waterways, potential project investment needs have been identified at 84 lock locations over the next 20 years. There are 14 other shallow draft lock chambers on tributaries of the FTWS that are not included in the FTWS, making a total of 221 lock chambers at 185 inland and intracoastal sites that the Corps operates or maintains.[12]

The economic service life for navigation structures is typically 50 years and is usually extended through major rehabilitation to 75 years. Currently, 54% of the Inland Marine Transportation System's (IMTS) structures are more than 50 years old and 36% are more than 70 years old.[12] Figure 3.1 depicts the distribution of locks and dams by age.

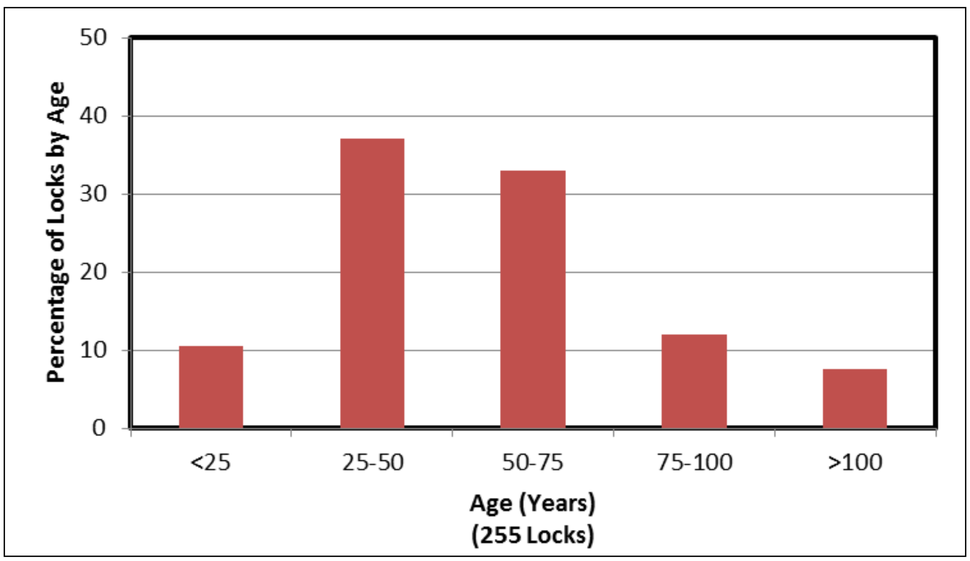


Figure 3.1. Age of Lock and Dam Infrastructure.
Source: James McCarville, Issues Up Close: Great Lakes and Ohio River Division, 8th Annual Waterways Symposium, Pittsburgh, PA, October 19–21, 2011

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[11] Not all of the Inland Waterway System is "fuel-taxed". This study focuses strictly on the "fuel-tax" portion, which is a high percentage of the total system.
[12] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model, Final Report, Revision 1, April 13, 2010.

The age of these facilities is reflected in lock outage statistics. On the Ohio River, for example, navigation outages have increased more than 3-fold since 2000, going from approximately 25,000 hours to 80,000 hours.[13] Figure 3.2 reflects the growing trend in lock outages.

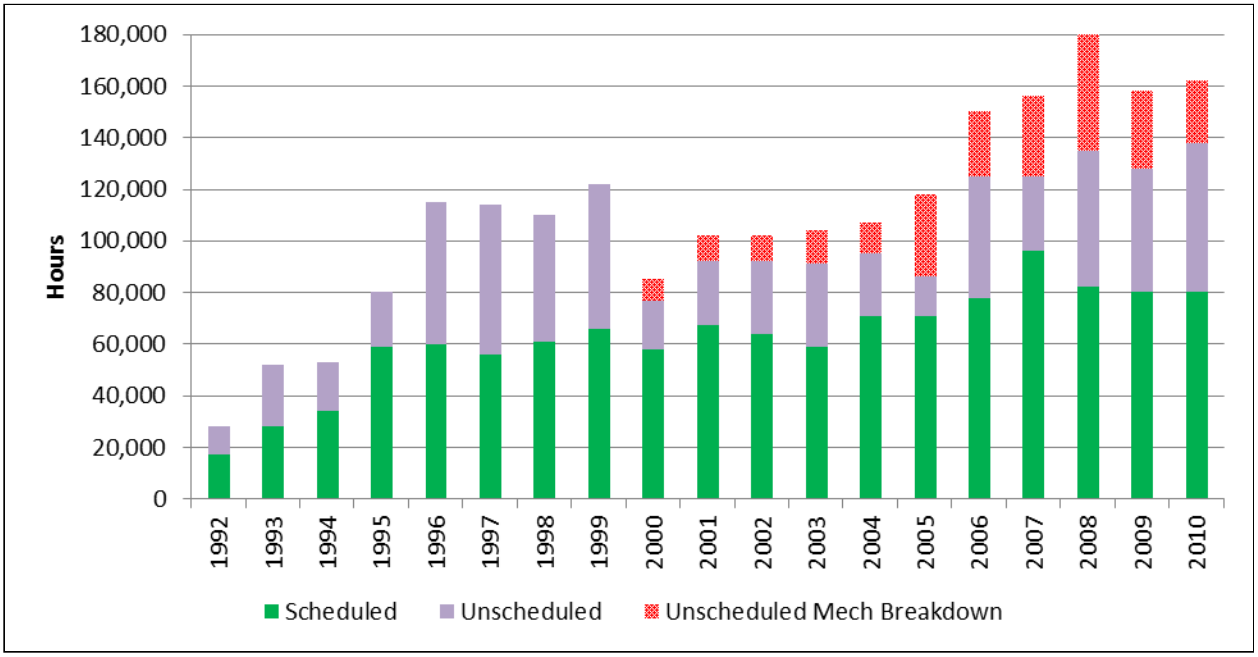

Figure 3.2. Hours of Lock Outages by Year and by Type of Outage.

Source: Steven L. Stockton, PE, The Challenge: Keeping Our Inland Waterways System Reliable, 8th Annual Waterways Symposium, Pittsburgh, PA, October 19–21, 2011.
Mark L. Mazzanti, Civil Works Program, 8th Annual Waterways Symposium, Pittsburgh, PA, October 19–21, 2011.

The age and increase in hours of outage are a valid concern. There have been two recent failures. Markland Lock on the Ohio River experienced a gate failure in 2009. The unexpected failure of the main chamber miter gates in fall 2009 resulted in significant delays which continued over a 5-month period. Greenup Lock (also on the Ohio River) experienced an anchorage failure in the main chamber and was closed for nearly one month in 2010.

In recent testimony before the House Transportation and Infrastructure Committee, Stephen Little, former chairman of the Inland Waterways User Board (IWUB) noted, "In the past our nation could build 26 projects in 10 years on the Upper Mississippi River, 7 lock and dam projects in 9 years on the Illinois River, locks and dams at 10 sites in 12 years on the Tennessee-Tombigbee Waterway, and 7 new projects in 4 to 8 years following the Water Resources and Development Act of 1986 (WRDA 86). Today it is taking 30 years to build new projects in each of 2 locations and 14 years to build what it took 3 years to build at another location." [14] IMTS

[13] Background Memorandum, Hearing on "the Economic Importance and Financial Challenges of Recapitalizing the Nation's Inland Waterways Transportation System", U.S. House of Representatives Committee on Transportation and Infrastructure, September 16, 2011.
[14] http://transportation.house.gov/news/PRArticle.aspx?NewsID=1398

Projects that were authorized in WRDA 86 were completed within an average of 6 years. However, projects authorized since then have on average taken 20 years to complete and cost more than twice the estimated amount.[3] Given the time it takes to bring projects to completion, it is imperative for the federal government to prioritize critical projects and bring them to completion in the shortest time possible.

Delays and budget overruns have become so severe that they are causing other projects to lose funding or be delayed by a number of years. An example is the Olmsted Locks and Dam Project that was authorized by the Water Resources Development Act of 1988 (WRDA 1988, Public Law 99-662) to replace the locks and wicket dams at Ohio River Locks and Dams 52 and 53 with a single lock and dam project. The original estimate was $775M in 1988. The latest estimated total cost for the project is $2.124 billion, an increase of $1.3 billion over the original estimate. In addition, the construction completion date has been delayed from 2005 to 2018, 13 years beyond the original estimate. The cost escalation in this project can be linked to factors such as design and scope changes, differing site conditions, and omissions (some of which were within the Corps' control), while others, such as some of the escalation (approximately 30%) has been attributed to inefficient funding.

The Lower Monongahela (Lower Mon) Locks and Dams 2, 3, & 4 Project encountered similar cost escalation and schedule delay.[15] The original estimate for this project in 1992 was $554M. The latest estimate for the project is $1.4 billion. The unfunded amount is $896M—62% more than the original estimate.

Of particular concern in both of these cases is the fact that industry is required to pay 50% of the total cost without any say as to whether the overruns and delays were justified—a situation that is clearly contrary to the goal of establishing mutually satisfactory partnerships between industry and the Corps.

Lock Condition, Replacement/Maintenance Costs, and Probability of Failure

Much of the evaluation and prioritization work for maintenance and rehabilitation has already been done in a collaborative effort between navigation industry representatives and Corps inland navigation experts. At the request of the IWUB, a working group known as the Inland Marine Transportation System Capital Investment Strategy Team (IMTS CIS Team, or Team) was formed for this purpose. The Team's findings were published a document titled "Inland Marine Transportation Systems (IMTS) Capital Projects Business Model (CPBM)," dated April 13, 2010.

The Team concluded that the most useful representation of system value and return on investment should include assessments on an asset-by-asset basis using the following:

- The asset's current condition.
- The likelihood of diminished asset performance.

[15] U.S. Army Corps of Engineers Great Lakes and Ohio River Division, Inland Navigation Construction Selected Case Studies, July 2008.

- The consequence of diminished performance in terms of repair costs, outages, and economic losses.
- How the proposed investment would improve performance or reduce the asset's likelihood of diminished performance.
- For new assets, whether the project could be expected to improve system performance.

Each Corps district identified new construction or major rehabilitation projects that were (1) under construction (Phase 1 projects) or (2) that were authorized but not yet under construction (Phase 2 projects). They also designated Phase 3 projects. Phase 3 projects are potential projects based on a district's knowledge of its operational requirements, facility condition, and the (unrealistic) assumption that unconstrained funding will be available. Neither a feasibility study nor a Rehabilitation Evaluation Report (RER) has been completed for these projects (although a few studies have been started). The criteria selected by the Team for ranking projects fell into two broad categories: (1) structural and operational risk and reliability and (2) economic return. Structural and operational risk and reliability metrics were represented either by a Dam Safety Action Classification (DSAC) rating or a Condition Index (CI) rating. Table 3.1 and Table 3.2 display the criteria used to prioritize the unconstrained project list.

Table 3.1. IMTS Investment Strategy Criteria Weighting.

Criteria	Weight
Risk and Reliability	40
Condition Index for Locks (rated A through F)	
DSAC for Dams (rated 5 through 1)	
Economic Return	60
Net Benefits	15
Benefit-Cost Ratio (BCR)	5
Remaining Benefit Remaining Cost Ratio (RBRCR)	25
Economic Impact	15
Total	**100**

Table 3.2. IMTS Investment Strategy Condition Weights.

Risk and Reliability		
DSAC	Condition Index Rating	Weight
1	F	40
2	D	25
3	C	10
4	B	5
5	A	0

The risk and reliability criteria were depicted as numeric grades of 1 through 5 for DSAC ratings (with 1 being the worst/failed condition), and as letter grades of A through F for CI ratings (with F being the worst/failed condition). Table 3.3 defines the facility condition for each level of the index.

Table 3.3. Condition Index.

Condition	Definitions
A – Adequate	Limited probability of failure
B – Probably Adequate	Low probability of failure
C – Probably Inadequate	Moderate probability of failure
D – Inadequate	High probability of failure
F – Failed	The feature has FAILED

The five levels of the DSAC ratings can be characterized as follows:

- LEVEL 1 – Urgent and Compelling (unsafe).
- LEVEL 2 – Urgent.
- LEVEL 3 – High Priority.
- LEVEL 4 – Priority (marginally safe).
- LEVEL 5 – Normal.

The risk and reliability criteria metrics were then converted to numeric scores. The economic criteria were depicted as dollars for net benefits, as ratios for BCRs and RBRCRs, and as numeric grades of 1 through 100 for economic impact. These metrics were normalized to the highest value observed for that metric in the project list, with a maximum weight of 60. When combined with economic factors, the most distressed assets with the greatest financial benefit were identified as the projects at the high end of the prioritization list.

New construction and major rehabilitation projects are financed 50% from diesel fuel taxes paid by inland waterway users and 50% from the General Fund. Table 3.4 lists projects in the study area that were cost-shared in this manner and were completed as of the date of the CPBM.

As of the date of the CPBM, the study area projects shown in Table 5 were underway. Table 6 lists the Phase 2 projects included in the CPBM.

Table 3.4. Study Area Completed Projects Cost-Shared from the Inland Waterways Trust Fund.

Project	Start Year	Completion Year[a]	Construction Duration (Years)	$ (Million) IWTF Cost	Total Cost
RC Byrd New 1200" and 600"	1987	1993	7	106.3	212.6
Illinois Waterway (4 Rehabs)	1993	1996	4	13.6	27.2
Upper Miss 13 Rehab	1993	1996	4	10.4	20.7
Upper Miss 15 Rehab	1993	1996	4	9.8	19.6
Upper Miss 25 Rehab	1994	2000	7	13.0	25.9
Upper Miss 3 Rehab	1998	2009	19	3.7	71.2
Upper Miss 12 Rehab	2000	2003	4	5.2	14.7
Upper Miss 11 Rehab	2002	2008	7	20.3	47.3
Upper Miss 19 Rehab	2003	2008	6	15.8	31.6
Upper Miss 27 Rehab	2007	2011	5	3.4	37.3
Upper Miss 24 Rehab	1996	N/A	N/A	N/A	N/A
McAlpine 1200' Auxiliary	1996	2009	14	212.9	429.3
Lockport Rehab	2006	2012	7	0	136.8[b]

[a] *Year placed in service*

[b] *Funded with American Recovery and Reinvestment Act of 2009 funds*

Table 3.5 List of Study Area Corps Projects – Phase 1.

Project	Waterway	Div/Dist	Project Type[a] D/L/C	MR/NC	Current Cost Estimate $(M)[b]	Total Remaining Base Cost $(M)[c]
Olmsted Dam	Ohio River	LRD/LRL	D	NC	2,044.0	835.5
Emsworth Dams Major Rehabilitation	Ohio River	LRD/LRP	D	MR	160.0	15.6
Markland Locks – Lock Major Rehabilitation	Ohio River	LRD/LRL	L	MR	35.8	5.4

[a] *Key for Project Type: D=Dam, L=Lock, C=Channel, MR=Major Rehabilitation, NC=New Construction*

[b] *Cost estimates were current at time of report, not necessarily recent approved estimate*

[c] *Remaining cost is FY2011 through project completion base cost (2008)*

Table 3.6. List of Study Area Corps Projects – Phase 2.

Project	Waterway	Div/Dist	Project Type[a] D/L/C	MR/NC	Current Cost Estimate $(M)[b]	Total Remaining Base Cost $(M)[c]
Greenup Lock Extension	Ohio River	LRD/LRH	L	NC	242.2	242.2
John T. Myers Lock Extension	Ohio River	LRD/LRL	L	NC	315.1	315.1
NESP Upper Mississippi Lock 25	Mississippi River	MVD/MVT	L	NC	396.6	396.6
NESP Upper Mississippi Lock 22	Mississippi River	MVD/MVR	L	NC	304.5	304.5
NESP Upper Mississippi Lock 24	Mississippi River	MVD/MVR	L	NC	379.0	379.0
NESP Upper Mississippi Lock 21	Mississippi River	MVD/MVR	L	NC	394.5	394.5
NESP Upper Mississippi Lock 20	Mississippi River	MVD/MVR	L	NC	269.5	269.5
NESP LaGrange Lock	Illinois Waterway	MVD/MVR	L	NC	320.9	320.9
NESP Peoria Lock	Illinois Waterway	MVD/MVR	L	NC	322.1	322.1
Lock & Dam 25 Mississippi River – Dam Rehabilitation	Mississippi River	MVD/MVS	D	MR	40.0	27.0
LaGrange Lock Rehabilitation	Illinois Waterway	MVD/MVR	L	MR	53.2	53.2
John T. Myers Dam Rehabilitation	Ohio River	LRD/LRL	D	MR	44.8	44.8

[a] *Key for Project Type: D=Dam, L=Lock, C=Channel, MR=Major Rehabilitation, NC=New Construction*

[b] *Cost estimates were current at time of report, not necessarily recent approved estimate*

[c] *Remaining cost is FY2011 through project completion base cost (2008)*

Table 3.7 shows the 10 highest ranked (most urgent) projects and includes projects from both Phase 1 and 2. Olmsted Lock and Dam was by far the highest-ranking project based on the CI rating (for Locks and Dams 52 and 53, which Olmsted will replace) and the economic rating, highest in all areas except Economic Impact.

Table 3.7. Total Ranking for the 10 Highest Ranked Projects Nationwide.

Project Name	Subproject Name	Criteria Total	Rank
Olmsted Locks and Dams	Olmsted L/D Construction	90.5	1
Monongahela Locks and Dams 2,3, and	Lower Mon 2,3,4, Dam	69.5	2
Monongahela Locks and Dams 2,3, and	Lower Mon 2,3,4, Dam	68.8	3
Greenup Lock, Ohio River	Greenup Lock Extension	59.0	4
Chickamauga Lock	Chickamauga Replacement	40.2	5
Upper Mississippi & Illinois Waterway	1200' Lock Addition	26.9	6
Upper Mississippi & Illinois Waterway	1200' Lock Addition	26.5	7
Kentucky Lock Addition	Kentucky Lock Addition	26.3	8
Inner Harbor Navigation Canal Lock	IHNC	23.9	9
Upper Mississippi & Illinois Waterway,	1200' Lock Addition	23.2	10

This technical memorandum focuses on the Upper Mississippi River, the Illinois Waterway, and the Ohio River. Table 3.8 shows the listing of locks/dams on these rivers and their priority ranking by the Team. This table includes the latest publicly available information from the following sources:

- US Army Corps of Engineers.
    - Mississippi Valley Division.
        - St. Paul District.
        - Rock Island District.
        - St. Louis District.
    - Great Lakes and Ohio River Division.
        - Huntington District.
        - Louisville District.
- Inland Waterway Users Board.
- Transportation Research Board—Marine Board Presentations.

Only the Phase 1 and Phase 2 projects (shown in red font) were urgent enough that they already had some activity. Therefore, the researchers focused on them in order to determine the locks that would be most likely to fail and/or would have the greatest economic impact in the event of a failure. Additionally, this memo specifically considers those projects that are of a rehabilitation or construction nature, not design (PED) projects.

The six projects selected for detailed analysis and modeling are highlighted in yellow. Figure 3.3 shows the location of these locks.

- Upper Mississippi River Lock and Dam 25.
- Ohio River Olmsted Lock and Dam (replacement for L&D 52 and 53).
- Ohio River Emsworth Lock and Dam.
- Ohio River Markland Lock and Dam.
- Illinois River LaGrange Lock and Dam.
- Upper Mississippi River Lock and Dam 20.

Figure 3.3. Location of Selected Locks.

Initially, the project team selected the first five locks for detailed analysis; however, Upper Mississippi River Lock and Dam 20 was added to provide broader geographical coverage. The IWUB's Capital Projects Business Model indicated that Locks 20–25 were roughly equivalent in terms of condition and priority, so the northernmost lock (Lock 20) was chosen.

After the study was initiated, the Markland Lock and Dam project was placed on the fast track using funds awarded from the American Recovery and Reinvestment Act of 2009 (ARRA). In fact, it was scheduled to be completed before this analysis was completed. However, the researchers kept it within the scope of the project because of its location and importance to the system as a whole.

Several of the listed projects received funds from ARRA. These are shown as ARRA funds in the table.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Mississippi River					
1	Rehab	3	31	$3.5M (not funded)	Last major rehab was 1983. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.
2	Rehab	3	35	$9.3M (not funded)	Last major rehab was 1995. The lock is 60 years old and the dam over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
3	Rehab	3	35	$71.0M (funded)	Last major rehab was 1991. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, including the ongoing embankment repairs and guide wall extension, additional rehabilitation will be required to ensure reliability over the next 30 years. Using ARRA funds ($70.2M) to perform rehab. All work to be completed by fall 2012.
4	Rehab	3	36	$5.5M (not funded)	Last major rehab was 1994. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
5	Rehab	3	36	$525,000 (not funded)	Last major rehab was 1998. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. Dewatering and some maintenance done in FY 10.
5a	Rehab	3	36	$11.3M (not funded)	Last major rehab was 2000. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
6	Rehab	3	38	$6.2M ($2.7M funded)	Last major rehab was 1999. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. ARRA provided $6M for bulkhead slot installation at 6 and 7.
7	Rehab	3	38	$6.3M (3.3M funded)	Last major rehab was 2002. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. Maintenance is scheduled for FY 12. ARRA provided $6M for bulkhead slot installation at 6 and 7.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
8	Rehab	3	38	$10M (not funded)	Last major rehab was 2003. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.
9	Rehab	3	39	$11M (not funded)	Last major rehab was 2006. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
10	Rehab	3	40	$8.6M (not funded)	Last major rehab was 2006. The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. Some major maintenance was done in FY11.
11 – Not ranked				$74.5M (still need $12.9M)	Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. Most critical repairs are funded and expected to be completed in FY 12. ARRA contributed $4.8M.
12	Rehab	3	42	$27.2M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
13	Rehab	3	42	$25.2M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.
14	Rehab	3	44	$29.4M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.
15	Rehab	3	41	$35.5M (Amt funded?)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. Will repair lock strut arms In FY 12.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
16	Rehab	3	45	$32.6M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.
17	Rehab	3	45	$34.1M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
18	Rehab Lock & Dam	3	46	$51.9M (Amt funded?)	Recent periodic inspections have noted a significant increase in the rate of concrete deterioration of the dam structure. A concrete condition survey completed in 2005 confirmed that the dam concrete is deteriorating due to an expansive reaction and freeze-thaw cycling. Immediate concrete repairs are needed. Additionally, the lock and dam are over 70 years old and additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. In FY 12 will perform dam concrete repairs and procure miter gates.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
19	Rehab	3	48	$51.2M (not funded)	The dam is nearly 100 years old and the lock 50 years old. Upper miter gates are leaking. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. Potential unscheduled closures of 90 days have been estimated and associated with failures of mechanical equipment.
20	1,200' Lock Addition	2	25.8	$269.5M (not funded)	
	Lock and Dam Rehab	3	48	$41.6M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
21	1,200' Lock Addition	2	26.4	$394.5M (not funded)	
	Lock and Dam Rehab	3	50	$31.5M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.
22	1,200' Lock Addition	2	26.5	$304.5M (not funded)	
	Lock and Dam Rehab	3	50	$35.1M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. In FY 12 will construct Bulkhead Slots Repair.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
24	1,200' Lock Addition	2	26.9	$379.0M (not funded)	
	Lock and Dam Rehab	3	51	$13.8M ($2.15M funded)	An $85 million major rehabilitation was substantially completed at Lock and Dam 24 in 2003. Only remaining item is repair to tainter gate trunions. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete ARRA provided $4.3M for L/D 24 & 25 (tainter gate chains and sprockets).

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
25	1,200' Lock Addition	2	26.9	$396.6M (not funded)	
	Rehab scour repairs	2	58.8	$11.0M ($8.2M funded)	Scour upstream is beginning to undercut the dam structure (repairs are under construction), and there are sand boils in the upstream levee (dike), sand boils downstream of the overflow portion of the dam, and a past history of voids under the dam. This work was underway and may have been completed by the date of this report. ARRA provided $6.085M: $4.3M for L/D 24 & 25 (tainter gate chains and sprockets) and $435,000 (spillway rehab), $200,000 for diesel compressors, $1.2M for culvert valve machinery, $1.9M to install downstream bulkhead slots, and $200,000 to repair concrete.
	Rehab	3	51	$18.3M ($6.1M funded)	
27 – Not Ranked				$28.3M (funded)	ARRA will completely fund the major rehabilitation of Locks 27. According to IWUB, ARRA provided $28.3M. Completed in 2011.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Melvin Price	Rehab	3	54	$9.5M ($4.7M funded)	Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete. ARRA provided $4.73M: $230,000 for spur dike, $2M to replace fenders on main lock miter gate, $2M to replace 4 bulkheads, and $500,000 for lock bulkhead lifting beam.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Ohio River					
52-53 (Olmsted)	Lock/Dam Construction	1	90.5	$2.044B (492.4M still needed post FY 12)	The existing structures have deteriorated structurally and are overstressed during normal operating conditions. The temporary locks at Locks & Dam 52 & 53 have significantly passed their design life. ARRA provided $29.3M.
Belleville	Dam Rehab PED and Const Lock & Dam Rehab PED and Const	3 3	32 11	$150M ($1.8M funded)	Needs major repairs to main chamber. ARRA has contributed $1.8M.
Cannelton	Dam Major Rehab Main Lock Major Rehab	3 3	39 12	$30M (not funded)	Dam needs repairs to stilling basins and baffle blocks, repairs to the skin sheets on the tainter gates, installation of new tainter gate side seals, welding of wire rope lay areas on all tainter gates, and refurbishing the bulkhead crane power feed and controls. Lock needs replacement or major repairs to components of the miter gates, miter gate machinery, electrical and hydraulic systems, and culvert valves.
Captain Anthony Meldahl	Lock Extension PED and Construction Dam Rehab Const Lock & Dam Rehab PED and Const	3 3 3	34.7 58 35	$220M (not funded)	Diminishing lock reliability and insufficient auxiliary lock capacity are in question.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Dashields	Locks & Dam Improvements	3	36.3	$590M (not funded)	Needs two 600' locks and rehab of main lock. (Lower guidewall repairs were made in FY11.)
Emsworth	Dam Major Rehab	1	53.3	$160M (still need 7.1M post FY 12)	Four significant dam rehab project features—the scour protection, vertical lift gates, gate operating machinery, and emergency bulkheads—were identified to have a high risk of failure. With efficient funding, project could be completed in 2014. ARRA provided $32.4M.
	Lock Addition and Main Chamber Rehab	3	50.9	$550M (not funded)	2 new 600' locks and main chamber rehab.
Greenup	Lock Extension PED and Construction	2	59.0	$60M (not funded)	Extension of the auxiliary lock chamber, replacement of the miter gates, and TBD.
	Greenup Dam Rehab PED and Const	3	91	$80M (not funded)	Address all mechanical and electrical deficiencies at the dam and taking action to replace, rehabilitate, or construct in order to bring the safety and efficiencies of the components to current standards.
Hannibal – Not ranked					

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
John T. Myers	Auxiliary Lock Extension	2	23.3	$315.1M (not funded)	Extend to 1200'.
	Dam Major Rehab	2	23.3	$44.8M (not funded)	In recent years, the 33-year old gated-dam has sustained significant structural damage. There are large holes in the reinforced concrete stilling basin, piers, and baffle blocks within several gate bays of the dam. Other areas of concern include seizing of hinged-brackets that attach hoisting cables to the tainter gates, and major maintenance needs for operating machinery and associated electrical service and controls.
	Main Lock Major Rehab	3	48	$40M (not funded)	
Markland	Lock Major Rehab	1	23.1	$35.8M (finished Nov 11)	The risk is very high that a failure of the lock gates will occur. The auxiliary lock miter gates are now showing signs of fatigue cracking also. Markland is now being dewatered annually instead of every 5 years. Construction will take approximately 4 years. ARRA contributed $8.6M.
McAlpine	Dam Major Rehab	3	38	$10M (not funded)	Needs repairs to stilling basins and baffle blocks, replacement of the tainter gate hoist cables, overhaul of the bulkhead cranes, replacement of bulkhead crane lifting cables, upgrades to the dam electrical system, and replacement of the safety warning signs on the dam. Replacing two small locks with one large one.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Montgomery	Dam Major Rehab	3	54	$190M (not funded)	This is one of the oldest gated structures on the Ohio River and currently shows significant signs of structural and operational degradation. Scour has eroded the downstream erosion protections and scour surveys indicate scour immediately downstream from the end sill as deep as 13 feet. In addition, the dam gates are extremely corroded. Recently spent $3.5M for temporary repairs.
	Lock Addition	3	36.1	$500M (not funded)	Add two 600' chambers and rehab main chamber.
New Cumberland	Major Rehab	3	45	$200M (not funded)	Replace the miter gates, gate operating machinery, replacement of filling and emptying valves and valve operating equipment, complete electrical system rehabilitation, tow haulage system replacement and removal and replacement of deteriorated vertical and horizontal wall concrete surfaces.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Newburgh	Dam Major Rehab	3	45	$10M (not funded)	Dam needs repairs to stilling basins and baffle blocks, replacement of tainter gate hoist cables and connections, overhaul of tainter gate operating machinery, refurbishing the bulkhead crane power feed and controls, and replacement of the bulkhead crane lifting cables. Probably not needed until after 2020.
	Main Lock Major Rehab	3	28	$30M (not funded)	Major repairs to the 1200-foot lock chamber from FY 2016 through FY 2018. The work will include replacement or major repairs to components of the miter gates, miter gate machinery, electrical and hydraulic systems, and culvert valves.
Pike Island	Lock Major Rehab	3	30	$200M (not funded)	Replace the gate operating machinery, replacement of filling and emptying valves and valve operating equipment, complete electrical system rehabilitation, tow haulage system replacement and removal, and replacement of deteriorated vertical and horizontal wall concrete surfaces. (New miter gates were installed in FY 2011).

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Racine	Dam Rehab PED and Const Lock Rehab PED and Const	3 3	33 32	$60M (not funded) $90M (not funded)	Address concrete deterioration in critical areas of the dam piers, rehabilitation and painting of critical members of the roller gates, replacement of seized roller gate lifting chains and upgrade of obsolete electrical and mechanical operating equipment. Address all mechanical and electrical deficiencies at the locks and take action to replace, rehabilitate, or construct in order to bring the safety and efficiencies of the components to current standards.
Robert C. Byrd – Not ranked					ARRA provided $584,000.
Smithland	Dam Major Rehab	3	50	$10M (not funded)	Repairs to stilling basins and baffle blocks, replacement of the tainter gate hoisting cables, and upgrades to the dam electrical equipment.
Willow Island	Dam Rehab PED and Const Lock Rehab PED and Const	3 3	51 11	$60M (not funded) $90M (not funded)	Address concrete deterioration in critical areas of the dam piers, rehabilitation and painting of critical members of the roller gates, replacement of seized roller gate lifting chains and upgrade of obsolete electrical and mechanical operating equipment. Address all mechanical and electrical deficiencies at the locks and take action to replace, rehabilitate, or construct in order to bring the safety and efficiencies of the components to current standards.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Illinois River					
LaGrange	1200' Lock Addition	2	23.2	$320.9 (not funded)	
	Rehab	2	37.3	$78.8M (not funded)	In need of major rehabilitation of lock concrete, electrical and mechanical systems. The vertical concrete has deteriorated to the point that sections have had to be removed and/or threaten to fall into the lock chamber. Barges can become wedged under the armor, resulting in a dangerous situation for deck hands, lock personnel, and potential damage to the barges. Hazardous working conditions exist due to deteriorated horizontal concrete on the land and river walls of the lock chamber. The mechanical and electrical systems require constant patching and labor-intensive repairs. Parts are difficult to obtain and have to be specially made in most cases. The probability of failure of the mechanical and electrical systems, requiring extensive and expensive repairs, in the next several years is very high. The potential at any time for an incident to occur due to deteriorated lock concrete, in which the lock had to be closed for more than a week, is very probable with the potential increasing every year the lock concrete is not repaired. Funding for this Major Rehabilitation project as a new start is not expected before FY 2013.

Table 3.8. Listing of Study Area Lock and Dam Rehab, Maintenance, and Improvement Needs – Continued.

Lock/Dam	Project Type	Phase	Priority Ranking	Cost Estimate $(M)	Condition/Comments
Peoria	Rehab	3	41	$22.9M (not funded)	The lock and dam are over 70 years old. While some major maintenance and rehabilitation have been performed, additional rehabilitation will be required to ensure reliability over the next 30 years. Long-established programs for preventative maintenance of major lock components have essentially given way to a fix-as-fail strategy, with repairs sometimes requiring weeks or months to complete.

Analysis of Impediments to Modal Shift (Water to Land)

Four different lock closure time horizons—two weeks, one month, whole quarter, and one year—are considered for each of the six locks that are the focus of this study. Thus, 24 lock closure scenarios are simulated using the International Grain Transportation Model (IGTM). Changes in modal splits and associated transportation costs by type of transportation mode under each scenario are estimated.

Table 3.9 and Table 3.10 provide changes in the total volume and associated costs of domestic grain transportation by each mode as a result of lock closures under different scenarios. In all scenarios, lock closures reduce the total volume (all modes combined) of domestic transportation of grain (see Table 3.9). Though alternative transport modes will haul more grain in some of the regions to partially offset the reduced barge transport due to lock closures, the net effect is negative under any scenario. Except for LaGrange Lock in the three-month lock closure scenario, lock closure of any duration decreases the volume of domestic grain transported by barge, as well as the total volume transported by all three modes.

The volume of domestic grain transportation by rail is projected to increase and the volume of truck transportation to decrease under most scenarios. When US grain is exported to EU countries from the Ports of Duluth and Toledo, the grain is first transported on small ships to the port of Montreal, Canada, and then transferred to ocean-going vessels. Unavailability of barge transportation above the closed locks would normally cause more export grain shipments via the Great Lakes to compensate for the loss of exports via New Orleans. During lock closures of one month or less, unavailability of barge transportation above the closed locks does not increase the small ship transportation volume. However, when the locks are closed for three months or longer, small ships start moving an increased volume of grain via the Great Lakes. The effect of lock closures on modal splits in grain transportation is not equal across the locks. For example, Lock 52 is affected the most under any lock closure scenario. If it is closed for two weeks, the total volume of grain transportation by barge will be reduced by 1.6 million tons and this reduced barge volume will be offset by rail. At the same time, the volume of truck transportation will also be reduced in the same amount, since there will no longer be a need for trucking the grain from storage facilities to barge locations. This pattern at Lock 52 holds under all scenarios. Under lock closures of one year, the reductions in barge transportation at Lock 20 and Lock 25 surpass that of Lock 52.

Table 3.9. Changes in Total Volume of Domestic Grain Transportation by Mode (Thousand Tons).

Lock	Truck	Rail	Barge	Small Ship	Ocean Vessel	Total
Scenario: Two weeks						
LaGrange	76	−37	−256	0	0	**−217**
Lock 20	−11	6	−245	0	0	**−250**
Lock 25	−11	6	−245	0	0	**−250**
Markland	7	−26	−177	36	−12	**−172**
Lock 52	−1,599	1,599	−1,598	0	0	**−1,598**
Scenario: Month						
LaGrange	−258	163	−250	0	0	**−345**
Lock 20	−149	143	−834	0	0	**−840**
Lock 25	−149	143	−834	0	0	**−840**
Markland	4	−43	−339	165	−12	**−225**
Lock 52	−1,990	1,971	−2,166	20	−12	**−2,177**
Scenario: Quarter						
LaGrange	172	−331	51	0	−1	**−109**
Lock 20	−818	685	−1,936	102	0	**−1,967**
Lock 25	−695	562	−1,814	102	0	**−1,845**
Markland	−333	−22	−539	300	−45	**−639**
Lock 52	−5,637	5,552	−5,486	300	−47	**−5,318**
Scenario: Year						
LaGrange	−5,799	5,862	−4,494	300	−78	**−4,209**
Lock 20	−4,646	4,788	−7,523	300	−13	**−7,094**
Lock 25	−5,719	5,859	−8,516	300	−53	**−8,129**
Markland	−234	6	−776	445	−45	**−604**
Lock 52	−5,421	5,725	−5,641	583	−47	**−4,801**

Note: negative values indicate reduction in volume of transportation.

The overall cost of transportation decreases under all scenarios due to the decreased volume of total shipments (see Table 3.10). In all scenarios, total transportation costs for truck and barge shipments will decrease due to reduced shipment volumes via those two modes and rail transportation costs will increase due to higher demand for rail services. The overall cost of transportation per ton for the total volume increases since the rail rates are higher than barge rates. For instance, under a three-month lock closure scenario, the volume of rail transportation increases by nearly the same amount as the decrease in volume by barge (5.5 million tons). In this case, the cost of transporting 5.5 million tons of grain amounts to $137.5 million—a $71.6 million net increase in transportation cost over the base scenario.

Table 3.10. Changes in the Cost of Domestic Grain Transportation by Mode (Million USD).

Lock	Truck	Rail	Barge	Small Ship	Ocean Vessel	Total
Scenario: Two weeks						
LaGrange	−0.5	7.5	−4.3	1.8	68.2	**72.7**
Lock 20	−2.0	8.4	−4.1	0.9	2.9	**6.1**
Lock 25	−1.6	7.8	−3.9	−0.2	−28.5	**−26.4**
Markland	−0.8	0.3	−1.6	1.4	−42.3	**−43.0**
Lock 52	−18.4	33.0	−16.4	−0.5	−76.5	**−78.8**
Scenario: Month						
LaGrange	−5.5	17.2	−4.5	1.5	−60.2	**−51.5**
Lock 20	−3.5	25.7	−13.2	0.3	−78.7	**−69.4**
Lock 25	−2.1	25.4	−14.3	0.3	21.9	**31.2**
Markland	−0.7	0.9	−4.2	3.8	−43.1	**−43.3**
Lock 52	−20.1	42.1	−25.8	0.1	−42.5	**−46.2**
Scenario: Quarter						
LaGrange	−3.5	26.8	4.7	1.5	−23.8	**5.7**
Lock 20	−4.3	61.2	−32.5	3.6	−25.4	**2.6**
Lock 25	−2.4	57.1	−31.6	4.2	−41.8	**−14.5**
Markland	−3.1	3.0	−7.3	6.7	−48.9	**−49.6**
Lock 52	−69.8	137.5	−65.9	5.0	−60.2	**−53.4**
Scenario: Year						
LaGrange	−15.8	127.2	−93.2	5.3	−96.3	**−72.8**
Lock 20	−29.9	241.2	−149.1	7.9	−35.9	**34.2**
Lock 25	−45.8	272.4	−162.6	7.0	−30.7	**40.3**
Markland	0.2	2.3	−10.6	7.7	−19.9	**−20.3**
Lock 52	−64.7	134.0	−70.7	10.4	−62.5	**−53.5**

Note: negative values indicate reduction in cost of transportation.

Table 3.11 and Table 3.12 provide flows of U.S. grain for export and the transportation costs of exported grain by each mode. Under the two-week and one-month lock closure scenarios, grain exports are diverted from the Gulf ports to the ports on the West Coast when Illinois and Mississippi River locks are closed and to Great Lakes and East Coast ports when Ohio River locks are closed. For instance, with a one-month lock closure, 339,000 tons of grain will be diverted from the Gulf Coast to the Great Lakes and East Coast in the amounts of 165,000 and 149,000 tons, respectively. This will increase rail and ocean-going vessel transportation costs by $15.9 million and $20.4 million, respectively. Under the same lock closure scenario, 728,000 tons of grain will be diverted from the Gulf Coast to ports on the West Coast, which results in higher rail and ocean-shipping costs in the amount of $37 million and $47 million, respectively. When locks are closed for three months or more, the biggest portion of all the exported grain that is diverted from the Gulf ports will be directed to the West Coast, followed by the Great Lakes and then the East Coast. In general, lock closures under each scenario will result in reduced barge transportation costs and higher rail transportation costs.

Table 3.11. Changes in the Volume of U.S. Grain Exports by Mode (Thousand Tons).

Lock	Truck	Rail	Barge	Small Ship	Ocean Vessel	Total
Scenario: Two weeks						
LaGrange	−256	0	257	0	0	**1**
Lock 20	−245	0	245	0	0	**0**
Lock 25	−245	0	245	0	0	**0**
Markland	−177	36	3	126	0	**−12**
Lock 52	0	0	0	0	0	**0**
Scenario: Month						
LaGrange	−501	0	518	−17	0	**0**
Lock 20	−728	0	728	0	0	**0**
Lock 25	−728	0	728	0	0	**0**
Markland	−339	165	13	149	−20	**−32**
Lock 52	−166	20	8	126	0	**−12**
Scenario: Quarter						
LaGrange	−1,115	0	1,158	−44	−20	**−21**
Lock 20	−1,830	102	1,720	8	0	**0**
Lock 25	−1,708	102	1,597	8	0	**−1**
Markland	−620	300	119	156	−20	**−65**
Lock 52	−1,857	300	1,353	157	−20	**−67**
Scenario: Year						
LaGrange	−1,063	300	346	339	0	**−78**
Lock 20	−3,834	300	3,226	295	33	**20**
Lock 25	−4,250	300	3,489	409	33	**−19**
Markland	−693	445	37	167	−20	**−64**
Lock 52	−2,004	583	1,034	340	−20	**−67**

Note: negative values indicate reduction in volume of transportation.

Table 3.12. Changes in the Cost of Transportation of U.S. Grain Exports by Mode (Million USD).

Lock	Truck	Rail	Barge	Small Ship	Ocean Vessel	Total
Scenario: Two weeks						
LaGrange	−2.9	−12.1	−8.7	−2.1	−55.6	**−81.4**
Lock 20	−0.9	6.8	−7.1	−0.2	−1.9	**−3.3**
Lock 25	−2.4	25.1	−15.6	1.4	20.8	**29.3**
Markland	−1.7	33.2	−21.3	0.1	28.4	**38.7**
Lock 52	0.5	27.5	2.1	1.3	47.4	**78.8**
Scenario: Month						
LaGrange	−0.9	24.7	−1.3	−1.1	24.0	**45.4**
Lock 20	−3.4	37.2	−6.7	−0.2	47.3	**74.2**
Lock 25	0.3	28.1	−41.5	−0.2	−13.2	**−26.5**
Markland	0.7	15.9	−1.5	0.2	20.4	**35.7**
Lock 52	0.2	29.4	−13.8	1.4	25.2	**42.4**
Scenario: Quarter						
LaGrange	−3.4	16.2	−7.2	−0.8	2.2	**7.0**
Lock 20	−0.5	22.1	−11.2	−0.6	3.6	**13.4**
Lock 25	0.1	22.3	−5.8	−0.7	14.5	**30.4**
Markland	0.1	23.4	−6.4	−0.9	15.2	**31.4**
Lock 52	−5.1	49.3	−20.4	0.3	16.3	**40.4**
Scenario: Year						
LaGrange	−3.5	47.9	−9.2	2.1	50.6	**87.9**
Lock 20	0.2	37.5	−15.3	−0.3	−10.7	**11.4**
Lock 25	0.5	38.4	−18.3	1.0	−19.0	**2.6**
Markland	1.3	34.0	−34.8	2.0	1.8	**4.3**
Lock 52	−2.5	56.6	−33.6	2.7	20.3	**43.5**

Note: negative values indicate reduction in cost of transportation.

The volumetric measure of grain movements by mode of transportation in Table 3.13 tends to inflate the true magnitude of grain movement between the origin and the final destination due to double counting when the same cargo changes modes on the way to final destination. For example, if 1,000 tons of grain that normally originate from Minneapolis (MN) are transported by barge to their final destination at the Port of Baton Rouge are loaded onto rail at Burlington (IA) due to a lock closure at Lock 20, the volumetric measure counts this cargo twice by regarding it as two shipments (one by barge and one by rail). The true volume of grain flow can be represented by a “ton-mile” metric. It also complements volumetric measures when they are used together to gain more insight. For example, recall the two-week lock closure at LaGrange Lock where truck volume increase by 76,000 tons and rail and barge volumes decrease by 37,000 tons and 256,000 tons, respectively. Looking at this scenario, one may assume that 217,000 thousand tons of grain are not transported due to disruptions in barge movements. However, the same scenario analyzed using a ton-mile metric (Table 3.13) shows that rail volume increases by 252 million ton-miles and barge and truck volumes decrease by 299 million tons and 34 million ton-miles, respectively. Assuming a 1,000-mile rail haul between LaGrange and Baton Rouge, the reduction of 81 million ton-miles suggests that the total transportation volume will be reduced by only 81,000 tons instead of 217,000 tons.

Table 3.13 shows similar patterns as Table 3.9, where the most affected lock is Lock 52 under a lock closure scenario of one month or less. For instance, a one-month lock closure is projected to decrease barge shipments by 1.986 billion ton-miles and a sizeable percentage of this lost volume will be handled by rail transportation—1.321 billion ton-miles.[16] When locks are closed for one year, reductions in total transportation at all locks are nearly similar and reductions in barge transportation at locks on the Illinois and Upper Mississippi Rivers surpass those at Lock 52 on the Ohio River.

[16] Since river miles between origin-destination pairs are generally greater than rail miles, an appropriate discount factor (approximately 0.8) could be used to deflate the barge ton-miles before comparison with rail ton-miles.

Table 3.13. Changes in the Total Volume of Domestic Grain Transportation by Mode (Million Ton-Miles).

Lock Name	Truck	Rail	Barge	Small Ship	Total
Scenario: Two weeks					
LaGrange	−34	252	−299	0	**−81**
Lock 20	−9	248	−320	0	**−81**
Lock 25	−9	248	−320	0	**−81**
Markland	−3	45	−201	19	**−140**
Lock 52	−163	1,018	−1,332	0	**−477**
Scenario: Month					
LaGrange	−57	514	−420	0	**37**
Lock 20	−29	819	−997	0	**−207**
Lock 25	−29	819	−997	0	**−207**
Markland	−5	64	−384	87	**−238**
Lock 52	−189	1,321	−1,986	10	**−844**
Scenario: Quarter					
LaGrange	−104	796	−499	0	**193**
Lock 20	−63	1,946	−2,389	106	**−400**
Lock 25	−37	1,796	−2,308	106	**−443**
Markland	−9	76	−682	158	**−457**
Lock 52	−673	3,909	−5,273	158	**−1,879**
Scenario: Year					
LaGrange	65	3,626	−5,985	158	**−2,136**
Lock 20	−254	7,284	−9,535	211	**−2,294**
Lock 25	−380	8,186	−10,406	211	**−2,389**
Markland	34	58	−902	235	**−575**
Lock 52	−565	3,715	−5,632	308	**−2,174**

Note: negative values indicate reduction in volume of transportation.

Surface Transportation System Capacity

Introduction

One may assume that a waterway closure would cause a shift of agricultural shipments from barge to rail or truck; however, this may not be practical or cost effective. The research team examined the major flows of agricultural commodities via the rivers, assessed the accessibility to rail for those flows and/or the need for truck transportation, and assessed the capacity of the rail and highway systems to effectively accommodate the increase in volume.

To a considerable extent, the location of a catastrophic event that closes the river is central to determining the extent of the impediment. Grain flows from north to south—if the impediment is in Minneapolis, the impact may not be great. Conversely, if the impediment is at locks near St. Louis on the lower Mississippi River or Lock 52 on the Ohio River, for example, the impact would be comparatively larger.

Rail is the primary substitute for barge transport, so the capacity of the rail system (defined as the correct equipment to accommodate the additional freight and available horsepower) and the efficiency of the system in accessing various regional grain demand centers (domestic or foreign) are important. In some cases, it may be conceptually feasible to truck the grain to grain elevators that are situated below the impeded lock, in which case the availability and capacity of grain handling infrastructure becomes an issue, as does the availability of trucks and highway infrastructure.

Rail Capacity

Introduction/Background

A recent report by the USDA and the U.S. Department of Transportation (USDOT) thoroughly examined the issues surrounding rail capacity for agricultural shipments.[17] In the absence of barge transportation, moving many agricultural products to market in an efficient and (next-best) cost-effective manner would require adequate rail capacity. Because agricultural shippers are price-takers, who receive a price for their commodity net of transportation costs, increased transportation costs come directly out of producer incomes. Barge has the least transportation cost, followed by rail, while the most expensive is typically truck.

Agricultural shippers and consumers have been concerned about the capacity of railroads to serve their needs for several years. Forecasts of demand for rail transportation for growing fields such as energy and intermodal transportation predict increasing demand system wide. Some studies, such as one by Cambridge Systematics, indicate that railroads currently have few constraints in infrastructure capacity.[18] The same study found that capacity would be constrained in the future unless investments are made in infrastructure. The recession, however, delayed the effect of such constraints as much as five years. Another report by Christensen Associates states that although predictions by individual researchers and agencies vary, the overall growth of traffic is widely accepted and only the magnitude of growth is in question.[19] The magnitude may be determined largely by railroad pricing policies, which can either encourage or discourage traffic growth.

Rail capacity requirements must be examined in light of the characteristics of agricultural movements rather than aggregate models and investment strategies. The production and marketing characteristics of agricultural products create special needs and different criteria to

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[17] U.S. Department of Agriculture and U.S. Department of Transportation. *Study of Rural Transportation Issues.* April 2010.
[18] Cambridge Systematics, Inc. National Rail Freight Infrastructure Capacity and Investment Study. September 2007.
[19] Laurits R. Christensen Associates, Inc. Supplemental Report to the U.S. Surface Transportation Board on Capacity and Infrastructure Investment. March 2009.

evaluate capacity. Testimony and shipper complaints emphasize the seasonal needs of agriculture, the density of those movements in specific corridors, and the perishable nature of the products being moved.

Given these characteristics of agricultural shipments, determining rail capacity is a complex issue. Capacity depends on the availability and productivity of trackage, power units, the size of the railcar fleet by type, terminal capacity, intermodal facilities, engineers and crew, and more. It is not enough to evaluate capacity at the aggregate rail corridor level, which has been done in various studies. The needs of agriculture and the regional variation of agricultural production—and often nodes of congestion on the rail line—require attention to specific components in the capacity framework. Building capacity for peak movements is expensive and could be inefficient for railroad operations. Any excess capacity during some times of the year has to be balanced against the value of peak service needs. Investing in the system to provide capacity occurs in various ways. The Christensen study[19] identified three components needed to achieve necessary rail capacity:

- Investment in technology to improve the productivity and efficiency of the current infrastructure.
- Repairs, maintenance, and replacement of current infrastructure.
- Investment in new infrastructure.

Rail Network Volume-to-Capacity and Level of Service

Cambridge Systematics used USDOT's Freight Analysis Framework (FAF) to examine overall railroad infrastructure needs and compared them to expected rail transportation demands. They found that only 1% of lines were over capacity and that 88% were below capacity. However, that study did not examine the multiple components of capacity listed above. Aggregate analysis is an incomplete evaluator of the specific capacity needs of shippers, especially agricultural shippers.

Figure 3.4 depicts rail capacity in the year 2007. Few sections of the rail network were above aggregate capacity at that time although significant portions were approaching capacity. The orange lines indicate rail lines in the United States where traffic is at capacity; the yellow lines are lines approaching capacity. Only in extreme rural or agricultural areas was there much track that was below capacity (green lines). Again, this evaluation is based on annual aggregate volumes, not peak or seasonal movements or congestion nodes.

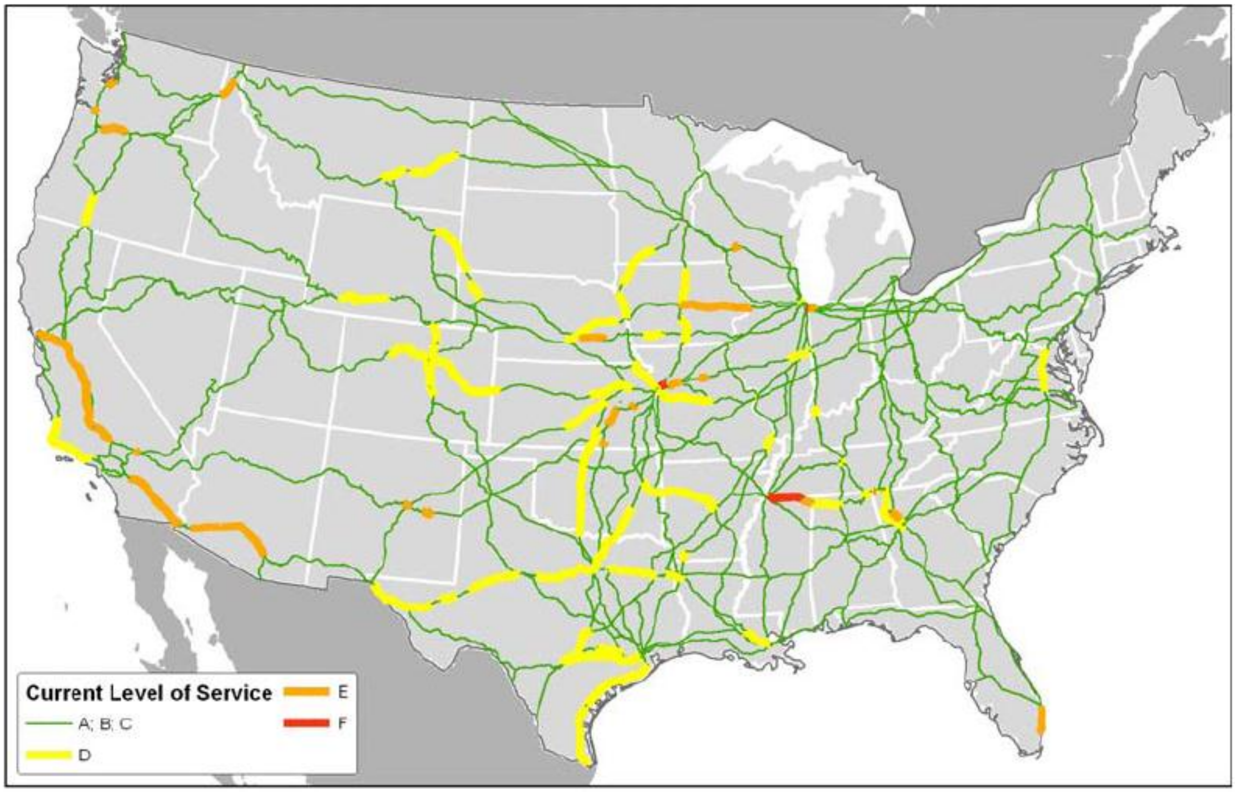

Figure 3.4. Rail Capacity (2007).
Source: Cambridge Systematics, Inc. National Rail Freight Infrastructure Capacity and Investment Study. *September 2007.*

Figure 3.5 shows the results of the analysis of the 2035 levels of service (LOS) without improvements: 45% of primary corridor mileage will be operating below capacity (LOS A/B/C – green lines), 25% will be operating near or at capacity (LOS D/E – yellow and orange lines), and 30% will be operating above capacity (LOS F – red lines). The resulting level of congestion would affect nearly every region of the country and would likely shut down the national rail network. Again, this evaluation is based on annual aggregate volumes, not peak or seasonal movements or congestion nodes.

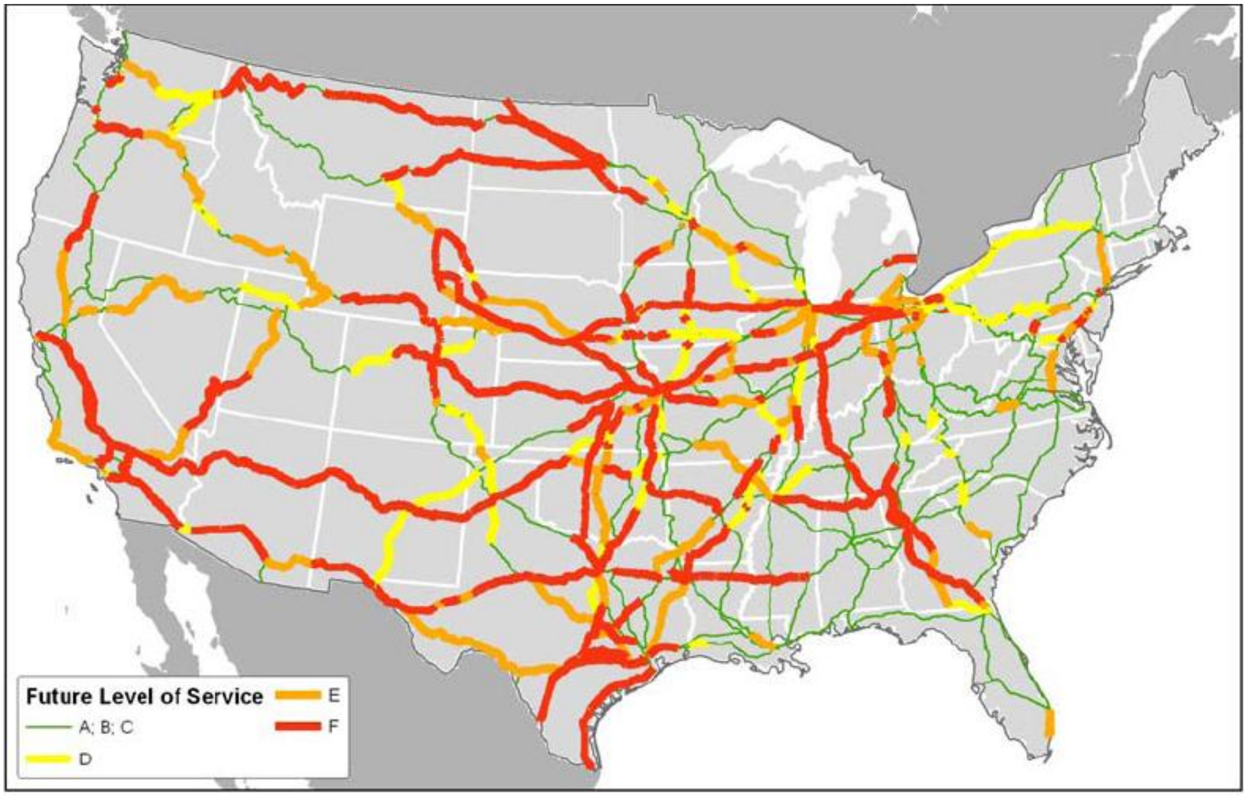

Figure 3.5. Rail Capacity (2035 w/o Improvements).
Source: Cambridge Systematics, Inc. National Rail Freight Infrastructure Capacity and Investment Study. *September 2007.*

The overall rail system may be unconstrained in the aggregate, but agriculture cares about constraints to specific corridors. Agricultural commodities are by far the majority of the movements in some sections of the nation, such as on many Midwestern secondary rail lines and several primary rail corridors. The long distance movements of agricultural products from the Midwest production areas to the Pacific Northwest and to Los Angeles/Long Beach, CA, dominate the movement on the northern BNSF rail line and its line from Chicago through the Southwest. Agricultural products also dominate traffic on the BNSF and UP rail lines from Chicago and Kansas City to the Houston region. The heavy total shipments out of Wyoming to the Midwest locations near or on the Mississippi are due to the volume of coal shipments for energy and power plants. Figure 3.6 shows the ratio of annual tonnage of agricultural commodities to total rail flows on all major corridors in the United States for 2006. It can be readily seen that the primary rail lines for agricultural commodities are expected to operate above capacity in 2035 in the absence of improvements.

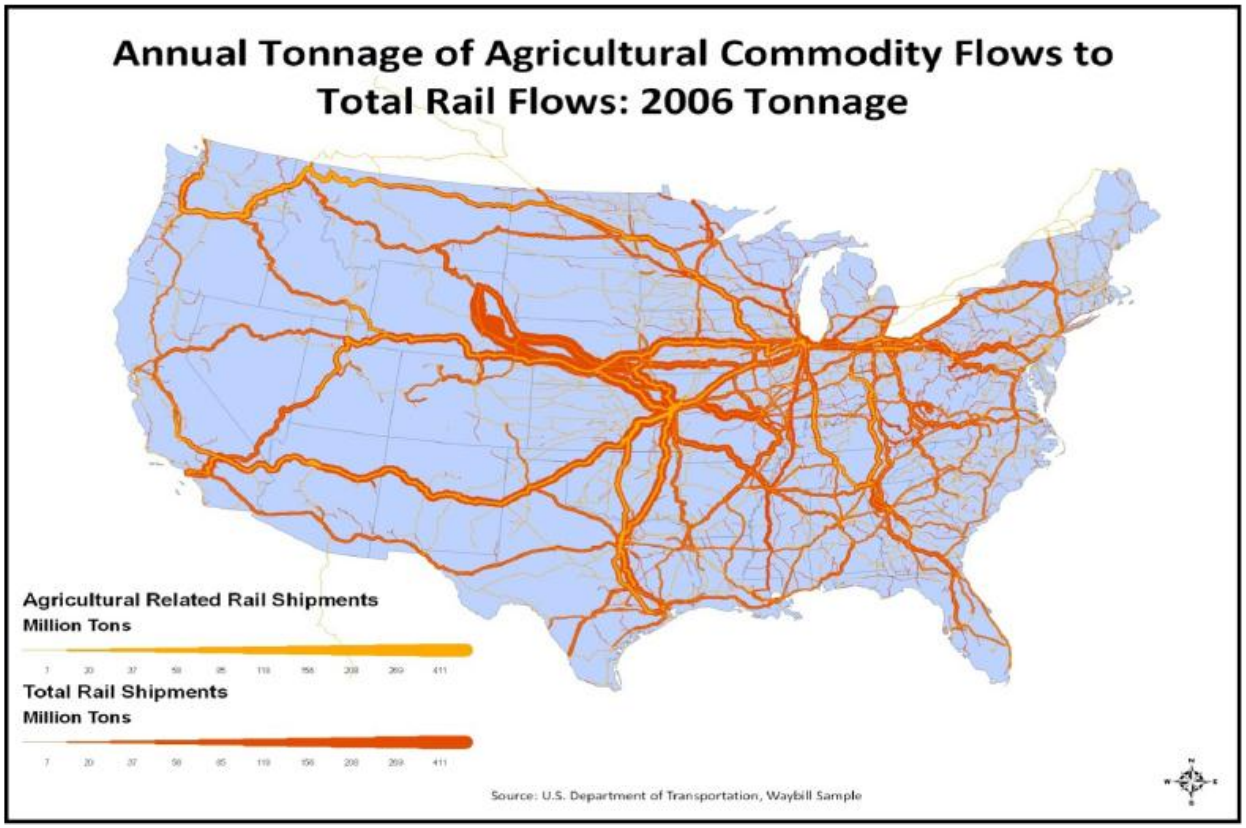

Figure 3.6. Rail Commodity Flows (2006).

Source: U.S. Department of Agriculture and U.S. Department of Transportation. Study of Rural Transportation *Issues. April 2010.*

Factors Influencing Rail Capacity and Performance

Current and future availability of rail capacity and performance can be examined through these rail system indicators:

- Miles of track.
- Rail equipment availability (railcar and locomotive fleets).
- Average train speed.
- Terminal dwell times.

Investments or changes in the first two indicators are reflected in the growth or shrinkage of rail capacity, which is usually verified at a later stage by the last two indicators. For example, the aggregate railcar capacities in tons and the aggregate locomotive horsepower have both increased. As train speed increases and terminal dwell times decrease, rail capacity increases. Dwell times are influenced by the following factors, the first of which is the focus of this discussion:

- Changes in demand for rail transportation leading to rail line congestion.
- Rail merger integration resulting in operational difficulties and congestion.

- Availability of train-crew personnel.
- Extreme weather.

Excess demand for rail transportation often results in congestion on rail lines and in switch yards. Because rail capacity cannot be expanded rapidly, congestion on the rail lines and at switch terminals slows trains. As rail lines and switch yards become congested, their capacity is lower than when the lines are fluid, in much the same way that traffic backs up on a busy highway due to congestion. Access to rail lines and switch yards, however, is more tightly controlled than access to the highway; rail traffic controllers keep trains a specified distance apart and control entry to the rail network. Relative efficiency decreases and marginal costs could increase rapidly as portions of the rail network approach capacity. For instance, train speeds slowed from 2003 through 2006 as demand increased in response to a robust economy. Since then, the demand for rail transportation has slowed, particularly during the last half of 2008 and early 2009, and train speeds increased. This reduction in demand eliminated the congestion that slowed service from 2003 through 2006.

Miles of Track

One of the primary influences on overall rail capacity is the amount of track available to the railroad system. The Christensen study[19] used the R-1 annual reports of the Class I railroads filed with the Surface Transportation Board (STB) to examine capacity at the aggregate level. Selected tables and graphs from this study are shown below. Note that these are only aggregate indicators, and the geographical dispersion, seasonal availability, or functional use (switch or line haul, for example) of the tracks are not examined here. These latter characteristics determine the amount of rail capacity actually available for agricultural shipments, not just aggregate miles. However, the total miles are still indicators of system-wide capacity. Total miles of Class I railroad track decreased rather dramatically and steadily from 1987 to about 1998 and have remained steady at about 200,000 miles since then. The miles of main-line track decreased until 1993 and have remained steady, at slightly more than 140,000 miles, since then.

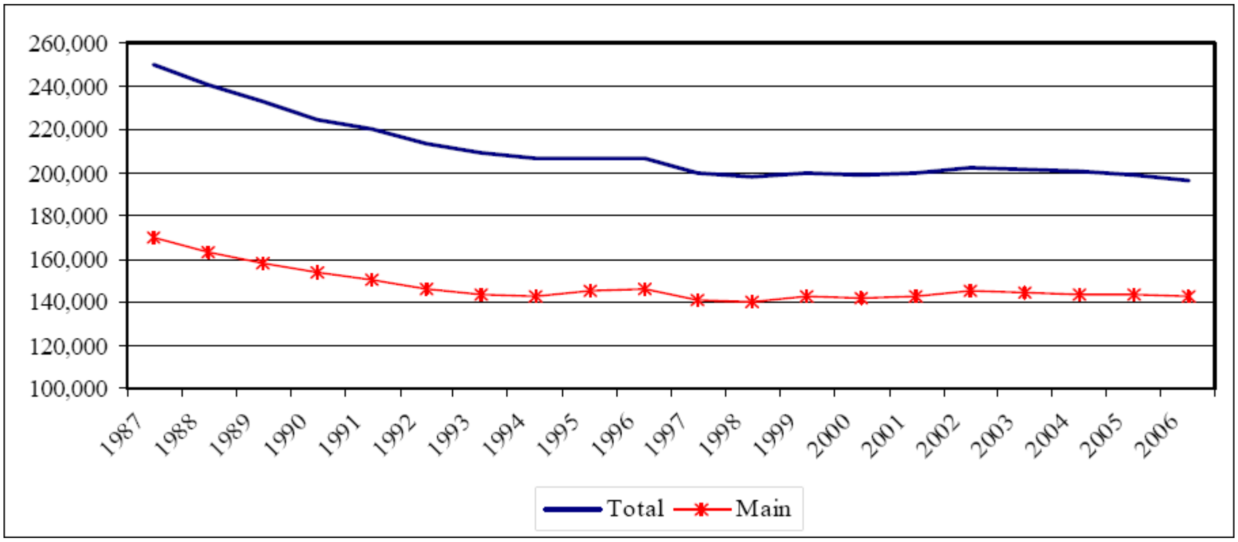

Figure 3.7. Miles of Track of Class I Railroads (1987–2006).
Source: U.S. Department of Agriculture and U.S. Department of Transportation. Study of Rural Transportation *Issues. April 2010.*

Short line and regional railroads often provide rail service to rural shippers on lines that otherwise would have been abandoned. By the end of 2007, short line and regional railroads operated nearly 46,000 main-line miles of track, a little more than 30% of the U.S. railroad network.

The ton-miles handled by the railroads increased from 919 billion in 1980 to 1,771 billion in 2007, a rise of 93%. Due to the economic crisis however, they decreased to 1,532 billion in 2009. During this same period, the route miles operated decreased from 197,804 miles in 1980 to only 140,695 miles in 2007.[20] Each route mile during 2007 carried an average of 171% more ton-miles—nearly triple the traffic—than in 1980. This shows an increased usage of rail lines, which benefited the railroads financially, but also contributed to rail congestion.

Rail Equipment

Rail capacity is also a function of the number of railcars and locomotives available to shippers. This section discusses the ownership of railcars and freight car acquisitions, the railcar fleet, and locomotives.

Railroads are relying more and more on privately owned cars to provide the capacity to handle shipper demand, shifting the investment burden from carriers to shippers. Railroads have not been significant contributors to the freight car acquisitions in the industry and the number of system-owned cars on line decrease in proportion with the decrease in acquisitions.

[20] Association of American Railroads, Railroad Facts, various years.

Table 3.14 shows characteristics of the car fleet that have implications regarding capacity and the provision of capacity. Total cars in the fleet decreased from 1.7 million in 1976 to 1.39 million in 2007. A modest increase occurred from 2004 through 2007. The number of new cars varied widely, from 12.4 to 86.7 thousand. The average from 2005 through 2007 was a little less than 70,000 per year, a significant increase over the average for the 30-year period.

The capacity of the car fleet in tons increased nearly 14%, even though the number of railcars decreased by more than 18%, primarily because of greater loads per railcar. The number of ton-miles, however, increased nearly 93% from 1980 through 2007. It is apparent that railcars in 2007 were loaded more often than in 1976, with shorter cycle times. Because of the increase in the number of shuttle trains and unit trains since 1976, and their widespread use, this appears to be a reasonable conclusion.

Although the number of cars decreased, the average age of the cars increased, indicating that older cars are still being maintained on the lines. Both the average tonnage and total capacity in tons is increasing.

Table 3.14. Selected Railcar Fleet Statistics (1976–2007).

Year	Total Cars (millions)	New Cars (thousands)	Avg. Age (Years)	Avg. Capacity (tons)	Fleet Capacity (million tons)
1976	1.70	53.6	14.6	73.8	125.5
1980	1.71	86.7	14.9	78.5	134.2
1984	1.49	12.4	16.3	84.1	125.3
1988	1.24	22.5	17.7	87.4	108.4
1992	1.17	25.8	19.2	90.6	106.0
1993	1.17	35.2	19.5	91.3	106.8
1994	1.19	48.8	19.7	92.0	109.5
1995	1.22	60.9	19.9	92.9	113.3
1996	1.24	57.9	19.9	95.6	118.5
1997	1.27	50.4	20.0	96.5	122.6
1998	1.32	75.7	19.8	97.2	128.3
1999	1.37	74.2	20.1	98.2	134.5
2000	1.38	55.8	20.4	98.7	136.2
2001	1.31	34.3	20.9	99.1	129.8
2002	1.30	17.7	21.2	99.7	129.6
2003	1.28	32.2	21.9	100.1	128.1
2004	1.29	46.9	22.3	100.5	129.6
2005	1.31	68.6	22.3	101.2	132.6
2006	1.35	74.7	22.5	102.0	137.7
2007	1.39	63.2	22.5	102.8	142.9

Source: U.S. Department of Agriculture and U.S. Department of Transportation. Study of Rural Transportation *Issues. April 2010.*

The number of power units (locomotives) available to Class I railroads increased in most years and is up 34% since 1992. The aggregate horsepower of those locomotives also steadily increased, 71.5% greater in 2007 than in 1992. Most of these units are new rather than rebuilt, and the average power increased to 3,516.5 horsepower (hp). Four percent (4%) of the fleet consisted of new units, with some annual variation (Table 3.15).

Table 3.15. Selected Locomotive Fleet Statistics (1992–2007).

Year	Units in Service	Aggregate Horsepower (millions)	Purchased & Leased New	Rebuilt Acquired	HP/Unit	% New
1992	18,004	49.5	321	139	2,749.4	1.8%
1993	18,161	50.4	504	203	2,775.2	2.8%
1994	18,505	52.4	821	393	2,831.7	4.4%
1995	18,812	55.1	928	201	2,929.0	4.9%
1996	19,269	57.5	761	60	2,984.1	3.9%
1997	19,684	60.2	743	68	3,058.3	3.8%
1998	20,261	63.3	889	172	3,124.2	4.4%
1999	20,256	64.8	709	156	3,199.1	3.5%
2000	20,028	65.3	640	81	3,260.4	3.2%
2001	19,745	64.7	710	45	3,276.8	3.6%
2002	20,506	69.3	745	33	3,379.5	3.6%
2003	20,774	70.9	587	34	3,412.9	2.8%
2004	22,015	76.1	1121	5	3,456.7	5.1%
2005	22,779	79.0	827	84	3,468.1	3.6%
2006	23,372	82.7	922	158	3,484.7	3.9%
2007	24,143	84.9	902	167	3,516.5	3.7%

Source: U.S. Department of Agriculture and U.S. Department of Transportation. Study of Rural Transportation *Issues. April 2010.*

Train Speed

An evaluation of rail capacity includes consideration of the speed of the trains. Faster trains mean more output per dollar spent in rolling stock, less congestion, and more rail capacity to handle the demand, but at the potential expense of increased rail damage. Figure 3.8 from the Association of American Railroads' (AAR) Railroad Performance Measures (RPM) reveals the year-over-year trends in realized grain train speed.[21]

In the five years from 2004 to 2008, train speeds overall were more stable than previous years, both within the year and from year to year. Gains in train speeds and rail capacity are expected due to positive train control and electronically controlled pneumatic braking technologies. The

[21] American Association of Railroads. *Railroad Performance Measures.* http://www.railroadpm.org/

average speed of all trains, with the exception of the last five months in 2008, decreased since 2004 due to demand-based rail congestion—particularly during the harvest months of 2005—and the early retirement of experienced railroad management and labor, causing a loss of experience in crisis situations, dispatcher capabilities, yard masters, and train masters, which in turn results in higher levels of caution and greater inefficiency. The performance of grain trains was similar to that of other trains from 2004 to 2008. Improvement is seen in almost all of 2008. The earlier years were stable, consistently around 18 mph, again slightly less than other trains (around 20 mph). Rail traffic declined during 2008; combined with prior investments in new rail capacity, this eliminated congestion on the rail network, resulting in faster trains.

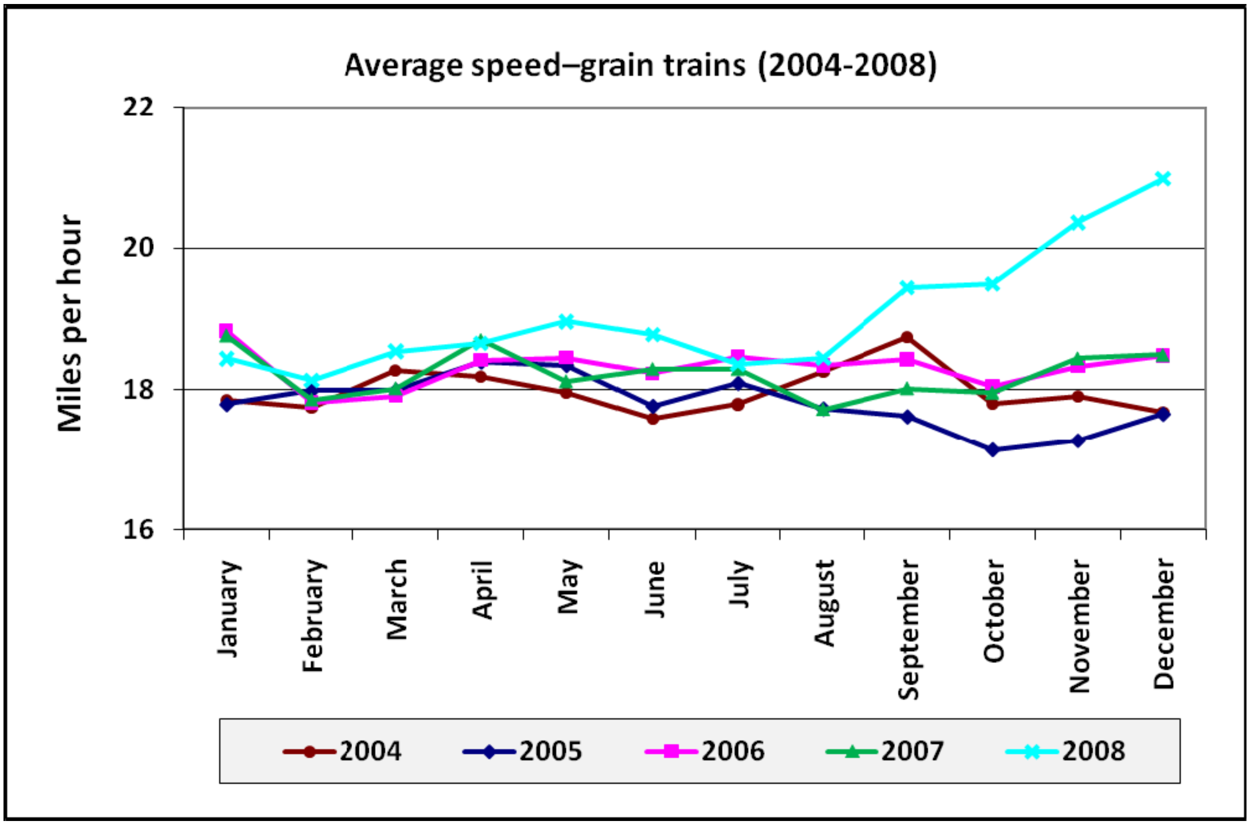

Figure 3.8. Average Speed—Grain Trains (2004–2008).
Source: U.S. Department of Agriculture and U.S. Department of Transportation. Study of Rural Transportation *Issues. April 2010.*

Overall, it is evident that the railroads have been successful in improving the speed of their trains for all trains, as well as for grain movements. The improvement from year to year is not as evident within the five-year period, though 2008 did offer some improvements. This suggests that without significant increases in trackage past speed improvements may not be sustainable unless positive train control and electronically controlled pneumatic brake technologies fulfill their potential.

Dwell Times in Terminals

When cars and power units are not moving, they are not available to provide service and capacity to shippers. The length of time that cars spend in switch terminals is an indicator of lost capacity if the dwell time (the time a railcar sits in a rail yard) is more than that necessary to switch the car to the proper train. Dwell time is an indication of efficiency within the terminal and it discloses problems, such as terminal congestion, that are affecting the efficiency and performance of the railroad. Terminal dwell time, though, does not pinpoint the cause of any such inefficiency. The AAR RPM information utilized for train speeds also tracks and reports the terminal dwell times for the industry and individual railroads. The four-year period from 2005 to 2008 saw a steady improvement in terminal dwell times, with 2008 having the lowest average dwell times (Figure 3.9).

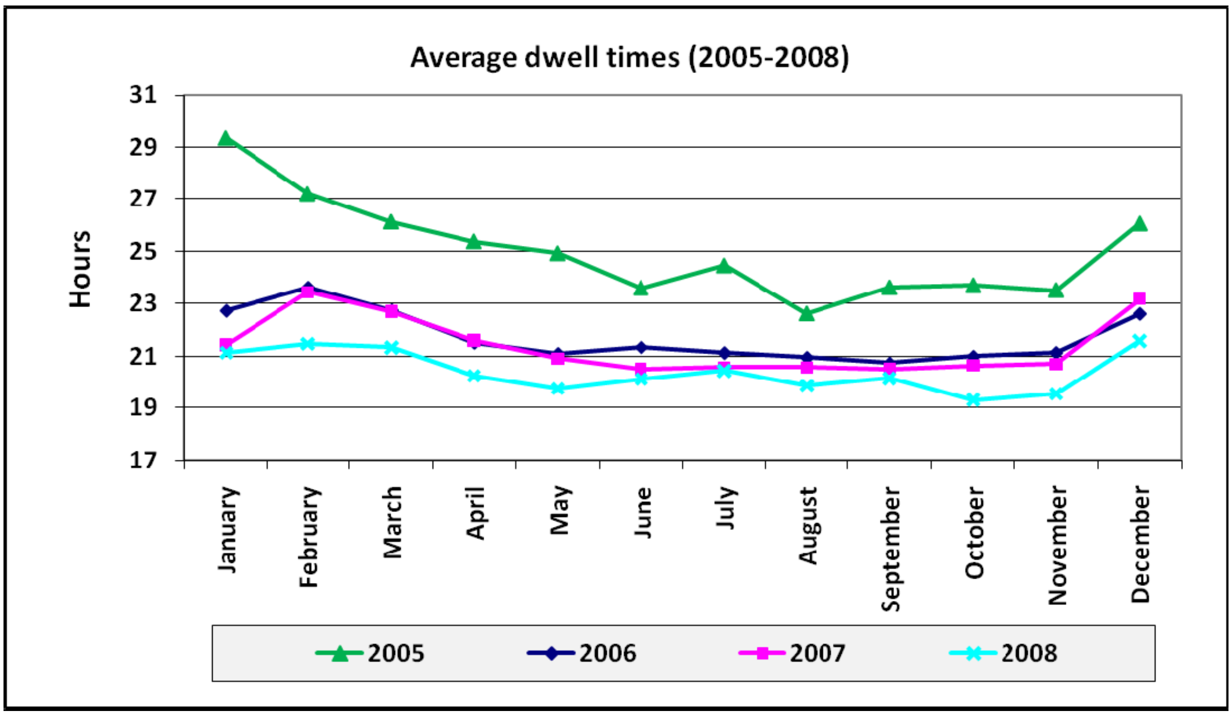

Figure 3.9. Average Terminal Dwell Times (2005–2008).
Source: U.S. Department of Agriculture and U.S. Department of Transportation. Study of Rural Transportation *Issues. April 2010.*

Conclusions

Currently, rail capacity cannot be considered constrained. However, general demand for rail transportation (all commodities) is projected to grow at a fast rate through 2035. The resulting level of congestion would affect nearly every region of the country and would likely cause severe price adjustments and congestion delays without significant investment in railroad infrastructure. A potential diversion of barge traffic to rail would further add to the forecasted demand resulting in devastating effects on rail infrastructure, our economy, and our standard of living.

Rural rail network lines have declined, and abandonments by Class I railroads, short lines, and regional companies continue. The push to trainload operations increased overall capacity while making individual shippers and smaller elevator firms carry the cost of assembly of those unit train volumes. Guaranteed railcar ordering systems provide efficiency but at increased cost. Determining effective capacity available to agriculture is complex and cannot be separated from service issues, rate levels, structure, and competition for traffic.

Adequate rail capacity is necessary to move agricultural products to market in an efficient and cost-effective manner. Rail capacity constraints force traffic from rail to truck, increasing transportation costs and damage to highways. Capacity constraints were common from 2003 through the first half of 2006. Weaker demand for rail freight transportation beginning in late 2006, and a recession that began in December 2007 resulted in adequate rail capacity for agricultural products during the harvest of 2006, and from 2007 through the first half of 2009. However, capacity constraints are expected to occur again when the economy recovers.

Increased use of the rail lines, which benefited the railroads financially, also contributed significantly to rail congestion. Each route mile during 2007 carried, on average, 171% more traffic in ton-miles—nearly three times the traffic—than in 1980. By the end of 2007, short line and regional railroads operated nearly 46,000 main line miles of track—a little more than 30% of the U.S. railroad network. Short line and regional railroads often provide rail service to rural shippers on lines that otherwise would have been abandoned.

The capacity of the car fleet in tons increased nearly 14% from 1976 to 2007, even though the number of railcars decreased by more than 18%. %. The ton-miles increased nearly 93% from 1980 through 2007, indicating that railcars in 2007 were loaded more frequently than in 1976 due to shorter cycle times. The number of engines available to the Class I railroads has increased 34% since 1992. The aggregate horsepower of those locomotives also steadily increased, up 71.5% since 1992. Railroads are relying more and more on privately owned cars to provide the capacity to handle shipper demands, shifting the investment burden from the carriers to the shippers. Since 1981, shippers and other investors have provided 88% of all new railcar acquisitions.

Highway Capacity

The report by the U.S. Department of Agriculture and the U.S. Department of Transportation also examined the issues surrounding highway capacity for agricultural shipments.[22] The linkage between the highway mode and barge and rail facilities is especially important because of the complementary and competitive relationship among modes of transport. In the supply chain that stretches from the farm to the consumer, trucking provides the first miles, the last miles,

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[22] U.S. Department of Agriculture and U.S. Department of Transportation. *Study of Rural Transportation Issues.* April 2010.

and sometimes all the transportation miles. Flexibility, timeliness, and door-to-door service are vital to shippers who handle perishable agricultural products. Most farming states are rural and sparsely populated. Distances from farms to suppliers, grain elevators, ethanol plants, storage facilities, and markets have increased because of the consolidation of farms and facilities.

Rail capacity constraints can force barge traffic—that would otherwise divert to rail—to divert to truck instead. When traffic is forced to trucks, it usually results in increased transportation costs and increased damage to the highway system.

Trucking rates are kept low by the number of trucks available and truck efficiency increases. Truck capacity depends on three components: drivers, the roads they travel on, and their vehicles and their operation. There are several issues that concern the trucking industry and agricultural shippers due to their potential impact on the availability of service, including the need for operating flexibility, agricultural exemptions, driver availability, environmental regulations, vehicle capacity, and issues affecting roads. This discussion will focus on the latter two.

Vehicle Capacity

A debate is under way concerning the appropriate size and weight limits for commercial motor vehicles on the nation's highways. National weight limits (gross vehicle weight [GVW] of 80,000 lb) apply to commercial vehicle operations on the Interstate Highway System, a 46,876-mile system of divided highways with limited access that spans the nation. The current weight and size restrictions reflect the design capacities of interstate highway pavement and bridges.

Agricultural and forest products shippers are generally in favor of increasing the truck weight limits for the nation's Interstate highways. They believe size and weight limits should be increased because:

- Agricultural and forest products are generally heavy and bulky.
- The markets for these products are highly competitive.
- A high percentage of the final price of the products is spent on transportation.
- Trucking is the largest single mode for transporting these products.

Opponents of increasing size and weight limits cite the following concerns:

- The need for highway system preservation.
- Wear and tear on underfunded roads and bridges.
- Highway safety.
- Competition between large and small trucking companies.
- The need to buy new equipment in order to compete.
- The need for fewer drivers.
- Competition between truck and rail.
- The environmental benefits of shifting truck traffic to rail.

Any revisions to size and weight standards must address the costs of maintenance and capital replacement of highways at a minimum. These factors are precipitating a debate over changes to commercial motor vehicle size and weights.

Roadway Capacity

Rural agriculture, manufacturing, and service industries depend on access to the national highway network. Maintenance and improvement of the nation's roads and bridges affects congestion, productivity, and the competitiveness of these industries in world markets. Maintaining the trucking industry's ability and capacity to serve agriculture and rural areas requires more than drivers and vehicles. It also requires a road and bridge infrastructure, and the funds to maintain and improve them.

According to 2004 federal data, 77% of the nation's bridges, 75% of the 4 million miles of public roads, and 36% of all vehicle miles traveled are in rural areas (population less than 5,000). Only 23% of rural road mileage is eligible for federal grants; the rest is maintained by state and local funding. Over one-half of the federal aid highways are in less-than-good condition, and more than one-quarter of the nation's bridges are structurally deficient or functionally obsolete.[23]

Substantial funds could be provided in the highway reauthorization bill that will succeed the current authorization, Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which expired September 30, 2009, and was extended through March 31, 2012. The National Surface Transportation Infrastructure Financing Commission[24] and the National Surface Transportation Policy and Revenue Study Commission[25] both recommended increasing fuel taxes and alternative ways of raising revenue to address the backlog of road, bridge, and transit system maintenance and improvement needs. The financing commission stated the average annual federal, state, and local revenue needed for maintenance of highway and transit systems was $172 billion per year. The average annual revenue needs for improvements were an additional $42 billion per year. Based on these revenue needs, the estimated average annual gaps in funding over 28 years were $96 billion for maintenance, and $42 billion for improvements.

The annual cost of congestion in the nation's 439 urban areas was estimated to be more than $100 billion in 2010, including over 4.8 billion hours waiting in traffic while wasting 1.9 billion

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[23] U.S. Department of Transportation, Federal Highway Administration. *2006 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance*. March 2007. http://www.fhwa.dot.gov/policy/2006cpr/es02h.htm

[24] National Surface Transportation Infrastructure Financing Commission. *Paying Our Way. A New Framework for Transportation Finance*. Washington, DC. February 2009.

[25] National Surface Transportation Policy and Revenue Study Commission. *Transportation for Tomorrow.* Washington, DC. December 2007.

gallons of fuel.[26] Many of agriculture's movements are through these congestion bottlenecks that need to be maintained and improved. Figure 3.10 and Figure 3.11 show congestion estimates used in a Federal Highway Administration (FHWA) study of interstate highway capacity.[27] By 2035, interstate highway capacity is expected to be constrained in areas with dense population and commercial activity, denoted by the red lines in Figure 3.11. As highways reach capacity constraints, increased pressure may result in shipments moving to railroads, at least to some degree.

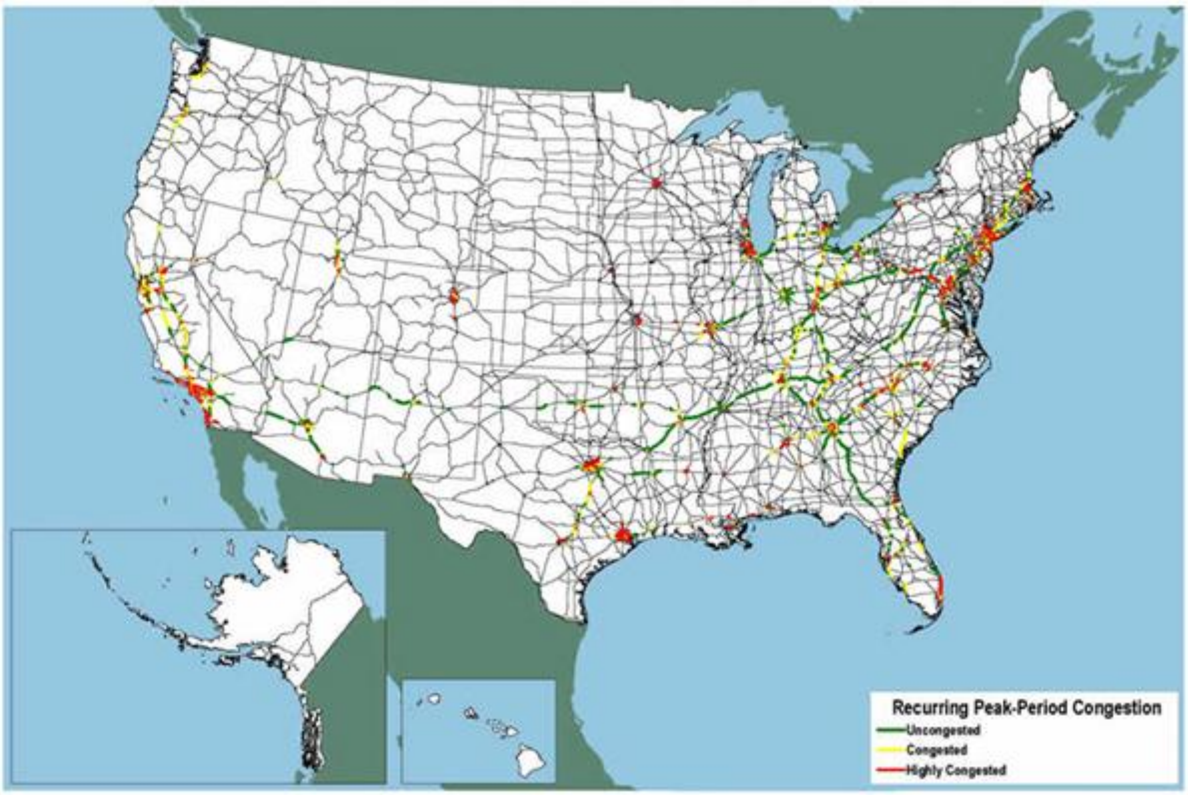

Figure 3.10. Peak-Period Congestion on High-Volume Portions of the National Highway System (2002).
Source: U.S. Department of Transportation, Federal Highway Administration, Freight Management and Operations. Freight Story 2008*. November 2008.*

[26] Texas Transportation Institute. *The 2011 Annual Urban Mobility Report.* September 2011. http://mobility.tamu.edu/ums/
[27] U.S. Department of Transportation, Federal Highway Administration, Freight Management and Operations. *Freight Story 2008.* November 2008.

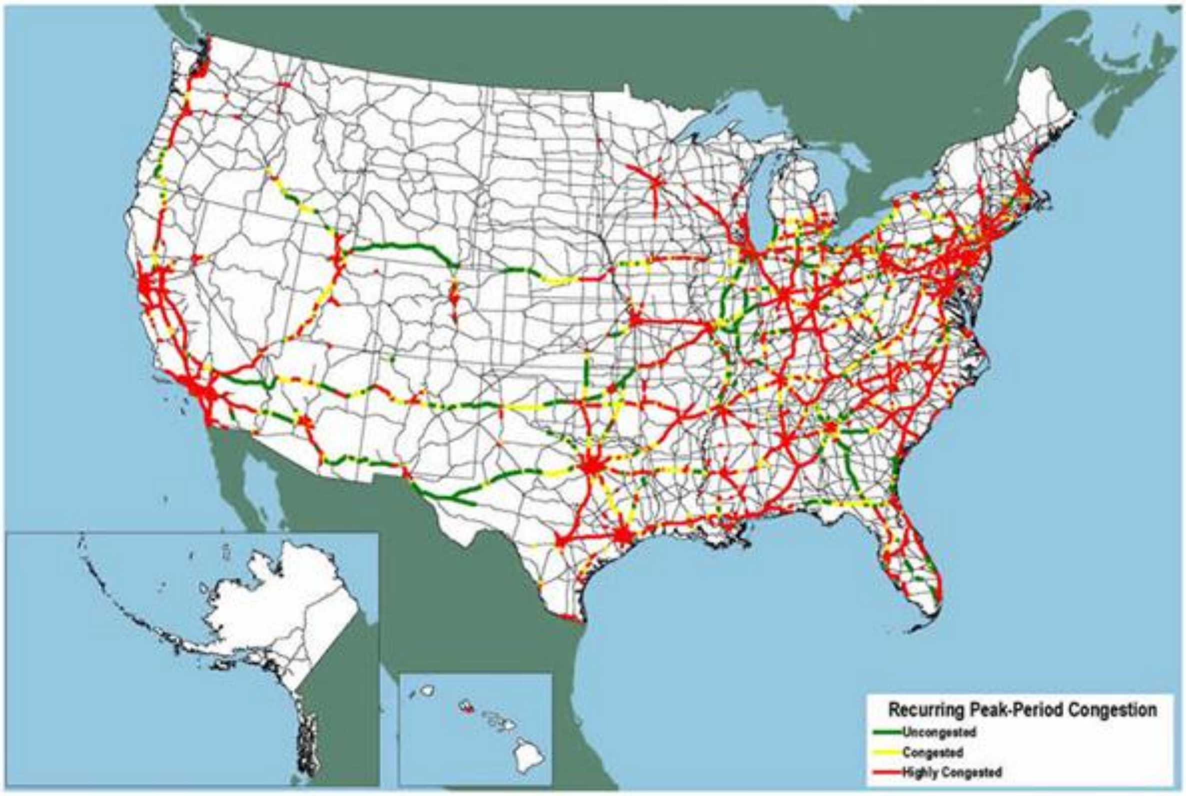

Figure 3.11. Peak-Period Congestion on High-Volume Portions of the National Highway System (2035).

Source: U.S. Department of Transportation, Federal Highway Administration, Freight Management and Operations. Freight Story 2008*. November 2008.*

Conclusions

Deficiencies exist in funds to maintain and improve our nation's roads. A potential diversion of barge traffic to long haul truck would more than likely have a strongly deleterious effect on our infrastructure, economy, and standard of living. That said, trucking is critical for American agriculture. More than 80% of America's communities are served exclusively by trucks. The first and last movements in the supply chain from farm to grocery store are usually trucks, while barge is the most efficient and cost-effective mode for the long haul when available.

The capacity of the trucking industry is governed by three main components: drivers, trucks, and the roads they travel. The second component of the trucking industry, the trucks themselves, is governed by national law limiting axle and gross vehicle weights on the Interstate Highway System. Agricultural interests argue that farm and forest products are heavy, bulky, and of low value, making transportation a large component of their final price, and would like to see higher weight limits on the Interstates. Heavier vehicles are currently restricted to non-Interstate highways and state and local roads.

America's roads are vital to truck transportation. Federal data in 2004 reported that over half of federal-aid highways are in less-than-good condition and more than one quarter of the nation's bridges are structurally deficient or functionally obsolete. Although additional funds for highways and mass transit were made available under ARRA, Omnibus Appropriations Act of 2009, and the restoration of $7 billion to the Highway Trust Fund, average annual gaps in funding are still $96 billion for maintenance and $42 billion in improvements.

Because many agricultural products are exported, reducing congestion in urban and port areas will provide national benefits in reduced emissions and transportation costs and will also lower costs for agricultural exports and improve the competitiveness of U.S. farm products in world trade.

CHAPTER 4
ECONOMIC IMPACT AT CONGRESSIONAL DISTRICT/REGIONAL LEVEL

Economic Impact at Congressional District/Regional Level

This analysis focuses on locks given high priority for maintenance, rehabilitation, or replacement by the Corps and users. The locks selected in previous tasks are:

- LaGrange Lock - Illinois River.
- Lock 20 - Upper Mississippi River.
- Lock 25 - Upper Mississippi River.
- Markland Lock - Ohio River.
- Lock 52 - Ohio River.
- Emsworth Lock – Ohio River.

Emsworth Lock and Dam had negligible agricultural flows, so it was dropped from the grain flow model.

The research team utilized a recently updated spatial equilibrium model that reflects recent changes in the dynamics of grain production, consumption, and transportation. The Integrated Grain Transportation Model (IGTM) is the latest version of a model originally developed by Fuller et al., and was updated in conjunction with the Texas Transportation Institute for this and a related biofuel study.[28] The model simulates flows of corn and soybeans by transport mode between U.S. regions, barge loading/unloading locations, locks, seaports, and foreign destinations. It was created with the objective of being able to outline requirements and justifications for targeted development of transportation infrastructure in order to mitigate projected traffic congestion, and examine potential opportunities for switching rail and truck-transported commerce on North American transport corridors to the inland and intracoastal waterways.

In the model, the primary corn and soybean production and demand regions of the contiguous U.S. are divided into 303 regions (Crop Reporting Districts, [CRDs]) with demand and supply estimated for each of the regions. Each region is then linked with various transport modes (truck, rail) to ports, other CRDs, and barge-loading sites on the river system for shipment to the lower Mississippi River (export) or the Tennessee River (domestic). U.S. ports are subsequently linked with ship rates to about 20 foreign demand regions, as are other exporting countries such as Brazil, Argentina, Ukraine, etc. Rail to Canada and Mexico are also depicted.

To accommodate the significant seasonal variations in grain production and transportation, the model output relates grain flows for all involved regions (domestic, foreign) by quarter and

[28] Fuller, S., L. Fellin, and K. Eriksen. 2000. Panama Canal: How Critical to U.S. Exports. *Agribusiness: An International Journal* 16(4): 435–455, and Fuller, S., L. Fellin, and W. Grant. 1999. Grain Transportation Capacity of the Upper Mississippi and Illinois Rivers. *Journal of the Transportation Research Forum* 38(1): 38–54.

selected transport mode. For example, northwest Iowa may ship grain in any combination of the following:

- By truck to a neighboring region that has an excess demand.
- By truck/rail to a barge-loading site at Clinton, Iowa.
- By truck/rail to southeast U.S. excess demand region (poultry, pork).
- By truck/rail to southwest U.S. demand region (cattle).
- By truck/rail to Pacific northwest ports for export.
- By truck/rail to Gulf ports for export, etc.

For example, if we follow the Clinton, Iowa flow, then we would expect to see the barge flows from Clinton, Iowa to Lower Mississippi ports or to locations on the Tennessee River. In addition, the model relates the price of grain in all regions included in the model.

Four types of catastrophic events were depicted at each of the locks shown above. In particular, closures of two weeks, one month, one quarter, and one year duration were examined. To do this, the model was reconfigured to represent the impediment. In turn, to analyze the cost of the failure, the model was run with a failure of each of the four durations at each lock in each quarter of the year. This caused the model to redirect grain to ports and consumers via alternative modes at a higher cost. For quarterly outages, the largest of the increases in costs by quarter was used in reporting for each lock. Additionally, we computed:

- Costs of storing grain in transit at the time of the failure, assuming that it would be stored for either the length of the failure or one month whichever is shorter.
- Costs of unloading the in-transit grain with a clamshell loader for closures of one quarter or one year.
- Lost revenues to barge companies.

The results allow us to observe a number of items including:

- Cost to U.S. producers by region.
- Cost to U.S. users of grain by region.
- Benefits to International producers by region.
- Cost to international users of grain by region.
- Cost to barge companies.
- Volume shipped by mode in terms of tons and ton-miles.
- Cost of shipping.
- Grain prices by region.
- Transport flows by mode.
- Transport flows by port to exports.

The volume of these results is quite large; therefore, for quarterly outages, we chose to focus on the results under the worst of the four quarters of the year, which is most relevant to agricultural commodities due to their substantial seasonal variations, and we use the distributional results under a one-year failure.

Aggregate Results under Failures of Differing Durations

To get an overall feel for the effects of lock failures on grain markets, we ran the grain model with and without lock failures. In turn, we observed the costs borne by those who supply and consume grain, including the welfare loss to consumers due to higher grain prices coupled with the welfare losses and gains to producers when prices are affected by the loss of transportation services. The difference between the solution with a lock failure and the base model run without lock failures is a measure of the total cost of lock failures. We also observed the loss in barge company revenues. The aggregate measure of these losses summed over all regions for four different lock failure durations is shown in Table 4.1 and Table 4.2. In particular, for a failure of Lock 20 on the Upper Mississippi, we see:

- A two-week failure costs the industry $2.8 million.
- A one-month failure costs $4.9 million.
- A three-month failure costs $15.4 million.
- A one-year failure costs $44.0 million.

In addition to these costs, barge companies would lose revenues of between $5.1 million and $150.1 million, depending on the duration of the lock failure.

Table 4.1. Cost to Agricultural Producers of Lock Closures (Thousand USD).

	Two Weeks	One Month	Three Month	One Year
LaGrange Lock - Illinois River	2,712	4,789	21,197	30,369
Lock 20 - Upper Mississippi	2,821	4,884	15,444	44,030
Lock 25 - Upper Mississippi	2,821	4,884	15,445	44,706
Markland Lock - Ohio River	895	1,024	3,764	4,864
Lock 52 - Ohio River	2,911	3,118	11,857	13,881

Table 4.2. Lost Revenue to Barge Companies from Lock Closures (Thousand USD).

	Two Weeks	One Month	Three Month	One Year
LaGrange Lock - Illinois River	3,555	5,617	4,277	104,753
Lock 20 - Upper Mississippi	5,103	15,001	33,324	150,154
Lock 25 - Upper Mississippi	5,056	14,223	32,351	162,936
Markland Lock - Ohio River	2,232	4,674	7,389	11,037
Lock 52 - Ohio River	17,239	26,120	68,003	71,522

Impacts by Crop Reporting District

For each of the lock failures we tabulated the crop reporting districts that were most affected. Table 4.3 shows the districts and effects on commodity prices. This table contains the 10 most affected districts and the maximum drop in price to producers plus the maximum rise in price to grain consumers for both corn and soybeans. This, then, includes not only districts close to the river where the effects are primarily on producers but also districts elsewhere that have substantial consumption related to processing and feeding industries, which are affected because grain prices rise.

In terms of the table, note that when LaGrange Lock on the Illinois River fails, the most vulnerable crop reporting district is Illinois CRD 20. This district loses $4.3 million, and the price of corn is reduced $0.70 per ton with the price for soybeans reduced $2.45 per ton. In turn, the second most vulnerable district is Illinois CRD 10 where $3.1 million is lost. The third to the sixth most vulnerable are consumption areas in North Carolina, Texas, California, and Georgia. Similar information is presented for the failure of the other four locks.

Table 4.3. Most-Affected Crop Reporting Districts and Price Effects.

Lock	Vulnerability Ranking	Crop Reporting District	Total Cost	Corn Price		Soybeans Price	
				Maximum Reduction	Maximum Increase	Maximum Reduction	Maximum Increase
LaGrange Lock - Illinois River	1	IL 20	−4,266	−0.7		−2.45	
LaGrange Lock - Illinois River	2	IL 10	−3,090			−2.65	
LaGrange Lock - Illinois River	3	NC 90	−1,916		0.31		0.27
LaGrange Lock - Illinois River	4	TX 11	−1,534		0.36		2.24
LaGrange Lock - Illinois River	5	CA 51	−1,354		0.36	−6.12	2.21
LaGrange Lock - Illinois River	6	GA 10	−1,032		0.31		0.8
LaGrange Lock - Illinois River	7	AR 10	−751		0.36		0.23
LaGrange Lock - Illinois River	8	IL 60	−679	−0.61		−0.44	0.46
LaGrange Lock - Illinois River	9	TX51	−666		0.36		1.43
LaGrange Lock - Illinois River	10	CO 90	−624		0.36		15.83
Lock 20 - Upper Mississippi	1	IA 20	−4,762	−1.41		−0.97	
Lock 20 - Upper Mississippi	2	IA 90	−4,253	−2.34		−2.11	
Lock 20 - Upper Mississippi	3	IA 60	−4,017		0.49	−1.12	
Lock 20 - Upper Mississippi	4	MN 80	−2,374	−1.4		−0.64	
Lock 20 - Upper Mississippi	5	MO 30	−2,257		0.06		0.15
Lock 20 - Upper Mississippi	6	IA 10	−2,088	−0.13		−1.19	
Lock 20 - Upper Mississippi	7	IA 50	−2,026	−0.19	0.17	−0.97	
Lock 20 - Upper Mississippi	8	IL 40	−1,814		0.32	−0.93	
Lock 20 - Upper Mississippi	9	NE 30	−1,811	−0.13	0.22	−1.19	0.14
Lock 20 - Upper Mississippi	10	IN 10	−1,567	−0.82			0.35
Lock 25 - Upper Mississippi	1	IA 20	−5,314	−1.53		−0.7	
Lock 25 - Upper Mississippi	2	IA 90	−5,071	−2.7		−2.95	
Lock 25 - Upper Mississippi	3	IA 60	−3,953		0.37	−1.61	
Lock 25 - Upper Mississippi	4	MN 80	−3,111	−1.45		−0.38	
Lock 25 - Upper Mississippi	5	IA 50	−2,093	−0.31	0.05	−1.66	
Lock 25 - Upper Mississippi	6	IN 10	−2,039	−0.94		−0.76	0.12

Table 4.3. Most-Affected Crop Reporting Districts and Price Effects – Continued.

Lock	Vulnerability Ranking	Crop Reporting District	Total Cost	Corn Price		Soybeans Price	
				Maximum Reduction	Maximum Increase	Maximum Reduction	Maximum Increase
Lock 25 - Upper Mississippi	7	MO 60	−1,951		2.91		0.57
Lock 25 - Upper Mississippi	8	IA 10	−1,728	−0.19		−0.93	
Lock 25 - Upper Mississippi	9	NE 30	−1,720	−0.19	0.17	−0.97	0.35
Lock 25 - Upper Mississippi	10	WI 90	−1,472	−1.62		−3.18	
Markland Lock - Ohio River	1	IA 40	−2,628				1.09
Markland Lock - Ohio River	2	MN 80	−2,556				1.12
Markland Lock - Ohio River	3	IN 50	−1,487		1.08	−2.36	
Markland Lock - Ohio River	4	KY 40	−1,386		1.91	−0.64	
Markland Lock - Ohio River	5	IL 30	−1,176	−0.03			1.09
Markland Lock - Ohio River	6	GA 10	−1,147				1.12
Markland Lock - Ohio River	7	AL 20	−1,089				1.12
Markland Lock - Ohio River	8	IL 40	−1,056				1.12
Markland Lock - Ohio River	9	OH 70	−898		2.14	−2	0.14
Markland Lock - Ohio River	10	GA 70	−896				0.94
Lock 52 - Ohio River	1	IN 50	−4,637	−0.14	1.36	−2.4	
Lock 52 - Ohio River	2	OH 40	−3,591	−0.14	1.6	−2.66	
Lock 52 - Ohio River	3	MO 90	−3,296	−1.22	0.26	−0.84	
Lock 52 - Ohio River	4	MO 30	−2,450	−0.91	0.14		1.49
Lock 52 - Ohio River	5	TX 11	−1,834		0.44	−0.19	3.87
Lock 52 - Ohio River	6	CA 51	−1,623		0.44		17.92
Lock 52 - Ohio River	7	MN 80	−1,599		0.53		1.34
Lock 52 - Ohio River	8	GA 10	−1,279	−0.14			1.34
Lock 52 - Ohio River	9	IA 40	−1,239		0.44		1.49
Lock 52 - Ohio River	10	GA 70	−1,102				1.16

Impacts by Congressional District

Generally, CRDs contain a number of Congressional Districts (CD). Therefore, we developed a mapping between them. In particular, we identified CDs as they overlapped with CRDs in two classes. CDs that made up more than 25% of the land area in a CRD went into the "Largest Overlap CDs" category. This would generally be the production side (the CD covers a lot of the farmland in the CRD). The second category is a list of CDs that comprise less than 25% of the area in the CRD but greater than 1%.

The table below provides this overlap and includes a vulnerability measure. For example, when the LaGrange Lock on the Illinois River fails, the most vulnerable crop reporting district is CRD 20 in Illinois, incurring a loss of $4.3 million; this is principally composed of CD 11 in Illinois; however, CDs 1, 2, 3, 6, 8, 9, 10, 13, 14, and 16 contain small parts of this CRD. Similarly, the second most vulnerable area under a LaGrange Lock failure scenario is Illinois CRD 10, incurring a loss of $3.1 million. CRD 10 is principally composed of CD 16 but CDs 11, 14, 17, and 18 also have parts of their area in this CRD.

Table 4.4. Mapping of Crop Reporting Districts and Congressional Districts.

Lock	Vulnerability Ranking	State	CRD	Total Cost (1000 $)	Largest Overlap CDs	Smallest Overlap CDs
LaGrange Lock - Illinois River	1	IL	20	4266	11	01,02,03,06,08,09, 10,13,14,16
LaGrange Lock - Illinois River	2	IL	10	3090	16	11,14,17,18
LaGrange Lock - Illinois River	3	NC	90	1916	7	02,03,08
LaGrange Lock - Illinois River	4	TX	11	1534	13	19
LaGrange Lock - Illinois River	5	CA	51	1354	21,22	11,18,19,20
LaGrange Lock - Illinois River	6	GA	10	1032	09,11	-
LaGrange Lock - Illinois River	7	AR	10	751	3	-
LaGrange Lock - Illinois River	8	IL	60	679	17,18,19	12
LaGrange Lock - Illinois River	9	TX	51	666	01,04,05	6
LaGrange Lock - Illinois River	10	CO	90	624	03,04	5
Lock 20 - Upper Mississippi	1	IA	20	4762	4	1

Table 4.4. Mapping of Crop Reporting Districts and Congressional Districts – Continued.

Lock	Vulnerability Ranking	State	CRD	Total Cost (1000 $)	Largest Overlap CDs	Smallest Overlap CDs
Lock 20 - Upper Mississippi	2	IA	90	4253	2	3
Lock 20 - Upper Mississippi	3	IA	60	4017	01,02	3
Lock 20 - Upper Mississippi	4	MN	80	2374	1	2
Lock 20 - Upper Mississippi	5	MO	30	2257	9	-
Lock 20 - Upper Mississippi	6	IA	10	2088	5	4
Lock 20 - Upper Mississippi	7	IA	50	2026	03,04	-
Lock 20 - Upper Mississippi	8	IL	40	1814	18	11,15,17
Lock 20 - Upper Mississippi	9	NE	30	1811	01,03	-
Lock 20 - Upper Mississippi	10	IN	10	1567	01,02	4
Lock 25 - Upper Mississippi	1	IA	20	5314	4	1
Lock 25 - Upper Mississippi	2	IA	90	5071	2	3
Lock 25 - Upper Mississippi	3	IA	60	3953	01,02	3
Lock 25 - Upper Mississippi	4	MN	80	3111	1	2
Lock 25 - Upper Mississippi	5	IA	50	2093	03,04	-
Lock 25 - Upper Mississippi	6	IN	10	2039	01,02	4
Lock 25 - Upper Mississippi	7	MO	60	1951	9	01,02,03,08
Lock 25 - Upper Mississippi	8	IA	10	1728	5	4
Lock 25 - Upper Mississippi	9	NE	30	1720	01,03	-
Lock 25 - Upper Mississippi	10	WI	90	1472	01,05	4
Markland Lock - Ohio River	1	IA	40	2628	5	4

Table 4.4. Mapping of Crop Reporting Districts and Congressional Districts – Continued.

Lock	Vulnerability Ranking	State	CRD	Total Cost (1000 $)	Largest Overlap CDs	Smallest Overlap CDs
Markland Lock - Ohio River	2	MN	80	2556	1	2
Markland Lock - Ohio River	3	IN	50	1487	04,05,06	07,09
Markland Lock - Ohio River	4	KY	40	1386	4	-
Markland Lock - Ohio River	5	IL	30	1176	17,18	-
Markland Lock - Ohio River	6	GA	10	1147	09,11	-
Markland Lock - Ohio River	7	AL	20	1089	03,04	05,06
Markland Lock - Ohio River	8	IL	40	1056	18	11,15,17
Markland Lock - Ohio River	9	OH	70	898	3	01,02,07,08
Markland Lock - Ohio River	10	GA	70	896	2	-
Lock 52 - Ohio River	1	IN	50	4637	04,05,06	07,09
Lock 52 - Ohio River	2	OH	40	3591	04,08	05,07
Lock 52 - Ohio River	3	MO	90	3296	8	-
Lock 52 - Ohio River	4	MO	30	2450	9	-
Lock 52 - Ohio River	5	TX	11	1834	13	19
Lock 52 - Ohio River	6	CA	51	1623	21,22	11,18,19,20
Lock 52 - Ohio River	7	MN	80	1599	1	2
Lock 52 - Ohio River	8	GA	10	1279	09,11	-
Lock 52 - Ohio River	9	IA	40	1239	5	4
Lock 52 - Ohio River	10	GA	70	1102	2	-

The model also allows us to get insights into incidence of the costs and effects on welfare distribution, costs, flows, etc. (Table 4.5). The results for year-long failures can be summarized as:

- International consumers have the most to lose.
- Barge companies lose significant revenue.
- Barge use is reduced and replaced by rail and small ship.
- The U.S. loses a small amount of export share.
- Cost of closure is about $1.50 per ton that traverses a lock.

Table 4.5. Incidence of Costs and Effects by Lock.

Effects	Market	Mode	Unit of Measure	LaGrange Lock Illinois River	Lock 20 Upper Miss	Lock 25 Upper Miss	Markland Lock Ohio River	Lock 52 Ohio River
Consumers surplus	Domestic		1000 USD	−25,831	8,626	15,957	−8,017	−15,548
Consumers surplus	International		1000 USD	−106,143	−81,776	−86,957	−75,339	−127,594
Producers surplus	Domestic		1000 USD	46,755	−9,525	−14,284	35,074	68,319
Producers surplus	International		1000 USD	58,841	41,034	42,969	44,804	66,892
Failure related storage	Domestic		1000 USD	−1,800	−1,263	−1,264	−817	−2,893
Failure related unloading	Domestic		1000 USD	−2,191	−1,127	−1,127	−569	−3,057
Failure related lost barge revenue	Domestic		1000 USD	−104,753	−150,154	−162,936	−11,037	−71,522
Total welfare	Both		1000 USD	−30,369	−44,030	−44,706	−4,864	−13,881
Total welfare	Domestic		1000 USD	20,923	−899	1,674	27,057	52,771
Total welfare	International		1000 USD	−47,302	−40,741	−43,988	−30,535	−60,702
Cost of transport	Domestic		1000 USD	−116,284	−69,002	−84,243	−82,387	−112,940
Cost of transport	US exports		1000 USD	100,986	23,217	41,289	98,207	122,924
Cost of transport	International to International		1000 USD	13,256	35,246	40,864	17,123	29,194
Cost of transport by mode	Domestic	Truck	1000 USD	46,583	28,725	44,840	−1,165	62,605
Cost of transport by mode	Domestic	Rail	1000 USD	−167,164	−241,195	−271,887	−1,838	−132,764
Cost of transport by mode	Domestic	Barge	1000 USD	104,753	150,154	162,936	11,037	71,522
Cost of transport by mode	Domestic	Small Ship	1000 USD	−4,221	−6,011	−4,774	−8,211	−10,953

Table 4.5. Incidence of Costs and Effects by Lock – Continued.

Effects	Market	Mode	Unit of Measure	LaGrange Lock Illinois River	Lock 20 Upper Miss	Lock 25 Upper Miss	Markland Lock Ohio River	Lock 52 Ohio River
Cost of transport by mode	Domestic	Big Ship	1000 USD	−96,234	−676	−15,358	−82,210	−103,349
Cost of transport by mode	US exports	Truck	1000 USD	6,303	−47	−673	1,233	3,405
Cost of transport by mode	US exports	Rail	1000 USD	−12,233	−25,292	−25,082	−6,540	−12,407
Cost of transport by mode	US exports	Barge	1000 USD	38,086	17,701	24,102	41,609	46,944
Cost of transport by mode	US exports	Small Ship	1000 USD	−2,017	−768	−2,409	−1,021	−3,294
Cost of transport by mode	US exports	Big Ship	1000 USD	70,846	31,624	45,351	62,926	88,276
Cost of transport by mode	International to International	Truck	1000 USD	−550	5,294	5,294	−550	−550
Cost of transport by mode	International to International	Rail	1000 USD		−2,925	−2,928	1,337	1,641
Cost of transport by mode	International to International	Big Ship	1000 USD	13,806	32,878	38,498	16,336	28,103
Volume supply	Domestic		1000 Tons	58	65	47	−119	−119
Volume demand	Domestic		1000 Tons	135	46	66	−54	−52
Volume demand	International		1000 Tons	−77	20	−20	−65	−67
Volume export	Domestic		1000 Tons	−77	20	−20	−65	−67
Volume export by source	Gulf		1000 Tons	−1,063	−3,835	−4,251	−693	−2,004
Volume export by source	Great Lakes		1000 Tons	300	300	300	445	583

Table 4.5. Incidence of Costs and Effects by Lock – Continued.

Effects	Market	Mode	Unit of Measure	LaGrange Lock Illinois River	Lock 20 Upper Miss	Lock 25 Upper Miss	Markland Lock Ohio River	Lock 52 Ohio River
Volume export by source	West Coast		1000 Tons	346	3,226	3,489	36	1,034
Volume export by source	East Coast		1000 Tons	340	295	409	167	341
Volume export by source	To Mexico		1000 Tons		33	33	−20	−20
Volume loaded		Truck	1000 Tons	−8,206	−4,646	−5,719	−234	−5,421
Volume loaded for transport	Domestic	Rail	1000 Tons	8,269	4,788	5,859	6	5,725
Volume loaded for transport	Domestic	Barge	1000 Tons	−5,697	−7,523	−8,516	−776	−5,641
Volume loaded for transport	Domestic	Small Ship	1000 Tons	300	300	300	445	583
Volume loaded for transport	Domestic	Big Ship	1000 Tons	−77	−13	−52	−45	−47
Volume ton-miles by mode	Domestic	Truck	Million Ton-Miles	−230,983	−253,666	−379,860	34,016	−565,167
Volume ton-miles by mode	Domestic	Rail	Million Ton-Miles	4,589,039	7,284,486	8,186,152	57,581	3,715,397
Volume ton-miles by mode	Domestic	Barge	Million Ton-Miles	−6,784,537	−9,535,160	−10,405,868	−901,538	−5,631,689
Volume ton-miles by mode	Domestic	Small Ship	Million Ton-Miles	158,400	210,600	210,600	234,893	307,574
Volume ton-miles by mode	US exports	Big Ship	Million Ton-Miles	900,311	824,893	889,641	1,007,262	1,543,747
Volume stored	Domestic		1000 Ton Quarters	−1,150	−1,063	2,591	4,192	1,453

Table 4.5. Incidence of Costs and Effects by Lock – Continued.

Effects	Market	Mode	Unit of Measure	LaGrange Lock Illinois River	Lock 20 Upper Miss	Lock 25 Upper Miss	Markland Lock Ohio River	Lock 52 Ohio River
Volume stored	International		1000 Ton Quarters	379	−1,064	−4,800	−3,136	−395
Consumer price	Domestic	Corn	$/Ton	0.29	−0.03	−0.1	−0.01	0.1
Consumer price	Domestic	Soybeans	$/Ton	0.02	−0.22	−0.27	0.34	0.27
Consumer price	International	Corn	$/Ton	0.59	0.53	0.55		0.4
Consumer price	International	Soybeans	$/Ton	0.76	0.48	0.53	1.1	1.33
Producer price	Domestic	Corn	$/Ton	0.23	0.1	0.06		0.2
Producer price	Domestic	Soybeans	$/Ton	0.31	0.06	0.07	0.72	0.8
Producer price	International	Corn	$/Ton	0.88	0.64	0.66	−0.01	0.42
Producer price	International	Soybeans	$/Ton	0.8	0.54	0.57	1.12	1.34
Lock shadow price	LaGrange Lock Illinois River	Fall	$/1000 Tons	372.64	372.64	372.64	372.64	372.64
Lock shadow price	LaGrange Lock	Winter	$/1000 Tons	381.11	381.11	381.11	381.11	381.11
Lock shadow price	LaGrange Lock	Spring	$/1000 Tons	383.66	383.66	383.66	383.66	383.66
Lock shadow price	LaGrange Lock	Summer	$/1000 Tons	387.19	387.19	387.19	387.19	387.19
Lock shadow price	LaGrange Lock	annual	$/1000 Tons	1524.61	1524.61	1524.61	1524.61	1524.61
Lock shadow price	Lock 20 Upper Mississippi	Fall	$/1000 Tons		372.91		372.91	372.91
Lock shadow price	Lock 20 Upper Mississippi	Spring	$/1000 Tons		383.43		383.43	383.43
Lock shadow price	Lock 20 Upper Mississippi	Summer	$/1000 Tons		387.14		387.14	387.14

Table 4.5. Incidence of Costs and Effects by Lock – Continued.

Effects	Market	Mode	Unit of Measure	LaGrange Lock Illinois River	Lock 20 Upper Miss	Lock 25 Upper Miss	Markland Lock Ohio River	Lock 52 Ohio River
Lock shadow price	Lock20 Upper Mississippi	Annual	$/1000 Tons		1143.47		1143.47	1143.47
Lock shadow price	Lock 25 Upper Mississippi	Fall	$/1000 Tons		373.37	373.37	373.37	373.37
Lock shadow price	Lock 25 Upper Mississippi	Spring	$/1000 Tons		384.17	384.17	384.17	384.17
Lock shadow price	Lock 25 Upper Mississippi	Summer	$/1000 Tons		387.93	387.93	387.93	387.93
Lock shadow price	Lock 25 Upper Mississippi	Annual	$/1000 Tons		1145.47	1145.47	1145.47	1145.47
Lock shadow price	Markland Lock Ohio River	Fall	$/1000 Tons				372.2	372.2
Lock shadow price	Markland Lock Ohio River	Winter	$/1000 Tons				379.74	379.74
Lock shadow price	Markland Lock Ohio River	Spring	$/1000 Tons				383.69	383.69
Lock shadow price	Markland Lock Ohio River	Summer	$/1000 Tons				385.15	385.15
Lock shadow price	Markland Lock Ohio River	annual	$/1000 Tons				1520.78	1520.78
Lock shadow price	Lock 52 Ohio River	Fall	$/1000 Tons					377.86
Lock shadow price	Lock 52 Ohio River	Winter	$/1000 Tons					385.15
Lock shadow price	Lock 52 Ohio River	Spring	$/1000 Tons					387.14

Table 4.5. Incidence of Costs and Effects by Lock – Continued.

Effects	Market	Mode	Unit of Measure	LaGrange Lock Illinois River	Lock 20 Upper Miss	Lock 25 Upper Miss	Markland Lock Ohio River	Lock 52 Ohio River
Lock shadow price	Lock 52 Ohio River	Summer	$/1000 Tons					391.87
Lock shadow price	Lock 52 Ohio River	Annual	$/1000 Tons					1542.03

Effects on Agricultural Input and Energy Prices

The inland waterway also plays an important role in the transportation of agricultural inputs, especially fertilizers and pesticides, which account for 16% of waterway traffic. Most agricultural input traffic on the inland waterway moves upriver, over 80% of which is fuel products, while another 12% is fertilizer. According to Casavant and sources cited therein, the cost of fertilizer increases by around $8 per ton if alternative transportation modes are used instead of inland waterways.[29] Based on this estimate, we calculated the additional cost in agricultural input for each river for 2010. Note that these results are larger than those for grain prices. This is because the results for agricultural inputs are reported by river due to the fact that no lock-specific information is available for agricultural input prices. We report in Table 4.6 the quarterly additional cost in transporting fertilizers due to lock closures during the agricultural growing season.

Table 4.6. Estimated Effect on Agricultural Inputs.

River	Effect on Agricultural Inputs ($ Million)
Illinois	11.75
Mississippi	49.28
Ohio	105.05

We next estimated the impact of lock closure on energy prices. Since the transportation of coal on the inland waterway system differs from that of agricultural products, we used different models and approaches to assess the impacts of lock closures on energy prices.

The Corps surveyed shipper and carrier responses to planned closures of the Greenup Lock in 2003 and the McAlpine Lock in 2004.[30,31] Given the information is based on only those responding in these surveys, cost estimates are conservative. Further, the closures were at least partially planned closures that were announced months in advance of the closure, potentially allowing firms to prepare for the closures. Cost estimates are not broken up by industry type.

The Greenup Lock, located at mile 341.0 on the Ohio River, was a planned closure, scheduled to be closed for 18 days, but the closure stretched to 52 days because of the discovery of series

[29] Casavant, K, "Inland Waterborne Transportation-An Industry Under Siege", USDA-Agricultural Marketing Service Report, 2000. Their estimates of cost increase for fertilizer is comparable to those for corn and wheat, which are suggested to be $9.58 and $5.88 respectively.

[30] U.S. Army Corps of Engineers. "Shipper and Carrier Response to the September – October Greenup Main Lock Closure." The Navigation Economic Technologies Program. IWR Report 05-NETS-R-02. Available at http://www.corpsnets.us/bookshelf.cfm

[31] U.S. Army Corps of Engineers. "McAlpine Lock Closure in August 2004 Shipper and Carrier Response Results of Surveys." The Navigation Economic Technologies Program. IWR Report 05-NETS-R-08. Available at http://www.corpsnets.us/bookshelf.cfm

cracking in the lock gates and the need for emergency repairs. The auxiliary lock remained operational during the closure, which was noted as mitigating some of the adverse impacts. Coal, by tonnage, represents approximately 58% of the total tonnage passing through the lock. Both upbound and downbound traffic of coal exists, but 82% of the coal moves downbound. Total costs of the closure were estimated to be $41 million (2004 dollars). Responses from a utility firm indicated every closure is unique and actual response to a closure depends on coal and transportation markets conditions at the time of the closure, strategies will be on a plant-by-plant basis. The company's potential responses to a closure were noted as: a) use of stockpile coal (increase stockpile if the closure is planned); b) divert coal traffic to other modes; c) shift coal sources to avoid the closed facility; or d) close plants that cannot receive coal and either re-dispatch the remaining plants or purchase power off the grid.

Another option not mentioned by this utility but available to some plants is the use of a fuel other than coal (dual fuel plants). Price of coal delivered to a utility plant before the closure was $30-50/ton and during the closure was $50-60/ton—price increases of 20–66% based on 500–600,000 tons. Based on 50–100,000 tons, a coal sales company noted delivered prices prior to closure of $30–35/ton but $50–60/ton during closure. The study notes "The traffic effects of the closure at Greenup vary depending on the commodity and individual company decisions…[A] sizable amount of coal traffic as well as some aggregates traffic diverted to other modes/sources during the closure. Additionally, some critical commodity movements were given priority by the towing companies…" The ability of the auxiliary lock to handle traffic lowered the costs of the closure; tonnage through the auxiliary lock during closure was approximately the same as tonnage through the main lock before closure.

The Corps issued a notice on May 20, 2004, that the McAlpine Lock would be closed August 3 through August 16, 2004, for emergency repairs. At the time, McAlpine lock was a single chamber; therefore, the closure meant all Ohio River traffic at Louisville, KY (the lock location) would be closed for approximately two weeks. Actual closure dates were between August 8 and August 19—11 days instead of the planned 14 days. Cost to carriers and shippers totaled $6.3 million (2004 dollars) based on respondents accounting for 52% of tonnage that moved through the lock in 2004. Coal accounted for approximately 33% of the total tonnage at this lock in 2004, with approximately 43% downbound and 46% upbound. Three coal companies responded. One company indicated it switched product source to an entirely new source affecting 25,000 tons of coal. The second indicated they stockpiled coal and switched to a different waterway routing for delivery affecting 30,000 tons of coal. The third company changed suppliers between plants above and below the lock.

A Corps-series of events at the Hannibal Locks and Dam lead to the total closure of the Ohio River for five days and closure of one of the locks between October 21 and November 16, 2005. Two chambers—a 600' and a 1200'—comprise the Hannibal Locks. The Hannibal Locks are located on the Ohio River, 126.4 miles down the Ohio from Pittsburgh, PA at New Martinsville, WV. In 2005, coal represented 76% of the tonnage passing through the lock. Most of the coal is from the Appalachian coal fields moving to electric generating plants located on the Ohio. On September 15, the 1200' chamber failed, causing the lock to be closed for two days. The 600' chamber was closed on October 21 for normal inspection and did not reopen until November 6. The 1200' chamber failed on November 1 and did not reopen until November 15. Conservatively estimated, the series of closures cost \$5.1 million dollars, broken down into \$2.9 million for delays, \$1.6 million on waterside industries, and \$0.6 million Corps costs. Costs were minimal given the short duration of the total closure. The study notes power plants are generally at the lowest risk because of the stockpile of coals.

Two studies looked at planned closures of Lock 27 on the Mississippi River located at mile 185.0 in the Greater St. Louis area. Lock 27 consists of both a main and a smaller auxiliary chamber. In 2004, coal accounted for approximately 11% of the commodity traffic tonnage, with upbound traffic accounting for the majority. Grain shipments accounted for 41% of the traffic with chemicals, crude materials, petroleum, and others accounting for 9–11% each. Scheduled repairs on the main lock chamber occurred between July 26 and August 10, 2004. All tonnage increased during the closure, including coal. Increased tonnage was a result of carriers increasing tow size and decreasing the proportion of empty barges. Total estimated costs were \$4.1 million. The auxiliary chamber was closed for nine weeks between October 17 and December 22, 2005, whereas, the main chamber was closed for seven weeks between January 3 and February 25, 2006 for scheduled maintenance.[32] Survey responses were similar to the previous survey of this lock. Reported closure costs were estimated at \$0.6 million. Timing of the closures is the most likely reason for the smaller cost of the second closure. The winter months are generally light traffic months. Only one comment in either study pertains directly to a utility that indicated the company was affected by other navigation system disruptions, but the disruptions did not influence their response to the Lock 27 closure.

Finally, a Corps-sponsored study was in its preliminary stages and not available for distribution at the time this report was written. Preliminary results suggest that complete and permanent closure of the Lower Monongahela River would have sizable effects on utilities.[33] Utility costs will increase but there were no projected blackouts, brownouts, or utilities closing down. Other issues, such as the effect of the development of shale gas on natural gas prices, environmental issues, and improvement in scrubbers, may further coal's importance and its transportation issues. One reason that both upbound and downbound coal movements on the Ohio River are significant is the necessary mixing of different coals to help meet environmental regulations.

An alternative measure of the effect of closures on the energy sector is coal price. Percentage changes from the week before to the week after the closure are presented in Table 4.7 through Table 4.9. These percentages are limited in their usefulness because the weekly coal prices show little variability. Coal is generally purchased with long-term contracts; therefore, the data are based on few trades. The percentages do not include other factors affecting coal prices during the closure periods, and there are a limited number of closures at each lock and dam.

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[32] U.S. Army Corps of Engineers. "Shipper and Carrier Response to the October – December 2005 and January – February 2006 Lock 27 Closures." The Navigation Economic Technologies Program. IWR Report 06-NETS-R-08. Available at http://www.corpsnets.us/bookshelf.cfm
[33] Kelz, D. 2011. U.S. Army Corps of Engineers. Huntington District. Personal Communication.

Four price series encompass coal prices starting in the Pennsylvania coal beds (Penn) and moving down the Ohio River to the Big Sandy and on to the Illinois coal basin. Powder River Basin is included to encompass coal prices that are removed from the Ohio River. Locks included start on the Ohio River in Pittsburgh (Emsworth) and extend to where the Ohio River joins the Mississippi (Cairo, Illinois - Lock 52). Most of the closures were planned, with the average length of closure being 12 days for Lock 52, 16 days for Emsworth, and 18 days for Markland. River traffic may not have been significantly restricted during the closures because all locks have both a main and an auxiliary chamber. Transportation rates may show a larger change, but we are not aware of published transportation rates for this period.

Closure of Lock 52 (Table 4.7 through Table 4.9) generally had the smallest effects on the four price series. Closure of the Emsworth and Markland Locks appear to have some effect on the prices of both Pennsylvania coal beds and Big Sandy barge prices, with Emsworth having a slightly larger effect. Percentage changes ranged from to 0% to a very large 29% for the Powder River Basin. A large percentage change for January 2010 is evident in all price series. Factors other than the Markland closure most likely are the cause of these large percentage changes.

Table 4.7. Percentage Change in Coal Prices ($/Short Ton) for At Least a One-Week Partial Closure at Emsworth Lock and Dam.[1]

Closure		River			
Beginning Date	End Date	Big Sandy[2]	Penn[3]	Illinois[4]	PRB[5]
6/1/1994	6/30/1994	0.00	0.00		0.00
10/4/1994	10/14/1994	0.00	0.00		0.00
11/1/1994	11/30/1994	0.00	0.00		0.00
6/16/1995	6/23/1995	0.00	0.00		0.00
12/22/1995	12/31/1995	0.00	0.00		0.00
2/12/1996	2/22/1996	0.00	0.00		0.00
6/6/1997	6/14/1997	0.00	0.00		0.00
11/2/1998	11/10/1998	3.33	0.00	0.00	4.55
11/1/2001	11/9/2001	−3.54	−1.47	0.00	−2.94
9/8/2003	9/19/2003	1.49	0.78	0.00	7.54
10/1/2003	10/11/2003	0.36	1.49	0.00	−3.12
9/7/2004	9/30/2004	2.46	14.04	−1.56	0.00
10/1/2007	10/18/2007	6.82	−1.06	0.00	0.00
7/6/2009	7/25/2009	2.20	0.00	0.00	0.00
5/3/2010	5/24/2010	5.64	1.67	0.00	0.00
Average All		**1.25**	**1.03**	**−0.20**	**0.40**
Average Since January 1998		**2.34**	**1.93**	**−0.20**	**0.75**

1) Data Source Bloomberg Financial Services.
2) Big Sandy Barge Cost FOB, 12,000 BTU, 13.5% ash, 1% or less sulfur. On the Big Sandy River or Ohio River between Huntington, WV and Big Sandy River.
3) Pennsylvania Pittsburgh coal bed FOB, 12,500-13,000 BTU, 7–9% ash, 2–3% sulfur.
4) Illinois Basin Spot Price, 11,000BTU, 8–9% ash, 2% sulfur.
5) Powder River Basin mines in Wyoming and Montana, 8,800 BTU, 5.5% ash, 0.3% sulfur.

Table 4.8. Percentage Change in Coal Prices ($/Short Ton) for At Least a One-Week Partial Closure at Markland Lock and Dam.

Closure		River			
Beginning Date	End Date	Big Sandy[2]	Penn[3]	Illinois[4]	PRB[5]
7/18/1994	7/31/1994	−0.41	0.00		0.00
7/11/1995	8/1/1995	0.00	0.00		0.00
8/6/1995	9/1/1995	0.00	0.00		0.00
9/1/1995	10/1/1995	0.00	0.00		0.00
10/1/1995	11/1/1995	0.00	0.00		0.00
6/5/1996	6/15/1996	0.00	0.00		0.00
4/7/1998	4/30/1998	−3.22	−4.67		0.00
5/1/1998	5/20/1998	1.91	0.00		0.00
6/19/1999	6/28/1999	−1.06	−5.19	0.00	−1.52
8/13/2003	8/27/2003	4.76	2.44	3.23	5.33
6/1/2007	6/15/2007	7.78	2.20	0.00	8.11
9/7/2009	9/14/2009	0.00	0.00	0.00	0.00
9/14/2009	9/25/2009	0.00	0.00	0.00	0.00
1/1/2010	1/31/2010	7.02	8.50	2.47	29.17
2/1/2010	2/28/2010	1.73	8.18	0.00	1.38
9/19/2010	9/30/2010	0.00	0.00	0.00	3.47
10/1/2010	10/31/2010	2.37	−2.11	1.07	−9.40
11/1/2010	11/22/2010	0.00	0.00	0.00	−1.85
11/22/2010	11/30/2010	0.00	0.00	0.00	−1.85
12/11/2010	12/21/2010	0.00	0.00	0.00	1.13
Average All		**1.04**	**0.47**	**0.56**	**1.70**
Average Since January 1998		**1.52**	**0.68**	**0.56**	**2.43**

1) Data Source Bloomberg Financial Services.
2) Big Sandy Barge Cost FOB, 12,000 BTU, 13.5% ash, 1% or less sulfur. On the Big Sandy River or Ohio River between Huntington, WV and Big Sandy River.
3) Pennsylvania Pittsburgh coal bed FOB, 12,500-13,000 BTU, 7–9% ash, 2–3% sulfur.
4) Illinois Basin Spot Price, 11,000BTU, 8–9% ash, 2% sulfur.
5) Powder River Basin mines in Wyoming and Montana, 8,800 BTU, 5.5% ash, 0.3% sulfur.

Table 4.9. Percentage Change in Coal Prices ($/Short Ton) for At Least a One-Week Partial Closure at Lock 52.[1]

Closure		River			
Beginning Date	End Date	Big Sandy[2]	Penn[3]	Illinois[4]	PRB[5]
8/8/2006	8/31/2006	−5.05	−2.47	−2.70	4.44
10/1/2006	10/11/2006	−3.23	0.00	0.00	2.33
8/7/2007	8/14/2007	−2.30	0.00	3.39	0.00
8/21/2007	8/29/2007	3.53	0.00	−1.64	0.00
9/8/2009	9/21/2009	0.00	0.00	0.00	0.00
10/1/2010	10/8/2010	0.00	0.00	−3.61	−1.01
10/18/2010	10/28/2010	0.21	0.00	0.00	−3.09
Average		**−0.98**	**−0.35**	**−0.65**	**0.38**

1) Data Source Bloomberg Financial Services.
2) Big Sandy Barge Cost FOB, 12,000 BTU, 13.5% ash, 1% or less sulfur. On the Big Sandy River or Ohio River between Huntington, WV and Big Sandy River.
3) Pennsylvania Pittsburgh coal bed FOB, 12,500-13,000 BTU, 7–9% ash, 2–3% sulfur.
4) Illinois Basin Spot Price, 11,000BTU, 8–9% ash, 2% sulfur.
5) Powder River Basin mines in Wyoming and Montana, 8,800 BTU, 5.5% ash, 0.3% sulfur.

The review of previous studies of lock closures and ad hoc coal price percentage changes indicates that short-term closure of the Ohio River increases costs, but not dramatically. The energy sector has the ability to withstand short-term closures. Often, the closure of a lock is for only one chamber—either the main or the auxiliary chamber. The ability of traffic to continue even though a chamber is experiencing a closure mitigates some of the costs. Fortunately for commerce, but unfortunately for studying effects, longer-term closures and complete closures are not in the data sets.

Although the response will be specific to each utility company and particular electricity generating plant, some responses can be generalized. These responses include:

1. **Use of stocks.** One of the first responses would be to rely on coal stocks at the plants. Figure 4.1 shows average coal stocks at electricity generating facilities over time. Plants have approximately two months of coal on hand.

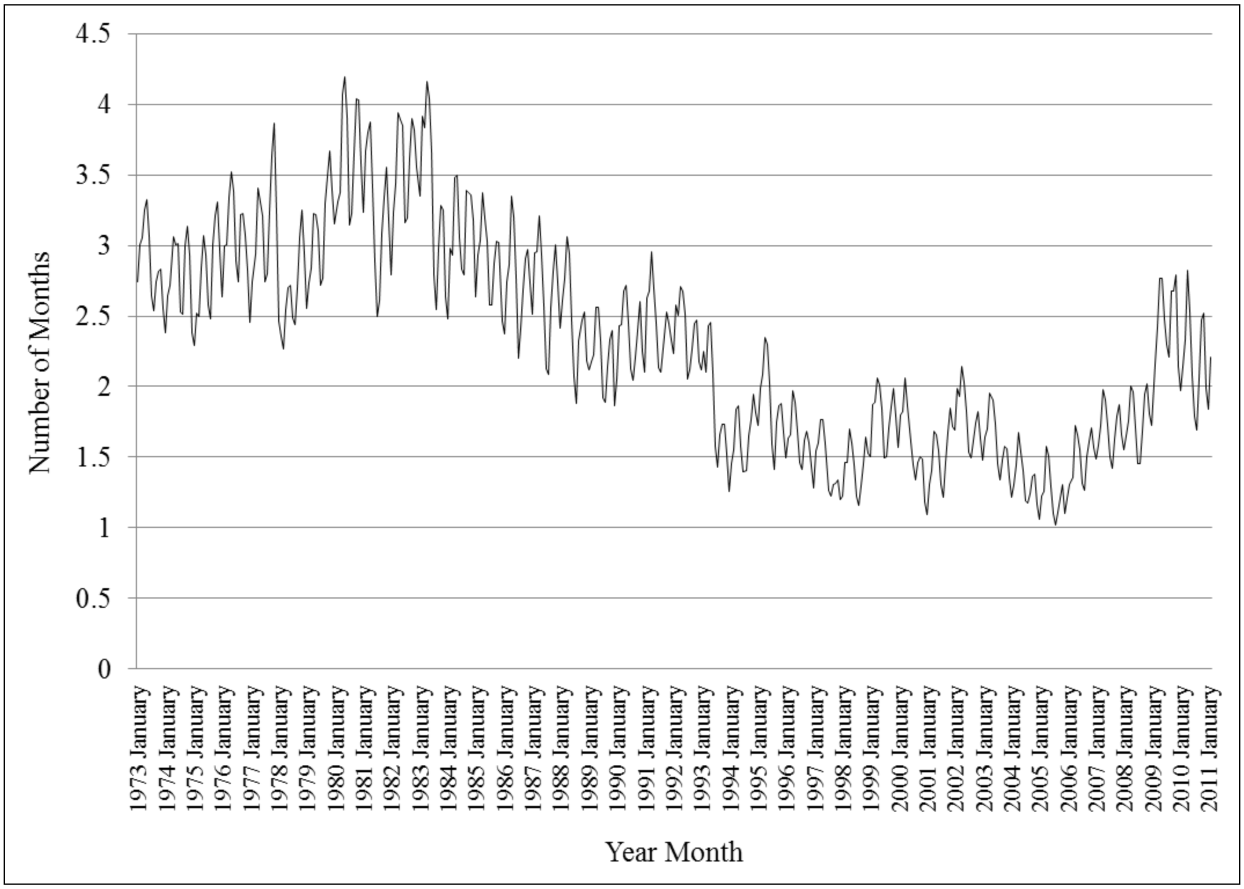

Figure 4.1. Monthly Stocks of Coal Divided by Monthly Consumption for Electric Power Sector.
Source: EIA

2. **Multifuel plants.** The current wildcard in the energy industry is the development of shale natural gas. Plants are being built and retrofitted to be able to use dual fuels, usually coal and natural gas. For the PJM Interconnection region[34] for 2007, coal plants had capacity of approximately 78,000 megawatts. Of this capacity, approximately 63% is associated with coal plants that have backup fuel capacity.[35]

3. **Change suppliers.** Coal moves both up and down the Ohio River, with a closure, plants upriver of the closure may be forced to change to only upriver suppliers, while plants downriver may have to use downriver suppliers. Two issues are 1) the availability of barges above and below the closure and 2) environmental regulations. Coal is partially moved on the Ohio River to meet environmental regulations through the mixing of low and high sulfur coal. Improved scrubbers and the possibility of relaxed environmental regulations in an emergency are unknowns.

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[34] A map of this region is included in Appendix A.
[35] PJM Interconnection, 2009. 2008 PJM 411 Report 2008 PJM Load, Capacity and Transmission Report. Historical and Projected Peak Demand Monthly.

4. **Change mode of transportation.** The most likely change is from barge to railroad transportation. One limiting factor is the availability of railcars in the affected region and the time necessary to increase the number of cars in the region. Many, if not most, plants that obtain coal by barges also have railroad spurs to the plant.

5. **Purchase electricity off the grid.** Additional purchases will cause an increase in both peak and off-peak wholesale electricity prices. Fluctuations in electricity prices cause by different shocks have been seen in PJM, which coordinates the movement of wholesale electricity in all or parts of the Eastern U.S. states of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia, is the world's largest competitive wholesale electricity market.[36]

6. **Short-term plant closures, blackouts, and brownouts.** This is the worst case scenario, but the likelihood of occurrence is small. Nothing in the previous closures or studies indicates this will happen.

Any combination of these responses will increase costs to the utility plants.

Mjelde and Bessler developed a multivariate time series model that allows for dynamic price information flows among U.S. electricity wholesale spot prices. The prices of the major electricity generation fuel sources—natural gas, uranium, coal, and crude oil—are studied.[37] The model is based on weekly data and can simulate the effect of a shock in any of the prices included in the model. Input prices included are uranium (U_3O_8), coal, natural gas, and crude oil. Of primary interest is the coal price, which is the Pennsylvania weekly railcar coal price. These four fuel sources accounted for 91% of the net electricity generated in the U.S. Electricity prices included are peak and off-peak prices for PJM and mid-Columbia markets. The PJM market is of interest to this study.

Previous studies and the ad hoc analysis of the coal price series all indicate an increase in costs to utility plants associated with coal delivery. Using the Bessler and Mjelde model, the potential impacts of a closure on the wholesale electricity market are simulated by shocking the price of coal. This shock or price increase is assumed to simulate potential cost increases associated with the closure. The effect on retail prices cannot be determined because 1) retail price series are not readily available and 2) retail prices are set by contracts between providers and consumers.

[36] PJM Interconnection, 2007. Overview. http://www.pjm.com/about/overview.html Accessed August 2007
[37] Mjelde, J.W. and D.A. Bessler. "Market Integration among Electricity Markets and their Major Fuel Source Markets." *Energy Economics* 31, 3 (May 2009): 482-491.

The above model is used as follows to examine how a lock closure may influence electricity prices. First, because transportation costs are not explicit in the model, it is assumed that a lock closure's costs would be reflected in an increase in price of Pennsylvania coal—the lock closure is assumed to cause an initial increase in coal price. Coal price increase is then input into the model and changes in peak and off-peak PJM electricity prices are simulated. To illustrate potential effects on consumers, weekly total consumption by residential, commercial, industrial, and other sectors are used to obtain additional costs associated with buying the electricity on the wholesale market. Because the week of the lock closure is not known, the weekly average based on all weeks of the year (no seasonality) is used.[38] Average total sales in megawatt-hours (MWh) for New Jersey (1,501,435), Pennsylvania (2,784,751), and Massachusetts (1,068,160) are used for the years 2001–2010 before adjusted by own-price elasticity.[39] Weekly consumption is modified based on short-run own price elasticity of electricity and the weekly price change. Short-run own price from Alberinia and Filippinib of −0.11, an inelastic value, is used.[40] Given the nature of forecasting with a weekly model, effects throughout out 24–week period (approximately six months) are simulated. Finally, because of lack of data, it is assumed that one-half of the electricity consumed is on-peak and one-half is off-peak.

Table 4.10 gives the increases in weekly PJM wholesale electricity prices caused by the shock in coal prices assuming all other factors are held constant. As expected, because coal-generated electricity supplies the base load, the initial increase in off-peak prices is larger than peak prices. Both prices continue to increase throughout the six-month timeframe. Increases in prices become similar by the end of the timeframe. Wholesale prices would be expected to increase by slightly over 3% for off-peak and slightly less than 2% for peak prices.

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[38] U.S Energy Information Administration, 2011c. Coal Data. Accessed June 2011. http://www.eia.gov/coal/data.cfm

[39] Own-price elasticity refers to the sensitivity of demand (or supply) of a good with respect to changes in its own price (rather than changes in the prices of other goods, which defines the cross-price elasticity).

[40] Alberinia, A. and M. Filippinib. 2011. "Response of Residential Electricity Demand to Price: The Effect of Measurement Error." *Energy Economics* 33(5): 889-895.

Table 4.10. Weekly Wholesale Electricity & PA Coal Price Increases with a 2.5% Increase in Coal Prices in Week Zero.

	Coal		Off-Peak		Peak	
Week	Price Increase	Percentage[3]	Price Increase	Percentage[1]	Price Increase	Percentage[2]
1	1.030	2.46	1.014	3.14	0.986	1.76
2	1.032	2.46	1.004	3.11	0.985	1.76
3	1.033	2.47	1.005	3.11	0.993	1.77
4	1.033	2.47	1.006	3.11	0.995	1.77
5	1.033	2.47	1.008	3.12	0.998	1.78
6	1.033	2.47	1.009	3.12	1.000	1.78
7	1.033	2.47	1.011	3.13	1.003	1.79
8	1.033	2.47	1.012	3.13	1.005	1.79
9	1.034	2.47	1.014	3.14	1.006	1.79
10	1.034	2.47	1.015	3.14	1.008	1.80
11	1.034	2.47	1.016	3.14	1.009	1.80
12	1.034	2.47	1.017	3.15	1.011	1.80
13	1.034	2.47	1.018	3.15	1.012	1.80
14	1.034	2.47	1.019	3.15	1.013	1.81
15	1.034	2.47	1.020	3.15	1.014	1.81
16	1.034	2.47	1.021	3.16	1.015	1.81
17	1.034	2.47	1.022	3.16	1.016	1.81
18	1.034	2.47	1.022	3.16	1.017	1.81
19	1.034	2.47	1.023	3.16	1.018	1.81
20	1.035	2.47	1.024	3.17	1.019	1.82
21	1.035	2.47	1.025	3.17	1.020	1.82
22	1.035	2.47	1.025	3.17	1.021	1.82
23	1.035	2.47	1.026	3.17	1.021	1.82
24	1.035	2.47	1.026	3.17	1.022	1.82

[1] *Percentage of the mean off-peak price of $32.33/MWh from Mjelde and Bessler (2009) data.*
[2] *Percentage of the mean peak price of $56.10/MWh from Mjelde and Bessler (2009) data.*
[3] *Percentage of the mean coal price of $41.89/short ton from Mjelde and Bessler (2009) data.*

To examine potential total cost to the wholesale electricity market, the increase in weekly wholesale prices are multiplied by consumption (Table 4.11). Over a six-month closure, potential increases in wholesale costs are $129.9 million for the three states. If it is assumed that consumers do not change their behavior (i.e., an own-price elasticity of zero), the overall increases in wholesale costs are slightly higher at $130.1 million over the 24 weeks. Individual states' increases in costs are $36.4, $67.7, and $26 million for New Jersey, Pennsylvania, and Massachusetts, respectively.

Table 4.11. Changes in Consumption & Increases in Wholesale Costs for Electricity for NJ, PA, and MA with a 2.5% Increase in Coal Price.

	Total Consumption 1000s MWh			Increase Wholesale Cost (1000s $)		
Week	NJ	PA	MA	NJ	PA	MA
1	1496.26	2775.15	1064.48	1498.68	2779.64	1066.20
2	1496.31	2775.24	1064.51	1490.69	2764.82	1060.51
3	1496.30	2775.23	1064.51	1496.96	2776.45	1064.98
4	1496.30	2775.22	1064.50	1499.30	2780.79	1066.64
5	1496.29	2775.21	1064.50	1503.02	2787.68	1069.29
6	1496.28	2775.19	1064.49	1506.17	2793.54	1071.53
7	1496.27	2775.17	1064.49	1509.03	2798.83	1073.56
8	1496.26	2775.16	1064.48	1511.57	2803.54	1075.37
9	1496.26	2775.15	1064.48	1513.85	2807.77	1076.99
10	1496.25	2775.13	1064.47	1515.92	2811.61	1078.46
11	1496.24	2775.12	1064.47	1517.83	2815.15	1079.82
12	1496.24	2775.11	1064.46	1519.60	2818.44	1081.08
13	1496.23	2775.10	1064.46	1521.27	2821.53	1082.27
14	1496.23	2775.10	1064.46	1522.84	2824.45	1083.39
15	1496.23	2775.09	1064.45	1524.34	2827.22	1084.45
16	1496.22	2775.08	1064.45	1525.76	2829.87	1085.46
17	1496.22	2775.07	1064.45	1527.12	2832.39	1086.43
18	1496.21	2775.06	1064.44	1528.42	2834.80	1087.36
19	1496.21	2775.06	1064.44	1529.67	2837.12	1088.25
20	1496.21	2775.05	1064.44	1530.87	2839.34	1089.10
21	1496.20	2775.04	1064.44	1532.02	2841.47	1089.92
22	1496.20	2775.04	1064.43	1533.12	2843.52	1090.70
23	1496.20	2775.03	1064.43	1534.18	2845.48	1091.46
24	1496.19	2775.03	1064.43	1535.20	2847.37	1092.18
Total	**35,909.80**	**66,602.82**	**25,547.15**	**36,427.41**	**67,562.85**	**25,915.40**
Aggregate 3- State Total			**128,059.77**			**129,905.65**

These cost increases need to be placed in the proper perspective. Using the mean off-peak and peak electricity prices, wholesale electricity cost would have been $5.1 billion in the three states. The increase in cost associated with the coal price increases is 2.52% of the total wholesale electricity costs. Under the assumption of no change in behavior, the increase in cost associated with the coal price increases is 2.29% of the total wholesale electricity costs. The small difference in percentage terms is associated with the slight increase in consumption under the assumption of no behavioral change. Further, the standard deviation of wholesale electricity prices is $17.38/MWh for off-peak and $30.52/MWh for peak prices. Increases associated with the assumed coal price increase are well within the limits of weekly fluctuations. Whether these increases are passed on to final consumers or absorbed at the wholesale will depend on contractual arrangements.

PROFILES OF MODE USE AND COSTS

Table 4.12 provides annual production, storage, and demand for grain for a representative farmer, country grain elevator, and biofuels (biodiesel and ethanol) producer, respectively. We present the results for biofuel producers because they have emerged as an important consumption force of grain and are expected to continue growing in the next few decades. The table includes the three most vulnerable CRDs at each lock in terms of the effects of closures. For each CRD, their corresponding CDs are reported, with CDs that make up more than 25% of the land area of a CRD shown in red font. All results reported in this section are annual quantities.

Table 4.12. Profile of Representative Farmer, Country Grain Elevator, and Biofuels Producer.

Lock	CRD	Congressional District	Country Elevator Capacity (1000 T)	SUPPLY		DEMAND	
				Average Farmer's Corn Production (1000 T)	Average Farmer's Soybean Production (1000 T)	Soybean for Biodiesel Production (1000 T)	Corn for Ethanol Production (1000 T)
LaGrange	IL CRD 20	01,02,03,06,08, 09,10,11,13,14, 16	116,878	1,193	187	87,749	
LaGrange	IL CRD 10	11,14,16,17,18	116,878	1,348	159		996,737
LaGrange	NC CRD 90	02,03,07,08	116,878	194	170	64,206	537,566
Lock 20	IA CRD 20	01,04	116,878	1,099	209		852,426
Lock 20	IA CRD 90	02,03	116,878	964	233	64,206	604,762
Lock 20	IA CRD 60	01,02,03	116,878	1,118	212		1,687,360
Lock 25	IA CRD 20	01,04	116,878	1,099	209		852,426
Lock 25	IA CRD 90	02,03	116,878	964	233	64,206	604,762
Lock 25	IA CRD 60	01,02,03	116,878	1,118	212		1,687,360
Markland	IA CRD 40	04,05	116,878	1,091	231	44,944	822,476
Markland	MN CRD 80	01,02	116,878	1,062	219	64,206	863,689
Markland	IN CRD 50	04,05,06,07,09	116,878	827	284		528,607
Lock 52	IN CRD 50	04,05,06,07,09	116,878	827	284		528,607
Lock 52	OH CRD 40	04,05,07,08	116,878	608	217		985,538
Lock 52	MO CRD 90	08	116,878	304	229	6,421	

In the survey of Illinois country grain elevators, Whitacre and Spaulding[41] found that the average size of elevator capacity was 4.6 million bushels or the equivalent of 116,878 metric tons. This average storage capacity is used to represent the potential country grain elevator's storage capacity in each CRD.

Average farm size in 2007 was 418 acres.[42] This average acreage is used to represent the potentially affected farmer in Table 4.12. The share of corn and soybean acreage and corresponding yields in each CRD were obtained from a USDA database[43] and used to estimate the representative farmer's corn and soybean production.

In aggregate, the biodiesel industry had 2.69 billion gallons of installed capacity and 311 million gallons of production in 2010.[44,45] This represented an industry-wide capacity utilization rate of 12%. Thus, a 12% capacity utilization rate was used to obtain grain requirements for biofuels plants in each CRD. Since the capacity used in the calculation reflects the actual installed capacity in the CRD, the grain requirements of biofuels plants in the last two columns of Table 4.12 represent the actual total annual grain requirements within the corresponding CRD.

Based on the estimated impacts of lock closures, we calculated the damages incurred by the representative farmer, grain elevator, and grain consumer depicted above. All three entities can be severely affected by lock closures; however, since not all entities in the affected areas are affected, we report in Table 4.13 only those that are identified in our grain flow model simulations as being adversely affected by the listed lock closure. The smaller quantities reported for a representative farmer are partially due to their smaller size compared with the large elevators and biofuel producers. Nonetheless, our estimates clearly illustrate the substantial economic damage that can be caused by extended lock closures.

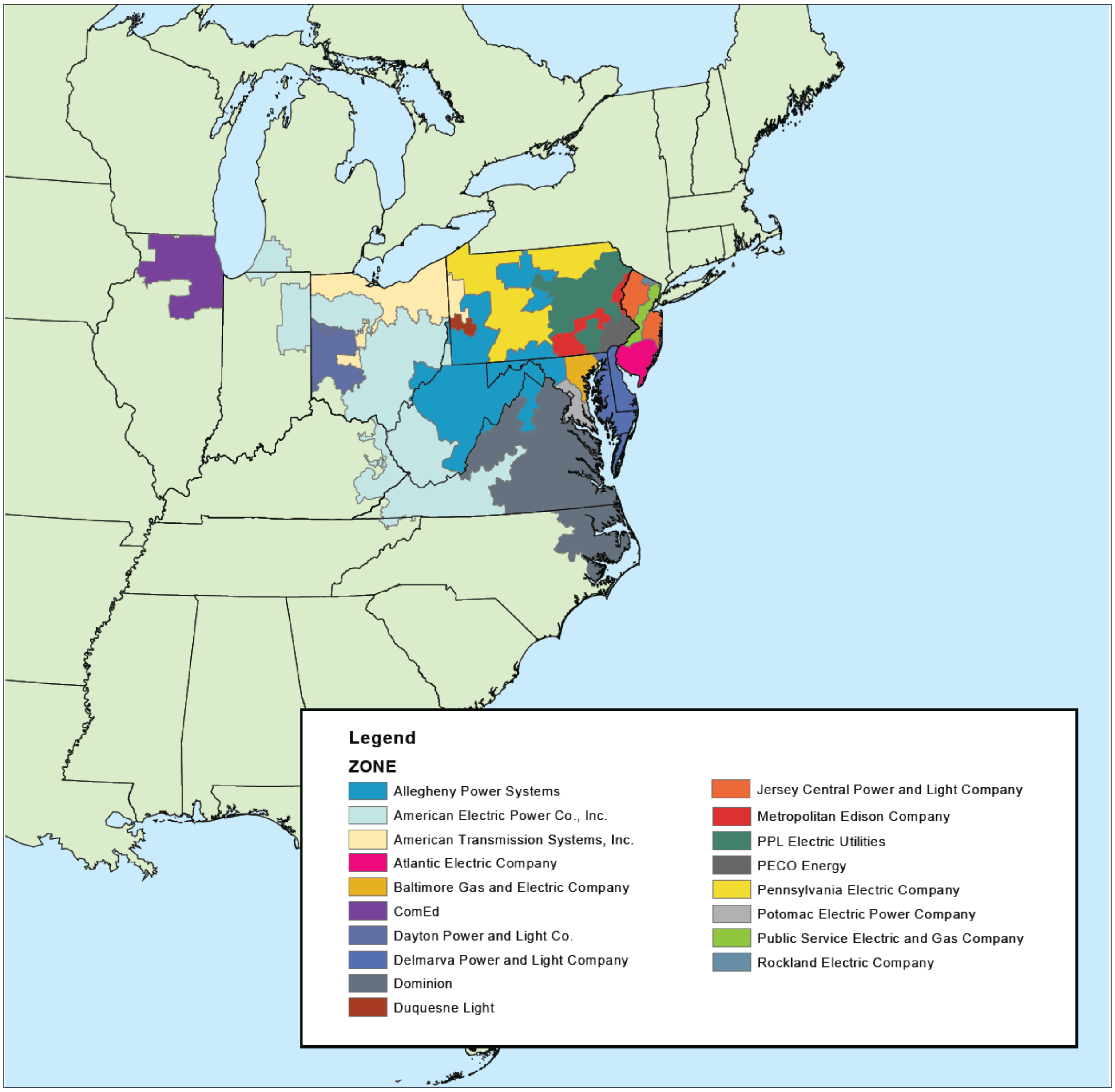
[41] Whitacre, R.C. and Spaulding, A.D., "Grain Marketing Tools: A Survey of Illinois Grain Elevators ", Selected paper presented at the 2007 Annual Meetings of the American Agricultural Economics Association Meeting, July 29-August 1, 2007.
[42] USDA, Economic Research Service. URL: http://www.ers.usda.gov/StateFacts/US.htm
[43] USDA, National Agricultural Statistics Service. URL: http://www.ers.usda.gov/Data/baseacres/Download.aspx
[44] U.S. Department of Energy, Energy Information Administration. URL: http://www.eia.doe.gov/totalenergy/data/monthly/#renewable
[45] National Biodiesel Board. URL: http://www.biodiesel.org/

Table 4.13. Estimated Damages Associated with Lock Closures.

Lock	CRDs	Congressional District	Country Elevator Loss ($1000)	Corn Farmer's Loss ($1000)	Soybean Farmer's Loss ($1000)	Loss of Biodiesel Production using soybean ($1000)	Loss of Ethanol Production using corn ($1000)
LaGrange	IL CRD 20	01,02,03,06,08, 09,10,11,13,14, 16	3,506	838	458		
LaGrange	IL CRD 10	11,14,16,17,18	3,506		421		
LaGrange	NC CRD 90	02,03,07,08	3,506			17,335	145,142
Lock20	IA CRD 20	01,04	3,506	1,550	203		
Lock20	IA CRD 90	02,03	3,506	964	233		
Lock20	IA CRD 60	01,02,03	3,506	2,615	447		1,687,360
Lock25	IA CRD 20	01,04	3,506	1,099	209		852,426
Lock25	IA CRD 90	02,03	3,506	2,256	545		
Lock25	IA CRD 60	01,02,03	3,506		242		826,806
Markland	IA CRD 40	04,05	3,506			48,989	
Markland	MN CRD 80	01,02	3,506			71,911	
Markland	IN CRD 50	04,05,06,07,09	3,506		670		570,896
Lock52	IN CRD 50	04,05,06,07,09	3,506	827	683		
Lock52	OH CRD 40	04,05,07,08	3,506		577		1438,885
Lock52	MO CRD 90	08	3,506	292	192		

APPENDIX A

MAP OF PJM INTERCONNECTION REGION



APPENDIX B

LIST OF ACRONYMS AND ABBREVIATIONS

AAR	Association of American Railroads
AR	Additional Autoregressive
ARIMA	Auto-Regressive Integrated Moving Average model
ARRA	American Recovery and Reinvestment Act of 2009
ASM	Agricultural Sector Model
BCR	Benefit-Cost Ratio
CB	Corn Belt
CD	Congressional District
CI	Condition Index
Corps	U.S. Army Corps of Engineers
CPBM	Capital Projects Business Model
CRD	Crop Reporting District
DSAC	Dam Safety Action Classification
ERS	Economic Research Service
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
FTWS	Fuel-Taxed Inland Waterway System
GCM	Global Circulation Model
GP	Great Plains
GVW	Gross Vehicle Weight
hp	Horsepower
IGTM	International Grain Transportation Model
IMTS	Inland Marine Transportation System
IPCC	Intergovernmental Panel on Climate Change
IWUB	Inland Waterways User Board
LOS	Level of Service
Lower Mon	Lower Monongahela

LS	Lake States
MA	Moving Average
MWh	Megawatt-hours
NE	Northeast
NOAA	National Oceanic and Atmospheric Administration
Penn	Pennsylvania coal beds
PNW	Pacific Northwest
PSW	Pacific Southwest
RBRCR	Remaining Benefit Remaining Cost Ratio
RER	Rehabilitation Evaluation Report
RM	Rocky Mountains
RPM	Railroad Performance Measures
SAFETEA-LU	Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users
SC	South Central
SE	Southeast
STB	Surface Transportation Board
SW	Southwest
USDA	United States Department of Agriculture
USDOT	United States Department of Transportation
WRDA 86	Water Resources Development Act of 1986