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Inland Waterway Operational Model & Simulation Along the Ohio River

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Inland Waterway Operational Model & Simulation Along the Ohio River

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Inland Waterway Operational Model & Simulation Along the Ohio River

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Executive Summary

The inland waterway system of the U.S. is a vital network for transporting key goods and commodities from the point of production to manufacturers and consumers. Shipping materials via the inland waterways is arguably the most economical and environmentally friendly option (compared to hauling freight by trains or railways). Despite the advantages the inland waterways enjoys over competing modes, key infrastructure – such as locks and dams, which help to control water levels on a number of rivers and make navigation possible – is declining. Limited funds have been allocated to make the necessary repairs to lock and dam facilities. Over the past 10 years Inland Waterways Trust Fund resources (which historically funded maintenance and improvement projects) has steadily declined.

Locks and dams are of particular importance, because they assist in the maintenance of navigable depths on many of the major inland waterways (Ohio River, Upper Mississippi River, Tennessee River). To better understand the operation of the inland waterway system, this report examines a portion of the Ohio River (extending from Markland Locks and Dam to Lock 53). The specific focus is to determine what delays barge tows as they attempt to lock through these critical facilities. The Ohio River is a particularly important study area. In many ways it is representative of the conditions present throughout the inland waterways system. The average age of the lock and dam facilities exceed 50 years along our study segment. Most of these facilities are operating beyond their intended design life. As locks age, they increasingly demand more scheduled and unscheduled maintenance activities. Maintenance activities often require temporarily shuttering a lock chamber and diverting traffic through another onsite chamber (often of smaller capacity). All of the facilities included in the research area have two lock chambers - thus, if one goes down for maintenance all vessels are diverted through the second chamber. In many cases this situation can produce extensive delays, which precludes cargo from reaching the destination in a timely manner.

Recently, the aggregate number of hours that shippers and carriers lose due to delays has escalated. Although the U.S. Army Corps of Engineers – the agency responsible for the management and oversight of locks and dams – has worked to keep traffic flowing on the river, tightening budgets hamper efforts. For shippers and carriers to make informed decisions about when and where to deploy freight on the river, they require knowledge that illuminates factors that are most significant in affecting transit times. In particular this applies to certain conditions that are likely to create delays at lock and dam facilities.

The purpose of this report is to 1) develop a comprehensive profile of the Ohio River that provides an overview of how it is integral to U.S. economic security 2) identify salient river characteristics or externally-driven variables that influence the amount of water flowing through the main channel which consequently impacts vessels' capacity to navigate 3) use this information (along with a 10-year data set encompassing over 600,000 observations) to develop an Inland Waterways Operational Model (IWOM). The IWOM objective is to provide the U.S. Army Corps of Engineers, shippers, carriers, and other interested parties with access to a robust method that aids in the prediction of where and when conditions will arise on the river that have the potential to significantly impact lockage times and queue times (i.e. how long a vessel has to wait after it arrives at a facility to lock through).

After qualitatively reviewing different features of the river system that affect vessel traffic, this report outlines two approaches to modeling inland waterway system behavior – a discrete event simulation (DES) model which uses proprietary software, and the IWOM. Although the DES produced robust findings that aligned with the historical data (because it relies upon proprietary software), it does not offer an ideal platform to distribute knowledge to stakeholders. Indeed, this is the major drawback of the DES given a critical objective of this project is to generate usable information for key stakeholders who are involved with inland waterway operations. Conversely, the IWOM is a preferable option given it relies on statistical analysis – in this sense, it is more of an open-source solution. The IWOM uses linear regression to determine key variables affecting variation in lockage time. The final model accounts for over two-thirds of the observed variation in lockage times from 2002-2012, which is our study period. Practically, this means that the difference between predicted values and observed delay times is significantly less than how the delays vary around the composite average seen in the river system (R^2 = 0.69).

The IWOM confirms that variations in river conditions significantly affect vessel travel times. For example, river discharge - the direction a vessel moves up or down a river - meaningfully influences lockage times. The freight amount a vessel carries, which is represented by the amount of draft and newness of a vessel, influences lockage times. Larger vessels with more draft tend to wait longer and take longer to complete their lockage. The IWOM is less successful at predicting delay times. Because there is greater instability in this data only a modest amount of variation is explained by the model (R^2 = 0.23). This, in turn, partly reflects in spillover from one vessel to the next that is difficult for the simulation to impose and account for therefore requiring additional logic.

Once completed, the IWOM was used to parameterize a simulation model. This provided a graphical representation of vessels moving along the river. Users have the capability of adjusting the effects of different variables to anticipate how the system may react, and what changes in vessel traffic patterns emerge. This information will be of great use for stakeholders wanting to gain a better understanding of what conditions lockage times will increase or decrease, why delays emerge, and consequently how these impact traffic flows on the river. In programming a simulation model, users are able to visualize and intuit what causes vessel travel times to vary. Although the regression model accomplishes this, for many users this would prove unwieldy and difficult to grasp beyond a conceptual, abstract level. Matching up regression results with a visual counterpart lets users gain immediate and intimate knowledge of river and vessel behavior – this in turn can positively affect shipper and carrier modal choices. The report concludes with some recommendations for IWOM implementation and thoughts on future research needs. Also discussed are the implications results from the present study have for improving our ability to safely, securely, and swiftly move freight on the inland waterways network.

Background

The U.S. relies on an extensive inland waterway system to transport material goods to market and promote economic growth. The inland waterway system consists of over 25,000 miles of navigable waterways - which includes rivers, lakes, canals, and other bodies of water. The U.S. Army Corps actively maintains approximately 12,000 miles of these waterways. Collectively, these comprise the Inland Marine Transportation System (IMTS).[1] This waterway system directly serves 38 states and transports $415 million worth of goods across our nation each day.[2] Bulk commodities and aggregate products make up the largest percentage of goods moved on the inland waterways. For the Ohio and Mississippi Rivers, coal and agricultural products are the most frequently transported cargo.

To operate effectively, the river systems incorporate the use of humanly made infrastructure along their corridors. For example, on major rivers like the Ohio, locks and dams facilitate the passage of vessels. Inland ports are key nodes on the inland waterway system. They serve as vital intermodal transfer points that move cargo to and from different transportation modes. This section briefly describes the inland waterway system as it relates to infrastructure components, their operators, types and volume of cargo shipped, benefits accrued from using waterborne transportation, and future concerns pertaining to system resiliency.

Inland Waterway Infrastructure

The U.S. is a resource-rich nation; movement of extracted resources requires networks of reliable transportation. The inland waterway system is a critical component of the U.S. transportation network (consisting of rivers, lakes, canals, and other water bodies that function as major transport corridors for bulk commodities). Infrastructure such as locks and dams are often required to fully utilize these marine highways. In addition to locks and dams, levees, hydroelectric power, water storage reservoirs, and other facilities fall into this category.[3]

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[1] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model Final Report. IMTS Capital Investment Strategy Team. 13 Apr 2010

[2] Statement of the American Society of Civil Engineers before the Subcommittee on Water Resources and Environment, U.S. House of Representatives on the Economic Importance and Financial Challenges of Recapitalizing the Nation's Inland Waterways Transportation System. 21 Sept 2011

[3] Sustainable Solutions to America's Water Resources Needs: Civil Works Strategic Plan 2011-2015. U.S. Department of the Army, Corps of Engineers, pg. 10. Sept 2011

The U.S. Army Corps of Engineers is the primary federal agency charged with operating, maintaining, and constructing the inland waterway infrastructure. The U.S. Army Corps of Engineers serves the nation in many roles, and has a multi-faceted and expansive mission set. To this extent, the U.S. Army Corps of Engineers has six primary missions:

- **Civil Works**
- **Military**
- **Environmental**
- **Emergency Operations**
- **Research and Development**
- **Sustainability**[4]

The Civil Works Program operates, maintains, and constructs infrastructure comprising the inland waterway system. The program also provides safe and navigable shipping lanes for vessel movement. Initially, the Corps will construct a capital project on the waterway and then hold responsibility for operation and maintenance once it is functional. The Corps maintains the navigational channel for the waterways, which allows vessels to safety traverse without running aground. For the purpose of this report, the focus is on the locks and navigational channels along the Ohio River. Each of these infrastructure types serves a critical role in supporting commercial shipments, recreational activities, and national security interests. The Corps operates and maintains 241 locks across 195 sites.[5] This report examines the segment of the Ohio River from Cincinnati, Ohio to Cairo, Illinois. The following lock and dam facilities are contained in the study area:

- **Markland Lock and Dam**
- **McAlpine Lock and Dam**
- **Cannelton Lock and Dam**
- **Newburgh Lock and Dam**
- **John T. Meyers Lock and Dam**
- **Smithland Lock and Dam**
- **52 Lock and Dam**
- **53 Lock and Dam**

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[4] http://www.usace.army.mil/Missions.aspx. U.S. Army Corps of Engineers, Headquarters. Mission Menu. 31 Jan 2014

[5] Department of the Army, U.S. Army Corps of Engineers Civil Works Program Five-Year Development Plan. Fiscal Year 2011 to Fiscal Year 2015, pg. 22.

A lockmaster is responsible for overseeing each facility. The lockmaster continuously monitors incoming and outgoing vessel traffic, opens and closes lock gates on the structure, and allows vessels to pass through. More details on the inner workings of a lock system are discussed in the "Lock and Dam Operations" section. Furthermore, the Corps performs maintenance on all of the lock and dam facilities it manages. This includes both scheduled and unscheduled maintenance activities. In an equally important role, the Corps is charged with maintaining the navigational channel of the inland waterways.

The Corps is responsible for maintaining a 9-foot minimum channel depth for the Ohio River.[6] This depth allows barges to operate at full capacity without running aground. The locks serve a critical role in maintaining the 9-foot depth. Lock and dams hold back standing pools of water at a defined hydraulic gradient. This ensures water levels will maintain the minimum depth required for vessel navigation. More details on the nature of pools and channels are discussed in the "Pools and Channels" section.

Commodity Movements on the Ohio River

The majority of cargo shipped in the Ohio River is coal. In total, coal accounts for over 50 percent of the commodity tonnage. This proportion has been relatively invariant from 2004-2011. However, what this does *not* reflect are the absolute increases or decreases in coal volume on a year-over-year basis. In recent years, the amount of coal (and related byproducts) shipped on the Ohio River has dwindled. This slip in volume is attributable to the rapid growth of natural gas as an energy source. Natural gas is a cleaner, more efficient technology than coal. This explains why there has been increased investment in natural gas extraction. Conversations with port operators confirmed that the significant declines in coal shipments regarding the Ohio River will persist if natural gas expansion continues.

For a more detailed picture of why coal shipments have dropped in recent years, readers should consult the statistics that are maintained by the United States Energy Information Administration (EIA). This department keeps records on barge-transported commodities such as petroleum and coal. Scrutinizing data from the EIA reveals that from 2007-2011 the price of coal – in real terms – rose approximately 50 percent. During this time frame, overall tonnage shipped erratically fluctuated downward. Although there is some relationship between slumping coal movements and pricing, other factors must be considered (like the economic recession that began in late 2007). Eventually, falling shipments may produce increases in system capacity - or at the very least redistribute the commodity mix.

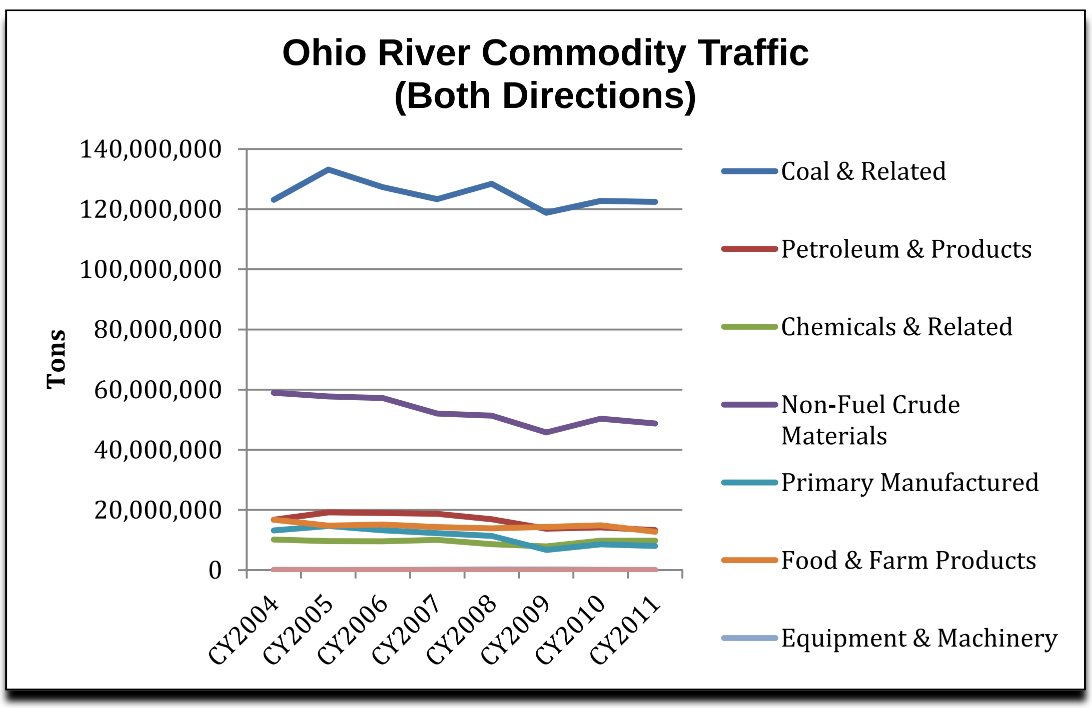
Figure A, constructed using data from the Center of Waterway Commerce Statistics, illustrates the aggregate tonnage of major commodities moved on the Ohio River. Aside from the dominance of coal, there are other interesting trends. The volume of non-fuel crude materials has declined approximately 20 percent from 2004-2011. This category includes materials like

[6] U.S. Army Corps of Engineers, Great Lakes and Ohio River Division. http://www.lrd.usace.army.mil/Missions/CivilWorks/Navigation/OhioRiverNavigation.aspx. 3 Feb 2014

gravel, sand, and limestone. After coal and aggregate products, there is a steep drop-off among other commodity groups with respect to total tonnage moved. Each of these classes accounted for less than 20 million tons shipped annually, during the entire study period. This data clearly shows that in addition to coal, bulk/dry commodities are the primary materials transported via the Ohio River. Small quantities of petroleum and other chemical products are moved along the river. However, traffic is quite small compared to the figures for coal, lignite, and non-fuel aggregates.

Currently, a limited quantity of non-bulk commodities is moved on barges using containers. And while inland waterways can support more containers on barge traffic than they currently do, there are logistical and financial obstacles that will likely prevent this form of shipment from taking root on the Ohio River. Port operators would need to make significant financial investments to upgrade their facilities in order to support container on barge traffic. Most of the ports along the Ohio River are very small and have limited operating capital, therefore, they cannot afford to make the improvements necessary to handle container on barge. Second, commodities moved in containers (e.g. electronics) are time sensitive; manufacturers want quick delivery to generate sales. There are significant restrictions on how quickly commodities can be dispatched via barge. As such, these materials – barring unforeseen changes in U.S. infrastructure availability – will continue to be transported by rail and truck. This leaves barge vessels to specialize in heavy or bulk commodities that do not require immediate delivery.

Figure A: Ohio River Commodity Traffic



Source: U.S. Army Corps of Engineers, Navigation Data Center

Coal traffic on the Ohio River dwarfs all other commodity types. Although coal traffic has decreased slightly from a peak in 2005, coal shipments have leveled off at slightly more than 120 million tons during 2010 and 2011.

Benefits of the Inland Waterway System

The Inland Waterway System provides an efficient and robust multimodal method of transporting high-volume bulk goods, yielding significant and tangible benefits for users and society. These benefits directly impact system users (i.e., shippers and industry). There are also indirect effects to society at large in the form of improved transportation networks and reduced environmental impacts. Some of these benefits are discussed below - including those focused on economic considerations, reduced congestion, and the environment.

The Ohio River provides economic benefits to its direct users (including shippers and industry) along with segments of the population that benefit from proximity to the waterway system. For example, economists from the Center for Transportation Research (University of Tennessee) recently completed a study on the inland waterway system. They looked at the Ohio River and estimated benefits that are conferred to potential beneficiaries. To this extent, they assigned monetary values to each benefit realized across multiple scenarios. This included shipper savings, economic impacts, recreation, flood damage avoidance, hydropower generation, irrigation, water supply, property values, congestion, and safety impacts. Shipper savings, economic impacts, and water supply benefits were particularly notable for the Ohio River. The study defined the benefits as:

> **Shipper savings** – "The summed differences between the costs for tonnages of commodities shipped by barge and - had the shipper not used barge - that of the next least costly transport mode."
>
> **Economic impacts** – "The additional value generated by the shipper savings (and possibly, other navigational advantages such as electric utility maintenance or cooling efficiencies) that resulted from increased production efficiencies and lower prices, as the savings work their way through the economy."
>
> **Water supply** – "This deals with the value of water taken from the Ohio River Basin as a water supply to the residential, commercial and industrial consumers."

The study estimated that the Ohio River region has garnered approximately $21.45 billion per year in monetary benefits as a result of barge shipment on the Ohio River.[7] A primary benefit of the Inland Waterway System is the ability to significantly alleviate congestion on rail and highway transportation networks. As Figure B shows, barge tows move large volumes of commodities along the Ohio River every year. Transferring these shipments to alternative

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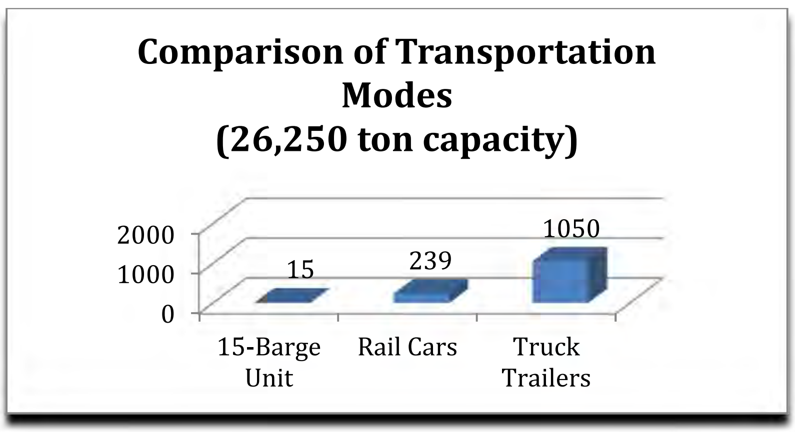
[7] Toward A Full Accounting of the Beneficiaries of Navigable Waterways, pg. i-iii. Center for Transportation Research, University of Tennessee. January 2011

modes of transportation would significantly increase the pressure on rail and highway networks.

According to a study performed at the Texas Transportation Institute, a standard single barge unit carrying dry-bulk cargo (such as coal) can move approximately 1,750 tons. A single truck trailer or rail car, however, can only move approximately 25 tons and 110 tons, respectively.[8] Furthermore, a typical barge configuration moving on the Ohio River typically consists of 15-barge units. As such, a 15-barge unit with a carrying capacity of 26,250 tons would be equivalent to approximately 239 rail cars or 1,050 truck trailers. Bearing this in mind, a typical barge tow load on the Ohio River vastly exceeds similar commodity movements across rail or tractor-trailer trucks (see Figure B).

Figure B: Equivalent Capacities across Modes



Source: Texas Transportation Institute, Center for Ports and Waterways

Incapacitation of the inland waterway system (due to a lock and dam closure or some other capacity-restricting event) would dramatically increase the overall demand on the highway and/or rail network and increase congestion. For example, the Texas Transportation Institute examined the consequences of a complete shut down of barge traffic on the Ohio River that shifted all commodity transportation to rail operators. In this example, they projected 100 percent of the load onto nearby CSX railroad, which owns the largest number of railroads parallel to the Ohio River and would be best positioned to handle additional loads. The study found that "133.1 million tons of Ohio River coal traffic" would increase demand on CSX rail lines by "an additional 1,010,250 car loadings of coal annually with 112 tons of coal in each car." Furthermore, they estimated that the overall rail network speeds would decrease from 19.2 mph to 12.88 mph for moving the additional loads, resulting in severe system congestion.[9]

[8] A Modal Comparison of Domestic Freight Transportation Effects on the General Public, pp. 10. Texas Transportation Institute, Center for Ports and Waterways. December 2007

[9] A Modal Comparison of Domestic Freight Transportation Effects on the General Public, pp. 25-26. Texas Transportation Institute, Center for Ports and Waterways. December 2007

Lastly, the Inland Waterway System provides an environmentally-friendly means to transport goods in comparison to other conventional transportation modes. Barge tows have the ability to transport large volumes of bulk goods with minimal fuel consumption relative to other modes. Researchers have found that a barge tow is able to carry one ton of cargo approximately 576 miles on a single gallon of fuel. Conversely, a rail engine and tractor-trailer truck can only move that same amount of cargo 413 miles and 155 miles, respectively, on one gallon of fuel.[10] On a fuel-consumption basis, barge tows outperform other strategies of transporting cargo and emit less greenhouse gases.

Infrastructure Breakdowns

Due to aging infrastructure, the Inland Waterway System lock and dam facilities continue to experience mechanical breakdowns at an increasing rate. This situation causes delays for shippers and places the overall system at increased risk for catastrophic failure. The average age of the nation's federally owned or operated 257 inland waterway locks is 60 years, which is well past their intended 50-year design life.[11] Approximately 47 percent of the U.S. Army Corps of Engineers' maintained locks have been deemed functionally obsolete.[12] As a result, many of these lock facilities are experiencing structural fatigue and mechanical malfunctions, putting them at risk to go out of service for extended stretches of time. In some cases, the Corps schedules maintenance activities. When a lock unexpectedly fails (or is at risk of imminent failure), it prompts an emergency unscheduled closure that can lead to significant and prolonged traffic delays.

To illustrate this point, several locks on the Ohio River have recently experienced unanticipated closures due to mechanical failures. In August 2004, the Corps identified the McAlpine lock at risk of imminent failure and subsequently removed the lock from service for two weeks. With no auxiliary chamber at this facility, all shipments needing to traverse the lock were halted. Soon after, the National Waterways Council conducted a survey of businesses relying on these shipments and estimated fiscal impacts from the closure ranged from moderate to severe.[13]

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[10] Ibid., pp. 38.

[11] Statement of the American Society of Civil Engineers before the Senate Committee on Environment and Public Works on the Water Resources Development Act of 2010: Jobs and Economic Opportunities. pp. 5, 6 May 2010

[12] Statement of the American Society of Civil Engineers before the Subcommittee on Water Resources and Environment, U.S. House of Representatives on the Economic Importance and Financial Challenges of Recapitalizing the Nation's Inland Waterways Transportation System. pp. 3, 21 Sept 2011

[13] David Grier, The Declining Reliability of the U.S. Inland Waterway System, Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, VA, 2009. http://onlinepubs.trb.org/onlinepubs/archive/Conferences/MTS/4A%20GrierPaper.pdf

In another case, the Markland lock suffered catastrophic failure when a miter gate collapsed in September 2009. As a result, the Corp was forced to immediately close the lock and perform extensive repairs. The closure led to significant delays that stretched over a five-month period.[14] In response, the Corps has increased efforts to rehabilitate and maintain their locks and dams. However, a corresponding increase in the number of mechanical malfunctions (due to aging infrastructure and budgetary constraints) has limited the effectiveness of these efforts. Rehabilitation and maintenance provide short-term fixes that can lengthen the service life of many of these facilities, but neither activity solves the problem of rapidly aging infrastructure.

Essentially, these repairs provide piecemeal solutions to specific issues as they emerge - not a holistic remedy. Consequently, the continued deterioration of the inland waterway system contributes to unexpected lock delays and closures, which primarily affects shippers and carriers. Table A (below) lists the number of hours lost due to lock outages along the Ohio River from 2002 through 2012.

Table A: Total Hours of Closure by Lock Year

LOCKS	CY2002	CY2003	CY2004	CY2006	CY2007	CY2008	CY2009	CY2010	CY2011	CY2012
Lock 53	1,467.3	672.0	0.0	0.0	11.2	14.3	2.3	0.0	0.0	55.9
Lock 52	171.4	42.8	42.8	1,729.7	1,099.9	209.5	473.7	1,474.2	3,834.5	122.1
Smithland	754.2	332.9	474.5	812.8	488.7	505.7	553.9	911.4	1,611.5	282.6
John T Myers	883.8	2,048.4	633.9	49.3	962.5	643.5	998.5	604.4	1,024.6	91.5
Newburgh	1,439.6	217.4	41.2	1,296.5	0.8	44.9	284.8	264.7	419.9	342.6
Cannelton	561.6	104.3	181.2	2,261.7	724.2	2,639.3	1,394.9	1,302.7	1,209.2	63.4
McAlpine	109.8	130.4	404.4	101.4	189.2	324.5	397.8	405.9	849.7	88.2
Markland	125.9	516.3	112.8	69.1	492.5	87.1	1,119.0	4,515.9	8,148.7	6,014.6
TOTAL	5,513.6	4,064.5	1890.8	6,320.5	3,969	4,468.8	5,224.9	9,479.2	17,098.1	7,060.9

Source: Kentucky Transportation Center[15]

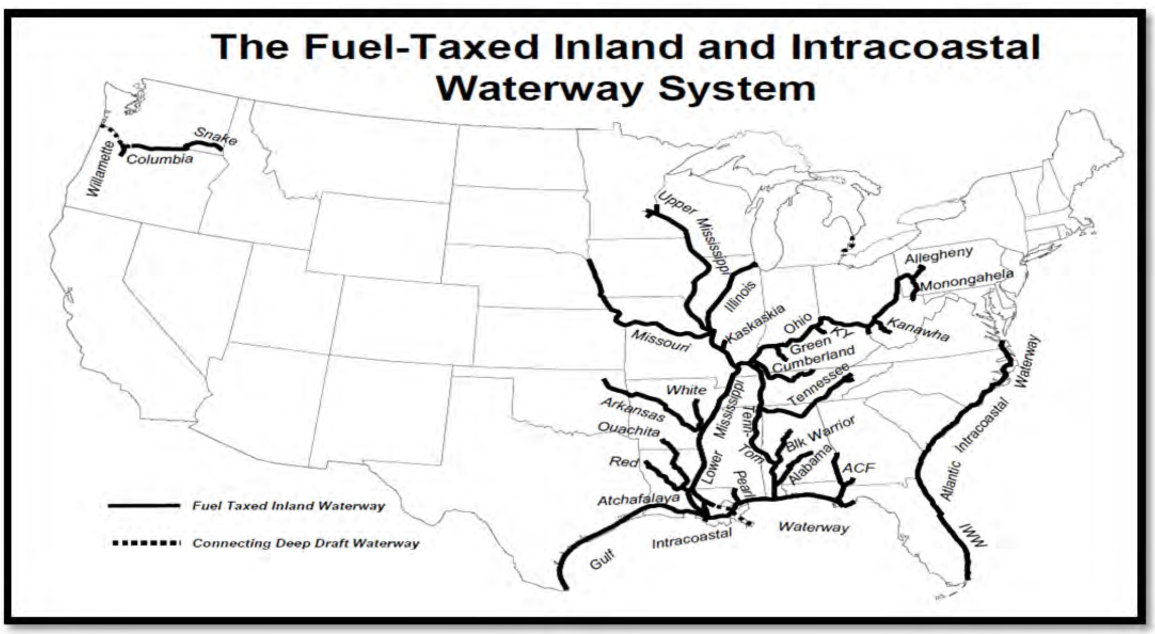
[14] America's Locks & Dams: "A Ticking Time Bomb for Agriculture?", pp. 58. Texas Transportation Institute, Center for Ports and Waterways. December 2011.

[15] This table represents an aggregated analysis conducted on several data sources including: USACE, Louisville District Public Notices and the USACE, Lock Performance Monitoring System taken from 2002-2012.

Inland Waterway Trust Fund

The Inland Waterway System receives financing for construction and major rehabilitation projects through a combination of the Inland Waterway Trust Fund (IWTF) and the Federal Government's general revenues. Congress originally created the IWTF through the *Inland Waterways Revenue Act of 1978* to raise funds for inland waterway infrastructure through a "tax on fuel used in commercial transportation on inland waterways".[16] Later, Congress amended the IWTF through the *Water Resources Development Act (WRDA) of 1986* and established the current fuel tax rates and cost sharing measures in place today. Starting in 1995, commercial users of the federally maintained inland waterway system begin paying a $0.20 per gallon fuel tax; it remains at that level today.[17] IWTF fuel tax receipts accumulate, and the U.S. Department of the Treasury invests the aggregate balance in interest-bearing obligations. The combination of fuel tax receipts and interest earned on investments forms the overall IWTF balance.[18] Figure C displays those portions of the inland waterway system that are subject to this tax.

Figure C: Taxable Inland Waterways



Source: Inland Waterways User Board, 2012 Annual Report[19]

[16] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model Final Report. IMTS Capital Investment Strategy Team. pp. 6, 13 Apr 2010

[17] Statement of the American Society of Civil Engineers before the Subcommittee on Water Resources and Environment, U.S. House of Representatives on the Economic Importance and Financial Challenges of Recapitalizing the Nation's Inland Waterways Transportation System. pp. 3, 21 Sept 2011

[18] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model Final Report. IMTS Capital Investment Strategy Team. pp. 8, 13 Apr 2010

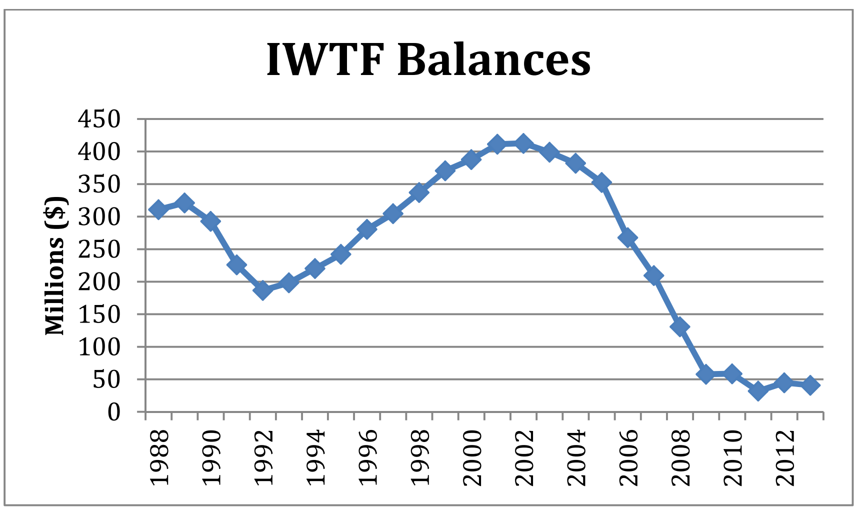
[19] Inland Waterways Users Board. 2012. 25th Annual Report. Available at: http://www.iwr.usace.army.mil/Portals/70/docs/IWUB/annual/IWUB_Annual_Report_2012.pdf.

The IWTF provides funding for half of the cost concerning new construction and major rehabilitation projects, while the federal government general revenue pays for the remaining half.[20] The term “construction” describes all activities required for project completion from start to finish including “planning, designing, engineering, surveying, the acquisition of all lands, easements, and rights-of-way necessary for the project, including lands for disposal of dredged material, and relocations necessary for the project.” Once built, the federal government’s general revenues pay the full cost of operations and maintenance on all facilities.[21]

Declining IWTF Balances

In recent years, the IWTF balances have steadily declined. As a result of this shortfall, there are insufficient funds to pay the full costs of required infrastructure capital and rehabilitation improvements. Since its creation in 1978, the IWTF balance has varied significantly, hitting a peak of $413 million in 2002. Thereafter, annual expenditures began exceeding the annual revenues collected leading to a steady and sizable drop in the total balance. Furthermore, some IWTF projects exceeded their original budget (thereby accelerating the decline).[22] As a result, the U.S. Department of the Treasury showed an IWTF balance of $40.7 million in its December 2013 Audit Report. This represents a ten-fold drop in the total fund balance in a little over ten years. The IWTF balances from 1988 through 2013 are shown below (Figure D), and provide a clear illustration of the long-term volatility and the recent downward turn.

Figure D: IWTF Balances



Source: U.S Department of the Treasury

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[20] Statement of the American Society of Civil Engineers before the Subcommittee on Water Resources and Environment, U.S. House of Representatives on the Economic Importance and Financial Challenges of Recapitalizing the Nation’s Inland Waterways Transportation System. pp. 3, 21 Sept 2011

[21] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model Final Report. IMTS Capital Investment Strategy Team. pp. 7-8, 13 Apr 2010

[22] Inland Waterways: Recent Proposals and Issues for Congress. Charles V. Stern, Analyst in Natural Resources Policy, U.S. Congressional Research Service. pp. 6-7, 12 Apr 2012

The Inland Waterways User Board (IWUB), a federal advisory board which is made up of representatives from the commercial industry, cites an inadequate funding model for this precipitous decline. The IWUB sees the current funding model as structurally unsound, because it uses an incremental funding approach (projects are typically funded through annual appropriations). These appropriations provide funds for only one year in the budget cycle, often at insufficient levels. This piecemeal approach creates uncertainty for project management and limits more efficient, long-term construction methods that may lead to overall cost savings.[23] The Inland Marine Transportation System Capital Investment Strategy Team (a group consisting of the Corps and commercial users) traces the funding decline, in part, to poor program performance within the U.S. Army Corps of Engineers. In 2010, the group released a report (Inland Marine Transportation Systems (IMTS) Capital Projects Business Model) that outlines present challenges and suggests proposed solutions to the IWTF budgetary shortfall.[24] This report highlights Corps practices of reprogramming funds from one project to another for the purpose of dealing with cost overruns. This leads to eventual shortfalls for certain projects that were not matched by provided appropriations.[25]

Finally, and perhaps most significantly, massive cost overruns at the still-ongoing Olmsted Lock and Dam project have depleted the IWTF in recent years. Overruns on the project are projected for years to come. Originally authorized in 1988, the Olmsted Lock and Dam project was designed to replace the outdated and obsolete existing structures at Locks and Dams 52 and 53. These structures were built in 1929 and no longer accommodate current traffic demands without excessive delays. The Olmsted Lock and Dam located near Olmsted, Illinois at river mile 964.4 on the Ohio River, is just upstream from the confluence of the Ohio and Mississippi Rivers.[26] The project was originally budgeted for $775 million in the Water Resources Development Act of 1988 with a scheduled completion date of 2005.[27/28] The Corps currently projects project completion costs at $2.918 billion, a 276 percent increase over the original project budget. It is expected to become operational in 2020 - 15 years beyond the original timeline.[29]

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[23] Statement of the American Society of Civil Engineers before the Subcommittee on Water Resources and Environment, U.S. House of Representatives on the Economic Importance and Financial Challenges of Recapitalizing the Nation's Inland Waterways Transportation System. pp. 3, 21 Sept 2011

[24] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model Final Report. IMTS Capital Investment Strategy Team. 13 Apr 2010

[25] Ibid, pp. 16

[26] Olmsted Locks & Dam, Ohio River Brochure. U.S. Army Corps of Engineers, Louisville District. Available at: http://www.lrl.usace.army.mil/Portals/64/docs/Ops/Navigation/Olmsted/OlmstedComprehensive.pdf.

[27] Olmsted Fact Sheet. U.S. Army Corps of Engineers, Louisville District. Available at: http://www.lrl.usace.army.mil/Portals/64/docs/Ops/Navigation/Olmsted/OlmstedFactsheet10-25-13.pdf.

[28] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model Final Report. IMTS Capital Investment Strategy Team. pp. 3, 13 Apr 2010

[29] Olmsted Fact Sheet. U.S. Army Corps of Engineers, Louisville District. Available at: http://www.lrl.usace.army.mil/Portals/64/docs/Ops/Navigation/Olmsted/OlmstedFactsheet10-25-13.pdf.

The Olmsted Lock and Dam project will continue to consume a significant amount of IWTF revenues for the foreseeable future and constrain other capital construction and major rehabilitation projects. The FY 2014 Energy & Water Development Appropriations bill, signed into law in January 2014, applies a new formula to the Olmstead funding. A new cost-sharing agreement, which takes 75 percent of Olmsted funding from General Funds and 25 percent from the IWTF, is now effective. This will relieve some of the pressure on the IWTF, allowing the Corps to redirect financial resources to the approximately 100 projects that have been identified elsewhere on the inland waterway system. Of these projects, 45 reside in the Ohio River basin and will require funds for construction and/or rehabilitation in the next 20 years.[30] However, while the IWTF is on more stable ground fiscally, the large number of anticipated projects works against the IWTF obtaining funding balances last seen in the early 2000s.

River Characteristics

Stretching approximately 980 miles long, the Ohio River provides a vital commercial and transportation service to the nation. The river is shaped by dynamic, external forces - such as weather events and fluctuating water inputs - which can dramatically impact underlying navigable conditions for waterborne vessel users. The Ohio River plays a large role due in part to its sheer size and number of people impacted. The Ohio River Basin is home to over 25 million people - nearly 10 percent of the U.S. population. The river flows through six states (including Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia). The river originates near Pittsburgh, Pennsylvania at the confluence of the Allegheny and Monongahela Rivers. It ends near Cairo, Illinois, where it discharges into the Mississippi River.[31] As the second largest river in the U.S., the Ohio River is a vital piece of the inland waterway system and essential for moving bulk commodities to market.

The Ohio River (like most rivers) is non-linear, lacks uniformity in width and depth, and is exposed to seasonal changes affecting both water currents and river stages. The river's complex geometry varies across space and therefore affects the ability of a vessel to navigate. External factors, such as weather, are frequently critical in predicting river conditions and overall navigability. As such, further examination of these variables and their potential to impact vessel travel times is warranted. This report examines several elements and their capacity to influence vessel travel times. The elements are listed below:

- **Seasonal Variability (Monthly)**
- **Current (Vessel Direction of Travel and Velocity)**
- **Water Stage (Depth)**

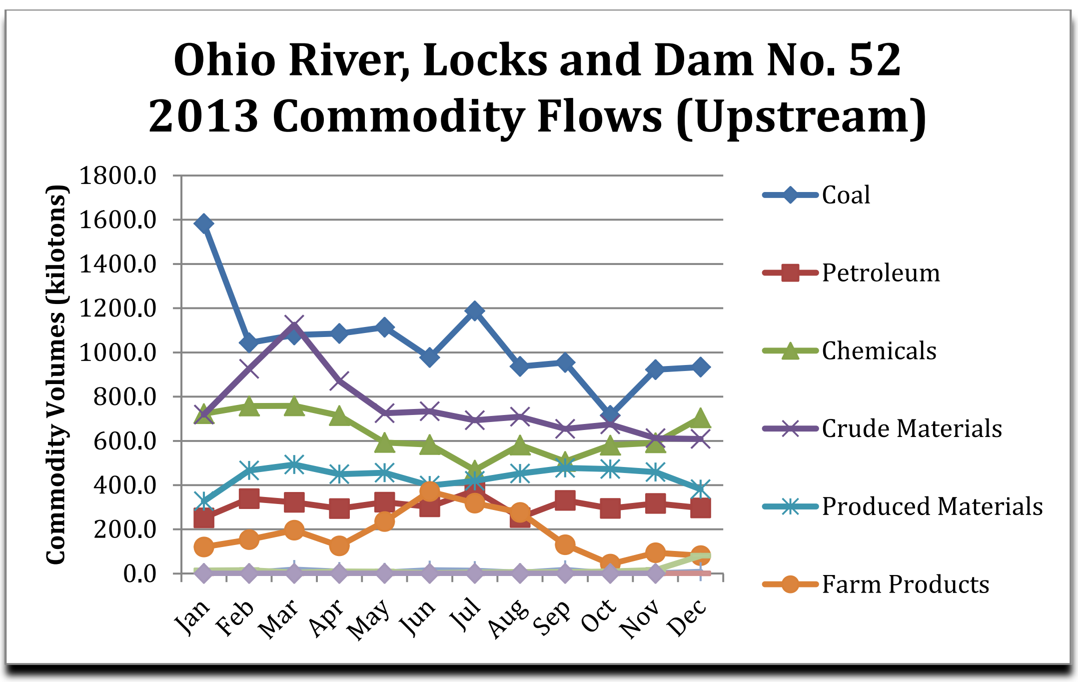
[30] Inland Marine Transportation Systems (IMTS) Capital Projects Business Model Final Report. IMTS Capital Investment Strategy Team. pp. 33-34, 13 Apr 2010

[31] Ohio River Valley Water Sanitation Commission (ORSANCO). River Facts / Conditions, 21 February 2014. http://www.orsanco.org/factcondition

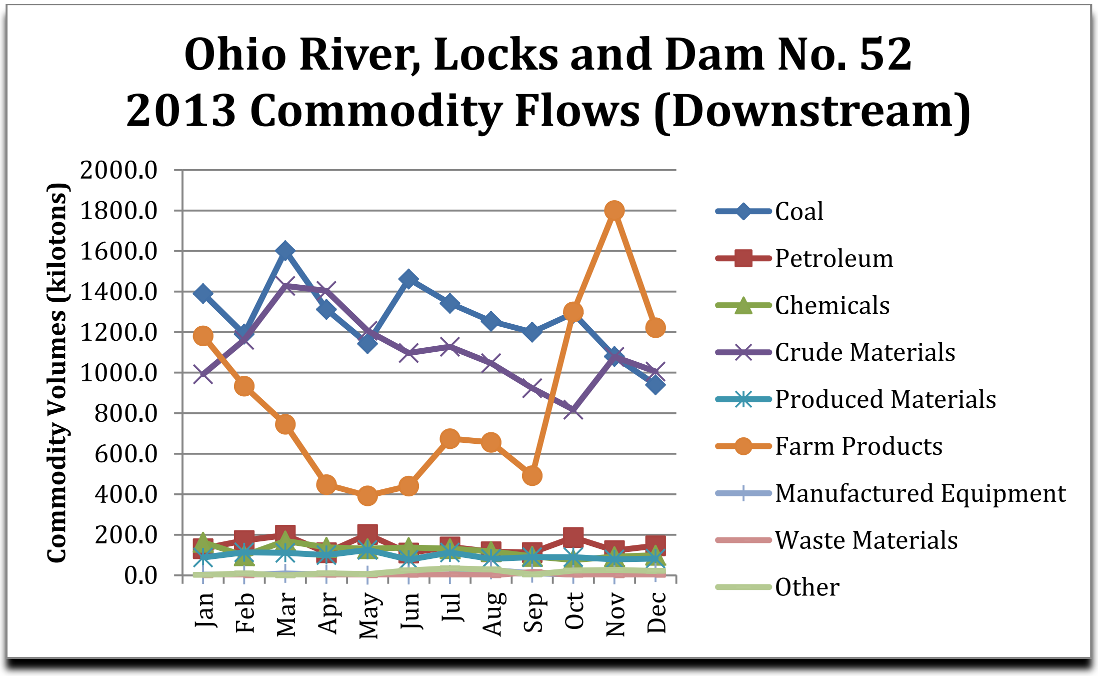
Regarding the "Operational Model" being constructed as part of this project, these variables will be used as inputs (independent variables). The model will estimate the magnitude of their impact on vessel travel times as they move through the study area. Additional details on the data type and processing of data are described further in the model chapter - although a brief summary of these factors ensues. Seasonal changes create variability in river conditions, and therefore months are a useful indicator to measure the impact that seasonal changes have on vessel travel times.

For the purposes of this model, seasonal variability will be measured on a monthly basis. First, river cargo traffic (which is heavily influenced by changes in the weather) experiences significant fluctuations in supply and demand from month to month. Agricultural commodity flows exemplify this pattern. The Ohio River Basin's agricultural growing season begins during the spring months and wraps up in the fall months with the conclusion of the harvest. As agricultural producers harvest their goods, it increases the volume of agricultural products moving on the river. Previous studies of commodity flows have shown that significant increases in grain shipments occur during the summer and fall months.[32] Figure E breaks down the commodity movements by type, direction, and month at Lock and Dam 52 in the 2013 calendar year.

Figure E: Locks and Dam No. 52 Commodity Flows (Upstream and Downstream)



[32] America's Locks & Dams: "A Ticking Time Bomb for Agriculture?", pp. 3. Texas Transportation Institute, Center for Ports and Waterways. December 2011.



Source: U.S. Army Corps of Engineers, Navigation Data Center[33]

Figure D indicates that the amount of agricultural commodities moving downstream spikes dramatically in the fall months, from September through November. This coincides with the conclusion of the harvest season and farmers shipping their product to market. The downstream movement of agricultural commodities also greatly exceeds the volume of flows moving upstream. This trend is largely due to the export-driven demand for agricultural goods. In fact, the majority of agricultural commodities originating from this region proceed down the Mississippi River to the port of New Orleans, where they are loaded onto ships bound for international markets. Due to the perishable nature of agricultural goods, it is critical that these products move through the inland waterway system expeditiously without experiencing unnecessary delays at locks and dams. However, past studies have demonstrated that seasonal volatility—particularly for the obsolete Lock and Dam 52 facility—can negatively impact travel times and result in increased delays for getting products to market.[34]

Seasonal variability effects can emerge from extreme changes in temperature. During the winter months, prolonged stretches of below-freezing temperatures can lead to the formation of ice jams on the river's surface, which increases travel times for barge tows. Travel difficulties resulting from ice accumulation typically occur in the narrower parts of the river, along riverbeds, or in the most northerly areas of the Ohio River. Moreover, river facilities such as locks and dams may have to deal with ice deposits along the facility's surface water perimeter,

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[33] U.S. Army Corps of Engineers, Navigation Data Center. 2013 Key Lock Reports, 21 February 2014. http://www.navigationdatacenter.us/lpms/keylock/keyl13r.html

[34] America's Locks & Dams: "A Ticking Time Bomb for Agriculture?", pp. 4. Texas Transportation Institute, Center for Ports and Waterways. December 2011.

which can further exacerbate barge delays.[35] Beyond hydrologic considerations, freezing temperatures make operational activities more challenging. For example, icy conditions frequently impact river port and barge company operations, hampering workers engaging in outdoor activities in performance of their duties. River docks quickly accumulate surface-layer ice, which poses a threat to workers who must walk and perform activities on these same surfaces.[36] The freezing conditions may also increase the difficulty in cleaning out barges. Normally, high-pressure water is used to spray barge containers out between cargo loads. However, under freezing conditions, the water can freeze on contact with the barge surface and make it difficult to clean containers in a timely manner.[37]

As a vector quantity, the direction and speed of river currents significantly influences the movement of vessels and their corresponding travel times along the Ohio River. Vessels moving downstream (i.e., Cincinnati to Cairo) are travelling in the direction of the prevailing current and should incur a measurable gain in speed without a corresponding increase in fuel usage. Conversely, vessels moving upstream are moving against the natural flow of water and must perform more work (i.e., motor horsepower) to sufficiently overcome the current and obtain a desired speed. This additional work appears in the form of increased fuel usage and travel delays.

Quantifying the directional impact, the overall magnitude of the river current directly influences vessel travel times. This quantity reflects the "speed" at which the river current is moving and is shown as a unit of velocity (measured in feet per second). Intuitively, an increasing current (velocity) moving in the same direction as a moving vessel will produce a corresponding decrease in the amount of work the vessel must perform to move at a defined speed. In other words, the vessel will gain speed at no extra energy cost. Conversely, a vessel moving in the opposite direction of a current must exert additional energy to obtain and maintain a desired speed. This added energy cost is proportional to the magnitude of the opposing current force. All of this ultimately relates back to travel times. Currents can either accelerate or hinder a fully-loaded barge tow vessel and its corresponding total travel time to the final destination. The velocities used for the Operational Model reflect historical data obtained by the National Weather Service - Ohio River Forecast Center. The Center models velocity values using rain gauge observations, radar estimates, snow reports, and other meteorological observations to generate velocity values at distinct locations along the Ohio River.[38]

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[35] "Ice on the Ohio makes river traffic tricky". The Herald-Dispatch, Huntington, West Virginia. 29 January 2014. http://www.herald-dispatch.com/news/briefs/x238620720/Ice-on-the-Ohio-makes-river-traffic-tricky

[36] "Cold and ice create dangerous conditions for river workers." WPSD Local 6 News, Paducah, Kentucky. 8 January 2014. http://www.wpsdlocal6.com/news/ky-state-news/Cold-and-ice-create-dangerous-conditions-for-river-workers-239334811.html

[37] "Traffic on the river is moving, but slow". Farm and Dairy. 19 February 2014. http://www.herald-dispatch.com/news/briefs/x238620720/Ice-on-the-Ohio-makes-river-traffic-tricky

[38] National Weather Service, Ohio River Forecast Center. The OHRFC HAS Forecaster, 24 February 2014. http://www.erh.noaa.gov/er/ohrfc/has.html

River Stages

Although "river stage" is often used as a shorthand way to denote water elevation, it has a more specific meaning. When evaluating a river stage, elevation of the water surface above a fixed datum – with the stage being set at zero - is measured (USGS). This local datum is arbitrary, but in many cases is spotted at an elevation near the streambed. When normal and near normal flow conditions prevail on the Ohio River, vessels can safely and easily navigate the channel. However, climatic fluctuations that drive changes in river stage (essentially raising or lowering the water surface) add to the complexity of predictive modeling because significant increases or decreases in river stage can either slow vessel and cargo movement or halt it entirely.

Extremely low or high river stages create hazardous conditions on the river. Such events, because they are infrequent, have a low probability of occurring in a given year. However, accounting for them is essential for producing an analytically faithful model. In the past both the Ohio and Mississippi rivers have experienced spatially extensive swings in river stage that led to traffic bottlenecks. For example, the historic flooding of the Mississippi and Ohio rivers in 2011 led to significant disruptions in river traffic. On the opposite end of the spectrum, the 2012 drought brought vessels on many segments of the Mississippi River to a halt; if they pressed on they risked running aground in the shallow waters.

In spring 2011, a large proportion of the inland waterway system endured severe and near-historic levels of flooding. National Weather Service records show that the Ohio and Mississippi rivers last experienced flooding of comparable magnitude in 1937. After floodwaters had receded, direct and indirect damages totaled approximately $8.5 billion.[39] As river stages crept upward, carriers were negatively affected as it became increasingly difficult to navigate the Ohio and Mississippi. The loss of navigability prompted the U.S. Coast Guard to implement a series of measures consistent with its Waterway Action Plans. This entailed shutting down segments of the Cumberland, Tennessee, Ohio, and Mississippi Rivers. During the flooding, several locks and dams along the Ohio River were forced to suspend operations, including the Smithland facility.[40/41]

[39] National Oceanic and Atmospheric Administration, National Weather Service, Hydrologic Information Center. United States Flood Loss Report – Water Year 2011, http://www.nws.noaa.gov/hic/summaries/wy2011.pdf
[40] U.S. Coast Guard, Commander Doug Simpson. May 3, 2011, http://www.bloomberg.com/news/2011-05-03/ohio-river-sets-new-record-mississippi-waters-still-rising.html
[41] U.S. Army Corps of Engineers, Louisville District. Notice to Navigation Interests, Notice No. 2011-006. May 11, 2011, http://155.80.93.250/optm/article.asp?id=796&MyCategory=31

High-magnitude floods produce the following conditions, which carriers must cope with:

- **Reduction of bridge clearance spacing for vessels to safely clear the structure**
- **Strong currents restricting the ability of a tow to adequately control the vessel**
- **Increased drift in water, which can increase the probability of drift collisions**
- **Increased out draft conditions, or cross-currents, adjacent to lock and dam entrances which could force a vessel toward the dam structure or the riverbank**[42]

Due to the floods, barge companies were forced to cancel or postpone many of their runs along high-flowing segments of the Ohio River. With their ability to move goods significantly dialed back, many barge companies incurred appreciable financial losses. The events of 2011 demonstrated vessel traffic is highly sensitive to oscillations in river stage, as did the catastrophic drought the ensuing year.[43] Although many regions suffered from unusually dry conditions in 2012, the Mississippi River basin was particularly devastated by the drought. Rainfall was in short supply during the months leading up to summer 2012, which yielded precipitous river stage declines along much of the lower Mississippi River. As channel flow declined, the river became increasingly shallow, causing a number of barges to run aground.[44,45] As river stages declined, carriers were forced to cut back on the volume of goods moved by barges; removing cargo reduces a vessel's draft (submerged depth).

Tom Allegretti, President and CEO of the American Waterways Operators, commented on problems issued by the drought. He observed that "every one-inch loss of water decreases the carrying capacity of a single barge by 17 tons of cargo." Most tows moving along the Upper Mississippi or Ohio rivers push 15 barges; thus a one-foot reduction in draft will shrink a tow's capacity by 3,000 tons.[46] Another effect of droughts is channel narrowing. As flow abates and stage subsides, large portions of a channel that would otherwise be inundated become exposed and dry out (as a river channel contracts, the amount of navigable waterway declines). Along some segments of the Mississippi River, channel narrowing was severe enough that only one-way traffic was permitted – that is, a barge headed north would have to wait until south bound

[42] U.S. Coast Guard, Sector Ohio Valley Waterways Action Plan. Nov 1, 2003, http://www.uscg.mil/d8/westernrivers/docs/Ohio_Valley_Annex.pdf

[43] Wall Street Journal, *Barge Operators Struggle Along the Mississippi*. Aug 25, 2013, http://online.wsj.com/news/articles/SB10001424127887323997004578639921136985476

[44] AWO Letter, the American waterways operators. "AWO Members Responding to Low Water Conditions". Volume 69, No. 15, July 23, 2012.

[45] The New York Times, *In Midst of a Drought, Keeping Traffic Moving on the Mississippi*. Aug 19, 2012, http://www.nytimes.com/2012/08/20/us/in-midst-of-drought-keeping-cargo-moving-on-mississippi.html?pagewanted=1&nl=todaysheadlines&emc=edit_th_20120820

[46] AWO Letter, the American waterways operators. "Nation's Waterways Operators Concerned About Impact of Drought Conditions, Low Water Levels". Volume 69, No. 15, July 23, 2012.

traffic cleared the intended passage.[47] The Ohio River has locks and dams helping to regulate water levels, and was able to support a comparatively steady stream of traffic. However, given that many barges traveling up the Ohio River originate from a point along the Mississippi, the drop off in traffic on the Mississippi spilled over onto the Ohio River. Travel restrictions on one river will likely reverberate through the entire inland waterway system. Predicting vessel movements requires a localized understanding of river stage (i.e. on the river of interest) as well as having a regional awareness of how conditions on adjoining rivers impact traffic flows on the system being studied. Drought – much like the flooding – produces costly delays and reductions in cargo transport capacity, ultimately leading to financial losses for many barge companies.[5]

Under normal weather conditions, the Ohio River provides a safe and easily navigable channel for cargo movement. But severe climatic fluctuations or meteorological events (in the form of floods or droughts) can produce large swings in river stages. This essentially raises or lowers water surfaces to unnavigable levels. This, in turn, creates hazardous conditions for travel along the river – which may significantly delay or halt vessel traffic. Normally, these types of events are infrequent and have a low probability of occurring in a given year. However, as recent years have shown, the Ohio River can experience massive flooding and/or drought conditions, which dramatically impedes the movement of vessels. Shippers and barge companies increasingly need to plan for such events and create contingency plans, or will find themselves captive to the whims of nature.

The historic flood of 2011 and the severe drought of 2012, provide clear illustrations on the damaging effects of extreme water stages and their impact on the continuity of vessel movement. Several locks and dams responded to the flooding by fully opening their lock and dam gates and allowing the water to freely flow through (Figure F). In other instances, inherently unsafe conditions forced the complete closures of lock facilities.

[47] NBC News, *Drought sends Mississippi into 'unchartered territory'*. Aug 15, 2012, http://usnews.nbcnews.com/_news/2012/08/15/13295072-drought-sends-mississippi-into-uncharted-territory?lite

Figure F: Barge Tow Vessel Moving Through the Newburgh Lock (March 2011)

Source: Evansville Courier Press[48]

In the cases of a closure, carriers were forced to curtail their movement along the Ohio River. As a result, barge companies bore significant financial losses during this period.[49] This flood provided clear and overwhelming evidence of the direct impact high water stages have on commodity movements (along with the sensitivity and vulnerability of shipping practices to unusually elevated water levels). The Operational Model will analyze these different types of river conditions and assess their impact on vessel travel times.

Lock & Dam Preliminary Analysis (Lock and Dam Functions)

Locks and dams are critical for maintaining the navigability of the inland waterway system, because they provide increased resilience against adverse weather conditions. Since the 1800's, Americans have relied on the Ohio River for transportation and commerce - particularly concerning the movement of coal. As demand steadily increased, the impact of severe weather events on the system grew more conspicuous and increasingly problematic. Droughts and floods, for example, restrict vessel movement on rivers. This scenario slows down the movement of cargo. High-magnitude flooding drives up the current speeds and raises water to unsafe levels, preventing vessels from adhering to a normal schedule.

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[48] Evansville Courier Press, Lock and dam operators keeping a close watch on the Ohio River. 7 March 2011. https://www.courierpress.com/news/2011/mar/07/wary-watch-on-the-river/

[49] Wall Street Journal, *Barge Operators Struggle Along the Mississippi*. 25 August 2013. http://online.wsj.com/news/articles/SB10001424127887323997004578639921136985476

Likewise, droughts (like those seen on the Mississippi River in 2012) reduce the amount of water in channels, shrinking the amount of navigable channels. Seeking to reduce the unpredictability of the inland waterways, the U.S. Congress sought measures to stabilize the inland water system in the areas where they could feasibly do so. This was done primarily through the mitigation of drought-related impacts.[50] Drought events stem from extended periods of below-average precipitation across a watershed. For example, if the Ohio River Watershed endures drought conditions, less water will flow into tributaries. This consequently attenuates the amount of water flowing into the Ohio River. Constructing lock and dam facilities on the Ohio River (and other rivers) was a strategy designed to attenuate the impacts of extreme weather conditions. Dams mitigate the effects of droughts or floods. They accomplish this by forming pools that maintain the minimum water levels required for river travel. Each dam requires an accompanying lock chamber, which enables the passage of vessels through the river system.

Lock chambers raise or lower the vessel to the water level in the pool they are about to enter. Thus, the idea of a lock and dam system took hold as a way to optimize the inland waterway system and help protect vessels against the dangers of drought. The first lock and dam on the Ohio River was authorized and completed in 1885 at Davis Island, just downstream from Pittsburgh.[51] The construction of additional locks and dams would soon follow, which provided the U.S. with the inland waterway infrastructure network that remains in use today.

Locks and dams are complementary types of infrastructure that work in conjunction to regulate river flow and allow safe passage of vessels along the river corridor. Dams located on the Ohio River regulate the flow of water but do not completely restrict the flow. They accomplish this by impeding flow near the river surface while still allowing for restricted passage of water at a defined depth closer to the river bed. Water is allowed to move through the dam using a series of inset gates, typically tainter gates.[52] The U.S. Army Corps of Engineers (hereafter, "Corps") controls gate operations in an effort to regulate flow through the dam. Corps officials can monitor and adjust water levels on each side of the dam, including the incoming side (upstream) and the outgoing side (downstream).

[50] Locks and dams are not designed to mitigate the high-water stage impacts attributed to flood events. This will be discussed in greater detail on the following page.

[51] U.S. Army Corps of Engineers, Great Lakes and Ohio River Division. History of navigation development on the Ohio River, 14 February 2014.
http://www.lrd.usace.army.mil/Missions/CivilWorks/Navigation/OhioRiver/History.aspx

[52] All of the dams found within this segment of the Ohio River—with the exception of the Wicket Dams of 52 and 53—utilize tainter gates.

Accompanying locks needs to be placed beside of each dam to allow for the passage of moving vessels. Each lock consists of a rectangular concrete chamber with two sets of gates (an entrance and exit) that converge at a centerline that point at a slight angle upstream. The lock has the ability to hold fluctuating volumes of water as levels are raised and lowered. The lock must change water levels to match the adjoining river levels - both the upstream and downstream side - as each gate opens and closes. This enables the vessel to either enter or exit the chamber on a consistent hydraulic gradient. Figure G shows a push boat with a barge load exiting the Smithland Lock chamber.

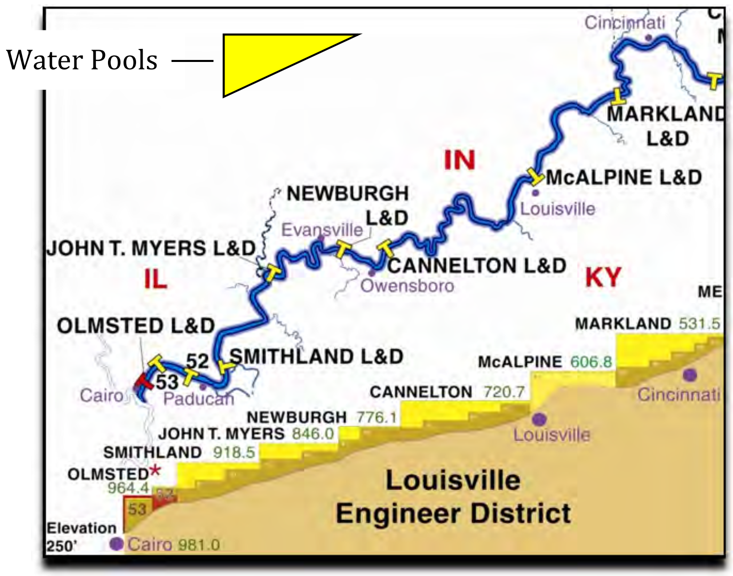
Figure G: Smithland Lock Chamber

Source: USACE, Louisville District[53]

[53] U.S. Army Corps of Engineers, Louisville District. Smithland Locks and Dam, 14 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/SmithlandLocksandDam.aspx

The lock and dam system is designed to suppress water. Pools maintain minimum channel depths, and each lock and dam connects to a distinct pool. When viewed in sequence the pools produce a staircase effect, with river elevations incrementally declining in a downstream direction (see Figure H).

Figure H: Ohio River Staircase Diagram



Source: USACE, Louisville District[54]

The pools formed by locks and dams provide safe and navigable shipping lanes for vessel movement on the inland waterway system. The Corps is legally responsible for maintaining a nine-foot navigable channel on inland waterways.[55] The pools formed by locks and dams provide the initial channel depth required for vessel movement. However, additional maintenance efforts are required in order to maintain those channel depths. Periodic dredging of the pools reduces the amount of sediment that accumulates at the bottom of the channel, and maintains channels in a navigable condition. The main source of sediment is surface water runoff that transports sediment from upland areas in the watershed to tributaries and the main stem. In combination, these activities provide shipping vessels with a minimum river depth channel to safely traverse pools without running aground.

[54] U.S. Army Corps of Engineers, Louisville District. Ohio River Mainstem Navigation System: General Plan and Profile, 13 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams.aspx

[55] U.S. Army Corps of Engineers, Great Lakes and Ohio River Division. History of navigation development on the Ohio River, 17 February 2014. http://www.lrd.usace.army.mil/Missions/CivilWorks/Navigation/OhioRiver/History.aspx

Contrary to popular misconception, river dams are not designed for flood control (nor are they used for that purpose). The pools of water that form behind each dam lack the storage capacity to capture the amount of storm water runoff generated during a high-magnitude flood event. This holds true even if the river could be completely drained before a flood event in the anticipation of collecting floodwaters. For example, previous hydraulic studies have shown that the volumes of water associated with major flood events significantly exceed the volumetric capacity of a river channel. In such a flood, the empty river channel would fill up again in a matter of hours before upstream flooding would commence - eventually inundating riverfront property. The legal mandate (of the Corps) does not extend to protecting downstream stakeholders. Any action to protect downstream stakeholders from flooding would merely transfer risk and potentially increase the vulnerabilities of upstream stakeholders.[56]

Lock and Dam Operations

The Corps operates, maintains, and constructs locks and dams on the inland waterway system. The Corps performs these roles through the framework of their “Civil Works” mission, a program area servicing the nation’s water resources infrastructure.[57] At present, the Corps operates and maintains 241 locks across 195 sites.[58] Maintenance activities consist of routine and periodic checks/repairs, along with major rehabilitation activities. The Corps also leads all new lock and dam construction. New locks and dams are constructed using a combination of federal appropriations (most often from the pool of General Funds) and money from the Inland Waterway Trust Fund. Once built, the Corps assumes complete responsibility for the operations and maintenance regarding existing lock and dam infrastructure.

A Corps lock supervisor - or lockmaster - oversees and directs vessel traffic moving through locks. In this role, the lockmaster continuously monitors incoming and outgoing vessel traffic, operates the opening and closing of lock gates on the structure, and facilitates the passage of commercial and recreational vessels through the lock chamber. The lockmaster retains oversight authority for safety procedures in lock operations. As such, they work to ensure that vessels follow all prescribed safety protocols as they proceed through the lock. A brief summary of lock operation procedures from start to finish is discussed below. The following sequence description does not capture all complex operations associated with locks and dams; it is a simplified narrative intended as a representative version of a typical lockage scenario. As a vessel approaches a lock and dam, the vessel operator will signal the lockmaster that the vessel is approaching and ready to enter the lock.

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[56] U.S. Army Corps of Engineers, Rock Island District. Why do we have locks and dams?, 14 February 2014. http://www.mvr.usace.army.mil/Media/NewsStories/tabid/6636/Article/4550/why-do-we-have-locks-and-dams.aspx

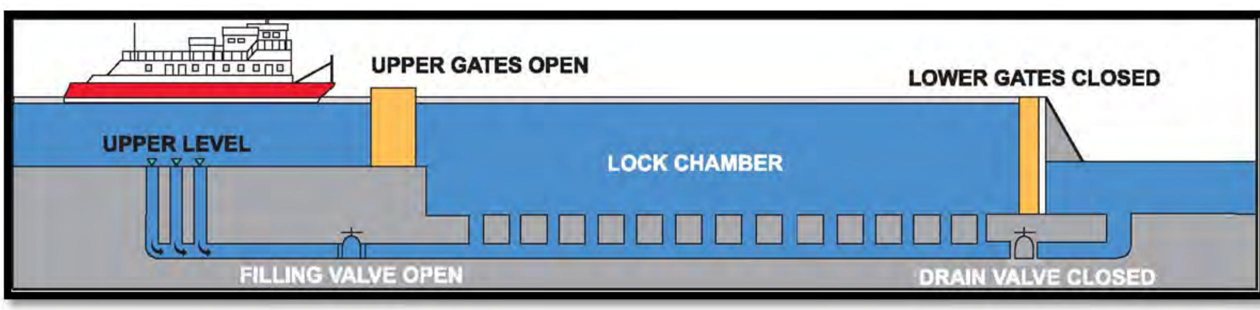
[57] http://www.usace.army.mil/Missions.aspx. U.S. Army Corps of Engineers, Headquarters. Mission Menu. 31 Jan 2014

[58] Department of the Army, U.S. Army Corps of Engineers Civil Works Program Five-Year Development Plan. Fiscal Year 2011 to Fiscal Year 2015, pg. 22.

That signal consists of one long blast of a whistle followed immediately by a short blast, both of which emanate from the vessel. Ideally, the operator will initiate this signal when it is one mile from the lock. Next, the vessel approaches the lock. When there are traffic queues, the vessel will wait as other vessels pass through the facility. In the absence of a queue (or once the queue has cleared), the vessel will harbor in place 400 feet from the guide wall. The vessel may also communicate directly with the lockmaster through pre-defined Corps Maritime Band Channels. The vessel remains in place until directed to move forward by the lockmaster.[59] Before lockage begins, the lockmaster clears the lock chamber of any existing vessels. For the purposes of this illustration, assume that a vessel has just exited the chamber in the downstream direction (e.g., lower hydraulic gradient) and the approaching vessel lies just upstream from the lock. Once cleared, the lockmaster begins filling the lock chamber with water. The lock chamber receives water through a series of pipes underneath the chamber. This allows the flow of water into and away from the chamber.

These pipes connect the chamber to both the upstream and downstream sides of the river, and direct flow through inset valves. The valves can be opened or closed to fill or empty the water chamber as needed. In this case, the upstream valve is opened to allow flow into the chamber and the downstream valve remains closed to prevent water from leaving (see Figure I).

Figure I: Lock Chamber Fills



Source: U.S. Army Corps of Engineers, Louisville District[60]

By using the natural flow of water, locks minimize energy usage by eliminating the need for energy-intensive pumps. Total energy requirements consist of mechanical actions involved in the opening and closures of the lock gates and pipe valves. This relatively straightforward and proven technology has proven remarkably effective over the years.

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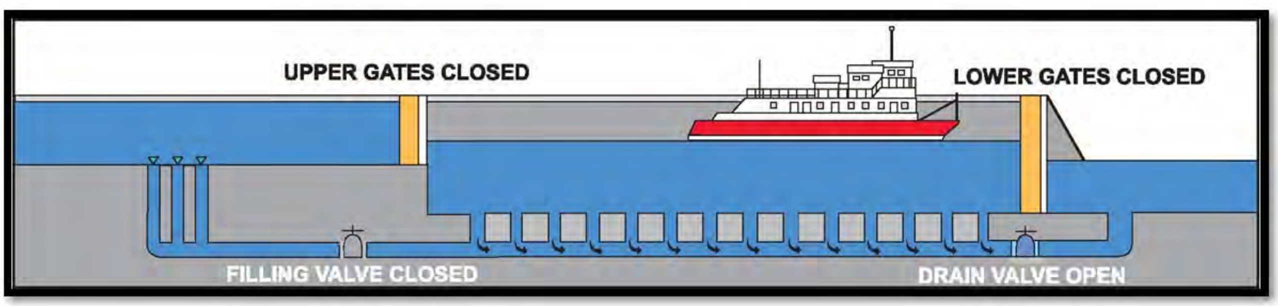
[59] U.S. Army Corps of Engineers, Louisville District. "How to Pass through Locks", 17 February 2004. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/HowToLockThrough.aspx

[60] U.S. Army Corps of Engineers, Louisville District. "How Locks Operate", 13 February 2014. http://www.lrl.usace.army.mil/Portals/64/docs/Ops/Navigation/lockthru.jpg

Once the chamber water elevation matches that of the upstream water elevation, the chamber is ready for use. The lockmaster opens the upstream gates leading into the chamber and notifies the vessel operator to proceed forward. The lockmaster communicates this message through the use of traffic light signals or air horns. A "Flashing Green" signal light or "Two Long Blasts" of an air horn indicates it is safe to proceed forward.[61] The vessel moves forward slowly, stops in the chamber, and ties mooring line from the boat to the lock wall. This will keep the vessel in place during the water drainage phase. Also, vessel operators continuously provide slack to the mooring line (or "take in" for chamber fill operations) to stay in place through this operation.

Next, the lockmaster will close the upstream gates and drain the chamber. These chambers are drained by inverting the process used to fill them (the upstream valve is closed, the downstream valve is opened, and water flows out of the chamber) which lowers the vessel to the appropriate water elevation (see Figure J below).

Figure J: Lock Chamber Drains

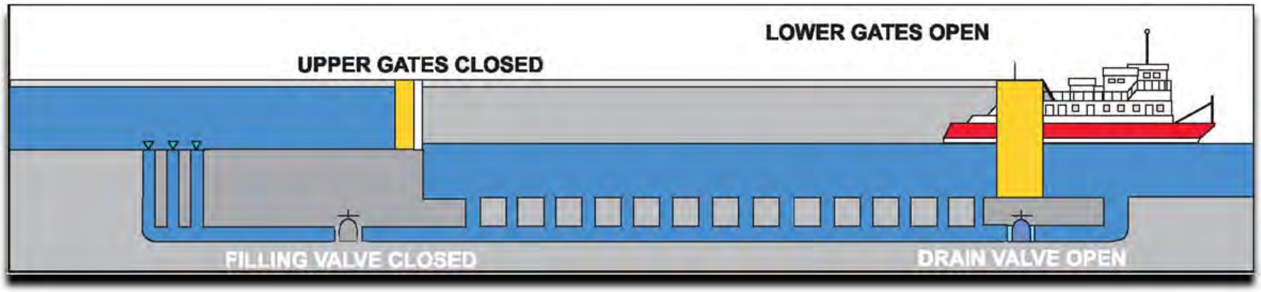


Source: U.S. Army Corps of Engineers, Louisville District[62]

Once drained, the chamber water elevation matches that of the downstream reach. The lockmaster will open the downstream gates and notify the vessel that it can exit the chamber (Figure K). Upon exiting, the lockmaster can begin this sequence again to pass through subsequent vessels.

[61] U.S. Army Corps of Engineers, Louisville District. "How to Pass through Locks", 17 February 2004. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/HowToLockThrough.aspx
[62] U.S. Army Corps of Engineers, Louisville District. "How Locks Operate", 13 February 2014. http://www.lrl.usace.army.mil/Portals/64/docs/Ops/Navigation/lockthru.jpg

Figure K: Vessel Exist Lock Chamber



Source: U.S. Army Corps of Engineers, Louisville District

Locks on the Ohio River

The U.S. Army Corps of Engineers (Louisville, KY District) operates and maintains eight locks on the Ohio River from mile marker 436 to 981. This stretch of the Ohio River stretches from just upstream of Cincinnati (Ohio) to Cairo (Illinois) near the confluence of the Mississippi and Ohio Rivers. The lock and dam facilities located in the study area include:

- **Markland Lock and Dam**
- **McAlpine Lock and Dam**
- **Cannelton Lock and Dam**
- **Newburgh Lock and Dam**
- **John T. Meyers Lock and Dam**
- **Smithland Lock and Dam**
- **52 Lock and Dam**
- **53 Lock and Dam**

(A brief description of each facility and defining characteristics is explained in the following information)

Moving downstream, the first lock and dam in this segment is the Markland Locks and Dam (located at river mile 531.5). The river mile indicates the distance downstream from Pittsburgh, Pennsylvania. The facility has 12 tainter gates along the dam, and a 35-foot lift - which signifies the difference in water surface elevation between the upper and lower pools. The locks include a main chamber, which has a water surface area of 1,200 feet by 110 feet and an auxiliary chamber of 600 feet by 110 feet. The locks began operations in 1959 and the dam was finished in 1964.[63]

[63] U.S. Army Corps of Engineers, Louisville District. Markland Locks and Dam, 17 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/MarklandLocksandDam.aspx

The McAlpine Locks and Dam (located at river mile 606.8 on the northwestern end of Louisville, KY) are equipped with 9 tainter gates and the steepest lift of dams in the group, at 37 feet. Originally built in the 1960's, the McAlpine auxiliary lock received a major upgrade in 2009. It was rehabilitated to the same dimensions as the main lock chamber - 1,200 feet by 110 feet.[64]

The Cannelton Locks and Dam lies at river mile 720.7 near Cannelton, Indiana. This dam has 12 tainter gates and a 25-foot lift separates the pools. Similar to Markland, it contains a main chamber of 1,200 feet by 110 feet and an auxiliary chamber sized at 600 feet by 110 feet. The locks were finished in 1967, and the dam in 1974.[65]

Located near Newburgh, Indiana, (at river mile 776.1) are the Newburgh Locks and Dam. This dam has nine tainter gates and a 16-foot lift. The main chamber is 1,200 feet by 110 feet, while the auxiliary is 600 feet by 110 feet. The Newburgh locks commenced operations in 1969 and the ensuing dam structure came online in 1975.[66]

John T. Myers Locks and Dam are located near Uniontown, Kentucky at river mile 846. Formerly known as the Uniontown Lock and Dam, this lock and dam was renamed to honor former Congressman John T. Myers, who was an active supporter of inland waterway system infrastructure. The dam contains 10 tainter gates and has a lift of 18 feet. The main chamber is 1,200 feet by 110 feet while the auxiliary is 600 feet by 110 feet. The original locks first began operations in 1969, and the dam became operational in 1977.[67]

The Smithland Locks and Dam (river mile 918.5) are across the river from Smithland, Kentucky. This facility is located on the Illinois side of the river and is accessible from nearby Brookport, Illinois. The dam has 11 tainter gates across its span and has a lift of 22 feet. The two chambers are equal in size (1,200 feet by 110 feet) and were the first twin locks of their size on the Ohio River. The locks became operational in 1979, and the dam in 1980.[68]

Locks and Dams 52 and 53 are located at river miles 938.9 and 962.6, respectively. Both sets of locks are situated on the Illinois side of the river, with Lock 52 just downstream of Brookport (Illinois) and Lock 53 11 miles upstream from Cairo (Illinois). Both dams are unique, as they are the last remaining wicket dams on this stretch of river. Both sets of locks are identical with a main chamber of 1,200 feet by 110 feet and an auxiliary chamber at 600 feet by 110 feet. Locks

[64] U.S. Army Corps of Engineers, Louisville District. McAlpine Locks and Dam, 17 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/McAlpineLocksandDam.aspx
[65] U.S. Army Corps of Engineers, Louisville District. Cannelton Locks and Dam, 17 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/CanneltonLocksandDam.aspx
[66] U.S. Army Corps of Engineers, Louisville District. Newburgh Locks and Dam, 17 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/NewburghLocksandDam.aspx
[67] U.S. Army Corps of Engineers, Louisville District. John T. Myers Locks and Dam, 17 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/JohnTMyersLocksandDam.aspx
[68] U.S. Army Corps of Engineers, Louisville District. Smithland Locks and Dam, 17 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/SmithlandLocksandDam.aspx

and Dams 52 and 53 were finished in 1928 and 1929, respectively. These locks and dams will be replaced by the Olmsted Locks and Dam.[69]

Table B: Locks on the Ohio River

Lock	Chamber	River Mile	Bank	Lift	Length	Width
Markland	Auxiliary	531.5	L	35	600	110
Markland	Main	531.5	L	35	1200	110
McAlpine	Auxiliary	606.8	L	37	1200	110
McAlpine	Main	606.8	L	37	1200	110
Cannelton	Auxiliary	720.7	R	25	600	110
Cannelton	Main	720.7	R	25	1200	110
Newburgh	Auxiliary	776.1	R	16	600	110
Newburgh	Main	776.1	R	16	1200	110
John T. Myers	Auxiliary	846	R	18	600	110
John T. Myers	Main	846	R	18	1200	110
Smithland	Auxiliary	918.5	R	22	1200	110
Smithland	Main	918.5	R	22	1200	110
52	Auxiliary	938.9	R	12	600	110
52	Main	938.9	R	12	1200	110
53	Auxiliary	962.6	R	12	600	110
53	Main	962.6	R	12	1200	110

Source: U.S. Army Corps of Engineers, Louisville District

Lock Modeling

Locks and dams provide a vital service to commercial waterway shippers by reducing the length of travel delays associated with drought events. Due to their mechanical nature, they may also create delays when malfunctions occur. As discussed earlier, locks and dams were originally constructed on the Ohio River to stabilize water levels due to severe droughts and provide navigable lanes throughout the year. They have been largely successful in that regard, with over a 100-year track record promoting waterborne commodity shipments. However, locks and dams are humanly-made structures that are subject to the inherent design limits and maintenance issues associated with any engineering-type structure. Locks and dams have the ability to influence waterway vessel traffic operations in a manner analogous to how highway intersections mediate automotive traffic. Each structure serves as a transportation node on the network facilitating the flow of traffic through its hub.

[69] U.S. Army Corps of Engineers, Louisville District. Locks and Dams 52 and 53, 17 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/LocksandDams52and53.aspx

At a lock and dam, the vessel must stop by at a defined distance (x_i) from the lock entrance. At that point, the vessel must wait on any existing traffic queues as well as vessels in the lock chamber to clear before entering. In the same way, a car approaching a red light at a traffic intersection must stop and wait for the traffic queue in front of it and the light to turn green before proceeding. For both traffic lights and locks, external system factors related to the transportation node impact the ability of a vessel operator to proceed.

Under ideal conditions, the system operates as intended and maximizes traffic throughput given known constraints. However, oftentimes congestion forestalls traffic operations - negatively affecting them and resulting in increased delays through locks. The Operational Model in this study examines multiple factors that potentially impact traffic operations down the Ohio River. This includes the characteristics of locks and dams, the Ohio River, and vessel traffic. The dependent variable for this model, output, will consist of vessel travel times. The Operational Model analyzes a defined set of independent variables and determines how they shape or define the dependent variable. In this section, the independent variables related to the characteristics of locks and dams along this Ohio River segment are discussed.

This Operational Model will focus on five predominant factors related to a lock structure, and investigate what impact they have on vessel travel times (including delays). The five factors are listed below:

- **Chamber Size**
- **Age of Lock**
- **Hydraulic Lift**
- **Type of Dam**
- **Planned Outages**

The chamber size of a lock facility directly impacts cargo throughput capacity. Each of the eight locks in this study has two lock chambers (a main and auxiliary lock). Typically, the main chamber is the primary lock used for conveying vessel traffic. The main chambers described have surface area dimensions of 1,200 feet by 110 feet. Alternately, an auxiliary chamber is located adjacent and parallel to the main chamber. Traditional auxiliary chambers were constructed at half the length of the main chamber, or 600 feet by 110 feet. Some auxiliary chambers that have been constructed in recent years, however, were designed to have dimensions equal to the main chambers.

The chamber size is critical because it impacts the number of barges that can move through the lock in one pass. A typical barge-tow configuration consists of 15 barge units connected to a push tow. This configuration is able to pass through a standard main chamber lock (1,200 x 110) as one unit. There are occasions when the main chamber goes offline for scheduled rehabilitation activities (planned outage) or due to unforeseen circumstances (unplanned outage). At this point, vessels will have to rely on auxiliary chambers - which are often half the size of the main chamber. In such a scenario, a barge-tow moving 15 barges would need to break the tow configuration in half and transport the total load through the lock in two separate trips. This more than doubles the travel time of the vessel through the lock due to time associated with two lock trips, the time needed to station the left-behind barge units between trips, and the time spent reassembling the barge units back into a single configuration. Auxiliary chambers, equal in size to the main chamber, mitigate these unnecessary travel time delays and optimize throughput traffic if the main chamber is shuttered.

Lock age can play a significant role in determining travel times. As described previously, the inland waterway system is deteriorating. Many locks still in use have greatly exceeded their intended design life. Along the segment of the Ohio River this study looks at, the average age of the locks is 55 years old.[70] The majority of locks were designed for a 50-year life cycle. The average age of the system is past the intended design period. As locks age, it leads to increased maintenance and rehabilitation efforts to address deteriorating structures and mechanical malfunctions.

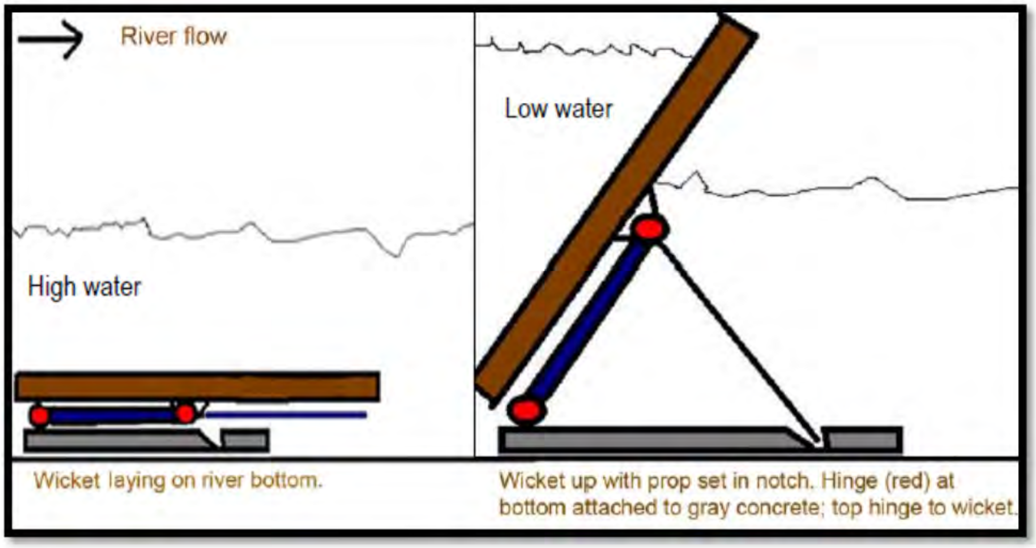
The hydraulic lift of a lock determines the amount of time a vessel spends within the lock chamber. The Ohio River experiences changes along the hydraulic gradient (i.e., slope) in a downstream direction. At certain points, those changes are quite pronounced and sharp. This is documented in the case of the historical "Falls of the Ohio", a previously difficult-to-navigate section of rapids near the McAlpine Locks and Dam.[71] The locks and dams helped to stabilize those rapid changes in hydraulic gradients by generating level pools behind each structure. Locks located between an upstream and downstream pool (with large differences in water elevation) require an equally large hydraulic lift to bring the vessel from one pool level to the next. The time associated with filling and draining lock chambers to create this lift is directly proportional to the elevation change. As such, hydraulic lifts impact travel times for vessels travelling through lock chambers.

Although most of the locks on the Ohio River operate according to the principles outlined above, wicket dams are an exception to this rule. First pioneered in the 1800s, wicket dams were used to construct the original series of locks and dams on the Ohio River. A wicket dam uses a series of in-line wickets that extends across the river and is oriented perpendicular to the flow. Each wicket is a solid plate made of timber, which are approximately four feet wide and 20 feet long. Under high water conditions, the wickets lie parallel to the river bottom and allow vessels to pass directly over them.

[70] This calculation excludes the McAlpine Locks which received recent upgrades to its auxiliary chamber in 2009.
[71] U.S. Army Corps of Engineers, Louisville District. McAlpine Locks and Dam, 18 February 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/McAlpineLocksandDam.aspx

As water levels decrease, the wickets are raised perpendicularly to the flow to create a pool and produce the required nine-foot navigable channel.[72] Corps staff manually raises the dam as low water conditions dictate by hooking each wicket from behind and sliding the connecting bar into a notch (Figure L).

Figure L: Wicket Dam Configurations



Source: U.S. Army Corps of Engineers, Louisville District[73]

Locks and Dams 52 and 53 are the only wicket dams along the study segment. Originally constructed in the 1920s, both facilities have vastly exceeded their design life. As a result, these structures have suffered considerable structural deterioration, which has led to costly and lengthy repairs. The ongoing Olmsted Locks and Dam project is scheduled to replace Locks and Dams 52 and 53, although it will not be completed until at least 2020. [74]

Locks and dams sometimes experience outage events that can significantly delay vessel movements. An outage event is any event causing the lock to temporarily go out of service. Outage events may stem from routine, periodic inspections - but also more urgent and unexpected malfunctions that demand immediate attention. For unexpected malfunctions, a chamber is taken out of service while repairs are made. Outage events are categorized as either "planned", intentionally scheduled, or "unplanned" (as is the case when malfunctions arise). This model will examine planned outages and their adverse impact on delays and travel times for vessels requiring procession through the chamber. Although unplanned outages

[72] U.S. Army Corps of Engineers, Louisville District. Navigation Dams, 18 February 2014.
http://www.lrl.usace.army.mil/Portals/64/docs/Ops/Navigation/Olmsted/NavigationDams.pdf
[73] Ibd, pg. 1
[74] U.S. Army Corps of Engineers, Louisville District. Olmsted facts, 18 February 2014.
http://www.lrl.usace.army.mil/Portals/64/docs/Ops/Navigation/Olmsted/OlmstedFactsheet10-25-13.pdf

frequently cause more severe disruptions due to their unforeseen nature, data on their frequency is not readily available. Existing data can also be unreliable.

To illustrate what happens during an outage, imagine the following scenario: the Corps staff identifies a structural failure in a lock chamber during a routine inspection. First, the Corps will determine corrective actions (including repairs, if needed) and release a public notice informing shippers and vessels of a planned lock outage. Often, main lock chambers experience more frequent outages because they are the most heavily trafficked. The auxiliary chamber will serve as the primary chamber for vessel travel until the main chamber returns to normal operations. Normal commercial vessel traffic volumes diverted through an auxiliary chamber will likely lead to increased travel times and significant delays, as barge tows will have to separate into two pieces for passing through the smaller lock chamber. This increases the amount of time it takes for a single vessel to pass through a facility, and therefore leads to the higher incidence of delays.

Lock and Dam Outages

As noted in the introduction, despite the inland waterways offering an efficient, cost effective, and environmentally friendly method of transporting bulk commodities and other goods, the U.S. lock and dam infrastructure is rapidly aging. Many of the locks and dams are currently operating far beyond their forecasted lifespan. With aging comes the deterioration of structures. This has led to an upward trend in outages while repair crews attempt to correct whatever problems arise. Consequently, an accurate predictive model should account for the probability of lock outages impacting facilities on the Ohio River. Aside from structural deficiencies, delays can also result from extended vessel queues waiting to lock through. To assist with model development, the research team collected data on lock outages covering 2002-2012.

This data was obtained from the annual reports issued by the Navigation and Civil Works Decision Support Center (NDC), which maintains the Lock Performance Monitoring System (LMPS). This data offered a composite picture of lock outages. However, they are imperfect and do not capture every outage and the corresponding duration. For example, data is not available for calendar year 2005, so this has been omitted from tables and graphs. Therefore, it cannot be accounted for regarding the predictive model.

Because of the data gaps contained in the LMPS, the research team collected additional information from the public notices issued by the Louisville District of the USACE - as well as from trade journals and other periodical sources such as web archives. However, reporting on lock outages was usually restricted to only the most significant events. This means that many of the data points captured from these sources were already embedded in the LMPS data. There are other caveats associated with the LMPS data – it does not record specific outage events. Rather, it only preserves raw counts of annual closures and the number of hours a lock was unavailable. Additionally, the LMPS data set does not specify the time of year when an outage occurred, nor does it indicate which chamber was impacted.

This absence of information is problematic because traffic patterns on the Ohio River are seasonally inflected (an outage during the summer months would have more significant consequences than one during the winter because the bulk of vessel traffic passes through the system during the summer). Lacking information about which chamber is affected by an outage presents difficulties because most facilities have main *and* auxiliary chambers. An outage that afflicts an auxiliary chamber would cause less traffic disruption versus a main chamber outage. Lastly, not having information about the timing of lock outages is problematic because it is possible that, in some cases, two outages impacting separate facilities materialized concurrently, which could create a snowball effect in delays throughout the river system, and having a multiplicative effect when compared to delays due to a single outage.

Tables C and D summarize lock closure events and the aggregate number of hours each lock was out of commission, respectively. These tables, derived principally from the LMPS data, give readers a nice overview of 1) the extent and magnitude of outages annually, and 2) which locks were sources of the most disruption. From a systematic and synoptic perspective, Table D (which sums the number of hours each lock was closed) is most consequential for model development. A complete summary of each table is beyond the scope of this report, but there are several important trends worth noting.

Based on Table C, from 2002-2012, the Smithland and John T. Myers locks experienced the largest number of discrete outage events. At first glance it would seem these facilities would disproportionately impact traffic flows. However, Table D, (which displays the number of hours each lock was closed in a given year) tells a different story. During this interval, the Markland facility totaled over 21,000 hours of outage time. Cannelton, on aggregate, was next with approximately 10,000 hours - during which the locks were unavailable to vessels. Spatial and temporal trends are worth scrutinizing as well. For example, Markland clearly does not perform well in the latter area given the upward trend in outage hours it suffered over the past five years.

Table C: Number of Lock Outages Per Year

LOCKS	CY02	CY03	CY04	CY06	CY07	CY08	CY09	CY10	CY11	CY12	Total/Lock
Lock 53	4	1	0	0	5	11	1	0	0	46	68
Lock 52	88	12	20	34	90	88	77	148	132	52	741
Smithland	276	309	450	447	389	492	408	480	546	238	4035
John T Myers	100	192	125	96	181	141	200	288	232	107	1662
Newburgh	11	42	16	11	2	22	208	286	182	113	893
Cannelton	46	34	61	68	47	72	100	69	59	23	579
McAlpine	60	94	96	45	69	109	118	96	128	28	843
Markland	48	57	46	33	49	34	169	182	233	102	953
Total/CY	633	741	814	734	832	969	1281	1549	1512	709	

Table D: Number of Outage Hours Per Lock (Figures Rounded to the Nearest Hour)

LOCK	CY02	CY03	CY04	CY06	CY07	CY08	CY09	CY10	CY11	CY12	Total/Lock
Lock 53	1467	672	0	0	11	14	2	0	0	56	**2223**
Lock 52	171	43	43	1730	1100	210	474	1474	3835	122	**9201**
Smithland	754	333	475	813	489	506	554	911	1612	283	**6728**
John T Myers	884	2048	634	49	963	644	999	604	1025	92	**7940**
Newburgh	1440	217	41	1297	1	45	285	265	420	343	**4352**
Cannelton	562	104	181	2262	724	2639	1395	1303	1209	63	**10443**
McAlpine	110	130	404	101	189	325	398	406	850	88	**3001**
Markland	126	516	113	69	493	87	1119	4516	8149	6015	**21202**
Total/CY	**5514**	**4065**	**1891**	**6321**	**3969**	**4469**	**5225**	**9479**	**17098**	**7061**	

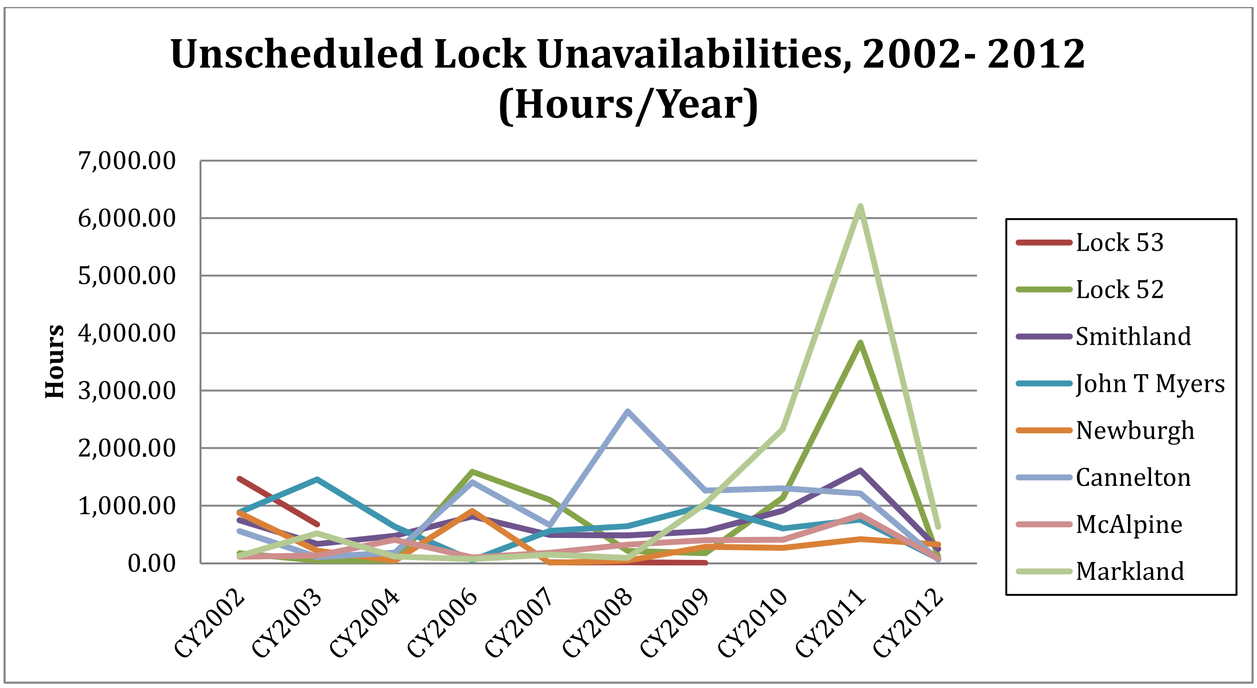
From 2002-2012, the Louisville District USACE Office issued 337 navigation notices (145 of these were related to lock closures). Analysis of these notices revealed that most lock closures are caused by repair work. However the occasional high river stages, flooding, or other natural disturbances force lock outages. While the LMPS data distinguishes between planned and unplanned outages, notices typically do not give a reason for an outage. However, the language and/or context of the notice can indicate why an outage has occurred. For example, if a notice references emergency repairs, it is reasonable to infer a lock has experienced an unplanned outage.

When repairs are scheduled, they are usually announced in several navigation notices, sometimes up to a year in advance. Clearly, outages of this kind would qualify as planned. Instances like these, when the distinction between planned and unplanned outages is clear-cut, present little interpretive difficulties. However, planned maintenance work schedules are often subject to revision. Projects can be cancelled, rescheduled, or added with little advance notice – all of which creates data ambiguities and increases the challenge of factoring planned and unplanned lock outages into a predictive model.

Combining LMPS data with information obtained from navigation notices and other sources, the research team was able to determine the number of hours each lock was unavailable for navigation for the 2002-2012 period (Figure M plots this data). Unscheduled outage hours fluctuate yearly. However, the variability has remained relatively steady with the exception of sporadic jumps. Exceptions to this general trend are observable in the data for Markland and Lock 52 facilities, both of which underwent dramatic increases in total outage hours in 2008-2009. After peaking in 2011, both facilities had outage hours plummet in 2012.

Inter-annual variability regarding unplanned lock outages is a key variable that shapes traffic flow through the system. Unscheduled hours are especially problematic for shippers and carriers because, without prior warning, making different shipping arrangements for goods is logistically untenable. Once a vessel is on the river, there are limited opportunities to offload cargo. In most cases carriers must simply wait until the problem driving the outage is resolved.

Figure M: Annual Sum of Unscheduled Outages for Ohio River Locks



Vessel Characteristics

Commercial vessels transport significant quantities of cargo on the Ohio River each year. These vessels serve a vital role in meeting the demands of domestic energy markets as well as international agricultural markets. In this role, they provide a robust and reliable means to transport dense, high-volume commodities in an economical and environmentally friendly manner over other available transportation models (including rail and highway). In 2013 alone, the Ohio River's Locks and Dam 53 structure received over 73 million tons of cargo.[75] This facility is the last lock and dam on the Ohio River before the confluence with the Mississippi River, and it provides a useful snapshot of cargo traffic at a critical juncture. Furthermore, the shipping vessels operating on the Ohio River contributed to the nation's economic bottom line. In their annual testimony to Congress in 2011, representatives from the American Society of Civil Engineers stated that the inland waterways system moved approximately 630 million tons of cargo annually, with an estimated value of $73 billion.[76]

The most commonly used commercial vessel is the towboat. It is frequently found on the Ohio River and pushes barges loaded with commodities to their final destination. These towboats are powerfully built, and able to push thousands of tons of cargo. More impressively, towboats are able to haul excessively heavy loads with optimal fuel efficiency. For example, a previous Texas Transportation Institute study compared the fuel usage rates of inland waterway towboats with usage rates for other transportation modes. Inland waterway towboats haul, on average, one ton of cargo approximately 576 miles on a single gallon of fuel. Railroad and highway truck carriers can move the same ton of cargo just 413 and 155 miles, respectively, with a single gallon of fuel.[77]

Low fuel usage rates give shippers the ability to haul commodity loads at a low cost, while being environmentally friendly. As a part of its "Civil Works" portfolio, the Corps maintains, operates, and retains primary responsibility for managing the inland waterway system. The Corps monitors commercial vessel traffic on the inland waterway system (typically through locks and dams) and collects data on various segments for future use. The Corps uses this information - along with user provided information by the shipping companies - to assist in the development of *Waterborne Transportation Lines of the United States* (a series published annually.)[78]

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[75] U.S. Army Corps of Engineers, Navigation Data Center. Lock Use, Performance, and Characteristics: Locks by Waterway, Tons Locked by Commodity group, Calendar Years 1993-2013. 27 February 2014. http://www.navigationdatacenter.us/lpms/cy2013comweb.htm

[76] Statement of the American Society of Civil Engineers before the Subcommittee on Water Resources and Environment, U.S. House of Representatives, on the Economic Importance and Financial Challenges of Recapitalizing the Nation's Inland Waterways Transportation System. pg. 2, 21 September 2011.

[77] Texas Transportation Institute, Center for Ports and Waterways. "A Modal Comparison of Domestic Freight Transportation Effects on the General Public". Pg. 38, December 2007.

[78] U.S. Army Corps of Engineers, Navigation Data Center. Vessel Characteristics, Waterborne Transportation Lines of the United States, Calendar Year 2011. 30 November 2012. http://www.navigationdatacenter.us/veslchar/veslchar.htm

The *Waterborne Transportation Lines of the United States* series provides a snapshot of the operations, shipping vessels, and corresponding companies making use of the inland waterway system. This series consists of three volumes: Volume 1 – National Summaries, Volume 2 – Vessel Company Summary, and Volume 3 – Vessel Characteristics. The National Summaries (Volume 1) summarize much of the data and statistics found within the other two volumes and captures the information in graphs and tables. The Vessel Company Summary (Volume 2) outlines the commercial vessel companies using the inland waterway system. It includes company addresses, the types of commodities typically shippers move, waterway use locations, and other relevant information. The final publication, Vessel Characteristics (Volume 3), contains the Corp's most detailed analysis. This publication offers details on individual vessels which utilize the inland waterway system. It includes information about vessels, such as: vessel names, identification codes, dimensions, draft, horsepower, and others data points.

Within this context, the Operational Model will examine several vessel characteristics and determine how they affect vessel travel times. Specific factors to be examined, and discussed in further detail below, include:

- **Vessel Type**
- **Vessel Tonnage**
- **Vessel Horsepower**
- **Year of Vessel Model**
- **Number of Barges**
- **Draft**
- **Vessel Freight**

Vessel Type

The tow vessel fleet consists of towboats and tugboats. Towboats include the majority of tow vessels found on the inland waterways. These powerful boats have a flat, perpendicular surface in the front that allows them to push the barges in front of them. As a result, towboats are sometimes referred to as "pushboats." Towboats also have a rectangular shape and fairly flat hull. This design helps the towboat navigate the shallower depths of the inland waterway and avoid potential grounding scenarios.[79] In the Vessel Characteristics – Volume 3 publication, the Corps classifies a towboat as a "self-propelled vessel" and lists the towboats along with tugboats as the two types of vessels being actively tracked. A tugboat, on the other hand, typically pulls a cargo load from behind. This vessel type is most frequently associated with ocean towing activities, harbor-based activities, and open water operations. Sometimes, however, tugboats work the inland waterways by transporting uncharacteristically large loads.

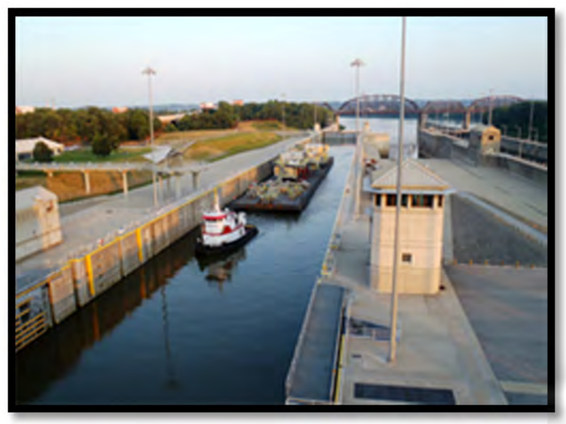
[79] Reddington, Krista. Not Just Another Day at the Office: Careers in the tugboat, towboat, and barge industry. Pg. 6-7, Fall 2008.
http://www.uscg.mil/nmc/announcements/archive/proceedings/career_pdfs/6_NOT_JUST_ANOTHER.pdf

This topic must be taken into account for the study. Tugboats primarily operate within ocean port harbors, where they actively assist in the movement of larger ships through tight spaces. Tugboats may also perform seagoing operations in which they move cargo loads across open ocean water. For both modes of operation, the tugboat connects long towlines to the larger ship or barge in order to "tug" the sizable object to the final destination. Tugboats are designed with a V-shaped bow, which assists with the towing process.[80] During operation, tugboats incorporate slack into their towlines to account for potential rough waters and unfavorable weather conditions. They draw in or provide slack as conditions dictate, to maintain safe control. Tugboats can also push their loads, typically a larger boat, instead of simply towing. They have rubber fenders wrapped around the perimeter specifically for that effort.[81]

The Corps tracks towboats and tugboats on the Ohio River and assigns each vessel a distinct *Vessel Type, Construction, and Characteristics* (VTCC code). These codes let the Corps identify the vessel types as they move through locks and dams. The Operational Model will investigate each vessel type to determine their respective impacts on commodity travel times. Figures A and B show a towboat and tugboat, respectively, moving barge loads through the McAlpine Locks and Dam near Louisville, Kentucky. As the images indicate, the towboat pushes a coal-filled hopper load through the lock while the tugboat pulls the load.

Figure N: Towboat pushing coal hoppers

Figure O: Tugboat pulling barge load



Source: Figures A and B, U.S. Army Corps of Engineers, Great Lakes and Ohio River Division[82]

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[80] U.S. Army Corps of Engineers, Navigation Data Center. Vessel Characteristics, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. viii, 30 November 2012.
http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl3_11.pdf

[81] Reddington, Krista. Not Just Another Day at the Office: Careers in the tugboat, towboat, and barge industry. Pg. 6, Fall 2008.
http://www.uscg.mil/nmc/announcements/archive/proceedings/career_pdfs/6_NOT_JUST_ANOTHER.pdf

[82] U.S. Army Corps of Engineers, Great Lakes and Ohio River Division. Ohio River Navigation, 28 February 2014.
http://www.lrd.usace.army.mil/Missions/CivilWorks/Navigation/OhioRiver.aspx

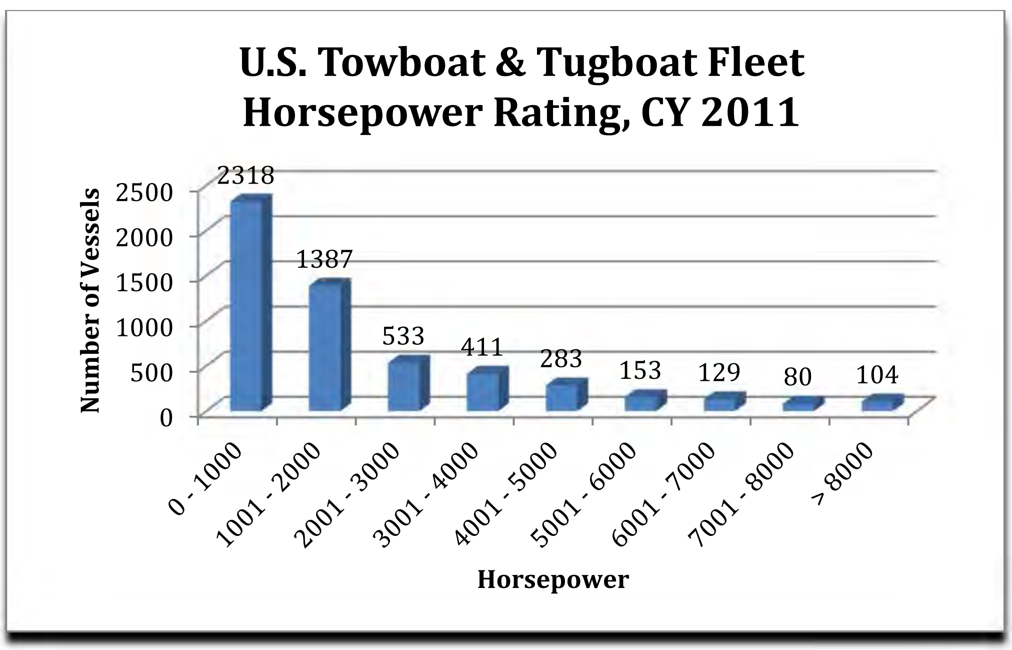
Vessel Tonnage

Vessel tonnage is the weight of the vessel itself, excluding the additional weight of the cargo it hauls.

Vessel Horsepower

The engine horsepower of a shipping vessel measures the amount of power available for transporting cargo loads. The Corps defines horsepower as the "horsepower rating when the vessel was new or when the present engine was installed".[83] Tow vessels with higher horsepower engines have the ability to push increasingly heavy loads without a corresponding loss in overall engine performance. As such, it stands to reason that an engine's performance figures significantly in the vessel's overall travel time. At the same time, tow vessels performing the bulk of their operations on the Ohio River system may not require as much horsepower as their Mississippi River or seagoing counterparts. This is because vessels travelling on the Mississippi River or ocean frequently have much larger and heavier loads. In the case of ocean travel, they may experience more severe weather conditions. Increased horsepower is required to cope with both of these issues. Inland waterway vessels demonstrate a wide range of engine horsepower ratings as shown below in the Corps National Summaries Publication (Figure P)

Figure P: Towboat & Tugboat Fleet Horsepower



Source: U.S. Army Corps of Engineers, WTLUS Volume 1 – National Summaries[84]

[83] U.S. Army Corps of Engineers, Navigation Data Center. National Summaries, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. iv, 30 November 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_11.pdf
[84] Ebd, pg. 12

Year of Vessel Model

The year or vessel model refers to the year in which a vessel was built or rebuilt. The Corps defines a rebuilt vessel as one that is modified with a "significant improvement that extends the working life of the vessel".[85] Aging vessels tend to experience an increase in required maintenance activities, which can adversely impact performance and travel times on rivers. Many of the vessels currently operating on the inland waterway system are indeed aging as evidenced by the 2011 National Summaries results. The Corps found that 3,881 of the 5,458 towboats currently in operations (approximately 71 percent of the total fleet) exceeded 25 years of age.[86] This far outpaced the overall fleet age averages in other sectors, including passenger and tanker vessels.

Number of Barges

One of the most critical factors affecting a commercial vessel's travel time is the number of barges it pushes (or pulls). Inland waterway shippers maximize cargo loads by increasing the number of barges used on individual hauls. Barges are added to the vessel until external system constraints reduce the incentive to continue. System constraints on the Ohio River include river channel widths, lock chamber widths, and weather-related impacts. Towboats on the Ohio River typically push a maximum of 15 barges.[87] As previously discussed, this is due in large part to the size of the existing main lock chambers on the Ohio River which allow 15 barge-tow configurations to pass in a single trip.[88] Any increase to the number of barges would require the vessel to break apart the tow prior to entering the chamber and subsequently rebuild the tow following multiple passes through the chamber. As a result, the increased travel times associated with oversize barge loads would offset any potential gains from upping the cargo loads.

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[85] Ebd, pg. v

[86] U.S. Army Corps of Engineers, Navigation Data Center. National Summaries, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. 10, 30 November 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_11.pdf

[87] DePuy, G., Drosos, D., Taylor, G, and Whyte, T. Grouping and Assignment of Barges. University of Louisville and American Commercial Barge Line. 19 May 2002. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.19.2185&rep=rep1&type=pdf

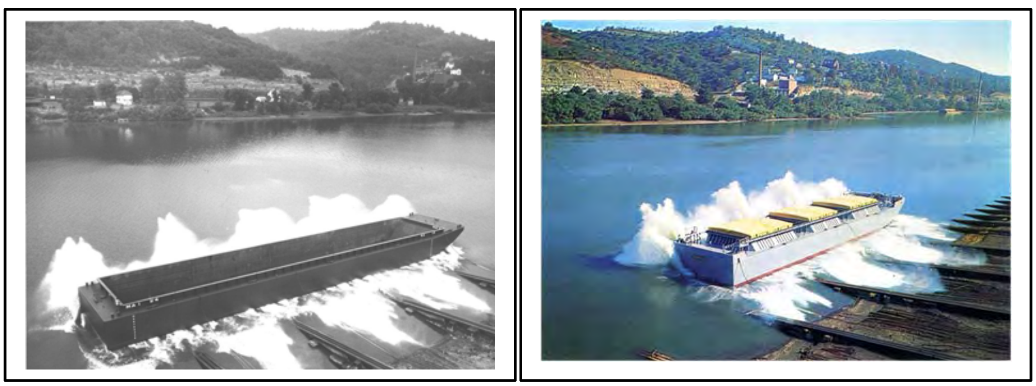
[88] A main lock chamber has a water surface area of 1,200 x 110 feet, enough to accommodate a 15-barge tow movement.

The Corps classifies barges into eight types and characterizes all types as not being self-propelled. The eight types include:

- **Dry Covered**
- **Dry Open**
- **Deck**
- **Lash / Seabee**
- **Other Dry**
- **Single Hull Tank**
- **Double Hull Tank**
- **Other Tank**[89]

Dry barges account for the bulk of barge traffic on the Ohio River. Dry barges consist of flat bottoms, vertical walls providing compartmentalization, and have a rectangular shape (Figure Q).[90] Also known as hopper barges, they come in two forms (covered and open). Covered barges protect cargo from the weather and open barges are used if the cargo is non-perishable. Dry barges are commonly used to transport bulk commodities such as coal and agricultural products.

Figure Q: Dry Barge (Open and Covered)



Source: http://www.blueheronwings.com/

[89] U.S. Army Corps of Engineers, Navigation Data Center. National Summaries, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. v, 30 November 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_11.pdf

[90] Ebd, pg. viii

Deck barges have a flat surface deck with a rectangular shape. These barges lack walls and would not be used for commodities requiring containerization. Often, they are used to move heavy equipment loads. Deck barges comprise the second largest barge fleet in the nation's inventory. The shipping industry refers to deck barges as scows, lighters, or hoys (Figure R).[91]

Figure R: Deck Barge

Source: http://www.blueheronwings.com/

A Lash or Seabee barge is a flat-bottomed, rectangular barge designed for uploading into larger vessels (i.e., a "mother ship").[92] Essentially, a Lash or Seabee barge can be thought of as a type of floating container. Oftentimes, towboats will transport these units on the inland waterway system for an ocean carrier rendezvous. Upon reaching an ocean harbor port, the Lash or Seabee barge is lifted onto the larger vessel and consolidated for movement abroad, reducing the time required to transfer goods from one container to another (Figure S).

Figure S: Lash & Seabee Barge

Source: http://www.towboatjoe.com/

[91] U.S. Army Corps of Engineers, Navigation Data Center. National Summaries, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. viii, 30 November 2012.
http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_11.pdf
[92] Ebd, pg. viii

Tanker barges are used to transport liquids, which are primarily petroleum products. Tanker barges can be either a single hull or double hull.[93] The hull, or watertight body of the ship, is the interface between the ship's bottom, side surface areas, and body of water. Double hulls provide increased protection for the contents (and against potential spills) by providing a second hull layer in the ship's interior, which is separated from the outer hull layer. Tanker barges ship the third largest barge fleet in the nation (see Figure T).

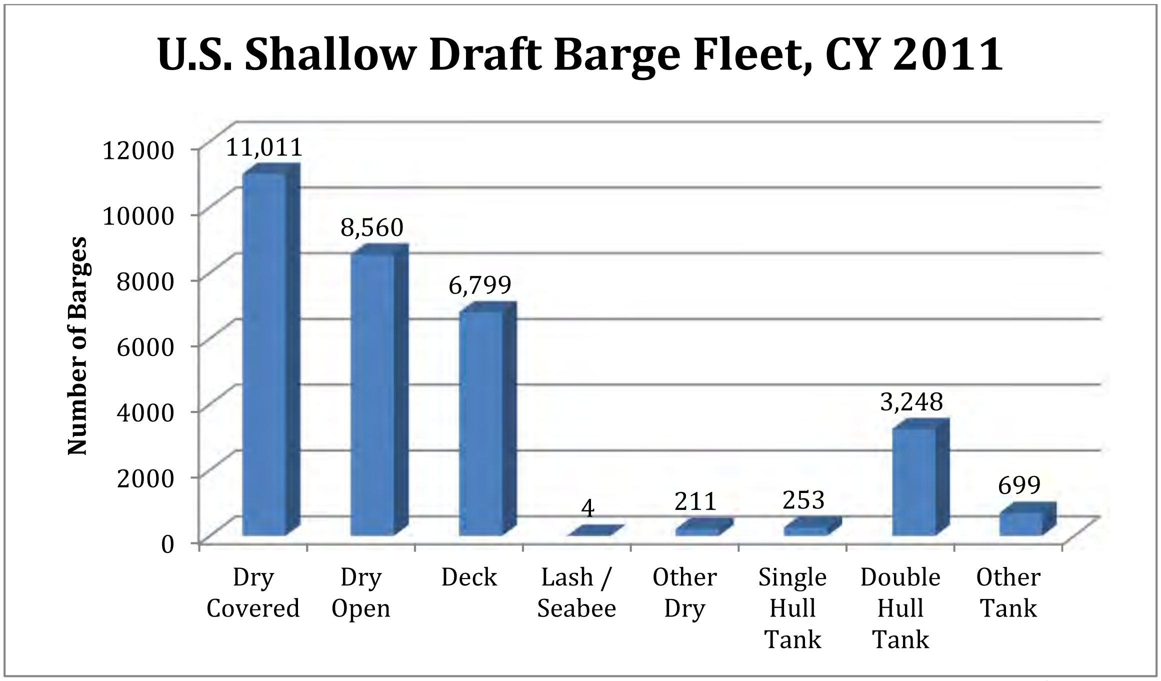
Figure T: Tanker Barge

Source: http://www.blueheronwings.com/

[93] U.S. Army Corps of Engineers, Navigation Data Center. National Summaries, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. viii, 30 November 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_11.pdf

Lastly, the Corps uses separate, miscellaneous categories for all barges that fall outside of the prescribed range in the previous categories, to include “Other Dry Barge” and “Other Tank Barge”.[94] Barges that most resemble one of the previous categories will be categorized per Corps judgment regarding one of the two categories. In the 2011 National Summaries publication, the Corps provides a snapshot into the volume of the different barge types across the nation’s inland waterway system (as shown in Figure U below).

Figure U: United States Shallow Draft Barge Fleet



Source: U.S. Army Corps of Engineers, WTLUS Volume 1 – National Summaries[95]

Draft

Draft indicates the depth to which the vessel and accompanying barge are submerged in the water. Specifically, the Corps defines draft as the “submerged depth of a ship below the water line measured vertically to the lowest part of the hull”.[96] In a typical barge tow movement, the draft would be the overall lowest point of the combined ship, encompassing the barge and vessel. Barges are categorized either as loaded (cargo carrying) or unloaded (empty). Correspondingly, they are classified as having a loaded draft or light draft condition,

[94] Ebd, pg. viii

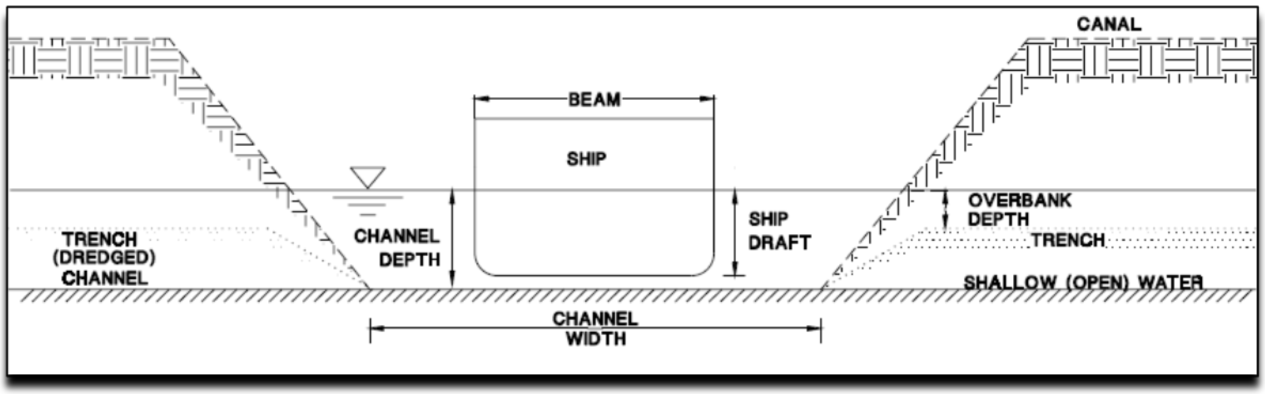
[95] U.S. Army Corps of Engineers, Navigation Data Center. National Summaries, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. iv, 30 November 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_11.pdf

[96] U.S. Army Corps of Engineers, Engineering and Design. Hydraulic Design of Deep-Draft Navigation Projects (EM 1110-2-1613). Glossary-12, 31 May 2006.

respectively.[97] The draft of a vessel is critical because it provides the vessel operator with water depth parameters to which it can safely navigate.

For example, the Corps is required to maintain a minimum nine-foot navigable channel on each of the inland waterways it is responsible for overseeing, including the Ohio River.[98] Therefore, a shipping company knows not to exceed a loaded draft of nine feet (in low water/drought conditions) or risk running aground. The Corps tracks and lists draft conditions for each vessel and barge unit. The variability of draft conditions impacts vessel travel times as barges become increasingly loaded, which decreases speed. Figure V illustrates a ship's draft (draft and channel depth are both shown).

Figure V: Draft of Ship



Source: U.S. Army Corps of Engineers, Engineer Manual (EM 1110-2-1613)[99]

Vessel Freight

Commercial vessels transport a variety of goods on the Ohio River. The types of goods conveyed will affect travel times. Shippers primarily transport energy and agricultural commodities on the Ohio River, including coal and agricultural products. Many different commodity types move along the river each day, and the different types are tracked by the Corps. Each cargo load has distinct weight and volumetric properties, which may ultimately impact the ability to navigate and reach a destination in a fixed time frame.

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[97] U.S. Army Corps of Engineers, Navigation Data Center. Vessel Characteristics, Waterborne Transportation Lines of the United States, Calendar Year 2011. pg. iii, 30 November 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl3_11.pdf

[98] U.S. Army Corps of Engineers, Great Lakes and Ohio River Division. History of navigation development on the Ohio River, 17 February 2014. http://www.lrd.usace.army.mil/Missions/CivilWorks/Navigation/OhioRiver/History.aspx

[99] U.S. Army Corps of Engineers, Engineering and Design. Hydraulic Design of Deep-Draft Navigation Projects (EM 1110-2-1613). pg. 6-9, Figure 6-4, 31 May 2006.

As such, the characteristics of commodities being transported by commercial vessels should be investigated to understand how freight loads influence travels times. It is useful to understand the types of freight moving on the Ohio River. The Corps presently tracks commodity movement across nine separate categories at each of its locks and dams.

These general categories include the following:

- **Coal**
- **Petroleum**
- **Chemicals**
- **Crude Materials**
- **Primary Manufactured Products**
- **Farm Products**
- **Manufactured Equipment**
- **Waste Materials**
- **Other**[100]

[100] U.S. Army Corps of Engineers, Navigation Data Center. 2013 Key Lock Report. 5 March 2014. http://www.navigationdatacenter.us/lpms/keylock/keyl13r.html

These general categories can be further subdivided into a number of sub-categories. The commodity sub-categories consist of 143 distinct categories.[101] Table E highlights the most notable sub-categories for each commodity type.

Table E: Commodity Types

Commodity	**Sub-Category Names**
Coal	Coal, Coal Lignite, Coal Coke
Petroleum	Crude Petroleum, Gasoline, Kerosene, Asphalt, and Lube Oil/Greases
Chemicals	Agricultural Fertilizers, Hydrocarbons, Ammonia, Plastics, Pesticides, and Explosives
Crude Materials	Lumber, Logs, Wood Chips, Sand, Gravel, Salt, Iron Ore, Copper Ore, and Aluminum Ore
Primary Manufactured Goods	Paper, Lime, Cement, Concrete, Glass, Pig Iron, and Fabricated Metal Products
Food and Farm Products	Wheat, Corn, Soybeans, Rice, Barley & Rye, Cotton, Fruits, Nuts, Fish, Coffee, and Sugar
Manufactured Equipment	Machinery, Vehicles and Parts, Aircraft and Parts, Ships and Boats, Wood Products, Textile Products, and Rubber Products
Waste Material	Waste and Scrap
Unknown	Unknown or Not Elsewhere Classified

Source: U.S. Army Corps of Engineers, Waterborne Commerce Statistics Center[102]

Throughout history, coal shipments on the Ohio River have constituted the largest single commodity transported. Despite recent downward shifts in movements, coal makes up the majority of freight moving through the system. Crude materials and food/farm products weigh in as the second and third largest commodities moved on average. Since 2007, the rate of growth for Ohio River commodity flows has slowed. This trend continues unabated as commodity flows in 2013 were less than in 2012. It remains to be seen if the inland waterway system will offset potential future declines by increasing shipments of other commodities, such as natural gas. Locks and Dam No. 52 resides 11 miles upstream of Cairo, Illinois - and is located at the confluence of the Ohio and Mississippi Rivers.[103]

[101] U.S. Army Corps of Engineers, Waterborne Commerce Statistics Center. 2011 Region to Region Public Domain Data Base by Commodity. Pg. 3-5, 5 March 2014. http://www.navigationdatacenter.us/wcsc/pdf/pdrgcm11.pdf
[102] Ebd, pg. 3-5
[103] U.S. Army Corps of Engineers, Louisville District. Locks and Dams 52 and 53. 5 March 2014. http://www.lrl.usace.army.mil/Missions/CivilWorks/Navigation/LocksandDams/LocksandDams52and53.aspx

Due to its strategic location for inter-river commerce, Locks and Dam No. 52 provides a useful representation of commodity flows entering and leaving the Ohio River. In Table F, commodity flows across the major categories are shown for a five-year period (CY 2009 – 2013).

Table F: Commodity Tonnage at Locks and Dam No. 52 (in tons)

Commodity	CY 2009	CY 2010	CY 2011	CY 2012	CY 2013
Coal, Lignite, and Coal Coke	30,018,629	34,729,577	37,445,479	38,283,723	27,740,089
Petroleum Products	3,967,798	4,015,974	3,961,906	4,422,198	5,447,968
Chemicals	7,320,079	8,644,690	8,355,123	8,267,691	9,008,798
Crude Materials	24,160,158	27,568,006	26,974,108	24,516,609	22,339,067
Primary Manufactured Goods	2,889,806	3,114,511	3,931,837	5,263,598	6,401,122
Food and Farm Products	11,131,496	11,517,704	10,018,227	10,089,896	12,434,397
Manufactured Equipment	140,281	102,479	108,557	161,660	181,983
Waste Material	12,500	14,150	8,411	35,683	28,550
Unknown	121,433	170,655	164,246	372,415	372,427
Total	**79,762,180**	**89,877,746**	**90,967,894**	**91,413,473**	**83,954,401**

Source: USACE, Navigation Data Center[104]

[104] U.S. Army Corps of Engineers, Navigation Data Center. Locks by Waterway, Tons Locked by Commodity Group, Calendar Years 1993-2013. Locks and Dam No. 52, 5 March 2014. http://www.navigationdatacenter.us/lpms/cy2013comweb.htm

Discrete-Event Simulation Approach to Inland Waterway Modeling

Introduction

Discrete-event simulation (DES) modeling offers a simplified way to understand system change over time. Although the mathematics underlying DES can be quite complex, their basic operations are quite straightforward. Take a hypothetical, abstract simulation model. At any point in time, the simulation model will be defined by a *state S*. The state consists of relevant independent variables, which influence the value of some dependent variables. Partitioning systems into states improves modeling efficiency.

System evolution takes place over time. This state trajectory over time *S (t)*, "is abstracted as a step function, whose jumps (discontinuities) are triggered by discrete *events*, which induce *state transactions* (changes in the system state) at particular points in time" (Altiok and Melamed, 2007:11). Events are associated with particular data structures and times. A clock and a chronologically ordered event list control a DES, so that events are enumerated in the event list to correspond with their scheduled order of occurrence. DES modeling is not temporally dynamic; that is, it does not model changes to a system on a continuous basis. Rather, DES assumes that a system changes states only *after* an event occurs. The advantage of using modeling system behavior as discrete series of events is the reduced computational burden. Once an event takes place, a state transition occurs. More simply put, an event takes place within the context of a particular system state. After an event unfolds, it shifts a system towards a new state (e.g. Figure x). Between events, DES modeling assumes the system state is constant, although in reality there may be any number of activities working to alter the condition of the system (these will appear in a DES model following the next event).

A common problem studied with DES modeling is queuing behavior. Traffic along the Ohio River (or any river for that matter) can be studied through this lens because as vessels arrive at a lock and dam facility there are frequently other vessels waiting to lock through. This creates a queue since vessels cannot pass through a lock until another has cleared the lock chamber and water levels have been restored to the appropriate level. Queuing systems are modeled as either open-loop or closed-loop systems. Inland waterways are an example of an open-loop system because the rate at which vessels enter the system is independent of the current state of the system.

At the very least, the rate at which vessels arrive into the system is not dictated by the USACE or other agencies tasked with managing different elements of the system. However, carriers may shift their behavior depending on known bottlenecks in the system. If significant traffic delays occur then carriers may opt to wait until some of the vessel traffic clears, or if the congestion persists, they may decide to ship using a different mode. A large number of variables influence traffic patterns and queue length at lock and dam facilities (see Chapter x for a discussion of these factors).

Background

DES has previously been used to model traffic on the inland waterway system – specifically on the Upper Mississippi River. [105]As part of the research team's effort to develop a statistical predictive model, the team initially pursued a discrete-event simulation approach to determine if it alone would be sufficient to generate a reasonably accurate model of the Ohio River. Despite their complexity, rivers function as systems – vessels move in and out, their progression influenced by a range of variables like hydrological/climatic variability and the operation of lock and dam facilities.

Historical data was collected from the USACE on vessel movements for the 2002-2012 time frames (see Chapter "x" for details). The pace of vessel movements was extracted from the data. By determining when each vessel locked through a lock and dam facility, it is possible to track a shipment as it moves up and down the river. It is also possible to track the amount of time it spends in each pool (a pool is the segment of river that separates lock and facilities. In this sense, DES provided a convenient starting point because lockage events were the only data points that could be used to 1) develop a historical understanding of vessel traffic 2) conceptualize what factors exert the most influence over traffic patterns and therefore the operational parameters of the Ohio River system.

The purpose of DES modeling was to inform the development of more robust statistical predictive models; it is best to view the DES modeling executed during this project as *exploratory*. Exploratory analysis is an integral component of complex modeling projects as it gives researchers insights into the underlying data structure. This analysis enabled the research team to formulate preliminary inferences about operations along the Ohio River, and guided the examination of critical factors that impact system behavior.

Methods

The essence of any model is simplification. If a model contained every variable that could potentially impact system behavior, the end result would be a reproduction of reality. However, for most systems it is not possible to know every variable that reverberates through their operational profile. Thus, the main goal of a model is to strike an appropriate balance between simplicity and complexity – keeping it simple enough to preserve computational efficiency, yet complex enough that the model provides an accurate representation of the system.

[105] *A Discrete Event Simulation Model of a Congested Segment of the Upper Mississippi River Inland Navigation System*. IWR Report 04-NETS-R-01, by Donald C. Sweeney.

DES modeling lets researchers quickly change the combinations of variables that control the progression of events and system states. It offered a parsimonious starting point, and gave researchers the flexibility to quickly determine which model configuration gave the most correct results. Following methods set out by Law and Kelton (2000) DES simulation of the Ohio River preceded in six steps:

1. **Define study objectives**
2. **Collect and analyze data**
3. **Test and validate the conceptual model**
4. **Construct the DES model**
5. **Run trials**
6. **Validate the Simulation**

Broadly, this sequence speaks to all of the work involved in model development. However, it has little to say about what was necessary to create a DES for the inland waterways. Table G describes the key properties of DES models used during the design and development. The software used to create DES model was EZStrobe, a user-friendlier version of the Stroboscope simulation package. The research team decided to move beyond DES modeling because the software employed was propriety – disseminating the model to public and private stakeholders would have proven cost prohibitive.

Table G: Key Properties of Discrete Event Simulation Models

Component or Process	**Purpose**
System State	Collection of variables describing the system
Simulation Clock	Coding controlling simulation time
Event List	Variables or logic controlling the timing of events
Statistical Counters	Variables storing the statistical controls of the model
Initialization Routine	Programming start the simulation at time zero
Timing Routine	Programing controlling the time of next occurring even
Event Routine	Programing controlling the model event logic
Library Routines	Programing to capture information during the simulation
Report Generator	Programming to develop reports from the collected information
Main Program	Programming to control the subroutines, programing, and model function

Data Analysis and Model Development

A DES requires parameterization to accurately model system behavior. Below are the parameters used to develop the DES. To produce a model that is manageable and runs quickly, we limited the number of unique trips to a sample of 72. Various simplifying assumptions were used – these were necessary due to the limitations inherent to the LPMS data.

- LPMS data includes the times at which a vessel arrived at a lock (when lockage began, and when it exited into the next river pool).
- During pre-processing, data gaps were eliminated. Lockages were organized chronologically and spatially according to individual vessels, to accelerate model construction.
- Analyzing vessel activity enabled identification of discrete trips. For instance, if a vessel moving downstream leaves the system (passes Lock and Dam 53), changes directions, or spends more than 24 hours in a single pool, the working assumption is that the vessel has concluded the trip. The next time that vessel appears, it is categorized as a new trip.
- Model based on a sample of 72 unique trips.
- The locks which they initiated or concluded were used to define 72 unique trips. Although this sacrifices realism, using this assumption was necessary because LPMS data does not identify what a vessel does upstream or downstream of lock and dam facilities. Figure W shows the 72 trips and their frequency according to data from 2002 through 2011.

Figure W: Trip Frequencies per Year by Lock and Dam, 2002-2011

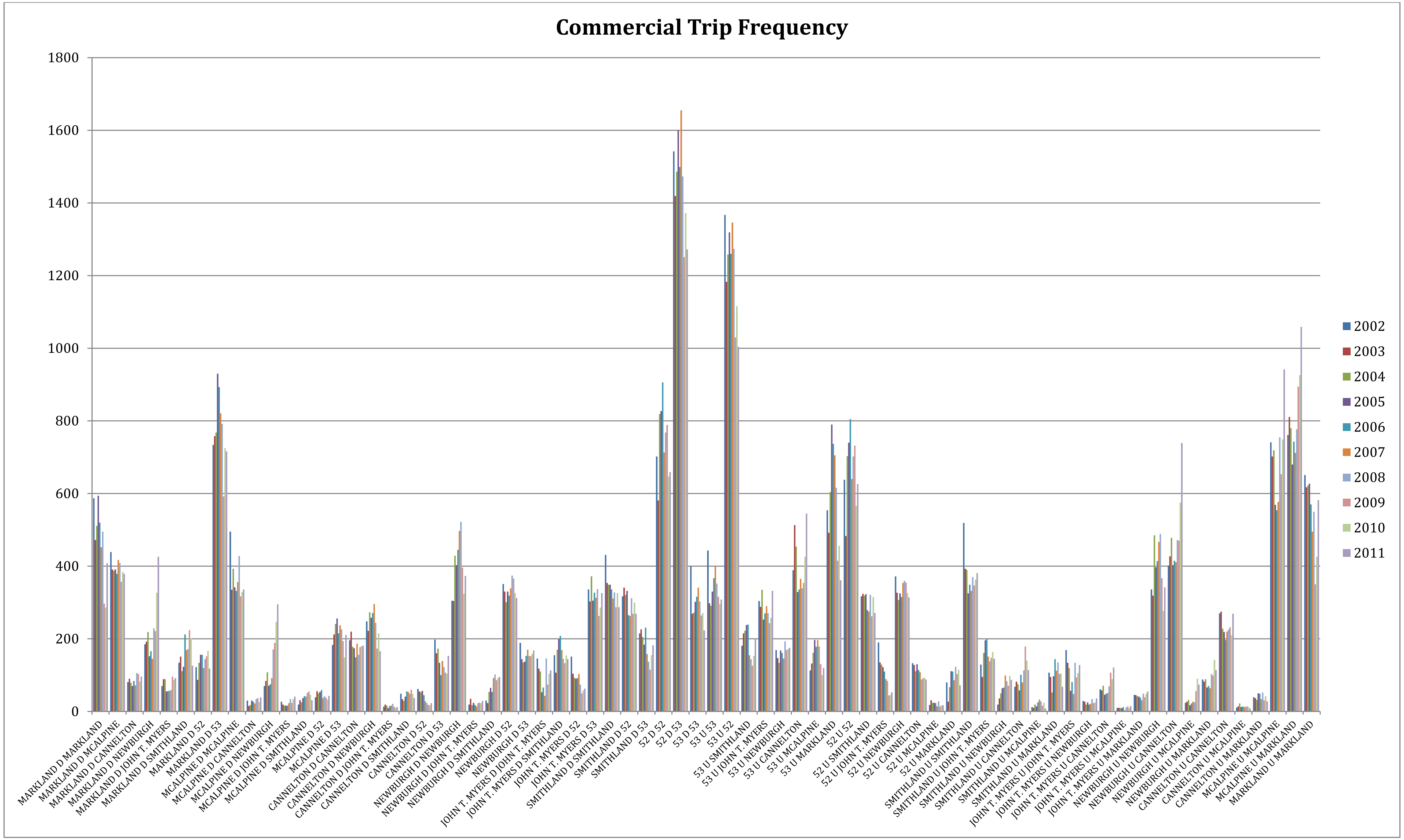


Figure W

- Number of trips and trip frequency used to parameterize the simulation and calculate basic descriptive statistics that were later used to generate probability density functions.
- Figure (x) illustrates that trips were not evenly distributed throughout the system.
- Statistical analysis was used to define trips. Parsing out these trips according to statistical distributions allows the simulation software to define a trip's occurrence by the probability that it occurred.
- Beyond this, the only other inputs required by the model were the number of trips that occurred in a specified time period. We derived this from data from the number of annual trips. Parameterizing the model in this way set it up so that it would simulate system operations for an entire year.

Model Parameters

The previous section described some of the basic parameters used during model development. But a number of other simplifying assumptions were incorporated in the model to reduce runtime while also maintaining accuracy. These are sketched out below:

- The trip for a vessel is defined as the time between starting on the journey (entering the system) and when the vessel arrives at the destination. After a trip concludes, a vessel may begin a new trip or be assigned a new purpose. For this model, commercial vessels are the main focus. This is not to imply recreational vessels are inconsequential, but they are a non-significant factor when analyzing system behavior as a whole. The first step in addressing issues in the USACE LPMS data was to discriminate between commercial and recreational vessel traffic. Recreational vessels were removed from the data set to facilitate identification of discrete commercial vessel trips. Omitting recreational vessels, although it muted the actual complexity of the system in the final DES, did not significantly impact model runs or results.

- The DES also simplified the system by preserving a vessel's anonymity. One drawback of removing this from consideration is that vessel characteristics have an effect on both their operation and the functionality of the overall system. The final operational model *did not* maintain this assumption, as it would have adversely influenced the predictive utility.

- The inland waterway DES treated single trips as individual events. Similarly, each lockage and pool passage functions as a separate lockage. Depending on trip characteristics, the research team was able to identify the number of discrete processes that constituted the trip, and calculate the total amount of time required from origin to destination.

- When a vessel arrives at a lock, it can encounter any number of scenarios. If there are no other vessels present, it can begin locking through immediately. However, if other vessels are present, it will enter a queue and will remain there until obtaining clearance to lock through. Modeling system behavior is tricky because of variable traffic patterns and potential delays at lock and dam facilities. This complicates the modeling at locks, but can be controlled by a system of constrained resources, the number of vessels able to lock at one time, and queues of waiting vessels (both upstream and downstream).

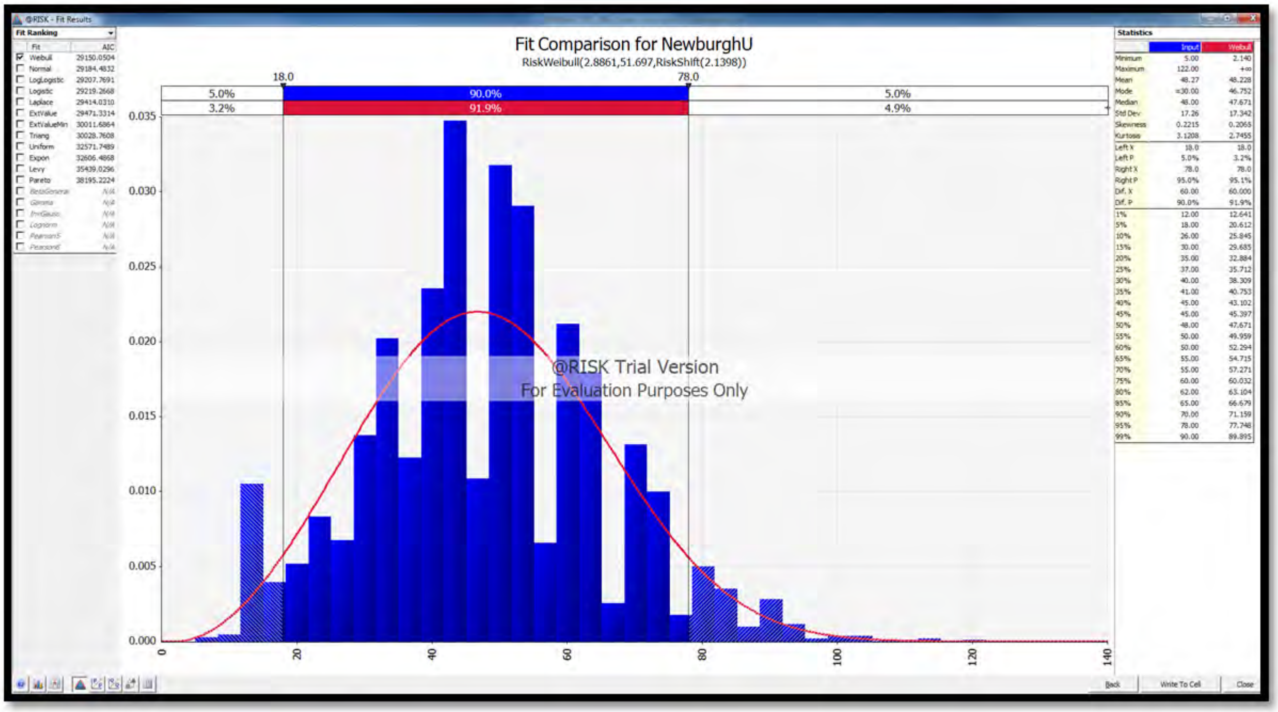
- Simplifying model assumptions and inputs allowed for the use of DES. The model assumed the system consists of vessel trips. The duration of a trip hinged on an antecedent system state and the progression of events – and the relation between them. The research team was able to program additional constraints into the model. For example, only one vessel is able to lock through a facility at a given time in the model, as this preserves the realism of queuing activities. While there may be instances where multiple vessels lock through at the same time, these are infrequent and were not considered in the DES model.

- After the model was parameterized, the next step was to define probabilities and functions that govern system behavior, along with determining event sequencing and identifying state transitions.

Data Analysis & Statistics

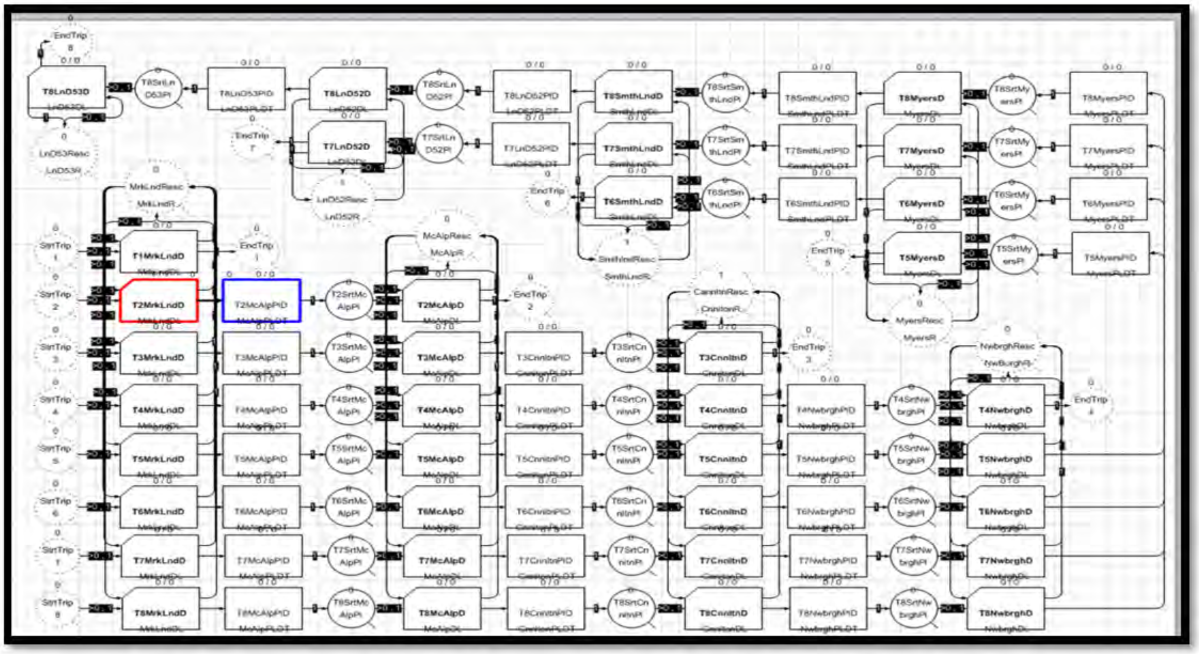
LPMS data was analyzed at the level of individual events. Data on queuing and lockage times for each lock and dam facility were collected. Once the data was assembled, descriptive statistics were run to initially characterize the system. This yielded histograms that were used to select a probability density function (PDF) that best matched the empirical data. The PDF's used in the model varied depending on the shape of individual histograms. Based on this analysis, the research team concluded that three PDF's were useful – normal, gamma, and exponential distributions. Figure "X" gives one example of a PDF that was derived from information about the Newburgh lock and dam facility. A normal distribution offered the best fit in this case.

Figure X: Example of a Fitted Probability Density Function



After a PDF has been selected, the DES can use that distribution to randomly select the duration of an event – in this case a lockage. This process was repeated for all defined events within the system. As shown in Figure Y, separate PDF's were calculated for each lock and the system of event connected through model logic. Facility characteristics vary, however, as each has at least one lock for upstream- and downstream-moving vessels. The DES model was run for a number of simulation times, ranging from 320 to 400 days of activity, for an average of 364.7 days (or one year).

Figure Y: Discrete Event Simulation Model, Illustrating Logic



Outcomes

After model validation, EZStrobe software offers the ability to complete preliminary visualizations and generate comprehensive statistical reports. Visualization can occur through a number of methods. The most common, however, is simply highlighting the model components to be visually depicted (as illustrated in Figure Y) or by taking advantage of the live reporting parameter (see Figure Z). The visualization of the live reporting parameter allows users to watch the simulation and note where large queues develop and infer other salient information about system operations. These can later be reported from the system as seen in Figure AA (next page).

Figure Z: Live Simulation from EZStrobe

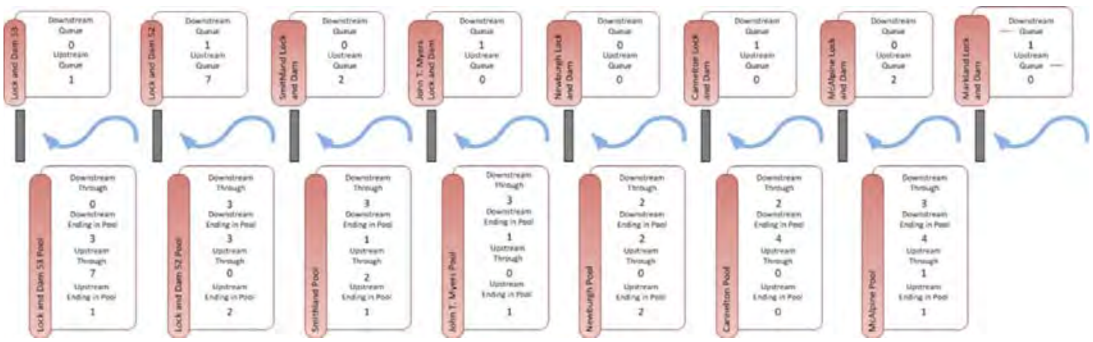
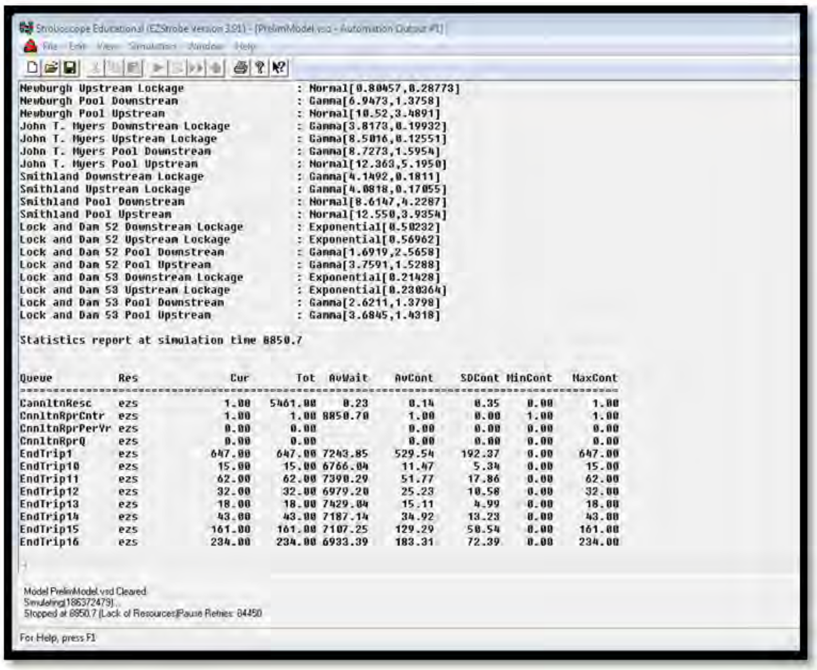


Figure AA: EZStrobe Report



```
Newburgh Upstream Lockage                 : Normal[0.80457,0.28773]
Newburgh Pool Downstream                  : Gamma[6.9473,1.3758]
Newburgh Pool Upstream                    : Normal[10.52,3.4891]
John T. Myers Downstream Lockage          : Gamma[3.8173,0.19932]
John T. Myers Upstream Lockage            : Gamma[8.5016,0.12551]
John T. Myers Pool Downstream             : Gamma[8.7273,1.5954]
John T. Myers Pool Upstream               : Normal[12.363,5.1950]
Smithland Downstream Lockage              : Gamma[4.1492,0.1811]
Smithland Upstream Lockage                : Gamma[4.0818,0.17055]
Smithland Pool Downstream                 : Normal[8.6147,4.2287]
Smithland Pool Upstream                   : Normal[12.550,3.9354]
Lock and Dam 52 Downstream Lockage        : Exponential[0.50232]
Lock and Dam 52 Upstream Lockage          : Exponential[0.56962]
Lock and Dam 52 Pool Downstream           : Gamma[1.6919,2.5658]
Lock and Dam 52 Pool Upstream             : Gamma[3.7591,1.5288]
Lock and Dam 53 Downstream Lockage        : Exponential[0.21428]
Lock and Dam 53 Upstream Lockage          : Exponential[0.230364]
Lock and Dam 53 Pool Downstream           : Gamma[2.6211,1.3798]
Lock and Dam 53 Pool Upstream             : Gamma[3.6845,1.4318]

Statistics report at simulation time 8850.7
```

Queue	Res	Cur	Tot	AvWait	AvCont	SDCont	MinCont	MaxCont
CanltnResc	ezs	1.00	5461.00	0.23	0.14	0.35	0.00	1.00
CnnltnRprCntr	ezs	1.00	1.00	8850.70	1.00	0.00	1.00	1.00
CnnltnRprPerVr	ezs	0.00	0.00		0.00	0.00	0.00	0.00
CnnltnRprQ	ezs	0.00	0.00		0.00	0.00	0.00	0.00
EndTrip1	ezs	647.00	647.00	7243.85	529.54	192.37	0.00	647.00
EndTrip10	ezs	15.00	15.00	6766.04	11.47	5.34	0.00	15.00
EndTrip11	ezs	62.00	62.00	7390.29	51.77	17.86	0.00	62.00
EndTrip12	ezs	32.00	32.00	6979.20	25.23	10.58	0.00	32.00
EndTrip13	ezs	18.00	18.00	7429.04	15.11	4.99	0.00	18.00
EndTrip14	ezs	43.00	43.00	7187.14	34.92	13.23	0.00	43.00
EndTrip15	ezs	161.00	161.00	7107.25	129.29	50.54	0.00	161.00
EndTrip16	ezs	234.00	234.00	6933.39	183.31	72.39	0.00	234.00

Model PrelimModel.vsd Cleared
Simulating(186372479)...
Stopped at 8850.7 (Lack of Resources)Pause Retries: 84450

For Help, press F1

Conclusion

DES modeling carries strengths and limitations. First, DES permitted a thorough exploratory analysis of the LPMS data. The final model highlighted potential areas of concern in the system where delays are the most likely to occur. Initial runs also revealed there were problems and inconsistences in the LPMS data that demanded correction before a statistical model could be produced. DES illustrated Ohio River system operations using an aggregated approach by obtaining averages for different events, such as the length of delays vessels are exposed to while waiting in lockage queues. The simulation gave researchers the power to manipulate some variables, or change PDF's to determine how they would impact system operations.

Arguably, the deficiencies of DES modeling outweigh the advantages. For example, the LPMS data shows a clear seasonal trend in system operations (recall, traffic density increases during warmer months). But there are other factors that influence how quickly a vessel can move along the river. Placing additional variables into the DES would have resulted in an untenably complex model, one that is slow to estimate the duration of events. As noted, a key objective of the research was to develop an application that could be transferred to stakeholders.

Because EZStrobe is a proprietary modeling environment, it did not lend itself to widespread dissemination. Developing an original statistical model from scratch was therefore the most pragmatic option because it would be able to account for all of the critical variables (e.g. water level, season) that affect patterns of movement. While DES is relatively flexible, a statistical model gives users greater flexibility to independently adjust model factors. While the DES offered an ideal platform to conduct exploratory data analysis by clarifying aggregate system operations and providing the means to visualize traffic bottlenecks, the research team deemed the platform insufficient for developing a final product.

The Predictive Model: Modeling Delays on the Ohio River

Introduction

The locks along the Ohio River serve as bottlenecks that slow movement of cargo. Hindrances along a supply chain can also interfere with cargo delivery, but delays at a transport bottleneck carry special importance. This is because the impact typically spreads beyond individual vessels to others that queue up. For that reason, the attractiveness of waterborne transport hinges not only on considerations unique to one cargo or business model, but also on complex features of the river system that can determine the speed and reliability of movement. This includes the structural reliability of locks and the nature of vessels plying their trade along the routes.

From a carrier's perspective, the delay encountered at a lock stretches from when a vessel first arrives until it exits the lock. Total delay time results from two theoretically distinct processes: the actual duration of the lockage, and the amount of time spent in queue waiting for permission to begin a lockage. Sources of delay that influence one process may have little bearing on the next process, and vice versa. The models below therefore use two dependent variables: the delay between arrival and start of lockage (i.e., queuing time), and the amount of time that elapses between start and completion (i.e., lockage time).

As described previously, we benefited from access to LPMS delay data starting in January 2002 and ending on September 30th, 2012. This data represented almost 600 thousand lockages and therefore provided more than one million data points when counting both types of delay. The aim of this chapter is to provide a comprehensive narrative for the multiple statistical models that were developed during the course of this project to explain (and predict) system operations. Using a narrative approach also provides readers with a better understanding of how we coped with (and responded to) challenges that arose during the modeling process. After presenting, discussing, and justifying the ways in which we parameterized our different models, we provided the reader with an overview of the results. While our models have been successful in accounting for the variability in lockage times, modeling the queuing delays provided more challenges and did not yield particularly robust results. The findings of this project clearly set in place the groundwork for future work that seeks to improve the modeling of vessel behavior along the Ohio River - as well as other critical inland waterways that are vital for moving cargo across the U.S.

Analysis

The statistical distributions of queuing time and lockages are not normal, as is assumed in a classical regression model. Rather, in practice, the vast majority of delays are short. Most vessels begin their lockage almost as soon as they arrive, and most lockages run into no special difficulties that slow them down. Occasionally, though, either a lock or an individual vessel will run into particular trouble. This can result in very lengthy delays. In technical terms, the distribution is positively skewed, with a long tail stretching toward very high values. This combined with the bounded nature of the distribution on the left-hand side – it is impossible to wait in queue or pass through a lockage and have a negative delay – the nature of these dependent variables might seem to argue against use of linear-normal regression and instead require a Maximum Likelihood Model, on the order of a hazard or Operational Model.[106]

[106] For some of the key models reported in the analysis to follow, we experimented with parametric hazard models – in particular the Weibull form, as recommended by Wu et al. (2001) – for purposes of checking the robustness of our results. These models did change the behavior of some of our control variables, but did not undermine the main conclusions presented here. Furthermore, to the extent the findings differed between the two modeling techniques, the linear regressions were less likely to produce coefficient estimates that were nonsensical because they were contrary to one-tailed hypotheses.

We found that performing a log transformation on delay times, so as to reduce the disproportionate impact of outliers, converted the pair of dependent variables so they closely followed the standard normal distribution even before incorporation of systematic predictors. Earlier, we discussed the practical problems that accompany working with LPMS data (flaws that have been addressed through painstaking data corrections). Two additional methodological issues emerging from the nature of these dependent variables also are worth addressing: one is an opportunity for the advanced analysis to come, the other an almost intractable complication. The opportunity springs from the impact of logging the dependent variables. Queue delays and lockage delays may seem as though they bear little relation to each other (Most obviously, the wait in queue is contingent upon what happens with other vessels in the system – e.g. how many there are, what sorts of delays they are experiencing – whereas the speed of lockage itself likely will be unrelated to the amount of traffic).

Certainly it is true that extreme delays in queue and extremely slow lockages are so rare that they reveal no tendency to appear in tandem. Our two dependent variables are weakly correlated at the 0.19 level.[107] The two procedures are so distinct that it might seem tempting to separate predictive models for the two stages completely, as other researchers have done (Wu et al., 2001). Yet some of the measured, and likely some of the unmeasurable, influences on vessel speed should work on both varieties of the duration. Logging the two delays reduces the impacts of stray and extreme values. This scenario draws more heavily on patterns among standard lockages, for which the queue delay and the lockage delay correlate modestly with each other. The logged versions of the queue delay and the lockage delay show a stronger correlation of 0.35, a pattern that has little chance of appearing purely by accident. That correlation represents a valuable opportunity, and as we move closer to a fully specified model of Queue Delay and Lockage Delay, we are able to employ regression methods that exploit the relationship between these two seemingly unrelated delays to gain more information about how each one behaves. The research presented here removes limitations that appeared in previous research, which was caused by analyzing each delay in isolation.

The essentially intractable dilemma posed by these lockage-specific delay data, stems from the sequential nature of vessel movement through a lock chamber. Irrespective of what process drives speed through the bottleneck, delay values necessarily spike when a vessel obstructs traffic (blocking progress). The way that one vessel's delay can back up a lock queue violates assumptions of independence found in conventional regression models. However, this interdependence bears little resemblance to the type of autocorrelation for which time-series models have been designed.

[107] Even this weak relationship achieves statistical significance in data with almost 600 thousand observations. The relationship did not appear by accident, but so many possible explanations – both theoretically interesting and trivial – might account for it that substantive significance is not worth exploring until we move closer to a properly specified model.

The frequency of vessel trips will have ebbs and flows, and the gap between one vessel's arrival time and another vessel's arrival time therefore varies widely. As such, no clean relationship can arise between one observation and the next. Nor would the spillover in delay from one vessel to another emerge simply from a measure of when each one arrived, or how many vessels tend to move around during any one period in the data. Usually a vessel only significantly delays its successors when suffering an uncharacteristically long delay. Predicting this lag in the data using a simple time-series model would produce worse results than ignoring it entirely.

For example, suppose we hypothesize that movement upstream during high-volume currents will slow vessel passage. Further suppose that three vessels are moving upstream toward a given lock. The effect of any hypothesized delay on the third vessel in queue must take into account not only the speed with which it moves upstream, but also the atypical slowness exhibited by the second vessel in queue. That sluggishness in turn reflects not just the effect of the water flow on the second vessel itself, but also the unexpectedly lengthy wait it endured while the first vessel completed the lockage process. Treating the long delay experienced by the third vessel as a primary function (of the presence of other vessels) would both exaggerate the importance of an increase in traffic and vastly underestimate the causal importance of river movement.

A simpler model - one that looks at how speeds change as river flow varies and eliminating as much of the dependence as possible through thorough model specification - might err in the opposite direction by missing some of the dependence across observations. That imperfection would seem more desirable than the alternative, given that the eventual goal of this project is to implement the predictive models through a computer simulation of the river system that imposes additional bounds on vessel behavior. That is, if vessels in the simulation have optimistic speed estimates in the presence of other vessels, they still would end up proceeding at a slower pace once the simulation forced them to wait for the lock to clear. Thus, it makes sense for the statistical model to focus on the overall expected delay, and to allow a portion of the bottleneck effect to fluctuate with traffic in a simulation environment.[108]

[108] In principle, a researcher would not be forced to choose between the two imperfect options described here. Rather than use a simple model that assumes independence outside of the systematic causal influences (and the atheoretical seasonal influences) that unite different observations, or apply a time-series model developed for less-complex conditions that threatens to make matters worse, one could imagine a model that makes a vessel's estimated delay (a) a function of the previous vessel's expected delay, (b) conditioned on the gap in time between them. This sort of complex recursive time-series model is well past the scope of this report, however, and will have to remain a goal of future research.

Independent Variables

Queue and lockage delays are not purely random, nor are they a simple matter of discrete-event processing through a bottleneck. Rather, we hypothesize that the observed delays on the Ohio River depend systematically on 1) known, measurable traits of the locks and dams that are responsible for giving the Ohio River pools their morphological structures regarding the vessels plying those waters, and 2) the fluctuations in weather and climate, and concerning seasonal variations in commerce and recreation. Not all of these systematic influences on inland-waterway performance are equally susceptible to manipulation by policymakers. But directly or indirectly, mass behavior and public policy combine to influence most of the inputs that will appear in the predictive models below. We have already discussed most of these features of the inland waterway system in prior sections of the report, by sketching out both their significance and the patterns they reveal. Therefore, the following focus will be on how they might be incorporated into the regression model.

Seasonal Patterns

Delays will correlate with the month and year in which a particular trip takes place. These correlations reflect a number of phenomena. Some sources of seasonal patterning represent influences that we hope to model directly. However, model residuals likely would correlate with the date of the trip even after specifying the model as fully as possible. The obvious reason is that we're not directly targeting dependence across different lockages, so the seasonal variables can catch up some of the effects of traffic fluctuations across time.
Also, the Ohio River Valley is fed by a widely dispersed set of hydrological sources, and the data available is unable to capture the response of the river's pools to complex hydrological processes cleanly. Thus, accounting for lingering seasonal variation in the form of a fixed-effects model should improve model behavior.

We start with a baseline seasonal model that predicts logged delays solely as a function of a series of binary (or dummy) variables: one set to capture the year of the trip, and another to capture the calendar month of the trip. More succinctly, we are allowing for a trend in delays that appears in a given year, and also for a trend among all delays that appeared in January regardless of year. Because the regression includes a constant term (which anchors predictions to a y-intercept) we must leave out one year and one month. The coefficients on the dummy variables therefore represent deviations from the reference category. Regression Table 1 displays a pair of models using July 2006 as the baseline captured by the constant term. The models present robust standard errors to account for any heteroscedasticity that we might have neglected to theorize.

Both the model predicting queue delays and the model predicting lockage delays show that these events are not constant over time. Queuing delays tended to be shorter in the early 2000's, as indicated by the negative coefficients for 2003 and 2004. These delays have lengthened in later years, specifically from 2010-2012. Similarly, these queuing delays consistently stretch out as summer progresses - reaching their peak in August and September.

These results should not be surprising given the descriptive information about delays provided earlier in this document, but it sets up the model to present relationships adjusted for known patterning. Note that while these patterns reach statistical significance, which is to say that they were highly unlikely to occur by accident in the data, knowing the year and/or the month actually does not offer much precision for predicting delays. The decline in prediction error that comes with using estimates from the seasonal model, rather than simply always guessing the average delay, is tiny (barely more than two percent in either case).

River Characteristics

Simply looking at the month and year - allowing for temporal fixed effects - provides little predictive accuracy. However, we have data that allows us to model seasonal difference directly (the amount of water present in the river at the time of a vessel's lockage). Water flow varies seasonally - at some points during the late winter and spring, faster and deeper currents prevail, whereas slower and shallower conditions are more typical during the summer months. Adding climate and weather variables when building a fully specified model at the outset makes sense. This is because they are sources of systematic uncertainty that policymakers often cannot address through the introduction of new regulations, while other sources of delay can be added in at later stages.

Shifts in climatic forces may alter seasonal patterns in the long run. Control of tributaries that feed the Ohio River allows the U.S. Army Corps of Engineers to somewhat regulate water flow. In the short term, Corps officials and policymakers are stuck adapting to what nature provides them. That is (technically speaking) river characteristics are for the most part causally antecedent to human behavior on the river system and can thus be treated as exogenous factors. We can begin with Regression Table 2, which adds a new explanatory variable. This variable is the observed discharge river gages near lock facilities.

The information is available from the U.S. Geological Survey's Water Resources Data.[109] Including discharge as a parameter significantly improves the prediction of Queue Delay *and* Lockage Delay - in both cases shortening delays. When river discharge is higher, vessels move faster. Two possible reasons for this fall-off in delays are listed below:

- Higher discharges improve downriver navigation. If that is the reason then the effect of discharge should depend on which direction the vessel wishes to move – or, to put it technically, discharge should interact with direction. For that reason, Regression Table 3 adds a dummy variable (capturing whether the vessel is moving downriver, and an interaction between that dummy variable and discharge). Results for this idea are mixed. When predicting Queue Delays, they tend to be somewhat shorter on

[109] The Water Resources Data provide Discharge data for five relevant stations. We apply the data from USGS 03611500 (Metropolis, IL) for Lock 52 and Lock 53. We apply data from USGS 03399800 to Smithland. USGS 03381700 at Old Shawneetown applies to Newburgh and J.T. Myers. Finally, USGS 03303280, USGS 03294500, and USGS 03277200 apply to Cannelton, McAlpine, and Markland respectively.

downriver journeys. But the tendency of greater discharge to shorten delays applies roughly equally irrespective of travel direction - as indicated by the small and insignificant interaction term for direction and discharge. The same is not true when predicting Lockage Delays. Downstream-moving lockages are faster, and the advantages brought by greater water flow are even more pronounced when moving in that direction. This is indicated by the negative and significant coefficient on the interaction term.

- A second possibility is the volume of water moving through the Ohio River. This matters because travel becomes treacherous at either high (flood) or low (drought) water levels. The data reveals more drought-related problems than flood-related delays. If it is true that we are mistaken in giving discharge a single coefficient because the effect will be negative at both high and low values, then one simple way to capture that trend in the systematic component of the regression is to allow a bend in the effect. That is, to include a quadratic measure of discharge. Regression Table 4 shows that the data does support this idea. The coefficients on discharge are negative, but those on the squared measure of discharge are negative. That means that at low (drought) discharge, an increase in the amount of discharge will shorten delays. However, as discharges begin approaching very high flood levels, the delays start increasing rapidly again.

Of course, the volume of water could produce effects simultaneously, both aiding downriver travel in the abstract yet generally hindering travel when approaching either extreme. However, when we tried combining the interactive effect with the quadratic effect, the data did not support a robust conclusion that both phenomena were taking place at once (and sacrificing the model's parsimony in this fashion did not add notably to the predictive power). Our best guess is that water volume works in one or both of the ways hypothesized. In later models, we will keep only the quadratic bend and not the interaction.

The speed at which water moves through the river system may not seem the most direct way to determine the impact of weather and climate on inland movements. Both floods and droughts matter because they affect the water depth (or stage) of the river. As discussed in a previous section, if the river falls too low then the navigation channel may not allow the passage of vessels. Whereas if the river experiences very high discharges, a new set of problems arise. Unfortunately, the available data concerning water depths does not meet the same scope and quality as the discharge data.

Our original source only applied gage depth for one site (Old Shawneetown) and the data did not cover the entire region. The River Gages data provided by USACE broaden the scope, because they took readings from stations close to each lock and dam in the Louisville Region of the Ohio River Valley. However, the data only started for most of the locks on July 12th 2007. In the case of the gage near Cannelton, data only started on September 5th 2008 and ended before our data ran out. This forced us to substitute data for a different gage upriver.[110] Regression Table 5 presents models that include river stage as a predictor of delay time.

The listwise deletion (i.e. the exclusion of data records because of missing values) it forces due to missing data wreck the models, taking out several years of data (and therefore the dummy variables associated with those years). These models, however, certainly are suggestive: a higher river stage strongly and significantly predicts shorter delays both in queue and later when passing through the lock. However, the variable takes such a terrible toll on the data. This weakens any other conclusions we might wish to draw, and it makes the most sense to remove the river stage variable again and let discharge volume serve as the proxy for water flow.[111]

Before moving on, though, we must consider two possible wrinkles in how river stage could work. First, the effect of stage might be greater with vessels that have a deeper draft. But it could matter less with a craft that sits higher in the water (especially recreational vessels). Regression Table 6 includes the vessel's draft when loaded, first adding that variable alone, then allowing the effect to vary depending on river stage. It shows that the vessel's draft when loaded does indeed slow progress somewhat. When we allow the effect of draft to depend on river stage, the negative interaction term means that draft does not delay a trip as much when the water is high. Or to put it another way, the effect of low water is less pronounced when vessels have less draft.

Regression Table 7 drops the measures of draft, and instead looks at the effect of wicket dams (specifically looking at Lock 52 and Lock 53). First, we look at the impact of adding a dummy variable for wicket dams alone and then allowing their effect to depend on river stage. Wicket dams can be raised and lowered, so that they block river flow and force a lockage some of the time. At other times the wicket dam allows vessels to float right over them. We would expect travel past a wicket dam to be especially speedy when no lockage is required, but if for no other reason than because these lock chambers are the oldest on the river. Because the auxiliary chambers are only half as long we expect delays to be lengthier than usual when they are required. Thus, we can add a dummy variable for the wicket dam, and also include the effect of having that type of dam to hinge on river stage.

[110] Specifically, we use Gage 4 (Markland), Gage 6 (McAlpine), Gage 10 supplemented with Gage 8 for Cannelton. Gage 13 (Newburgh), Gage 16 (J.T. Myers), Gage 17 (Smithland), Gage 20 (Lock 52), and Gage 23 (Lock 53).

[111] If future research does not turn up a better source of data on River Stage, a valid alternative would be to impute the State using the Old Shawneetown Gage Depth, the discharge seen at various places along the river, and possibly other predictors.

The first two models show that, on average, passing a wicket dam takes less time than passing the other dams on the river. On the other hand, the second two models with negative interaction terms suggest that the benefit actually only applies when the river stage is high. Lockage delays are not shorter otherwise, and if anything, the queue delays are even longer at wicket dams when river stage is low. For now, we drop the draft and wicket variables along with river stage, but we will return to those explanatory variables soon.

Vessel Characteristics

Not all vessels are going to move with equal alacrity through river pools and locks. They also may not be permitted to move as quickly up through a vessel queue, depending on the prioritization system imposed at each lock and dam. The following questions, related to vessel characteristics, address what factors play a role in creating delays:

- **Is a tugboat or pushboat responsible for propelling barges?**
- **How old is that vessel? (a variable we hypothesize should only influence lockage speed, not queue speed)**
- **How many barges is the vessel moving?**
- **How much horsepower is pushing the vessel and the barges? (again which we envision influences lockage speed but not queuing)**
- **How much tonnage does the vessel itself represent?**
- **How low does the vessel sit in the water, both the draft when loaded and otherwise?**

Regression Table 8 initially deals with the first three concepts: a dummy variable for both tugboats and pushboats, a variable for number of barges being processed through the lock, and (for the lockage delay dependent variable) the year the vessel was built. These variables strike us as less problematic in their hypothesized effects, and for the most part our intuitions hold up. Commercial vessels (both tugboats and even more so the pushboats) must wait longer in queue and take longer to complete a lockage than other vessels. Also, a vessel with more barges typically sits longer in queue, and requires a longer period of time to lock through. The second set of models in Regression Table 8 adds the remaining vessel traits. Rather fortuitously, all four variables behave as hypothesized. Both types of draft independently appear to slow progress through the queue and the lockage (as does the tonnage). Also, greater horsepower speeds up both types.

Our lack of access to proprietary USACE data on cargo prevents us from taking into account what the barges contain, or even if they contain anything. However, based on information derived from the USACE vessel database, we added a series of dummy variables that indicated what commodity category a vessel owner primarily deals with. This serves as an imperfect, but best available proxy for the contents of barges. Given the imperfect nature of these proxy measures for cargo, it is striking that even with serious measurement error the dummy variables introduced in Regression Table 9 operate much as one would hypothesize. Tow barges moving food-related produce have a shorter queuing time, typically moving more quickly through the lockage process than vessels shipping aggregates and non-fuel materials. Manufactured goods may have a slight advantage getting through the queue, but this disappears once they initiate lockage.

Companies that move fossil fuels (such as coal and petroleum) as well as companies that trade in other chemical products, tend to suffer the longest delays. There are several possible explanations for this. Fossil fuels and chemical products can traverse the system slowly without unduly harming the financial performance of shippers. Another possibility is that shippers are more willing to move those commodities through river bottlenecks known to be slow, whereas shippers moving time-sensitive products are more prudent in their modal and route decisions. To separate the priorities of the industry actors from the behavior of the policymakers who fund and maintain inland waterways, we need to scrutinize the variables directly related to locks and dams.

Lock and Dam Characteristics

We already have packages of dummy variables to fix the estimates by year and month. However, the data comes from only eight locks and dams. Either due to traffic or some aspect of the lockages themselves, delays may vary systematically depending on what facility a vessel is attempting to pass. Regression Table 10 therefore adds dummy variables for each lock, with “J.T. Myers” serving as the reference point. Clearly the lock and dam a vessel approaches matters greatly for queuing and delay times. The two wicket dams, Locks 52 and 53, experience the shortest queues on average. Vessels pass these locks much more quickly than others in the system. But we see other important differences, such as the shorter queues at McAlpine and Smithland. The slower lockage at McAlpine appears to explain the slow movement of coal along the Ohio River, given that the coefficient on coal drops sharply with these additions. The peculiar finding that newer vessels waited in queue longer goes away also, suggesting that it was a matter of where the newer vessels were moving to.

What sets Smithland and McAlpine apart, relative to Markland or some of the other slower locks? For the entirety of this period, Smithland had two 1,200 foot lock chambers instead of one. Later in the period, McAlpine opened up a second 1,200 foot chamber. Repairs, delays, and backlogs do not last as long at these locks because they can transfer traffic from one chamber to the other without instigating excessive congestion. For that reason, the same Regression Table 11 presents a model with the size of the smaller chamber included.

A second set of models includes a measure of each lock's lift, which could explain some of the differences observed here, with the effect that the dummy variable for Markland must be excluded from the equation to avoid perfect collinearity. When accounting for these dimensions and attributes, the theoretically meaningful influence of delays washes out the previously unexplained advantage for Smithland and McAlpine. Queue delays were shorter due to that second chamber, even though filling a larger chamber slows down the lockage itself.

We now return our variable for the wicket dams. That addition requires removing the dummy variable for Lock 53. Thus, wicket represents the behavior of Lock 53 relative to J.T. Myers, and the variable for Lock 52 in turn represents its deviation from the performance of Lock 53. One set of models looks at the effect of wicket dams in general, but a second set allows the performance of Lock 52, in particular, to be contingent on the discharge of the nearby part of the river system. Regression Table 12 contains the results of this elaborate, and now almost fully specified, model. Rather than interpreting the models in Table 12 we now consider the possibility that contrary to findings in previous research, the queue delays and lockage delays are correlated with one another even after taking into account all of the systematic effects in our two models. We therefore substitute the standard regressions reported thus far with a Seemingly Unrelated Regression Equation (or SURE) model. A Breusch-Pagan test endorses the value of this alteration, as the correlation between the two sets of residuals had a negligible probability of appearing by chance (if these two sets of delays were unrelated to each other). SURE models can be interpreted in a similar fashion as the classical regression model, but the standard errors have been improved based on the information contained in each standalone model's residuals.

What do these results tell us about the nature of the system's operation? Lockage delays are fairly predictable, due to their systematic relationship with the variables included in our model ($R^2 = 0.68$). Vessel movements slow down when discharges are extremely low. This is reflected in the negative coefficient on the discharge variable. Likewise, very high discharges can also hinder traffic - as indicated by the positive coefficient on the squared discharge variable. Lockages stretch out when the vessel is moving upriver rather than downriver. Commercial vessels (tugboats and pushboats) take longer to lock than others. This happens especially when they have significant tonnage, and the delay lengthens when the vessel is older or it pushes more barges.[112] Furthermore, vessels with significant drafts move slower than vessels with less draft. This effect, however, is halved when a vessel as a substantially lower "light draft." Vessels lock faster through smaller chambers, presumably due to the smaller volume of water that must be displaced to fill or empty the chamber.

The models also demonstrate facilities that are home to two larger chambers handle vessels more slowly than their counterparts. This reveals one downside to doubling up on large chambers, a move McAlpine undertook during the study period. Locks requiring more lift also

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[112] One counterintuitive result does appear: Vessels with greater horsepower tend to take longer. Any number of logical explanations might account for this unexpected result, but for our purposes it's sufficient to note that the effect is not strong – the coefficient is very small.

slow down lockage time. Wicket dams do not show a pattern of consistent behavior, with Lock 53 often moving vessels through quickly while Lock 52 more frequently serves as a bottleneck.

However, when river discharges exceed a specified threshold, vessels are able to move over the lowered dams without having to lock through - which improves performance. Finally, the type of cargo a vessel carries appears to help predict lockage speed. Even with all of these explanatory variables taken into account, however, we still note that lockages are slower in late summer and early fall than they are at other times of the year. This is presumably due to impacts from weather and climate that our data could not capture. But even this observation must be qualified because lockage delays vary noticeable from year to year. Some locks also operate more slowly than others. The dummy variables capturing these fixed effects account for some of the remaining variation missed by the rest of the model.

Delays in queue are much harder to predict (R^2 = 0.2). This is not surprising: much of the arbitrary variation in queue times comes from the presence of other vessels using the lock chamber, a source of variation that our simulation captures. Despite its limited predictive power, the model illustrates a few systematic patterns of interest that would apply to general system operations. Delays lengthen when the river discharge approaches extreme values. Downriver vessels often receive priority while commercial tugs and pushboats wait longer, especially when they are responsible for more barges. Vessels with more draft and tonnage run a greater risk of being asked to wait, as are vessels owned by companies that move commodities less vulnerable to spoilage. Locations with two long lock chambers can shorten delays, whereas locks with more lift required will prolong them. Wicket dams behave inconsistently. Lock 53 has demonstrated better performance than Lock 52, which typically can slow down the movement of vessels (although high river discharges positively benefits both facilities). During the late summer and early fall, delays are quite lengthy - while they are less problematic during other portions of the year. However, the overall trend during the study period is that delays inch upward on the Ohio River.

While our combined model produced almost no counterintuitive results (a rarity in a statistical model with so many variables) one exception does appear – horsepower. With all other variables considered, vessels with more horsepower take longer to lock. We should stress that no raw pattern to this effect appears in the data; horsepower reveals almost no simple correlation with time of lockage. Rather, this finding emerges only after the full package of other variables enters the model. Why would the model cause horsepower to behave erratically? First, vessels with more horsepower tend also have substantial tonnage (Pearson's r = .74) and more barges (r = .58), so the meaning of the horsepower variable after controlling for those two inputs is unclear. These vessels are more closely associated with some types of cargo than with others. Because we lack access to USACE data on what is in the barges, the horsepower variable could be picking up some of the unmeasured variation regarding what is being transported.

Lock Outages

We have delayed until the final stage of model development, the explanatory variables related to lock outages. Lock outages, from a theoretical perspective, lack the distinctiveness of some other variables already included in the model – especially seasonal variables such as river discharge and the dummy variables capturing the month of the lockage. Even more problematic is that, unlike with some of the other concepts captured by our models, it is unclear how to parse the effects of possible causal factors related to outages. Thus, rather than rolling variables into the model using a stepwise procedure (the way the model has proceeded up to this point) we will need to present an array of possibilities, none of which are definitive.

A handful of explanatory variables capture, directly or indirectly, the risk of an outage significantly impeding progress. First, coding USACE navigation notices allows us to indicate when a full or partial outage has been scheduled intentionally. We have the option of running a model to determine whether these outages correspond to significant delays. A second approach would be to adjust our variable that captures the length of the smaller chamber. Until now, that variable assumes that the larger chamber is always the same size (it does not need to be coded). The variation between 600 feet and 1,200 feet on the smaller chamber might make a difference. But the effects from these chamber sizes are only theoretical. If one or more of the chambers is closed for repair (for a planned or unplanned outage) then the largest chamber available at one dam may not be available at the same time as another.

Rather than the smaller chamber being at least 600 feet long, no second chamber might be available at all and the length of lockage space is zero. A second option is to shift from theoretical lockage capacity to effective lockage capacity at the time of vessel arrival. We also identified instances in which a vessel has needed to make multiple trips to bring through all of the barges it is moving. Typically, this elaborate procedure must take place when the larger lock chamber has been incapacitated and a sizeable shipment must pass through a smaller auxiliary chamber (thus providing a way to capture outages that focuses on vessels they would impact the most). A fourth possibility would be to allow the effect of a chamber outage to depend on the size of the smaller chamber. The outage might present less of a problem if the functioning chamber still has the capacity to pass through a large number of barges, whereas we might expect longer delays otherwise.

Regression Table 14 adds dummy variables to capture outages directly. Both have variables to capture if the main and auxiliary chamber was under a partial outage, which is to say it might or might not be closed at the specific time when a vessel arrived. What separates the two sets of models is that the first set uses a count of how many chambers have been closed fully on that day, whereas the second set specifically distinguishes whether the main chamber is closed as opposed to whether the auxiliary chamber is closed. In either case, we see that queue delays are notably longer if chambers have been closed, and that the delays are especially severe if the main chamber has been shuttered. Intermittent closures in the secondary chamber can create notable delays as well, probably because that often leads to recreational vessels and other small craft jumping ahead of commercial vessels, whereas otherwise they might have slipped through the auxiliary chamber and not added to the queue.[113] Results are similar with regard to lockage delays: closing a chamber significantly slows the speed of lockages, and that is especially noticeable when the main chamber goes down. Partial closures of the auxiliary chamber also can have a measurable effect, although less significant.

Regression Table 15 looks at these outage delays in a different way, replacing the theoretical lock chamber sizes with the effective lock chamber sizes - as dictated by the outage variables used in the previous model. We ask whether the effective lengths of the bigger lock and of the smaller lock help predict delays. Why do we use the terms bigger and smaller, rather than main and auxiliary? Because if the main lock chamber has been closed, effectively taking on a length of zero, then the working auxiliary lock has become the biggest available chamber. This determines the value of that variable – whereas the zero represented temporarily by the main lock determines the size of the backup. Queue delays are notably shorter as more chamber space becomes available, both with regard to the bigger and smaller lock. Lockage delays do not respond, detectably, very much to the size of the smaller chamber. Most vessels, and especially most commercial vessels, pass through the largest chamber so it makes little difference to them whether the auxiliary chamber is closed or just short. But, the lockages are much faster when the biggest lock chamber is a full 1200 feet.

Using effective chamber sizes to predict queue and lockage delays works as well as coding outages bluntly, however, it seems like a superior method because it captures directly how the outages alter the locking conditions when the vessel arrives. That approach does not account for partial outages, however. Regression Table 16 retains the richer approach to capturing chamber size but combines it with the dummy variables for partial outage. Having smaller chambers still appears to slow the queue (as does partial disruption in the functioning of the secondary chamber).

It makes sense that losing the 1200 foot chamber would slow down a queue, but why would losing the larger chamber also slow down lockages once they have been initiated? This result has emerged twice during our modeling procedure. However, it may not seem intuitive given that earlier findings suggest smaller chambers may provide for quicker vessel processing. The most likely reason is that, when the biggest chamber is not as long, then commercial vessels pushing lots of barges may need to engage in a double lockage (decoupling the barges and moving them through in sections in multiple trips). To test this hypothesis directly, Regression Table 17 adds a binary variable indicating whether the vessel made two trips, thereby tying up the lock chamber for longer than usual.

The new model fully supports this hypothesis. Vessels that require a double lockage are held up longer in queue, and when they do receive clearance their lockage time extends longer than vessels that do not perform double lockages. Under this model, the peculiar result that longer

[113] Having the first chamber under a partial closure seems as though it speeds up the queue, which is absurd on its face. That effect persists throughout the models being reported here, but the effect is always small, and therefore questionable.

chambers provide for faster lockage vanishes. Instead of longer chambers speeding up lockages, they produce a slight slowing effect.

One last possibility remains to be tested. The effect of a chamber outage might not fall on all vessels equally. Rather, our preliminary exploration of the LPMS data seemed to indicate that commercial vessels moving substantial amounts of cargo (as indicated by their quantity of barges) were the ones stuck waiting in queue for the longest time. Vessels pushing few or no barges sailed through at a decent clip. Thus, Regression Table 18 adds an interaction term that assesses whether the effect of an outage at the main chamber hinges on the number of barges attached to a vessel. With queue delay, having the effective size of the bigger chamber drop slows the queue. The process of requiring multiple lockage results in longer waiting times for the vessels. Once we know whether a vessel would require multiple passes through the lock, the effect of having more barges, if anything, seems to result in slightly higher prioritization. On the other hand, during periods when the main chamber is out, the slowness arising from having more barges more than doubles when navigating them into the auxiliary chamber.

Summary of Results

Having settled on a final model that incorporates outages, we can return to the SURE framework and re-examine the last set of models. A Breusch-Pagan test underscores correlation between the queue delay and the lockage delay, therefore allowing a SURE model to incorporate from one dependent variable to improve modeling of the other. In summary, our analysis shows:

- We can account for more than two-thirds of the variation in lockage times using our predictive model. This means that the difference between our predicted values and the actual delay times observed in the data is much smaller than how these delays varied around the overall average seen in the river system ($R^2 = 0.69$).

- We enjoy less success predicting delays in queue ($R^2 = 0.23$), which exhibit a lot more instability and partly reflect spillover from one vessel to the next that we rely on the simulation to impose.

- Contrary to some prior research, we find that queue delays and lockage delays are correlated with one another even after adjusting predictions based on the systematic effects captured in our model ($r = 0.18$, Breusch-Pagan χ^2 gives $p < 0.001$). We can take this remaining correlation into account using a Seemingly Unrelated Regression Equation (SURE) to improve standard-error estimates for the models predicting our two dependent variables.

- River conditions clearly influence both queue delays and lockage speeds. In both instances, extreme conditions of either drought (i.e., low river discharge) or flood (i.e., high river discharge) cause delays compared to typical conditions with average river discharge.

- Current, as represented by discharge, is not the only river characteristic that assists with the prediction of delays. River stage has clear significance as well (directly – especially at the wicket dams – and interactively, with the draft of a vessel). Unfortunately, data for river stage does not extend back to the earlier periods of our LPMS archive, so that was excluded from the predictive model we developed. Our attempt to allow vessel draft to interact with river discharge, hoping data on current could proxy for stage, did not have the same predictive benefit and was excluded.

- As expected, the direction in which a vessel travels also correlates with the level of delay. Upriver lockages take longer, and vessels seeking to travel upriver usually are asked to wait longer in queue, other things being equal.

- Commercial vessels – the tugboats and pushboats on the river – take longer to lock through than other vessels and wait longer in queue. The same is true of vessels with more tonnage and those moving more barges.

- We looked at the year when a vessel was built and the horsepower of its engines only when predicting lockage time.
    - The age of the vessel works as one might predict: newer vessels lock faster.
    - The horsepower variable behaves counterintuitively. Other things being equal, the vessels with more horsepower take longer to lock. Because we captured the effect of vessel capacity in multiple ways correlated with horsepower, and perhaps because horsepower is related to cargo data we lack permission to obtain, this peculiarity should not be especially troubling.

- Vessels with more draft (both loaded and light) are asked to wait longer in queue. After receiving permission to proceed, vessels with more loaded draft lock more slowly as well. These delays on average will be less severe, though, if the vessel loses significant draft when light.

- Locks linking river pools that are farther apart in elevation appear to cause slightly longer lockage delays. Perhaps this makes sense given that it would correspond to how much water must be displaced to raise or lower water levels in the lock chamber. We cannot say anything confident about the effect of lift on queue delays. The estimate is highly unstable, and fairly clearly depends on whether we are separating out the wicket dams. This lack of a consistent relationship makes sense given that the relatively small variation in lockage times that might be produced by lift will be dwarfed by other determinants of how long a vessel ties up a lock chamber.

- We could not measure the amount or type of cargo being moved by each vessel, but for most of them we could identify the company owning the vessel. From this data we were able to infer the kind of shipping activity a vessel is likely engaged in.

    - The final model clearly indicates that vessels from companies moving coal, petroleum, and other chemicals typically must wait longer in queue (while those moving food and farm products, as well as those moving crude materials, experienced shorter queue delays).
    - Lockage times also correlate with the type of cargo a vessel owner carries. Vessels likely to be moving fuel or chemicals tend to lock more slowly, as do farm-related vessels. While those moving other materials (including manufactured goods and equipment) lock more swiftly.

- The locks/dams vary significantly in their queue and lock time. Smithland and McAlpine, with their longer auxiliary chambers, have shorter queues compared to Markland, Cannelton, and J.T. Myers. Queues at the wicket dams depend on the level of river discharge, with their speeds especially quick when river volume is high. Under normal conditions, Lock 52 often sees some of the worst queue and lockage delays.

- Seasonal variation remains unexplained even after taking into account these other influences. Queue delays from August through November tend to be much longer than those experienced in January through June (with July and December roughly corresponding to the transition points between fast and slow times. The lockage process takes longer from August to November (and is faster from January through June). The pattern partly represents changes in traffic, which the model cannot capture. However, the simulation program can; as well as changes in river conditions that our data was too limited to represent.

- Lock outages are not easily incorporated into a predictive model of this kind, and the analyst must exercise caution so as to parse out the direct and indirect relationships that delays might exhibit with these potential sources. However, our analysis shows that:

    - Outages in both the main chamber and the auxiliary chamber will cause longer queues. Shippers cannot, or do not adapt to changes in lock availability enough that the effect of an outage would fail to appear in the data.
    - We can capture the effect of these outages - not through the blunt approach of adding variables for whether an outage has appeared, but instead through the indirect method of measuring the effective chamber sizes available to vessels. As the length of available chambers declines, queues become longer. Even during periods of partial outages for the auxiliary chamber, delays could be substantial.
    - Lockages also progress more slowly during outages. This is only because the loss of the main lock chamber can force vessels pushing a large number of barges to decouple and take them through in multiple passes using the smaller chamber.

Because our final model captures the effect of double lockages, the effect of chamber size for this stage reverses (and if anything, bigger chambers take longer).

- Finally, outages do not slow all lockages equally. Rather, after taking into account the delays caused by decoupling the barges, losing the main chamber correlates with particularly slow lockage speeds for vessels moving a large number of barges.

Simulation

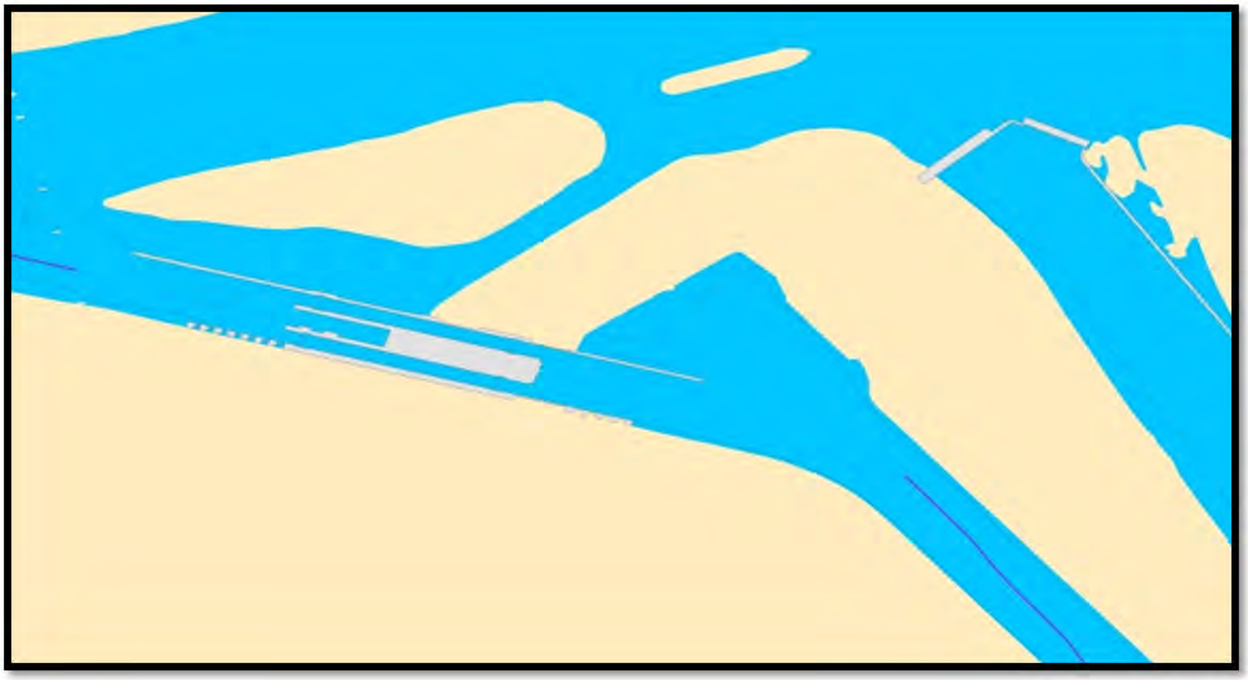
Having concluded the modeling techniques, the next project objective was to simulate the final model of the system. The employment of various visualization methods coupled with programming produced the simulation seen in Figure AB.

Figure AB: Simulation from IWOM

The background of the simulation is the geographic representation of the river segment used in the study. Programming then overlays this background using the selected modeling features to illustrate trips according to their assigned origins/destinations, randomly encountered delays, and selected speeds/lockage times.

The simulation also allows for zooming features into specific areas of the river segment such at the locks and dams as seen in Figure AC.

Figure AC: Zoomed Image of McAlpine Lock & Dam Simulation from IWOM



The simulation and programming also incorporate a graphical user interface. This allows the user to manipulate functions of the model by adjusting the amount of river traffic, and the typical length of delays, speed, and other topics. The simulation can also allow the user to either view historical traffic data through a visual display (2002 through 2012), or to run a modeled simulation.

The display is implemented in OpenGL with the GUI as a combination of AWT/JOGL windows for creating OpenGL windows in Java. NiftyGui was used to create utility windows in OpenGL. The basic structure of the program uses a few classes to abstract out the specific functionalities of the program. A SimMain class houses the main function, and creates the main window for the application. This window holds the NiftyGui controls and displays the controls for the user to manipulate the display. A LockWindow class is used to create an OpenGL context and window for each Lock. These use the data from the SimMain class to display the boats as they queue up and pass through the locks. A boat class stores the historical data for each boat in the form of a List of ProcessRecords.

The ProcessRecord class contains the data from each row of the historical data table. Finally, the simulation and programming offer the ability to report on various aspects of the simulation and model. The simulation and reporting functionality offer the user and applicable stakeholders the ability to test manipulations of the river system and offer an avenue for communication rich in detail.

Conclusion

The U.S. inland waterway system holds great promise to serve as the backbone of multiple supply chain networks currently, and in the upcoming century. However, this promise is subdued by the increasingly perilous conditions found within the system. Shrinking budgets and rapidly declining balances in the Inland Waterways Trust Fund has made it increasingly difficult for the U.S. Army Corps of Engineers to keep up with the maintenance demands posed by infrastructure that is reaching the end of its designed lifespan.

Making recommendations about how to alleviate these problems is beyond the report scope. Rather, the main purpose was to give readers a snapshot of the major variables controlling traffic patterns on the Ohio River. Our study area encompassed a representative segment of the river stretching from Cincinnati to Locks and Dams 52 and 53, which are immediately upstream of the confluence of the Mississippi and Ohio rivers. The Ohio River remains a critical link in the U.S. energy supply chain. This is because of the large amounts of coal that are transported each year. While coal movements have declined slightly in recent years (due to energy suppliers increasingly opting for natural gas to generate electricity) there is little doubt that coal will remain a vital component of the energy portfolio for the foreseeable future. Knowing this information and that transporting cargo on the inland waterways is the most economic and environmentally friendly manner of moving freight, this report sought to develop a quantitative model that described inland waterway operations. Specifically, it has attempted to understand the critical variables that determine how quickly vessels are able to pass through lock and dam facilities.

The resulting models (see Appendix A for all of the regression models developed to explain variations in system behavior) focused on lockage and delay times. Lockage times encompass the period from when a vessel begins to lock through a facility to when it exits a facility. Delay times refer to the amount of time a vessel must wait after arriving at a facility to begin its lockage. All of the models that were produced rely principally on linear regression to predict the behavior of specific vessels. The most robust model generated during the research accounts for approximately two-thirds of the variation in lockage times ($R^2 = 0.69$). Accounting for this level of variation gives this model significant predictive utility, and potentially could be used to help stakeholders understand how long it will take vessels to pass a lock and dam facility under a particular constellation of conditions. This is important because it will give shippers and carriers the knowledge they need to more effectively time freight movements that optimize speed moving through the system.

Although our models handled lockage times quite well, we experienced less success with predicting delay times; the most robust model accounted for just under a quarter of total variation (R^2 = 0.23). The diminished level of predictive success associated with the delay model is attributable to more instability. This partly reflects the spillover from one vessel to the next that we rely on the simulation to impose. Future modeling efforts should attempt to determine more precise explanations for why current efforts have accounted for a fraction of the variation in delay times.

Using the regression results, along with statistical distributions of travel times based on a sample of vessel trips, we developed an animated computer simulation that gives users the opportunity to manipulate variables to understand how shifting conditions amongst different factors influences travel times for vessels. This simulation, although in many ways preliminary, establishes a platform that future modeling efforts could use as a springboard. Additionally, it offers the benefit of visualizing traffic patterns and river conditions as opposed to relying solely on the outputs of regression analyses – which, although useful, can sometimes be cumbersome to interpret for those who are unfamiliar with statistics. Perhaps it is best to view the results obtained to this point as a foundation upon which modeling work can build regarding subsequent research projects.

There are a number of system components that remained under-explored because they were beyond the ambition of this project. To achieve a fully calibrated (and validated) model of the entire river system, it will be necessary to develop more accurate modeling techniques to understand what factors affect the speed of vessel movements between lock and dam facilities (i.e. within river pools). Our simulations, at the moment, rely heavily on statistical averages and probability density functions that do not represent the full complexity of vessel behavior. Future research, however, could refine these initial forays into understanding pool travel times.

Another priority of future work should be focused on synchronizing models into a single package. This will enable simulations that are entirely underwritten by regression analyses – but it is possible more sophisticated methods will be required to develop a complete picture of the system's behavior and variability. Arguably, the results obtained from this project constitute a good starting point to pursue new avenues of research. It will be essential to continually find innovative ways to improve our understanding of the inland waterways if they are to remain a critical part of the country's infrastructure in the years to come. Though there remains great uncertainty over funding levels. This relates to the capacity of the U.S. Army Corps of Engineers (and other agencies) to tackle large scale projects. One of the potential benefits of refining and expanding upon the investigation undertaken is to show how essential and viable the waterways are for efficiently transporting freight - particularly across the Eastern and Central portions of the U.S.

The waterways are threads that solder together domestic and international trade networks – which is why they are critical. Future research will not only have to contend with funding issues but also the role climatic variability will play in shaping its operation. While there is uncertainty over this question, it is indisputable that the climate is changing and will eventually impact river behavior. Of primary concern is how a changing climate will influence key factors (such as discharge and river stage), which significantly impacts vessels and U.S. Army Corps of Engineers efforts to maintain navigable channel depths. The variability seen on the Mississippi River in 2011 and 2012 could be a precursor of what is to come. Climate is an externality that will be an integral aspect of future model development.

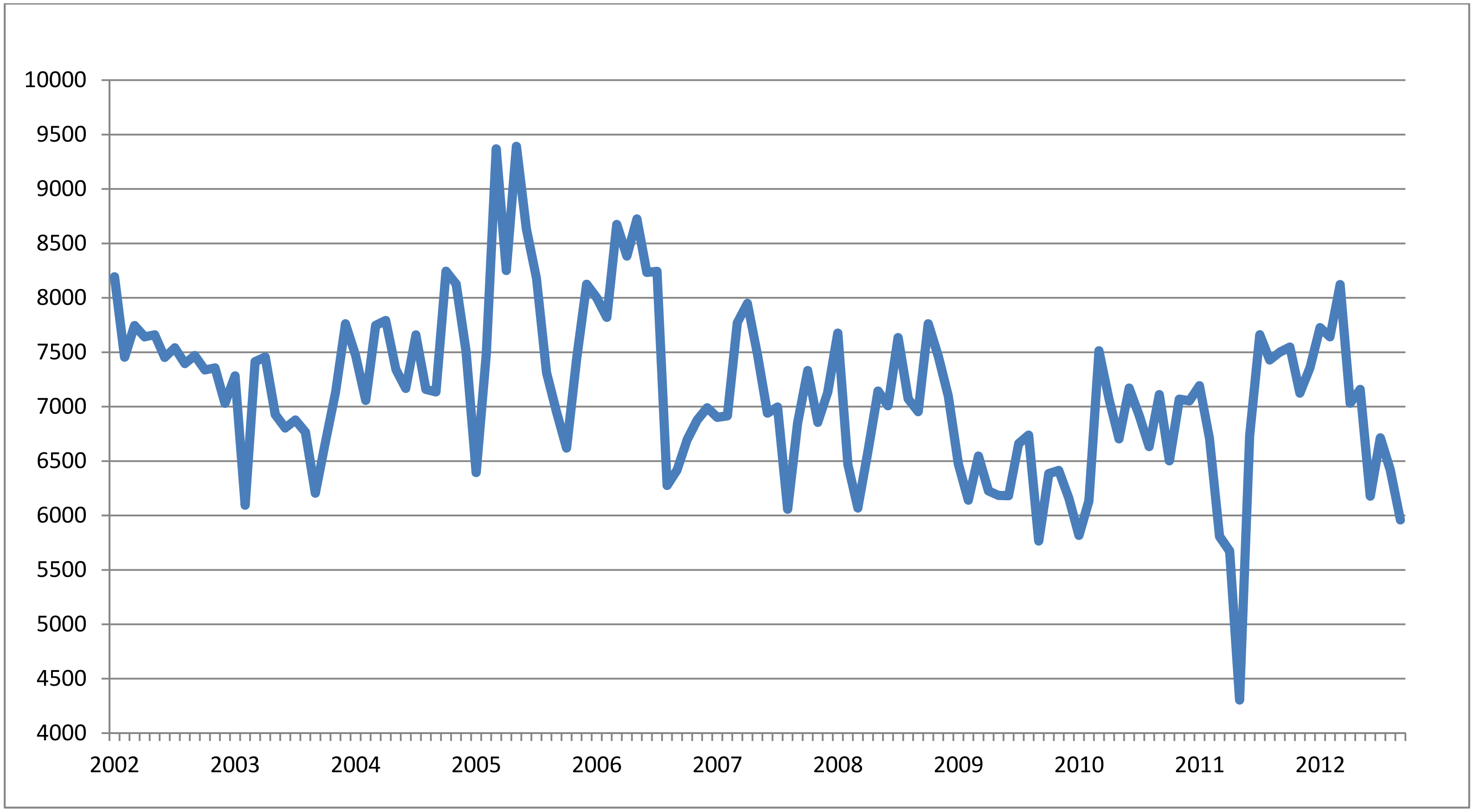
Indeed, without a firm understanding of how the system will behave under a wide range of conditions, the viability of the inland waterways as a reliable mode of transportation will remain unclear. Although statistical modeling cannot be entirely predictive or offer all of the solutions to the challenges facing us, it does represent a powerful tool that can illuminate how waterways react to different constraints. If this knowledge can be put to use by stakeholders to modestly enhance the performance of the inland waterways and develop adaptive management and operational procedures so they remain functional and resilient well into an uncertain future, its value is inestimably large.

Appendices

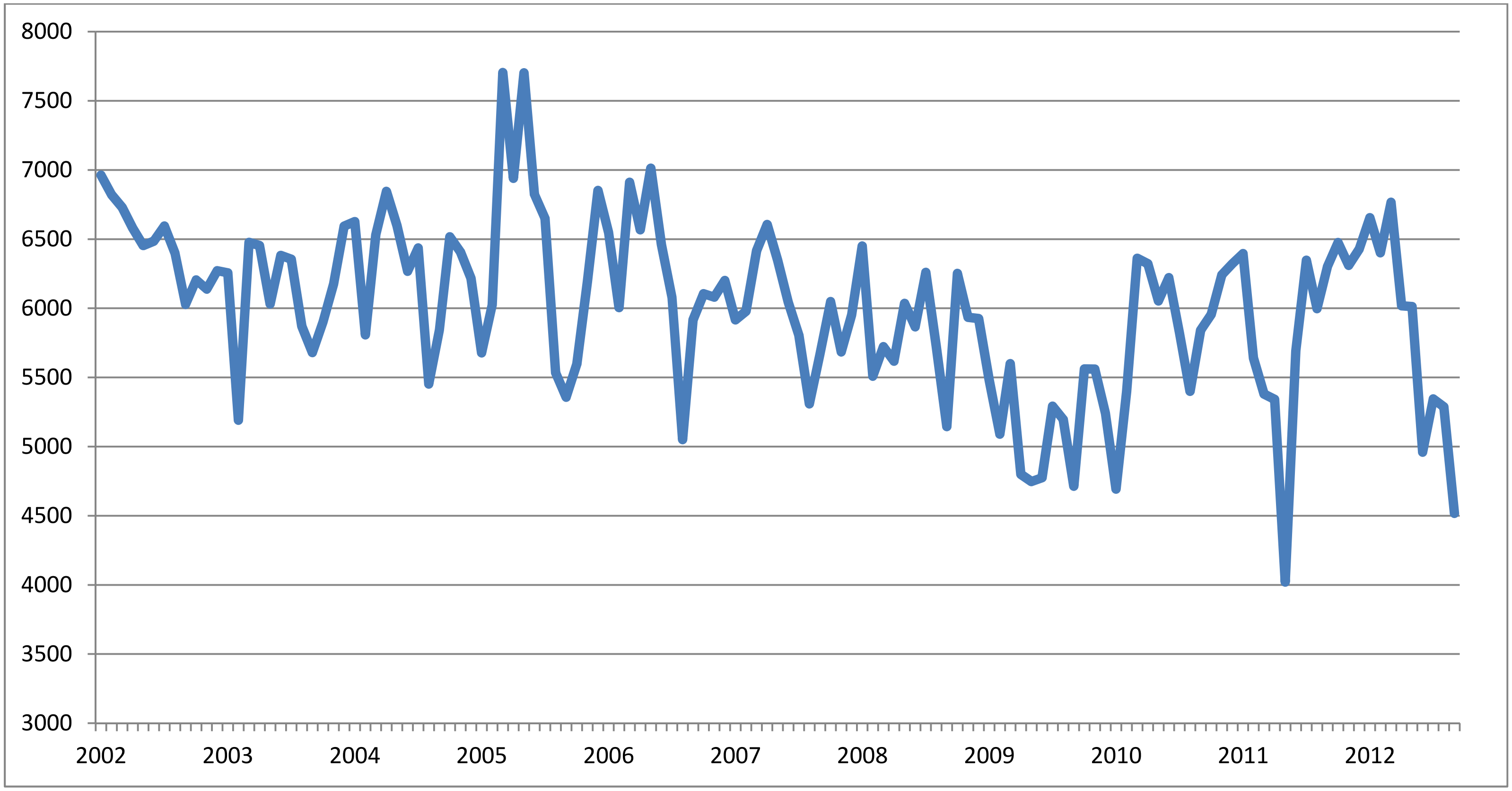
LPMS Data Analysis Tables
Other Data Source Tables
DES Model
Regression Models
Simulation Programming

Monthly Trips by Lock

Lock 52



Lock 53



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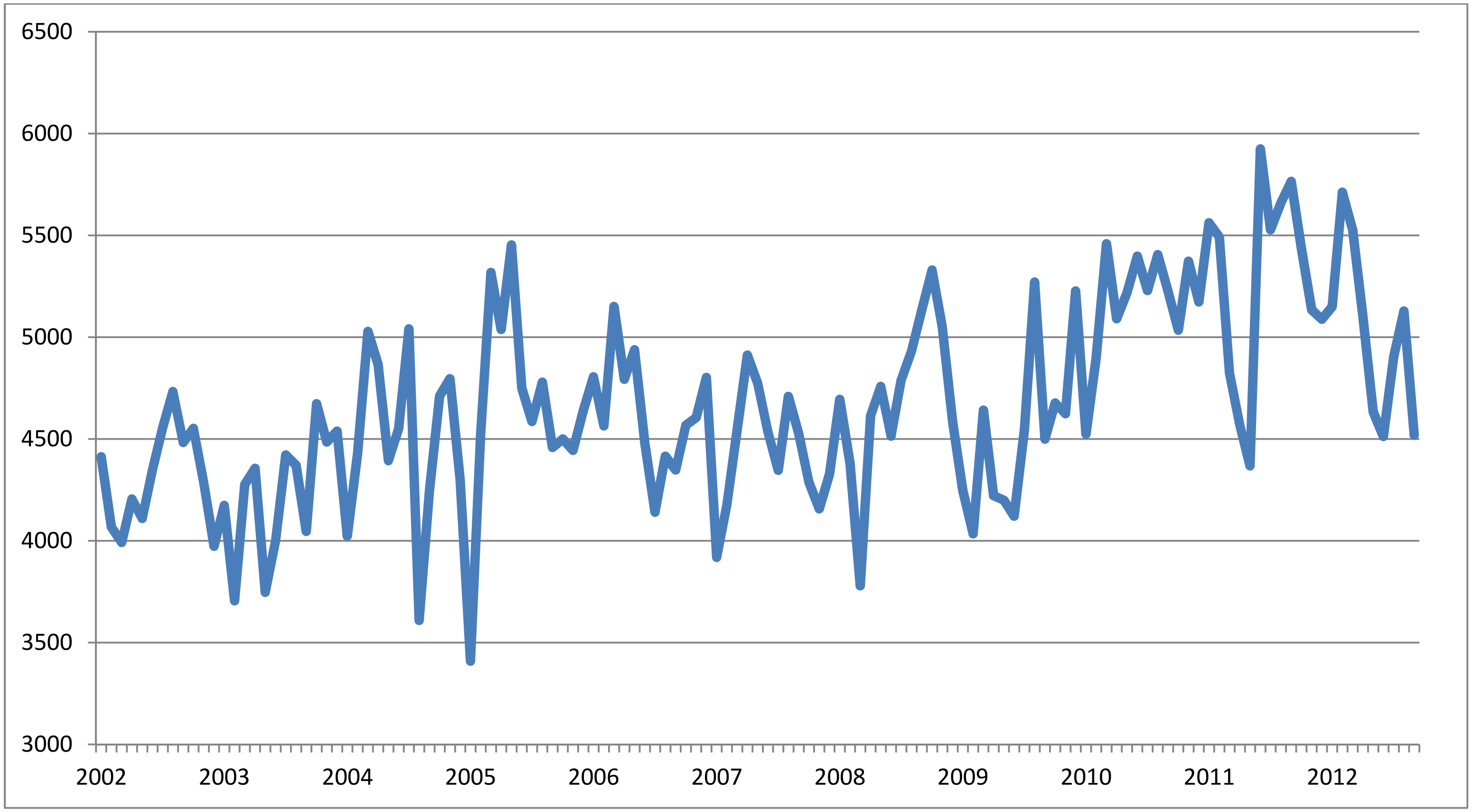
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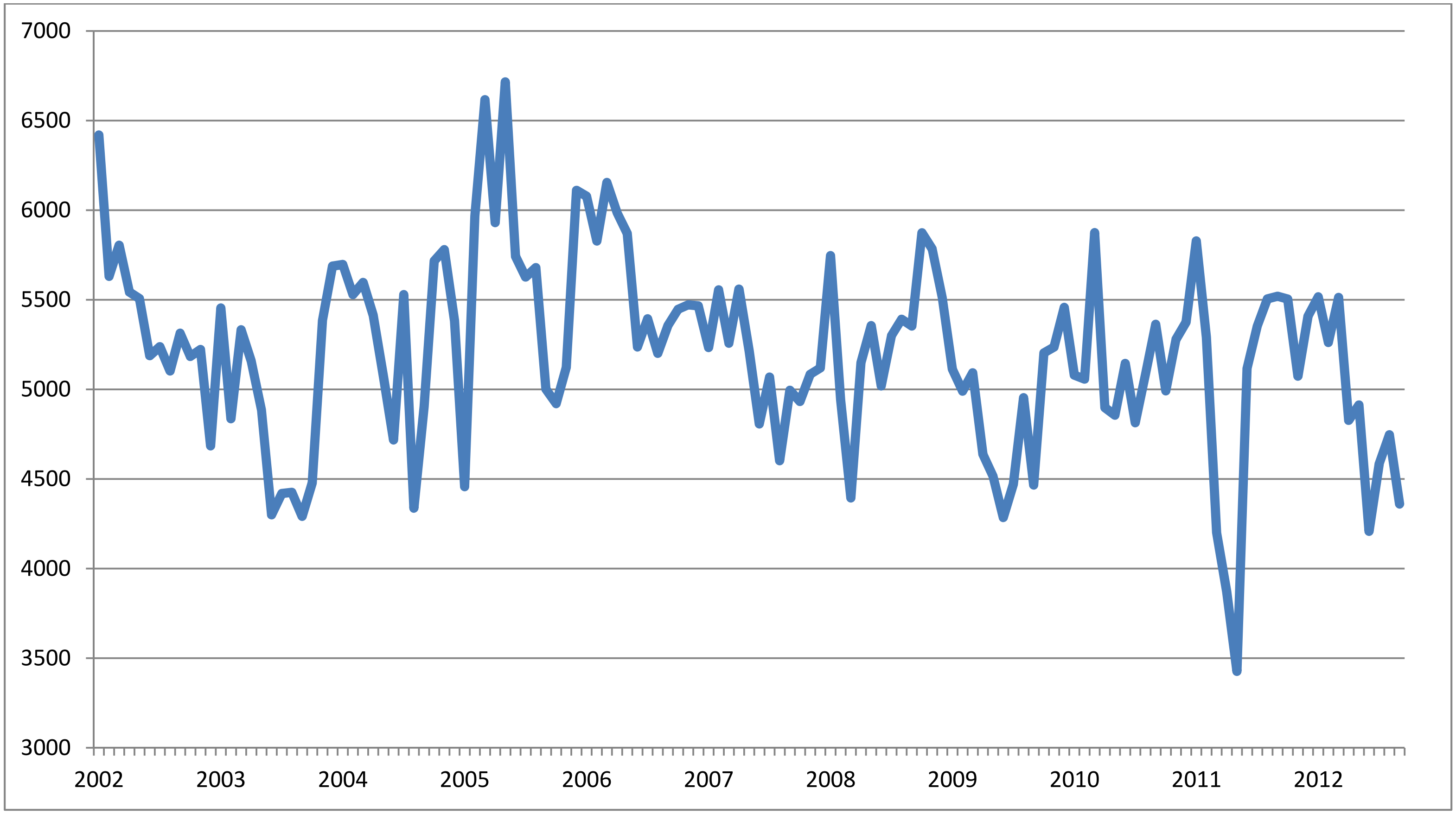
John T. Myers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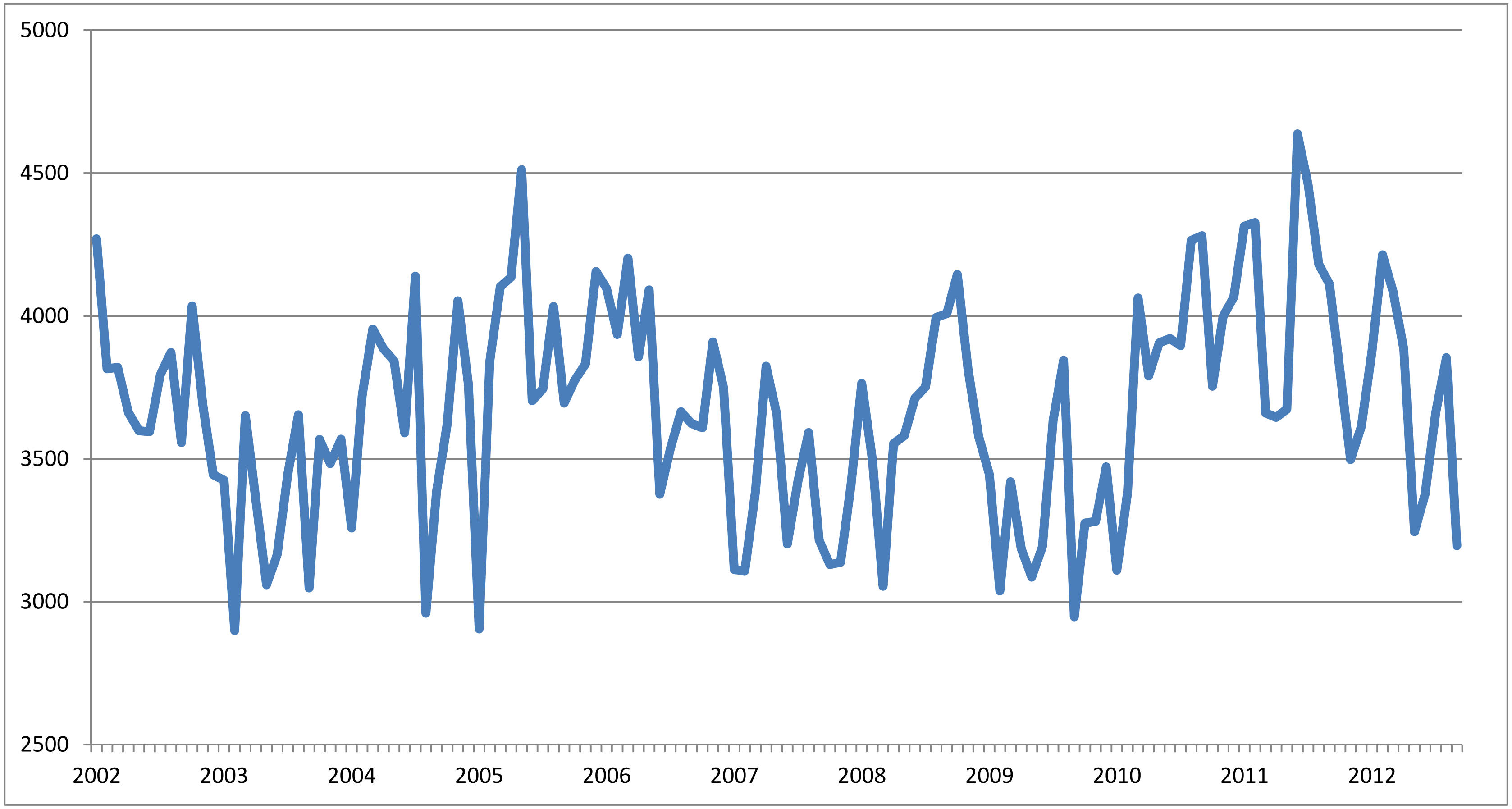
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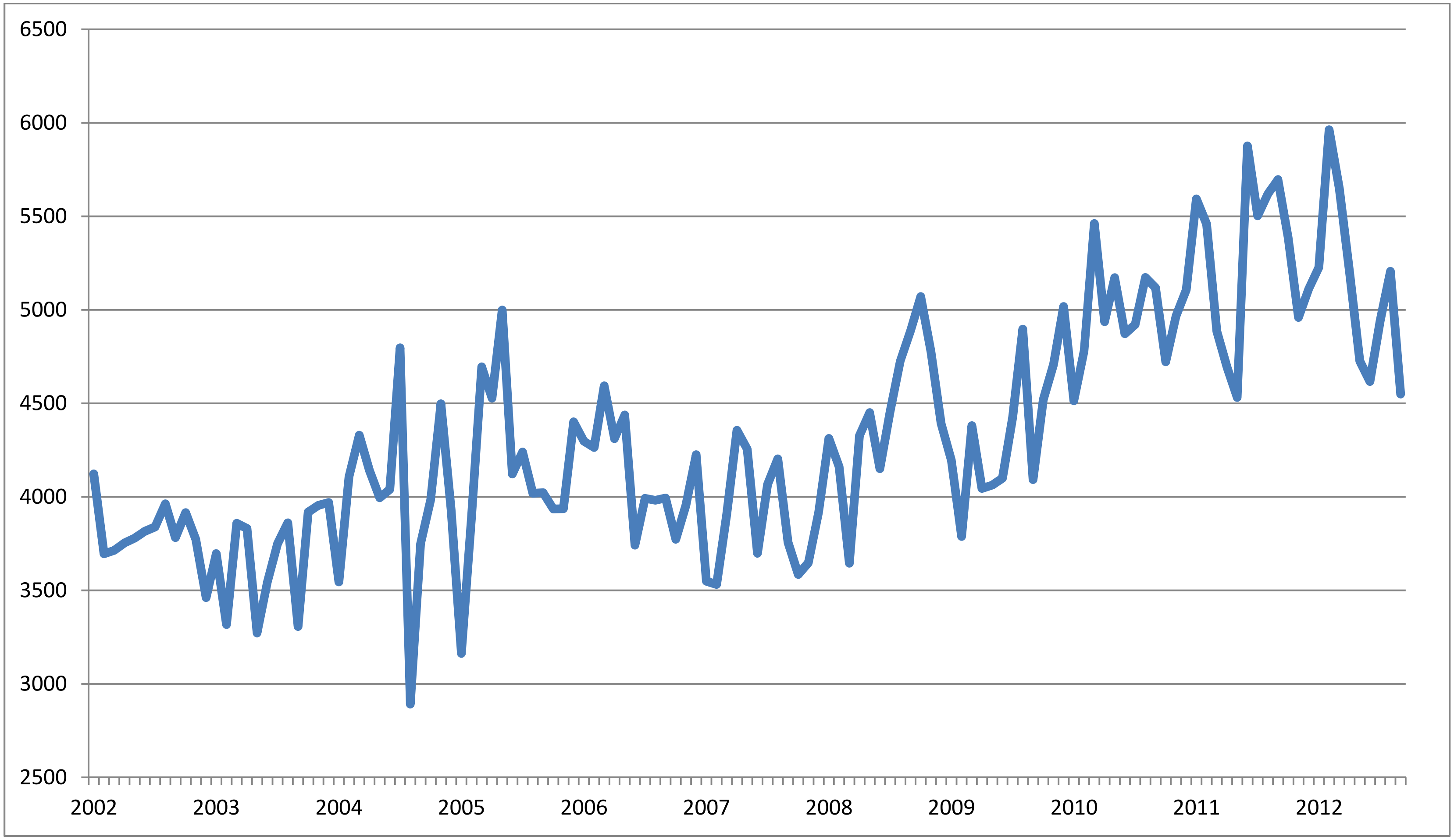
McAlpine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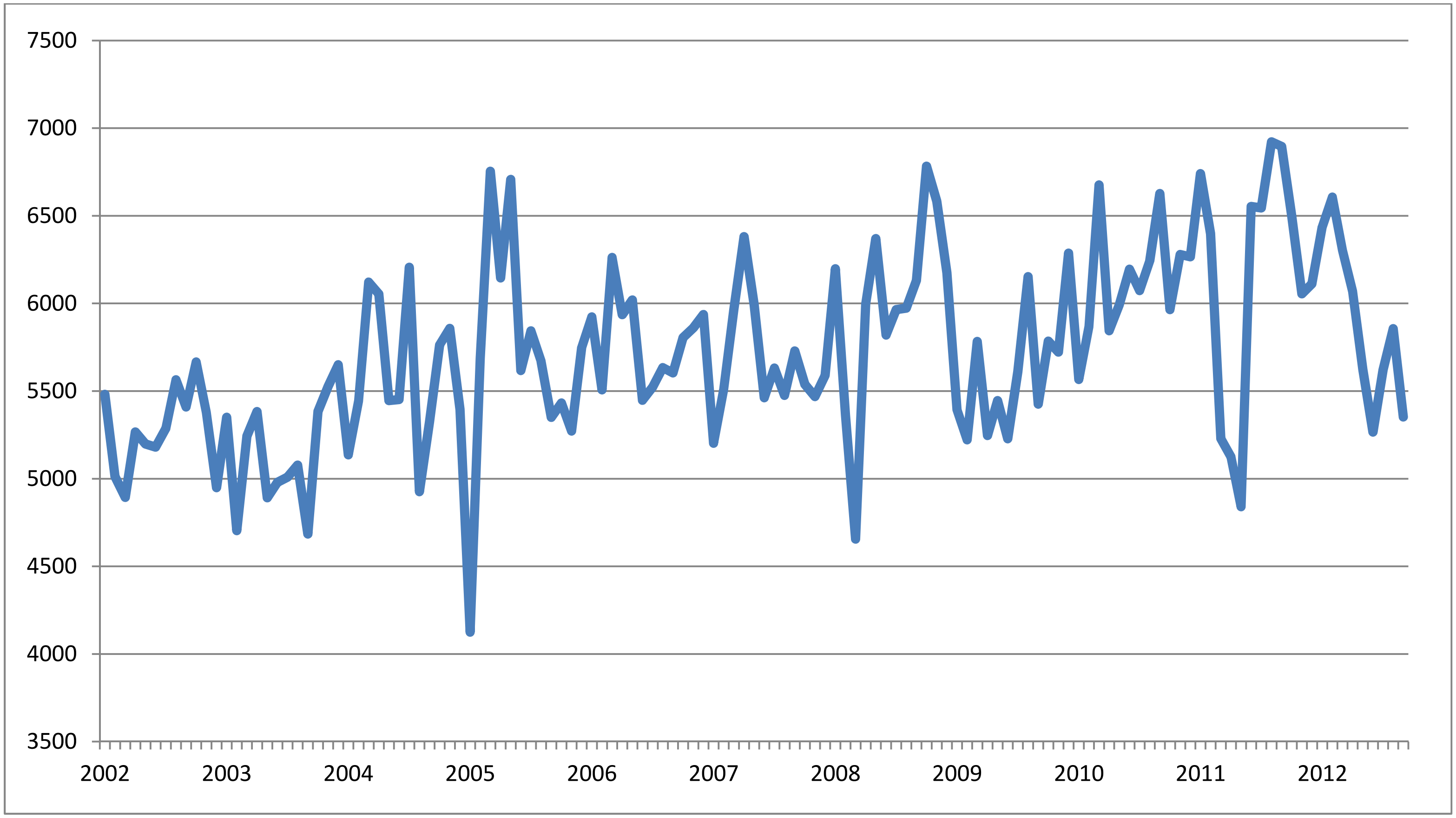

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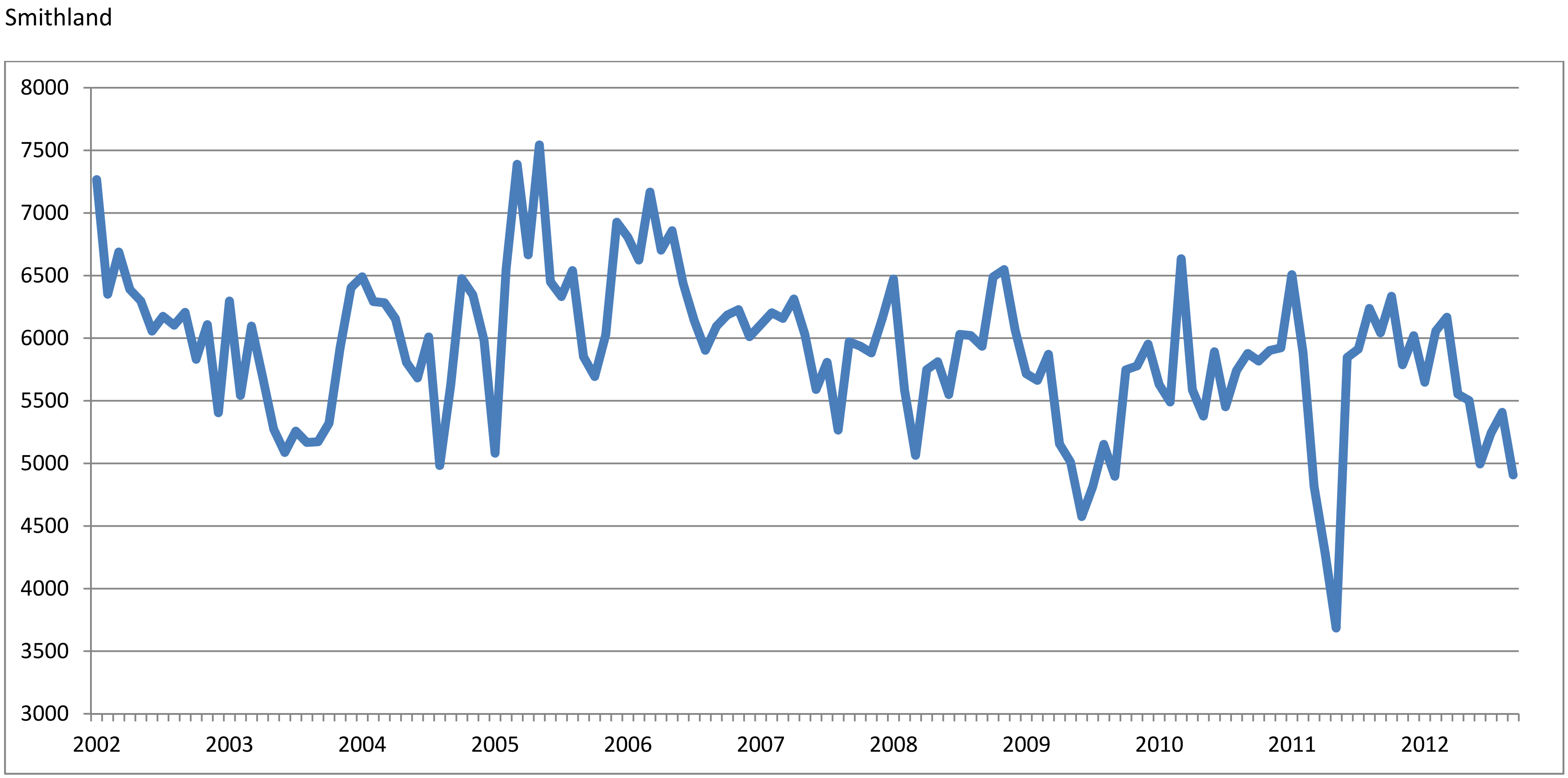

Smithland
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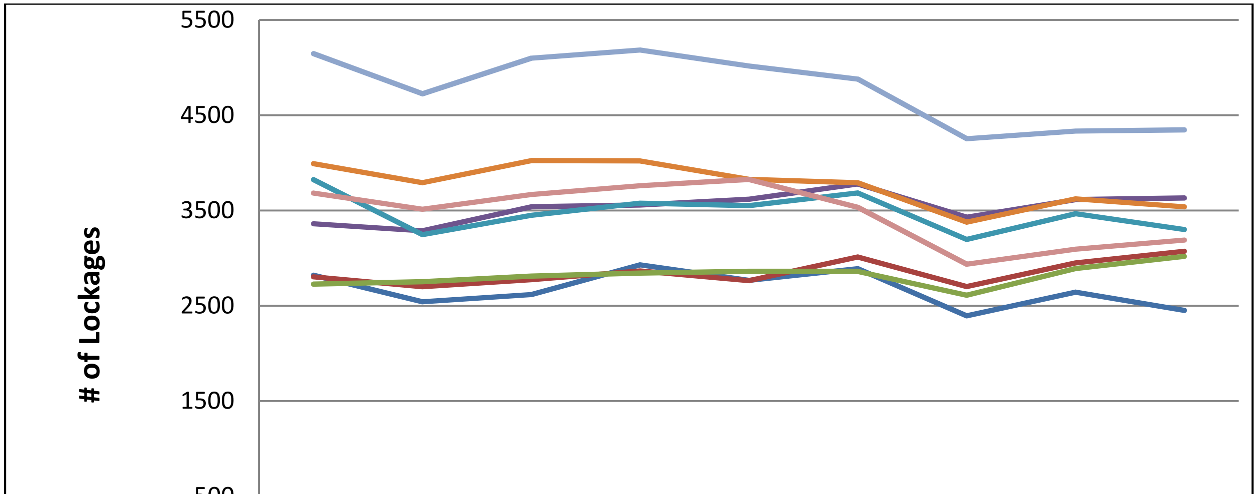
Annual number of trips at selected Ohio River lock and dam facilities

Source: LPMS



	2002	2003	2004	2006	2007	2008	2009	2010	2011
Markland	2821	2542	2617	2930	2766	2889	2395	2642	2451
McApline	2804	2699	2774	2865	2764	3011	2702	2950	3072
Cannelton	2727	2751	2811	2843	2861	2860	2610	2891	3018
Newburgh	3360	3286	3539	3557	3618	3778	3430	3614	3631
John T. Myers	3824	3246	3450	3577	3551	3684	3197	3467	3301
Smithland	3991	3792	4024	4020	3827	3790	3377	3622	3539
52	5146	4725	5099	5184	5017	4879	4253	4333	4345
53	3682	3514	3668	3760	3825	3533	2936	3094	3190

Lock 52	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	90,967,894	89,877,746	79,762,180	89,660,443	88,953,035	96,403,710	97,325,729	94,954,424	87,419,731	93,381,739	96,710,124	94,686,283
10 - All Coal, Lignite, and Coal Coke	37,445,479	34,729,577	30,018,629	34,425,270	28,837,700	29,321,501	30,110,363	25,509,614	23,080,399	28,552,314	29,729,412	24,569,905
20 - All Petroleum and Petroleum Products	3,961,906	4,015,974	3,967,798	4,799,227	6,011,909	6,393,622	7,150,309	7,270,020	6,804,931	7,386,909	9,121,167	9,309,697
30 - All Chemicals and Related Products	8,355,123	8,644,690	7,320,079	8,643,575	9,645,846	9,493,289	10,077,149	10,147,081	9,852,823	9,236,785	9,242,588	10,250,922
40 - All Crude Materials, Inedible, Except Fuels	26,974,108	27,568,006	24,160,158	25,736,101	27,726,606	32,017,694	30,142,005	30,534,268	28,470,855	26,228,851	25,596,224	25,543,539
50 - All Primary Manufactured Goods	3,931,837	3,114,511	2,889,806	5,785,534	6,659,691	8,348,745	8,049,316	8,474,900	7,590,300	6,911,683	6,761,566	9,024,093
60 - All Food and Farm Products	10,018,227	11,517,704	11,131,496	9,893,170	9,634,901	10,224,487	10,471,711	11,729,006	10,164,022	11,641,322	12,532,834	11,054,334
70 - All Manufactured Equipment & Machinery	108,557	102,479	140,281	161,590	129,198	128,996	316,141	117,901	136,282	1,231,617	1,771,162	2,590,226
80 - All Waste Material	8,411	14,150	12,500	10,000	18,800	3,100	14,400	4,600	3,250	3,143	7,300	11,300
90 - All Unknown or Not Elsewhere Classified - 90	164,246	170,655	121,433	205,976	288,384	472,276	994,335	1,167,034	1,316,869	2,189,115	1,947,871	2,332,267

Lock 53	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	81,160,173	79,628,233	67,787,247	77,823,840	78,274,085	84,969,978	85,844,718	85,459,437	81,729,614	85,614,147	86,971,493	89,153,252
10 - All Coal, Lignite, and Coal Coke	28,046,705	23,926,464	18,372,059	22,937,277	18,830,706	19,481,193	19,515,985	17,162,251	15,509,075	20,582,801	21,176,023	19,621,641
20 - All Petroleum and Petroleum Products	4,298,890	4,465,382	4,313,267	5,233,932	6,119,752	6,547,152	7,301,351	7,584,647	7,122,176	7,852,810	9,538,329	9,527,765
30 - All Chemicals and Related Products	8,505,771	8,799,838	7,509,703	8,801,003	10,044,227	9,974,177	10,374,291	10,400,246	10,204,282	9,447,323	9,418,292	10,335,773
40 - All Crude Materials, Inedible, Except Fuels	25,151,415	26,119,900	21,381,576	23,955,171	25,437,147	28,644,289	27,670,032	27,498,327	27,079,372	24,183,052	23,259,005	24,096,557
50 - All Primary Manufactured Goods	4,112,635	3,519,940	3,447,279	6,493,096	7,332,713	8,785,864	8,566,634	8,862,115	8,351,123	7,507,421	7,074,038	9,423,972
60 - All Food and Farm Products	10,828,004	12,567,563	12,581,238	10,222,016	10,358,622	11,392,394	11,334,362	12,849,671	12,043,636	12,647,448	12,767,280	11,259,612
70 - All Manufactured Equipment & Machinery	102,402	95,205	147,648	168,345	132,076	116,261	288,802	91,605	128,677	1,215,194	1,755,599	2,534,110
80 - All Waste Material	13,900	13,850	14,250	10,000	15,800		7,500	9,100	3,250	1,743	4,500	12,985
90 - All Unknown or Not Elsewhere Classified - 90	100,451	120,091	20,227	3,000	3,042	28,648	785,761	1,001,475	1,288,023	2,176,355	1,978,427	2,340,837

Cannelton	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	72,305,153	67,974,378	56,792,867	58,061,097	52,641,143	58,886,988	58,310,461	56,888,368	54,001,876	55,840,895	56,653,105	55,786,612
10 - All Coal, Lignite, and Coal Coke	46,081,298	40,695,449	34,039,788	30,022,809	21,637,454	24,244,238	23,100,908	20,068,999	18,551,926	22,027,247	21,491,474	18,095,280
20 - All Petroleum and Petroleum Products	2,937,389	2,715,937	2,912,703	3,357,843	3,871,678	4,683,741	4,195,173	4,394,660	4,358,926	3,856,876	4,630,731	4,528,642
30 - All Chemicals and Related Products	5,322,075	5,472,590	4,767,192	5,731,892	6,440,044	6,351,084	6,861,829	6,610,300	6,514,444	6,028,432	5,870,112	6,534,035
40 - All Crude Materials, Inedible, Except Fuels	12,694,649	12,921,260	10,177,482	12,344,296	13,306,504	14,876,061	14,841,360	15,708,232	15,805,670	13,453,975	13,237,242	13,687,723
50 - All Primary Manufactured Goods	2,497,254	2,168,776	1,600,195	3,639,444	4,020,445	4,944,622	5,269,671	5,712,053	4,996,504	4,960,622	4,599,086	6,382,820
60 - All Food and Farm Products	2,592,537	3,738,830	3,019,862	2,458,225	2,849,835	3,266,259	3,297,914	3,484,993	2,623,958	3,102,775	3,873,286	3,312,023
70 - All Manufactured Equipment & Machinery	65,945	91,960	113,798	128,014	218,004	155,695	179,150	132,478	134,486	802,841	1,347,214	1,379,569
80 - All Waste Material	1,700	4,000	6,000	2,000	7,800			7,900	5,280	8,500		1,500
90 - All Unknown or Not Elsewhere Classified - 90	112,306	165,576	155,847	376,574	289,379	365,288	564,456	768,753	1,010,682	1,599,627	1,603,960	1,865,020

John T. Myers	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	72,163,999	71,500,600	63,280,721	69,506,212	64,565,146	72,168,865	71,879,958	67,854,575	62,655,573	68,964,140	75,279,059	72,450,329
10 - All Coal, Lignite, and Coal Coke	41,287,636	39,706,206	36,235,301	36,330,808	28,649,295	32,652,260	31,493,802	26,293,332	23,660,274	30,095,140	33,658,145	28,535,982
20 - All Petroleum and Petroleum Products	3,538,373	3,229,056	3,371,138	4,093,698	4,999,939	5,380,544	4,916,009	4,832,107	5,075,984	5,421,438	6,392,251	6,342,214
30 - All Chemicals and Related Products	6,647,147	6,800,091	5,725,536	7,004,323	7,775,584	7,514,931	8,135,071	7,852,127	7,685,761	7,238,004	6,975,972	7,781,767
40 - All Crude Materials, Inedible, Except Fuels	10,871,823	10,961,783	8,248,466	11,252,192	12,036,737	13,459,638	13,850,849	14,463,682	13,871,113	11,639,480	11,743,155	12,193,581
50 - All Primary Manufactured Goods	2,737,223	2,388,456	1,887,018	3,853,418	4,283,017	5,497,963	5,789,349	6,196,100	5,379,957	5,398,756	5,150,367	7,227,426
60 - All Food and Farm Products	6,805,341	8,072,532	7,527,339	6,424,999	6,379,254	7,127,315	6,925,787	7,216,554	5,753,917	6,462,176	8,136,355	6,936,907
70 - All Manufactured Equipment & Machinery	83,475	92,880	116,791	159,757	157,807	124,610	128,480	153,293	119,291	910,870	1,426,843	1,476,013
80 - All Waste Material	10,200	13,450		2,000	10,800	4,600		10,500	5,530	2,743	1,500	3,000
90 - All Unknown or Not Elsewhere Classified - 90	182,781	236,146	169,132	385,017	272,713	407,004	640,611	836,880	1,103,746	1,795,533	1,794,471	1,953,439

Markland	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	61,400,920	57,595,083	47,323,224	53,191,406	46,062,181	52,696,926	53,847,422	50,049,799	45,247,538	49,624,602	55,805,813	56,056,176
10 - All Coal, Lignite, and Coal Coke	37,024,515	32,847,530	26,688,216	27,169,661	18,158,739	22,163,060	22,009,175	18,236,713	14,828,772	19,363,618	23,944,751	21,669,220
20 - All Petroleum and Petroleum Products	4,374,487	4,857,227	4,919,616	5,710,715	5,863,733	5,887,110	5,344,691	4,614,878	4,894,940	4,882,907	5,678,756	5,218,237
30 - All Chemicals and Related Products	4,528,156	4,570,185	3,922,253	4,964,679	5,712,329	5,498,921	5,925,309	5,611,735	5,498,305	5,226,269	5,099,133	5,617,607
40 - All Crude Materials, Inedible, Except Fuels	11,127,790	10,194,193	7,900,295	9,892,707	10,035,497	11,564,716	12,321,075	12,621,574	12,046,918	10,603,375	10,850,390	12,236,569
50 - All Primary Manufactured Goods	2,317,907	2,169,196	1,576,674	3,237,351	3,665,713	4,767,071	5,119,891	5,544,776	5,018,641	4,861,908	4,489,697	5,822,719
60 - All Food and Farm Products	1,804,779	2,706,296	2,097,080	1,768,182	2,161,365	2,406,580	2,551,217	2,735,499	1,985,120	2,306,906	2,878,140	2,523,220
70 - All Manufactured Equipment & Machinery	86,645	99,065	88,988	79,010	182,022	92,780	146,530	87,585	94,320	731,890	1,268,413	1,181,789
80 - All Waste Material			6,000		6,300	3,000	6,100	6,950	5,280		1,500	1,500
90 - All Unknown or Not Elsewhere Classified - 90	136,641	151,391	124,102	369,101	276,483	313,688	423,434	590,089	875,242	1,647,729	1,595,033	1,785,315

McAlpine	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	73,589,479	67,659,818	55,872,708	57,318,568	49,141,306	55,204,934	55,695,237	52,753,233	49,482,158	51,870,711	56,166,704	55,803,713
10 - All Coal, Lignite, and Coal Coke	45,726,078	39,120,222	32,183,410	28,284,320	18,127,516	21,566,255	20,610,934	17,439,420	16,014,634	18,817,243	21,149,154	19,099,728
20 - All Petroleum and Petroleum Products	4,596,906	4,985,072	5,055,111	5,848,155	5,981,136	6,072,265	5,666,141	4,835,880	5,207,286	5,133,182	5,922,192	5,381,801
30 - All Chemicals and Related Products	5,016,364	5,192,573	4,416,105	5,416,878	6,264,554	5,993,279	6,476,399	6,318,218	6,087,643	5,793,485	5,653,168	6,161,979
40 - All Crude Materials, Inedible, Except Fuels	12,715,492	11,709,544	9,114,650	10,943,322	11,072,323	12,484,983	13,085,358	13,518,933	12,842,213	11,134,948	11,379,976	12,060,212
50 - All Primary Manufactured Goods	2,711,247	2,553,286	1,847,213	3,880,434	4,313,435	5,363,746	5,884,115	6,365,231	5,671,219	5,735,066	5,398,152	6,673,635
60 - All Food and Farm Products	2,573,746	3,743,520	2,981,320	2,409,120	2,796,022	3,207,009	3,252,508	3,432,405	2,631,099	3,084,924	3,840,940	3,344,296
70 - All Manufactured Equipment & Machinery	86,182	161,685	117,297	185,945	283,302	142,945	185,735	157,473	148,860	811,764	1,317,698	1,344,039
80 - All Waste Material	1,700	8,000	6,000	2,000	7,800	1,500	3,700	13,350	5,280	9,800	1,500	1,500
90 - All Unknown or Not Elsewhere Classified - 90	161,764	185,916	151,602	348,394	295,218	372,952	530,347	672,323	873,924	1,350,299	1,503,924	1,736,523

Newburgh	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	81,828,616	78,301,824	68,289,788	71,228,447	65,132,826	69,188,293	67,475,208	67,151,167	62,475,964	64,198,484	66,527,886	64,450,887
10 - All Coal, Lignite, and Coal Coke	52,492,342	47,643,606	42,670,730	39,262,559	30,356,089	30,599,814	28,166,292	26,234,488	23,905,022	27,197,588	27,736,210	23,004,757
20 - All Petroleum and Petroleum Products	3,328,498	3,057,724	3,104,303	3,781,658	4,420,530	5,218,778	4,713,376	4,958,672	4,585,697	4,419,809	5,072,198	5,135,204
30 - All Chemicals and Related Products	5,789,508	5,962,867	5,119,359	6,119,269	6,853,232	6,694,693	7,302,650	6,946,114	6,903,433	6,433,708	6,249,203	6,940,601
40 - All Crude Materials, Inedible, Except Fuels	13,009,239	13,532,534	10,647,058	13,900,920	14,734,802	16,314,183	16,442,708	17,396,678	16,941,479	14,133,810	14,210,314	14,675,328
50 - All Primary Manufactured Goods	2,700,712	2,282,891	1,739,120	3,807,063	4,290,174	5,356,685	5,659,897	6,122,021	5,390,660	5,214,563	4,928,962	6,997,747
60 - All Food and Farm Products	4,284,259	5,477,691	4,672,763	3,764,917	3,966,810	4,461,781	4,396,577	4,507,655	3,536,741	4,089,655	5,131,183	4,383,596
70 - All Manufactured Equipment & Machinery	117,230	142,695	153,693	197,092	187,014	125,753	136,132	162,337	129,595	885,666	1,411,425	1,413,645
80 - All Waste Material	1,700	4,000	6,000	2,000	7,800			13,900	5,530	11,736	3,000	6,000
90 - All Unknown or Not Elsewhere Classified - 90	105,128	197,816	176,762	392,969	316,375	416,606	657,576	809,302	1,077,807	1,811,949	1,785,391	1,894,009

Smithland	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
All Commodities	77,707,781	78,404,771	68,254,151	77,098,337	73,679,422	81,025,336	80,696,611	77,019,752	72,304,979	79,040,926	85,915,439	82,519,665
10 - All Coal, Lignite, and Coal Coke	43,268,558	42,203,579	37,847,213	40,797,749	33,955,011	36,298,065	35,528,701	30,941,776	28,811,268	35,994,865	40,402,297	35,548,386
20 - All Petroleum and Petroleum Products	3,466,982	3,246,156	3,369,867	4,096,863	5,070,752	5,418,022	4,929,813	4,925,308	5,049,868	5,469,495	6,374,238	6,353,683
30 - All Chemicals and Related Products	6,765,224	6,851,607	5,781,008	7,089,262	7,796,874	7,560,695	8,186,564	7,919,916	7,773,386	7,265,930	7,131,397	7,890,327
40 - All Crude Materials, Inedible, Except Fuels	13,610,137	14,299,976	10,558,173	13,547,707	14,920,740	17,797,253	17,945,636	18,220,569	17,836,233	15,104,778	14,870,869	14,547,552
50 - All Primary Manufactured Goods	2,737,250	2,392,300	1,936,163	3,867,022	4,375,446	5,548,702	5,804,207	6,285,272	5,422,593	5,378,132	5,120,778	7,161,030
60 - All Food and Farm Products	7,530,797	9,062,612	8,434,669	7,161,780	7,119,690	7,891,375	7,523,329	7,778,457	6,191,370	7,010,383	8,791,076	7,525,995
70 - All Manufactured Equipment & Machinery	118,330	95,410	135,971	121,862	156,104	109,180	119,970	115,289	107,906	912,648	1,409,587	1,462,647
80 - All Waste Material	10,200	16,950		2,000	11,800	1,600	9,000	1,500	2,330	4,236	1,500	
90 - All Unknown or Not Elsewhere Classified - 90	200,303	236,181	191,087	414,092	273,005	400,444	649,391	831,665	1,110,025	1,900,459	1,813,697	2,030,045

Whole Ohio River

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)	186	165	201	221	109	31	43	16	169	40	19	9	47	31	25	66	46	28	101
Scheduled Unavailable Time (Hrs)	5,215.46	9,256.53	10,079.96	11,914.61	7,119.10	2,386.06	3,251.29	864.68	6,778.80	5,935.82	2,979.07	1,595.43	4,032.58	2,324.18	3,963.55	4,479.27	5,367.28	6,910.98	7,092.58
Unscheduled unavailability (#)	797	1,532	1,071	1,364	1,054	833	1,012	1,213	1,155	1,151	1,393	1,674	1,500	1,887	1,935	2,028	2,459	2,275	907
Unscheduled Unavailable Time (Hrs)	2,770.30	4,854.06	2,091.80	6,674.59	5,734.43	5,699.20	6,622.38	6,210.92	5,862.73	9,559.38	9,347.35	14,674.42	11,290.08	13,280.88	13,278.20	9,617.38	16,828.57	23,431.23	4,377.85
Unavailable Time (Hrs)	7,985.76	14,110.59	12,171.76	18,589.20	12,853.53	8,085.26	9,873.67	7,075.60	12,641.53	15,495.20	12,326.42	16,269.85	15,322.67	15,605.07	17,241.75	14,096.65	22,195.85	30,342.22	11,470.43
unavailability (#)	983	1,697	1,272	1,585	1,163	864	1,055	1,229	1,324	1,191	1,412	1,683	1,547	1,918	1,960	2,094	2,505	2,303	1,008

Lock 53

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)																			4
Scheduled Unavailable Time (Hrs)																			4.62
Unscheduled unavailability (#)							44	23	6	4	1			5	11	1			42
Unscheduled Unavailable Time (Hrs)							76.27	39.58	5.57	1,467.30	671.98			11.17	14.25	2.33			51.32
Unavailable Time (Hrs)	0.00	0.00	0.00	0.00	0.00	0.00	76.27	39.58	5.57	1,467.30	671.98	0.00	0.00	11.17	14.25	2.33	0.00	0.00	55.93
unavailability (#)	0	0	0	0	0	0	44	23	6	4	1	0	0	5	11	1	0	0	46

Lock 52

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)			18	31	7								1			1	2		2
Scheduled Unavailable Time (Hrs)			86.38	278.85	5.86								141.50			302.25	334.98		10.32
Unscheduled unavailability (#)	13	133	109	33	62	42	70	106	79	88	12	20	33	90	88	76	146	132	50
Unscheduled Unavailable Time (Hrs)	16.59	155.16	189.46	64.44	146.62	311.69	278.98	202.07	144.68	171.37	42.78	42.80	1,588.23	1,099.92	209.50	171.45	1,139.23	3,834.52	111.73
Unavailable Time (Hrs)	16.59	155.16	275.84	343.29	152.48	311.69	278.98	202.07	144.68	171.37	42.78	42.80	1,729.73	1,099.92	209.50	473.70	1,474.22	3,834.52	122.05
unavailability (#)	13	133	127	64	69	42	70	106	79	88	12	20	34	90	88	77	148	132	52

Smithland

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)	4		88	17	3				2	4					2				6
Scheduled Unavailable Time (Hrs)	748.95		378.02	167.12	242.81				7.50	8.10					24.75				35.82
Unscheduled unavailability (#)	243	425	341	293	232	185	146	221	204	272	309	450	447	389	490	408	480	546	232
Unscheduled Unavailable Time (Hrs)	360.77	508.84	266.88	271.67	657.45	427.37	125.87	198.82	213.43	746.08	332.92	474.45	812.75	488.65	480.90	553.85	911.40	1,611.47	246.78
Unavailable Time (Hrs)	1,109.72	508.84	644.90	438.79	900.26	427.37	125.87	198.82	220.93	754.18	332.92	474.45	812.75	488.65	505.65	553.85	911.40	1,611.47	282.60
unavailability (#)	247	425	429	310	235	185	146	221	206	276	309	450	447	389	492	408	480	546	238

John T. Myers

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)	2	2	6	24	7						1			2		2	2	1	13
Scheduled Unavailable Time (Hrs)	2.38	3.67	314.75	439.41	9.70						592.98			400.52		0.60	0.55	266.83	11.17
Unscheduled unavailability (#)	78	104	135	241	158	111	76	89	121	100	191	125	96	179	141	198	286	231	94
Unscheduled Unavailable Time (Hrs)	132.57	140.71	109.62	304.16	436.33	201.28	56.82	347.78	733.85	883.77	1,455.40	633.90	49.33	562.00	643.50	997.90	603.85	757.72	80.32
Unavailable Time (Hrs)	134.95	144.38	424.37	743.57	446.03	201.28	56.82	347.78	733.85	883.77	2,048.38	633.90	49.33	962.52	643.50	998.50	604.40	1,024.55	91.48
unavailability (#)	80	106	141	265	165	111	76	89	121	100	192	125	96	181	141	200	288	232	107

Newburgh

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)	1			2						1			1			2	1	2	10
Scheduled Unavailable Time (Hrs)	1.52			165.50						568.48			388.23			1.97	1.35	1.88	18.72
Unscheduled unavailability (#)	16	40	6	31	12	7	6	8	3	10	42	16	10	2	22	206	285	180	103
Unscheduled Unavailable Time (Hrs)	41.30	94.93	12.69	71.06	208.26	10.07	9.54	19.70	3.88	871.07	217.38	41.18	908.28	0.82	44.92	282.87	263.32	417.98	323.87
Unavailable Time (Hrs)	42.82	94.93	12.69	236.56	208.26	10.07	9.54	19.70	3.88	1,439.55	217.38	41.18	1,296.52	0.82	44.92	284.83	264.67	419.87	342.58
unavailability (#)	17	40	6	33	12	7	6	8	3	11	42	16	11	2	22	208	286	182	113

Cannelton

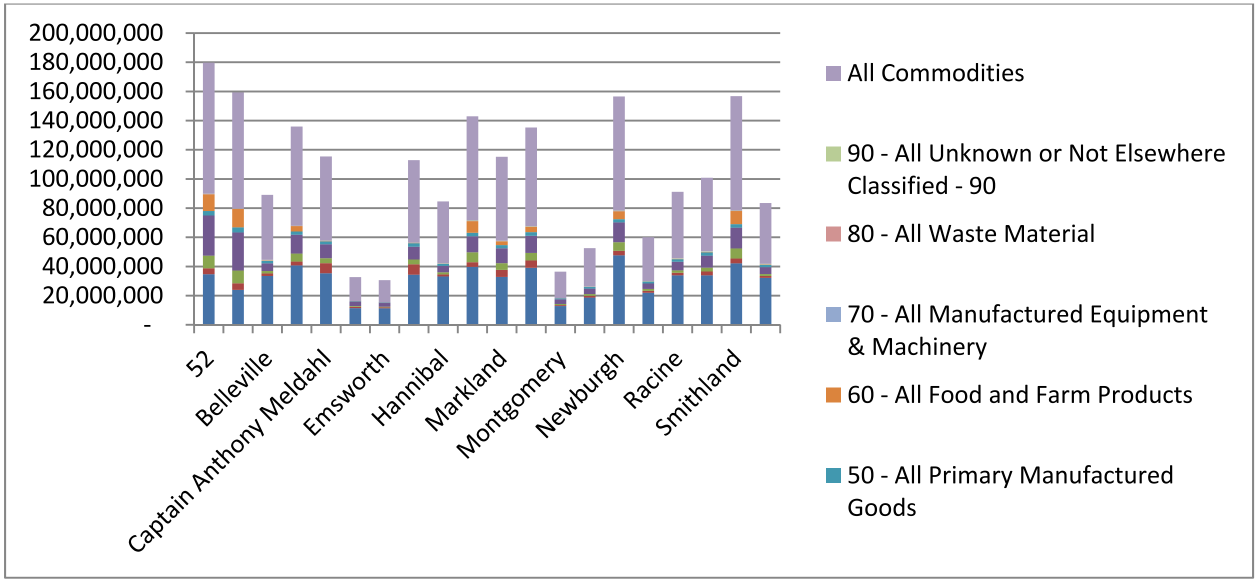
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)	2	2	3	8	3		4			1			2	3		2	1		1
Scheduled Unavailable Time (Hrs)	2.22	209.00	90.13	372.68	7.58		546.08			5.98			856.82	64.07		134.32	4.25		2.90
Unscheduled unavailability (#)	118	151	100	71	84	36	97	49	50	45	34	61	66	44	72	98	68	59	22
Unscheduled Unavailable Time (Hrs)	212.87	240.37	177.09	907.54	605.96	91.19	2,761.21	219.10	131.12	555.60	104.28	181.20	1,404.85	660.15	2,639.30	1,260.58	1,298.43	1,209.20	60.50
Unavailable Time (Hrs)	215.09	449.37	267.22	1,280.22	613.54	91.19	3,307.29	219.10	131.12	561.58	104.28	181.20	2,261.67	724.22	2,639.30	1,394.90	1,302.68	1,209.20	63.40
unavailability (#)	120	153	103	79	87	36	101	49	50	46	34	61	68	47	72	100	69	59	23

McAlpine

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled Unavailability (#)	34	4	2	9	29			1					1	1	2		1	2	2
Scheduled Unavailable Time (Hrs)	29.69	3.90	0.63	10.81	882.67			3.38					1.00	8.07	3.13		1.50	16.78	6.22
Unscheduled unavailability (#)	74	151	71	103	96	56	59	64	86	60	94	96	44	68	107	118	95	126	26
Unscheduled Unavailable Time (Hrs)	345.07	165.21	81.37	126.56	301.80	77.92	478.57	154.63	226.02	109.82	130.42	404.43	100.35	181.15	321.37	397.83	404.35	832.93	81.93
Unavailable Time (Hrs)	374.76	169.11	82.00	137.37	1,184.47	77.92	478.57	158.02	226.02	109.82	130.42	404.43	101.35	189.22	324.50	397.83	405.85	849.72	88.15
unavailability (#)	108	155	73	112	125	56	59	65	86	60	94	96	45	69	109	118	96	128	28

Markland

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Scheduled unavailability (#)	4	37	10	15	1									1		2	22	8	8
Scheduled Unavailable Time (Hrs)	6.57	1,266.18	2,699.99	941.70	3.00									345.48		83.82	2,183.35	1,941.60	5,382.30
Unscheduled unavailability (#)	26	67	21	36	16	16	27	28	47	48	57	46	33	48	34	167	160	225	94
Unscheduled Unavailable Time (Hrs)	173.65	857.77	349.07	753.21	838.75	510.62	312.77	94.23	115.77	125.88	516.28	112.77	69.07	147.02	87.12	1,035.17	2,332.57	6,207.13	632.27
Unavailable Time (Hrs)	180.22	2,123.95	3,049.06	1,694.91	841.75	510.62	312.77	94.23	115.77	125.88	516.28	112.77	69.07	492.50	87.12	1,118.98	4,515.92	8,148.73	6,014.57
unavailability (#)	30	104	31	51	17	16	27	28	47	48	57	46	33	49	34	169	182	233	102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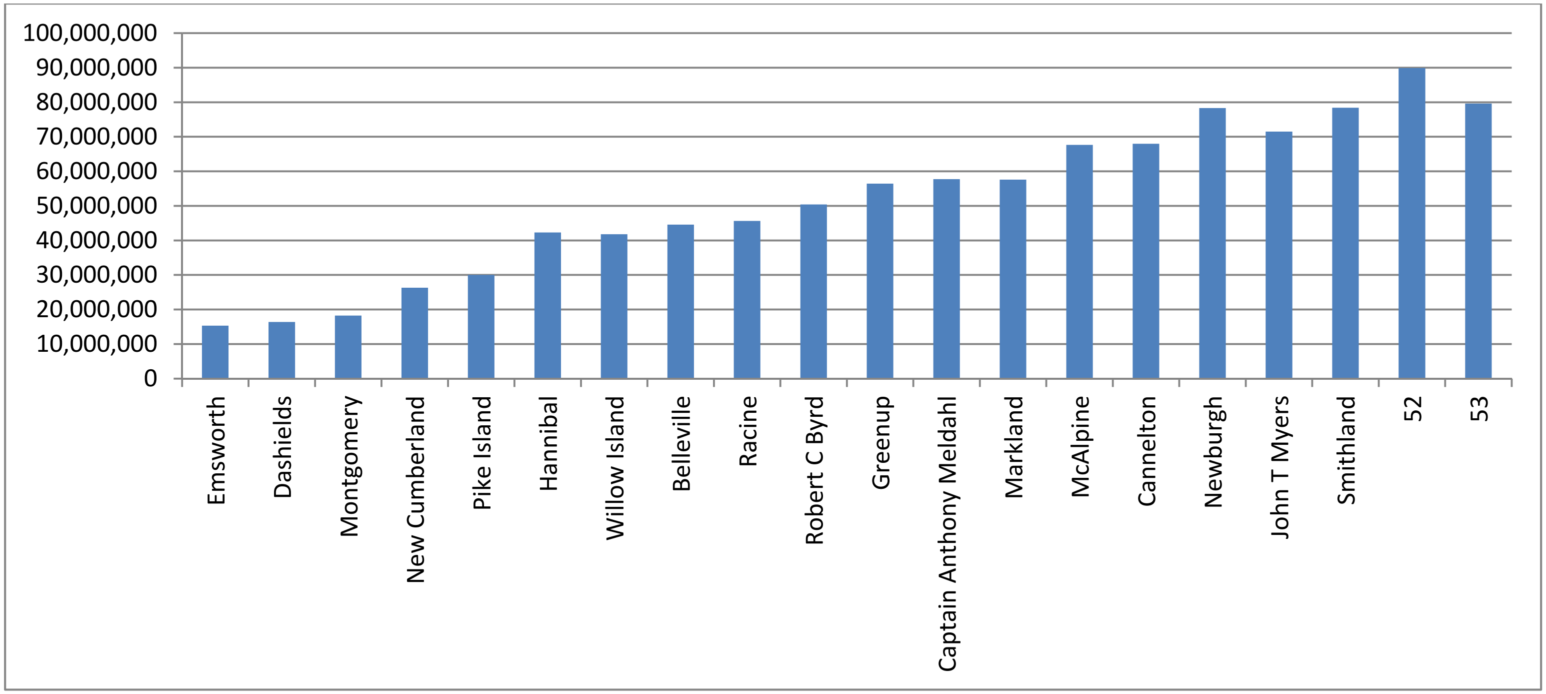
Belleville
Captain Anthony Meldahl
Emsworth
Hannibal
Markland
Montgomery
Newburgh
Racine
Smithland
All Commodities
90 - All Unknown or Not Elsewhere Classified - 90
80 - All Waste Material
70 - All Manufactured Equipment & Machinery
60 - All Food and Farm Products
50 - All Primary Manufactured Goods

Short Tons Locked in 2010 by Commodity Type

source: USACE Lock Use, Performance, and Characteristics: http://www.ndc.iwr.usace.army.mil/lpms/cy2011comweb.htm

Lock Name	10 - All Coal, Lignite, and Coal Coke	20 - All Petroleum and Petroleum Products	30 - All Chemicals and Related Products	40 - All Crude Materials, Inedible, Except Fuels	50 - All Primary Manufactured Goods	60 - All Food and Farm Products	70 - All Manufactured Equipment & Machinery	80 - All Waste Material	90 - All Unknown or Not Elsewhere Classified - 90	All Commodities
52	34,729,577	4,015,974	8,644,690	27,568,006	3,114,511	11,517,704	102,479	14,150	170,655	89,877,746
53	23,926,464	4,465,382	8,799,838	26,119,900	3,519,940	12,567,563	95,205	13,850	120,091	79,628,233
Belleville	33,433,222	1,809,146	1,661,566	5,299,446	1,755,775	200,020	127,109	5,600	267,719	44,559,603
Cannelton	40,695,449	2,715,937	5,472,590	12,921,260	2,168,776	3,738,830	91,960	4,000	165,576	67,974,378
Captain Anthony Meldahl	35,387,908	6,872,065	3,407,778	9,531,342	2,000,917	236,787	89,550	1,500	209,708	57,737,555
Dashields	11,487,117	809,350	517,485	3,138,897	332,360	13,250	25,431	22,250	18,812	16,364,952
Emsworth	11,291,727	703,800	476,877	2,443,358	329,418	13,750	17,900	23,200	25,582	15,325,612
Greenup	34,388,644	7,108,679	3,256,504	8,848,489	2,321,631	284,879	79,608	1,500	153,335	56,443,269
Hannibal	33,202,685	1,350,483	1,452,070	4,377,739	1,400,015	180,265	80,249	1,400	239,230	42,284,136
John T Myers	39,706,206	3,229,056	6,800,091	10,961,783	2,388,456	8,072,532	92,880	13,450	236,146	71,500,600
Markland	32,847,530	4,857,227	4,570,185	10,194,193	2,169,196	2,706,296	99,065		151,391	57,595,083
McAlpine	39,120,222	4,985,072	5,192,573	11,709,544	2,553,286	3,743,520	161,685	8,000	185,916	67,659,818
Montgomery	12,818,808	757,224	678,488	3,258,175	572,495	14,130	24,200	9,650	103,938	18,237,108
New Cumberland	18,682,735	1,221,639	1,236,130	3,649,514	1,143,081	146,134	22,500		187,647	26,289,380
Newburgh	47,643,606	3,057,724	5,962,867	13,532,534	2,282,891	5,477,691	142,695	4,000	197,816	78,301,824
Pike Island	21,958,002	1,330,477	1,280,030	3,786,123	1,272,631	152,484	31,625		214,428	30,025,800
Racine	33,906,799	1,784,211	1,680,472	5,875,935	1,729,462	212,007	119,665	5,600	296,558	45,610,709
Robert C Byrd	33,886,958	2,716,557	2,556,427	8,267,828	2,288,675	253,118	84,652		344,220	50,398,435
Smithland	42,203,579	3,246,156	6,851,607	14,299,976	2,392,300	9,062,612	95,410	16,950	236,181	78,404,771
Willow Island	32,138,281	1,402,248	1,252,549	4,766,194	1,655,272	190,765	128,254	5,600	240,930	41,780,093
Grand Total	**613,455,519**	**58,438,407**	**71,750,817**	**190,550,236**	**37,391,088**	**58,784,337**	**1,712,122**	**150,700**	**3,765,879**	**1,035,999,105**

Lock Name	2010 Tons locked	Change downstream
Emsworth	15,325,612	
Dashields	16,364,952	1,039,340
Montgomery	18,237,108	1,872,156
New Cumberland	26,289,380	8,052,272
Pike Island	30,025,800	3,736,420
Hannibal	42,284,136	12,258,336
Willow Island	41,780,093	-504,043
Belleville	44,559,603	2,779,510
Racine	45,610,709	1,051,106
Robert C Byrd	50,398,435	4,787,726
Greenup	56,443,269	6,044,834
Captain Anthony Meldahl	57,737,555	1,294,286
Markland	57,595,083	-142,472
McAlpine	67,659,818	10,064,735
Cannelton	67,974,378	314,560
Newburgh	78,301,824	10,327,446
John T Myers	71,500,600	-6,801,224
Smithland	78,404,771	6,904,171
52	89,877,746	11,472,975
53	79,628,233	-10,249,513
Total	**1,035,999,105**	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Emsworth
Dashields
Montgomery
New Cumberland
Pike Island
Hannibal
Willow Island
Belleville
Racine
Robert C Byrd
Greenup
Captain Anthony Meldahl
Markland
McAlpine
Cannelton
Newburgh
John T Myers
Smithland
52
53

		Total by Chamber		Direction by Chamber				Total by Direction	
Lock Name	**2010 Tons locked**	**Main**	**Aux**	**Main - up**	**Main - down**	**Aux - up**	**Aux - down**	**Up**	**Down**
Emsworth	15,325,612	14,486	840	10,091	4,395	653	187	10,744	4,582
Dashields	16,364,952	16,059	306	11,641	4,418	171	135	11,812	4,553
Montgomery	18,237,108	17,764	474	11,598	6,166	295	179	11,893	6,345
New Cumberland	26,289,380	24,701	1,589	19,790	4,911	1,203	386	20,993	5,297
Pike Island	30,025,800	23,965	6,062	19,490	4,475	4,863	1,199	24,353	5,674
Hannibal	42,284,136	41,330	954	19,337	21,993	685	269	20,022	22,262
Willow Island	41,780,093	41,230	549	21,040	20,190	354	195	21,394	20,385
Belleville	44,559,603	43,377	1,183	22,993	20,384	753	430	23,746	20,814
Racine	45,610,709	44,810	801	23,222	21,588	448	353	23,670	21,941
Robert C Byrd	50,398,435	43,490	6,908	24,773	18,717	4,038	2,870	28,811	21,587
Greenup	56,443,269	47,602	8,841	19,975	27,627	3,893	4,948	23,868	32,575
Captain Anthony Meldahl	57,737,555	56,521	1,216	27,495	29,026	682	534	28,177	29,560
Markland	57,595,083	48,905	8,690	30,053	18,852	5,714	2,976	35,767	21,828
McAlpine	67,659,818	42,463	25,196	23,983	18,480	22,717	2,479	46,700	20,959
Cannelton	67,974,378	62,953	5,021	41,823	21,130	2,922	2,099	44,745	23,229
Newburgh	78,301,824	77,285	1,017	54,910	22,375	722	295	55,632	22,670
John T Myers	71,500,600	69,289	2,211	43,271	26,018	1,324	887	44,595	26,905
Smithland	78,404,771	34,371	44,034	2,286	32,085	39,264	4,770	41,550	36,855
52	89,877,746	83,576	6,302	43,914	39,662	3,082	3,220	46,996	42,882
53	79,628,233	79,088	540	35,976	43,112	152	388	36,128	43,500
Totals	**1,035,999,105**	**913,265**	**122,734**	**507,661**	**405,604**	**93,935**	**28,799**	**601,596**	**434,403**

Lock	Chamber	River/Mile	Year Opened	Length	Width	Lift
Elmsworth	Main	6.2	1921	600	110	18
Elmsworth	Aux 1	6.2	1921	360	56	18
Dashields	Main	13.3	1929	600	110	10
Dashields	Aux 1	13.3	1929	360	56	10
Montgomery	Main	31.7	1936	600	110	18
Montgomery	Aux 1	31.7	1936	360	56	18
New Cumberland	Main	54.4	1959	1200	110	21
New Cumberland	Aux1	54.4	1959	600	110	21
Pike Island	Main	84.2	1965	1200	110	18
Pike Island	Aux1	84.2	1965	600	110	18
Hannibal	Main	126.4	1973	1200	110	21
Hannibal	Aux1	126.4	1973	600	110	21
Willow Island	Main	161.7	1972	1200	110	20
Willow Island	Aux1	161.7	1972	600	110	20
Belleville	Main	203.9	1969	1200	110	22
Belleville	Aux1	203.9	1969	600	110	22
Racine	Main	237.5	1967	1200	110	22
Racine	Aux1	237.5	1967	600	110	22
Robert C. Byrd	Main	279.2	1993	1200	110	23
Robert C. Byrd	Aux1	279.2	1993	600	110	23
Greenup	Main	341	1959	1200	110	30
Greenup	Aux1	341	1959	600	110	30
Captain Anthony Meldahl	Main	436.2	1962	1200	110	30
Captain Anthony Meldahl	Aux1	436.2	1962	600	110	30
Markland	Main	531.5	1959	1200	110	35
Markland	Aux1	531.5	1959	600	110	35
McAlpine	Main	606.8	1961	1200	110	37
McAlpine	Main	606.8	2009	1200	110	37
Cannelton	Main	720.7	1971	1200	110	25
Cannelton	Aux1	720.7	1971	600	110	25
Newburgh	Main	776.1	1975	1200	110	16
Newburgh	Aux1	776.1	1975	600	110	16
John T. Myers	Main	846	1975	1200	110	18
John T. Myers	Aux1	846	1975	600	110	18
Smithland	Main	918.5	1980	1200	110	22

Smithland	Aux1	918.5	1980	1200	110	22
52	Main	938.9	1969	1200	110	12
52	Aux1	938.9	1928	600	110	12
53	Main	962.6	1980	1200	110	12
53	Aux1	962.6	1929	600	110	12
Olmsted	Main	964.4	2020	1200	110	
Olmsted	Main	964.4	2020	1200	110	
Note: Olmsted Locks will replace Locks 52 and 53 once they become operational						

Top 9 Ports by Tonnage

Top Ports	Number of terminals	Tonnage	Rail	Highway
Cincinnati	29	13.3mm/tons	CSX, I&O	265
Henderson	11	600,000 (http://transportation.ky.gov/Riverports/Documents/Kentucky%20Water%20Transportation%20Corridors.PDF)	CSX	Breathitt Pennyrile Parkway
Jeffersonville	11	1.7mm/tons (http://www.1si.org/EXTERNAL/WCPAGES/WCNEWS/NEWSARTICLEDISPLAY.ASPX?ArticleID=171)	CSX, NS, P&L	264
Louisville	27	7.4mm/tons	CSX, NS, I&O	264
Mt. Vernon/Evansville	20	5.5mm/tons (http://www.ndc.iwr.usace.army.mil//wcsc/webpub09/Part2_Ports_tonsbycommCY2009.HTM)	Evansville Western with connections to CSX, NS, CN, BNSF, UP	Highway 69 to I64
New Albany	3	4.2mm/tons (http://www.1si.org/EXTERNAL/WCPAGES/WCNEWS/NEWSARTICLEDISPLAY.ASPX?ArticleID=171)	NS	I-64
Owensboro	11	616,000 (http://transportation.ky.gov/Riverports/Documents/Kentucky%20Water%20Transportation%20Corridors.PDF)	CSX	Audubon Parkway, Natcher Parkway
Paducah	8	1mm tons (http://transportation.ky.gov/Riverports/Documents/Kentucky%20Water%20Transportation%20Corridors.PDF)	P&L to CSX	I-24 loop
Tell City	3	150m/tons (http://www.indianaeconomicdigest.net/print.asp?ArticleID=31139&SectionID=31&SubSectionID=62)	HOS to NS	Highway32 to I64

Name	Ohio River	City
Agrico Chemical Co.	Ohio River	Melbourne
Aquarius Marine, Inc. - Barge Loading Facility	Ohio River	Melbourne
ADM Milling Co. - Mid States Terminals - Silver Grove Terminal Wharf	Ohio River	Silver Grove
Countrymark, Inc.	Ohio River	Silver Grove
Lafarge North America	Ohio River	Silver Grove
Hilltop Basic Resources - East Cincinnati Terminal	Ohio River	Cincinnati
Cargill, Inc. - Cincinnati Terminal Wharf	Ohio River	Cincinnati
Washington Marine, LLC	Ohio River	Cincinnati
Tucker Marine	Ohio River	Cincinnati
Martin Marietta Aggregates - Dravo Basic	Ohio River	Cincinnati
Kinder Morgan - Queen City Terminal	Ohio River	Cincinnati
Liquid Transfers Terminals - Arcadian Chemical Corp.	Ohio River	Cincinnati
Cincinnati Barge & Rail Terminal, LLC - Noramco Cincinnati	Ohio River	Cincinnati
Hilltop Basic Resources - Cincinnati River Terminal	Ohio River	Cincinnati
River Trading Co. - Cincinnati Bulk Terminal - Hatfield Terminal Docks	Ohio River	Cincinnati
River Trading Co. - Port of Cincinnati	Ohio River	Cincinnati
Noramco Cincinnati	Ohio River	Cincinnati
Maxim Crane - Greater Cincinnati Marine Service - Ludlow Dock	Ohio River	Ludlow
Aquaius Marine, Inc. - Ludlow	Ohio River	Ludlow
McGinnis, Inc. - Ludlow Facility	Ohio River	Ludlow
Consolidated Grain & Barge Co. - Anderson Ferry	Ohio River	Cincinnati
CEMEX - Kosmos Cement Co. - Cincinnati Southside Terminal Wharf	Ohio River	Cincinnati
Kinder Morgan - Cincinnati Steel Terminal	Ohio River	Cincinnati
Peter Cremer North America - South Terminal	Ohio River	Cincinnati
Cargill - Cincinnati Molasses Terminal	Ohio River	Cincinnati
Westway Terminal Co., LLC - Cincinnati	Ohio River	Cincinnati
Trans Montaigne - ITAPCO Ludlow Wharf	Ohio River	Ludlow

Marathon Petroleum, LLC - Ashland Oil, Inc. - Cincinnati Terminal Wharf	Ohio River	Cincinnati
Intertate Asphalt Co. - Constance Plant Dock	Ohio River	Constance
Benchmark Terminals - River Road Barge & Rail Terminal	Ohio River	Cincinnati
Defense Logistics Agency - DFSP Station Cincinnati	Ohio River	Cincinnati
Buckeye - Cincinnati Dock	Ohio River	Cincinnati
C.F. Industries - Cincinnati Warehouse Wharf	Ohio River	Cincinnati
Kinder Morgan - River T Liquid Terminal	Ohio River	Cincinnati
Cargill, Inc. - Cincinnati River Road Terminal Wharf	Ohio River	Cincinnati
Excell Marine Corp. - Cincinnati Facility	Ohio River	Cincinnati
Marathon Petroleum Co., LLC - Ashland Oil, Inc. - Stringtown Dock	Ohio River	Stringtown
McGinnis, Inc. - Excell Marine Corp. - Cincinnati Terminal Fleet Mooring & Wharf	Ohio River	Cincinnati
Buzzi Unicem - Lone Star Industries, Incorporated	Ohio River	Cincinnati
Hilltop Basic Resources - Constance Terminal	Ohio River	Hebron
McGinnis, Inc. - Hebron Facility	Ohio River	Hebron
Consolidated Grain & Barge co. - Marine Services - Sayler Park	Ohio River	Cincinnati
Monsanto Chemical Co. - Addyston Plastics Plant Wharf	Ohio River	Addyston
Consolidated Grain & Barge Co. - North Bend Facility	Ohio River	North Bend
Chervon USA - Cincinnati Facility Dock	Ohio River	North Bend
Koch Materials Asphalt Co.	Ohio River	North Bend
Agrium US, Inc. - Vigoro Industries - North Bend	Ohio River	North Bend
Marathon Petroleum - North Bend Terminal Wharf	Ohio River	North Bend
Cinc. Gas & Electric Co. - Miami Fort	Ohio River	North Bend
E.I. DuPont DeNemours & Co. - Fort Hill Plant Dock	Ohio River	North Bend
AEP - Indiana & Michigan Electric Corp. - Tanner Creek Plant	Ohio River	Lawrenceburg

Consolidated Grain & Barge co. - Aurora Wharf	Ohio River	Aurora
Northern Kentucky Aggregates - Petersburg Dock	Ohio River	Petersburg
Martin-Marietta Aggregates - Petersburg Gravel Dock	Ohio River	Petersburg
Belleview Sand & Gravel	Ohio River	Petersburg
Kentucky Utilities Co. - Ghent Plant	Ohio River	Ghent
Gallatin Steel	Ohio River	Ghent
Kinder Morgan - Arrow Terminals, LP - North American Stainless	Ohio River	Ghent
Adams Boat Co., Inc. - Madison Dock	Ohio River	Madison
Nugent Sand Co. - Milton/Carrollton Dock	Ohio River	Milton
Consolidated Grain & Barge Co. - Madison Wharf	Ohio River	Madison
Indiana-Kentucky Power Corp. - Clifty Creek Station Coal Dock	Ohio River	Madison
Louisville Gas & Electric Co. - Trimble Co. Plant	Ohio River	Bedford
Nugent Sand Co. - Bethlehem Plant	Ohio River	New Washington
Mulzer Crushed Stone Co. - Charlestown Quarry Wharfs	Ohio River	Charlestown
American Commercial Lines - Utica & Twelve Mile Island Fleet Moorings	Ohio River	Utica
American Commercial Lines - Utica & Twelve Mile Island Fleet Moorings	Ohio River	Utica
McBride Towing Co., Inc. - Drydock	Ohio River	Louisville
Mount Vernon Barge Service, Inc. - MVBS Jeffersonville, LLC	Ohio River	Jeffersonville
Consolidated Barge & Grain Co. - Jeffersonville Facility (Indiana Port Commission)	Ohio River	Jeffersonville
Juniper Beach Docks, LLC	Ohio River	Louisville
Kinder Morgan - Jeffersonville Facility (Indiana Port Commission)	Ohio River	Jeffersonville
Nugent Sand Co. - Utica Dock & Sales Yard	Ohio River	Jeffersonville
Eagle Steel Products, Inc. (Indiana Port Commission)	Ohio River	Jeffersonville
Marine Builders, Inc. - Utica Facility Wharf	Ohio River	Jeffersonville

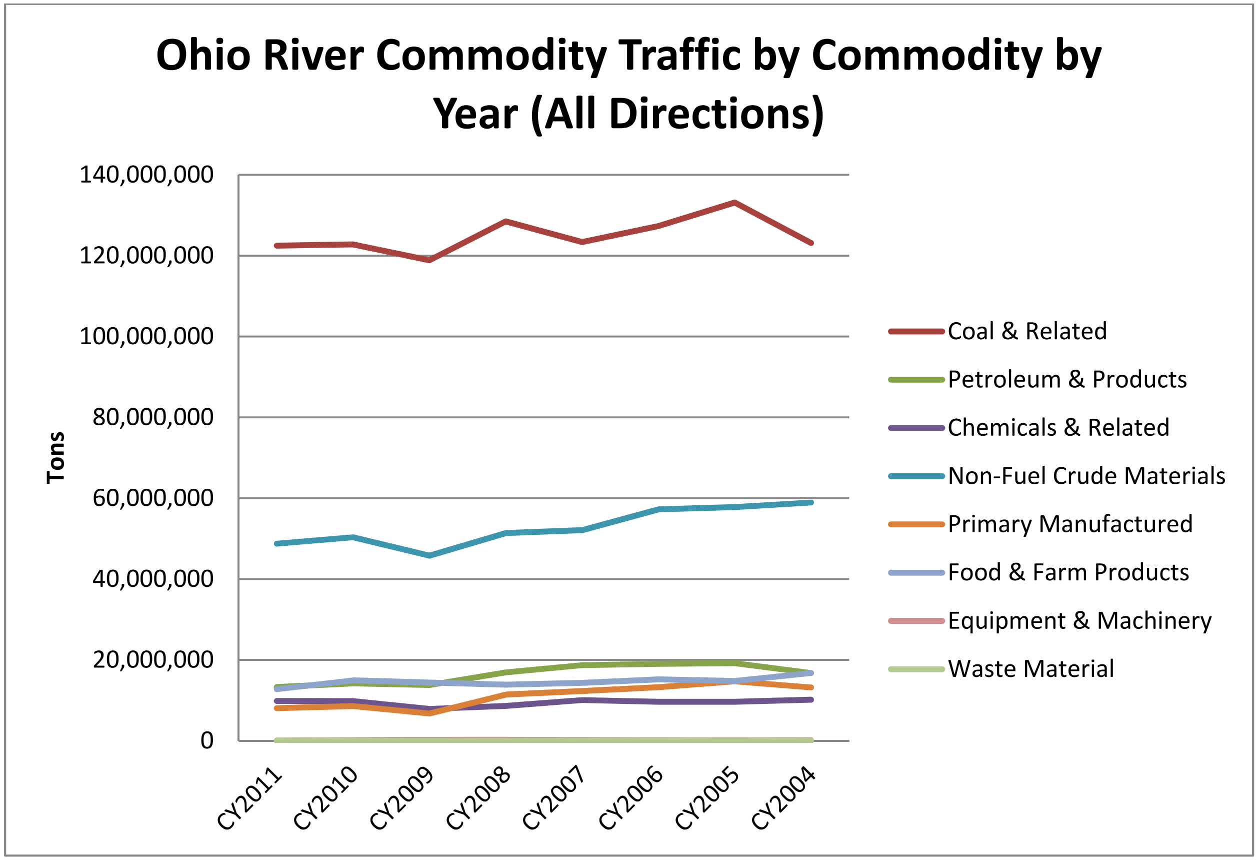
Indiana Port Commision Terminal - Jeffersonville, Clark Maritime Centre	Ohio River	Jeffersonville
Wooten's River Service	Ohio River	Jeffersonville
Airgas Specialty Products	Ohio River	Jeffersonville
Buddekeww - River Road Terminal, Inc.	Ohio River	Louisville
Kinder Morgan - Louisville Terminal	Ohio River	Louisville
River Metal Recycling, LLC	Ohio River	Louisville
American Commercial Lines - Lousiana Dock Co.	Ohio River	Louisville
American Commercial Lines - Jeffboat, Inc. - Drydocks	Ohio River	Jeffersonville
Mosaic Co. - Louisville Terminal Facility	Ohio River	Louisville
Nugent Sand Co. - Louisville Wharf	Ohio River	Louisville
Marine Works - Marine Industries Corp.	Ohio River	Clarksville
Marathon Petroleum, LLC - Ashland Oil, Inc. - Clarksville Terminal Wharf	Ohio River	Jeffersonville
US Army Corps of Engineers - Louisville Repair Station Mooring	Ohio River	Louisville
ITAPCO - TransMontaigne - Kentuckiana	Ohio River	New Albany
Duke Energy - PSI Energy - Robert Gallagher Power Plant Dock	Ohio River	New Albany
Marathon Petroleum, LLC - Ashland Oil, Inc. - Louisville Refinery Upper Dock	Ohio River	Louisville
Buckeye - BP Oil Co. - Louisville Terminal	Ohio River	Louisville
Carbide Industries, LLC - Louisville Wharf	Ohio River	Louisville
Arkema, Inc. - Altuglas International Louisville Plant	Ohio River	Louisville
Marathon Petroleum, LLC - Ashland Oil, Inc. - Louisville Refinery Lower Dock	Ohio River	Louisville
Citgo Petroleum Corp. - Kerr McGee - Louisville Terminal	Ohio River	Louisville
Chevron USA, Inc. - Louisville	Ohio River	Louisville
McBrides Fleet - Five M Transportation Co.	Ohio River	New Albany
ITAPCO - TransMontaigne - Louisville	Ohio River	Louisville
Borden Chemicals - Louisville Dock	Ohio River	Louisville
Stauffer Chemical Co. (INACTIVE?)	Ohio River	Louisville
Louisville Gas & Electric - Cane Run Plant Dock	Ohio River	Louisville

Jefferson Riverport International - Bulk Terminal & General Cargo Docks	Ohio River	Louisville
Sun Refining & Marketing Co. - Thorton's Transportation - Louisville Terminal Wharf	Ohio River	Louisville
Marathon Petroleum, LLC - Ashland Oil, Inc. - Louisville Asphalt Terminal Wharf	Ohio River	Louisville
CEMEX - Kosmos Cement Co. - Stone & Cement Docks	Ohio River	Kosmosdale
Arch Chemicals, Inc. - Doe Run Plant Dock	Ohio River	Brandenburg
Vulcan Materials Co.-brandenburg Quarry	Ohio River	Brandenburg
Kosmos Cement Co.-Oolite Wharf	Ohio River	Oolite/Battletown
Hilltop Basic Resources-Big Bend Quarry, LLC-meade County Wharf	Ohio River	Battletown
Mulzer Crushed Stone Co. - Cape Sandy Quarrt Upper & lower Wharfs	Ohio River	Cape Sandy
Yager Materials Co.-Riverside Stone Co.-Upper and Lower Docks	Ohio River	Wolf Creek
Kinder morgan-Southern Shores Terminal, Inc.-Hawesville Dock	Ohio River	Hawesville
Tell City Riverport	Ohio River	Tell City
Mulzer Crushed Stone Co.-Tell City Dock	Ohio River	Tell City
Big Rivers Electric Corp.-Kenneth C. Coleman Plant Wharf	Ohio River	Hawesville
Yager Materials,Inc.-Hancock County Read-Mix Haweville Dock	Ohio River	Hawesville
Evansville Marine Services-Tell City Harbor	Ohio River	Tell City
Indiana-Michigan Electric Corp.- Rockport Plant Dock	Ohio River	Rockport
Rockport River Terminals-Spencer County Riverport	Ohio River	Rockport
Mulzer Crushed Stone Co.-Rockport Yard Dock& Wharfs	Ohio River	Rockport
Mulzer Crushed Stone Co.-Evansville Materials Inc.	Ohio River	Rockport
Kinder Morgan-Owensboro Gateway Terminal/Iceland Terminal Inc.	Ohio River	Owensboro
Evansville Marine Services-Owensboro	Ohio River	Owensboro

Harbor		
Yellow Banks River Terminal-Daviess County River Sand & Gravel	Ohio River	Owensboro
Yager Materials, Inc.-Marine Industries	Ohio River	Owensboro
Yager Materials, Inc.-Yager Dock/Owensboro River Sand	Ohio River	Owensboro
U.S. Coast Guard-Owensboro Depot Wharf	Ohio River	Owensboro
Southern States-River Terminal Co.Wharf	Ohio River	Owensboro
Trans Montaigne-Owensboro Terminal	Ohio River	Owensboro
LaFarge Cement Corp.-Owensboro Terminal Wharf	Ohio River	Owensboro
Owensboro Grain Co.-Owensboro Soybean Oil Dock	Ohio River	Owensboro
Yager Materials, Inc.-Owensboro River Rail Terminal Wharf	Ohio River	Owensboro
Owensboro Riverport Authority	Ohio River	Owensboro
Rampstop Marine Services-Owensboro Facility	Ohio River	Evansville
Mulzer Crushed Stone Co.-Newburgh Yard Wharf	Ohio River	Newburgh
Ohio Valley Marine Service, Inc.	Ohio River	Henderson
Mulzer Crushed Stone Co.-Evansville Wharf	Ohio River	Evansville
Northern AG Service-Valley Terminal-Evansville Wharf	Ohio River	Evansville
Evansville Marine Service-Evansville Harbor	Ohio River	Evansville
Cargill Inc.-Evansville Wharf	Ohio River	Evansville
Archer Daniels Midland-Terminal Services-Evansville	Ohio River	Evansville
Mulzer Crushed Stone Co.-Evansville Materials, Incorporarted	Ohio River	Evansville
Mulzer Crushed Stone Co.-West Yard Wharf	Ohio River	Evansville
Trans Montaigne-Home Oil Co & Gas Co.Inc.	Ohio River	Henderson
Peavey Co.-Henderson Wharf	Ohio River	Henderson
Mosaic Co.-Henderson Dock	Ohio River	Henderson
Consolidated Grain & Barge-Henderson Dock	Ohio River	Henderson

Henderson County Riverport Authority	Ohio River	Henderson
Evansville Marine Services-Henderson Harbor	Ohio River	Henderson
Owensboro Grain Co., Genever River Terminal	Ohio River	Henderson
Countrymark, Inc.-Henderson Terminal Wharf	Ohio River	Henderson
Henderson Materials, Inc.Wharf	Ohio River	Henderson
Mount Vernon Transfer Terminal, LLC-Transfer Terminal/MAPCO Coal Dock	Ohio River	Mount Vernon
Mount Vernon Basrge Service, Inc.Dock	Ohio River	Mount Vernon
Indiana Port Commision-Port of Indiana-Mount Vernon Dock	Ohio River	Mount Vernon
Consolidated Grain & Barge Co.-Mount Vernon River Dock	Ohio River	Mount Vernon
Mount Vernon Marine, LLC-Barge Service	Ohio River	Mount Vernon
Archer Daniels Midland Milling Co.-Fuhrer-Ford Division, Mount Vernon Wharf	Ohio River	Mount Vernon
Country Mark Inc.-Mount Vernon Terminal Wharf	Ohio River	Mount Vernon
Continental Grain Co.-Mount Vernon Grain Elevator Dock	Ohio River	Mount Vernon
Marathon Oil Co.-Mount Vernon Dock	Ohio River	Mount Vernon
Babcock & Wilcox Co.-Mount Vernon Plant Dock	Ohio River	Mount Vernon
Sabic Innovative Plastics	Ohio River	Mount Vernon
Mount Vernon Marine, LLC-Fleeting Service, Hovey Fleet Mooring	Ohio River	Mount Vernon
Consolidated Grain & Barge Co.-Union Dock	Ohio River	Uniontown
Industrial marine Service Inc.-Old Shawneetown Facility	Ohio River	Shawneetown
Hunter Sand and Gravel	Ohio River	Shawneetown
Bunge Corp.-Shawneetown Wharf	Ohio River	Shawneetown
Shawneetown Harbor Service, Inc.	Ohio River	Shawneetown
Dekoven Dock Inc.-Dekoven Dock/Kanipe Coal Dock	Ohio River	Sturgis
Hunter Sand & Gravel Co.-Caseyville Dock/Pyro Dock	Ohio River	Caseyville
Wabash marine, Inc.-Pyro Mining Co.-	Ohio River	Caseyville/Sturgis

Caseyville Dock		
American Minerals, Inc.-Rosiclare Wharf	Ohio River	Rosiclare
Wepfer Marine Inc.-Hickman Dock and Fleet Mooring	Ohio River	Hickman
Ingram materials Co.-Ledbetter Docks	Ohio River	Ledbeter
Three River Boats & Barge, Inc.-Ledbeter Facility	Ohio River	Ledbeter
Hunter Sand & Gravel-Ledbeter Dock	Ohio River	Ledbeter
National Maintenance & Repair of Kentucky-Ledbeter Facility	Ohio River	Ledbeter
Precision Machine, Inc.	Ohio River	Paducah
Midwest Terminal-Paducah Dock	Ohio River	Paducah
Kotter Ready Mix-Metropolis Dock	Ohio River	Metropolis
Mid-South Towing Co.-Metropolis Fleet Moorings & Dock	Ohio River	Metropolis
Hunter Sand & gravel Co.-Metropolis Dock	Ohio River	Metropolis
American Electric Power-Cook Coal Dock	Ohio River	Metropolis
LaFarge Cement Corp.-Joppa Plant Wharf	Ohio River	Joppa
Consolidated Grain & Barge Co.-Mound City Dock	Ohio River	Mound City
ADM/Growmark CO.-Mound City Wharf	Ohio River	Mound City
American Commercial Lines-Louisiana Dock Co. Cairo Fleet	Ohio River	Cairo
Bunge Crop.-Cairo Wharf	Ohio River	Cairo
Consolidated Grain & Barge Co.-Waterfront Servicea Co.-Cairo Dock & Fleet	Ohio River	Cairo
Hunter Sand & Gravel Co.-Henderson County Sand Co.Dock	Ohio River	Henderson
American Commercial Lines - Jeffboat, Inc.	Ohio River	Jeffersonville
Louisville Gas & Electric - Mill Creek Station	Ohio River	Kosmosdale


Ohio River Commodity Traffic by Commodity by Year (All Directions)
Tons
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
CY2011
CY2010
CY2009
CY2008
CY2007
CY2006
CY2005
CY2004
Coal & Related
Petroleum & Products
Chemicals & Related
Non-Fuel Crude Materials
Primary Manufactured
Food & Farm Products
Equipment & Machinery
Waste Material

	CY2011	CY2010	CY2009	CY2008	CY2007	CY2006	CY2005	CY2004
All Commodities	215,077,094	220,594,275	207,446,759	230,812,272	230,844,602	241,535,140	249,212,064	238,980,352
Coal & Related	122,437,012	122,746,226	118,819,010	128,441,212	123,342,834	127,311,257	133,147,771	123,113,533
Petroleum & Products	13,273,936	14,179,767	13,772,477	16,907,547	18,695,826	18,982,949	19,168,997	16,755,314
Chemicals & Related	9,808,359	9,767,096	7,869,679	8,588,895	10,061,778	9,597,285	9,610,350	10,130,868
Non-Fuel Crude Materials	48,724,385	50,324,763	45,763,900	51,368,691	52,052,567	57,210,432	57,751,926	58,935,470
Primary Manufactured	8,031,303	8,548,018	6,705,688	11,399,660	12,257,950	13,213,570	14,698,514	13,189,882
Food & Farm Products	12,736,974	14,902,457	14,371,111	13,851,609	14,285,176	15,141,830	14,777,025	16,740,549
Equipment & Machinery	49,085	125,190	144,894	254,658	148,471	77,817	56,384	113,891
Waste Material	16,040	758	0	0	0	0	1,097	845

Report Output from 19 Various Regression Models

Linear regression Number of obs = 596437

Regression Model 1A R-squared = 0.0231

Root MSE = 6.5891

a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	-.0687229	.0384211	-1.79	0.074	-.1440271	.0065813
year2003	-.8401787	.0382243	-21.98	0.000	-.9150971	-.7652603
year2004	-.9166814	.0377309	-24.30	0.000	-.9906328	-.8427299
year2005	.7394726	.0390127	18.95	0.000	.6630089	.8159364
year2007	.6638964	.0391524	16.96	0.000	.5871589	.7406338
year2008	.795969	.0390803	20.37	0.000	.7193729	.8725651
year2009	-.4295522	.0395464	-10.86	0.000	-.5070619	-.3520424
year2010	.3874251	.0398575	9.72	0.000	.3093056	.4655446
year2011	.7045527	.0404097	17.44	0.000	.6253508	.7837545
year2012	1.858432	.0443093	41.94	0.000	1.771587	1.945277
January	-.8394824	.0408455	-20.55	0.000	-.9195382	-.7594266
February	-.8399421	.0412638	-20.36	0.000	-.9208179	-.7590663
March	-1.234106	.0399879	-30.86	0.000	-1.312481	-1.155731
April	-.984426	.0400901	-24.56	0.000	-1.063001	-.9058507
May	-1.080657	.0396566	-27.25	0.000	-1.158383	-1.002932
June	-.4706567	.0401907	-11.71	0.000	-.5494293	-.3918842

August	.6023125	.0406544	14.82	0.000	.5226312	.6819939
September	.760884	.04112	18.50	0.000	.68029	.8414779
October	.6387137	.0419922	15.21	0.000	.5564103	.7210172
November	.4045619	.0426834	9.48	0.000	.3209037	.48822
December	-.6560993	.0417397	-15.72	0.000	-.7379079	-.5742908
_cons	-3.886021	.0385057	-100.92	0.000	-3.961491	-3.810551

Linear regression   Number of obs = 596573

Regression Model 1B   R-squared   = 0.0229

Root MSE   = 1.0647

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s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.084912	.0058798	14.44	0.000	.0733878	.0964363
year2003	-.0409272	.0062155	-6.58	0.000	-.0531094	-.0287451
year2004	-.0894829	.0063508	-14.09	0.000	-.1019303	-.0770354
year2005	.1393309	.0060535	23.02	0.000	.1274663	.1511955
year2007	.1566054	.006162	25.41	0.000	.144528	.1686828
year2008	.1434513	.0061227	23.43	0.000	.131451	.1554516
year2009	.0363501	.0068784	5.28	0.000	.0228687	.0498316
year2010	.0947879	.006786	13.97	0.000	.0814876	.1080882
year2011	.0916331	.0069208	13.24	0.000	.0780686	.1051976

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    year2012 |   .3357139   .0070548    47.59   0.000     .3218868    .3495411
     January |  -.1102755   .0066293   -16.63   0.000    -.1232687   -.0972824
    February |   -.147423   .0067509   -21.84   0.000    -.1606545   -.1341915
       March |  -.2070223   .0066492   -31.13   0.000    -.2200546     -.19399
       April |  -.1962501    .006596   -29.75   0.000    -.2091781   -.1833221
         May |  -.2187427   .0065117   -33.59   0.000    -.2315055   -.2059799
        June |  -.0880008   .0063226   -13.92   0.000    -.1003929   -.0756087
      August |   .1424909   .0058302    24.44   0.000     .1310638    .1539179
   September |    .118236   .0060019    19.70   0.000     .1064724    .1299996
     October |   .1187921   .0063469    18.72   0.000     .1063524    .1312318
    November |   .0671979   .0065831    10.21   0.000     .0542952    .0801007
    December |  -.1034781   .0068776   -15.05   0.000    -.1169579   -.0899983
       _cons |   3.356712     .00605   554.83   0.000     3.344855     3.36857
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. regress a2s_ln year2002-year2005 year2007-year2012 January-June August-December discharge,
robust

Linear regression                               Number of obs =  596437
Regression Model 2A                                R-squared     =  0.0572
                                            Root MSE      =  6.4731

------------------------------------------------------------------------------
             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
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year2002	.2760823	.0378012	7.30	0.000	.2019931	.3501715
year2003	-.1332329	.0377091	-3.53	0.000	-.2071415	-.0593244
year2004	-.0903132	.0373428	-2.42	0.016	-.1635038	-.0171225
year2005	1.236027	.0385903	32.03	0.000	1.160391	1.311662
year2007	.9272341	.0386908	23.97	0.000	.8514014	1.003067
year2008	1.30054	.0384243	33.85	0.000	1.225229	1.37585
year2009	-.2833158	.0388614	-7.29	0.000	-.359483	-.2071487
year2010	.6976989	.0392459	17.78	0.000	.6207781	.7746196
year2011	1.134507	.0400232	28.35	0.000	1.056062	1.212951
year2012	1.72906	.0435987	39.66	0.000	1.643608	1.814512
January	.8712055	.0417018	20.89	0.000	.7894713	.9529398
February	.7479251	.0417754	17.90	0.000	.6660466	.8298036
March	.9457713	.0418112	22.62	0.000	.8638227	1.02772
April	.7984232	.0411574	19.40	0.000	.7177559	.8790905
May	.5862707	.0407472	14.39	0.000	.5064075	.666134
June	.0868224	.0398668	2.18	0.029	.0086848	.16496
August	.4188535	.0404741	10.35	0.000	.3395256	.4981815
September	.7448624	.0407678	18.27	0.000	.6649588	.824766
October	.6444167	.0418746	15.39	0.000	.5623438	.7264896
November	.9513339	.0425744	22.35	0.000	.8678894	1.034778
December	.6044239	.0418743	14.43	0.000	.5223516	.6864962
discharge	-8.43e-06	4.85e-08	-173.96	0.000	-8.53e-06	-8.34e-06
_cons	-3.464657	.0380993	-90.94	0.000	-3.53933	-3.389984

. regress s2e_ln year2002-year2005 year2007-year2012 January-June August-December discharge, robust

Linear regression   Number of obs = 596573

Regression Model 2B   R-squared   = 0.1615

Root MSE   = .98633

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1972081	.0054247	36.35	0.000	.1865759	.2078403
year2003	.1893136	.005646	33.53	0.000	.1782476	.2003796
year2004	.179653	.0058627	30.64	0.000	.1681624	.1911437
year2005	.3010545	.0056444	53.34	0.000	.2899916	.3121174
year2007	.242373	.0057861	41.89	0.000	.2310324	.2537136
year2008	.3077804	.0056352	54.62	0.000	.2967356	.3188251
year2009	.0839751	.0063758	13.17	0.000	.0714787	.0964716
year2010	.1958403	.0062734	31.22	0.000	.1835447	.2081359
year2011	.2316582	.0065663	35.28	0.000	.2187884	.244528
year2012	.29353	.006536	44.91	0.000	.2807196	.3063404
January	.4470665	.0062285	71.78	0.000	.4348588	.4592742
February	.3697311	.0062791	58.88	0.000	.3574242	.382038
March	.5029075	.0064634	77.81	0.000	.4902395	.5155755
April	.3842177	.0063912	60.12	0.000	.3716911	.3967444
May	.3240858	.0063818	50.78	0.000	.3115778	.3365939

June	.0935239	.006011	15.56	0.000	.0817424	.1053053
August	.0827523	.00558	14.83	0.000	.0718157	.0936889
September	.1130136	.0056847	19.88	0.000	.1018718	.1241554
October	.120638	.0061258	19.69	0.000	.1086317	.1326444
November	.2452621	.0063484	38.63	0.000	.2328195	.2577048
December	.3070443	.0063946	48.02	0.000	.294511	.3195776
discharge	-2.75e-06	8.45e-09	-324.77	0.000	-2.76e-06	-2.73e-06
_cons	3.493956	.0056988	613.10	0.000	3.482787	3.505126

Linear regression Number of obs = 596437

Regression Model 3A R-squared = 0.0573

Root MSE = 6.4726

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a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	.2763218	.0377972	7.31	0.000	.2022404	.3504032
year2003	-.1332533	.037706	-3.53	0.000	-.2071559	-.0593507
year2004	-.0903588	.0373391	-2.42	0.016	-.1635422	-.0171755
year2005	1.236018	.0385872	32.03	0.000	1.160389	1.311648
year2007	.9272508	.0386882	23.97	0.000	.8514231	1.003078
year2008	1.300189	.0384236	33.84	0.000	1.224879	1.375498

year2009	-.2833853	.0388575	-7.29	0.000	-.3595446	-.2072259
year2010	.6976176	.0392414	17.78	0.000	.6207058	.7745295
year2011	1.134356	.0400179	28.35	0.000	1.055922	1.212789
year2012	1.729704	.0435945	39.68	0.000	1.64426	1.815148
January	.8712962	.0416976	20.90	0.000	.7895703	.9530221
February	.7484615	.0417723	17.92	0.000	.6665891	.830334
March	.9470155	.0418113	22.65	0.000	.8650667	1.028964
April	.7995031	.0411542	19.43	0.000	.7188422	.880164
May	.5871139	.0407434	14.41	0.000	.5072581	.6669696
June	.0879558	.0398624	2.21	0.027	.0098268	.1660848
August	.4193184	.0404739	10.36	0.000	.3399909	.4986459
September	.7443673	.0407655	18.26	0.000	.6644682	.8242663
October	.6445431	.0418738	15.39	0.000	.5624719	.7266143
November	.9519598	.042571	22.36	0.000	.8685221	1.035398
December	.6043885	.0418696	14.44	0.000	.5223254	.6864515
discharge	-8.50e-06	6.30e-08	-134.91	0.000	-8.62e-06	-8.37e-06
dischdir	1.30e-07	7.87e-08	1.66	0.098	-2.39e-08	2.85e-07
dirdown	-.1827183	.0252529	-7.24	0.000	-.2322132	-.1332233
_cons	-3.372761	.0401943	-83.91	0.000	-3.45154	-3.293981

Linear regression Number of obs = 596573

Regression Table 3B R-squared = 0.1639

Root MSE = .98494

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	.1975236	.005419	36.45	0.000	.1869026	.2081447
year2003	.1893389	.005639	33.58	0.000	.1782865	.2003912
year2004	.1794816	.0058542	30.66	0.000	.1680075	.1909557
year2005	.3009725	.0056374	53.39	0.000	.2899234	.3120215
year2007	.2424877	.0057801	41.95	0.000	.2311589	.2538166
year2008	.3077574	.0056287	54.68	0.000	.2967252	.3187895
year2009	.0840936	.0063682	13.21	0.000	.0716121	.096575
year2010	.195924	.0062654	31.27	0.000	.1836441	.2082039
year2011	.2315994	.0065592	35.31	0.000	.2187435	.2444552
year2012	.2938263	.0065291	45.00	0.000	.2810294	.3066232
January	.4467462	.0062204	71.82	0.000	.4345544	.4589379
February	.3697567	.0062676	59.00	0.000	.3574725	.382041
March	.5037242	.0064525	78.07	0.000	.4910774	.5163709
April	.3847887	.0063809	60.30	0.000	.3722823	.3972951
May	.3245952	.0063709	50.95	0.000	.3121084	.3370819
June	.0941329	.0060022	15.68	0.000	.0823688	.105897
August	.0829994	.0055734	14.89	0.000	.0720756	.0939232
September	.1124714	.0056787	19.81	0.000	.1013414	.1236014
October	.1205673	.0061227	19.69	0.000	.1085669	.1325676
November	.2454892	.0063412	38.71	0.000	.2330606	.2579177
December	.3068831	.0063857	48.06	0.000	.2943672	.3193989

```
   discharge |  -2.67e-06   1.10e-08  -243.46   0.000    -2.69e-06   -2.65e-06
    dischdir |  -1.51e-07   1.40e-08   -10.74   0.000    -1.78e-07   -1.23e-07
     dirdown |  -.0711992   .0033969   -20.96   0.000     -.077857   -.0645414
       _cons |   3.529571   .0059436   593.84   0.000     3.517922     3.54122
------------------------------------------------------------------------------


Linear regression                               Number of obs =  596437
Regression Table 4A                               R-squared     =  0.0581
                                               Root MSE      =  6.4699

------------------------------------------------------------------------------
             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |   .2334819   .0378196     6.17   0.000     .1593566    .3076072
    year2003 |  -.0890617    .037723    -2.36   0.018    -.1629976   -.0151258
    year2004 |  -.0069935   .0375427    -0.19   0.852    -.0805759     .066589
    year2005 |   1.214113   .0385926    31.46   0.000     1.138473    1.289754
    year2007 |   .9194831   .0387012    23.76   0.000     .8436299    .9953363
    year2008 |   1.254224   .0384481    32.62   0.000     1.178867    1.329581
    year2009 |  -.2942623   .0388401    -7.58   0.000    -.3703878   -.2181369
    year2010 |   .6944335   .0392358    17.70   0.000     .6175326    .7713344
    year2011 |   1.061091    .040092    26.47   0.000     .9825123     1.13967
    year2012 |   1.678086   .0436418    38.45   0.000      1.59255    1.763623
```

```
    January |   1.010602   .0421685    23.97   0.000     .9279533    1.093251

   February |   .9290699   .0425211    21.85   0.000     .8457299     1.01241

      March |   1.116892   .0424707    26.30   0.000     1.033651    1.200133

      April |   .9800539    .041991    23.34   0.000     .8977529    1.062355

        May |   .7210202   .0412295    17.49   0.000     .6402117    .8018287

       June |   .1789685   .0400946     4.46   0.000     .1003844    .2575527

     August |   .3673596   .0405256     9.06   0.000     .2879308    .4467884

  September |   .7103753   .0407591    17.43   0.000     .6304888    .7902618

    October |   .6392279   .0418929    15.26   0.000     .5571191    .7213366

   November |   1.042765   .0427354    24.40   0.000     .9590054    1.126525

   December |   .7679938   .0426188    18.02   0.000     .6844623    .8515252

  discharge |  -.0000115   1.41e-07   -81.92   0.000    -.0000118   -.0000113

     disch2 |   4.16e-12   1.55e-13    26.79   0.000     3.85e-12    4.46e-12

    dirdown |  -.1585536   .0167578    -9.46   0.000    -.1913984   -.1257087

      _cons |  -3.137239   .0405823   -77.31   0.000    -3.216779   -3.057699

------------------------------------------------------------------------------


Linear regression                                 Number of obs =  596573

Regression Table 4B                                 R-squared     =  0.1676

                                                    Root MSE      =  .98275


------------------------------------------------------------------------------

             |               Robust

      s2e_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]

-------------+----------------------------------------------------------------
```

year2002	.1820091	.0053966	33.73	0.000	.171432	.1925863
year2003	.2051674	.0056126	36.55	0.000	.1941668	.216168
year2004	.2095236	.0058501	35.82	0.000	.1980577	.2209896
year2005	.2931722	.0056075	52.28	0.000	.2821818	.3041626
year2007	.2396114	.005776	41.48	0.000	.2282905	.2509322
year2008	.2910843	.0056067	51.92	0.000	.2800952	.3020733
year2009	.0800511	.0063423	12.62	0.000	.0676205	.0924818
year2010	.1946656	.0062414	31.19	0.000	.1824325	.2068986
year2011	.2052654	.006539	31.39	0.000	.1924492	.2180816
year2012	.2753853	.0065078	42.32	0.000	.2626301	.2881404
January	.4970959	.0062635	79.36	0.000	.4848195	.5093722
February	.4348723	.0063418	68.57	0.000	.4224426	.447302
March	.5647035	.006546	86.27	0.000	.5518735	.5775335
April	.44969	.0065098	69.08	0.000	.436931	.462449
May	.3727032	.0064195	58.06	0.000	.3601212	.3852852
June	.1268998	.0059969	21.16	0.000	.115146	.1386536
August	.0644028	.005528	11.65	0.000	.0535681	.0752374
September	.100456	.00564	17.81	0.000	.0894018	.1115102
October	.1187955	.0060988	19.48	0.000	.1068419	.130749
November	.2782408	.0063698	43.68	0.000	.2657561	.2907254
December	.3657321	.0064805	56.44	0.000	.3530306	.3784336
discharge	-3.86e-06	2.25e-08	-171.20	0.000	-3.90e-06	-3.81e-06
disch2	1.49e-12	2.71e-14	55.14	0.000	1.44e-12	1.55e-12
dirdown	-.1019191	.0025444	-40.06	0.000	-.1069059	-.0969322
_cons	3.634083	.0059198	613.89	0.000	3.62248	3.645685

Linear regression   Number of obs = 282765

Regression Table 5A   R-squared   = 0.0631

Root MSE   = 6.6051

----

a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	0 (omitted)					
year2003	0 (omitted)					
year2004	0 (omitted)					
year2005	0 (omitted)					
year2007	0 (omitted)					
year2008	-.106437	.0512891	-2.08	0.038	-.2069621	-.0059118
year2009	-1.53636	.0520075	-29.54	0.000	-1.638293	-1.434426
year2010	-.7403352	.0519745	-14.24	0.000	-.8422037	-.6384667
year2011	-.054921	.0530315	-1.04	0.300	-.1588613	.0490193
year2012	.3327431	.0579518	5.74	0.000	.2191592	.4463269
January	.9416078	.0625076	15.06	0.000	.8190947	1.064121
February	1.391782	.0651537	21.36	0.000	1.264083	1.519482
March	1.66246	.0658386	25.25	0.000	1.533418	1.791502
April	1.165179	.063183	18.44	0.000	1.041342	1.289016

May	1.335452	.0642611	20.78	0.000	1.209502	1.461402
June	.2659032	.0590166	4.51	0.000	.1502324	.381574
August	.3996735	.0562443	7.11	0.000	.2894362	.5099108
September	.7887135	.0575276	13.71	0.000	.675961	.9014661
October	1.099496	.0602729	18.24	0.000	.9813624	1.217629
November	1.515181	.0616938	24.56	0.000	1.394263	1.636099
December	.903639	.0617017	14.65	0.000	.7827053	1.024573
discharge	-7.39e-06	2.23e-07	-33.11	0.000	-7.82e-06	-6.95e-06
disch2	3.39e-12	2.35e-13	14.42	0.000	2.93e-12	3.85e-12
dirdown	-.1540479	.0248454	-6.20	0.000	-.2027442	-.1053515
istage	-.0962272	.0017787	-54.10	0.000	-.0997134	-.092741
_cons	-.6782045	.0664123	-10.21	0.000	-.8083707	-.5480382

Linear regression   Number of obs = 282901

Regression Table 5B   R-squared = 0.1547

Root MSE = 1.0333

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s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	0 (omitted)					
year2003	0 (omitted)					

year2004	0 (omitted)					
year2005	0 (omitted)					
year2007	.1738085	.0076315	22.78	0.000	.158851	.188766
year2008	.034049	.0065564	5.19	0.000	.0211987	.0468992
year2009	-.1720595	.0070453	-24.42	0.000	-.1858681	-.1582508
year2010	-.0744687	.0070338	-10.59	0.000	-.0882549	-.0606826
year2011	-.0277827	.0072014	-3.86	0.000	-.0418972	-.0136682
year2012	0 (omitted)					
January	.4110741	.0096884	42.43	0.000	.392085	.4300632
February	.5257746	.0101435	51.83	0.000	.5058936	.5456556
March	.7274508	.0106591	68.25	0.000	.7065592	.7483424
April	.5208801	.0103064	50.54	0.000	.5006798	.5410804
May	.5554605	.0103826	53.50	0.000	.5351108	.5758101
June	.1791051	.0090461	19.80	0.000	.161375	.1968353
August	.0320466	.0080916	3.96	0.000	.0161872	.0479059
September	.0255062	.0082178	3.10	0.002	.0093996	.0416128
October	.1732451	.0090205	19.21	0.000	.1555652	.1909249
November	.2827549	.0092757	30.48	0.000	.2645748	.300935
December	.3327258	.0098037	33.94	0.000	.3135107	.3519408
discharge	-3.50e-06	3.72e-08	-94.32	0.000	-3.58e-06	-3.43e-06
disch2	1.32e-12	4.25e-14	31.16	0.000	1.24e-12	1.41e-12
dirdown	-.1023804	.0038849	-26.35	0.000	-.1099948	-.094766
istage	-.0087124	.000288	-30.25	0.000	-.0092769	-.0081479
_cons	3.996837	.0086181	463.77	0.000	3.979946	4.013729

```
Linear regression                          Number of obs =  259688
Regression Table 6A                          R-squared     =  0.0793
                                          Root MSE      =  6.6139

------------------------------------------------------------------------------
             |               Robust
     a2s_ln  |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |          0  (omitted)
    year2003 |          0  (omitted)
    year2004 |          0  (omitted)
    year2005 |          0  (omitted)
    year2007 |  -.0779284   .0613341    -1.27   0.204    -.1981417    .0422849
    year2008 |  -.3575028   .0468379    -7.63   0.000    -.4493038   -.2657019
    year2009 |  -1.891316   .0474682   -39.84   0.000    -1.984353    -1.79828
    year2010 |  -1.040908   .0476372   -21.85   0.000    -1.134276   -.9475402
    year2011 |  -.4016834    .048604    -8.26   0.000    -.4969459   -.3064208
    year2012 |          0  (omitted)
     January |   .5202295     .06587     7.90   0.000     .3911262    .6493329
    February |   .9643296   .0683609    14.11   0.000      .830344    1.098315
       March |   1.320878   .0692271    19.08   0.000     1.185195    1.456561
       April |   .8399218   .0669073    12.55   0.000     .7087853    .9710582
         May |   1.134218   .0685682    16.54   0.000     .9998266     1.26861
```

June	.0936858	.0639958	1.46	0.143	-.0317441	.2191158
August	.4034865	.0618109	6.53	0.000	.2823387	.5246343
September	.6946182	.0627519	11.07	0.000	.5716263	.8176102
October	.8371182	.0648662	12.91	0.000	.7099822	.9642542
November	1.055825	.0653143	16.17	0.000	.9278111	1.18384
December	.4622504	.0652473	7.08	0.000	.3343675	.5901333
discharge	-8.92e-06	2.31e-07	-38.62	0.000	-9.38e-06	-8.47e-06
disch2	4.83e-12	2.41e-13	20.01	0.000	4.35e-12	5.30e-12
dirdown	-.1719637	.0259608	-6.62	0.000	-.2228463	-.1210812
istage	-.1020987	.001864	-54.78	0.000	-.105752	-.0984454
draftldft	.2143786	.0137612	15.58	0.000	.187407	.2413502
_cons	-1.360472	.138718	-9.81	0.000	-1.632356	-1.088589

Linear regression Number of obs = 259802

Regression Table 6B R-squared = 0.1764

Root MSE = 1.0396

	Robust					
s2e_ln	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	0 (omitted)					
year2003	0 (omitted)					

year2004	0 (omitted)					
year2005	0 (omitted)					
year2007	.2269873	.0079633	28.50	0.000	.2113795	.2425952
year2008	.0505381	.0068739	7.35	0.000	.0370655	.0640107
year2009	-.1681701	.0074007	-22.72	0.000	-.1826753	-.153665
year2010	-.0660971	.0074287	-8.90	0.000	-.0806572	-.051537
year2011	-.031608	.0075255	-4.20	0.000	-.0463579	-.0168581
year2012	0 (omitted)					
January	.3505277	.0102968	34.04	0.000	.3303464	.3707091
February	.4662324	.0107314	43.45	0.000	.4451992	.4872657
March	.6794729	.0112915	60.18	0.000	.6573419	.7016039
April	.4770401	.010992	43.40	0.000	.4554961	.498584
May	.5362299	.0112021	47.87	0.000	.5142741	.5581856
June	.1584638	.0099633	15.90	0.000	.1389361	.1779915
August	.0328469	.0089909	3.65	0.000	.015225	.0504688
September	.0163283	.008991	1.82	0.069	-.0012938	.0339504
October	.1385414	.0097179	14.26	0.000	.1194946	.1575883
November	.2080486	.0098907	21.03	0.000	.1886631	.2274342
December	.2647747	.0104397	25.36	0.000	.2443132	.2852362
discharge	-3.82e-06	3.83e-08	-99.59	0.000	-3.89e-06	-3.74e-06
disch2	1.61e-12	4.36e-14	36.95	0.000	1.52e-12	1.69e-12
dirdown	-.1168612	.0040782	-28.65	0.000	-.1248545	-.108868
istage	-.009342	.0002964	-31.52	0.000	-.009923	-.008761
draftldft	.0147481	.0022857	6.45	0.000	.0102682	.019228
_cons	4.010431	.022469	178.49	0.000	3.966392	4.05447

Linear regression Number of obs = 259688

Regression Table 6C R-squared = 0.0793

Root MSE = 6.6138

		Robust				
a2s_ln	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	0 (omitted)					
year2003	0 (omitted)					
year2004	0 (omitted)					
year2005	0 (omitted)					
year2007	-.0785902	.0613327	-1.28	0.200	-.1988008	.0416203
year2008	-.3590549	.0468395	-7.67	0.000	-.450859	-.2672509
year2009	-1.892745	.0474683	-39.87	0.000	-1.985782	-1.799709
year2010	-1.042174	.047637	-21.88	0.000	-1.135541	-.9488067
year2011	-.4022331	.0486031	-8.28	0.000	-.4974939	-.3069723
year2012	0 (omitted)					
January	.5196243	.0658694	7.89	0.000	.3905221	.6487266
February	.9636021	.0683606	14.10	0.000	.8296172	1.097587
March	1.319938	.0692285	19.07	0.000	1.184252	1.455624
April	.8375148	.0669079	12.52	0.000	.706377	.9686525

May	1.132631	.0685721	16.52	0.000	.9982316	1.267031
June	.0925364	.0639957	1.45	0.148	-.0328935	.2179663
August	.402964	.0618076	6.52	0.000	.2818226	.5241053
September	.6933731	.0627529	11.05	0.000	.5703791	.816367
October	.8362715	.0648684	12.89	0.000	.7091311	.9634119
November	1.054798	.0653127	16.15	0.000	.9267865	1.182809
December	.4618416	.0652431	7.08	0.000	.3339668	.5897163
discharge	-8.92e-06	2.31e-07	-38.61	0.000	-9.37e-06	-8.47e-06
disch2	4.83e-12	2.41e-13	20.01	0.000	4.35e-12	5.30e-12
dirdown	-.1717542	.0259605	-6.62	0.000	-.2226361	-.1208723
istage	-.0620101	.0119055	-5.21	0.000	-.0853445	-.0386757
draftldft	.3137916	.0342997	9.15	0.000	.2465652	.3810181
draftstage	-.0044918	.0013205	-3.40	0.001	-.00708	-.0019036
_cons	-2.246126	.3121107	-7.20	0.000	-2.857855	-1.634398

Linear regression Number of obs = 259802

Regression Table 6D R-squared = 0.1766

Root MSE = 1.0395

		Robust				
s2e_ln	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	

```
-------------+----------------------------------------------------------------
    year2002 |          0  (omitted)
    year2003 |          0  (omitted)
    year2004 |          0  (omitted)
    year2005 |          0  (omitted)
    year2007 |   .2267039    .007964    28.47   0.000     .2110948    .2423131
    year2008 |   .0498862   .0068738     7.26   0.000     .0364137    .0633586
    year2009 |  -.1687709   .0074005   -22.81   0.000    -.1832758   -.1542661
    year2010 |  -.0666303   .0074284    -8.97   0.000    -.0811898   -.0520708
    year2011 |  -.0318445   .0075251    -4.23   0.000    -.0465935   -.0170956
    year2012 |          0  (omitted)
     January |   .3502755   .0102952    34.02   0.000     .3300971    .3704538
    February |   .4659299   .0107292    43.43   0.000      .444901    .4869587
       March |   .6790782   .0112899    60.15   0.000     .6569504    .7012061
       April |   .4760411   .0109892    43.32   0.000     .4545026    .4975796
         May |   .5355714   .0112011    47.81   0.000     .5136177    .5575252
        June |    .157987    .009961    15.86   0.000     .1384636    .1775103
      August |   .0326301   .0089895     3.63   0.000     .0150108    .0502494
   September |   .0158102   .0089902     1.76   0.079    -.0018104    .0334307
     October |    .138189   .0097167    14.22   0.000     .1191445    .1572335
    November |   .2076212   .0098901    20.99   0.000     .1882368    .2270056
    December |   .2646042    .010438    25.35   0.000     .2441459    .2850624
   discharge |  -3.82e-06   3.83e-08   -99.59   0.000    -3.89e-06   -3.74e-06
      disch2 |   1.61e-12   4.35e-14    36.96   0.000     1.52e-12    1.69e-12
     dirdown |  -.1167737   .0040777   -28.64   0.000    -.1247658   -.1087816
```

```
     istage |     .00727   .0020621     3.53   0.000     .0032285    .0113116
   draftldft |   .0559422   .0050088    11.17   0.000     .0461251    .0657592
  draftstage |  -.0018613   .0002294    -8.11   0.000    -.002311   -.0014117
       _cons |   3.643451   .0455238    80.03   0.000     3.554225    3.732676
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Linear regression                               Number of obs =  282765
Regression Table 7A                             R-squared     =  0.0843
                                                Root MSE      =  6.5303

------------------------------------------------------------------------------
             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |          0  (omitted)
    year2003 |          0  (omitted)
    year2004 |          0  (omitted)
    year2005 |          0  (omitted)
    year2007 |          0  (omitted)
    year2008 |  -.0312529    .052668    -0.59   0.553    -.1344807    .0719749
    year2009 |  -1.362558     .05308   -25.67   0.000    -1.466594   -1.258523
    year2010 |  -.6571475   .0530322   -12.39   0.000    -.7610892   -.5532058
    year2011 |   .0503427   .0538309     0.94   0.350    -.0551644    .1558498
    year2012 |   .6579373   .0597513    11.01   0.000     .5408264    .7750481
```

January	.4437214	.0620274	7.15	0.000	.3221494	.5652933
February	.7065831	.0641421	11.02	0.000	.5808664	.8322998
March	.7505941	.0651577	11.52	0.000	.6228869	.8783013
April	.5376094	.0625639	8.59	0.000	.414986	.6602329
May	.5869089	.0635073	9.24	0.000	.4624364	.7113814
June	-.0099593	.0585377	-0.17	0.865	-.1246916	.104773
August	.4906197	.0568423	8.63	0.000	.3792104	.6020291
September	.9857999	.0584549	16.86	0.000	.8712298	1.10037
October	1.199364	.0608604	19.71	0.000	1.08008	1.318649
November	1.49524	.0617032	24.23	0.000	1.374304	1.616177
December	.5224951	.0607024	8.61	0.000	.4035201	.6414701
discharge	-2.75e-06	2.28e-07	-12.05	0.000	-3.20e-06	-2.30e-06
disch2	1.40e-12	2.27e-13	6.16	0.000	9.52e-13	1.84e-12
dirdown	-.1394261	.0245633	-5.68	0.000	-.1875695	-.0912827
istage	-.1046299	.001781	-58.75	0.000	-.1081205	-.1011393
wicket	-2.358351	.0286586	-82.29	0.000	-2.414521	-2.302181
_cons	-.3846263	.0672273	-5.72	0.000	-.5163899	-.2528627

Linear regression   Number of obs = 282901

Regression Table 7B   R-squared   = 0.4899

Root MSE   = .80276

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s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	0 (omitted)					
year2003	0 (omitted)					
year2004	0 (omitted)					
year2005	0 (omitted)					
year2007	-.0395131	.0076842	-5.14	0.000	-.054574	-.0244522
year2008	-.1299946	.0055704	-23.34	0.000	-.1409125	-.1190768
year2009	-.271414	.0056043	-48.43	0.000	-.2823983	-.2604297
year2010	-.233292	.005599	-41.67	0.000	-.2442658	-.2223182
year2011	-.1720659	.0057279	-30.04	0.000	-.1832923	-.1608395
year2012	0 (omitted)					
January	.0837563	.007592	11.03	0.000	.0688762	.0986364
February	.0762437	.0073983	10.31	0.000	.0617433	.0907442
March	.129488	.0076291	16.97	0.000	.1145351	.1444409
April	.1096087	.0077075	14.22	0.000	.0945022	.1247152
May	.0648155	.0076442	8.48	0.000	.0498331	.0797978
June	-.0014602	.0071661	-0.20	0.839	-.0155056	.0125852
August	.0914033	.0075456	12.11	0.000	.076614	.1061925
September	.1543828	.0078036	19.78	0.000	.139088	.1696775
October	.2385902	.0080541	29.62	0.000	.2228044	.2543759
November	.2695488	.0079809	33.77	0.000	.2539065	.285191
December	.0827482	.0072715	11.38	0.000	.0684963	.0970002
discharge	-4.63e-07	2.94e-08	-15.76	0.000	-5.20e-07	-4.05e-07

```
     disch2 |   1.94e-14   3.01e-14    0.64   0.520    -3.97e-14    7.84e-14

    dirdown |  -.0927507   .0030176   -30.74   0.000    -.0986651   -.0868362

     istage |  -.0142421   .0001964   -72.50   0.000    -.0146271    -.013857

     wicket |  -1.547306    .004915  -314.81   0.000     -1.55694   -1.537673

      _cons |   4.403402   .0074563   590.56   0.000     4.388788    4.418016

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Linear regression                               Number of obs =  282765

Regression Table 7C                               R-squared     =  0.1090

                                                  Root MSE      =  6.4413


------------------------------------------------------------------------------

             |               Robust

      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]

-------------+----------------------------------------------------------------

    year2002 |          0  (omitted)

    year2003 |          0  (omitted)

    year2004 |          0  (omitted)

    year2005 |          0  (omitted)

    year2007 |          0  (omitted)

    year2008 |  -.0645728   .0524621    -1.23   0.218     -.167397    .0382515

    year2009 |  -1.199063   .0546403   -21.94   0.000    -1.306156   -1.091969

    year2010 |   -.533783   .0532852   -10.02   0.000    -.6382204   -.4293455

    year2011 |  -.0078636   .0548875    -0.14   0.886    -.1154415    .0997144
```

year2012	.5555813	.058304	9.53	0.000	.4413071	.6698555
January	.594076	.061715	9.63	0.000	.4731162	.7150357
February	.8606476	.063909	13.47	0.000	.7353878	.9859075
March	.6774674	.0645018	10.50	0.000	.5510456	.8038891
April	.5934985	.0621326	9.55	0.000	.4717202	.7152767
May	.7517762	.0634778	11.84	0.000	.6273615	.8761909
June	.2489076	.058178	4.28	0.000	.1348803	.362935
August	.2996957	.0561317	5.34	0.000	.1896792	.4097122
September	.6986952	.0578001	12.09	0.000	.5854086	.8119818
October	.980385	.0610951	16.05	0.000	.8606403	1.10013
November	1.375395	.0615035	22.36	0.000	1.25485	1.49594
December	.7082605	.0613858	11.54	0.000	.587946	.8285749
discharge	-7.84e-06	2.34e-07	-33.46	0.000	-8.30e-06	-7.38e-06
disch2	1.09e-11	3.20e-13	34.06	0.000	1.03e-11	1.15e-11
dirdown	-.1254732	.0242301	-5.18	0.000	-.1729636	-.0779828
istage	-.0346345	.0022445	-15.43	0.000	-.0390336	-.0302354
wicket	3.362117	.1276729	26.33	0.000	3.111882	3.612353
wickstage	-.2549187	.0055247	-46.14	0.000	-.265747	-.2440904
_cons	-1.515951	.0678441	-22.34	0.000	-1.648924	-1.382979

Linear regression Number of obs = 282901

Regression Table 7D R-squared = 0.5558

Root MSE = .74911

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	0 (omitted)					
year2003	0 (omitted)					
year2004	0 (omitted)					
year2005	0 (omitted)					
year2007	-.0118258	.0069918	-1.69	0.091	-.0255295	.0018778
year2008	-.1112345	.0050482	-22.03	0.000	-.1211289	-.1013401
year2009	-.1997921	.0055271	-36.15	0.000	-.2106251	-.1889591
year2010	-.1724608	.0052359	-32.94	0.000	-.182723	-.1621986
year2011	-.1599778	.0055798	-28.67	0.000	-.170914	-.1490416
year2012	0 (omitted)					
January	.124135	.0072218	17.19	0.000	.1099805	.1382895
February	.1176852	.0070581	16.67	0.000	.1038516	.1315188
March	.1100367	.0071725	15.34	0.000	.0959787	.1240947
April	.1246166	.0073236	17.02	0.000	.1102625	.1389706
May	.1090953	.0075062	14.53	0.000	.0943833	.1238072
June	.0679665	.006682	10.17	0.000	.0548699	.0810631
August	.0402492	.0069768	5.77	0.000	.026575	.0539235
September	.0774206	.0073184	10.58	0.000	.0630767	.0917645
October	.1798577	.0078781	22.83	0.000	.1644169	.1952986
November	.2374324	.007652	31.03	0.000	.2224347	.2524301

```
   December |   .1326905   .0073681    18.01   0.000     .1182492    .1471317
  discharge |  -1.83e-06   3.23e-08   -56.66   0.000    -1.89e-06   -1.77e-06
     disch2 |   2.57e-12   5.94e-14    43.34   0.000     2.46e-12    2.69e-12
    dirdown |  -.0889662   .0028165   -31.59   0.000    -.0944864    -.083446
     istage |   .0045498   .0002902    15.68   0.000     .0039811    .0051186
     wicket |  -.0112865   .0252866    -0.45   0.655    -.0608476    .0382746
  wickstage |  -.0684553    .001118   -61.23   0.000    -.0706466   -.0662639
      _cons |   4.071887   .0072875   558.75   0.000     4.057604    4.086171
------------------------------------------------------------------------------

Linear regression                               Number of obs =  528778
Regression Table 8A                             R-squared     =  0.0766
                                                Root MSE      =  6.5083

------------------------------------------------------------------------------
             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |   .3475816   .0406964     8.54   0.000     .2678179    .4273452
    year2003 |  -.0676394   .0405396    -1.67   0.095    -.1470957    .0118169
    year2004 |   .1024994   .0403485     2.54   0.011     .0234177    .1815811
    year2005 |   1.372131   .0411928    33.31   0.000     1.291394    1.452867
    year2007 |   1.085773   .0413327    26.27   0.000     1.004762    1.166784
    year2008 |   1.365225   .0409084    33.37   0.000     1.285046    1.445404
```

year2009	-.3560433	.0415696	-8.56	0.000	-.4375184	-.2745682
year2010	.716988	.0418872	17.12	0.000	.6348904	.7990857
year2011	1.008894	.0425886	23.69	0.000	.925422	1.092367
year2012	1.694293	.0464826	36.45	0.000	1.603188	1.785397
January	.5025883	.0456182	11.02	0.000	.4131781	.5919985
February	.3832741	.0458649	8.36	0.000	.2933804	.4731678
March	.6517268	.046013	14.16	0.000	.5615428	.7419108
April	.5511533	.0456581	12.07	0.000	.4616649	.6406417
May	.4335362	.0454675	9.54	0.000	.3444213	.5226511
June	-.0183656	.0449128	-0.41	0.683	-.1063933	.069662
August	.4113702	.0458747	8.97	0.000	.3214572	.5012832
September	.6369056	.0457175	13.93	0.000	.5473008	.7265104
October	.3429193	.04653	7.37	0.000	.251722	.4341166
November	.5358222	.046403	11.55	0.000	.4448738	.6267706
December	.2715219	.0461583	5.88	0.000	.1810531	.3619907
discharge	-.0000134	1.50e-07	-89.07	0.000	-.0000137	-.0000131
disch2	5.69e-12	1.65e-13	34.47	0.000	5.37e-12	6.02e-12
dirdown	-.1776913	.0179065	-9.92	0.000	-.2127875	-.142595
tugboat	.9721237	.0987024	9.85	0.000	.7786702	1.165577
pushboat	1.538517	.0916808	16.78	0.000	1.358825	1.718208
num_processed	.0566828	.0014935	37.95	0.000	.0537555	.0596101
_cons	-4.258755	.1013612	-42.02	0.000	-4.45742	-4.060091

Linear regression   Number of obs = 524754

Regression Table 8B   R-squared   = 0.1952

Root MSE   = .97888

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.2243951	.0057038	39.34	0.000	.2132159	.2355743
year2003	.2276755	.0059353	38.36	0.000	.2160425	.2393084
year2004	.2342802	.0062193	37.67	0.000	.2220906	.2464698
year2005	.3237411	.0059262	54.63	0.000	.3121259	.3353562
year2007	.2722376	.0061182	44.50	0.000	.2602461	.2842291
year2008	.3067118	.0059271	51.75	0.000	.2950949	.3183288
year2009	.0726563	.0067359	10.79	0.000	.059454	.0858585
year2010	.1841422	.0066818	27.56	0.000	.1710461	.1972383
year2011	.1807678	.0069573	25.98	0.000	.1671316	.1944039
year2012	.2627935	.0069434	37.85	0.000	.2491846	.2764023
January	.411951	.0067717	60.83	0.000	.3986786	.4252234
February	.3438941	.0068323	50.33	0.000	.3305031	.3572852
March	.4853233	.0070768	68.58	0.000	.4714529	.4991937
April	.3783394	.0070602	53.59	0.000	.3645016	.3921773
May	.3343196	.0070672	47.31	0.000	.3204682	.348171
June	.1029644	.0067393	15.28	0.000	.0897556	.1161732
August	.0725384	.0062075	11.69	0.000	.0603719	.0847049

```
    September |   .0907788   .0062672    14.48   0.000     .0784952    .1030624
      October |   .0758497   .0067082    11.31   0.000     .0627018    .0889975
     November |   .1922639   .0069012    27.86   0.000     .1787377    .2057901
     December |   .2820804   .0069941    40.33   0.000     .2683722    .2957887
    discharge |  -4.15e-06   2.38e-08  -174.75   0.000    -4.20e-06   -4.11e-06
       disch2 |   1.73e-12   2.85e-14    60.55   0.000     1.67e-12    1.78e-12
      dirdown |   -.116809   .0027013   -43.24   0.000    -.1221035   -.1115145
      tugboat |   .9118617   .1143567     7.97   0.000     .6877261    1.135997
     pushboat |   1.003098   .1142303     8.78   0.000       .77921    1.226985
    yearbuilt |   .0028233    .000104    27.14   0.000     .0026194    .0030272
num_processed |   .0067533   .0002817    23.98   0.000     .0062012    .0073053
        _cons |   -2.84451   .2369237   -12.01   0.000    -3.308873   -2.380147
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```

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Linear regression                               Number of obs =  524633
Regression Table 8C                               R-squared     =  0.0767
                                             Root MSE      =  6.5105

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             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |    .353146   .0409137     8.63   0.000     .2729564    .4333356
    year2003 |  -.0627685   .0407504    -1.54   0.123    -.1426381     .017101
```

year2004 |	.0956651	.0404714	2.36	0.018	.0163423	.1749878
year2005 |	1.370187	.0413107	33.17	0.000	1.28922	1.451155
year2007 |	1.094662	.0414662	26.40	0.000	1.013389	1.175934
year2008 |	1.37796	.0410309	33.58	0.000	1.29754	1.458379
year2009 |	-.3327759	.0417067	-7.98	0.000	-.4145196	-.2510321
year2010 |	.7207479	.0420394	17.14	0.000	.6383521	.8031438
year2011 |	1.018416	.0427439	23.83	0.000	.9346395	1.102193
year2012 |	1.689674	.0468009	36.10	0.000	1.597945	1.781402
January |	.4977956	.0458204	10.86	0.000	.407989	.5876021
February |	.3811833	.0460837	8.27	0.000	.2908607	.4715058
March |	.6532647	.0462237	14.13	0.000	.5626677	.7438616
April |	.5525288	.0458853	12.04	0.000	.4625951	.6424626
May |	.4329069	.0456674	9.48	0.000	.3434002	.5224136
June |	-.0149474	.0451442	-0.33	0.741	-.1034285	.0735337
August |	.4190783	.0461286	9.09	0.000	.3286678	.5094888
September |	.6358857	.0459326	13.84	0.000	.5458592	.7259122
October |	.3521388	.0467506	7.53	0.000	.260509	.4437686
November |	.54603	.0466388	11.71	0.000	.4546193	.6374406
December |	.2684924	.0463587	5.79	0.000	.1776308	.359354
discharge |	-.0000133	1.51e-07	-88.53	0.000	-.0000136	-.000013
disch2 |	5.66e-12	1.66e-13	34.13	0.000	5.33e-12	5.98e-12
dirdown |	-.1807707	.0179846	-10.05	0.000	-.21602	-.1455214
tugboat |	4.694106	.4939652	9.50	0.000	3.72595	5.662262
pushboat |	5.288235	.4917617	10.75	0.000	4.324397	6.252072
num_processed |	.0442393	.0017385	25.45	0.000	.0408318	.0476468

draftldft	.0665147	.0113132	5.88	0.000	.0443412	.0886883
draftltft	.0839937	.0088977	9.44	0.000	.0665546	.1014328
tonnage	.0005275	.0000618	8.54	0.000	.0004064	.0006485
_cons	-9.321427	.5095193	-18.29	0.000	-10.32007	-8.322786

Linear regression Number of obs = 521534

Regression Table 8D R-squared = 0.1961

Root MSE = .97884

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.2262678	.0057054	39.66	0.000	.2150854	.2374501
year2003	.2290851	.0059363	38.59	0.000	.2174501	.2407201
year2004	.2336864	.0062149	37.60	0.000	.2215054	.2458674
year2005	.3232712	.0059212	54.60	0.000	.3116658	.3348766
year2007	.2732588	.0061135	44.70	0.000	.2612765	.2852411
year2008	.3087737	.0059327	52.05	0.000	.2971459	.3204015
year2009	.0711534	.0067629	10.52	0.000	.0578984	.0844085
year2010	.1804756	.0067184	26.86	0.000	.1673077	.1936436
year2011	.1795774	.0069977	25.66	0.000	.1658621	.1932927
year2012	.2612747	.0069877	37.39	0.000	.2475791	.2749703
January	.4134897	.0067992	60.81	0.000	.4001634	.4268159

February	.3438887	.0068607	50.12	0.000	.3304421	.3573354
March	.4844831	.0071013	68.22	0.000	.4705648	.4984014
April	.3782252	.0070855	53.38	0.000	.3643378	.3921126
May	.33306	.0070893	46.98	0.000	.3191651	.3469548
June	.1031746	.0067669	15.25	0.000	.0899117	.1164375
August	.0726877	.0062371	11.65	0.000	.0604631	.0849123
September	.0902051	.0062974	14.32	0.000	.0778623	.1025479
October	.0757526	.0067349	11.25	0.000	.0625524	.0889528
November	.1924781	.0069253	27.79	0.000	.1789048	.2060515
December	.2817759	.0070201	40.14	0.000	.2680167	.2955351
discharge	-4.15e-06	2.38e-08	-174.30	0.000	-4.20e-06	-4.10e-06
disch2	1.73e-12	2.86e-14	60.54	0.000	1.67e-12	1.79e-12
dirdown	-.1158264	.0027092	-42.75	0.000	-.1211363	-.1105164
tugboat	1.729984	.1282866	13.49	0.000	1.478547	1.981422
pushboat	1.84782	.1281561	14.42	0.000	1.596638	2.099002
yearbuilt	.0028037	.000108	25.96	0.000	.0025921	.0030154
num_processed	.006994	.000323	21.65	0.000	.0063608	.0076272
draftldft	.0107845	.0017985	6.00	0.000	.0072596	.0143095
draftltft	.0114822	.0014449	7.95	0.000	.0086503	.0143142
tonnage	.0002413	.0000131	18.44	0.000	.0002156	.0002669
horsepower	-.0000267	1.45e-06	-18.40	0.000	-.0000295	-.0000238
_cons	-3.813604	.2558761	-14.90	0.000	-4.315113	-3.312094

Linear regression Number of obs = 520330

Regression Table 9A R-squared = 0.0785

Root MSE = 6.5052

a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.3382331	.0411532	8.22	0.000	.2575742	.418892
year2003	-.1048701	.0409613	-2.56	0.010	-.185153	-.0245871
year2004	.0475055	.0406098	1.17	0.242	-.0320885	.1270994
year2005	1.356718	.0414022	32.77	0.000	1.275571	1.437865
year2007	1.088448	.0416272	26.15	0.000	1.00686	1.170036
year2008	1.361853	.0411897	33.06	0.000	1.281123	1.442584
year2009	-.3773128	.0418677	-9.01	0.000	-.4593723	-.2952533
year2010	.6890044	.042284	16.29	0.000	.606129	.7718797
year2011	.9632843	.0428971	22.46	0.000	.8792074	1.047361
year2012	1.626554	.0470943	34.54	0.000	1.53425	1.718857
January	.4550464	.0460383	9.88	0.000	.3648127	.5452801
February	.3352777	.0462821	7.24	0.000	.2445662	.4259892
March	.6032586	.0464203	13.00	0.000	.5122763	.6942409
April	.5060007	.0460749	10.98	0.000	.4156952	.5963061
May	.3957152	.0458668	8.63	0.000	.3058177	.4856127
June	-.029682	.0453348	-0.65	0.513	-.1185368	.0591729
August	.4159915	.0463454	8.98	0.000	.3251559	.5068271

September	.6367652	.0461841	13.79	0.000	.5462457	.7272847
October	.3519111	.0469503	7.50	0.000	.2598901	.4439321
November	.5296488	.0468197	11.31	0.000	.4378837	.6214139
December	.2357612	.0465238	5.07	0.000	.1445761	.3269463
discharge	-.0000131	1.52e-07	-86.39	0.000	-.0000134	-.0000128
disch2	5.50e-12	1.67e-13	33.02	0.000	5.17e-12	5.82e-12
dirdown	-.1800892	.0180452	-9.98	0.000	-.2154572	-.1447211
tugboat	6.699091	.5149786	13.01	0.000	5.689749	7.708433
pushboat	7.120311	.5126293	13.89	0.000	6.115574	8.125048
num_processed	.0434496	.0019071	22.78	0.000	.0397118	.0471874
draftldft	.1195268	.0116804	10.23	0.000	.0966335	.14242
draftltft	.0490546	.0093771	5.23	0.000	.0306758	.0674334
tonnage	.0010171	.0000665	15.29	0.000	.0008867	.0011475
clcc	.9110921	.0325123	28.02	0.000	.847369	.9748152
ppp	.2342696	.0248228	9.44	0.000	.1856177	.2829216
crp	.2833166	.0310812	9.12	0.000	.2223984	.3442347
cmief	-.4690916	.031047	-15.11	0.000	-.5299428	-.4082404
pmg	-.0607153	.0326259	-1.86	0.063	-.1246609	.0032304
ffp	-.6834786	.0399055	-17.13	0.000	-.7616921	-.605265
mem	-.0051786	.1197533	-0.04	0.966	-.2398913	.2295341
_cons	-11.6218	.5299659	-21.93	0.000	-12.66052	-10.58309

Linear regression Number of obs = 517229

Regression Table 9B R-squared = 0.2032

Root MSE = .97453

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.2257077	.0057456	39.28	0.000	.2144465	.2369688
year2003	.2217841	.0059619	37.20	0.000	.210099	.2334693
year2004	.2241712	.0062306	35.98	0.000	.2119594	.2363829
year2005	.322126	.0059345	54.28	0.000	.3104946	.3337575
year2007	.2691568	.0061294	43.91	0.000	.2571433	.2811702
year2008	.3001492	.005951	50.44	0.000	.2884855	.3118129
year2009	.0618997	.0067695	9.14	0.000	.0486318	.0751676
year2010	.1774015	.0067321	26.35	0.000	.1642068	.1905961
year2011	.1731111	.0069927	24.76	0.000	.1594057	.1868165
year2012	.2654774	.0070097	37.87	0.000	.2517387	.2792162
January	.3981077	.0068062	58.49	0.000	.3847677	.4114476
February	.3299966	.0068717	48.02	0.000	.3165284	.3434649
March	.4670784	.0071058	65.73	0.000	.4531513	.4810055
April	.3629836	.007089	51.20	0.000	.3490894	.3768778
May	.3208502	.0070911	45.25	0.000	.3069519	.3347485
June	.0984857	.0067701	14.55	0.000	.0852165	.1117548
August	.0738599	.0062429	11.83	0.000	.061624	.0860958
September	.089556	.0063125	14.19	0.000	.0771837	.1019284

October	.0753943	.0067375	11.19	0.000	.0621891	.0885996
November	.1869136	.0069304	26.97	0.000	.1733303	.2004969
December	.2712426	.0070248	38.61	0.000	.2574743	.2850109
discharge	-4.08e-06	2.39e-08	-171.15	0.000	-4.13e-06	-4.04e-06
disch2	1.69e-12	2.86e-14	59.04	0.000	1.63e-12	1.74e-12
dirdown	-.1151432	.0027082	-42.52	0.000	-.1204513	-.1098351
tugboat	1.968151	.1290134	15.26	0.000	1.715288	2.221013
pushboat	2.005606	.1288625	15.56	0.000	1.75304	2.258173
yearbuilt	.001988	.0001116	17.81	0.000	.0017692	.0022068
num_processed	.0039784	.0003707	10.73	0.000	.0032518	.0047049
draftldft	.0293451	.0019125	15.34	0.000	.0255966	.0330935
draftltft	.0055651	.0015193	3.66	0.000	.0025873	.008543
tonnage	.0002576	.0000135	19.04	0.000	.0002311	.0002841
horsepower	-.0000161	1.50e-06	-10.72	0.000	-.000019	-.0000131
clcc	.303236	.0044341	68.39	0.000	.2945453	.3119266
ppp	.0310074	.0041924	7.40	0.000	.0227905	.0392244
crp	.0992906	.0049601	20.02	0.000	.089569	.1090121
cmief	-.1290096	.0045956	-28.07	0.000	-.1380169	-.1200022
pmg	-.0050373	.0051242	-0.98	0.326	-.0150805	.0050059
ffp	-.1706948	.0063485	-26.89	0.000	-.1831376	-.158252
mem	-.111019	.0195065	-5.69	0.000	-.1492512	-.0727868
_cons	-2.560387	.2623502	-9.76	0.000	-3.074585	-2.046189

Linear regression Number of obs = 520330

Regression Table 10A R-squared = 0.1567

Root MSE = 6.2229

a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.2292784	.0394004	5.82	0.000	.1520549	.3065019
year2003	-.4660449	.0387893	-12.01	0.000	-.5420708	-.3900191
year2004	-.4188142	.0384076	-10.90	0.000	-.4940919	-.3435364
year2005	1.117432	.0398386	28.05	0.000	1.039349	1.195514
year2007	.948509	.0401759	23.61	0.000	.8697655	1.027253
year2008	1.07546	.0397707	27.04	0.000	.9975111	1.15341
year2009	-.5212921	.0396837	-13.14	0.000	-.599071	-.4435132
year2010	.4435448	.0400365	11.08	0.000	.3650745	.5220151
year2011	.7008668	.0401825	17.44	0.000	.6221103	.7796232
year2012	1.662758	.046098	36.07	0.000	1.572407	1.753109
January	-.5411987	.0444222	-12.18	0.000	-.6282649	-.4541326
February	-.6581938	.044288	-14.86	0.000	-.7449969	-.5713906
March	-.6554979	.0445832	-14.70	0.000	-.7428795	-.5681163
April	-.5653277	.044022	-12.84	0.000	-.6516094	-.479046
May	-.6071894	.043687	-13.90	0.000	-.6928146	-.5215643
June	-.389923	.0432414	-9.02	0.000	-.4746748	-.3051713
August	.5378975	.0454218	11.84	0.000	.4488723	.6269228

September	.6639333	.0452287	14.68	0.000	.5752865	.7525802
October	.3662921	.045357	8.08	0.000	.2773939	.4551903
November	.167401	.0449441	3.72	0.000	.0793119	.2554901
December	-.5681501	.0444155	-12.79	0.000	-.6552031	-.4810971
discharge	-6.13e-06	1.56e-07	-39.27	0.000	-6.43e-06	-5.82e-06
disch2	1.98e-12	1.64e-13	12.04	0.000	1.66e-12	2.30e-12
dirdown	-.1388782	.0172616	-8.05	0.000	-.1727104	-.1050461
tugboat	4.127506	.4751575	8.69	0.000	3.196212	5.0588
pushboat	4.614239	.4728853	9.76	0.000	3.687398	5.541079
num_processed	.0517247	.001773	29.17	0.000	.0482497	.0551998
draftldft	.087896	.0111663	7.87	0.000	.0660105	.1097815
draftltft	.0252386	.0090178	2.80	0.005	.007564	.0429131
tonnage	.0008742	.0000636	13.75	0.000	.0007495	.0009988
clcc	.1522694	.0318013	4.79	0.000	.0899399	.2145989
ppp	.2120469	.0235931	8.99	0.000	.1658052	.2582886
crp	.1369166	.029622	4.62	0.000	.0788583	.1949748
cmief	-.2574536	.0301911	-8.53	0.000	-.3166272	-.19828
pmg	-.0659391	.0313247	-2.11	0.035	-.1273346	-.0045436
ffp	-.0562804	.0384529	-1.46	0.143	-.1316469	.0190861
mem	.0338761	.1168658	0.29	0.772	-.1951772	.2629294
markland	-.0451818	.0424663	-1.06	0.287	-.1284144	.0380507
mcalpine	-.4937527	.0401444	-12.30	0.000	-.5724344	-.415071
cannelton	-.3306805	.0400164	-8.26	0.000	-.4091114	-.2522496
newburgh	-.258832	.0373375	-6.93	0.000	-.3320123	-.1856516
smithland	-3.544178	.0355704	-99.64	0.000	-3.613895	-3.474461

lock52	-2.600548	.0352607	-73.75	0.000	-2.669658	-2.531438
lock53	-5.880447	.0319737	-183.91	0.000	-5.943115	-5.81778
_cons	-7.169449	.4915394	-14.59	0.000	-8.132851	-6.206048

Linear regression   Number of obs = 517229

Regression Table 10B   R-squared = 0.6469

Root MSE = .6487

	Robust					
s2e_ln	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.156702	.0038762	40.43	0.000	.1491047	.1642993
year2003	.0448093	.0036014	12.44	0.000	.0377507	.0518678
year2004	.0117664	.0036084	3.26	0.001	.0046941	.0188386
year2005	.2085169	.0040212	51.85	0.000	.2006354	.2163983
year2007	.2100132	.0042173	49.80	0.000	.2017474	.218279
year2008	.1782007	.0041522	42.92	0.000	.1700624	.1863389
year2009	.013247	.0040114	3.30	0.001	.0053848	.0211092
year2010	.0807706	.0041444	19.49	0.000	.0726477	.0888936
year2011	.0713358	.0041945	17.01	0.000	.0631147	.0795569
year2012	.3109328	.0051678	60.17	0.000	.300804	.3210615
January	-.065498	.0045948	-14.25	0.000	-.0745036	-.0564924

February	-.129801	.0044523	-29.15	0.000	-.1385275	-.1210746
March	-.1111803	.0045376	-24.50	0.000	-.1200739	-.1022868
April	-.1252895	.0045367	-27.62	0.000	-.1341812	-.1163977
May	-.1371963	.004496	-30.51	0.000	-.1460084	-.1283842
June	-.0683237	.004627	-14.77	0.000	-.0773924	-.059255
August	.1248997	.0051921	24.06	0.000	.1147233	.135076
September	.0967571	.0050589	19.13	0.000	.0868417	.1066724
October	.0784401	.0051283	15.30	0.000	.0683887	.0884914
November	.0193791	.0049836	3.89	0.000	.0096114	.0291468
December	-.096719	.0046184	-20.94	0.000	-.1057709	-.0876671
discharge	-1.06e-06	1.70e-08	-61.93	0.000	-1.09e-06	-1.02e-06
disch2	3.11e-13	1.98e-14	15.66	0.000	2.72e-13	3.50e-13
dirdown	-.0935346	.0018024	-51.90	0.000	-.0970672	-.090002
tugboat	.2866525	.1037758	2.76	0.006	.0832553	.4900498
pushboat	.3152659	.1036836	3.04	0.002	.1120494	.5184824
yearbuilt	-.0004757	.0000749	-6.35	0.000	-.0006224	-.000329
num_processed	.0060976	.0002235	27.28	0.000	.0056595	.0065356
draftldft	.019915	.0012772	15.59	0.000	.0174118	.0224182
draftltft	-.0110952	.0010148	-10.93	0.000	-.013084	-.0091063
tonnage	.0000449	8.88e-06	5.05	0.000	.0000275	.0000623
horsepower	7.33e-06	1.01e-06	7.25	0.000	5.35e-06	9.32e-06
clcc	.0165209	.0030017	5.50	0.000	.0106377	.0224041
ppp	-.000469	.0027102	-0.17	0.863	-.0057809	.0048428
crp	.0088815	.0032213	2.76	0.006	.0025678	.0151952
cmief	-.0243308	.0031932	-7.62	0.000	-.0305893	-.0180723

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pmg |  -.0549521   .0034193   -16.07   0.000    -.0616538   -.0482504
ffp |   .0197104   .0042398     4.65   0.000     .0114006    .0280203
mem |  -.0543391   .0141093    -3.85   0.000    -.0819928   -.0266854
markland |   .1333112   .0025552    52.17   0.000     .1283032    .1383193
mcalpine |   .0677524   .0022923    29.56   0.000     .0632597    .0722452
cannelton |   .0919282    .002353    39.07   0.000     .0873165     .09654
newburgh |  -.0254207   .0021139   -12.03   0.000    -.0295639   -.0212774
smithland |   .0770753   .0022713    33.93   0.000     .0726235     .081527
lock52 |   -1.15779   .0040387  -286.68   0.000    -1.165706   -1.149874
lock53 |  -2.118428   .0041173  -514.52   0.000    -2.126497   -2.110358
_cons |   4.505408   .1847737    24.38   0.000     4.143257    4.867559
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Linear regression                               Number of obs =  520330
Regression Table 11A                            R-squared     =  0.1672
                                                Root MSE      =  6.1843

------------------------------------------------------------------------------
             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |   .2202103   .0392837     5.61   0.000     .1432154    .2972052
    year2003 |  -.4799853   .0386322   -12.42   0.000    -.5557032   -.4042674
    year2004 |    -.43124   .0381956   -11.29   0.000    -.5061021   -.3563778
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year2005	1.117138	.0397227	28.12	0.000	1.039283	1.194993
year2007	.9473858	.0401136	23.62	0.000	.8687645	1.026007
year2008	1.058205	.0396267	26.70	0.000	.9805381	1.135872
year2009	-.0232961	.039923	-0.58	0.560	-.101544	.0549518
year2010	.9539579	.0403338	23.65	0.000	.874905	1.033011
year2011	1.218589	.0402718	30.26	0.000	1.139657	1.29752
year2012	2.18528	.0457922	47.72	0.000	2.095529	2.275032
January	-.5460942	.0441783	-12.36	0.000	-.6326822	-.4595062
February	-.6584821	.0439808	-14.97	0.000	-.7446831	-.572281
March	-.6603731	.0443555	-14.89	0.000	-.7473084	-.5734378
April	-.5703849	.0437911	-13.03	0.000	-.6562142	-.4845557
May	-.6090074	.0434649	-14.01	0.000	-.6941972	-.5238176
June	-.3880202	.0429926	-9.03	0.000	-.4722844	-.3037561
August	.5428368	.0451865	12.01	0.000	.4542727	.6314009
September	.6647205	.0448943	14.81	0.000	.5767291	.752712
October	.3703518	.0451103	8.21	0.000	.281937	.4587667
November	.1660767	.0446852	3.72	0.000	.0784951	.2536583
December	-.5681771	.0441113	-12.88	0.000	-.6546338	-.4817203
discharge	-6.08e-06	1.55e-07	-39.19	0.000	-6.38e-06	-5.78e-06
disch2	1.98e-12	1.63e-13	12.10	0.000	1.66e-12	2.30e-12
dirdown	-.1373787	.0171546	-8.01	0.000	-.1710011	-.1037562
tugboat	4.058808	.4774243	8.50	0.000	3.123071	4.994545
pushboat	4.580293	.4751936	9.64	0.000	3.648929	5.511658
num_processed	.0550109	.0017673	31.13	0.000	.051547	.0584748
draftldft	.0832056	.0110963	7.50	0.000	.0614572	.1049541

draftltft	.0245502	.0089655	2.74	0.006	.006978	.0421223
tonnage	.0008453	.0000632	13.37	0.000	.0007213	.0009692
clcc	.2329871	.031543	7.39	0.000	.1711638	.2948104
ppp	.219207	.0234733	9.34	0.000	.1732001	.2652139
crp	.1399033	.0294647	4.75	0.000	.0821533	.1976532
cmief	-.2605091	.0300157	-8.68	0.000	-.3193389	-.2016792
pmg	-.033342	.0312007	-1.07	0.285	-.0944944	.0278104
ffp	-.1507262	.0381939	-3.95	0.000	-.225585	-.0758674
mem	-.1613283	.1155738	-1.40	0.163	-.3878493	.0651927
markland	-.0464904	.0422547	-1.10	0.271	-.1293082	.0363274
mcalpine	1.188187	.0447351	26.56	0.000	1.100507	1.275866
cannelton	-.3466043	.0399933	-8.67	0.000	-.4249898	-.2682187
newburgh	-.2756462	.0373156	-7.39	0.000	-.3487837	-.2025088
smithland	1.142645	.0708244	16.13	0.000	1.003832	1.281459
lock52	-2.592256	.0352959	-73.44	0.000	-2.661435	-2.523077
lock53	-5.870125	.0320354	-183.24	0.000	-5.932913	-5.807336
lengthsmall	-.0078023	.0001016	-76.77	0.000	-.0080015	-.0076031
_cons	-2.609062	.4971648	-5.25	0.000	-3.58349	-1.634635

Linear regression   Number of obs = 517229

Regression Table 11B   R-squared   = 0.6472

Root MSE   = .64844

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s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1569433	.0038762	40.49	0.000	.1493461	.1645406
year2003	.0451818	.0036035	12.54	0.000	.038119	.0522446
year2004	.0121042	.0036123	3.35	0.001	.0050242	.0191842
year2005	.2085273	.0040214	51.85	0.000	.2006454	.2164093
year2007	.2100427	.0042165	49.81	0.000	.2017784	.218307
year2008	.1786866	.0041521	43.04	0.000	.1705487	.1868245
year2009	6.50e-07	.0040933	0.00	1.000	-.0080221	.0080234
year2010	.0671672	.004243	15.83	0.000	.0588511	.0754833
year2011	.0575265	.0042924	13.40	0.000	.0491135	.0659395
year2012	.2970067	.0052808	56.24	0.000	.2866565	.307357
January	-.0653878	.0045938	-14.23	0.000	-.0743916	-.0563841
February	-.1297922	.0044512	-29.16	0.000	-.1385164	-.1210681
March	-.1110544	.0045359	-24.48	0.000	-.1199447	-.1021642
April	-.1251509	.0045365	-27.59	0.000	-.1340424	-.1162595
May	-.1371579	.0044957	-30.51	0.000	-.1459694	-.1283463
June	-.0683626	.0046264	-14.78	0.000	-.0774302	-.059295
August	.1247686	.0051892	24.04	0.000	.114598	.1349393
September	.0967322	.0050577	19.13	0.000	.0868191	.1066452
October	.0783248	.005125	15.28	0.000	.0682801	.0883696
November	.0194199	.0049806	3.90	0.000	.0096581	.0291816
December	-.0967278	.0046161	-20.95	0.000	-.1057751	-.0876804
discharge	-1.06e-06	1.70e-08	-62.04	0.000	-1.09e-06	-1.02e-06

disch2	3.11e-13	1.98e-14	15.67	0.000	2.72e-13	3.50e-13
dirdown	-.0935724	.0018017	-51.94	0.000	-.0971036	-.0900412
tugboat	.2850007	.1037053	2.75	0.006	.0817417	.4882598
pushboat	.3130068	.1036133	3.02	0.003	.109928	.5160856
yearbuilt	-.0004873	.0000748	-6.51	0.000	-.0006339	-.0003406
num_processed	.0059962	.0002235	26.83	0.000	.0055582	.0064341
draftldft	.0200309	.0012765	15.69	0.000	.0175289	.0225328
draftltft	-.0109947	.0010143	-10.84	0.000	-.0129826	-.0090067
tonnage	.0000448	8.87e-06	5.05	0.000	.0000274	.0000622
horsepower	7.42e-06	1.01e-06	7.35	0.000	5.44e-06	9.40e-06
clcc	.0144605	.0030007	4.82	0.000	.0085793	.0203417
ppp	-.0006243	.0027083	-0.23	0.818	-.0059326	.0046839
crp	.0088726	.0032199	2.76	0.006	.0025617	.0151834
cmief	-.0241939	.0031908	-7.58	0.000	-.0304477	-.0179401
pmg	-.0558783	.0034186	-16.35	0.000	-.0625786	-.0491781
ffp	.0221594	.004238	5.23	0.000	.013853	.0304657
mem	-.0491444	.0140898	-3.49	0.000	-.0767598	-.0215289
markland	.13339	.0025635	52.03	0.000	.1283657	.1384144
mcalpine	.0232598	.0027065	8.59	0.000	.0179552	.0285645
cannelton	.0924199	.0023562	39.22	0.000	.0878017	.097038
newburgh	-.024937	.0021183	-11.77	0.000	-.0290888	-.0207852
smithland	-.047674	.0044758	-10.65	0.000	-.0564464	-.0389017
lock52	-1.158002	.0040386	-286.73	0.000	-1.165918	-1.150087
lock53	-2.118641	.0041132	-515.09	0.000	-2.126703	-2.11058
lengthsmall	.0002077	6.37e-06	32.58	0.000	.0001952	.0002202

_cons | 4.409499 .1847146 23.87 0.000 4.047464 4.771534

Linear regression Number of obs = 520330

Regression Table 11C R-squared = 0.1672

Root MSE = 6.1843

	Robust					
a2s_ln	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.2202103	.0392837	5.61	0.000	.1432154	.2972052
year2003	-.4799853	.0386322	-12.42	0.000	-.5557032	-.4042674
year2004	-.43124	.0381956	-11.29	0.000	-.5061021	-.3563778
year2005	1.117138	.0397227	28.12	0.000	1.039283	1.194993
year2007	.9473858	.0401136	23.62	0.000	.8687645	1.026007
year2008	1.058205	.0396267	26.70	0.000	.9805381	1.135872
year2009	-.0232961	.039923	-0.58	0.560	-.101544	.0549518
year2010	.9539579	.0403338	23.65	0.000	.874905	1.033011
year2011	1.218589	.0402718	30.26	0.000	1.139657	1.29752
year2012	2.18528	.0457922	47.72	0.000	2.095529	2.275032
January	-.5460942	.0441783	-12.36	0.000	-.6326822	-.4595062
February	-.6584821	.0439808	-14.97	0.000	-.7446831	-.572281
March	-.6603731	.0443555	-14.89	0.000	-.7473084	-.5734378
April	-.5703849	.0437911	-13.03	0.000	-.6562142	-.4845557

May	-.6090074	.0434649	-14.01	0.000	-.6941972	-.5238176
June	-.3880202	.0429926	-9.03	0.000	-.4722844	-.3037561
August	.5428368	.0451865	12.01	0.000	.4542727	.6314009
September	.6647205	.0448943	14.81	0.000	.5767291	.752712
October	.3703518	.0451103	8.21	0.000	.281937	.4587667
November	.1660767	.0446852	3.72	0.000	.0784951	.2536583
December	-.5681771	.0441113	-12.88	0.000	-.6546338	-.4817203
discharge	-6.08e-06	1.55e-07	-39.19	0.000	-6.38e-06	-5.78e-06
disch2	1.98e-12	1.63e-13	12.10	0.000	1.66e-12	2.30e-12
dirdown	-.1373787	.0171546	-8.01	0.000	-.1710011	-.1037562
tugboat	4.058808	.4774243	8.50	0.000	3.123071	4.994545
pushboat	4.580293	.4751936	9.64	0.000	3.648929	5.511658
num_processed	.0550109	.0017673	31.13	0.000	.051547	.0584748
draftldft	.0832056	.0110963	7.50	0.000	.0614572	.1049541
draftltft	.0245502	.0089655	2.74	0.006	.006978	.0421223
tonnage	.0008453	.0000632	13.37	0.000	.0007213	.0009692
clcc	.2329871	.031543	7.39	0.000	.1711638	.2948104
ppp	.219207	.0234733	9.34	0.000	.1732001	.2652139
crp	.1399033	.0294647	4.75	0.000	.0821533	.1976532
cmief	-.2605091	.0300157	-8.68	0.000	-.3193389	-.2016792
pmg	-.033342	.0312007	-1.07	0.285	-.0944944	.0278104
ffp	-.1507262	.0381939	-3.95	0.000	-.225585	-.0758674
mem	-.1613283	.1155738	-1.40	0.163	-.3878493	.0651927
markland	0 (omitted)					
mcalpine	1.240147	.0497075	24.95	0.000	1.142721	1.337572

cannelton	-.3274612	.0355219	-9.22	0.000	-.3970829	-.2578394
newburgh	-.2811157	.0399053	-7.04	0.000	-.3593289	-.2029025
smithland	1.153584	.0690639	16.70	0.000	1.018221	1.288947
lock52	-2.608665	.0442665	-58.93	0.000	-2.695426	-2.521904
lock53	-5.886533	.0417439	-141.02	0.000	-5.96835	-5.804716
lengthsmall	-.0078023	.0001016	-76.77	0.000	-.0080015	-.0076031
lift	-.0027347	.0024856	-1.10	0.271	-.0076064	.0021369
_cons	-2.559837	.5005013	-5.11	0.000	-3.540804	-1.57887

Linear regression Number of obs = 517229

Regression Table 11D R-squared = 0.6472

Root MSE = .64844

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	.1569433	.0038762	40.49	0.000	.1493461	.1645406
year2003	.0451818	.0036035	12.54	0.000	.038119	.0522446
year2004	.0121042	.0036123	3.35	0.001	.0050242	.0191842
year2005	.2085273	.0040214	51.85	0.000	.2006454	.2164093
year2007	.2100427	.0042165	49.81	0.000	.2017784	.218307
year2008	.1786866	.0041521	43.04	0.000	.1705487	.1868245

year2009	6.50e-07	.0040933	0.00	1.000	-.0080221	.0080234
year2010	.0671672	.004243	15.83	0.000	.0588511	.0754833
year2011	.0575265	.0042924	13.40	0.000	.0491135	.0659395
year2012	.2970067	.0052808	56.24	0.000	.2866565	.307357
January	-.0653878	.0045938	-14.23	0.000	-.0743916	-.0563841
February	-.1297922	.0044512	-29.16	0.000	-.1385164	-.1210681
March	-.1110544	.0045359	-24.48	0.000	-.1199447	-.1021642
April	-.1251509	.0045365	-27.59	0.000	-.1340424	-.1162595
May	-.1371579	.0044957	-30.51	0.000	-.1459694	-.1283463
June	-.0683626	.0046264	-14.78	0.000	-.0774302	-.059295
August	.1247686	.0051892	24.04	0.000	.114598	.1349393
September	.0967322	.0050577	19.13	0.000	.0868191	.1066452
October	.0783248	.005125	15.28	0.000	.0682801	.0883696
November	.0194199	.0049806	3.90	0.000	.0096581	.0291816
December	-.0967278	.0046161	-20.95	0.000	-.1057751	-.0876804
discharge	-1.06e-06	1.70e-08	-62.04	0.000	-1.09e-06	-1.02e-06
disch2	3.11e-13	1.98e-14	15.67	0.000	2.72e-13	3.50e-13
dirdown	-.0935724	.0018017	-51.94	0.000	-.0971036	-.0900412
tugboat	.2850007	.1037053	2.75	0.006	.0817417	.4882598
pushboat	.3130068	.1036133	3.02	0.003	.109928	.5160856
yearbuilt	-.0004873	.0000748	-6.51	0.000	-.0006339	-.0003406
num_processed	.0059962	.0002235	26.83	0.000	.0055582	.0064341
draftldft	.0200309	.0012765	15.69	0.000	.0175289	.0225328
draftltft	-.0109947	.0010143	-10.84	0.000	-.0129826	-.0090067
tonnage	.0000448	8.87e-06	5.05	0.000	.0000274	.0000622

horsepower	7.42e-06	1.01e-06	7.35	0.000	5.44e-06	9.40e-06
clcc	.0144605	.0030007	4.82	0.000	.0085793	.0203417
ppp	-.0006243	.0027083	-0.23	0.818	-.0059326	.0046839
crp	.0088726	.0032199	2.76	0.006	.0025617	.0151834
cmief	-.0241939	.0031908	-7.58	0.000	-.0304477	-.0179401
pmg	-.0558783	.0034186	-16.35	0.000	-.0625786	-.0491781
ffp	.0221594	.004238	5.23	0.000	.013853	.0304657
mem	-.0491444	.0140898	-3.49	0.000	-.0767598	-.0215289
markland	0 (omitted)					
mcalpine	-.1258231	.0029786	-42.24	0.000	-.1316611	-.1199851
cannelton	.0374946	.0020845	17.99	0.000	.0334091	.0415801
newburgh	-.009244	.0022707	-4.07	0.000	-.0136945	-.0047936
smithland	-.0790599	.0043804	-18.05	0.000	-.0876454	-.0704745
lock52	-1.110924	.0042856	-259.22	0.000	-1.119323	-1.102524
lock53	-2.071562	.0043471	-476.54	0.000	-2.080083	-2.063042
lengthsmall	.0002077	6.37e-06	32.58	0.000	.0001952	.0002202
lift	.0078465	.0001508	52.03	0.000	.0075509	.008142
_cons	4.268262	.1847407	23.10	0.000	3.906176	4.630348

Linear regression   Number of obs = 520330

Regression Table 12A   R-squared = 0.1885

Root MSE = 6.1046

a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.0474641	.038721	1.23	0.220	-.0284278	.123356
year2003	-.4045675	.0384562	-10.52	0.000	-.4799403	-.3291946
year2004	-.3936844	.0379402	-10.38	0.000	-.4680461	-.3193227
year2005	1.000216	.0393115	25.44	0.000	.9231667	1.077265
year2007	.8293075	.0395114	20.99	0.000	.7518665	.9067486
year2008	.7660486	.039043	19.62	0.000	.6895256	.8425716
year2009	-.0862673	.0399368	-2.16	0.031	-.1645423	-.0079924
year2010	.9293271	.0403249	23.05	0.000	.8502914	1.008363
year2011	.7844598	.0403335	19.45	0.000	.7054073	.8635123
year2012	2.01502	.0442941	45.49	0.000	1.928205	2.101835
January	-.4496624	.0437068	-10.29	0.000	-.5353263	-.3639985
February	-.3861406	.0435704	-8.86	0.000	-.4715372	-.3007439
March	-.6754243	.0438735	-15.39	0.000	-.7614149	-.5894337
April	-.4714113	.0433335	-10.88	0.000	-.5563436	-.3864789
May	-.6013121	.0430071	-13.98	0.000	-.6856047	-.5170196
June	-.2851444	.0422504	-6.75	0.000	-.3679538	-.2023349
August	.4664965	.0439261	10.62	0.000	.3804027	.5525903
September	.6005984	.0435375	13.79	0.000	.5152664	.6859305
October	.3800741	.0447924	8.49	0.000	.2922825	.4678657
November	.3546724	.0447501	7.93	0.000	.2669637	.4423811
December	-.2194961	.044012	-4.99	0.000	-.3057583	-.1332339

discharge	-8.19e-06	1.55e-07	-52.79	0.000	-8.49e-06	-7.88e-06
disch2	1.57e-11	2.15e-13	73.00	0.000	1.53e-11	1.61e-11
dirdown	-.1316754	.0169348	-7.78	0.000	-.164867	-.0984837
tugboat	3.806524	.4688979	8.12	0.000	2.887499	4.725549
pushboat	4.312809	.4667292	9.24	0.000	3.398035	5.227583
num_processed	.0648419	.0017574	36.90	0.000	.0613975	.0682863
draftldft	.0823399	.010936	7.53	0.000	.0609056	.1037742
draftltft	.0225754	.0088346	2.56	0.011	.0052599	.0398909
tonnage	.0007052	.0000623	11.31	0.000	.000583	.0008273
clcc	.1895918	.0312653	6.06	0.000	.1283128	.2508709
ppp	.2466214	.0231926	10.63	0.000	.2011646	.2920782
crp	.1737565	.0291021	5.97	0.000	.1167174	.2307957
cmief	-.2665066	.0296243	-9.00	0.000	-.3245692	-.2084439
pmg	.0229822	.0307519	0.75	0.455	-.0372904	.0832549
ffp	-.1701082	.0377272	-4.51	0.000	-.2440523	-.0961641
mem	-.2416441	.1131282	-2.14	0.033	-.4633719	-.0199163
markland	-.9917243	.0445019	-22.28	0.000	-1.078947	-.9045019
cannelton	-.6554796	.0359915	-18.21	0.000	-.7260218	-.5849374
newburgh	-.1322203	.0393807	-3.36	0.001	-.2094053	-.0550353
smithland	.6558009	.0647921	10.12	0.000	.5288105	.7827914
lock52	3.283218	.024475	134.15	0.000	3.235247	3.331188
lengthsmall	-.0076309	.0001012	-75.40	0.000	-.0078292	-.0074325
lift	.0743136	.0023514	31.60	0.000	.069705	.0789222
wicket	-2.126946	.0518847	-40.99	0.000	-2.228639	-2.025254
wickdisch	-.0000141	1.27e-07	-111.25	0.000	-.0000143	-.0000138

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       _cons |  -4.168864   .4891479    -8.52   0.000    -5.127579    -3.21015
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Linear regression                               Number of obs =  517229
Regression Table 12B                               R-squared     =  0.6722
                                                Root MSE      =  .62504


------------------------------------------------------------------------------
             |               Robust
      s2e_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |   .1266761   .0037086    34.16   0.000     .1194074    .1339449
    year2003 |   .0582826   .0035514    16.41   0.000     .0513221    .0652432
    year2004 |   .0185758   .0035429     5.24   0.000     .0116319    .0255198
    year2005 |   .1880941   .0039382    47.76   0.000     .1803753    .1958129
    year2007 |   .1894257   .0040431    46.85   0.000     .1815013      .19735
    year2008 |   .1278506   .0039457    32.40   0.000     .1201171     .135584
    year2009 |    -.01101   .0041117    -2.68   0.007    -.0190687   -.0029512
    year2010 |   .0630046   .0042597    14.79   0.000     .0546557    .0713536
    year2011 |  -.0185009    .004326    -4.28   0.000    -.0269798   -.0100219
    year2012 |   .2672227   .0048685    54.89   0.000     .2576807    .2767648
     January |  -.0484798    .004437   -10.93   0.000    -.0571762   -.0397834
    February |  -.0821544   .0043051   -19.08   0.000    -.0905922   -.0737166
       March |  -.1135023   .0043671   -25.99   0.000    -.1220615    -.104943
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April	-.1076251	.0043972	-24.48	0.000	-.1162434	-.0990067
May	-.1354962	.0043681	-31.02	0.000	-.1440576	-.1269348
June	-.0504538	.0043951	-11.48	0.000	-.059068	-.0418397
August	.1112834	.0048082	23.14	0.000	.1018595	.1207072
September	.0854555	.004672	18.29	0.000	.0762985	.0946124
October	.0799343	.0050245	15.91	0.000	.0700865	.0897821
November	.0522845	.0049934	10.47	0.000	.0424977	.0620713
December	-.0358985	.0045725	-7.85	0.000	-.0448605	-.0269366
discharge	-1.42e-06	1.92e-08	-73.99	0.000	-1.46e-06	-1.39e-06
disch2	2.70e-12	3.46e-14	78.07	0.000	2.63e-12	2.77e-12
dirdown	-.0925813	.0017368	-53.30	0.000	-.0959854	-.0891772
tugboat	.2701971	.1001469	2.70	0.007	.0739123	.4664819
pushboat	.2970792	.1000584	2.97	0.003	.1009678	.4931905
yearbuilt	-.0004969	.0000723	-6.87	0.000	-.0006386	-.0003552
num_processed	.0079724	.0002206	36.14	0.000	.00754	.0084047
draftldft	.0201695	.0012279	16.43	0.000	.0177628	.0225762
draftltft	-.0106908	.0009758	-10.96	0.000	-.0126033	-.0087783
tonnage	.0000379	8.56e-06	4.42	0.000	.0000211	.0000546
horsepower	4.12e-06	9.68e-07	4.26	0.000	2.23e-06	6.02e-06
clcc	.0055919	.0028901	1.93	0.053	-.0000726	.0112563
ppp	.0044275	.0026295	1.68	0.092	-.0007263	.0095813
crp	.0144288	.0031168	4.63	0.000	.00832	.0205376
cmief	-.0255813	.0030608	-8.36	0.000	-.0315804	-.0195822
pmg	-.0456443	.0032874	-13.88	0.000	-.0520874	-.0392011
ffp	.0210364	.0040734	5.16	0.000	.0130527	.0290201

mem	-.0641074	.0134323	-4.77	0.000	-.0904342	-.0377805
markland	.133442	.0025796	51.73	0.000	.1283862	.1384979
cannelton	.1063245	.0020322	52.32	0.000	.1023415	.1103075
newburgh	-.0194499	.0022082	-8.81	0.000	-.023778	-.0151218
smithland	-.094009	.0039988	-23.51	0.000	-.1018465	-.0861714
lock52	.961396	.004874	197.25	0.000	.9518431	.970949
lengthsmall	.0002376	6.15e-06	38.61	0.000	.0002256	.0002497
lift	.0032819	.0001364	24.06	0.000	.0030146	.0035492
wicket	-1.523252	.0068223	-223.27	0.000	-1.536623	-1.50988
wickdisch	-2.46e-06	1.90e-08	-129.45	0.000	-2.49e-06	-2.42e-06
_cons	4.296649	.1785424	24.07	0.000	3.946712	4.646587

Linear regression Number of obs = 520330

Regression Table 12C R-squared = 0.1960

Root MSE = 6.0765

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a2s_ln	Coef. (Robust)	Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.047629	.0384857	1.24	0.216	-.0278018	.1230598
year2003	-.4086547	.0383103	-10.67	0.000	-.4837416	-.3335677
year2004	-.4005521	.0377816	-10.60	0.000	-.4746029	-.3265014

year2005	.994599	.039145	25.41	0.000	.9178761	1.071322
year2007	.8297767	.0392948	21.12	0.000	.7527601	.9067932
year2008	.7618434	.0389043	19.58	0.000	.6855922	.8380946
year2009	-.0874591	.0397909	-2.20	0.028	-.165448	-.0094703
year2010	.9249156	.0401851	23.02	0.000	.846154	1.003677
year2011	.7776346	.0401423	19.37	0.000	.698957	.8563123
year2012	2.022189	.0441068	45.85	0.000	1.935742	2.108637
January	-.4525527	.0433763	-10.43	0.000	-.5375688	-.3675365
February	-.389608	.0433541	-8.99	0.000	-.4745807	-.3046353
March	-.6801991	.0436495	-15.58	0.000	-.7657508	-.5946474
April	-.4744298	.0430671	-11.02	0.000	-.55884	-.3900197
May	-.6068661	.042792	-14.18	0.000	-.6907369	-.5229952
June	-.2891084	.0418828	-6.90	0.000	-.3711973	-.2070195
August	.4692481	.0436517	10.75	0.000	.3836921	.5548041
September	.6020004	.0431317	13.96	0.000	.5174636	.6865373
October	.381405	.0445677	8.56	0.000	.2940536	.4687563
November	.355156	.044724	7.94	0.000	.2674984	.4428136
December	-.2217018	.043966	-5.04	0.000	-.3078738	-.1355299
discharge	-8.06e-06	1.55e-07	-51.94	0.000	-8.37e-06	-7.76e-06
disch2	1.55e-11	2.15e-13	71.81	0.000	1.50e-11	1.59e-11
dirdown	-.1306232	.0168566	-7.75	0.000	-.1636616	-.0975848
tugboat	3.804045	.4579616	8.31	0.000	2.906454	4.701635
pushboat	4.312146	.4557602	9.46	0.000	3.41887	5.205422
num_processed	.0640589	.0017413	36.79	0.000	.060646	.0674717
draftldft	.0796613	.0108754	7.32	0.000	.0583458	.1009769

draftltft	.0254358	.0087918	2.89	0.004	.0082042	.0426674
tonnage	.0007206	.000062	11.63	0.000	.0005991	.000842
clcc	.2009731	.0311699	6.45	0.000	.1398811	.2620652
ppp	.242276	.0230372	10.52	0.000	.1971238	.2874281
crp	.171001	.028936	5.91	0.000	.1142873	.2277146
cmief	-.2717288	.0294941	-9.21	0.000	-.3295364	-.2139212
pmg	.0254091	.0305888	0.83	0.406	-.0345441	.0853622
ffp	-.1737013	.0375143	-4.63	0.000	-.2472281	-.1001745
mem	-.2331128	.1122083	-2.08	0.038	-.4530375	-.013188
markland	-.9918165	.044499	-22.29	0.000	-1.079033	-.9046
cannelton	-.6541062	.0359884	-18.18	0.000	-.7246423	-.58357
newburgh	-.1320367	.0393786	-3.35	0.001	-.2092175	-.0548559
smithland	.6559311	.0647682	10.13	0.000	.5289874	.7828748
lock52	6.084658	.0462297	131.62	0.000	5.994049	6.175267
lengthsmall	-.0076304	.0001012	-75.43	0.000	-.0078287	-.0074322
lift	.0743465	.002351	31.62	0.000	.0697387	.0789544
wicket	-3.738726	.0549462	-68.04	0.000	-3.846419	-3.631033
wickdisch	-8.60e-06	1.31e-07	-65.39	0.000	-8.85e-06	-8.34e-06
lock52disch	-9.54e-06	9.46e-08	-100.89	0.000	-9.73e-06	-9.36e-06
_cons	-4.172348	.4784848	-8.72	0.000	-5.110163	-3.234533

Linear regression Number of obs = 517229

Regression Table 12D R-squared = 0.6796

Root MSE = .61796

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1266868	.0036634	34.58	0.000	.1195066	.1338669
year2003	.0576919	.0035027	16.47	0.000	.0508267	.0645571
year2004	.0175584	.0035038	5.01	0.000	.0106911	.0244256
year2005	.1872165	.0039054	47.94	0.000	.179562	.194871
year2007	.1895337	.0040035	47.34	0.000	.1816869	.1973805
year2008	.1273031	.0039368	32.34	0.000	.119587	.1350191
year2009	-.0111373	.0040578	-2.74	0.006	-.0190904	-.0031841
year2010	.0623932	.0042321	14.74	0.000	.0540985	.0706879
year2011	-.0194078	.0042748	-4.54	0.000	-.0277863	-.0110293
year2012	.2685579	.0048747	55.09	0.000	.2590036	.2781122
January	-.0489544	.0043363	-11.29	0.000	-.0574533	-.0404555
February	-.0826616	.0042381	-19.50	0.000	-.090968	-.0743551
March	-.1142793	.0042947	-26.61	0.000	-.1226968	-.1058619
April	-.1080749	.0043138	-25.05	0.000	-.1165298	-.0996201
May	-.1364972	.0042885	-31.83	0.000	-.1449026	-.1280918
June	-.0511086	.0042833	-11.93	0.000	-.0595036	-.0427135
August	.1117631	.0047503	23.53	0.000	.1024526	.1210735
September	.0856954	.0045739	18.74	0.000	.0767307	.0946602
October	.0801535	.0049624	16.15	0.000	.0704274	.0898797

November	.0523964	.0049762	10.53	0.000	.0426431	.0621497
December	-.0362305	.0045532	-7.96	0.000	-.0451546	-.0273064
discharge	-1.40e-06	1.91e-08	-73.38	0.000	-1.44e-06	-1.37e-06
disch2	2.67e-12	3.45e-14	77.40	0.000	2.60e-12	2.74e-12
dirdown	-.0924227	.0017174	-53.82	0.000	-.0957888	-.0890567
tugboat	.2688334	.1005793	2.67	0.008	.0717011	.4659656
pushboat	.2954194	.1004921	2.94	0.003	.098458	.4923808
yearbuilt	-.0005124	.0000715	-7.16	0.000	-.0006525	-.0003722
num_processed	.0078602	.0002167	36.28	0.000	.0074356	.0082849
draftldft	.0198196	.0012134	16.33	0.000	.0174414	.0221977
draftltft	-.0103904	.0009639	-10.78	0.000	-.0122796	-.0085013
tonnage	.0000401	8.44e-06	4.75	0.000	.0000235	.0000566
horsepower	4.20e-06	9.55e-07	4.40	0.000	2.33e-06	6.08e-06
clcc	.0074666	.0028604	2.61	0.009	.0018603	.0130729
ppp	.0038627	.0025909	1.49	0.136	-.0012153	.0089408
crp	.0140436	.0030762	4.57	0.000	.0080144	.0200729
cmief	-.0266531	.0030281	-8.80	0.000	-.0325881	-.0207181
pmg	-.0449441	.0032458	-13.85	0.000	-.0513058	-.0385824
ffp	.0201973	.0040166	5.03	0.000	.0123248	.0280697
mem	-.0630339	.0133324	-4.73	0.000	-.0891651	-.0369028
markland	.1334205	.0025781	51.75	0.000	.1283676	.1384735
cannelton	.1065395	.0020305	52.47	0.000	.1025597	.1105192
newburgh	-.0193834	.0022065	-8.78	0.000	-.0237081	-.0150587
smithland	-.0939357	.003989	-23.55	0.000	-.1017541	-.0861173
lock52	1.410238	.0090562	155.72	0.000	1.392489	1.427988

lengthsmall | .0002376   6.14e-06   38.72   0.000   .0002256   .0002496

lift | .0032892   .0001362   24.15   0.000   .0030222   .0035561

wicket | -1.780662   .0083098 -214.28   0.000   -1.796949   -1.764375

wickdisch | -1.58e-06   2.29e-08   -69.18   0.000   -1.63e-06   -1.54e-06

lock52disch | -1.53e-06   2.00e-08   -76.36   0.000   -1.57e-06   -1.49e-06

_cons | 4.32841   .1774647   24.39   0.000   3.980585   4.676235

Regression Table 13

Seemingly unrelated regression

Equation	Obs	Parms	RMSE	"R-sq"	chi2	P
a2s_ln	5.2e+05	46	6.074109	0.1962	97891.40	0.0000
s2e_ln	5.2e+05	48	.6179152	0.6796	885526.02	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
a2s_ln						
year2002	.0495181	.0388075	1.28	0.202	-.0265431	.1255794
year2003	-.4071335	.0395793	-10.29	0.000	-.4847076	-.3295595

year2004	-.4000302	.039175	-10.21	0.000	-.4768119	-.3232485
year2005	.9950588	.0381465	26.09	0.000	.9202931	1.069825
year2007	.8293174	.0384362	21.58	0.000	.7539838	.904651
year2008	.7587913	.0385929	19.66	0.000	.6831507	.8344319
year2009	-.0874018	.0401601	-2.18	0.030	-.1661142	-.0086894
year2010	.9182322	.0396709	23.15	0.000	.8404786	.9959858
year2011	.7729029	.0398636	19.39	0.000	.6947717	.8510341
year2012	2.036713	.0436382	46.67	0.000	1.951184	2.122243
January	-.460083	.0433751	-10.61	0.000	-.5450965	-.3750694
February	-.395852	.0438999	-9.02	0.000	-.4818941	-.3098099
March	-.684375	.0445787	-15.35	0.000	-.7717477	-.5970023
April	-.4781526	.0437404	-10.93	0.000	-.5638821	-.392423
May	-.6083386	.0432692	-14.06	0.000	-.6931446	-.5235325
June	-.2937801	.0416486	-7.05	0.000	-.3754098	-.2121504
August	.4664052	.0412373	11.31	0.000	.3855815	.5472289
September	.599026	.0412442	14.52	0.000	.5181889	.6798632
October	.3741365	.0417931	8.95	0.000	.2922234	.4560495
November	.3519243	.0424073	8.30	0.000	.2688076	.435041
December	-.2242183	.0436989	-5.13	0.000	-.3098666	-.1385699
discharge	-8.06e-06	1.60e-07	-50.33	0.000	-8.37e-06	-7.75e-06
disch2	1.55e-11	2.22e-13	69.58	0.000	1.50e-11	1.59e-11
dirdown	-.1295154	.0169002	-7.66	0.000	-.1626391	-.0963917
tugboat	4.092493	.6135745	6.67	0.000	2.889909	5.295077
pushboat	4.652973	.611373	7.61	0.000	3.454704	5.851242
num_processed	.0630277	.0018835	33.46	0.000	.059336	.0667193

draftldft	.0786479	.0111847	7.03	0.000	.0567263	.1005694
draftltft	.0356993	.009097	3.92	0.000	.0178695	.053529
tonnage	.0007154	.0000628	11.38	0.000	.0005922	.0008385
clcc	.203531	.0305658	6.66	0.000	.1436231	.2634389
ppp	.2358189	.023778	9.92	0.000	.189215	.2824229
crp	.173447	.0292932	5.92	0.000	.1160334	.2308605
cmief	-.2660221	.0294346	-9.04	0.000	-.3237129	-.2083314
pmg	-1.28e-06	.0311501	-0.00	1.000	-.0610544	.0610518
ffp	-.1659893	.0381112	-4.36	0.000	-.2406859	-.0912927
mem	-.2225033	.1129424	-1.97	0.049	-.4438663	-.0011404
markland	-.9962002	.0408244	-24.40	0.000	-1.076215	-.916186
cannelton	-.6576196	.0330804	-19.88	0.000	-.722456	-.5927831
newburgh	-.145637	.0363621	-4.01	0.000	-.2169055	-.0743685
smithland	.6530749	.0610984	10.69	0.000	.5333243	.7728255
lock52	6.090555	.0508287	119.83	0.000	5.990932	6.190177
lengthsmall	-.0076311	.0000952	-80.17	0.000	-.0078177	-.0074446
lift	.073981	.0021942	33.72	0.000	.0696805	.0782816
wicket	-3.746869	.0558274	-67.12	0.000	-3.856289	-3.637449
wickdisch	-8.58e-06	1.44e-07	-59.70	0.000	-8.87e-06	-8.30e-06
lock52disch	-9.55e-06	1.38e-07	-69.40	0.000	-9.82e-06	-9.28e-06
_cons	-4.556895	.6287167	-7.25	0.000	-5.789157	-3.324633
s2e_ln						
year2002	.1266619	.0039486	32.08	0.000	.1189228	.134401
year2003	.0576489	.0040267	14.32	0.000	.0497567	.065541

year2004	.0175036	.0039853	4.39	0.000	.0096926	.0253145
year2005	.1871989	.0038807	48.24	0.000	.1795929	.1948049
year2007	.1895349	.0039102	48.47	0.000	.1818709	.1971988
year2008	.127349	.0039275	32.42	0.000	.1196511	.1350468
year2009	-.011156	.0040904	-2.73	0.006	-.019173	-.003139
year2010	.0623669	.0040441	15.42	0.000	.0544406	.0702931
year2011	-.0193756	.0040698	-4.76	0.000	-.0273523	-.011399
year2012	.268415	.0044604	60.18	0.000	.2596728	.2771572
January	-.0489115	.0044132	-11.08	0.000	-.0575611	-.0402618
February	-.0827246	.0044662	-18.52	0.000	-.0914782	-.0739709
March	-.1143204	.0045351	-25.21	0.000	-.123209	-.1054317
April	-.108115	.0044498	-24.30	0.000	-.1168365	-.0993935
May	-.1365401	.0044019	-31.02	0.000	-.1451676	-.1279125
June	-.0512598	.0042369	-12.10	0.000	-.059564	-.0429556
August	.1118896	.0041951	26.67	0.000	.1036673	.1201119
September	.0858455	.0041958	20.46	0.000	.0776219	.0940691
October	.0801821	.0042518	18.86	0.000	.0718487	.0885154
November	.0523608	.0043143	12.14	0.000	.0439049	.0608167
December	-.0362697	.0044455	-8.16	0.000	-.0449827	-.0275567
discharge	-1.40e-06	1.63e-08	-86.12	0.000	-1.44e-06	-1.37e-06
disch2	2.67e-12	2.26e-14	118.05	0.000	2.62e-12	2.71e-12
dirdown	-.0924418	.0017193	-53.77	0.000	-.0958115	-.0890721
tugboat	.2789916	.0640126	4.36	0.000	.1535292	.404454
pushboat	.3061943	.0639256	4.79	0.000	.1809023	.4314862
yearbuilt	-.0005203	.0000681	-7.64	0.000	-.0006537	-.0003869

num_processed	.0079172	.0002029	39.01	0.000	.0075195	.008315
draftldft	.0199083	.0011518	17.29	0.000	.0176509	.0221657
draftltft	-.0102477	.0009464	-10.83	0.000	-.0121026	-.0083928
tonnage	.0000439	8.16e-06	5.38	0.000	.0000279	.0000599
horsepower	3.50e-06	9.06e-07	3.86	0.000	1.72e-06	5.27e-06
clcc	.0072381	.0031436	2.30	0.021	.0010768	.0133994
ppp	.0039213	.0024508	1.60	0.110	-.0008822	.0087249
crp	.0139592	.0029924	4.66	0.000	.0080942	.0198242
cmief	-.0268075	.0030154	-8.89	0.000	-.0327176	-.0208974
pmg	-.0448718	.0032028	-14.01	0.000	-.0511493	-.0385943
ffp	.020681	.0039594	5.22	0.000	.0129207	.0284413
mem	-.0631643	.0114977	-5.49	0.000	-.0856993	-.0406292
markland	.1334968	.0041537	32.14	0.000	.1253557	.141638
cannelton	.1065762	.0033658	31.66	0.000	.0999793	.1131731
newburgh	-.0194429	.0037011	-5.25	0.000	-.0266969	-.0121889
smithland	-.0939744	.0062159	-15.12	0.000	-.1061573	-.0817914
lock52	1.410173	.0051734	272.58	0.000	1.400034	1.420313
lengthsmall	.0002377	9.68e-06	24.55	0.000	.0002187	.0002567
lift	.0032857	.0002233	14.72	0.000	.0028481	.0037233
wicket	-1.780985	.0056812	-313.49	0.000	-1.79212	-1.76985
wickdisch	-1.58e-06	1.46e-08	-107.99	0.000	-1.61e-06	-1.55e-06
lock52disch	-1.53e-06	1.40e-08	-109.16	0.000	-1.56e-06	-1.50e-06
_cons	4.332414	.1522227	28.46	0.000	4.034063	4.630765

Correlation matrix of residuals:

	a2s_ln	s2e_ln
a2s_ln	1.0000	
s2e_ln	0.1951	1.0000

Breusch-Pagan test of independence: chi2(1) = 19692.591, Pr = 0.0000

Linear regression Number of obs = 520330

Regression Table 14A R-squared = 0.2196

Root MSE = 5.9864

a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	.1196528	.0380373	3.15	0.002	.0451009	.1942048
year2003	-.2777292	.0377267	-7.36	0.000	-.3516723	-.203786
year2004	-.3442373	.0374449	-9.19	0.000	-.4176281	-.2708466
year2005	1.017341	.038536	26.40	0.000	.9418113	1.09287
year2007	.9043007	.0386606	23.39	0.000	.8285272	.9800742
year2008	.8300155	.0386108	21.50	0.000	.7543396	.9056914
year2009	-.1763574	.0389315	-4.53	0.000	-.2526619	-.1000529
year2010	.9166091	.0392122	23.38	0.000	.8397544	.9934638

year2011	.7276194	.0391651	18.58	0.000	.6508571	.8043817
year2012	1.906825	.0428074	44.54	0.000	1.822923	1.990726
January	-.3106906	.0427843	-7.26	0.000	-.3945465	-.2268348
February	-.2835621	.0426963	-6.64	0.000	-.3672455	-.1998787
March	-.5269775	.0431176	-12.22	0.000	-.6114867	-.4424684
April	-.4721807	.042478	-11.12	0.000	-.5554362	-.3889252
May	-.6988175	.0422937	-16.52	0.000	-.7817118	-.6159231
June	-.3861573	.041273	-9.36	0.000	-.4670511	-.3052634
August	.4248927	.0427894	9.93	0.000	.3410267	.5087586
September	.4685208	.0423618	11.06	0.000	.385493	.5515485
October	.3321825	.0440238	7.55	0.000	.2458972	.4184679
November	.2454454	.044039	5.57	0.000	.1591304	.3317604
December	-.0845948	.0433271	-1.95	0.051	-.1695146	.0003249
discharge	-8.12e-06	1.53e-07	-52.92	0.000	-8.42e-06	-7.82e-06
disch2	1.54e-11	2.12e-13	72.66	0.000	1.50e-11	1.58e-11
dirdown	-.1309382	.0166065	-7.88	0.000	-.1634864	-.0983901
tugboat	3.94776	.4473052	8.83	0.000	3.071056	4.824464
pushboat	4.429109	.4451441	9.95	0.000	3.55664	5.301577
num_processed	.0614827	.00171	35.95	0.000	.0581312	.0648342
draftldft	.0778421	.0107086	7.27	0.000	.0568535	.0988306
draftltft	.0282807	.0086688	3.26	0.001	.0112901	.0452713
tonnage	.0007413	.000061	12.16	0.000	.0006218	.0008607
clcc	.2327432	.0306982	7.58	0.000	.1725757	.2929108
ppp	.2217037	.0226775	9.78	0.000	.1772564	.2661509
crp	.1668082	.0285375	5.85	0.000	.1108756	.2227408

cmief	-.2917432	.0290636	-10.04	0.000	-.3487071	-.2347794
pmg	.0089402	.0302054	0.30	0.767	-.0502614	.0681418
ffp	-.1692591	.0369627	-4.58	0.000	-.2417048	-.0968134
mem	-.186275	.1101525	-1.69	0.091	-.4021704	.0296205
markland	2.049786	.049516	41.40	0.000	1.952736	2.146835
cannelton	.7197957	.0378177	19.03	0.000	.6456742	.7939172
newburgh	-.6087702	.0395512	-15.39	0.000	-.6862892	-.5312512
smithland	-2.119763	.06849	-30.95	0.000	-2.254002	-1.985525
lock52	5.875264	.0454947	129.14	0.000	5.786096	5.964432
lengthsmall	-.0012821	.0001146	-11.19	0.000	-.0015067	-.0010574
lift	-.142127	.0030225	-47.02	0.000	-.148051	-.136203
wicket	-4.784051	.0553096	-86.50	0.000	-4.892456	-4.675646
wickdisch	-8.59e-06	1.30e-07	-66.14	0.000	-8.85e-06	-8.34e-06
lock52disch	-9.29e-06	9.32e-08	-99.68	0.000	-9.47e-06	-9.11e-06
chambout	4.303113	.0375513	114.59	0.000	4.229514	4.376713
chamb1part	-.9573437	.0966891	-9.90	0.000	-1.146851	-.7678361
chamb2part	4.834428	.1622737	29.79	0.000	4.516377	5.15248
_cons	-4.467151	.4672477	-9.56	0.000	-5.382941	-3.55136

Linear regression Number of obs = 517229

Regression Table 14B R-squared = 0.6830

Root MSE = .6147

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1280672	.0036116	35.46	0.000	.1209885	.1351458
year2003	.0662824	.0034875	19.01	0.000	.059447	.0731178
year2004	.02043	.0034492	5.92	0.000	.0136697	.0271902
year2005	.1875949	.0038379	48.88	0.000	.1800727	.1951172
year2007	.190441	.0039171	48.62	0.000	.1827636	.1981184
year2008	.1299428	.0038822	33.47	0.000	.1223339	.1375517
year2009	-.0166552	.0039849	-4.18	0.000	-.0244654	-.008845
year2010	.0615642	.0041797	14.73	0.000	.053372	.0697563
year2011	-.0238665	.0042126	-5.67	0.000	-.032123	-.01561
year2012	.2637621	.0048262	54.65	0.000	.254303	.2732212
January	-.0391144	.0043214	-9.05	0.000	-.0475842	-.0306447
February	-.0751028	.0042239	-17.78	0.000	-.0833815	-.0668241
March	-.1041226	.0042819	-24.32	0.000	-.1125151	-.0957302
April	-.1047208	.0043079	-24.31	0.000	-.1131642	-.0962774
May	-.1379575	.0042935	-32.13	0.000	-.1463727	-.1295423
June	-.0554296	.0042882	-12.93	0.000	-.0638344	-.0470248
August	.1105913	.0047182	23.44	0.000	.1013439	.1198388
September	.0793471	.0045333	17.50	0.000	.070462	.0882323
October	.077516	.0049094	15.79	0.000	.0678938	.0871382
November	.0462882	.0049154	9.42	0.000	.0366541	.0559222
December	-.0268206	.0045359	-5.91	0.000	-.0357108	-.0179304

discharge	-1.42e-06	1.92e-08	-73.78	0.000	-1.46e-06	-1.38e-06
disch2	2.69e-12	3.50e-14	76.73	0.000	2.62e-12	2.76e-12
dirdown	-.0924647	.0017084	-54.12	0.000	-.095813	-.0891163
tugboat	.2710255	.0996456	2.72	0.007	.0757234	.4663277
pushboat	.2967117	.0995585	2.98	0.003	.1015802	.4918433
yearbuilt	-.0004962	.0000711	-6.97	0.000	-.0006357	-.0003568
num_processed	.0076932	.0002158	35.65	0.000	.0072703	.0081161
draftldft	.0195763	.0012069	16.22	0.000	.0172109	.0219417
draftltft	-.0101073	.0009597	-10.53	0.000	-.0119883	-.0082262
tonnage	.0000411	8.39e-06	4.90	0.000	.0000246	.0000575
horsepower	4.21e-06	9.50e-07	4.43	0.000	2.35e-06	6.07e-06
clcc	.0090827	.0028477	3.19	0.001	.0035012	.0146642
ppp	.0025975	.0025796	1.01	0.314	-.0024584	.0076533
crp	.0137774	.003063	4.50	0.000	.0077739	.0197808
cmief	-.0275909	.003015	-9.15	0.000	-.0335002	-.0216816
pmg	-.0460802	.0032295	-14.27	0.000	-.0524099	-.0397504
ffp	.0208724	.0039984	5.22	0.000	.0130357	.0287092
mem	-.0599932	.0133146	-4.51	0.000	-.0860894	-.033897
markland	.2965022	.0037336	79.41	0.000	.2891844	.30382
cannelton	.1791385	.0023673	75.67	0.000	.1744986	.1837783
newburgh	-.0429515	.0022745	-18.88	0.000	-.0474095	-.0384935
smithland	-.2396857	.0046532	-51.51	0.000	-.2488059	-.2305655
lock52	1.40035	.0090324	155.04	0.000	1.382647	1.418053
lengthsmall	.0005744	8.15e-06	70.51	0.000	.0005584	.0005903
lift	-.0082237	.0002255	-36.48	0.000	-.0086656	-.0077818

wicket	-1.830722	.0083395	-219.52	0.000	-1.847067	-1.814376
wickdisch	-1.59e-06	2.30e-08	-69.23	0.000	-1.64e-06	-1.55e-06
lock52disch	-1.52e-06	2.00e-08	-76.23	0.000	-1.56e-06	-1.48e-06
chambout	.2293348	.0035527	64.55	0.000	.2223717	.2362979
chamb1part	-.1625734	.0152689	-10.65	0.000	-.1924999	-.132647
chamb2part	.5525689	.0204818	26.98	0.000	.5124252	.5927126
_cons	4.286074	.1763165	24.31	0.000	3.9405	4.631649

Linear regression Number of obs = 520330

Regression Table 14C R-squared = 0.2247

Root MSE = 5.967

a2s_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf. Interval]	
year2002	.1177896	.0380123	3.10	0.002	.0432867	.1922925
year2003	-.3300284	.0376825	-8.76	0.000	-.4038848	-.2561719
year2004	-.3601414	.0374177	-9.62	0.000	-.433479	-.2868037
year2005	1.030486	.0385145	26.76	0.000	.9549987	1.105973
year2007	.8720903	.0385747	22.61	0.000	.7964852	.9476955
year2008	.8616049	.0385241	22.37	0.000	.7860988	.937111

year2009	-.3122364	.0388362	-8.04	0.000	-.3883542	-.2361186
year2010	.7872932	.0391806	20.09	0.000	.7105004	.864086
year2011	.6265709	.0391408	16.01	0.000	.5498563	.7032856
year2012	1.720279	.0428943	40.11	0.000	1.636208	1.804351
January	-.313741	.0425749	-7.37	0.000	-.3971864	-.2302956
February	-.2776907	.0424716	-6.54	0.000	-.3609336	-.1944477
March	-.5015254	.0429093	-11.69	0.000	-.5856263	-.4174245
April	-.4209954	.0422361	-9.97	0.000	-.5037768	-.3382139
May	-.6132103	.0420548	-14.58	0.000	-.6956363	-.5307843
June	-.3840754	.0409255	-9.38	0.000	-.464288	-.3038628
August	.464025	.0425654	10.90	0.000	.3805981	.5474519
September	.5534055	.0422859	13.09	0.000	.4705265	.6362846
October	.3166235	.0437618	7.24	0.000	.2308518	.4023953
November	.302218	.0437899	6.90	0.000	.2163913	.3880448
December	-.083692	.0430828	-1.94	0.052	-.1681331	.000749
discharge	-8.11e-06	1.53e-07	-52.99	0.000	-8.41e-06	-7.81e-06
disch2	1.53e-11	2.12e-13	72.09	0.000	1.49e-11	1.57e-11
dirdown	-.1315565	.0165527	-7.95	0.000	-.1639993	-.0991136
tugboat	3.983558	.4434869	8.98	0.000	3.114338	4.852779
pushboat	4.459356	.4413269	10.10	0.000	3.594369	5.324343
num_processed	.060558	.0017055	35.51	0.000	.0572152	.0639007
draftldft	.0764254	.0106801	7.16	0.000	.0554928	.097358
draftltft	.0298622	.0086431	3.46	0.001	.012922	.0468024
tonnage	.0007592	.0000608	12.49	0.000	.0006401	.0008784
clcc	.2421198	.0305685	7.92	0.000	.1822064	.3020332

ppp	.2148233	.0226166	9.50	0.000	.1704956	.2591511
crp	.1627868	.0284466	5.72	0.000	.1070323	.2185413
cmief	-.2946804	.028982	-10.17	0.000	-.3514842	-.2378766
pmg	.0052037	.0301154	0.17	0.863	-.0538215	.0642289
ffp	-.1706626	.0368299	-4.63	0.000	-.242848	-.0984773
mem	-.1471457	.1098053	-1.34	0.180	-.3623607	.0680693
markland	4.093374	.0516557	79.24	0.000	3.992131	4.194618
cannelton	1.643042	.0390995	42.02	0.000	1.566408	1.719676
newburgh	-.8276299	.0394131	-21.00	0.000	-.9048783	-.7503816
smithland	-3.982196	.0726632	-54.80	0.000	-4.124614	-3.839778
lock52	5.899513	.0456124	129.34	0.000	5.810114	5.988912
lengthsmall	.0027115	.0001253	21.63	0.000	.0024658	.0029572
lift	-.2807254	.0034274	-81.91	0.000	-.2874429	-.2740079
wicket	-5.650825	.0560553	-100.81	0.000	-5.760692	-5.540959
wickdisch	-8.58e-06	1.30e-07	-65.88	0.000	-8.84e-06	-8.33e-06
lock52disch	-9.33e-06	9.34e-08	-99.95	0.000	-9.51e-06	-9.15e-06
mainout	6.855582	.0474051	144.62	0.000	6.76267	6.948495
auxout	2.671019	.0497884	53.65	0.000	2.573435	2.768602
chamb1part	-.2510299	.0998953	-2.51	0.012	-.4468216	-.0552381
chamb2part	4.457936	.1659534	26.86	0.000	4.132672	4.783199
_cons	-4.324094	.4634639	-9.33	0.000	-5.232469	-3.415719

Linear regression Number of obs = 517229

Regression Table 14B R-squared = 0.6834

Root MSE = .61424

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1279873	.0036109	35.44	0.000	.1209099	.1350646
year2003	.0637135	.003494	18.23	0.000	.0568652	.0705617
year2004	.019656	.0034532	5.69	0.000	.0128879	.0264241
year2005	.1882483	.0038426	48.99	0.000	.180717	.1957797
year2007	.1888605	.0039171	48.21	0.000	.181183	.1965379
year2008	.1315137	.0038811	33.89	0.000	.1239069	.1391204
year2009	-.0233943	.0040022	-5.85	0.000	-.0312385	-.0155501
year2010	.0551829	.0041882	13.18	0.000	.0469741	.0633918
year2011	-.028842	.0042218	-6.83	0.000	-.0371166	-.0205675
year2012	.2544797	.0048713	52.24	0.000	.2449322	.2640272
January	-.0392438	.0043148	-9.10	0.000	-.0477006	-.030787
February	-.0748202	.0042158	-17.75	0.000	-.083083	-.0665575
March	-.1028415	.0042751	-24.06	0.000	-.1112205	-.0944625
April	-.1021543	.0043004	-23.75	0.000	-.1105829	-.0937257
May	-.1337001	.0042895	-31.17	0.000	-.1421075	-.1252928
June	-.0552884	.0042765	-12.93	0.000	-.0636702	-.0469065
August	.1125287	.0047119	23.88	0.000	.1032934	.1217639
September	.0835473	.004526	18.46	0.000	.0746765	.092418

October	.0767442	.0048963	15.67	0.000	.0671475	.0863408
November	.0491215	.0049087	10.01	0.000	.0395006	.0587424
December	-.0267509	.0045253	-5.91	0.000	-.0356204	-.0178815
discharge	-1.42e-06	1.92e-08	-73.78	0.000	-1.46e-06	-1.38e-06
disch2	2.68e-12	3.51e-14	76.45	0.000	2.61e-12	2.75e-12
dirdown	-.0924979	.0017071	-54.19	0.000	-.0958437	-.089152
tugboat	.2706395	.0998366	2.71	0.007	.0749629	.4663162
pushboat	.2961175	.0997498	2.97	0.003	.1006111	.4916239
yearbuilt	-.0004947	.0000711	-6.95	0.000	-.0006341	-.0003553
num_processed	.0076421	.0002157	35.42	0.000	.0072192	.0080649
draftldft	.0194932	.0012065	16.16	0.000	.0171285	.0218579
draftltft	-.0100277	.0009591	-10.46	0.000	-.0119075	-.0081479
tonnage	.0000416	8.38e-06	4.96	0.000	.0000252	.000058
horsepower	4.27e-06	9.49e-07	4.49	0.000	2.40e-06	6.13e-06
clcc	.0095472	.0028453	3.36	0.001	.0039705	.015124
ppp	.0022392	.0025791	0.87	0.385	-.0028157	.0072941
crp	.0135883	.0030623	4.44	0.000	.0075862	.0195904
cmief	-.0277038	.0030143	-9.19	0.000	-.0336118	-.0217958
pmg	-.0463091	.0032277	-14.35	0.000	-.0526354	-.0399829
ffp	.0207972	.0039966	5.20	0.000	.0129639	.0286305
mem	-.0580429	.0133205	-4.36	0.000	-.0841506	-.0319352
markland	.3974482	.0049893	79.66	0.000	.3876694	.4072271
cannelton	.2247493	.0027795	80.86	0.000	.2193015	.2301971
newburgh	-.0537448	.002291	-23.46	0.000	-.058235	-.0492545
smithland	-.3317203	.0056555	-58.65	0.000	-.3428048	-.3206357

lock52	1.401533	.0090401	155.04	0.000	1.383815	1.419252
lengthsmall	.0007717	.0000105	73.23	0.000	.000751	.0007923
lift	-.0150668	.0003115	-48.36	0.000	-.0156774	-.0144562
wicket	-1.873494	.0084761	-221.03	0.000	-1.890107	-1.856881
wickdisch	-1.59e-06	2.31e-08	-69.12	0.000	-1.64e-06	-1.55e-06
lock52disch	-1.52e-06	2.00e-08	-76.30	0.000	-1.56e-06	-1.48e-06
mainout	.3553818	.0052605	67.56	0.000	.3450715	.3656921
auxout	.1490089	.0044497	33.49	0.000	.1402876	.1577303
chamb1part	-.1276444	.0155455	-8.21	0.000	-.1581131	-.0971756
chamb2part	.5339744	.020711	25.78	0.000	.4933816	.5745672
_cons	4.292133	.1763858	24.33	0.000	3.946422	4.637844

Linear regression Number of obs = 520330

Regression Table 15A R-squared = 0.2226

Root MSE = 5.9749

	Robust				
a2s_ln	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]
year2002	.1231505	.0379358	3.25	0.001	.0487976 .1975034

year2003	-.3422922	.0376873	-9.08	0.000	-.4161582	-.2684262
year2004	-.3923822	.0374168	-10.49	0.000	-.465718	-.3190464
year2005	1.014129	.0385625	26.30	0.000	.9385475	1.08971
year2007	.8878543	.0386849	22.95	0.000	.8120331	.9636754
year2008	.8402751	.0385191	21.81	0.000	.7647789	.9157713
year2009	-.2997026	.0385945	-7.77	0.000	-.3753466	-.2240586
year2010	.7956164	.0390384	20.38	0.000	.7191024	.8721303
year2011	.588736	.0390588	15.07	0.000	.512182	.66529
year2012	1.675305	.0430109	38.95	0.000	1.591005	1.759605
January	-.3022149	.0426062	-7.09	0.000	-.3857217	-.2187081
February	-.2636118	.0425148	-6.20	0.000	-.3469395	-.1802842
March	-.5062293	.0429567	-11.78	0.000	-.5904231	-.4220355
April	-.4142415	.0422607	-9.80	0.000	-.4970712	-.3314118
May	-.6089981	.0420852	-14.47	0.000	-.6914837	-.5265125
June	-.3520909	.0408837	-8.61	0.000	-.4322217	-.2719601
August	.4423185	.0425953	10.38	0.000	.358833	.525804
September	.5592907	.0422308	13.24	0.000	.4765196	.6420618
October	.3580376	.0437882	8.18	0.000	.2722141	.4438612
November	.316425	.0438859	7.21	0.000	.23041	.40244
December	-.0875563	.0431019	-2.03	0.042	-.1720348	-.0030778
discharge	-8.03e-06	1.54e-07	-52.17	0.000	-8.34e-06	-7.73e-06
disch2	1.51e-11	2.16e-13	69.86	0.000	1.46e-11	1.55e-11
dirdown	-.1311165	.0165748	-7.91	0.000	-.1636027	-.0986304
tugboat	3.94949	.4532823	8.71	0.000	3.06107	4.837909
pushboat	4.427298	.4511421	9.81	0.000	3.543073	5.311522

num_processed	.0605774	.0017091	35.44	0.000	.0572276	.0639271
draftldft	.0778906	.0106966	7.28	0.000	.0569256	.0988557
draftltft	.0294636	.0086559	3.40	0.001	.0124984	.0464288
tonnage	.0007556	.0000609	12.40	0.000	.0006362	.000875
clcc	.2385789	.0305778	7.80	0.000	.1786475	.2985104
ppp	.2158595	.0226497	9.53	0.000	.1714667	.2602522
crp	.1627785	.0284908	5.71	0.000	.1069375	.2186195
cmief	-.2939463	.029018	-10.13	0.000	-.3508206	-.237072
pmg	.0050743	.0301696	0.17	0.866	-.0540572	.0642058
ffp	-.1685238	.0368491	-4.57	0.000	-.2407469	-.0963006
mem	-.1354123	.1100529	-1.23	0.219	-.3511126	.0802879
markland	.2374704	.0405691	5.85	0.000	.1579562	.3169846
cannelton	.0609043	.0347721	1.75	0.080	-.0072479	.1290565
newburgh	-.379615	.039134	-9.70	0.000	-.4563165	-.3029135
smithland	-.8439852	.0418867	-20.15	0.000	-.9260818	-.7618886
lock52	5.927354	.0455587	130.10	0.000	5.83806	6.016647
leneffbig	-.0073114	.0000928	-78.76	0.000	-.0074933	-.0071294
leneffsm	-.0041519	.0000421	-98.63	0.000	-.0042344	-.0040694
lift	-.0542831	.0020823	-26.07	0.000	-.0583643	-.050202
wicket	-4.349985	.0542026	-80.25	0.000	-4.456221	-4.24375
wickdisch	-8.44e-06	1.31e-07	-64.25	0.000	-8.69e-06	-8.18e-06
lock52disch	-9.30e-06	9.33e-08	-99.76	0.000	-9.49e-06	-9.12e-06
_cons	4.543105	.4818305	9.43	0.000	3.598733	5.487478

Linear regression Number of obs = 517229

Regression Table 15B R-squared = 0.6815

Root MSE = .61608

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1295862	.0036553	35.45	0.000	.122422	.1367504
year2003	.0573626	.0034869	16.45	0.000	.0505285	.0641968
year2004	.0161346	.0034985	4.61	0.000	.0092777	.0229916
year2005	.1881229	.0038991	48.25	0.000	.1804808	.195765
year2007	.1890324	.0039883	47.40	0.000	.1812155	.1968492
year2008	.1297431	.0039354	32.97	0.000	.1220299	.1374564
year2009	-.0051819	.0039913	-1.30	0.194	-.0130046	.0026408
year2010	.0710028	.0041525	17.10	0.000	.062864	.0791416
year2011	-.0183528	.0042323	-4.34	0.000	-.026648	-.0100576
year2012	.2573197	.004935	52.14	0.000	.2476471	.2669922
January	-.0398958	.0043148	-9.25	0.000	-.0483526	-.031439
February	-.0743792	.00422	-17.63	0.000	-.0826503	-.066108
March	-.1022776	.0042794	-23.90	0.000	-.1106651	-.09389
April	-.0997957	.0043003	-23.21	0.000	-.1082241	-.0913673
May	-.1275602	.0042893	-29.74	0.000	-.1359672	-.1191533
June	-.0497129	.0042626	-11.66	0.000	-.0580676	-.0413583

August	.1126984	.0047335	23.81	0.000	.1034209	.1219759
September	.0902817	.0045594	19.80	0.000	.0813454	.099218
October	.0806338	.0049311	16.35	0.000	.070969	.0902985
November	.0563224	.004958	11.36	0.000	.0466048	.0660401
December	-.0306036	.0045318	-6.75	0.000	-.0394859	-.0217214
discharge	-1.40e-06	1.94e-08	-72.33	0.000	-1.44e-06	-1.36e-06
disch2	2.64e-12	3.55e-14	74.40	0.000	2.57e-12	2.71e-12
dirdown	-.0924125	.0017122	-53.97	0.000	-.0957683	-.0890567
tugboat	.2716964	.1006845	2.70	0.007	.074358	.4690349
pushboat	.2983666	.1005974	2.97	0.003	.1011989	.4955342
yearbuilt	-.0004974	.0000713	-6.97	0.000	-.0006372	-.0003576
num_processed	.0077574	.0002164	35.85	0.000	.0073333	.0081815
draftldft	.0194969	.0012108	16.10	0.000	.0171237	.0218701
draftltft	-.0101364	.0009616	-10.54	0.000	-.0120212	-.0082516
tonnage	.0000418	8.41e-06	4.97	0.000	.0000253	.0000583
horsepower	4.19e-06	9.52e-07	4.40	0.000	2.32e-06	6.05e-06
clcc	.0117835	.0028491	4.14	0.000	.0061994	.0173677
ppp	.0028031	.0025886	1.08	0.279	-.0022705	.0078767
crp	.0134256	.0030729	4.37	0.000	.0074029	.0194483
cmief	-.0276185	.0030238	-9.13	0.000	-.0335449	-.021692
pmg	-.0448492	.0032382	-13.85	0.000	-.0511959	-.0385025
ffp	.0177339	.0040083	4.42	0.000	.0098777	.0255901
mem	-.0625961	.0133834	-4.68	0.000	-.0888272	-.036365
markland	.0349922	.0023965	14.60	0.000	.0302952	.0396893
cannelton	.07726	.0019484	39.65	0.000	.0734412	.0810788

```
    newburgh |  -.0102072   .0021899    -4.66   0.000    -.0144994    -.005915
   smithland |   .0376224   .0028693    13.11   0.000     .0319986    .0432462
      lock52 |   1.407009    .009065   155.21   0.000     1.389242    1.424776
   leneffbig |  -.0006258   .0000118   -52.91   0.000     -.000649   -.0006026
    leneffsm |   6.10e-06   3.10e-06     1.97   0.049     2.68e-08    .0000122
        lift |   .0061132   .0001196    51.10   0.000     .0058787    .0063477
      wicket |  -1.759685   .0083294  -211.26   0.000     -1.77601    -1.74336
   wickdisch |  -1.57e-06   2.32e-08   -67.64   0.000    -1.62e-06   -1.53e-06
  lock52disch |  -1.52e-06   2.00e-08   -76.11   0.000    -1.56e-06   -1.48e-06
       _cons |   5.126485   .1776763    28.85   0.000     4.778245    5.474725
------------------------------------------------------------------------------


Linear regression                                      Number of obs =  520330
Regression Table 16A                                   R-squared     =  0.2241
                                                       Root MSE      =   5.969

------------------------------------------------------------------------------
             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |    .117376   .0379922     3.09   0.002     .0429125    .1918395
    year2003 |  -.3299123   .0376946    -8.75   0.000    -.4037926    -.256032
    year2004 |  -.3672418   .0374291    -9.81   0.000    -.4406017   -.2938819
    year2005 |    1.02098   .0385469    26.49   0.000     .9454295    1.096531
```

year2007	.8740121	.0385767	22.66	0.000	.798403	.9496211
year2008	.8587695	.0385524	22.28	0.000	.7832081	.934331
year2009	-.2766347	.0386033	-7.17	0.000	-.3522959	-.2009734
year2010	.7947656	.0389452	20.41	0.000	.7184343	.8710969
year2011	.5889285	.0390754	15.07	0.000	.5123419	.6655151
year2012	1.686895	.0430466	39.19	0.000	1.602525	1.771265
January	-.2843716	.0426094	-6.67	0.000	-.3678847	-.2008585
February	-.2503981	.0425088	-5.89	0.000	-.3337141	-.167082
March	-.4903218	.042957	-11.41	0.000	-.5745161	-.4061275
April	-.3937964	.0422641	-9.32	0.000	-.4766327	-.31096
May	-.5899642	.0420979	-14.01	0.000	-.6724748	-.5074536
June	-.3619499	.0409357	-8.84	0.000	-.4421825	-.2817173
August	.4500483	.0426099	10.56	0.000	.3665342	.5335624
September	.5417987	.042255	12.82	0.000	.4589802	.6246172
October	.3170813	.043807	7.24	0.000	.2312209	.4029418
November	.2723774	.0438005	6.22	0.000	.1865299	.3582249
December	-.0853888	.0430968	-1.98	0.048	-.1698572	-.0009205
discharge	-8.13e-06	1.54e-07	-52.91	0.000	-8.43e-06	-7.83e-06
disch2	1.52e-11	2.16e-13	70.55	0.000	1.48e-11	1.56e-11
dirdown	-.1313131	.0165585	-7.93	0.000	-.1637672	-.0988591
tugboat	3.976127	.4431387	8.97	0.000	3.10759	4.844665
pushboat	4.452509	.4409724	10.10	0.000	3.588217	5.316801
num_processed	.0604454	.0017063	35.43	0.000	.0571011	.0637897
draftldft	.07695	.0106852	7.20	0.000	.0560074	.0978926
draftltft	.0295014	.0086468	3.41	0.001	.012554	.0464488

tonnage	.0007585	.0000608	12.48	0.000	.0006394	.0008777
clcc	.2403079	.0305667	7.86	0.000	.1803981	.3002178
ppp	.2148931	.0226261	9.50	0.000	.1705467	.2592394
crp	.1629568	.028461	5.73	0.000	.1071741	.2187394
cmief	-.2966108	.0289911	-10.23	0.000	-.3534324	-.2397892
pmg	.0048699	.0301319	0.16	0.872	-.0541878	.0639276
ffp	-.1662911	.0368405	-4.51	0.000	-.2384972	-.094085
mem	-.1407321	.1097315	-1.28	0.200	-.3558024	.0743382
markland	.2437542	.0406625	5.99	0.000	.1640569	.3234515
cannelton	.0594942	.0348009	1.71	0.087	-.0087144	.1277029
newburgh	-.3714346	.0391644	-9.48	0.000	-.4481957	-.2946735
smithland	-.8129213	.0420096	-19.35	0.000	-.8952589	-.7305838
lock52	5.904483	.0456233	129.42	0.000	5.815063	5.993903
leneffbig	-.0071332	.0000933	-76.48	0.000	-.007316	-.0069504
leneffsm	-.0041745	.0000423	-98.62	0.000	-.0042574	-.0040915
lift	-.054377	.0020837	-26.10	0.000	-.058461	-.0502931
wicket	-4.310974	.0542196	-79.51	0.000	-4.417243	-4.204705
wickdisch	-8.51e-06	1.31e-07	-64.74	0.000	-8.77e-06	-8.25e-06
lock52disch	-9.34e-06	9.34e-08	-100.05	0.000	-9.52e-06	-9.16e-06
chamb1part	-.1759445	.0988685	-1.78	0.075	-.3697235	.0178346
chamb2part	4.465592	.1659679	26.91	0.000	4.1403	4.790884
_cons	4.31424	.4721175	9.14	0.000	3.388904	5.239575

Linear regression Number of obs = 517229

Regression Table 16B R-squared = 0.6824

Root MSE = .61526

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1278023	.0036169	35.34	0.000	.1207133	.1348912
year2003	.0592593	.0035036	16.91	0.000	.0523925	.0661262
year2004	.0182045	.0034636	5.26	0.000	.0114159	.0249931
year2005	.1882608	.0038679	48.67	0.000	.1806799	.1958417
year2007	.1863638	.0039278	47.45	0.000	.1786655	.1940621
year2008	.1307786	.0038938	33.59	0.000	.1231469	.1384102
year2009	-.0032234	.0039627	-0.81	0.416	-.01099	.0045433
year2010	.0712221	.0041477	17.17	0.000	.0630928	.0793514
year2011	-.018597	.0042207	-4.41	0.000	-.0268694	-.0103246
year2012	.2598502	.0049349	52.66	0.000	.2501779	.2695225
January	-.0373676	.004314	-8.66	0.000	-.045823	-.0289123
February	-.0724593	.0042178	-17.18	0.000	-.0807262	-.0641925
March	-.1001198	.0042769	-23.41	0.000	-.1085023	-.0917372
April	-.0966035	.0043004	-22.46	0.000	-.1050321	-.0881749
May	-.1244148	.0042931	-28.98	0.000	-.132829	-.1160005
June	-.0501999	.0042729	-11.75	0.000	-.0585746	-.0418251
August	.1139136	.0047345	24.06	0.000	.104634	.1231931

September	.0890789	.0045509	19.57	0.000	.0801592	.0979986
October	.0771726	.0049004	15.75	0.000	.0675679	.0867774
November	.0523349	.0049125	10.65	0.000	.0427066	.0619633
December	-.0294025	.0045275	-6.49	0.000	-.0382762	-.0205288
discharge	-1.42e-06	1.94e-08	-73.23	0.000	-1.46e-06	-1.38e-06
disch2	2.67e-12	3.55e-14	75.12	0.000	2.60e-12	2.74e-12
dirdown	-.0924415	.0017099	-54.06	0.000	-.0957928	-.0890902
tugboat	.2695647	.1004636	2.68	0.007	.0726591	.4664703
pushboat	.296128	.1003766	2.95	0.003	.0993929	.492863
yearbuilt	-.0004956	.0000713	-6.96	0.000	-.0006353	-.000356
num_processed	.0077407	.0002161	35.81	0.000	.0073171	.0081643
draftldft	.0193774	.0012091	16.03	0.000	.0170076	.0217472
draftltft	-.0101438	.0009606	-10.56	0.000	-.0120265	-.0082611
tonnage	.0000418	8.40e-06	4.97	0.000	.0000253	.0000582
horsepower	4.23e-06	9.51e-07	4.45	0.000	2.37e-06	6.10e-06
clcc	.0119494	.0028479	4.20	0.000	.0063676	.0175311
ppp	.0027071	.0025854	1.05	0.295	-.0023602	.0077744
crp	.0134508	.0030687	4.38	0.000	.0074362	.0194653
cmief	-.027875	.0030202	-9.23	0.000	-.0337944	-.0219556
pmg	-.0448408	.0032325	-13.87	0.000	-.0511764	-.0385051
ffp	.0179619	.0040045	4.49	0.000	.0101133	.0258105
mem	-.0629679	.0133691	-4.71	0.000	-.0891709	-.0367649
markland	.0372647	.0024161	15.42	0.000	.0325292	.0420001
cannelton	.0771859	.0019567	39.45	0.000	.0733508	.081021
newburgh	-.0087351	.0022045	-3.96	0.000	-.0130559	-.0044142

```
  smithland |   .0430252   .0028579    15.05   0.000     .0374238    .0486265

     lock52 |   1.405804   .0090744   154.92   0.000     1.388018    1.423589

  leneffbig |  -.0006006   .0000118   -50.81   0.000    -.0006237   -.0005774

   leneffsm |   8.65e-07   3.06e-06     0.28   0.778    -5.13e-06    6.86e-06

       lift |   .0060694   .0001201    50.53   0.000      .005834    .0063048

     wicket |  -1.753891   .0083262  -210.65   0.000     -1.77021   -1.737572

  wickdisch |  -1.58e-06   2.32e-08   -68.21   0.000    -1.63e-06   -1.54e-06

lock52disch |  -1.53e-06   2.00e-08   -76.42   0.000    -1.57e-06   -1.49e-06

 chamb1part |  -.0720352   .0157934    -4.56   0.000    -.1029897   -.0410806

 chamb2part |   .5268643    .020763    25.38   0.000     .4861694    .5675592

      _cons |   5.098419   .1774104    28.74   0.000       4.7507    5.446137
------------------------------------------------------------------------------
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Linear regression                              Number of obs =  520330

Regression Table 17A                           R-squared     =  0.2247

                                               Root MSE      =  5.9671

------------------------------------------------------------------------------
             |               Robust
      a2s_ln |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    year2002 |   .1095472   .0379955     2.88   0.004     .0350771    .1840172

    year2003 |  -.3332459   .0376922    -8.84   0.000    -.4071213   -.2593704

    year2004 |  -.3591089   .0373959    -9.60   0.000    -.4324036   -.2858141
```

year2005	1.024818	.0385372	26.59	0.000	.9492858	1.100349
year2007	.876425	.0385717	22.72	0.000	.8008258	.9520243
year2008	.865703	.038536	22.46	0.000	.7901736	.9412324
year2009	-.2874506	.0385857	-7.45	0.000	-.3630772	-.2118239
year2010	.7929477	.0389291	20.37	0.000	.7166479	.8692474
year2011	.5774385	.0390687	14.78	0.000	.5008651	.6540119
year2012	1.665408	.0430257	38.71	0.000	1.581079	1.749737
January	-.2842174	.0426088	-6.67	0.000	-.3677294	-.2007055
February	-.2505748	.0425018	-5.90	0.000	-.333877	-.1672725
March	-.4912646	.0429566	-11.44	0.000	-.5754581	-.407071
April	-.3904925	.0422566	-9.24	0.000	-.473314	-.3076709
May	-.5845323	.0420769	-13.89	0.000	-.6670017	-.5020628
June	-.3620572	.0409243	-8.85	0.000	-.4422676	-.2818468
August	.4594805	.0425902	10.79	0.000	.3760052	.5429559
September	.5531463	.0422165	13.10	0.000	.4704033	.6358893
October	.3219125	.0437857	7.35	0.000	.236094	.4077311
November	.27536	.0437885	6.29	0.000	.1895359	.3611841
December	-.0848464	.0430832	-1.97	0.049	-.1692882	-.0004046
discharge	-8.14e-06	1.53e-07	-53.13	0.000	-8.44e-06	-7.84e-06
disch2	1.53e-11	2.14e-13	71.54	0.000	1.49e-11	1.57e-11
dirdown	-.1328519	.0165531	-8.03	0.000	-.1652954	-.1004084
tugboat	4.050208	.4440056	9.12	0.000	3.179971	4.920445
pushboat	4.519855	.4418401	10.23	0.000	3.653862	5.385848
num_processed	.0572047	.0017126	33.40	0.000	.0538482	.0605613
draftldft	.075739	.0106811	7.09	0.000	.0548044	.0966736

draftltft	.0296118	.0086437	3.43	0.001	.0126703	.0465532
tonnage	.000776	.0000608	12.77	0.000	.0006568	.0008951
clcc	.241853	.0305569	7.91	0.000	.1819624	.3017435
ppp	.2127982	.0226194	9.41	0.000	.1684648	.2571315
crp	.1625672	.0284557	5.71	0.000	.106795	.2183394
cmief	-.2957783	.0289801	-10.21	0.000	-.3525784	-.2389782
pmg	-.0030301	.0301242	-0.10	0.920	-.0620726	.0560123
ffp	-.1639159	.0368353	-4.45	0.000	-.2361118	-.0917199
mem	-.1196449	.1097029	-1.09	0.275	-.3346591	.0953693
markland	.1844878	.0406874	4.53	0.000	.1047418	.2642338
cannelton	.0617165	.0347659	1.78	0.076	-.0064236	.1298567
newburgh	-.3778169	.0391718	-9.65	0.000	-.4545924	-.3010413
smithland	-.8380227	.0420093	-19.95	0.000	-.9203596	-.7556858
lock52	5.899254	.0455974	129.38	0.000	5.809885	5.988624
leneffbig	-.0054554	.0001389	-39.27	0.000	-.0057277	-.0051832
leneffsm	-.0041461	.0000423	-98.01	0.000	-.004229	-.0040632
lift	-.0536216	.0020825	-25.75	0.000	-.0577032	-.04954
wicket	-4.294953	.054124	-79.35	0.000	-4.401034	-4.188871
wickdisch	-8.55e-06	1.31e-07	-65.44	0.000	-8.81e-06	-8.30e-06
lock52disch	-9.34e-06	9.33e-08	-100.06	0.000	-9.52e-06	-9.15e-06
chamb1part	-.181442	.0987094	-1.84	0.066	-.3749093	.0120253
chamb2part	4.415599	.1667519	26.48	0.000	4.088771	4.742428
decoupled	1.777333	.0881869	20.15	0.000	1.60449	1.950177
_cons	2.236098	.4897481	4.57	0.000	1.276208	3.195989

Linear regression Number of obs = 517229

Regression Table 17B R-squared = 0.6856

Root MSE = .61213

s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.124705	.003599	34.65	0.000	.1176512	.1317589
year2003	.0579298	.0034851	16.62	0.000	.051099	.0647606
year2004	.0214868	.0034443	6.24	0.000	.0147361	.0282374
year2005	.1898253	.0038522	49.28	0.000	.182275	.1973755
year2007	.1873224	.0039152	47.84	0.000	.1796486	.1949961
year2008	.1335159	.0038785	34.42	0.000	.125914	.1411177
year2009	-.0075785	.0039407	-1.92	0.054	-.0153023	.0001452
year2010	.0704495	.0041308	17.05	0.000	.0623534	.0785457
year2011	-.0232805	.0041988	-5.54	0.000	-.03151	-.0150509
year2012	.2510634	.0048939	51.30	0.000	.2414716	.2606552
January	-.0373686	.0042936	-8.70	0.000	-.0457839	-.0289533
February	-.0725681	.0041898	-17.32	0.000	-.0807799	-.0643563
March	-.1004762	.0042536	-23.62	0.000	-.1088132	-.0921392
April	-.0953023	.004272	-22.31	0.000	-.1036752	-.0869293
May	-.1222427	.0042573	-28.71	0.000	-.1305869	-.1138984

June	-.0502054	.0042436	-11.83	0.000	-.0585228	-.041888
August	.1176533	.004709	24.98	0.000	.1084239	.1268828
September	.0936631	.0045251	20.70	0.000	.084794	.1025322
October	.0791449	.0048795	16.22	0.000	.0695813	.0887085
November	.0536159	.0048871	10.97	0.000	.0440373	.0631945
December	-.0292013	.0044987	-6.49	0.000	-.0380186	-.0203839
discharge	-1.42e-06	1.90e-08	-74.88	0.000	-1.46e-06	-1.38e-06
disch2	2.69e-12	3.43e-14	78.59	0.000	2.63e-12	2.76e-12
dirdown	-.0930608	.0017012	-54.70	0.000	-.0963951	-.0897265
tugboat	.2876317	.1003781	2.87	0.004	.0908939	.4843696
pushboat	.3113641	.1002913	3.10	0.002	.1147962	.507932
yearbuilt	-.0004934	.000071	-6.95	0.000	-.0006325	-.0003544
num_processed	.0063449	.0002157	29.42	0.000	.0059221	.0067676
draftldft	.0187669	.0012036	15.59	0.000	.0164079	.021126
draftltft	-.0101532	.0009559	-10.62	0.000	-.0120267	-.0082797
tonnage	.000043	8.36e-06	5.14	0.000	.0000266	.0000594
horsepower	5.25e-06	9.47e-07	5.55	0.000	3.40e-06	7.11e-06
clcc	.0130569	.0028313	4.61	0.000	.0075076	.0186062
ppp	.0017932	.0025741	0.70	0.486	-.003252	.0068384
crp	.0134504	.0030552	4.40	0.000	.0074623	.0194386
cmief	-.0273363	.0030058	-9.09	0.000	-.0332276	-.021445
pmg	-.0482726	.0032181	-15.00	0.000	-.05458	-.0419653
ffp	.0182786	.0039899	4.58	0.000	.0104585	.0260988
mem	-.0535978	.0132924	-4.03	0.000	-.0796505	-.0275452
markland	.0133752	.0023034	5.81	0.000	.0088607	.0178898

cannelton	.0781841	.0019225	40.67	0.000	.0744161	.0819521
newburgh	-.0112658	.0021868	-5.15	0.000	-.0155519	-.0069797
smithland	.0329053	.0028357	11.60	0.000	.0273474	.0384632
lock52	1.40379	.0090619	154.91	0.000	1.386029	1.421551
leneffbig	.0000744	.0000138	5.39	0.000	.0000473	.0001014
leneffsm	.0000123	3.03e-06	4.05	0.000	6.35e-06	.0000182
lift	.0063805	.0001186	53.78	0.000	.006148	.006613
wicket	-1.747492	.0082545	-211.70	0.000	-1.763671	-1.731313
wickdisch	-1.60e-06	2.28e-08	-70.26	0.000	-1.65e-06	-1.56e-06
lock52disch	-1.53e-06	2.00e-08	-76.41	0.000	-1.57e-06	-1.49e-06
chamb1part	-.0742691	.0157116	-4.73	0.000	-.1050633	-.0434748
chamb2part	.5065662	.0207989	24.36	0.000	.4658011	.5473313
decoupled	.7149842	.008175	87.46	0.000	.6989614	.7310069
_cons	4.269961	.1770495	24.12	0.000	3.92295	4.616973

Linear regression   Number of obs = 520330

Regression Table 18A   R-squared   = 0.2247

Root MSE   = 5.9669

	Robust				
a2s_ln	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]

year2002	.108599	.0379912	2.86	0.004	.0341374	.1830607
year2003	-.3316232	.037687	-8.80	0.000	-.4054884	-.257758
year2004	-.3587002	.0373928	-9.59	0.000	-.4319889	-.2854114
year2005	1.024868	.0385316	26.60	0.000	.9493474	1.100389
year2007	.8778528	.0385658	22.76	0.000	.802265	.9534407
year2008	.8660519	.0385347	22.47	0.000	.790525	.9415788
year2009	-.2919614	.0385915	-7.57	0.000	-.3675996	-.2163233
year2010	.7886552	.038931	20.26	0.000	.7123517	.8649587
year2011	.5696029	.0390945	14.57	0.000	.492979	.6462268
year2012	1.658228	.0430506	38.52	0.000	1.57385	1.742606
January	-.2822822	.042607	-6.63	0.000	-.3657905	-.1987739
February	-.2490208	.0424995	-5.86	0.000	-.3323184	-.1657232
March	-.4900009	.0429585	-11.41	0.000	-.5741982	-.4058035
April	-.3908304	.0422579	-9.25	0.000	-.4736545	-.3080062
May	-.5866784	.0420825	-13.94	0.000	-.6691588	-.5041981
June	-.3622069	.0409246	-8.85	0.000	-.4424177	-.281996
August	.4583049	.0425859	10.76	0.000	.3748379	.5417719
September	.5505471	.0422151	13.04	0.000	.4678068	.6332874
October	.3221855	.0437855	7.36	0.000	.2363674	.4080037
November	.2726558	.043795	6.23	0.000	.186819	.3584926
December	-.0836275	.0430809	-1.94	0.052	-.1680648	.0008097
discharge	-8.14e-06	1.53e-07	-53.15	0.000	-8.45e-06	-7.84e-06
disch2	1.53e-11	2.14e-13	71.54	0.000	1.49e-11	1.57e-11
dirdown	-.132734	.0165526	-8.02	0.000	-.1651766	-.1002914

tugboat	4.044796	.4444639	9.10	0.000	3.173661	4.915931
pushboat	4.511301	.442304	10.20	0.000	3.644399	5.378203
num_processed	.0585178	.0017235	33.95	0.000	.0551397	.0618958
draftldft	.0753383	.0106802	7.05	0.000	.0544054	.0962712
draftltft	.0301239	.0086436	3.49	0.000	.0131827	.0470652
tonnage	.0007772	.0000608	12.79	0.000	.000658	.0008963
clcc	.2442262	.0305651	7.99	0.000	.1843195	.3041329
ppp	.2077906	.0226515	9.17	0.000	.1633945	.2521868
crp	.1615619	.0284547	5.68	0.000	.1057916	.2173322
cmief	-.289217	.029012	-9.97	0.000	-.3460796	-.2323543
pmg	-.0053835	.030124	-0.18	0.858	-.0644256	.0536585
ffp	-.1681302	.0368455	-4.56	0.000	-.2403463	-.0959141
mem	-.1314327	.1096416	-1.20	0.231	-.3463267	.0834614
markland	.074741	.0477348	1.57	0.117	-.0188177	.1682996
cannelton	.0164915	.036196	0.46	0.649	-.0544514	.0874345
newburgh	-.3671394	.0392445	-9.36	0.000	-.4440573	-.2902215
smithland	-.7900336	.0436483	-18.10	0.000	-.8755829	-.7044842
lock52	5.898291	.0455902	129.38	0.000	5.808935	5.987646
leneffbig	-.005612	.000142	-39.53	0.000	-.0058902	-.0053337
leneffsm	-.0042677	.0000511	-83.47	0.000	-.0043679	-.0041675
lift	-.0471837	.0025384	-18.59	0.000	-.0521588	-.0422085
wicket	-4.252538	.0549904	-77.33	0.000	-4.360318	-4.144759
wickdisch	-8.55e-06	1.31e-07	-65.45	0.000	-8.81e-06	-8.30e-06
lock52disch	-9.33e-06	9.33e-08	-100.01	0.000	-9.51e-06	-9.15e-06
chamb1part	-.2082472	.0988152	-2.11	0.035	-.401922	-.0145725

chamb2part	4.41765	.1667196	26.50	0.000	4.090885	4.744415
decoupled	1.888122	.0938381	20.12	0.000	1.704202	2.072041
bargeout	-.022459	.0051172	-4.39	0.000	-.0324885	-.0124295
_cons	2.373068	.4908168	4.83	0.000	1.411082	3.335053

Linear regression   Number of obs = 517229

Regression Table 18B   R-squared   = 0.6857

Root MSE   = .61203

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s2e_ln	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
year2002	.1249742	.0035976	34.74	0.000	.117923	.1320254
year2003	.0574655	.0034849	16.49	0.000	.0506352	.0642957
year2004	.0213678	.0034434	6.21	0.000	.0146189	.0281168
year2005	.1898105	.0038534	49.26	0.000	.182258	.1973631
year2007	.186909	.0039153	47.74	0.000	.1792352	.1945828
year2008	.1334246	.0038781	34.40	0.000	.1258236	.1410255
year2009	-.0062909	.0039428	-1.60	0.111	-.0140187	.0014369
year2010	.0716861	.0041337	17.34	0.000	.0635843	.079788
year2011	-.0210156	.0042075	-4.99	0.000	-.0292621	-.012769
year2012	.2531191	.0048956	51.70	0.000	.2435239	.2627143

January	-.0378913	.0042916	-8.83	0.000	-.0463027	-.0294798
February	-.0729987	.0041874	-17.43	0.000	-.0812059	-.0647914
March	-.1008246	.0042509	-23.72	0.000	-.1091562	-.0924931
April	-.0951823	.0042695	-22.29	0.000	-.1035503	-.0868143
May	-.121601	.0042553	-28.58	0.000	-.1299413	-.1132607
June	-.0501505	.0042414	-11.82	0.000	-.0584635	-.0418374
August	.1179856	.004709	25.06	0.000	.1087562	.1272151
September	.0944166	.0045241	20.87	0.000	.0855496	.1032836
October	.079055	.0048778	16.21	0.000	.0694947	.0886152
November	.0543851	.0048879	11.13	0.000	.0448051	.0639652
December	-.0295412	.0044972	-6.57	0.000	-.0383556	-.0207269
discharge	-1.42e-06	1.90e-08	-74.87	0.000	-1.46e-06	-1.38e-06
disch2	2.69e-12	3.42e-14	78.61	0.000	2.62e-12	2.76e-12
dirdown	-.0930966	.0017009	-54.73	0.000	-.0964303	-.0897629
tugboat	.2945367	.100523	2.93	0.003	.0975148	.4915587
pushboat	.319343	.1004372	3.18	0.001	.1224893	.5161966
yearbuilt	-.0004912	.000071	-6.92	0.000	-.0006302	-.0003521
num_processed	.005991	.0002186	27.41	0.000	.0055625	.0064194
draftldft	.0189062	.0012034	15.71	0.000	.0165475	.0212649
draftltft	-.0102412	.0009557	-10.72	0.000	-.0121144	-.008368
tonnage	.0000446	8.36e-06	5.33	0.000	.0000282	.0000609
horsepower	4.92e-06	9.47e-07	5.19	0.000	3.06e-06	6.77e-06
clcc	.0122214	.0028317	4.32	0.000	.0066715	.0177714
ppp	.0032351	.0025763	1.26	0.209	-.0018143	.0082846
crp	.0136872	.0030549	4.48	0.000	.0076997	.0196748

cmief	-.0292581	.0030074	-9.73	0.000	-.0351525	-.0233638
pmg	-.0475903	.0032194	-14.78	0.000	-.0539003	-.0412804
ffp	.0197529	.0039885	4.95	0.000	.0119355	.0275702
mem	-.0502274	.0132758	-3.78	0.000	-.0762476	-.0242071
markland	.0451347	.0028514	15.83	0.000	.039546	.0507235
cannelton	.0912395	.0020539	44.42	0.000	.0872139	.095265
newburgh	-.0143799	.0021932	-6.56	0.000	-.0186786	-.0100812
smithland	.0190504	.0030425	6.26	0.000	.0130871	.0250136
lock52	1.404006	.0090652	154.88	0.000	1.386239	1.421774
leneffbig	.0001194	.000014	8.53	0.000	.0000919	.0001468
leneffsm	.0000474	3.92e-06	12.10	0.000	.0000397	.0000551
lift	.004517	.0001565	28.87	0.000	.0042103	.0048237
wicket	-1.759727	.0082902	-212.27	0.000	-1.775975	-1.743478
wickdisch	-1.60e-06	2.28e-08	-70.26	0.000	-1.65e-06	-1.56e-06
lock52disch	-1.53e-06	2.00e-08	-76.45	0.000	-1.57e-06	-1.49e-06
chamb1part	-.0664891	.0157837	-4.21	0.000	-.0974246	-.0355536
chamb2part	.5059333	.0207975	24.33	0.000	.4651709	.5466958
decoupled	.6828919	.0081929	83.35	0.000	.666834	.6989498
bargeout	.0064908	.0003507	18.51	0.000	.0058035	.0071782
_cons	4.220555	.1771616	23.82	0.000	3.873324	4.567787

Regression 19

Seemingly unrelated regression

```
----------------------------------------------------------------------
Equation          Obs  Parms        RMSE    "R-sq"       chi2        P
----------------------------------------------------------------------
a2s_ln        5.2e+05     51     5.96443    0.2250  120718.91   0.0000
s2e_ln        5.2e+05     53    .6119732    0.6858  912896.32   0.0000
----------------------------------------------------------------------


------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
a2s_ln       |
    year2002 |   .1110624   .0381576     2.91   0.004     .0362749    .1858499
    year2003 |  -.3298803   .0388773    -8.49   0.000    -.4060784   -.2536823
    year2004 |  -.3579883   .0385092    -9.30   0.000    -.4334649   -.2825117
    year2005 |   1.025538   .0374763    27.36   0.000     .9520858     1.09899
    year2007 |   .8775064   .0377906    23.22   0.000     .8034382    .9515746
    year2008 |   .8630476   .0379538    22.74   0.000     .7886596    .9374357
    year2009 |  -.2930291   .0392575    -7.46   0.000    -.3699723   -.2160858
    year2010 |   .7797058   .0387631    20.11   0.000     .7037315    .8556801
    year2011 |   .5607897     .03912    14.34   0.000     .4841159    .6374635
    year2012 |   1.666492   .0430994    38.67   0.000     1.582019    1.750966
     January |  -.2885173   .0426278    -6.77   0.000    -.3720663   -.2049683
    February |  -.2531831   .0431349    -5.87   0.000     -.337726   -.1686403
       March |  -.4925917   .0438235   -11.24   0.000     -.578484   -.4066993
```

April	-.3930135	.043004	-9.14	0.000	-.4772998	-.3087272
May	-.5878927	.0425706	-13.81	0.000	-.6713295	-.5044558
June	-.366258	.0409223	-8.95	0.000	-.4464642	-.2860518
August	.455864	.0405015	11.26	0.000	.3764825	.5352454
September	.5475589	.0405582	13.50	0.000	.4680664	.6270515
October	.3156126	.0411218	7.68	0.000	.2350154	.3962098
November	.2704976	.04174	6.48	0.000	.1886888	.3523065
December	-.085306	.0429502	-1.99	0.047	-.1694868	-.0011251
discharge	-8.14e-06	1.57e-07	-51.75	0.000	-8.45e-06	-7.84e-06
disch2	1.53e-11	2.18e-13	69.95	0.000	1.49e-11	1.57e-11
dirdown	-.1316265	.0165952	-7.93	0.000	-.1641525	-.0991004
tugboat	4.214196	.6025134	6.99	0.000	3.033291	5.3951
pushboat	4.746721	.6003513	7.91	0.000	3.570054	5.923388
num_processed	.0572428	.0018789	30.47	0.000	.0535603	.0609253
draftldft	.0731777	.0109833	6.66	0.000	.0516508	.0947046
draftltft	.0437059	.0089337	4.89	0.000	.0261962	.0612156
tonnage	.0007617	.0000617	12.34	0.000	.0006407	.0008826
clcc	.246967	.0300139	8.23	0.000	.1881407	.3057932
ppp	.2003768	.0233739	8.57	0.000	.1545647	.2461889
crp	.1648324	.0287652	5.73	0.000	.1084536	.2212112
cmief	-.2797095	.0289381	-9.67	0.000	-.3364272	-.2229919
pmg	-.0355337	.0305937	-1.16	0.245	-.0954964	.0244289
ffp	-.1576405	.0374261	-4.21	0.000	-.2309943	-.0842867
mem	-.121191	.1109373	-1.09	0.275	-.3386241	.0962421
markland	.0700765	.0442613	1.58	0.113	-.0166741	.1568271

cannelton	.0129542	.0331493	0.39	0.696	-.0520173	.0779256
newburgh	-.3806734	.0357803	-10.64	0.000	-.4508016	-.3105453
smithland	-.7945297	.040656	-19.54	0.000	-.8742141	-.7148454
lock52	5.901052	.0499873	118.05	0.000	5.803078	5.999025
leneffbig	-.005652	.0001424	-39.69	0.000	-.0059312	-.0053729
leneffsm	-.0042675	.0000471	-90.55	0.000	-.0043599	-.0041752
lift	-.04721	.0023662	-19.95	0.000	-.0518476	-.0425724
wicket	-4.254911	.0553366	-76.89	0.000	-4.363369	-4.146454
wickdisch	-8.55e-06	1.41e-07	-60.44	0.000	-8.82e-06	-8.27e-06
lock52disch	-9.33e-06	1.35e-07	-69.04	0.000	-9.60e-06	-9.07e-06
chamb1part	-.1987594	.0859598	-2.31	0.021	-.3672375	-.0302813
chamb2part	4.403109	.1395764	31.55	0.000	4.129545	4.676674
decoupled	1.876583	.0985595	19.04	0.000	1.68341	2.069756
bargeout	-.022973	.0047853	-4.80	0.000	-.0323521	-.0135939
_cons	2.121825	.6381206	3.33	0.001	.8711317	3.372519
s2e_ln						
year2002	.1249196	.0039158	31.90	0.000	.1172447	.1325945
year2003	.0574298	.0039892	14.40	0.000	.049611	.0652486
year2004	.021294	.0039512	5.39	0.000	.0135498	.0290382
year2005	.1897768	.0038453	49.35	0.000	.1822401	.1973134
year2007	.1868884	.0038776	48.20	0.000	.1792884	.1944883
year2008	.1334532	.0038957	34.26	0.000	.1258178	.1410886
year2009	-.0063106	.0040329	-1.56	0.118	-.0142149	.0015938
year2010	.0716871	.0039857	17.99	0.000	.0638753	.0794989

year2011	-.0209627	.0040283	-5.20	0.000	-.028858	-.0130674
year2012	.2529879	.004443	56.94	0.000	.2442798	.2616961
January	-.0378396	.0043744	-8.65	0.000	-.0464133	-.0292659
February	-.0730535	.0044261	-16.51	0.000	-.0817285	-.0643785
March	-.1008563	.0044966	-22.43	0.000	-.1096695	-.0920432
April	-.0951799	.0044125	-21.57	0.000	-.1038283	-.0865316
May	-.1216222	.004368	-27.84	0.000	-.1301834	-.1130611
June	-.0502944	.0041988	-11.98	0.000	-.0585239	-.0420649
August	.1181173	.0041557	28.42	0.000	.1099723	.1262622
September	.0945815	.0041615	22.73	0.000	.0864252	.1027378
October	.0791125	.0042194	18.75	0.000	.0708425	.0873825
November	.0543772	.0042829	12.70	0.000	.0459828	.0627715
December	-.0295558	.0044069	-6.71	0.000	-.0381931	-.0209185
discharge	-1.42e-06	1.61e-08	-87.82	0.000	-1.45e-06	-1.39e-06
disch2	2.69e-12	2.24e-14	120.00	0.000	2.65e-12	2.73e-12
dirdown	-.0931141	.0017028	-54.68	0.000	-.0964514	-.0897767
tugboat	.304793	.0634098	4.81	0.000	.1805121	.4290739
pushboat	.3302327	.0633251	5.21	0.000	.2061178	.4543475
yearbuilt	-.0005036	.0000676	-7.44	0.000	-.0006362	-.000371
num_processed	.0060505	.0002037	29.70	0.000	.0056511	.0064498
draftldft	.0190071	.0011409	16.66	0.000	.016771	.0212431
draftltft	-.0100893	.0009375	-10.76	0.000	-.0119267	-.008252
tonnage	.0000484	8.09e-06	5.99	0.000	.0000326	.0000643
horsepower	4.19e-06	9.01e-07	4.65	0.000	2.42e-06	5.95e-06
clcc	.0120095	.0031138	3.86	0.000	.0059065	.0181125

ppp	.0033214	.00243	1.37	0.172	-.0014414	.0080842
crp	.0136127	.0029638	4.59	0.000	.0078039	.0194216
cmief	-.0294422	.0029901	-9.85	0.000	-.0353027	-.0235816
pmg	-.0474887	.0031729	-14.97	0.000	-.0537074	-.0412699
ffp	.0202249	.0039227	5.16	0.000	.0125366	.0279132
mem	-.0503525	.0113905	-4.42	0.000	-.0726774	-.0280275
markland	.0452759	.0045437	9.96	0.000	.0363704	.0541814
cannelton	.0912726	.0034014	26.83	0.000	.0846059	.0979392
newburgh	-.0144262	.0036734	-3.93	0.000	-.021626	-.0072264
smithland	.0190867	.0041721	4.57	0.000	.0109095	.0272638
lock52	1.403959	.0051315	273.60	0.000	1.393902	1.414017
leneffbig	.0001193	.0000146	8.16	0.000	.0000906	.0001479
leneffsm	.0000474	4.84e-06	9.80	0.000	.0000379	.0000569
lift	.0045116	.0002429	18.57	0.000	.0040355	.0049877
wicket	-1.760034	.0056791	-309.91	0.000	-1.771164	-1.748903
wickdisch	-1.60e-06	1.45e-08	-110.25	0.000	-1.63e-06	-1.57e-06
lock52disch	-1.53e-06	1.39e-08	-110.32	0.000	-1.56e-06	-1.50e-06
chamb1part	-.0676497	.0088199	-7.67	0.000	-.0849364	-.0503629
chamb2part	.5059282	.0143211	35.33	0.000	.4778594	.533997
decoupled	.6828155	.0101149	67.51	0.000	.6629907	.7026402
bargeout	.0064949	.0004912	13.22	0.000	.0055322	.0074576
_cons	4.233282	.1521023	27.83	0.000	3.935167	4.531397

Correlation matrix of residuals:

	a2s_ln	s2e_ln
a2s_ln	1.0000	
s2e_ln	0.1786	1.0000

Breusch-Pagan test of independence: chi2(1) = 16488.085, Pr = 0.0000