FACTORS AFFECTING LOCK DELAY ON THE UPPER MISSISSIPPI AND ILLINOIS RIVERS AND EFFECT OF LOCK DELAY ON BARGE RATES

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Abstract: The upper Mississippi and Illinois Rivers are important arteries for transporting export-destined grains from the north central United States to lower Mississippi River ports. An aged lock and dam system on these rivers and an anticipated increase in traffic have generated concern about their future navigational efficiency. Concern centers on locks in the lower reaches of these rivers where tow/vessel delay is comparatively great. This study (1) identifies and measures forces that cause barge delay at selected locks, and (2) measures the effect of lock delay on barge rates. Results show lock stalls, traffic levels, and critical locks that impact delay at nearby locks are forces influencing delay. In addition, the analysis shows lock delay increases barge rates but the affect is not large.

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EXECUTIVE SUMMARY

An aged lock and dam system on the upper Mississippi and Illinois Rivers and an anticipated increase in traffic have generated concern about the future navigational efficiency of these transport arteries. The greatest concern is on locking capacity in the lower reaches of the upper Mississippi and Illinois Rivers where tows/vessels experience comparatively high levels of lock delay. The purpose of this study is to (1) identify and measure forces that cause barge delay at selected locks in the lower reaches of the upper Mississippi and Illinois Rivers, and (2) measure the effect of lock delay on grain barge rates. This study focuses on locks 18, 19, 20, 21, 22, 24, and 25 on the upper Mississippi River, and the Peoria and LaGrange locks on the Illinois River (Figure 1). This summary lists facts about grain transportation and lock performance characteristics on these two river systems and studies findings regarding the causes of lock delay, and the effect of lock delay on barge rates.

- Annually, about 70 percent of U.S. corn and soybean exports exit via lower Mississippi River ports. It is estimated that over 60 percent of the corn and 50 percent of the soybeans exported from lower Mississippi River ports originate on the upper Mississippi and Illinois Rivers, hence the importance of these waterways to U.S. grain exports.

- If a grain barge traveling from Minneapolis, Minnesota to St. Louis, Missouri on the upper Mississippi River were to be delayed at each lock it would experience an average of 58 hours of lock delay or wait time, with 55 percent delay experienced at locks 18 through 27. Of the vessels transiting locks 18 to 27, 40 to 60 percent are delayed.

- If a grain barge traveling from Chicago, Illinois to St. Louis, Missouri on the Illinois River were to be delayed at each lock it would experience an average of 27 hours of delay with 57 percent experienced at the Peoria lock through lock 27. About one-third of all vessels are delayed at the Peoria lock and about half at the LaGrange lock.

- Analysis shows lock stalls are an important cause of lock delay at locks in the lower reaches of the upper Mississippi and Illinois Rivers. In addition, lock delay is caused by comparatively high lock traffic levels, and by critical locks whose lock delay causes nearby locks to also experience delay. Estimated lock delay equations explained 24 to 81 percent of the variation in lock delay.

- Analysis shows lock delay to increase barge rates, however, the estimated rate equations show the effect is not large. A one percent increase in lock delay is estimated to increase barge rates from 0.016 to 0.059 percent.

- Analyses show that if a grain tow originating on the Minnesota portion of the upper Mississippi River were to incur delay at all locks in the lower reaches of the upper Mississippi River, at the Melvin Price lock and at lock 27, the expected barge rate would increase $1,005/barge which equals about $0.67/ton. Historically, the barge rate linking Minnesota to the lower Mississippi River ports has averaged about $11.20/ton, hence lock delay at the above locks would increase the linking barge rate by about 6 percent. Similarly, if a grain tow originating on the Illinois River were to incur delay at the LaGrange and Peoria locks as well as at Melvin Price and lock 27, the expected barge rate would increase $555/barge or $0.37/ton. The grain barge rate linking the Illinois River to lower Mississippi River ports has historically averaged about $7.50/ton, therefore, barge delay at the above locks would increase the linking grain barge rate about 5 percent.

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FACTORS AFFECTING LOCK DELAY ON THE UPPER MISSISSIPPI AND ILLINOIS RIVERS AND THE EFFECT OF LOCK DELAY ON BARGE RATES

The upper Mississippi and Illinois Rivers are important arteries for transporting export-destined grains from the north central United States to lower Mississippi River ports. Efficient barge transportation is important to maintain the competitiveness of this region in international markets since much of the region is more than 1,000 miles from the lower Mississippi River ports, the most active grain port area in the United States. An aged lock and dam system on the upper Mississippi and Illinois Rivers in combination with an anticipated increase in traffic have generated concern about the future navigational efficiency of these transport arteries. The greatest concern is lock capacity in the lower portions of the upper Mississippi and Illinois Rivers where comparatively high traffic congestion generates extended delays for barges/tows. This study attempts to (1) identify and measure factors that cause barge delay at selected locks on the upper Mississippi and Illinois Rivers, and (2) measure the effect of lock delay on grain barge rates. Analyses are carried out with directed acyclic graphs, a recently developed methodology, and multiple regression.

The upper Mississippi River is a 663-mile segment of the Mississippi River that extends from Minneapolis, Minnesota to its juncture with the Missouri River near St. Louis, Missouri. The Illinois River (349 mile waterway) extends from Chicago to Grafton, Illinois, where it empties into the upper Mississippi River (Figure 1). The upper Mississippi River includes twenty-eight lock sites located at 10 to 46 mile intervals while the Illinois River includes eight lock sites located at 5 to 78 mile intervals (Table 1). The average age of upper Mississippi River locks is 61 years, except for lock 19. Lock 19 and two locks on the middle Mississippi River (Melvin Price (lock 26) and lock 27) were opened in the 1950s and 1990s. These three locks have chambers that are 1,200 feet long while remaining lock chambers are 600 feet or less in length. Most chambers are 110 feet wide. The average age of locks on the Illinois River is 64 years with all lock chambers 110 x 600 feet, except one. A barge is typically 195 feet long and 35 feet wide, therefore, a 600 foot lock will accommodate, at most, eight jumbo barges (plus the towboat) in a single lockage while a 1,200 foot lock can accommodate up to 17 jumbo-barges plus the towboat. Since the number of barges in a tow typically exceeds eight, it becomes necessary to break (cut) tows in order to pass a lock chamber that is 600 feet in length (Figure 2). The break-up and reassembly of the tow (double lockage) plus the hardware operations take approximately one hour to ninety minutes at 600 foot locks while passage of towboat and barges at a 1,200 foot lock often require no more than 30 minutes (Fuller, et al., 1998). As a result, some advocate replacing the 600-foot locks with 1,200 foot locks in the lower reaches of the upper Mississippi and Illinois Rivers where barge delay is comparatively high. However, others suggest there are more efficient means of improving navigational efficiency on the upper Mississippi and Illinois Rivers than lock enlargement (Gervais, et al. 2001 and Turner-Lowe, 2001).

Annually, about 70 percent of U.S. corn and soybean exports exit via the lower Mississippi River port area. Although no precise estimates are available, it is thought that over 60 percent of the corn and 50 percent of the soybeans exported from lower Mississippi River ports originate on the upper Mississippi and Illinois Rivers, hence the importance of these waterways to U.S. grain exports. From 1996-1999, an estimated 6.5 million tons of corn and 3.9 million tons of soybeans annually entered lock pools on the Illinois River with about 75 percent of the total entering below LaSalle, Illinois (Table 2). Over the same time period, an estimated 14.4 million tons of corn and 4.9 million tons of soybeans annually entered lock pools comprising the upper Mississippi River : an estimated 40 percent of the corn and 30 percent of the soybeans entered the Minnesota portion of the upper Mississippi River while an additional 50 percent of the corn and soybeans entered via the Iowa segment (Table 2).

Since towboat costs are estimated at $300-$400/hour, it is thought that barge delay at congested locks increases the cost of barge transportation from the north central United States to lower Mississippi River ports. And, conceptually, the increased barging cost may translate into higher barge rates that ultimately lower regional grain prices. This study measures the effect of lock delay on barge rates.

In the background portion of this paper, the performance of locks on the lower reaches of the upper Mississippi and Illinois Rivers are examined. This is followed by a description of the methodology used to carry out the study objectives and a description of the data used in the analyses. Next, results are presented and discussed. Finally, a summary and conclusions are presented.

Background

Lock Performance

The performance of locks in the lower reaches of the upper Mississippi and Illinois Rivers is examined to gain greater perspective into barge delay. Several indicators of lock performance are presented, including tonnage handled, capacity utilization, barge delay, and the frequency and duration of lock stalls. A lock is stalled when it is not able to perform the locking activity: this may result from a variety of forces. Selected indicators of lock performance are examined for locks 18, 19, 20, 21, 22, 24, and 25 on the upper Mississippi River, and the Peoria and LaGrange locks on the Illinois River (Figure 1). Barge operators experience greatest delays at these nine locks when barging grain from the north central U.S. to lower Mississippi River ports.

Lock Tonnage

Figure 3 is a plot of farm product and total traffic on the upper Mississippi River from 1980-1999 as reported by the U.S. Army Corps of Engineers. A modest upward trend in farm product and total traffic is exhibited over this period. The total annual traffic on the upper

Mississippi River averages about 80 million tons in recent years with farm products accounting for 45 million tons. It is estimated that grain comprises nearly 90 percent of the farm product.

The annual traffic at selected locks in the lower reaches of the upper Mississippi River is summarized in Figure 4 and Table 3. They show that lock traffic becomes increasingly heavy at locks in the lower portion of the river. For example, the average annual tonnage passing lock 18 was 29.80 million tons over the 1980-1999 period, while at locks 19, 20, 21, 22, 24, and 25 the annual average tonnage was 31.07, 31.76, 32.92, 33.46, 34.71, and 34.75 million tons, respectively (Table 3). Lock traffic levels were lowest in 1993, which was due to floods in the Midwest, while the highest traffic volumes were in 1990 (Figure 4).

Figure 5 offers information on monthly average quantities locked through the seven evaluated locks on the lower portion of the upper Mississippi River during 1980-1999. Because much of the upper Mississippi River is impassable during the winter season, little traffic moves in these months. Traffic significantly increases in March/April and remains comparatively constant until November when tonnage precipitously declines. The height of the shipping season is from May to November, and the monthly average tonnage is greatest in August and November; least in June and September.

Figure 6 is a plot of farm product and total traffic on the Illinois River from 1980-1999. Annual total traffic has increased since the mid-1980s averaging about 46 million tons in recent years while farm product traffic has been comparatively static at near 20 million tons.

The Illinois River's LaGrange lock is located approximately 80 river miles above the Illinois River's confluence with the upper Mississippi River while the Peoria lock is located at the 158 river mile marker (Figure 1, Table 1). From 1980-1999, the Peoria lock annually handled an average of 31.04 million tons while the LaGrange lock handled 33.56 million tons per year (Table 4). The standard deviation associated with annual tonnage handled at each of these two locks is comparatively small (2.5 to 2.7 million tons) indicating tonnage handled by these locks has varied modestly. Annual tonnage locked through the Peoria and LaGrange locks decreased during the 1980-1985 period then increased through 1999 (Figure 7). In contrast to the upper Mississippi River, the Illinois River is typically navigable throughout the year. From 1980-1999, monthly average quantities locked by the Peoria and LaGrange locks peaked in December at about 3.5 and 4.0 million tons, respectively, while monthly tonnage was lowest in August/September at 2.4 to 2.5 million tons (Figure 8).

Lock Utilization

Lock capacity utilization was estimated by dividing annual lock traffic by an estimate of annual lock capacity. The lock capacity estimate is a measure of the maximum tonnage of cargo that can transit a lock in a given time period under specified assumptions. This study uses annual lock capacity estimates developed by the U.S. Army Corps of Engineers (Corps) to generate the capacity utilization percentages presented in Table 5. During 1980-1999, lock 22 had the highest average capacity utilization level at 78 percent and lock 19 had the lowest at 41 percent. At lock 22, annual capacity utilization topped 80 percent for 10 of the

20 years. At locks 18, 24, and 25, annual capacity utilization ranged from 60 to 79 percent for more than 10 of the 20 years. Lock 19's comparatively low capacity utilization is most likely the result of its 1,200-foot lock chamber. All other evaluated locks (locks 18, 20, 21, 22, 24, and 25) on the upper Mississippi River have 600-foot lock chambers.

Lock capacity at Illinois River's Peoria and LaGrange locks was utilized at about a 50 percent rate from 1980-1999 (Table 6). The annual utilization rate exceeded 60 percent at the LaGrange lock for one year, whereas during the remaining portion of the study period, the annual utilization rate ranged from 40 to 59 percent. The Peoria lock was utilized at an average rate of 40 to 59 percent over the twenty-year study period. In general, lock capacity utilization levels were comparatively high at locks in the lower reaches of the upper Mississippi River relative to the lower portion of the Illinois River (Tables 5 and 6).

Lock Stalls

A lock stalls when it is unable to perform the locking activity. The Corps identifies five reasons for stalls. They include weather, surface conditions, lock conditions, tow conditions, and other conditions. Weather and surface conditions include fog, rain, snow, wind, ice, river current, flood, and drought as well as other unplanned and natural phenomena. Most of those conditions do not involve personnel or management factors, while three conditions (lock, tow, and other conditions) may be related to management and personnel issues. Lock conditions include factors such as debris in the lock chamber or lock recesses, lock hardware malfunction, lock maintenance or tests, and inadequate staff to efficiently manage various conditions. Tow-related stalls include tow breakdowns, obstructions from other vessels and no tow boat pilots. Other conditions represent any other factor that causes lock operations to cease such as, detainment of tow by Coast Guard or an accident.

The frequency and duration of stalls may affect tow/barge delay. The frequency of stalls is the number of stalls per unit of time, while the duration of stalls measures the length of time a lock is non-operational. Table 7 shows the frequency of stalls for the seven locks examined on the upper Mississippi River. Data that was obtained did not specify the reasons for the stalls. At lock 18, the frequency of stalls averaged about 45/year while remaining locks averaged about 60 or more stalls per year except lock 21, which averaged 53 stalls per year. In selected years, locks 19, 20, 22, 24, and 25 incurred 100 stalls/year or more. Over the 20-year study period, lock 25 had the most stalls (1,348) and lock 18 had the least (910). The total duration of stalls (hours) per shipping season is presented in Table 8. On the upper Mississippi River, the shipping season does not include the winter months. The duration of stalls at lock 18 averaged about 175 hours/season, the least of any examined lock, whereas the greatest duration of delay was at lock 25 which averaged 460 hours/season from 1980-1999 (Table 8).

The Illinois Rivers' LaGrange lock incurred an average of 42 stalls per year during 1980-1999, while the Peoria lock experienced 57 stalls per year (Table 9). During the twenty-year study period, there were three years when annual stalls of 100 or more were experienced at the Peoria lock. At the LaGrange lock, only one year had more than 100 stalls. The annual duration of stalls at the LaGrange lock averaged 161 hours, whereas the average stall period at the Peoria lock was 120 hours per year (Table 9). Interestingly, the annual duration of stalls at locks in the lower portion of the Illinois River was considerably shorter than those in the lower portion of the upper Mississippi River (Tables 8 and 9). This is unexpected since the shipping season is about three months shorter on the upper Mississippi River.

Lock Delay

Tow or vessel delay (wait time) at a lock is defined as the time elapsed from the arrival of a tow or vessel at a lock to the start of its approach to a lock chamber. Delay measures any waiting time experienced while other tows or vessels are being processed and/or delays otherwise attributed to lock unavailability. Unavailable time occurs when locks are not in operation, i.e., a stall has occurred. The weighted average annual delay time associated with delayed vessels at the seven locks on the upper Mississippi River between 1980-1999 are shown in Table 10. Lock 22 had the largest delay time at 5.19 hours per delayed vessel, while lock 19 had the least waiting time, 1.68 hours per delayed vessel. The remaining five locks incurred average delay of 2.75 to 4.45 hours per delayed vessel over the 20-year study period. Locks 22 and 24 experienced at least 4 hours of average delay for more than 10 of the 20 years and no years when average annual delays were less than 2 hours.

Figures 9 through 15 show plots of annual average delay for delayed vessels at each of the seven locks on the upper Mississippi River during 1980-1999. An upward trend in delay at lock 25 is exhibited, however, no obvious trend is associated with the remaining six locks. The percent of vessels delayed, generated by dividing the number of delayed vessels by the overall number of vessels passing a specific lock, is presented in Figure 16 and Table 11. There is no obvious trend regarding the percent of vessels that were delayed through time (Figure 16). The percent of vessels that were delayed ranged from 40 to 60 percent at the seven locks on the upper Mississippi River (Table 11). There were two years in which more than 80 percent of the passing vessels experienced delay at lock 24. In general, at each evaluated lock on the upper Mississippi River, 40 to 59 percent of vessels experienced delay for 10 to 15 years of the 20-year study period.

The average delay for delayed vessels/tows locking at the Illinois River's LaGrange and Peoria locks were 3.96 and 3.28 hours, respectively, over the 20-year study period (Table 12). Delayed vessels passing the LaGrange lock experienced average delay ranging from 4.23 to 10.44 hours in eight of the 20 years, while average delay at the Peoria lock exceeded four hours per delayed vessel/tow in only four years. On average, about 50 percent of the vessels passing the LaGrange lock were delayed during the study period while one-third of the vessels passing the Peoria lock were delayed during the same study period (Table 12). A plot of average annual delay of delayed vessels over the 20-year study period suggested no obvious trend for either lock, however, the percent of vessels that were delayed declined at both the LaGrange and Peoria locks (Figures 17 and 18).

Factors Influencing Lock Delay

Lock delay occurs when one or more tows/vessels have queued to await lockage. When the rate at which traffic entering a lock's pool exceeds the lock's service rate, the queue of vessels or tows that require locking increases as does barge delay. Hence, factors reflecting a lock's traffic level, such as tonnage locked, number of loaded and empty barges locked, number of commercial lockages, or number of hardware operations are candidates to influence lock delay. In the summer season, increased numbers of recreational vessels may compete with commercial navigation for lockage capacity on the upper Mississippi River and Illinois Rivers. Since recreational crafts usually require separate lockages due to their relatively fragile body, they increase the number of lock operations and, therefore, may increase lock delays. An increase in the frequency of lock stalls as well as an extended duration of stalls may also contribute to barge delay since the lock's effective lockage rate is reduced.

Effect of Lock Delay on Barge Rates

Some argue that lock delays on the upper Mississippi and Illinois Rivers unfavorably influence barge rates on these transport arteries which subsequently lowers grain prices in the north central region. Estimated towboat costs range from $300-$400 per hour, and as tow/vessel delay at selected locks increase, the cost of barging grain on these waterways is expected to increase correspondingly. It is argued that increased barge costs unfavorably affect regional grain prices. Intuitively, the greater the accumulated lock delay that a tow experiences on a segment of the upper Mississippi or Illinois Rivers, the higher the barge operator's cost and ultimately the higher the barge rate.

Methodology

A newly developed methodology referred to as directed acyclic graphs is employed to (1) identify forces which cause or influence barge delay at selected upper Mississippi and Illinois River locks and (2) evaluate whether barge delay is a partial cause of grain barge rates. After identification of causal forces influencing lock delay and grain barge rates, explanatory equations will be specified and estimated with ordinary least squares. Directed graphs methodology emanates from the field of artificial intelligence and computer science. A directed graph is a picture representing causal flows among variables that have been suggested by prior study or theory to be related. Sprites et al. (1993) developed a PC algorithm to infer causal relations from observational data. The following paragraphs describing the PC algorithm are taken from Bessler (2001).

> "The PC algorithm is an ordered set of commands beginning with a general unrestricted set of relationships among variables which proceeds step-wise to remove edges between variables and to direct "causal flow." Edge removal and direction of causal flow are based on independence or conditional

independence as represented by zero correlation or partial correlation. Basically, one forms the complete undirected graph G on the variable set **V**. The complete undirected graph shows an undirected edge between every variable of the system (every variable in **V)**. Edges between variables are removed based on zero correlation or partial correlation (condition/correlation). The conditioning variable(s) on removed edges between two variables is called the sepset of the variables whose edge has been removed (for vanishing zero-order-conditioning information the sepset is the empty set). Edges are directed by considering triples X – Y – Z, such that X and Y are adjacent, as the Y and Z, but X and Z are not adjacent. Direct edges between triples X – Y – Z as X→Y←Z if Y is not in the sepset of X and Z. If X→Y, Y and Z are adjacent, X and Z are not adjacent, and there is no arrowhead at Y, then orient Y - Z as Y→Z. If there is a directed path from X to Y and an edge between X and Y, then orient X – Y as X→Y.

Fisher's z is used to test whether conditional correlations are significantly different from zero, where

$$z[\rho(i, j|k)n] = ½(n - |k| - 3)^{1/2} \times \ln[|1+ \rho(i, j|k)| \times (|1 - \rho(i, j|k)^{-1}]$$

and, n is the number of observations, $\rho(i, j|k)$ is the population correlation between series i and j conditional on series k, and $|k|$ is the number of variables in k (that we condition on). If i, j, and k are normally distributed and $r(i, j|k)$ is the sample conditional correlation of i and j given k, then the distribution of $z[\rho(i, j|k)n] - z[r(i, j|k)n]$ is standard normal. The software TETRAD III is developed to process the PC algorithm and its extensions."

The directed graph methodology is superior to "Granger" causality for purposes of carrying out this study. Granger causality is limited to forecasting a variable based on the past information of itself and other variables. As an example, Granger causality would be appropriate to estimate a VAR(1) model that can be written as: $x_{t1} = a_{11} + a_{12}\, x_{t-1,1} + a_{13}\, x_{t-1,2} + e_{t1}$. However, Granger causality is not appropriate when the dependent variable and the independent variables have a contemporaneous relationship. In contrast, the directed graph methodology applies in both contemporaneous and lagged relationships (see Akleman et al) (1998). In this study, a contemporaneous relationship may exist among the various forces being evaluated. In addition, Griffiths, et al. (1993) states "Granger's concept of causality does not imply a cause-effect relationship, but rather is based only on "predictability." The directed graph method, as mentioned above, uses artificial intelligence and computer technology to proceed in a step-wise comparison so as to remove edges between variables and to direct "causal flow."

In this study, directed graph methodology is used to identify factors affecting delay at the seven locks on the lower portion of the upper Mississippi River and the two evaluated locks on the Illinois River. In addition, directed graphs are used to determine whether lock delay has an affect on grain barge rates. Based on the directed graph analyses, equations that explain lock delay and barge rates are specified and estimated with ordinary least squares.

Data

To identify forces that cause lock delay, directed graph analysis is performed on monthly data obtained from the Corp's Lock Performance Monitoring System (LPMS) data set. Evaluated in these analyses are numbers of loaded barges, unloaded barges, commercial lockages, hardware operations, tons locked, and recreational vessels. Also included in the analyses are season when shipment occurred, delay at nearby locks, frequency of stalls, and the average and total duration of stalls.

To determine the effect of lock delay on barge rates, accumulated lock delay for locks on selected segments of the upper Mississippi and Illinois Rivers were obtained from the LPMS data set. Monthly delay associated with locks located on various river segments were aggregated and included in the analysis. For analyses of the upper Mississippi River, the following segments were included: (1) lock 1 to lock 8 (L1-L8), (2) lock 9 to lock 17 (L9-L17), and (3) lock 18 to lock 27 (L18-L27) (Figure 1). For the Illinois River, the following segments were included: (1) Thomas O'Brien lock to Starved Rock lock (TOB-SR), (2) Peoria lock to LaGrange lock (PEO-LA), and (3) lock 26 (Melvin Price) to lock 27 (L26-L27) (Figure 1). See Table 13 for descriptive statistics on average accumulated delay for vessels traversing various river segments. Monthly grain barge rates were obtained for the following river sites: (1) south Minnesota (BRSM) and (2) north Iowa (BRNI) for grain shipments on the upper Mississippi River and (3) south of Peoria (BRSP) for Illinois River grain shipments. South Minnesota includes the St. Paul, Minnesota to McGregor, Iowa segment of the upper Mississippi River while north Iowa includes the segment extending from McGregor, Iowa to Clinton, Iowa (Table 13). Monthly rates are not evaluated during the winter season (December, January, and February) on the upper Mississippi River nor in July 1993 due to flooding, whereas rates on the Illinois River are generally available year-round. Hence, a total of 179 monthly barge rates were collected for each segment of upper Mississippi River while 240 monthly barge rates were obtained for Illinois River segments. Barge rates were from the Agricultural Marketing Service (AMS) of the U.S. Department of Agriculture. They collect spot barge rates from Midwest barge companies (or brokers). The spot rate is the current barge rate for shipping grain from river origins to export facilities located on the lower Mississippi River. The spot rate does not reflect any discounts, promotions, or contracted services (Marathon).

Results

The results section initially focuses on lock delay; in particular, identification of forces that appear to cause delay and estimated equations designed to explain lock delay. This is followed by an investigation into the effect of lock delay on barge rates. Results of the directed graph analysis are shown, as are estimated equations that relate the effect of delay on barge rates.

Results of the directed graph analysis are initially presented, followed by the estimated equations that attempt to explain the delay at each evaluated lock.

Factors Affecting Lock Delay

Directed graphs identifying forces causing lock delay at locks 18,19, 20, 21, 22, 24, and 25 on the upper Mississippi River are presented in Figures 19-25. Figures 26 and 27 feature directed graphs identifying factors causing delay at the Peoria and LaGrange locks. Table 14 identifies the variables included in the directed graph analyses, and the abbreviations for variables displayed in the directed graphs and estimated equations. Since the number of observations on each upper Mississippi River lock is comparatively large (213 to 235), the 5 percent significance level was used to select the displayed directed graph results.

Causality in a directed graph is revealed by the direction of the arrow connecting two nodes. Figure 19 shows the directed graph for lock 18. Note in Figure 19 that the node identified as x1 (ADELDV) represents average monthly delay of delayed vessels at lock 18, and nodes x7 (NUMUN) and x16 (L21) are connected to x1 by arrows that point toward x1. Hence, delay of delayed vessels at lock 18 (x1) is caused by frequency of stalls at lock 18 (x7), and delay at lock 21 (x16), a nearby lock. The simple correlation matrix shown in the appendix for lock 18 relates whether a negative or positive relationship exists between variables connected by the arrows. For lock 18, a positive relationship exists between delay, frequency of stalls, and delay at lock 21. Therefore, an increased frequency of stalls at L18 causes an increase in delay at lock 18. Furthermore, an increase in delay at lock 21 (Figure 19) causes delay at lock 18.

Lock 19 is a 1,200-foot lock that does not have serious delay problems. Empty barge traffic (x3), total duration of stalls (x9), and delay at lock 21 (x16) causes delay at lock 19 (Figure 20). The simple correlation presented in the appendix shows a negative relationship between delay and empty barge traffic at lock 19, an unexpected sign on this relationship. A positive relationship exists between lock delay at lock 19 and total duration of its stalls and delay at lock 21. In addition, empty barges (x3) were found to cause commercial lockages (x4) and tonnage passing lock 19 in the spring season, whereas winter tonnage (x13) caused empty barges (x3) (Figure 20). None of the evaluated variables cause delay at locks 20 and 21 (Figures 21 and 22).

The delay at lock 22 is caused by the average duration of stalls at lock 22 (x8) and delay at locks 21 (x17) and 24 (x18) (Figure 23). An increase in any of these forces will increase delay at lock 22. For lock 24, total hardware operations (x6), frequency of stalls (x7), total duration of stalls (x9) at lock 24, and delay at lock 25 (x19) cause delay (Figure 24). Hardware operations are closely related to traffic levels since they are related to commercial lockages (x4) and loaded barges (x2) (Figure 24). Loaded barge traffic (x2) and total duration of stalls (x9) cause delay at lock 25 (Figure 25). The delay at locks 26 (Melvin

Price) (x20) and 27 (x21) do not cause delay at lock 25, however, delay at lock 25 causes delay at lock 24.

The directed graphs for the Peoria and LaGrange locks on the Illinois River are presented in Figures 26 and 27, respectively. The sample size of both lock data series was comparatively large (240), therefore, the 5 percent significance level was selected.

At the Peoria lock, frequency of its stalls (x7) and average duration of stalls (x8) were the major factors causing delay (Figure 26). In addition, an association was found between delay at the Peoria and LaGrange locks, however, no causality was assigned. Causality was identified between delay at the Peoria lock and tonnage in the winter season (x13), however, the direction of causality could not be determined. The Illinois River is generally accessible the entire year, whereas the upper Mississippi River is closed during the winter. Possibly the closure of the upper Mississippi River during the winter generates the heightened traffic levels on the Illinois River during this season which affects delay at the Peoria lock (Figure 8).

The LaGrange lock's delay is caused by its empty barge traffic (x3) and frequency of its stalls (x7) (Figure 27). Thus, an increase in the number of empty barges transiting the lock and an increase in the frequency of stalls causes an increase in delay. In addition, delay at the LaGrange lock caused delay at the Starved Rock lock (x14) and there was an association between delay at the LaGrange and Peoria locks (x15), but no causality was identified.

In summary, the directed graph analyses show that stalls are an important cause of delay. In particular, either the frequency of stalls, average duration of stalls, or total duration of stalls had a role in causing lock delay at seven of the nine evaluated locks. Traffic levels, as measured by empty barges, loaded barges, and hardware operations caused delay at four of the nine locks. The traffic level variables included in the analysis were loaded barges, unloaded or empty barges, commercial lockages, total hardware operations, and recreational vessels. All traffic level variables were highly correlated. Further, delay at locks 18, 19, 22, and 24 were partially caused by delay at nearby locks. In particular, delay at lock 21 appeared to cause delay at three other upper Mississippi River locks (locks 18, 19, and 22). Interestingly, lock 21 had the greatest number of stalls per year of any evaluated lock. In addition, delay at lock 25, the lock with the longest average duration of stalls, caused delay at lock 24, and delay at lock 24 caused delay at lock 22. And on the Illinois River, delay at the LaGrange lock caused delay at the Starved Rock lock.

Selected barge companies operating on the upper Mississippi and Illinois Rivers were contacted to explain how delay at one lock could cause delay at a nearby lock. The most feasible explanation centered on the occurrence of stalls. In particular, once a stall has occurred at a lock, this information is transmitted to other tow operators on the affected segment of the river. Since fleeting capacity in the affected lock's pool may be limited or because the barge company has no fleeting capacity in the affected pool, tow operators may fleet in a nearby lock. Thus, stalls at a particular lock may increase fleeting in a nearby lock's pool. Once the stall at the affected lock has been remedied and traffic commences, the delay time at nearby locks may increase as a result of the accumulated traffic that must be locked. Hence, a stall and associated barge delay at a particular lock may cause an increase in delay at a nearby lock.

Estimated Equations Explaining Lock Delay

Based on the findings from the directed graph analyses, equations are specified and estimated that explain delay at five upper Mississippi River locks and two Illinois River locks. The dependent variable in each estimated equation is monthly average delay (hours) while the explanatory variables are those forces that were identified by the direct graph methodology as causing delay. Equations are not estimated for locks 20 and 21 on the upper Mississippi River since no factors causing their delay could be identified in the LPMS data set.

A statistical description of all variables included in the estimated equations is presented in Table 15. Monthly average delay times of delayed vessels presented in Table 15 differ somewhat from the estimated annual average values in Tables 10 and 12 because the values in these two tables are simple averages of the annual estimates, whereas, the values in Table 15 are monthly averages. Twenty years (1980-1999) of monthly data are included in each equation except for selected months when upper Mississippi River locks were closed for winter, repair, or flooding.

The estimated delay equations for each lock and the associated statistics are presented in Table 16. The seven estimated equations explain 24 to 81 percent (Adjusted R-Square) of the variation in lock delay times and all explanatory variables are significant at the 5 percent level (t-ratio >2). The Durbin-Watson statistic indicates no serial correlation in any equation except for lock 25 where the test was inconclusive regarding presence of serial correlation.

The estimated delay equation for lock 18 explains about 24 percent of the monthly variation in lock delay (Adjusted R-Square). The estimated coefficient associated with the frequency of stalls variable (NUMUN) is 0.146 and the coefficient associated with delay time at lock 21 (L21) is 0.614. The estimated coefficient on the frequency of stalls variable, 0.146, indicates that one additional stall per month will increase vessel delay 0.146 hours, or 8.76 minutes. One additional hour of delay at lock 21 will add 0.614 hours or 37 minutes to the average waiting time of delayed vessels at lock 18. The estimated elasticity associated with the lock 21 variable (L21) is 0.61: this indicates that a one percent increase in delay time at lock 21 will increase the delay time at lock 18 about 0.61 percent. The elasticity associated with the frequency of stalls variable (NUMUN) is 0.23, which indicates that a one percent increase in the frequency of stalls will increase delay time at lock 18 by 0.23 percent.

Lock 19’s estimated delay equation includes unloaded barge traffic (BRGU), total duration of stalls (TOTUN), and delay at lock 21(L21) as explanatory variables (Table 16). Delay at lock 21 (L21) (t-ratio 12.51) significantly explains the delay at lock 19 with an estimated coefficient of 0.075. This indicates that one additional hour of delay at lock 21 (L21) will increase delay of delayed vessels at lock 19 by 0.075 hours, or 4.5 minutes. The estimated elasticity for the L21 variable is 0.20, indicating that a one percent increase in delay time at lock 21 will increase the delay at lock 19 by 0.20 percent. The elasticity associated with total duration of stalls variable (TOTUN) is 0.13, indicating that a one percent increase in the duration of stalls will increase delay at lock 19 by 0.13 percent. The negative sign on the unloaded barge traffic variable (BRGU) is unexpected since it suggests an increasing level of unloaded barges will decrease lock delay. Possibly the negative sign is explained by the fact that unloaded barge movements occur when there is generally less traffic as well as less delay.

At lock 22, average duration of stalls (AVGUN) and delay at locks 21 (L21) and 24 (L24) explain about 80 percent of the variation in vessel delay (Table 16). The estimated coefficient on the AVGUN variable, 0.002, indicates that a one minute increase in the average duration of stalls will increase delay by 0.002 hours at lock 22. An increase in delay of one hour at lock 21(L21) will increase vessel delay by 0.13 hours at lock 22. The large t-ratio (28.58) associated with the L21 variable indicates the statistical importance of this force. An additional hour of vessel delay at lock 24 will increase delay at lock 22 by 0.23 hours.

Delay at lock 24 was positively affected by total hardware operations (TOTOP), frequency of stalls (NUMUN), total duration of stalls (TOTUN), and delay at lock 25 (L25) (Table 16). If total hardware operations (TOTOP) increase by one, estimated delay at lock 24 will increase 0.0025 hours, and a one percent increase in total hardware operation (TOTOP) will increase vessel delay at lock 24 by 0.58 percent. A one percent increase in frequency (NUMUN) and duration of stalls (TOTUN) is estimated to increase the delay at lock 24 by 0.193 and 0.126 percent, respectively. And, a one percent increase in vessel delay at lock 25 (L25) will increase delay at lock 24 by 0.216 percent.

The number of loaded barges transiting the lock (BRGL) and the total duration of stalls (TOTUN) explain about 25 percent of the variation (Adjusted R-square) in vessel delay at lock 25 (Table 16). The estimated coefficient on the loaded barges (BRGL) variable is 0.0013, indicating that an additional loaded barge transiting lock 25 will increase delay time 0.0013 hours. The estimated elasticity associated with the BRGL variable indicates that a one percent increase in loaded barges will increase average vessel delay time by 0.873 percent at lock 25. The total duration of stalls (TOTUN) has a comparatively small impact on delay with an elasticity of 0.133.

The Peoria lock's vessel delay equation includes duration of stalls (AVGUN), frequency of stalls (NUMUN), and delay time at the LaGrange lock (LAGRANGE) as explanatory variables (Table 16). The estimated equation explains about 36 percent of the variation (Adjusted R-Square) in delay time. The estimated frequency of stalls (NUMUN) parameter is 0.329. Thus, if the number of stalls per month were to increase by one, delay at the Peoria lock would increase by 0.329 hours or 19.74 minutes. The estimated elasticity associated with the NUMUN variable is 0.534, indicating that a one percent increase in frequency of stalls will increase delay at the Peoria lock by 0.53 percent. The elasticity associated with delay at the LaGrange lock (LAGRANGE) is comparatively high indicating that a one percent increase in delay at the LaGrange lock will increase delay at the Peoria lock by 0.256 percent.

Delay times at the LaGrange lock are positively related to empty barge traffic (BRGU), frequency of stalls (NUMUN), and delay at the Peoria lock (PEORIA) (Table 16). The coefficient associated with delay at the Peoria lock (PEORIA) is 0.366: this parameter indicates that an additional hour of delay at the Peoria lock will increase delay at the LaGrange lock by 0.366 hours or 21.96 minutes. The estimated elasticity associated with the BRGU variable is comparatively high indicating that a one percent increase in empty barges transiting the LaGrange lock will increase delay by 0.812 percent. The frequency of stalls at the LaGrange lock also increases its delay time, in particular, a one percent increase in stalls will increase delay by 0.32 percent. The LaGrange lock equation explains 29 percent of the variation in lock delay and all included variables are statistically significant at the 5 percent level.

In summary, stalls had a statistically important and unfavorable influence on delay in each of the seven estimated delay equations (Table 16). However, the influence of stalls on lock delay time varied widely as measured by the calculated elasticity values. For example, at lock 24, a one percent increase in the duration of stalls will increase delay time by 0.58 percent, whereas at lock 22, a one percent increase in the average duration of the stall will increase delay a comparatively modest 0.12 percent. In six of the estimated lock equations, delay at nearby locks unfavorably influences delay at the lock in question. Locks 21, 24, 25, Peoria, and LaGrange had an unfavorable affect on delay at adjacent or nearby locks. Their associated elasticity values ranged from 0.13 to 0.61. Traffic levels had an unfavorable impact on delay at locks 24, 25, and the LaGrange lock, where elasticity values were comparatively large ranging from 0.58 to 0.87. Although the explanatory power of the identified variables is limited in the estimated equations, they provide insight regarding the association between lock delay and various forces in the LPMS data set. If additional information were available on the source of stalls, it would be possible to make more definitive statements about factors influencing stalls. That is, if factors such as weather, surface conditions, or lock and tow conditions were identified as the source of stalls, more insightful analyses could be carried out.

Lock Delay and Barge Rates

Directed acyclic graph methods are used to determine if barge delay at locks on selected segments of the upper Mississippi and Illinois Rivers affect barge rates. Based on causality revealed by the directed graph analysis, regression methods are used to estimate specified equations that relate the effect of lock delay on barge rates.

Lock Delay and Barge Rates

Directed graph methodology is used to determine if the southern Minnesota barge rate (BRSM) is caused by accumulated monthly lock delay on three segments of the Mississippi River. The three segments are: (1) lock 1 to lock 8 (L1-L8), (2) lock 9 to lock 17 (L9-L17), and (3) lock 18 to lock 27 (L18-L27). The effect of accumulated barge delay at locks 9 to 17 (L9-L17) and locks 18 through 27 (L18-L27) on the north Iowa barge rate (BRNI) is also evaluated. In addition, the effect of accumulated lock delay at: (1) Thomas O’Brien lock to

Starved Rock lock (TOB-SR), (2) Peoria lock to LaGrange lock (PEO-LA), and (3) lock 26 to lock 27 (L26-L27) on the south of Peoria barge rate (BRSP) is evaluated. All rates link designated river segments to lower Mississippi River ports. A one and two period lag of barge rates is included in the analysis to prevent overestimating the contemporaneous impact of lock delay on the upper Mississippi River barge rates (south Minnesota and north Iowa rates). The Schwarz test showed the optimum length of lag was two time periods for both upper Mississippi River rates, whereas, a one period lag was appropriate for the south of Peoria rate, an Illinois River rate. When accumulated lock delay on a selected river segment was found to cause a particular barge rate, additional directed graph analysis was carried out to determine which particular lock or set of locks in the river segment caused the observed barge rate. Hence, two regressions were estimated for each of three barge rates: one equation included accumulated lock delay on selected river segments, while the second equation included selected locks in the segment as explanatory variables.

The directed graph analysis shows that accumulated monthly lock delay at lock 18 to lock 27 (L18-L27) in combination with the lagged south Minnesota barge rates (LBRSM, LLBRSM) cause the barge rates that link the south Minnesota portion of the upper Mississippi River to lower Mississippi River ports (Figure 28a, Table 17). Hence, lock delay in the most congested portion of the upper Mississippi River partially causes the south Minnesota barge rate. Monthly delay at each lock in the river segment extending from lock 18 through lock 27 is subsequently included in the directed graph analysis to isolate those locks which impact barge rates. These results show that delay at lock 25 (L25) affects the south Minnesota barge rate at the 10 percent significance level, and delay at lock 22 (L22) impacts the south Minnesota barge rate at the 20 percent level of significance (Figure 28b, Table 17).

North Iowa barge rates are also caused by accumulated lock delay at lock 18 through lock 27 (L18-L27) and the north Iowa barge rate lagged one (LBRNI) and two (LLBRNI) time periods at the 20 percent level of significance (Figure 29a, Table 17). Additional directed graph analysis that examines delay at each lock in the river segment extending from lock 18 through lock 27 shows that delay at lock 26 (L26) affects the north Iowa barge rate at the 10 percent significance level (Figure 29b, Table 17). Finding delay at lock 26 (Melvin Price) as a cause of the north Iowa barge rate and finding delay at locks 22 and lock 25 as a cause of the south Minnesota barge rate seem inconsistent. Grain barges from both river segments must pass the same locks in their journey to lower Mississippi River ports. An explanation may center on the differing time periods when grain tends to be shipped from each river segment. Because the fall grain harvest in Iowa precedes the Minnesota harvest, temporal shipment patterns may differ for each segment. Further, barge shipment patterns may differ by river segment because of the more difficult winter conditions on the south Minnesota portion of the upper Mississippi River, thus affecting their grain shipments in the late fall and early spring periods.

The directed graph analysis shows that the south of Peoria barge rate (BRSP) is caused by accumulated barge delay at the Peoria and LaGrange locks (PEO-LA), at locks 26 and 27 (L26-L27), as well as a one period lag in the south of Peoria barge rate (LBRSP) (Figure 30a, Table 17). Additional directed graph analysis shows delay at lock 26 (L26) and the Peoria lock (Peoria), as well as a one period delay in the south of Peoria barge rate (LBRSP) as central causes of this rate (Figure 30b, Table 17).

Earlier directed graph analysis showed lock delay at selected locks to be caused by delay at nearby or adjacent locks (e.g., Figures 23 and 24). The above directed graph analysis that focused on causes of barge rates also included delay at individual locks in the analysis, but in no case did delay at one lock cause delay at a nearby lock (e.g., Figures 28b and 29b). Hence, there is an appearance of different outcomes. In actuality, the two data sets are dissimilar, thus the likely reason for the different outcomes. In particular, the directed graph analysis that focused on causes of barge rates automatically excluded the winter months from the analysis even though some movements did occur in selected winter months, conversely, when the focus was on causes of lock delay, winter months were included if there were barge movements. Hence, differences in the two analyzed data sets.

In summary, the directed graph analysis shows accumulated lock delay on selected river segments to be a partial cause of barge rates. In particular, the most congested portion of the Mississippi River, locks 18 through 27, was found to be a partial cause of the south Minnesota and north Iowa barge rates. In addition, delay at the Peoria and LaGrange locks and delay at locks 26 and 27 were partial causes of the south of Peoria barge rate.

Estimated Equations to Explain Barge Rates

The above directed graph analysis identified forces that caused the south Minnesota, north Iowa and south of Peoria barge rates. Based on this information, equations explaining barge rates are specified and estimated with ordinary least squares. Two barge rate equations are estimated for each collected barge rate. One equation includes accumulated lock delay on selected river segments while the second equation includes specific locks where delay appears to be the partial cause of barge rates.

Descriptive statistics on barge rates and explanatory variables included in the estimated barge rate equations is presented in Table 13. Tables 18a, 18b, 19a, 19b, 20a, and 20b include the six estimated barge rate equations. The estimated equations explain 54 to 62 percent of the variation in barge rates (Adjusted R-Square): the t-ratio for the barge delay variables range from about 1.35 to 2.67, indicating statistical significance at the 20 to 5 percent levels, respectively. Autocorrelation was largely averted in all estimated rate equations by inclusion of the lagged barge rate variable.

Both estimated barge rate equations for the south Minnesota barge rate explain about 62 percent of the monthly variation in rates (Tables 18a and 18b). Accumulated delay at locks 18 to 27 (L18-L27) is significant at the 5 percent level: the estimated coefficient associated with the L18-L27 variable is 0.021 indicating that an additional hour of accumulated delay will increase the south Minnesota barge rate 2.1 cents/ton (Table 18a). The average vessel delay time of delayed vessels on this segment is 32.06 hours (Table 13), therefore, the average cost of delay is about \$0.67/ton (32.06 x 2.1 cents/ton) or about \$1,005/barge. This estimate (\$1,005/barge) is based on the assumption that each barge carries 1,500 tons and the barge is delayed at each lock on this river segment. The elasticity associated with the L18-L27 variable is 0.059 indicating that a one percent change in delay time will alter barge rates about 0.059 percent (Table 18a).

The additional directed graph analysis shows that delay at locks 22 and 25 had an affect on the south Minnesota barge rate. However, both variables offer marginal explanations (20 percent level) of this rate (Table 18b). The coefficients associated with lock 22 (L22) and lock 25 (L25) variables are 0.075 and 0.073, respectively. In which case, an additional hour of delay at lock 22 and 25 will increase the south Minnesota barge rate about 7.5 and 7.3 cents/ton. In 1999, vessels locking through locks 22 and 25 incurred about 4 hours of delay per delayed vessel at each lock. Based on the estimated parameters, this would have increased the south Minnesota barge rate about $0.60/ton or $900/barge, assuming the barge is delayed at both locks in this river segment (Table 18b).

The north Iowa barge rate is partially explained by accumulated delay at locks 18 through 27 (L18-L27): the L18-L27 variable is significant at the 20 percent level (Table 19a). The impact of delay is comparatively modest indicating that an additional hour of delay at locks 18 through 27 will increase the north Iowa barge rate about 1.1 cent per ton or $16.50/barge. Since the accumulated average vessel delay at locks 18 through 27 is 32.06 hours, the average delay at these locks added about $0.35/ton to the north Iowa barge rate or about $525/barge if barges are delayed at all locks. Additional directed graph analysis that focused on individual locks shows that delay at lock 26 (Melvin Price) was partially responsible for explanation of the north Iowa barge rate (Table 19b). The estimated north Iowa barge rate equation indicates that the lock 26 variable (L26) is significant at the 10 percent level (Table 19b). The elasticity associated with the L26 variable is 0.016, indicating that a one percent increase in delay at lock 26 will increase the north Iowa barge rate about 0.016 percent.

Statistical output associated with the estimated south of Peoria barge rate equation shows that accumulated delay at the Peoria and LaGrange locks (PEO-LA), and accumulated delay at locks 26 (Melvin Price) and 27 (L26-27) are statistically important explanations (5 percent level) of this rate (Table 20a). In particular, an additional hour of accumulated delay at the Peoria and LaGrange locks (PEO-LA) adds 1.9 cents per ton to the south of Peoria barge rate while an additional hour of delay at locks 26 and 27 (L26-L27) add about 2.9 cents per ton to this rate. Historically, lock delay at the Peoria and LaGrange locks averaged about 6.32 hours (Table 13): based on the estimated coefficient associated with PEO-LA variable, delay at these locks adds about $0.12/ton to the south of Peoria rate. Delay at locks 26 and 27 (L26-L27) adds about $0.25/ton to the south of Peoria rate. Delay on both river segments increases the south of Peoria rates about $0.37/ton or $555/barge if the barge is delayed at all involved locks. The elasticity associated with the PEO-LA variable is 0.016 indicating that a one percent increase in accumulated delay will increase the barge rate about 0.016 percent: the elasticity associated with the L26-L27 variable is comparatively large with an estimated value of 0.034 (Table 20a). Additional directed graph analysis shows barge delay at the Peoria lock (Peoria) and lock 26 (L26) to influence the south of Peoria barge rate (Table 20b). Estimated coefficients on both variables in the south of Peoria rate equation are statistically significant at the 5 percent levels. The elasticity associated with lock 26 variable (L26) is 0.024 while the elasticity associated with the Peoria lock (Peoria) is a more modest 0.017 (Table 20b).

Summary and Conclusions

This study investigates lock delay on the upper Mississippi and Illinois Rivers, and attempts to determine what forces cause lock delay, and if lock delay affects grain barge rates that link selected sections of these rivers to lower Mississippi River ports. Initial attention is given to historic lock performance data on selected upper Mississippi and Illinois River locks. Locks 18 through 25 on the upper Mississippi River, and the Peoria and LaGrange locks on the Illinois River are the focus of the analyses since their lock delay is comparatively great. Directed graph methods are used to identify forces that cause (1) lock delay at identified locks and (2) grain barge rates that link sections of the upper Mississippi and Illinois Rivers to lower Mississippi River ports. Based on the directed graph analysis, equations that measure the impact of the identified forces on lock delay and grain barge rates are specified and estimated.

Historic data from the U.S. Army Corps of Engineers shows a very modest upward trend in traffic on the upper Mississippi and Illinois Rivers since the mid-1980s. The Corp's Lock Performance Monitoring System data shows that annual traffic was highest at locks in lower reaches of the studied rivers. For example, at lock 18 (river mile 410) an average of 29.8 million tons were annually locked, while nearly 35 million tons were annually handled at lock 25 (river mile 241). Similarly, the Peoria lock (river mile 158) annually locked about 31 million tons while the LaGrange lock (river mile 80) handled an average of 33.56 tons. Lock capacity utilization at the upper Mississippi River locks was greatest at lock 22 with 78 percent of annual capacity utilized. Utilization was least at lock 19 with 41 percent of annual capacity utilized. At remaining upper Mississippi River locks, capacity utilization averaged about 60 percent while the two Illinois River locks utilized about half of their annual locking capacity.

Lock 21 had the lowest number of stalls averaging 53 per year while most remaining upper Mississippi River locks averaged in excess of 60 stalls per year: the Illinois River's LaGrange lock averaged about 42 stalls per year while the Peoria lock averaged 57 stalls per year. The average duration of stalls at upper Mississippi River locks ranged from 175 hours per season (lock 18) to 460 hours per season (lock 25), while the Peoria and LaGrange locks had average stall duration times of 120 and 161 hours per season, respectively. The portion of vessels experiencing delay at examined locks approached 60 percent at locks 22, 24, and 25, while about 50 percent of the vessels passing locks 20 and 21 were delayed, and about 40 percent were delayed at locks 18 and 19. Approximately one-third of the vessels at the Peoria lock experienced delay while half of the vessels at the LaGrange lock were delayed. In contrast to other examined locks, lock 25 showed an increasing portion of vessels delayed through time. Lock 22 had the highest average delay time, 5.19 hours per delayed vessel, while lock 19 had the least waiting time, 1.68 hours per delayed vessel. The average delay time of delayed vessels was about 4 hours at locks 20, 24, and 25, and nearly 3 hours at locks 18 and 21. Average delay time of delayed vessels at the LaGrange and Peoria locks were approximately 4 and 3 hours, respectively.

The directed graph analysis and the estimated multiple regressions show stalls had a statistically important and unfavorable influence on lock delay at seven of the nine evaluated locks. In general, stalls were a central force causing delay at all but two locks. At locks 20 and 21, the directed graph methodology could not identify any causes of delay in the LPMS data set. Six of the estimated lock equations showed delay at nearby locks to unfavorably affect delay at the lock in question. It is hypothesized that a stall at a lock increases fleeting in nearby lock pools that subsequently create barge delay at the nearby locks when the stall is remedied and accumulated traffic commences to move. In which case, delay at one lock may create delay at a nearby lock. At four locks, delay was partially caused by traffic levels. Three of these locks were high volume locks in the lowest reaches of the upper Mississippi and Illinois Rivers. Elasticity values associated with traffic levels were comparatively high indicating that a one percent increase in traffic would increase lock delay from 0.58 to 0.87 percent.

The directed graph analysis shows lock delay to increase barge rates, however, the estimated rate equations show that the affect is not large. Accumulated lock delay at the most congested portion of the upper Mississippi River, locks 18 through 27, was found to impact both examined upper Mississippi River rates (south Minnesota and north Iowa). And, accumulated lock delay time at locks 26 (Melvin Price) and 27, and the Peoria and LaGrange locks affected the examined Illinois River rate (south of Peoria). Estimated rate equations show that a one percent increase in accumulated lock delay at locks 18 through 27 will increase the south Minnesota and north Iowa rates to lower Mississippi River ports by 0.059 and 0.038 percent, respectively. The accumulated delay at the Peoria and LaGrange locks, and locks 26 (Melvin Price) and 27 increase the south of Peoria rate by 0.016 and 0.034 percent, respectively. Based on historic average delay at locks 18 through 27 (32.06 hours), the barge rate linking south Minnesota to lower Mississippi River ports is increased about $1,005/barge as a result of this delay while the north Iowa rate is increased about $525/barge. These estimates ($1,005 and $525/barge) are based on the assumption that a tow experiences delay at all involved locks. Further, it is estimated that delay time at the Peoria and LaGrange locks, and locks 26 (Melvin Price) and 27 increase barge rates on the Illinois River about $555/barge if the grain barge is delayed at each lock.

In summary, stalls at locks in the lower reaches of the upper Mississippi and Illinois Rivers appears to be an important cause of lock delay. In addition, lock delay is caused by comparatively high lock traffic levels and by critical locks whose lock delay causes nearby locks to experience delay. Lock delay in the lower reaches of the upper Mississippi and Illinois Rivers increases barge rates that link the north central United States to the lower Mississippi River ports, however, the impact on rates is not large.

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Glossary

AUXILIARY CHAMBER: A chamber of a multiple-chamber lock that is usually smaller and used less than the main chamber. Auxiliary chambers are normally used to maintain navigation during periods when the main chamber is shut down and to pass small tows, light boats, and recreational vessels.

AVERAGE LOCK DELAY TIME: The total delay or wait time for all vessels or tows at a lock or all locks in the system divided by the total number of vessels or tows. The average delay may be computed for all vessels, all tows, all delayed vessels, or all delayed tows. The latter two measures tend to be higher than the former two.

BARGE: A non-self-propelled, usually flat-bottomed vessel, used for carrying freight on inland and intracoastal waterways and open bodies of water.

CHAMBER: The part of a lock enclosed by the walls, floor, sills, and gates; the part of a lock within which the water level is changed as vessels are raised or lowered. A lock may have more than one chamber and they may be adjacent or laterally separated.

DELAY TIME: The time elapsed from the arrival of a vessel at a lock to the start of its approach to a lock chamber; the time spent in queue awaiting lockage. Also called wait time.

DOUBLE LOCKAGE: The type of lockage performed when a tow is passed through a lock chamber in two segments or "cuts".

LOCK: A facility containing one or more enclosed chambers, situated at a point (canal or dam) on a waterway, with gates at each end for raising or lowering vessels by admitting or releasing water. (See CHAMBER.)

LOCK CAPACITY: An estimate of the maximum number of tons of cargo of a specified mix that may transit a lock in a given period of time under a specific set of assumptions, such as level and type of future traffic, vessel operating practices, and lock operating conditions. Varying these assumptions developed the high and low estimates.

LOCK CAPACITY UTILIZATION: A rate computed by dividing actual annual total traffic in tons by the estimated lock capacity.

LOCK PERFORMANCE: Overall evaluation of the operation of a lock using a variety of indicators, such as tonnage, time and capacity utilization, delays, processing and idle time, unavailability, and competing usage (commercial vs. recreational lockages).

LOCK PERFORMANCE MONITORING SYSTEM (LPMS): A standardized system of lockage data collection and analysis which was introduced by the U.S. Army Corps of Engineers in 1975 to enable Corps planners and operations personnel to more effectively operate and maintain the Nation's inland waterways system.

LOCKAGE: The passage of a tow or other vessel through a lock. The series of events required to move a vessel or two through a lock in a single direction. A normal lockage cycle consists of an approach, entry, chambering, and exit.

MAIN CHAMBER: The larger or largest chamber through which most of the traffic moves at a multiple-chamber lock.

POOL: The body of water impounded by a navigation dam.

RECREATIONAL CRAFT: Non-commercial vessels used for recreational activity.

RIVER MILE: A number specifying the location of a point along a waterway, obtained as the distance from a reference point designated as mile zero.

STALL FREQUENCY: The number of times in a given period a lock is out of service or unavailable.

TOW: A towboat and one or more barges that are temporarily fastened together and operated as a single unit.

TOWBOAT: A shallow draft commercial vessel used to push or pull barges.

VESSELS: Towboats, barges, and other waterborne craft.

WATERWAY: Any body of water wide enough and deep enough to accommodate the passage of water craft, particularly commercial vessels.

Table 1: Characteristics of Locks on Upper Mississippi and Illinois Rivers, 1997.

Lock name or number	River Mile	Year Opened	Width	Length	Lift
	Upper Mississippi River				
Upper St. Anthony Falls	853.9	1963	56	400	49
Lower St. Anthony Falls	853.3	1959	56	400	25
1 Main Chamber	847.6	1930	56	400	38
1 Aux. Chamber	847.6	1932	56	400	38
2 Main Chamber	815.0	1930	110	500	12
2 Aux. Chamber	815.0	1948	110	600	12
3	769.9	1938	110	600	8
4	752.8	1935	110	600	7
5	738.1	1935	110	600	9
5A	728.5	1936	110	600	5
6	714.0	1936	110	600	6
7	702.0	1937	110	600	8
8	679.0	1937	110	600	11
9	647.0	1938	110	600	9
10	615.0	1936	110	600	8
11	583.0	1937	110	600	11
12	556.0	1938	110	600	9
13	522.0	1938	110	600	11
14 Main Chamber	493.3	1939	110	600	11
14 Aux. Chamber	493.1	1922	80	320	11
15 Main Chamber	482.9	1934	110	600	16
15 Aux. Chamber	482.9	1934	110	600	16
16	457.2	1937	110	600	9
17	437.1	1939	110	600	8
18	410.5	1937	110	600	10
19	364.2	1957	110	1,200	38
20	343.2	1936	110	600	10
21	324.9	1938	110	600	10
22	301.2	1938	110	600	10
24	273.4	1940	110	600	15
25	241.4	1939	110	600	15
26 Melvin Price[1]	200.8	1990	110	1,200	24
26 Melvin Price Aux. Chamber[1]	200.8	1992	110	600	24
27 [1]	185.1	1953	110	1,200	21
27 Aux. Chamber[1]	185.1	1953	110	600	21
	Illinois River				
Thomas J. O'Brien	326.5	1960	110	1,000	4
Lockport	291.1	1933	110	600	40
Brandon Road	286.0	1933	110	600	34
Dresden Island	271.5	1933	110	600	22
Marseilles	244.6	1933	110	600	24
Starved Rock	231.0	1933	110	600	19
Peoria	157.7	1939	110	600	11
LaGrange	80.2	1939	110	600	10

[1] Middle Mississippi River

Source: U.S. Army Corps of Engineers, The 1997 Inland Waterway Review. IWR Report 97-R-3, September 1997 (draft)

Table 2: Quantity and Percent of Corn and Soybeans Entering Lock Pools, 1,000 tons, 1996-1999.

	Corn									
	1996		1997		1998		1999		Average	
Upper Mississippi River	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent
Saint Anthony	212	1%	193	2%	203	2%	163	1%	193	1%
Minnesota River	2,102	14%	1,564	13%	2,250	18%	3,145	18%	2,265	16%
Miss 02	967	6%	901	8%	823	7%	1,080	6%	943	7%
Miss 04	411	3%	362	3%	398	3%	484	3%	414	3%
Miss 06	1,811	12%	1,539	13%	1,538	12%	2,227	13%	1,779	12%
Miss 08	312	2%	291	2%	274	2%	328	2%	301	2%
Miss 10	1,752	11%	1,347	11%	1,621	13%	2,116	12%	1,709	12%
Miss 12	1,728	11%	839	7%	705	6%	1,222	7%	1,124	8%
Miss 13	306	2%	290	2%	327	3%	347	2%	318	2%
Miss 14	2,424	16%	1,625	14%	1,676	13%	2,389	14%	2,029	14%
Miss 15	381	2%	265	2%	252	2%	340	2%	310	2%
Miss 16	416	3%	286	2%	349	3%	507	3%	390	3%
Miss 17	362	2%	240	2%	341	3%	205	1%	287	2%
Miss 18	382	2%	422	4%	410	3%	477	3%	423	3%
Miss 19	711	5%	728	6%	538	4%	530	3%	627	4%
Miss 20	216	1%	282	2%	235	2%	233	1%	242	2%
Miss 21	100	1%	145	1%	93	1%	124	1%	116	1%
Miss 22	184	1%	185	2%	120	1%	117	1%	152	1%
Miss 24	133	1%	142	1%	113	1%	109	1%	124	1%
Miss 26	56	0%	77	1%	45	0%	43	0%	55	0%
Miss 27	575	4%	290	2%	228	2%	970	6%	516	4%
Illinois River										
Thomas O'Brien	277	2%	234	2%	642	6%	428	3%	395	6%
Marseilles	1,148	10%	1,156	12%	1,313	12%	1,371	11%	713	11%
Starved Rock	1,044	9%	873	9%	868	8%	1,142	9%	561	9%
Peoria	5,313	45%	4,075	42%	4,093	39%	5,151	42%	2,662	41%
LaGrange	2,862	24%	2,406	25%	2,498	24%	2,938	24%	1,529	23%
LaGrange to Mouth	1,210	10%	1,074	11%	1,129	11%	1,261	10%	668	10%

Table 2 (continued)

	Soybeans									
	1996		1997		1998		1999		Average	
Upper Mississippi River	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent
Saint Anthony	102	2%	92	2%	73	2%	111	2%	95	2%
Minnesota River	1,090	21%	618	12%	682	15%	877	15%	352	7%
Miss 02	369	7%	294	6%	315	7%	429	7%	352	7%
Miss 04	NA	NA	NA	NA	110	2%	NA	NA	110	2%
Miss 06	392	7%	407	8%	345	8%	484	8%	407	8%
Miss 08	NA	NA	60	1%	NA	NA	82	1%	71	1%
Miss 10	483	9%	444	9%	430	10%	794	13%	538	11%
Miss 12	337	6%	379	7%	338	8%	529	9%	396	8%
Miss 13	57	1%	73	1%	60	1%	64	1%	64	1%
Miss 14	406	8%	470	9%	314	7%	408	7%	400	8%
Miss 15	183	3%	159	3%	220	5%	170	3%	183	4%
Miss 16	292	6%	376	7%	269	6%	484	8%	355	7%
Miss 17	151	3%	227	4%	324	7%	310	5%	253	5%
Miss 18	272	5%	277	5%	211	5%	278	5%	260	5%
Miss 19	516	10%	569	11%	381	9%	475	8%	485	10%
Miss 20	241	5%	248	5%	196	4%	149	2%	209	4%
Miss 21	31	1%	54	1%	6	0%	8	0%	25	1%
Miss 22	19	0%	30	1%	15	0%	NA	NA	21	0%
Miss 24	43	1%	41	1%	21	0%	20	0%	31	1%
Miss 26	NA	NA	83	2%	36	1%	30	1%	50	1%
Miss 27	284	5%	171	3%	95	2%	275	5%	206	
Illinois River										
Thomas O'Brien	237	6%	252	6%	221	7%	225	6%	234	6%
Marseilles	369	9%	420	10%	284	9%	391	10%	366	9%
Starved Rock	426	10%	448	11%	322	10%	447	11%	411	11%
Peoria	1,677	41%	1,532	37%	1,328	42%	1,678	41%	1,554	40%
LaGrange	1,016	25%	1,037	25%	805	25%	989	24%	962	25%
LaGrange to Mouth	335	8%	438	11%	226	7%	339	8%	335	9%

Source: USACE

Table 3: Total Tonnage Locked at Selected Upper Mississippi River Locks, 1,000,000 tons 1980-1999.

Year	**Lock 18**	**Lock 19**	**Lock 20**	**Lock 21**	**Lock 22**	**Lock 24**	**Lock 25**
1980	26.56	29.01	29.75	30.93	31.49	32.75	32.74
1981	29.27	30.94	31.56	32.39	32.85	33.91	34.23
1982	27.09	27.88	28.69	29.63	30.24	32.76	32.77
1983	34.16	34.63	35.00	35.81	36.35	37.35	37.44
1984	30.10	32.30	32.96	33.98	34.60	35.96	36.17
1985	22.29	23.24	23.66	24.42	25.07	26.10	26.11
1986	23.11	24.29	24.86	26.04	26.87	28.16	28.16
1987	29.84	31.22	31.94	33.38	34.21	35.31	35.32
1988	32.23	33.90	34.89	36.14	36.78	37.89	37.88
1989	31.37	32.91	33.52	34.36	34.94	36.14	36.22
1990	37.73	39.15	39.79	40.85	41.35	42.35	42.34
1991	32.70	34.41	35.06	36.13	36.55	37.34	37.50
1992	33.94	35.98	36.61	37.84	38.29	39.42	39.38
1993	21.24	22.79	23.35	24.76	25.21	26.58	26.56
1994	25.17	26.71	27.44	28.78	29.41	30.74	30.76
1995	31.53	33.22	34.31	35.35	36.05	37.54	37.43
1996	31.84	32.35	33.15	34.49	34.83	36.18	36.09
1997	28.79	29.62	30.35	31.91	32.30	33.61	33.64
1998	31.23	31.08	31.75	33.31	33.65	34.75	34.82
1999	35.71	35.80	36.51	37.86	38.07	39.30	39.54
Mean	***29.80***	***31.07***	***31.76***	***32.92***	***33.46***	***34.71***	***34.75***

Source: USACE, Lock Performance Monitoring System Data

Table 4: Total Tonnage Locked at Selected Illinois River Locks, 1,000,000 tons, 1980-1999.

Year	**Annual Tonnage**	
	Peoria	LaGrange
1980	33.96	33.65
1981	33.92	33.03
1982	31.25	32.84
1983	32.08	33.45
1984	28.84	31.25
1985	26.61	28.54
1986	28.76	30.01
1987	26.46	30.32
1988	29.06	31.25
1989	28.14	31.19
1990	32.87	36.03
1991	30.98	33.89
1992	30.99	33.15
1993	31.78	33.33
1994	35.45	38.35
1995	33.91	38.95
1996	31.23	35.42
1997	30.75	34.85
1998	32.58	36.10
1999	31.13	35.60
Mean	***31.04***	***33.56***

Source: USACE, Lock Performance Monitoring System Data

Table 5: Percent of Lock Capacity Utilized at Selected Upper Mississippi River Locks, 1980-1999.

Year	Lock 18	Lock 19	Lock 20	Lock 21	Lock 22	Lock 24	Lock 25
1980	57%	39%	52%	53%	73%	57%	56%
1981	63%	41%	55%	55%	76%	59%	59%
1982	58%	37%	50%	51%	70%	57%	56%
1983	73%	46%	61%	61%	85%	65%	64%
1984	64%	43%	58%	58%	81%	63%	62%
1985	48%	31%	41%	42%	58%	45%	45%
1986	49%	32%	44%	45%	63%	49%	48%
1987	64%	42%	56%	57%	80%	61%	61%
1988	69%	45%	61%	62%	86%	66%	65%
1989	67%	44%	59%	59%	81%	63%	62%
1990	81%	52%	70%	70%	96%	74%	73%
1991	70%	46%	61%	62%	85%	65%	64%
1992	73%	48%	64%	65%	89%	69%	68%
1993	45%	30%	41%	42%	59%	46%	46%
1994	54%	36%	48%	49%	68%	53%	53%
1995	67%	44%	60%	60%	84%	65%	64%
1996	68%	43%	58%	59%	81%	63%	62%
1997	62%	39%	53%	55%	75%	59%	58%
1998	67%	41%	56%	57%	78%	60%	60%
1999	76%	48%	64%	65%	89%	68%	68%
Mean	***64%***	***41%***	***56%***	***56%***	***78%***	***60%***	***60%***

Source: USACE, Lock Performance Monitoring System Data

Table 6: Percent of Lock Capacity Utilized at Selected Illinois River Locks, 1980-1999.

Year	**Capacity Utilization**	
	Peoria	LaGrange
1980	53%	52%
1981	53%	51%
1982	49%	51%
1983	50%	52%
1984	45%	49%
1985	41%	44%
1986	45%	47%
1987	41%	47%
1988	45%	49%
1989	44%	48%
1990	51%	56%
1991	48%	53%
1992	48%	52%
1993	49%	52%
1994	55%	60%
1995	53%	61%
1996	49%	55%
1997	48%	54%
1998	51%	56%
1999	48%	55%
Mean	***48%***	***52%***

Source: USACE, Lock Performance Monitoring System Data

Table 7: Number of Stalls Per Year at Selected Upper Mississippi River Locks, 1980-1999.

Year	Lock 18	Lock 19	Lock 20	Lock 21	Lock 22	Lock 24	Lock 25
1980	35	81	35	47	57	86	114
1981	37	71	43	51	63	62	87
1982	32	69	45	49	77	72	89
1983	82	164	74	50	74	104	90
1984	71	122	54	60	57	80	117
1985	41	39	102	88	83	76	77
1986	42	24	67	87	73	77	55
1987	36	54	150	46	30	40	49
1988	52	49	74	76	57	55	67
1989	35	100	81	80	89	58	50
1990	33	41	75	77	83	97	80
1991	86	52	61	45	56	67	76
1992	43	48	40	32	71	57	47
1993	45	33	46	34	48	57	51
1994	29	50	27	48	55	55	26
1995	53	45	59	65	106	42	65
1996	63	61	50	48	60	58	51
1997	31	60	34	27	75	54	31
1998	30	51	75	22	55	75	65
1999	34	31	56	25	49	58	61
Mean	***45.5***	***62.3***	***62.4***	***52.9***	***65.9***	***66.5***	***67.4***

Source: USACE, Lock Performance Monitoring System Data

Table 8: Total Duration of Stalls in Hours Per Year at Selected Upper Mississippi River Locks, 1980-1999.

Year	Lock 18	Lock 19	Lock 20	Lock 21	Lock 22	Lock 24	Lock 25
1980	46.6	278.4	125.8	126.5	606.8	154.2	141.7
1981	74.6	260.2	44.7	103.5	242.7	123.9	1,476.5
1982	115.0	179.8	84.7	151.4	310.7	278.7	306.2
1983	269.8	1,406.6	413.5	687.6	473.0	378.0	464.7
1984	246.8	2,314.7	95.5	212.0	152.0	286.4	345.5
1985	73.1	665.0	490.5	984.6	331.6	233.6	254.5
1986	101.2	42.4	233.9	618.9	346.3	442.0	224.2
1987	524.5	133.3	596.5	696.3	108.2	85.5	173.4
1988	58.2	40.6	108.2	152.6	1,131.8	74.4	127.4
1989	71.3	103.0	388.7	1,583.2	175.4	108.9	80.9
1990	79.9	71.1	216.7	302.3	285.0	183.4	175.0
1991	226.0	106.2	131.3	133.5	192.3	206.7	198.8
1992	81.9	200.1	72.4	42.7	187.9	120.0	1,632.0
1993	445.0	210.7	582.8	70.4	179.4	1,040.3	759.3
1994	60.1	133.8	59.3	95.7	138.6	215.6	152.2
1995	161.8	211.9	111.6	132.1	406.3	182.7	414.1
1996	106.5	459.4	599.0	328.2	378.1	193.7	302.8
1997	630.0	659.8	610.5	887.0	890.3	120.0	536.7
1998	50.9	520.2	548.2	108.1	224.5	741.8	1,223.3
1999	68.8	71.9	110.6	202.2	106.9	154.5	200.6
Mean	***174.6***	***403.4***	***281.2***	***380.9***	***343.4***	***266.2***	***459.5***

Source: USACE, Lock Performance Monitoring System Data

Table 9: Number of Stalls and Duration of Stalls Per Year at Selected Illinois River Locks, 1980-1999.

Year	**Number of Stalls**		**Stall Duration (hrs)**	
	Peoria	LaGrange	Peoria	LaGrange
1980	120	61	388.3	1,044.1
1981	100	92	144.4	161.1
1982	62	53	117.8	202.5
1983	43	28	80.0	71.5
1984	69	20	162.4	57.8
1985	54	24	120.8	148.0
1986	64	21	107.5	59.5
1987	117	118	164.9	230.0
1988	88	51	116.5	86.9
1989	91	59	147.2	117.1
1990	33	36	84.3	67.2
1991	23	21	29.9	48.1
1992	28	20	48.3	49.7
1993	6	4	19.3	21.0
1994	38	42	66.3	93.0
1995	46	18	84.3	38.4
1996	61	62	168.2	327.6
1997	34	47	172.9	159.7
1998	21	11	61.3	38.5
1999	43	47	114.0	198.7
Mean	***57.05***	***41.75***	***119.9***	***161.0***

Source: USACE, Lock Performance Monitoring System Data

Table 10: Average Delay of Delayed Vessels in Hours at Selected Upper Mississippi River Locks, 1980-1999.

Year	Lock 18	Lock 19	Lock 20	Lock 21	Lock 22	Lock 24	Lock 25
1980	3.00	2.74	4.23	5.07	7.23	2.10	2.08
1981	1.98	1.53	2.62	2.54	5.75	2.09	1.69
1982	1.94	1.13	2.60	3.54	3.92	3.36	1.90
1983	4.87	3.20	3.87	2.95	9.10	12.60	6.20
1984	2.68	2.72	1.98	2.04	3.88	3.93	3.02
1985	1.57	2.86	2.19	1.57	2.39	2.75	1.83
1986	2.11	0.99	2.65	3.29	5.51	2.71	1.44
1987	2.43	1.37	17.71	3.00	4.26	4.46	3.76
1988	2.43	1.25	3.93	4.69	7.04	5.33	4.32
1989	2.26	1.24	3.29	3.07	6.62	5.35	3.68
1990	3.73	1.62	6.16	2.93	5.64	6.59	3.52
1991	3.53	1.48	2.41	2.84	3.76	3.62	2.67
1992	3.28	1.64	3.47	2.94	4.67	4.75	6.12
1993	4.14	2.09	6.97	3.04	4.59	4.02	3.59
1994	1.75	1.34	1.64	1.84	2.69	2.26	4.01
1995	4.03	1.34	2.81	4.01	7.32	5.80	6.76
1996	3.12	1.41	4.03	3.60	8.78	5.30	4.44
1997	2.05	1.22	2.24	2.13	3.70	3.45	3.47
1998	1.89	1.15	2.19	1.98	3.06	5.26	5.20
1999	2.27	1.20	2.47	2.19	3.83	3.35	4.02
Mean	***2.75***	***1.68***	***3.97***	***2.96***	***5.19***	***4.45***	***3.69***

Source: USACE, Lock Performance Monitoring System Data

Table 11: Percent of Vessels Delayed at Selected Upper Mississippi River Locks, 1980-1999.

Year	Lock 18	Lock 19	Lock 20	Lock 21	Lock 22	Lock 24	Lock 25
1980	48%	44%	48%	52%	62%	87%	80%
1981	45%	42%	46%	50%	64%	88%	81%
1982	47%	39%	43%	49%	56%	63%	69%
1983	59%	49%	54%	57%	64%	66%	68%
1984	45%	40%	45%	48%	53%	58%	67%
1985	29%	25%	32%	32%	39%	42%	52%
1986	31%	28%	34%	37%	47%	43%	54%
1987	43%	37%	63%	49%	55%	53%	56%
1988	42%	38%	62%	58%	63%	59%	55%
1989	40%	35%	57%	51%	61%	56%	53%
1990	53%	41%	64%	56%	63%	60%	60%
1991	51%	38%	55%	49%	55%	52%	51%
1992	46%	43%	56%	54%	60%	57%	56%
1993	53%	43%	54%	55%	64%	64%	64%
1994	22%	30%	35%	31%	39%	39%	29%
1995	43%	44%	54%	49%	60%	58%	49%
1996	47%	43%	59%	52%	62%	61%	50%
1997	36%	45%	51%	54%	57%	54%	42%
1998	33%	46%	49%	58%	60%	56%	46%
1999	44%	48%	61%	63%	66%	56%	51%
Mean	***43%***	***40%***	***51%***	***50%***	***57%***	***59%***	***57%***

Source: USACE, Lock Performance Monitoring System Data

Table 12: Average Delay of Delayed Vessels and Percent of Vessels Delayed at Peoria and LaGrange Locks on the Illinois River, 1980-1999.

Year	**Average Delay (hrs)**		**Vessels Delayed (%)**	
	Peoria	LaGrange	Peoria	LaGrange
1980	2.98	3.87	69%	72%
1981	8.19	6.69	93%	94%
1982	2.88	2.17	85%	92%
1983	1.39	1.89	41%	45%
1984	2.84	1.48	37%	42%
1985	1.39	1.43	40%	44%
1986	2.98	1.57	25%	29%
1987	3.89	6.85	42%	61%
1988	2.47	2.30	31%	50%
1989	2.73	2.91	37%	63%
1990	3.69	3.81	16%	34%
1991	1.94	1.33	11%	26%
1992	2.53	1.72	21%	45%
1993	3.17	10.44	2%	2%
1994	2.97	2.54	23%	44%
1995	4.99	5.81	24%	50%
1996	4.12	8.00	40%	71%
1997	4.39	5.53	21%	51%
1998	3.02	4.23	21%	42%
1999	3.02	4.71	27%	45%
Mean	***3.28***	***3.96***	***35%***	***50%***

Source: USACE, Lock Performance Monitoring System Data

Table 13: Statistical Summary of Accumulated Barge Delays and Barge Rates on Upper Mississippi and Illinois River Segments, 1980-1999.

	Mean	Standard Deviation	Variance	Minimum	Maximum
Upper Mississippi Delay (hrs)					
L1-L8[1]	6.95	3.090	9.548	1.18	26.17
L9-L17[2]	18.93	8.358	69.856	8.56	58.08
L18-L27[3]	32.06	18.206	331.458	11.35	123.57
Illinois River Delay (hrs)					
TOB-SR[4]	11.44	11.322	128.188	0.65	141.68
PEO-LA[5]	6.32	10.126	102.536	0.00	102.73
L26-L27[6]	8.79	11.648	135.669	1.14	102.50
Barge Rate ($/ton)					
BRSM (south Minnesota)	11.24	3.577	12.795	5.22	23.33
BRNI (north Iowa)	9.39	2.891	8.358	5.06	19.13
BRSP (south of Peoria)	7.41	2.442	5.963	3.54	15.76

[1] Accumulated lock delay at lock 1 through lock 8.
[2] Accumulated lock delay at lock 9 through lock 17.
[3] Accumulated lock delay at lock 18 through lock 27.
[4] Accumulated lock delay at the Thomas O'Brien lock through Starved Rock lock.
[5] Accumulated lock delay at the Peoria lock through the LaGrange lock.
[6] Accumulated lock delay at lock 26 (Melvin Price) through lock 27.

Table 14: Definition of Variables Included in Directed Graphs Featured in Figures 19-27, and Equations in Tables 15 and 16.

Variable	**Definition**
ADELDV	Average delay time of delayed vessels in hours for lock *i*, month *j*
BRGL	Number of loaded barges at lock *i*, month *j*
BRGU	Number of empty barges at lock *i*, month *j*
COML	Number of commercial lockages at lock *i*, month *j*
RECV	Number of recreational vessels at lock *i*, month *j*
TOTOP	Number of total hardware operations at lock *i*, month *j*
NUMUN	Frequency of stalls in minutes at lock *i*, month *j*
AVGUN	Average duration of stalls in minutes at lock *i*, month *j*
TOTUN	Total duration of stalls in minutes at lock *i*, month *j*
SPRING	Number of tons locked in spring at lock *i*, month *j*
SUMMER	Number of tons locked in summer at lock *i*, month *j*
FALL	Number of tons locked in fall at lock *i*, month *j*
WINTER	Number of tons locked in winter at lock *i*, month *j*
L18	Average delay at lock 18 in hours in month *j*,
L19	Average delay at lock 19 in hours in month *j*
L20	Average delay at lock 20 in hours in month *j*
L21	Average delay at lock 21 in hours in month *j*
L22	Average delay at lock 22 in hours in month *j*
L24	Average delay at lock 24 in hours in month *j*
L25	Average delay at lock 25 in hours in month *j*
L26	Average delay at lock 26 in hours in month *j*
L27	Average delay at lock 27 in hours in month *j*
Starved Rock	Average delay at Starved Rock lock in hours in month *j*
Peoria	Average delay at Peoria lock in hours in month *j*
LaGrange	Average delay at LaGrange lock in hours in month *j*

Table 15: Statistical Summary of Variables Included in Lock Delay Equations[1].

	Variables	Obs (N)	Mean	Standard Deviation	Minimum	Maximum
Lock 18		213				
	ADELDV (hours)		2.70	2.64	0.00	30.65
	NUMUN (numbers)		4.27	3.28	0.00	19.00
	L21 (hours)		2.68	1.92	0.00	17.54
Lock 19		220				
	ADELDV (hours)		2.07	4.90	0.00	48.00
	BRGU (numbers)		1,076.10	607.45	0.00	2,269.00
	TOTUN (minutes)		2,200.6	8,882.5	0.00	0.11E+06
	L21 (hours)		5.42	41.15	0.00	612.32
Lock 22		231				
	ADELDV (hours)		4.79	6.18	0.32	83.03
	AVGUN (minutes)		246.52	403.58	0.00	4,239.90
	L21 (hours)		5.21	40.164	0.00	612.32
	L24 (hours)		3.91	4.17	0.00	33.32
Lock 24		234				
	ADELDV (hours)		3.86	4.17	0.00	33.32
	TOTOP (minutes)		907.32	429.31	12.00	1,627.00
	NUMUN (numbers)		5.68	4.05	0.00	27.00
	TOTUN (numbers)		1,365.20	3,305.60	0.00	30,668.00
	L25 (hours)		3.16	3.44	0.70E-01	24.30
Lock 25		234				
	ADELDV (hours)		3.16	3.44	0.00	24.30
	BRGU (numbers)		1,996.10	1,007.30	29.00	3,657.00
	TOTUN (numbers)		1,989.10	5,495.60	0.00	46,103.00
Peoria		240				
	ADELDV (hours)		2.93	5.15	0.00	59.50
	AVGUN (minutes)		95.64	139.72	0.00	1,455.80
	NUMUN (numbers)		4.75	6.20	0.00	48.00
	LAGRANGE (hours)		3.39	6.67	0.00	68.34
LaGrange		240				
	ADELDV (hours)		3.39	6.67	0.00	68.34
	BRGH (numbers)		912.87	332.92	42.00	2,152.00
	NUMUN (numbers)		3.48	6.10	0.00	41.00
	PEORIA (hours)		2.93	5.15	0.00	59.50

[1]See Table 14 for definition of variables.

Table 16: Estimated Lock Delay Equations for Upper Mississippi and Illinois River Locks[1].

	Variables	Obs (N)	Coefficient	Standard Error	t-ratio	Elasticity
Lock 18		213				
	NUMUN		0.146	0.048	3.026	0.232
	L21		0.614	0.083	7.421	0.611
	INTERCEPT		0.425	0.331	1.283	0.157
	Adj. R-Square		0.238			
	Durbin-Watson		1.908			
Lock 19		220				
	BRGU		-0.978E-03	0.404E-03	-2.421	-0.509
	TOTUN		0.121E-03	0.275E-04	4.399	0.129
	L21		0.746E-01	0.596E-02	12.51	0.196
	INTERCEPT		2.448	0.504	4.857	1.185
	Adj. R-Square		0.457			
	Durbin-Watson		2.151			
Lock 22		231				
	AVGUN		0.234E-02	0.427E-03	5.482	0.120
	L21		0.127	0.446E-02	28.58	0.139
	L24		0.229	0.447E-01	5.118	0.187
	INTERCEPT		2.652	0.324	8.193	0.553
	Adj. R-Square		0.812			
	Durbin-Watson		2.047			
Lock 24		234				
	TOTOP		0.249E-02	0.660E-03	3.766	0.585
	NUMUN		0.131	0.585E-01	2.240	0.193
	TOTUN		0.357E-03	0.708E-04	5.041	0.126
	L25		0.265	0.739E-01	3.580	0.216
	INTERCEPT		-0.464	0.687	-0.675	-0.120
	Adj. R-Square		0.299			
	Durbin-Watson		2.003			
Lock 25		234				
	BRGU		0.138E-02	0.195E-03	7.090	0.873
	TOTUN		0.212E-03	0.357E-04	5.930	0.133
	INTERCEPT		-0.202E-01	0.446	-0.453 E-01	-0.006
	Adj. R-Square		0.248			
	Durbin-Watson		1.640			
Peoria		240				
	AVGUN		0.421E-02	0.194E-02	2.176	0.137
	NUMUN		0.329	0.476E-01	6.921	0.534
	LAGRANGE		0.221	0.438E-01	5.059	0.256
	INTERCEPT		0.213	0.371	0.573	0.073
	Adj. R-Square		0.359			
	Durbin-Watson		1.738			
LaGrange		240				
	BRGU		0.301E-02	0.112E-02	2.700	0.812
	NUMUN		0.318	0.690E-01	4.621	0.327
	PEORIA		0.366	0.822E-01	4.454	0.317
	INTERCEPT		-1.546	1.058	-1.461	-0.456
	Adj. R-Square		0.294			
	Durbin-Watson		1.811			

[1] See Table 14 for definition of variables.

Table 17: Definition of Variables in Directed Graphs Featured in Figures 28a, 28b, 29a, 29b, 30a and 30b.

Variable	Definition
BRSM	South Minnesota barge rate in month *i*
LBRSM	South Minnesota barge rate lagged one month
LLBRSM	South Minnesota barge rate lagged two months
BRNI	North Iowa barge rate in month *i*
LBRNI	North Iowa barge rate lagged one month
LLBRNI	North Iowa barge rate lagged two months
BRSP	South of Peoria barge rate in month *i*
LBRSP	South of Peoria barge rate lagged one month
PEO-LA	Accumulated barge delay at Peoria and LaGrange locks in month *i*
TOB-SR	Accumulated barge delay at Thomas O'Brien through Starved Rock locks in month *i*
L1-L8	Accumulated barge delay at locks 1 through 8 in month *i*
L9-L17	Accumulated barge delay at locks 9 through 17 in month *i*
L18-L27	Accumulated barge delay at locks 18 through 27 in month *i*
L18	Barge delay at lock 18 in month *i*
L19	Barge delay at lock 19 in month *i*
L20	Barge delay at lock 20 in month *i*
L21	Barge delay at lock 21 in month *i*
L22	Barge delay at lock 22 in month *i*
L24	Barge delay at lock 24 in month *i*
L25	Barge delay at lock 25 in month *i*
L26	Barge delay at lock 26 (Melvin Price) in month *i*
L27	Barge delay at lock 27 in month *i*
Peoria	Barge delay at Peoria lock in month *i*
LaGrange	Barge delay at LaGrange lock in month *i*

Table 18a: Estimated Barge Rate Equation for South Minnesota Rate, Accumulated Lock Delay by River Segment as Explanatory Variable[1].

Variables	Coefficient	Standard Error	t-ratio	Elasticity
LBRSM	0.907	0.751E-01	12.09	0.906
LLBRSM	-0.191	0.754E-01	-2.527	-0.190
L18-L27	***0.210E-01***	***0.927E-02***	***2.269***	***0.059***
INTERCEPT	2.512	0.633	3.966	0.224
Obs (N)	179			
Adj. R-Square	0.622			
Durbin-Watson	1.981			

Table 18b: Estimated Barge Rate Equation for South Minnesota Rate, Individual Lock Delay as Explanatory Variable[1].

Variables	Coefficient	Standard Error	t-ratio	Elasticity
LBRSM	0.909	0.749E-01	12.12	0.908
LLBRSM	-0.201	0.749E-01	-2.682	-0.200
L22	***0.751E-01***	***0.533E-01***	***1.410***	***0.033***
L25	***0.733E-01***	***0.540E-01***	***1.357***	***0.024***
INTERCEPT	2.641	0.612	4.312	0.235
Obs (N)	179			
Adj. R-Square	0.621			
Durbin-Watson	2.013			

[1] See Table 17 for definition of variables.

Table 19a: Estimated Barge Rate Equation for North Iowa Rate, Accumulated Lock Delay by River Segment as Explanatory Variable[1]

Variables	Coefficient	Standard Error	t-ratio	Elasticity
LBRNI	0.880	0.752E-01	11.71	0.879
LLBRNI	-0.228	0.752E-01	-3.039	-0.228
L18-L27	***0.110E-01***	***0.819E-02***	***1.347***	***0.038***
INTERCEPT	2.918	0.581	5.025	0.311
Obs (N)	179			
Adj. R-Square	0.548			
Durbin-Watson	2.009			

Table 19b. Estimated Barge Rate Equation for North Iowa Rate, Individual Lock Delay as Explanatory Variable[1]

Variables	Coefficient	Standard Error	t-ratio	Elasticity
LBRNI	0.873	0.753E-01	11.58	0.872
LLBRNI	-0.223	0.752E-01	-2.972	-0.223
L26	***0.231E-01***	***0.139E-01***	***1.658***	***0.016***
INTERCEPT	3.143	0.5343	5.884	0.335
Obs (N)	179			
Adj. R-Square	0.550			
Durbin-Watson	1.977			

[1] See Table 17 for definition of variables.

Table 20a: Estimated Barge Rate Equation for South of Peoria Rate, Accumulated Lock Delay by River Segment as Explanatory Variable[1].

Variables	Coefficient	Standard Error	t-ratio	Elasticity
LBRSP	0.696	0.443E-01	15.70	0.696
PEO-LA	***0.194E-01***	***0.106E-01***	***1.822***	***0.016***
L26-L27	***0.289E-01***	***0.928E-02***	***3.118***	***0.034***
INTERCEPT	1.870	0.344	5.432	0.253
Obs (N)	240			
Adj. R-Square	0.546			
Durbin-Watson	1.808			

Table 20b. Estimated Barge Rate Equation for South of Peoria Rate, Individual Lock Delay as Explanatory Variable[1].

Variables	Coefficient	Standard Error	t-ratio	Elasticity
LBRSP	0.694	0.447E-01	15.54	0.695
PEORIA	***0.439E-01***	***0.209E-01***	***2.099***	***0.017***
L26	***0.277E-01***	***0.103E-01***	***2.694***	***0.024***
INTERCEPT	1.950	0.343	5.684	0.264
Obs (N)	240			
Adj. R-Square	0.543			
Durbin-Watson	1.785			

[1] See Table 17 for definition of variables

Figure 1: Map of Upper Mississippi and Illinois Rivers with Locks and Dams.

Upper Mississippi River and Illinois Waterway Navigation Systems.

Figure 2: Lock Operations at Lock 18.

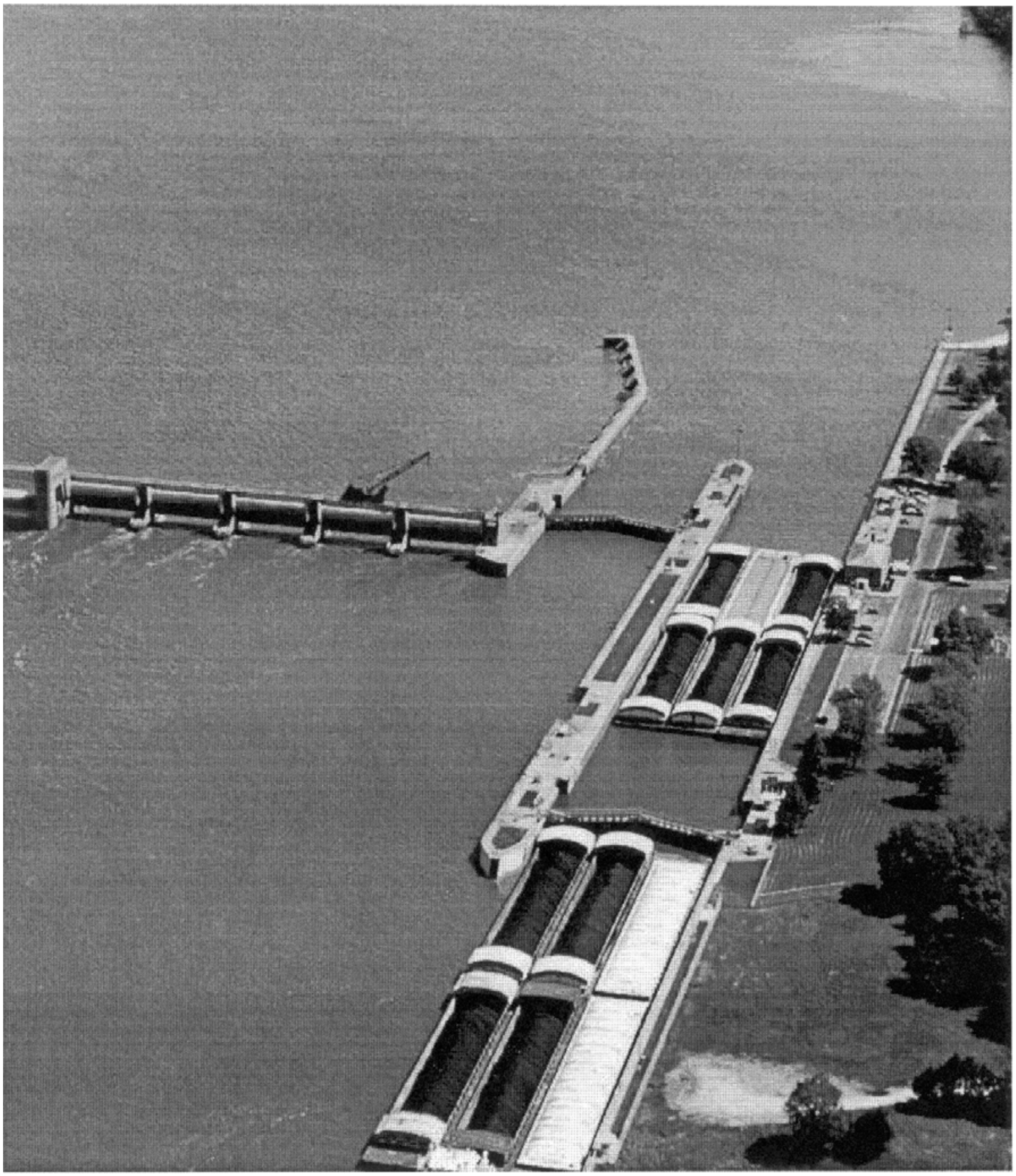
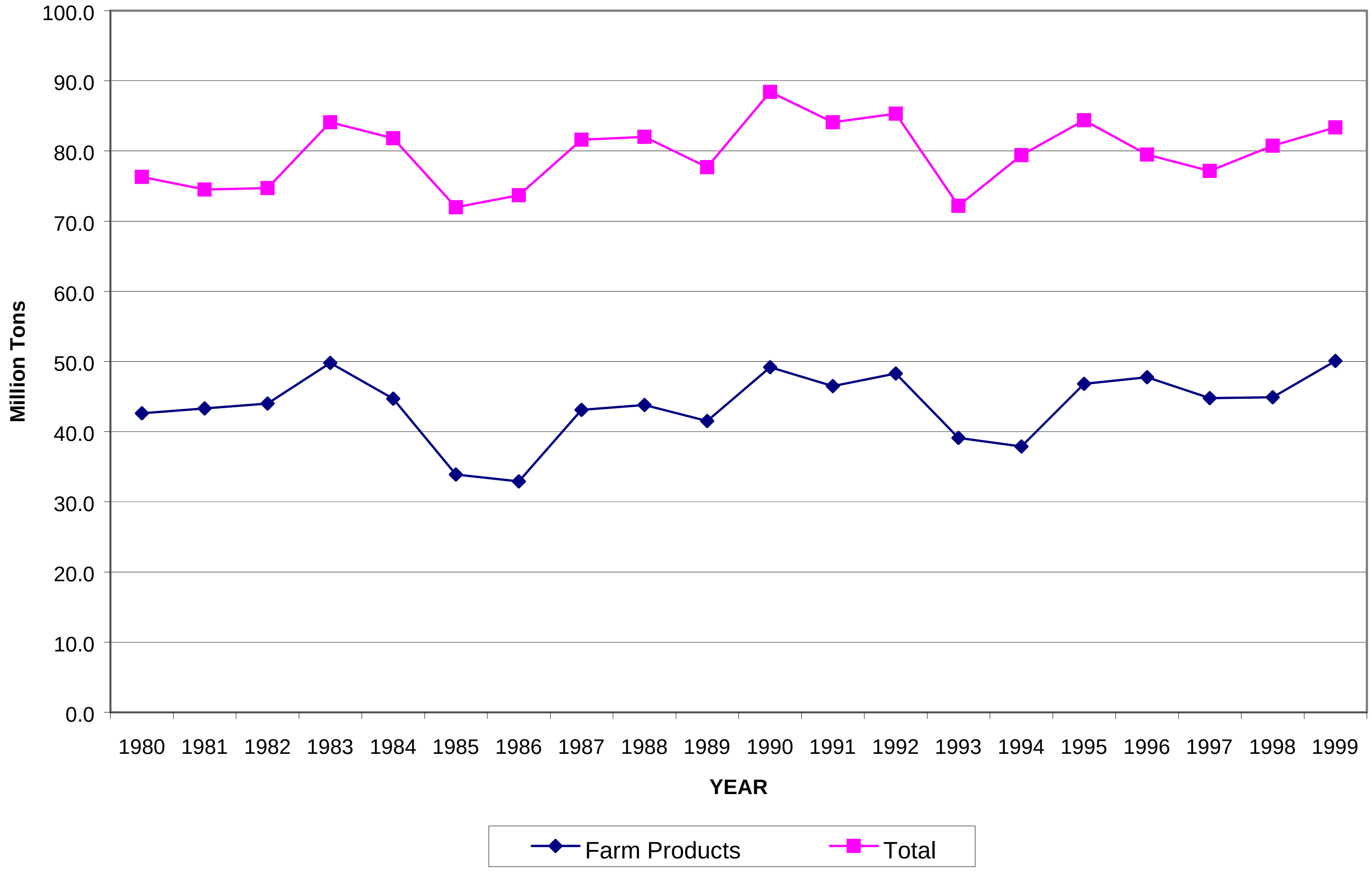
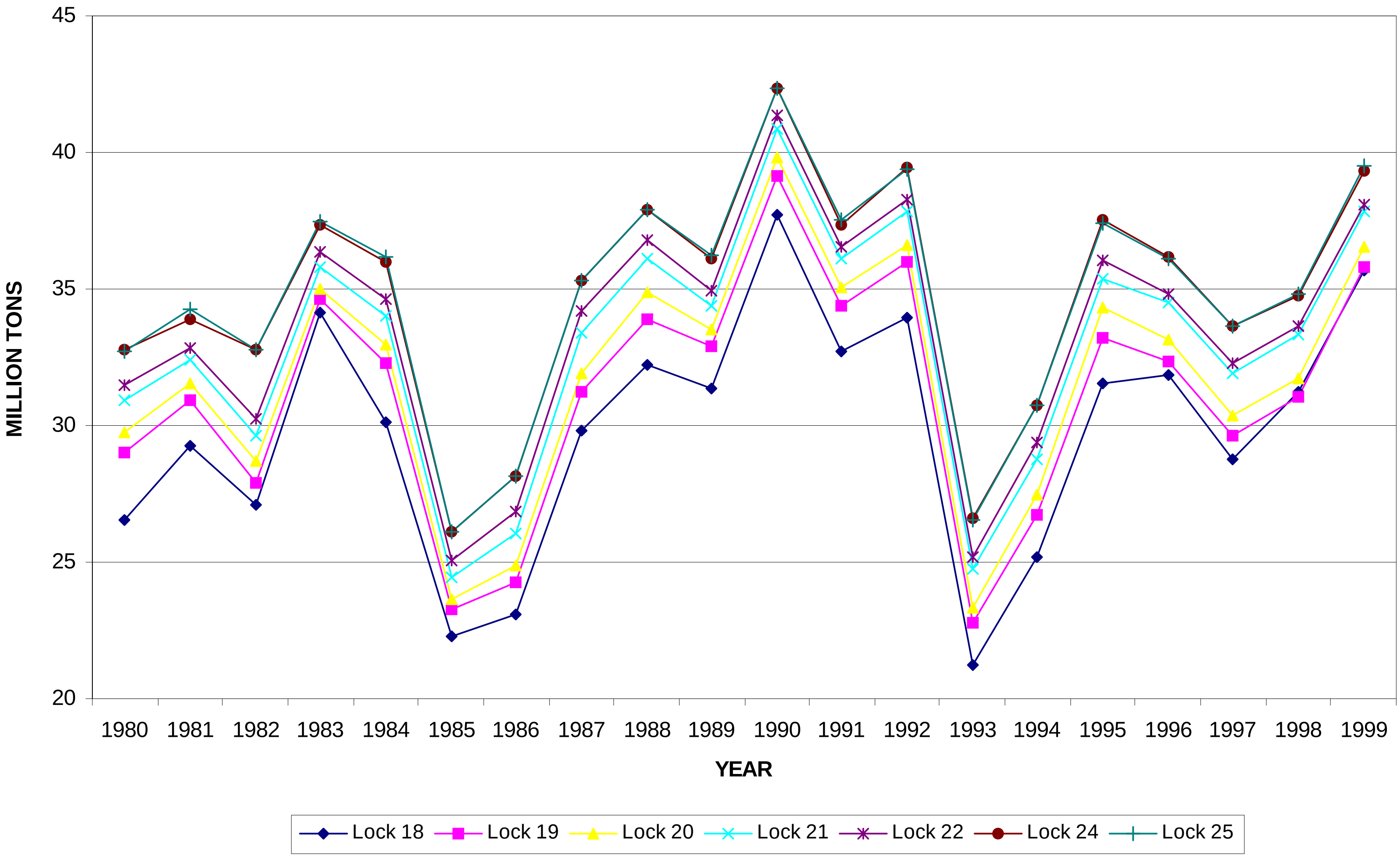


Figure 3: Total and Farm Product Traffic on the Upper Mississippi River, 1980-1999.



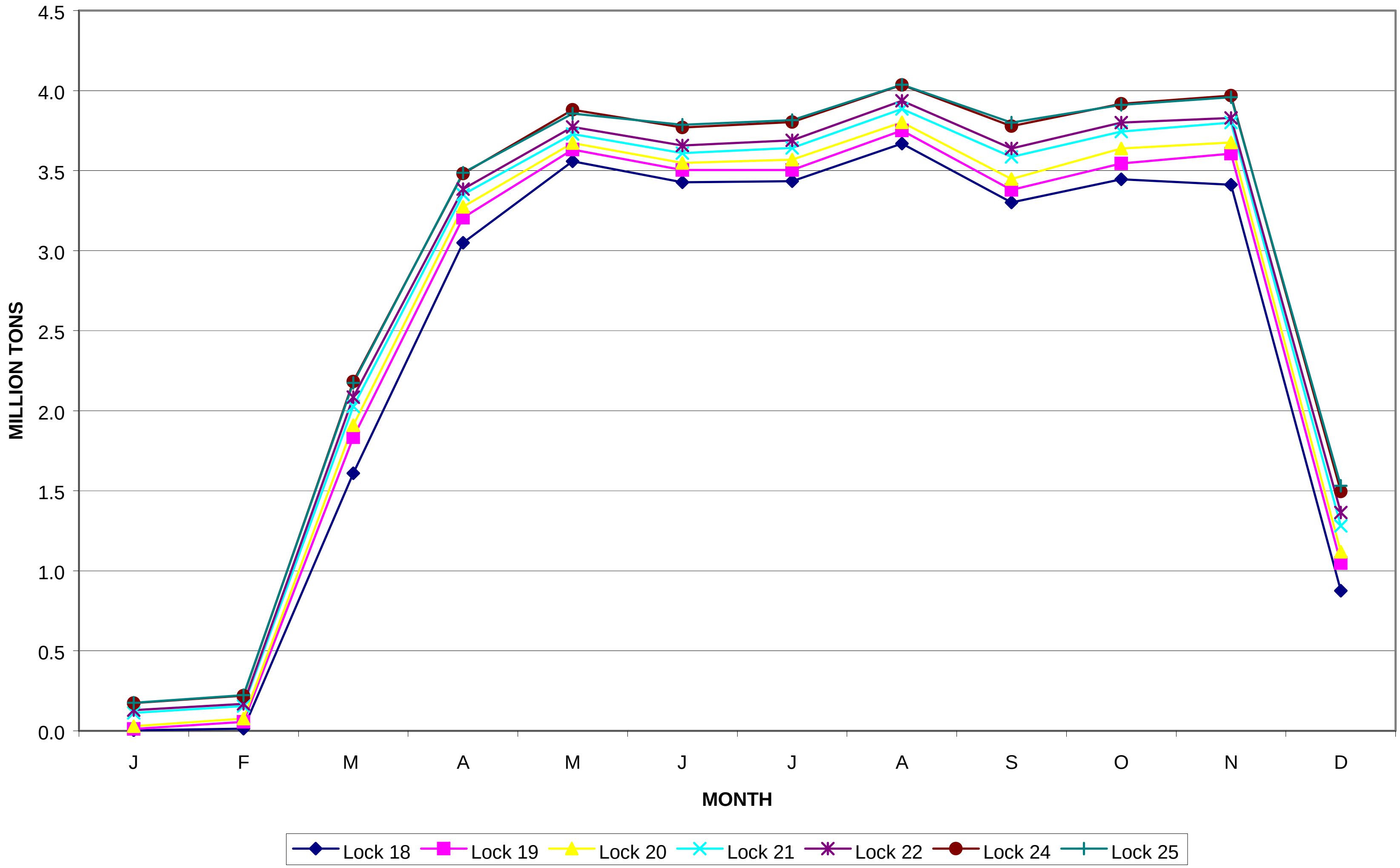
Sources: USACE, *The 1997 Inland Waterway Review*, IWR Report 97-R-3, September 1997 (draft).
USACE, Waterborne Commerce Statistics (2002)

Figure 4: Annual Tonnage Locked by Selected Upper Mississippi River Locks, 1980-1999.



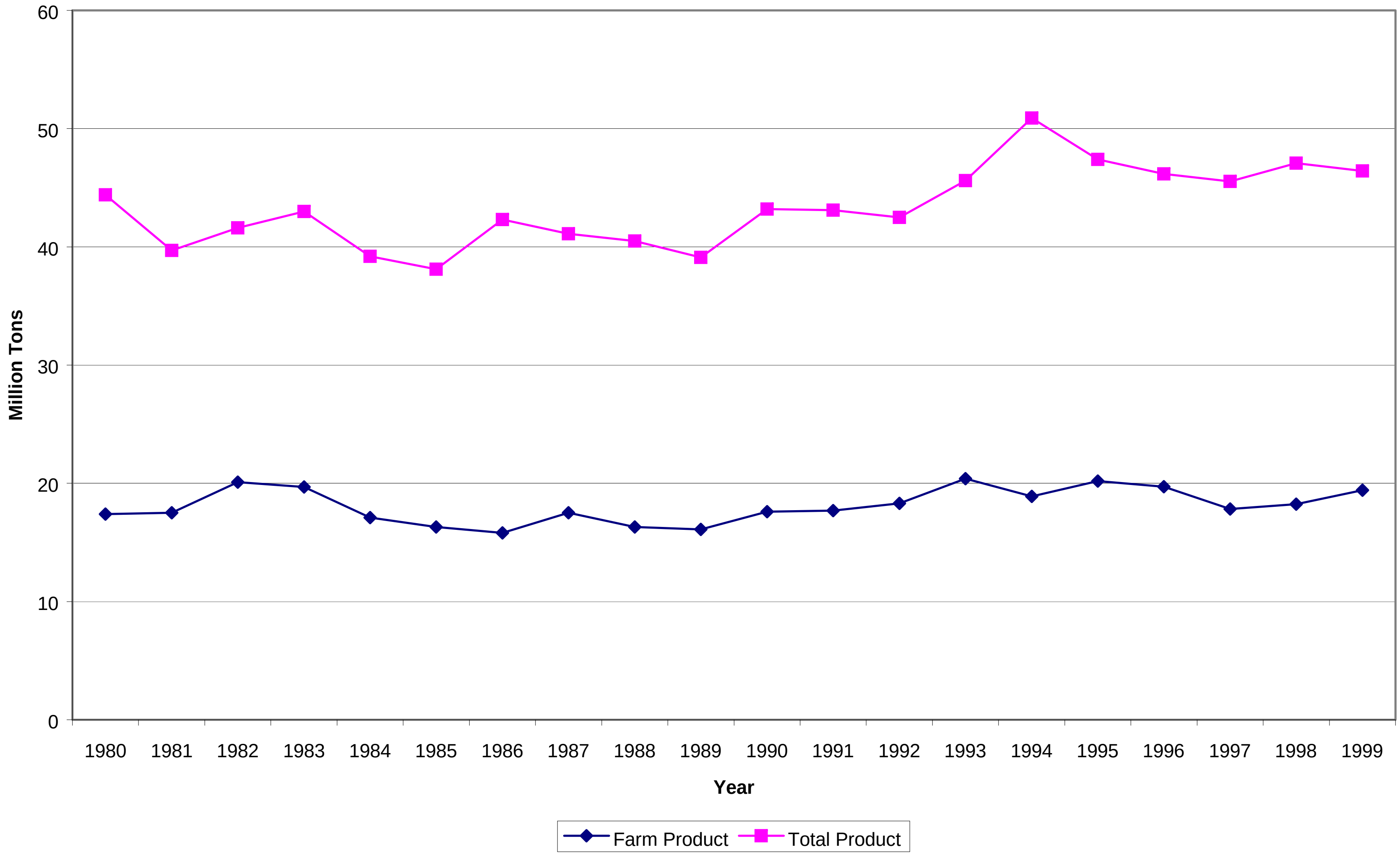
Source: USACE, Lock Performance Monitoring System Data

Figure 5: Monthly Traffic at Selected Locks on the Upper Mississippi River, 1980-1999.



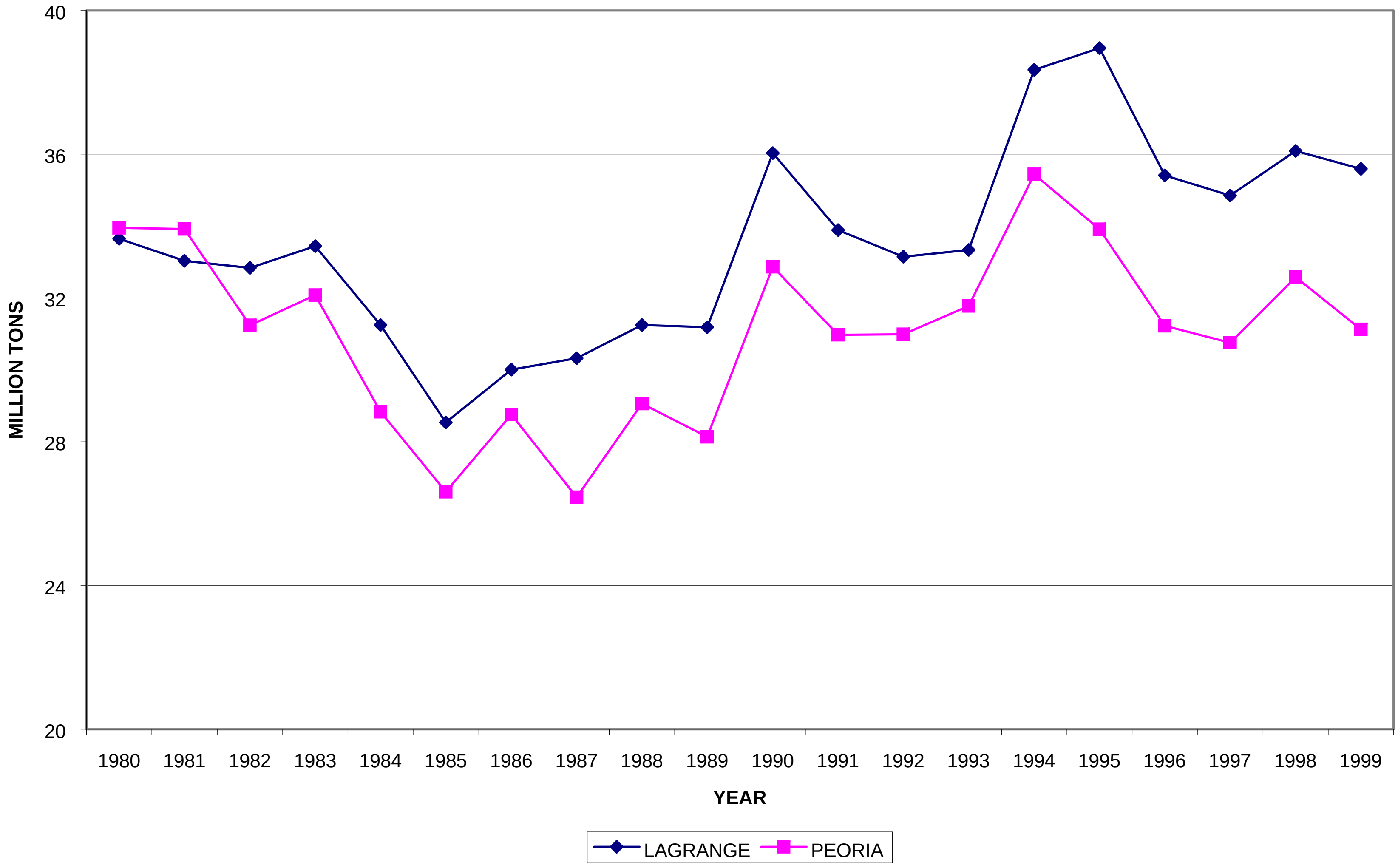
Source: USACE, Lock Performance Monitoring System Data

Figure 6: Total and Farm Product Traffic on Illinois River, 1980-1999.



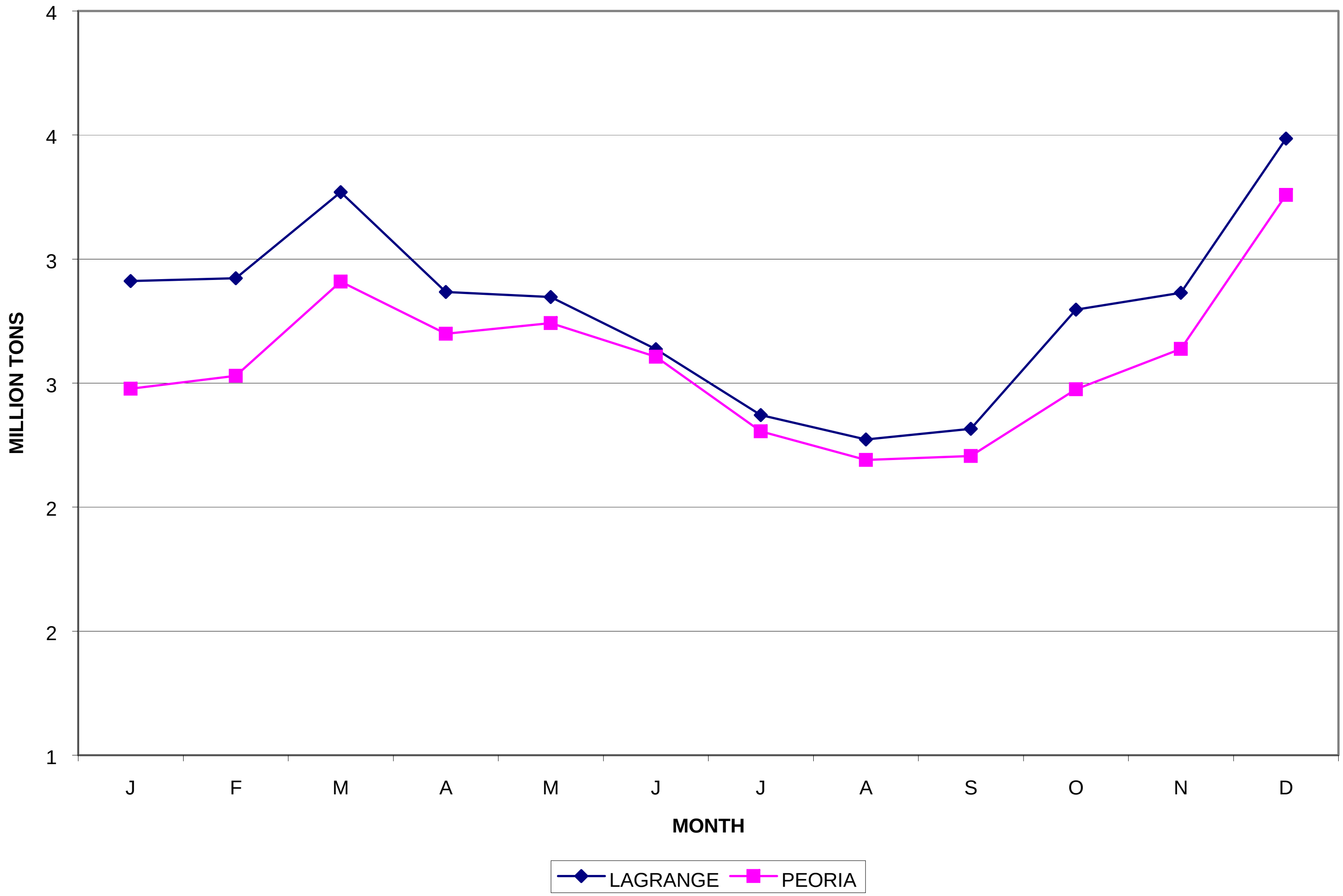
Source: USACE, *The 1997 Inland Waterway Review*, IWR Report 97-R-3, September 1997 (draft).
USACE, Waterborne Commerce Statistics (2002)

Figure 7: Annual Tonnage Locked by Selected Illinois River Locks, 1980-1999.



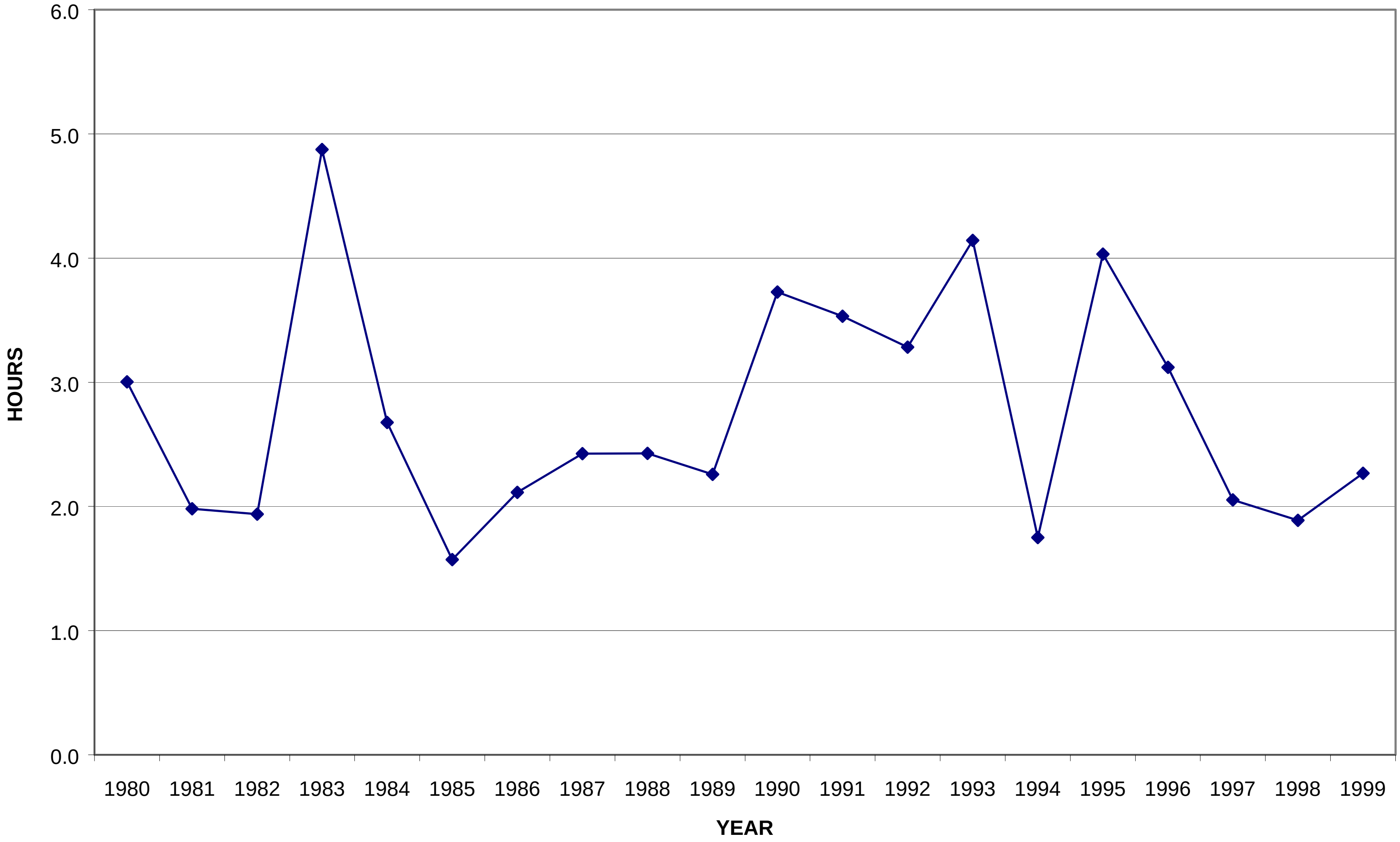
Source: USACE, Lock Performance Monitoring System Data

Figure 8: Monthly Traffic at Selected Locks on Illinois River, 1980-1999.



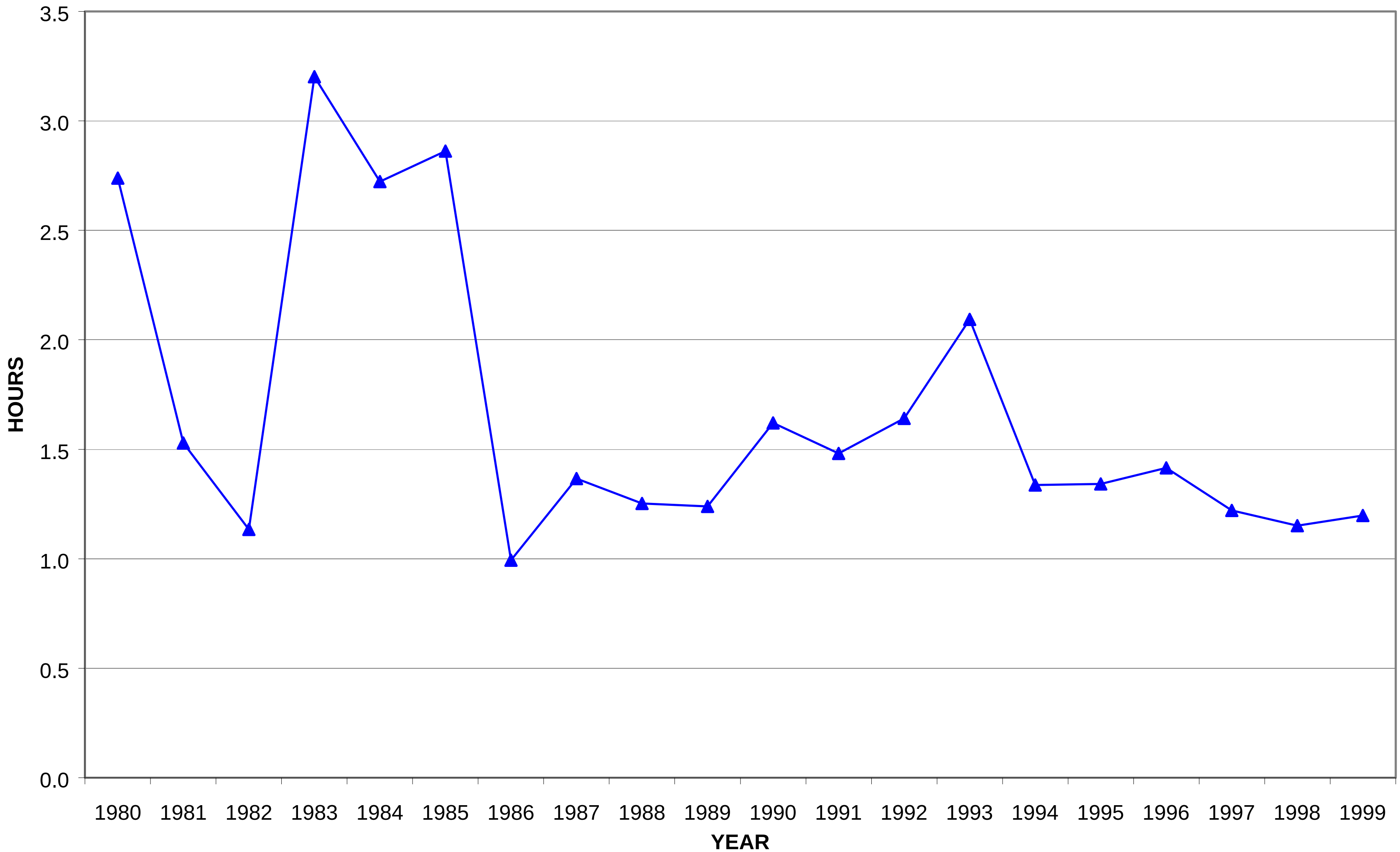
Source: USACE, Lock Performance Monitoring System Data

Figure 9: Average Delay of Delayed Vessels at Upper Mississippi River's Lock 18 in Hours, 1980-1999.



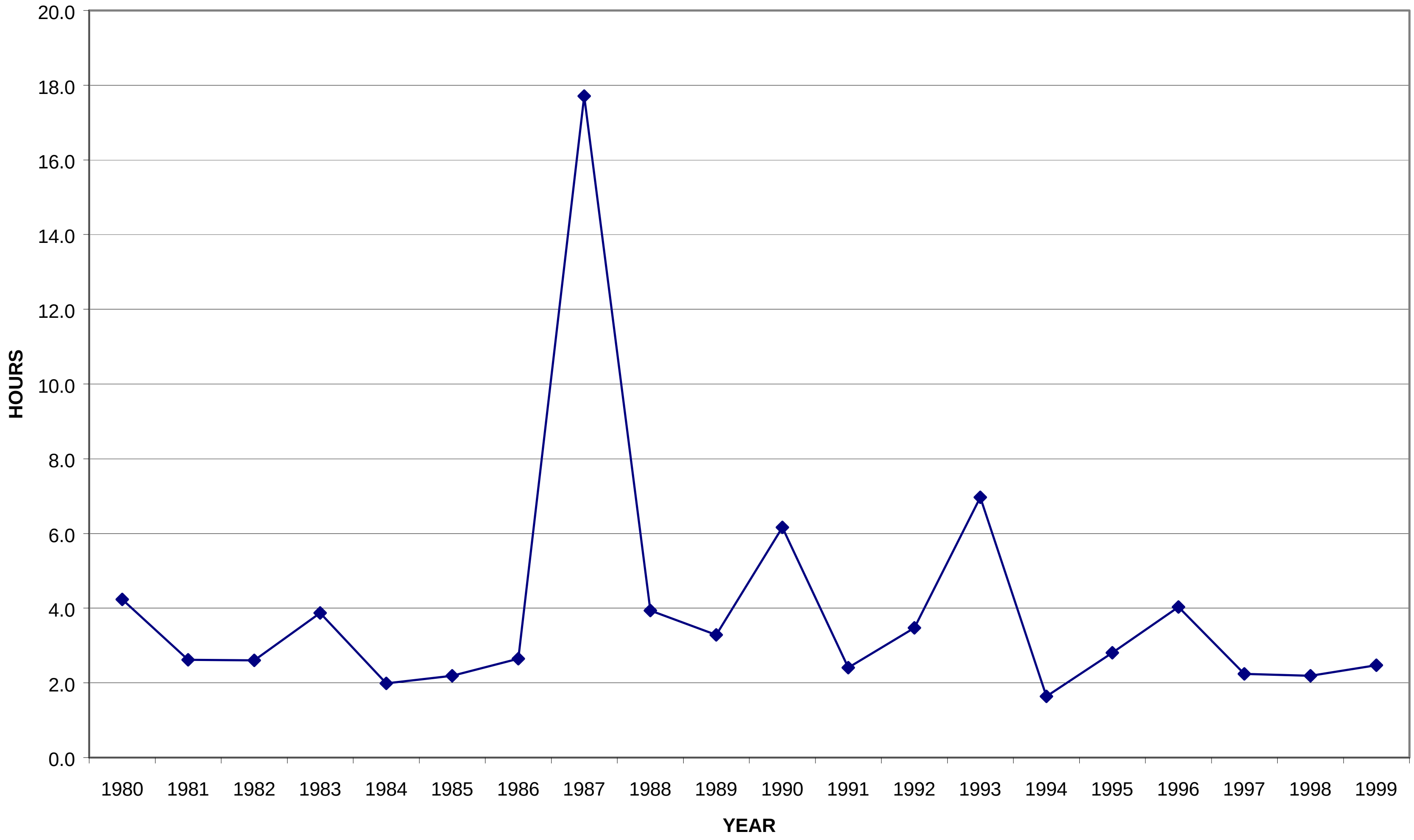
Source: USACE, Lock Performance Monitoring System Data

Figure 10: Average Delay of Delayed Vessels at Upper Mississippi River's Lock 19 in Hours, 1980-1999.



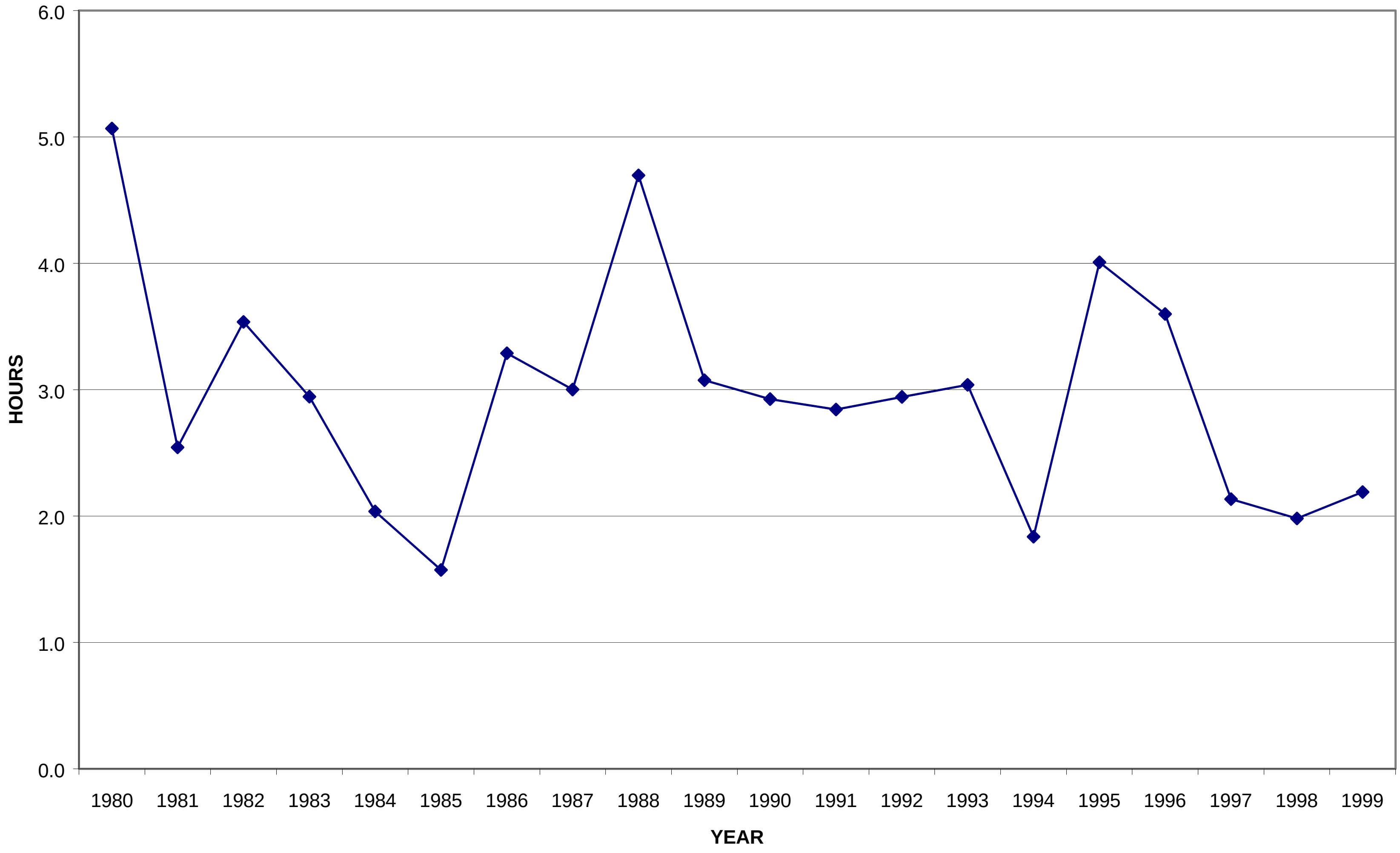
Source: USACE, Lock Performance Monitoring System Data

Figure 11: Average Delay of Delayed Vessels at Upper Mississippi River's Lock 20 in Hours, 1980-1999.



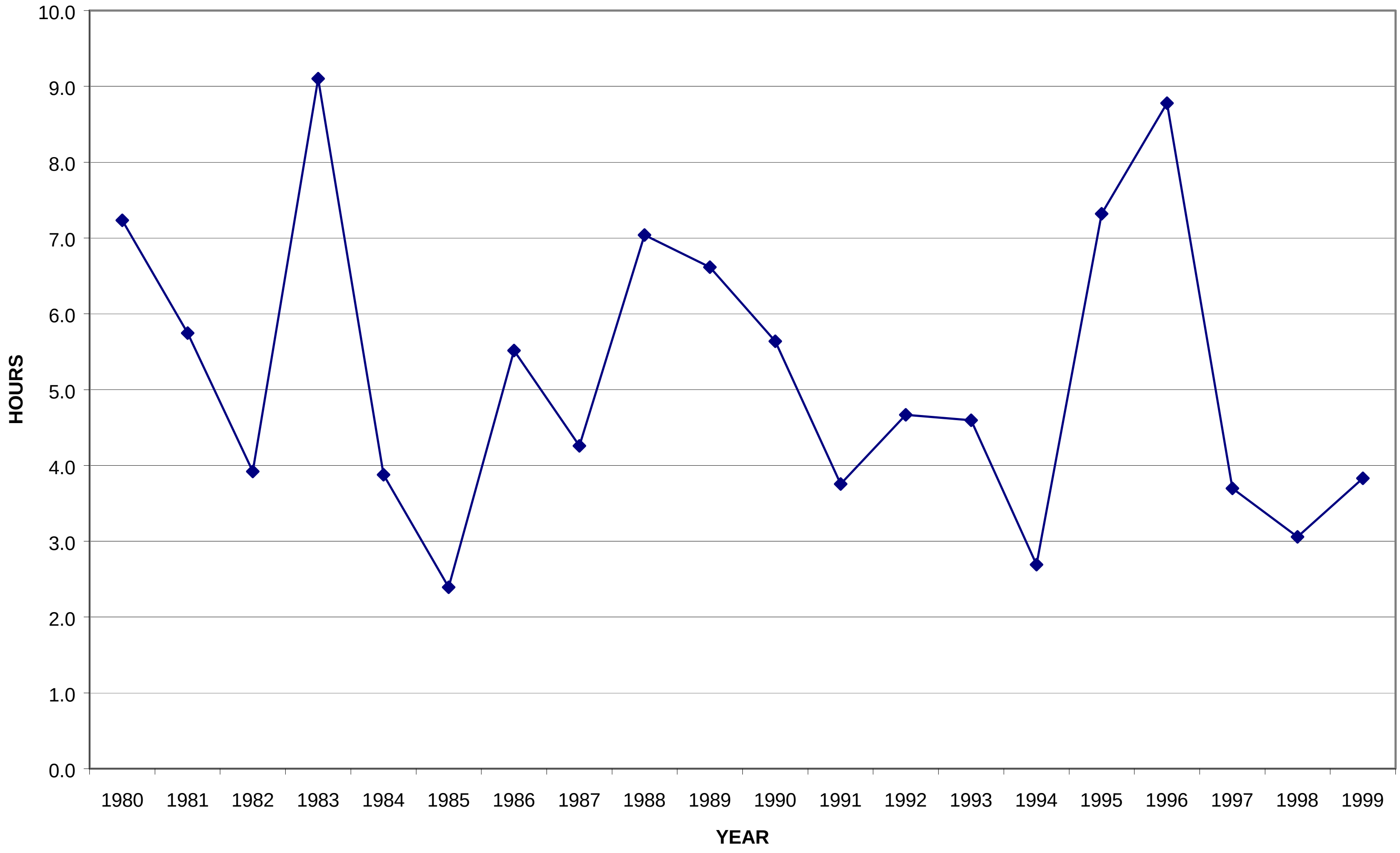
Source: USACE, Lock Performance Monitoring System Data

Figure 12: Average Delay of Delayed Vessels at Upper Mississippi River's Lock 21 in Hours, 1980-1999.



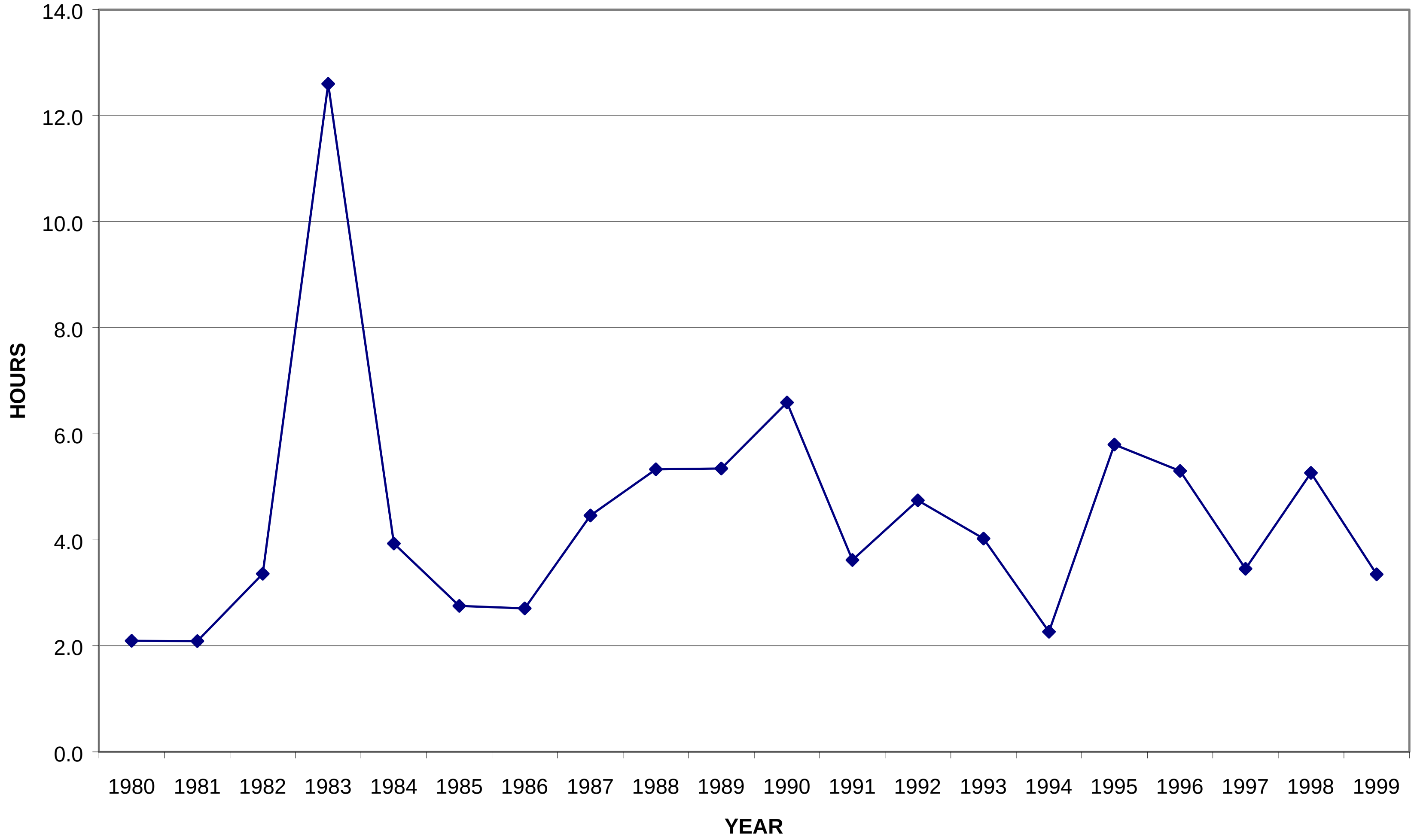
Source: USACE, Lock Performance Monitoring System Data

Figure 13: Average Delay of Delayed Vessels at Upper Mississippi River's Lock 22 in Hours, 1980-1999.



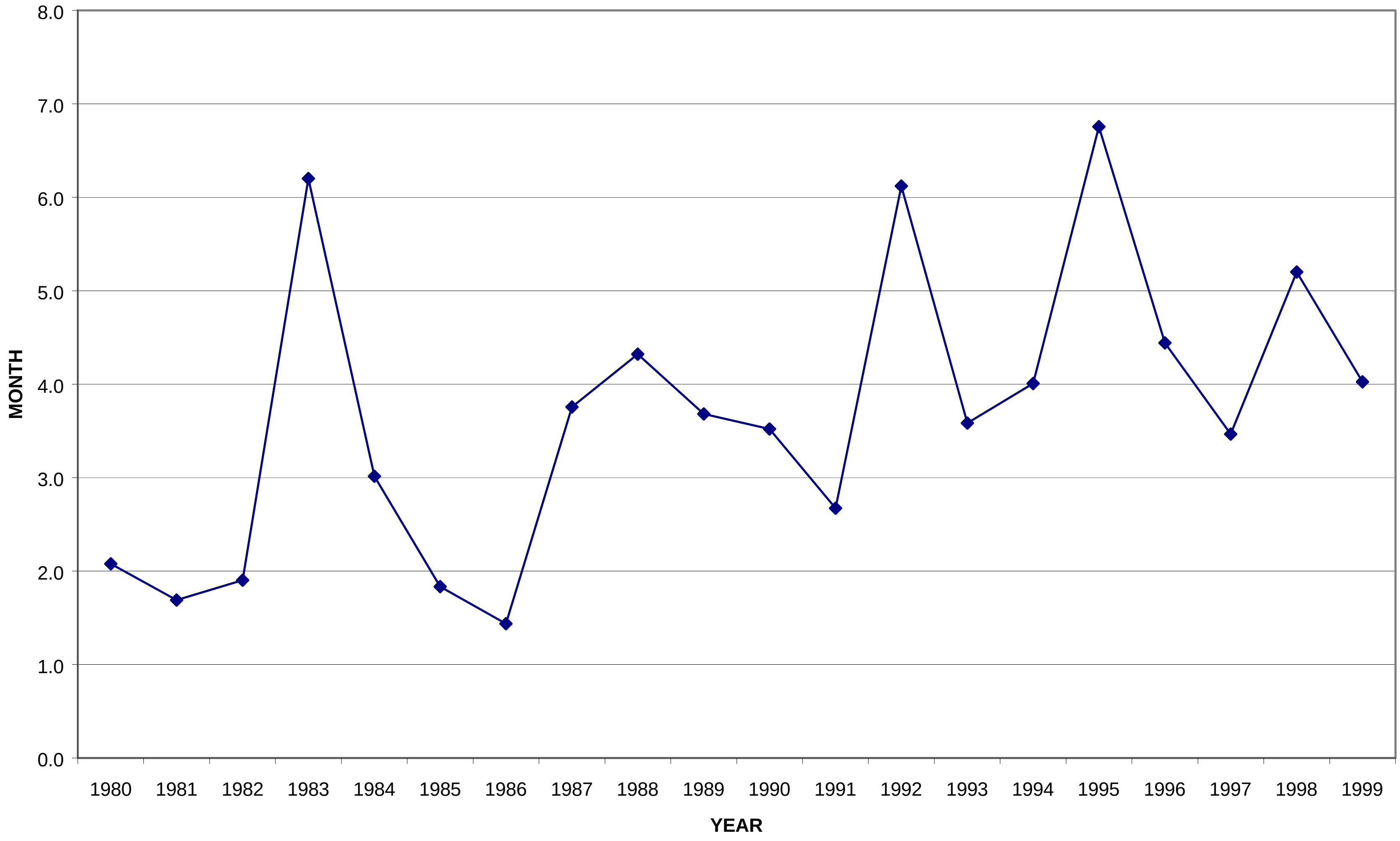
Source: USACE, Lock Performance Monitoring System Data

Figure 14: Average Delay of Delayed Vessels at Upper Mississippi River's Lock 24 in Hours, 1980-1999.



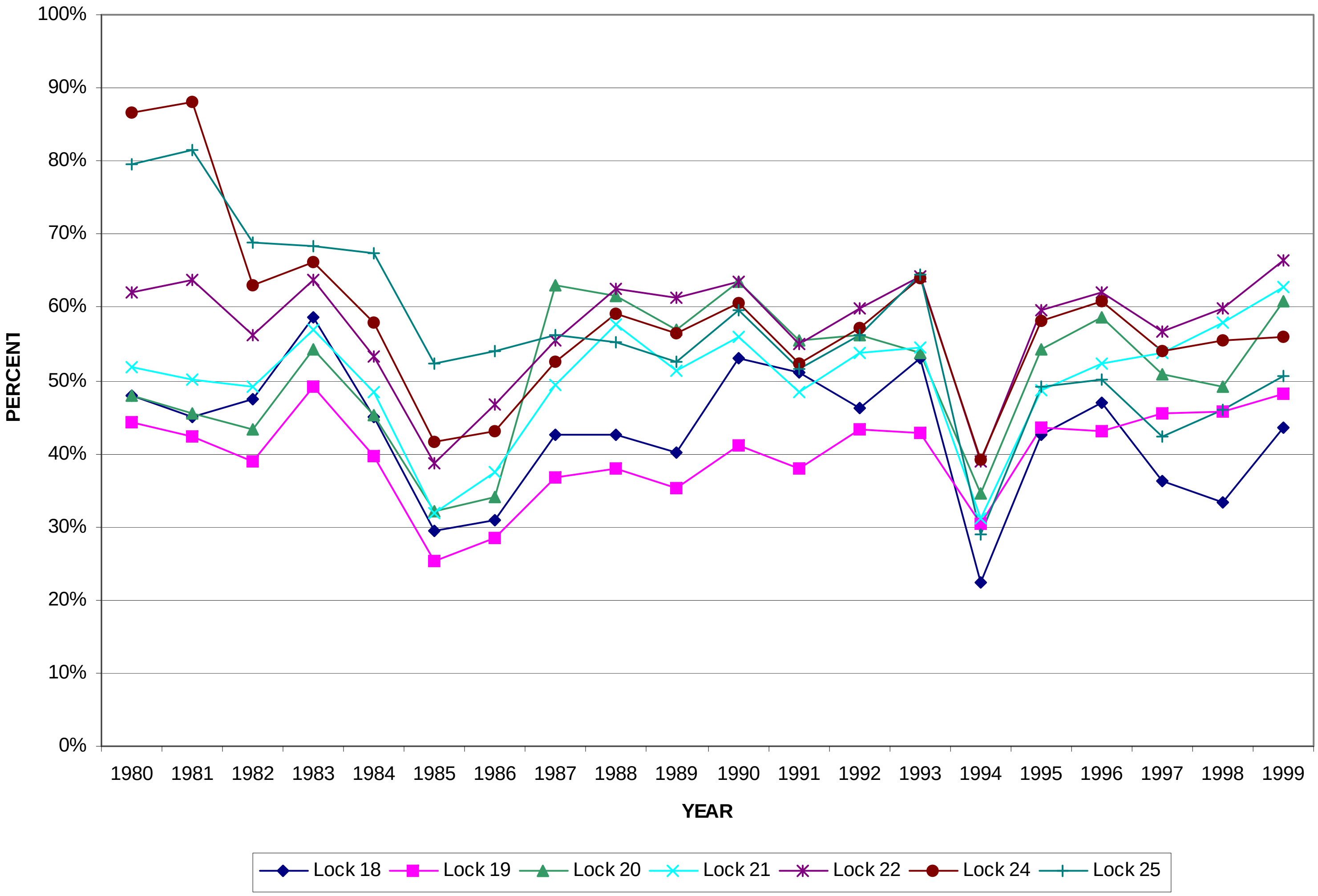
Source: USACE, Lock Performance Monitoring System Data

Figure 15: Average Delay of Delayed Vessels at Upper Mississippi River's Lock 25 in Hours, 1980-1999.



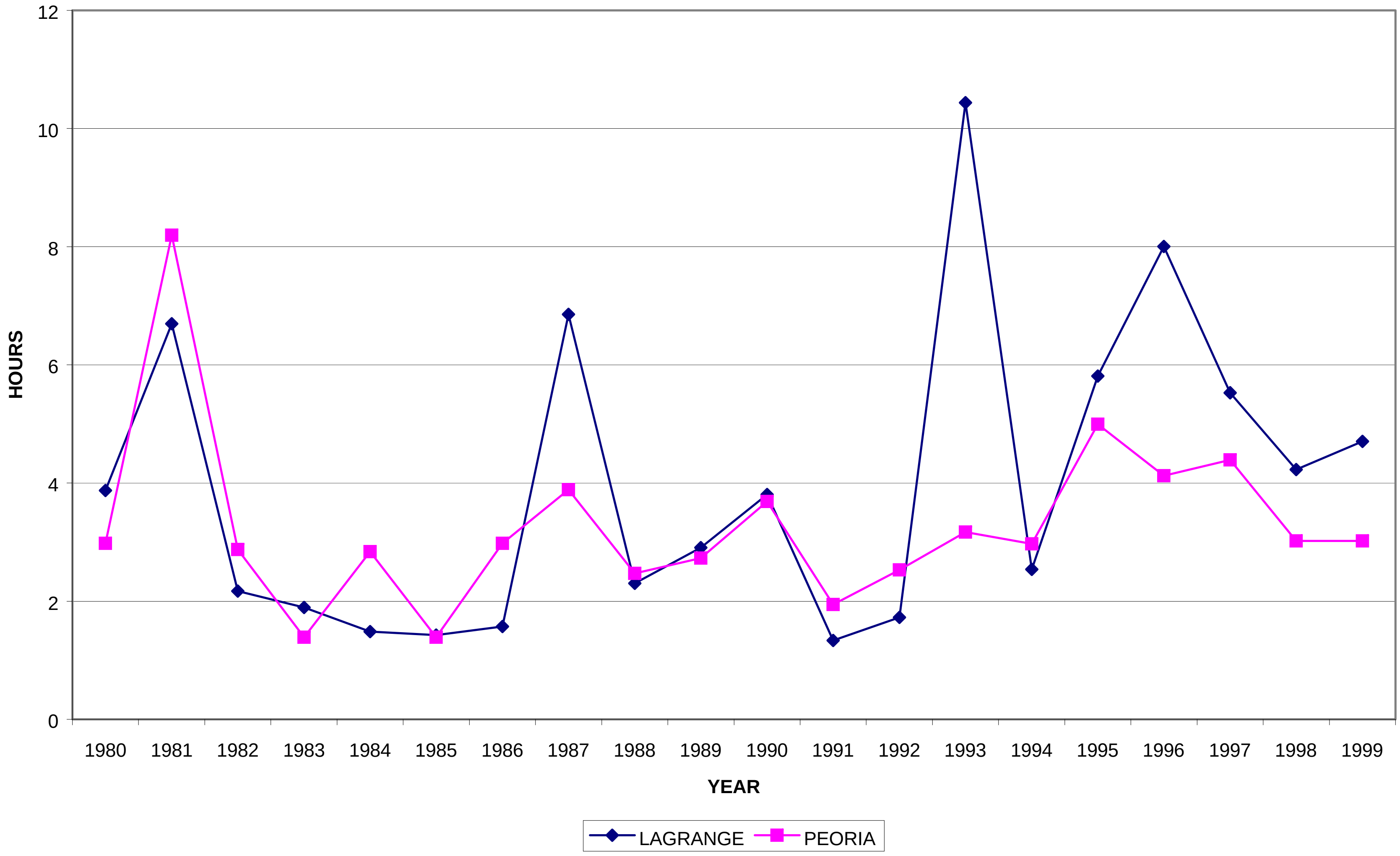
Source: USACE, Lock Performance Monitoring System Data

Figure 16: Percent of Vessels Delayed at Selected Upper Mississippi River Locks, 1980-1999.



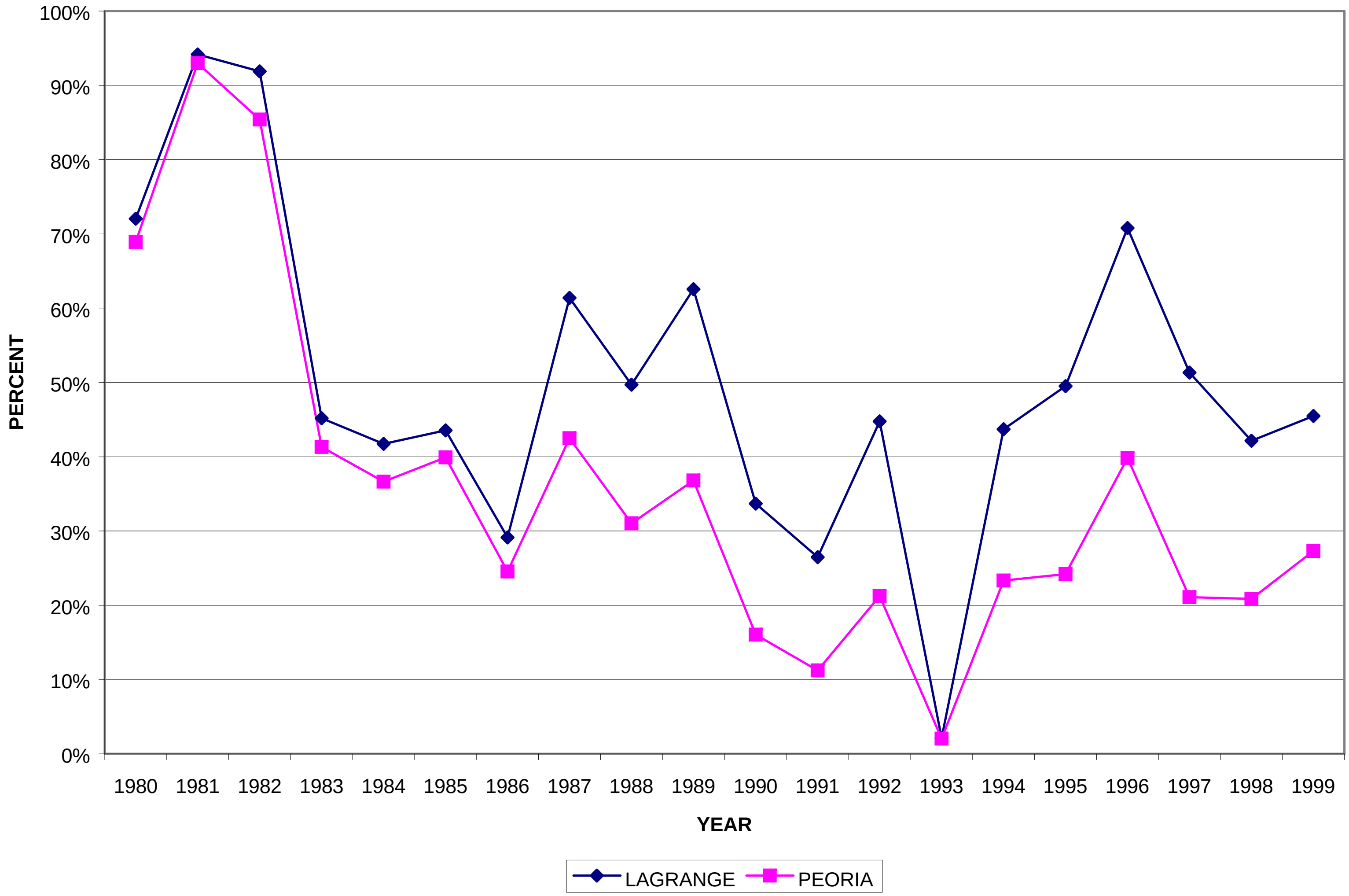
Source: USACE, Lock Performance Monitoring System Data

Figure 17: Average Delay of Delayed Vessels at Selected Illinois River Locks, 1980-1999.



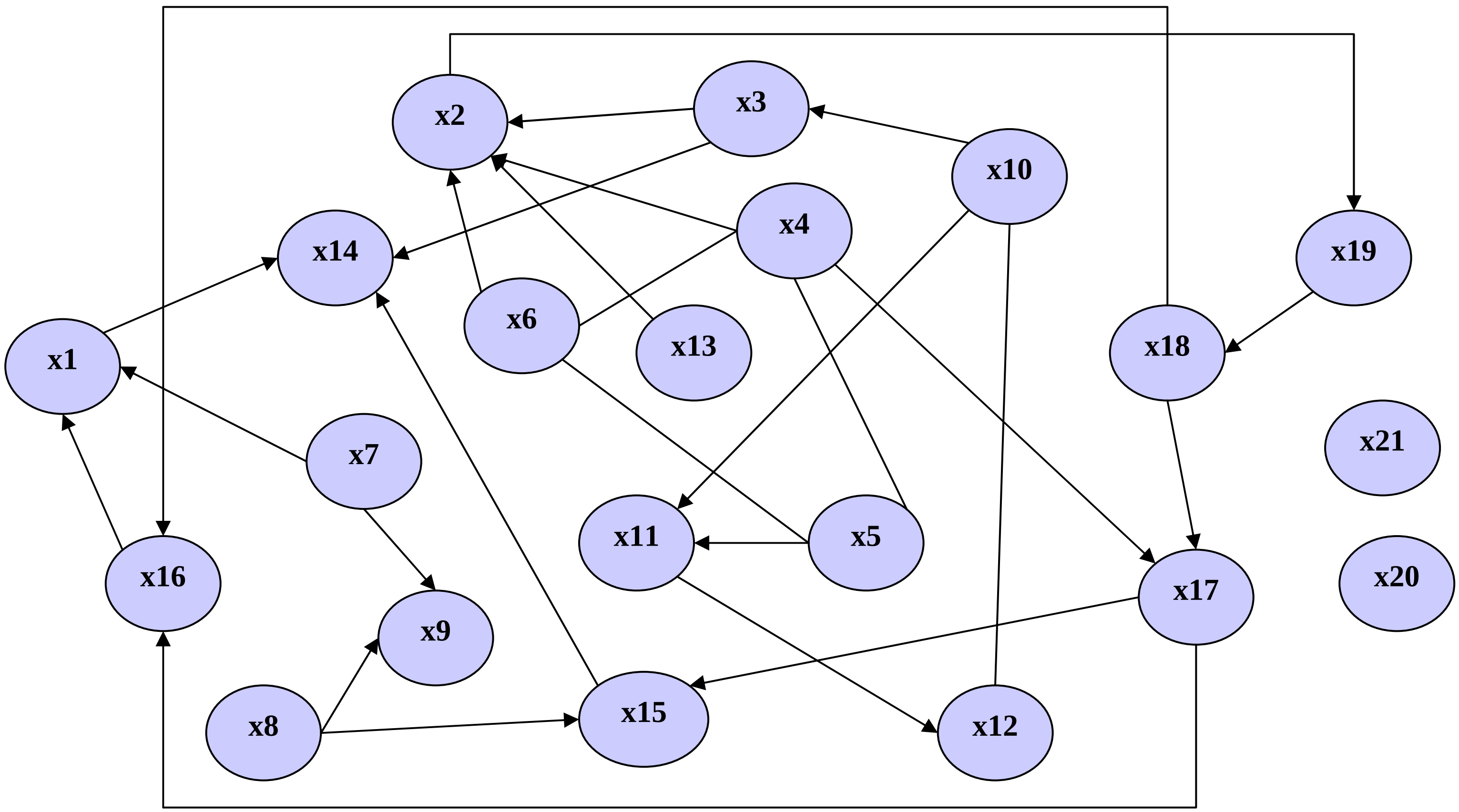
Source: USACE, Lock Performance Monitoring System Data

Figure 18: Percent of Vessels Delayed at Selected Illinois River Locks, 1980-1999.



Source: USACE, Lock Performance Monitoring System Data

Figure 19: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Upper Mississippi River's Lock 18, 5% Significance Level.

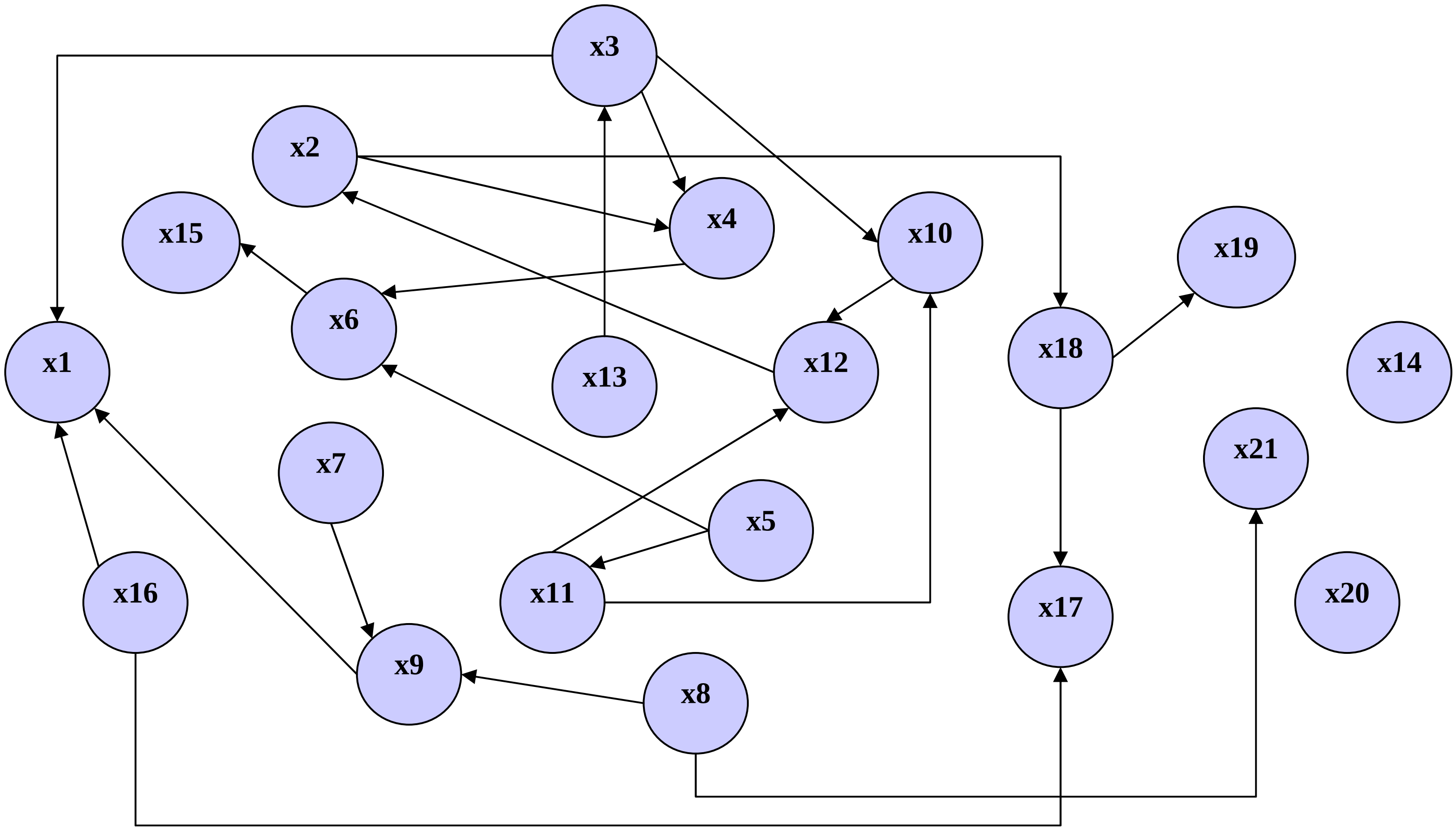


See Table 14 for definition of variables

x1	*x2*	*x3*	*x4*	*x5*	*x6*	*x7*	*x8*	*x9*	*x10*	*x11*	*x12*	*x13*
ADELDV	***BRGL***	***BRGU***	***COML***	***RECV***	***TOTOP***	***NUMUN***	***AVGUN***	***TOTUN***	***SPRING***	***SUMMER***	***FALL***	***WINTER***

x14	*x15*	*x16*	*x17*	*x18*	*x19*	*x20*	*x21*
L19	***L20***	***L21***	***L22***	***L24***	***L25***	***L26***	***L27***

Figure 20: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Upper Mississippi River's Lock 19, 5% Significance Level.

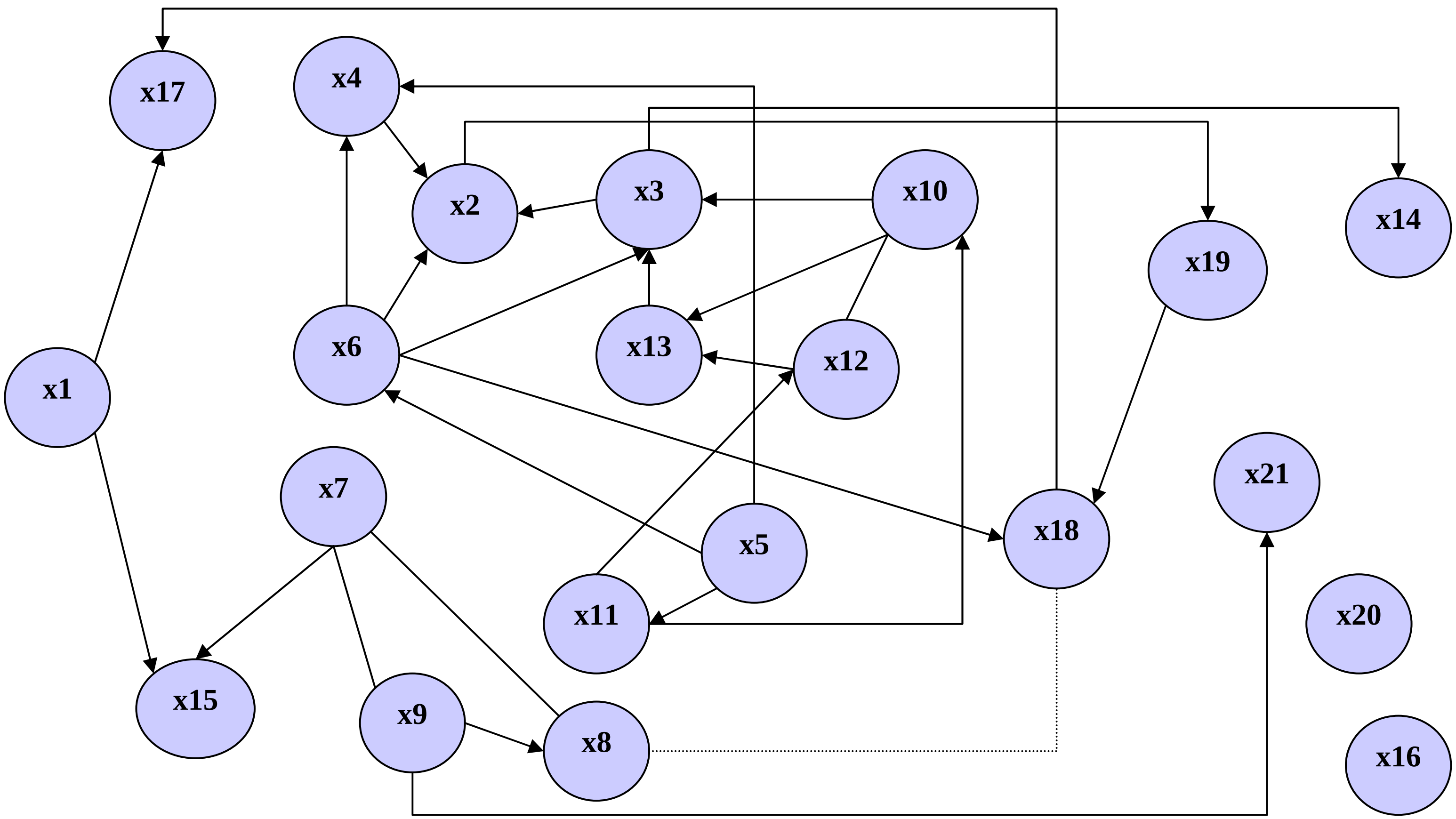


See Table 14 for definition of variables

x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
ADELDV	BRGL	BRGU	COML	RECV	TOTOP	NUMUN	AVGUN	TOTUN	SPRING	SUMMER	FALL	WINTER

x14	x15	x16	x17	x18	x19	x20	x21
L18	L20	L21	L22	L24	L25	L26	L27

Figure 21: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Upper Mississippi River's Lock 20, 5% Significance Level.

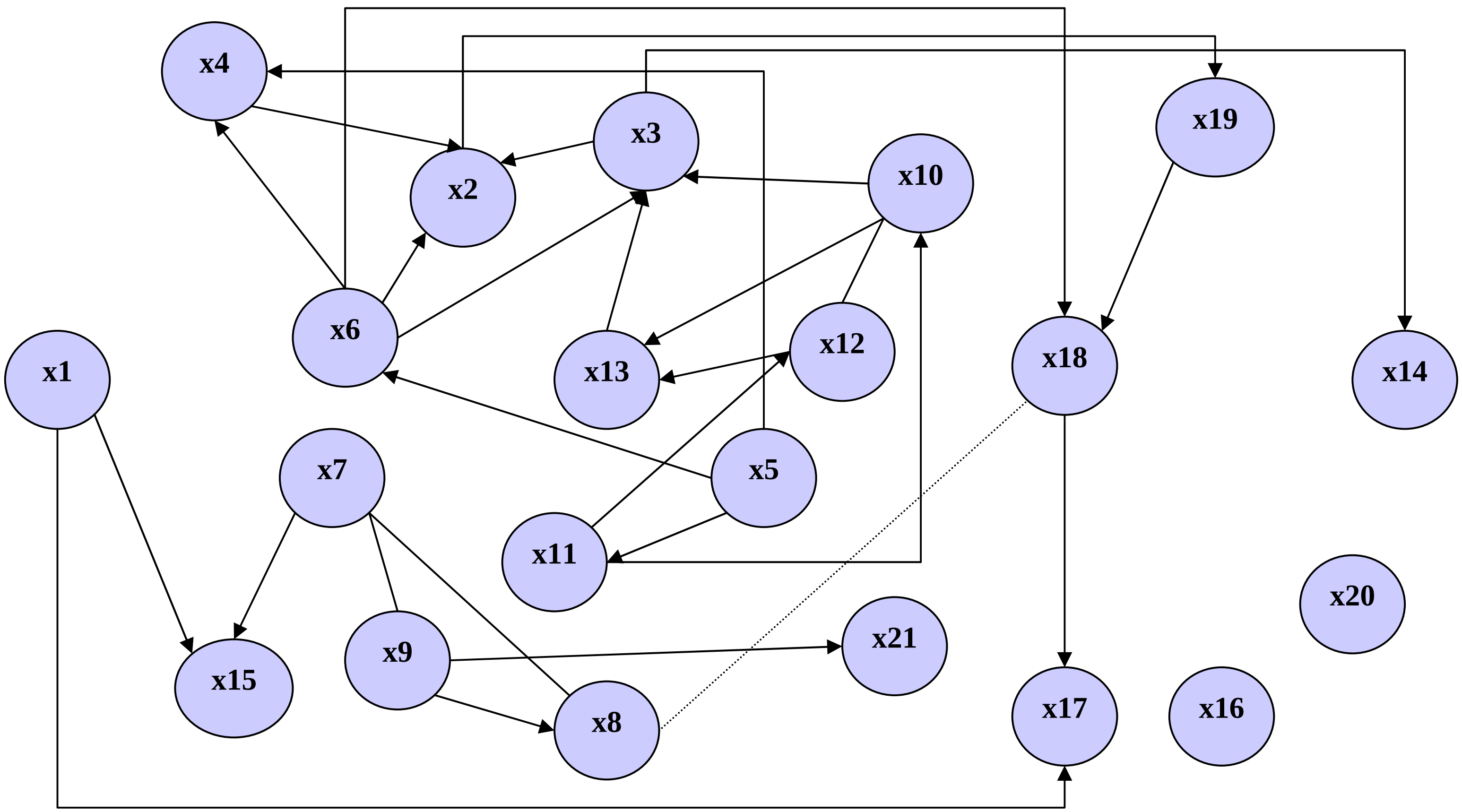


See Table 14 for definition of variables

x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
ADELDV	BRGL	BRGU	COML	RECV	TOTOP	NUMUN	AVGUN	TOTUN	SPRING	SUMMER	FALL	WINTER

x14	x15	x16	x17	x18	x19	x20	x21
L18	L20	L21	L22	L24	L25	L26	L27

Figure 22: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Upper Mississippi River's Lock 21, 5% Significance Level.

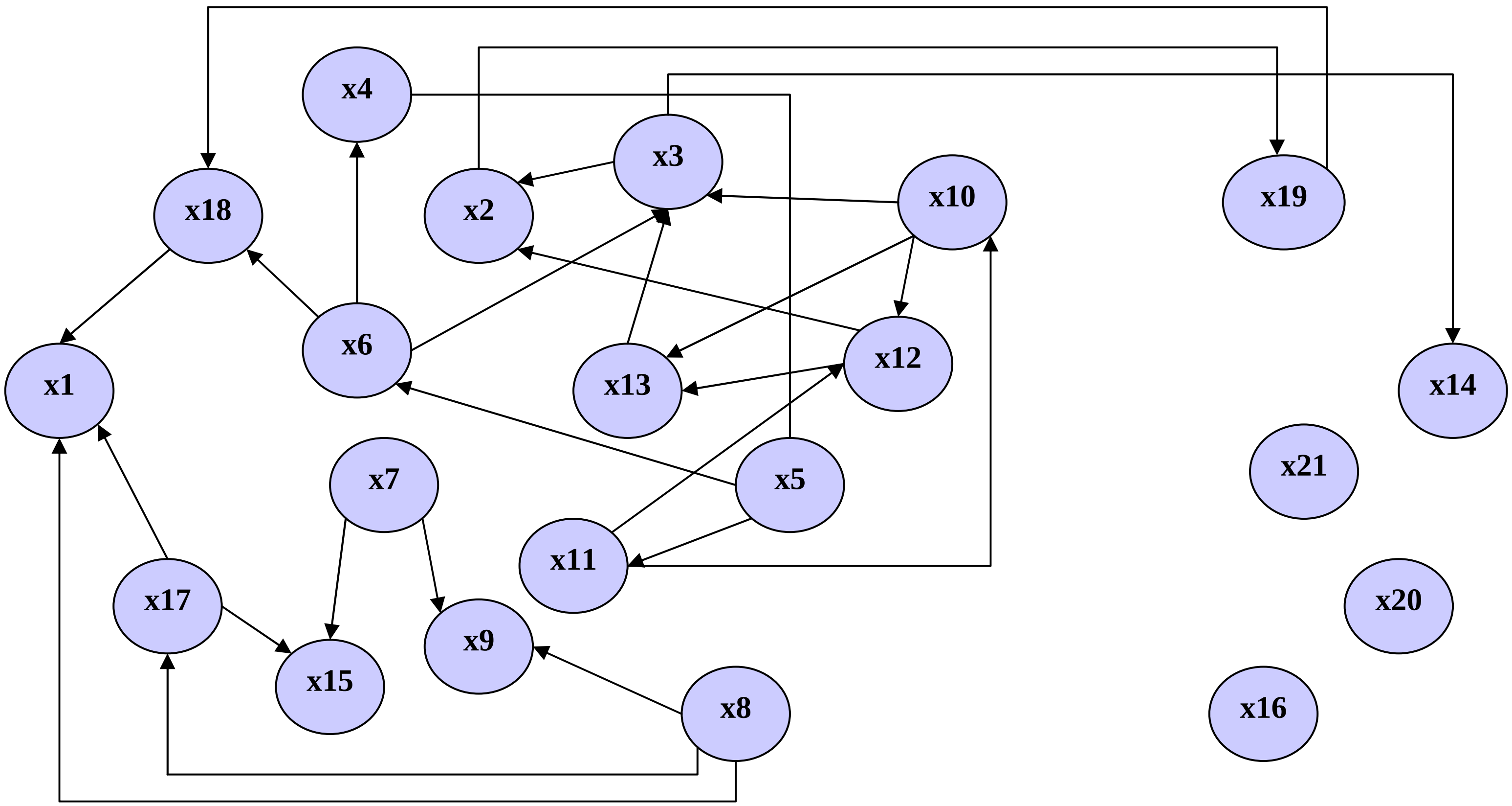


See Table 14 for definition of variables

x1	*x2*	*x3*	*x4*	*x5*	*x6*	*x7*	*x8*	*x9*	*x10*	*x11*	*x12*	*x13*
ADELDV	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*

x14	*x15*	*x16*	*x17*	*x18*	*x19*	*x20*	*x21*
L18	*L19*	*L20*	*L22*	*L24*	*L25*	*L26*	*L27*

Figure 23: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Upper Mississippi River's Lock 22, 5% Significance Level.

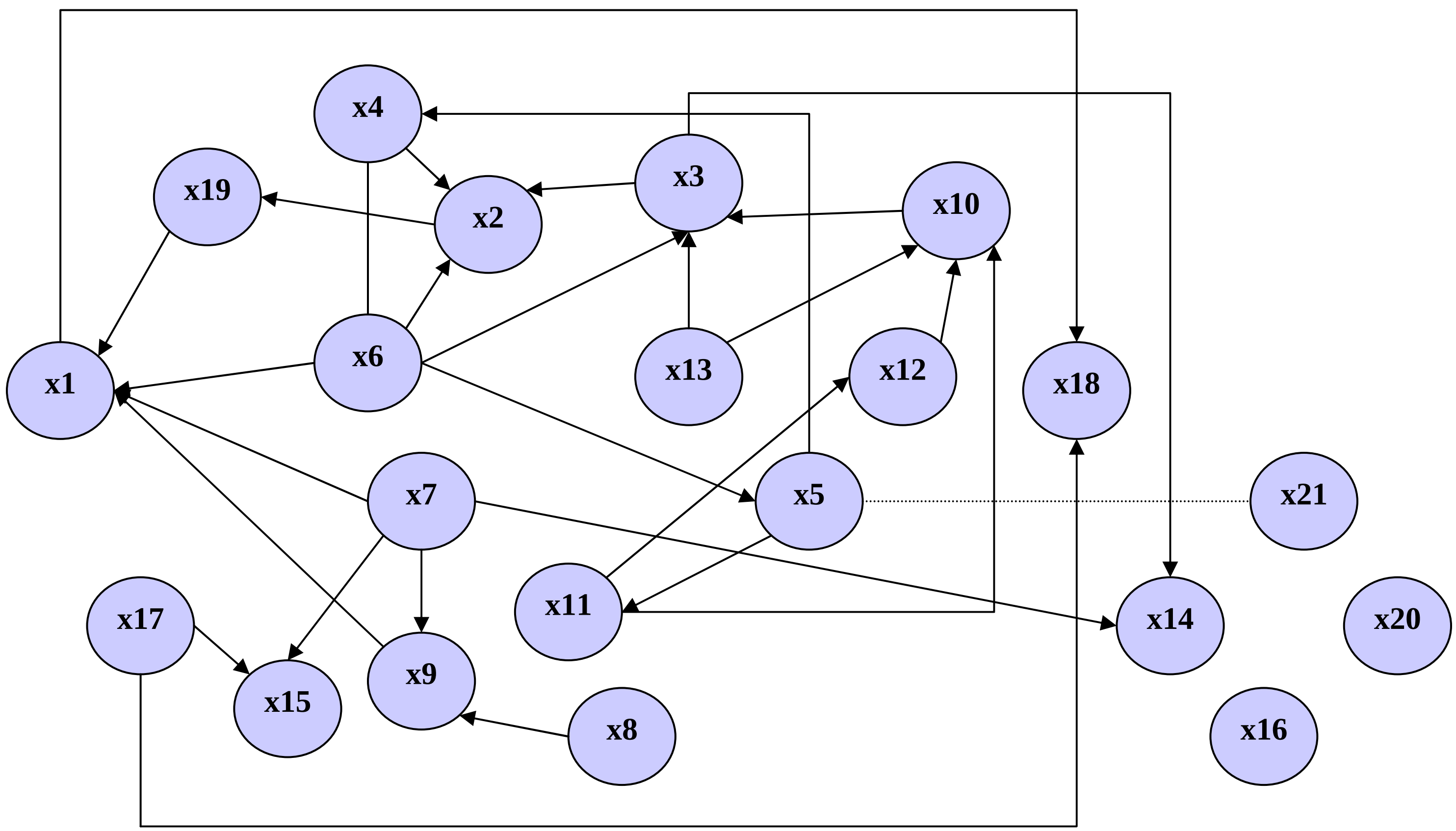


See Table 14 for definition of variables

x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
ADELDV	BRGL	BRGU	COML	RECV	TOTOP	NUMUN	AVGUN	TOTUN	SPRING	SUMMER	FALL	WINTER

x14	x15	x16	x17	x18	x19	x20	x21
L18	L19	L20	L21	L24	L25	L26	L27

Figure 24: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Upper Mississippi River's Lock 24, 5% Significance Level.

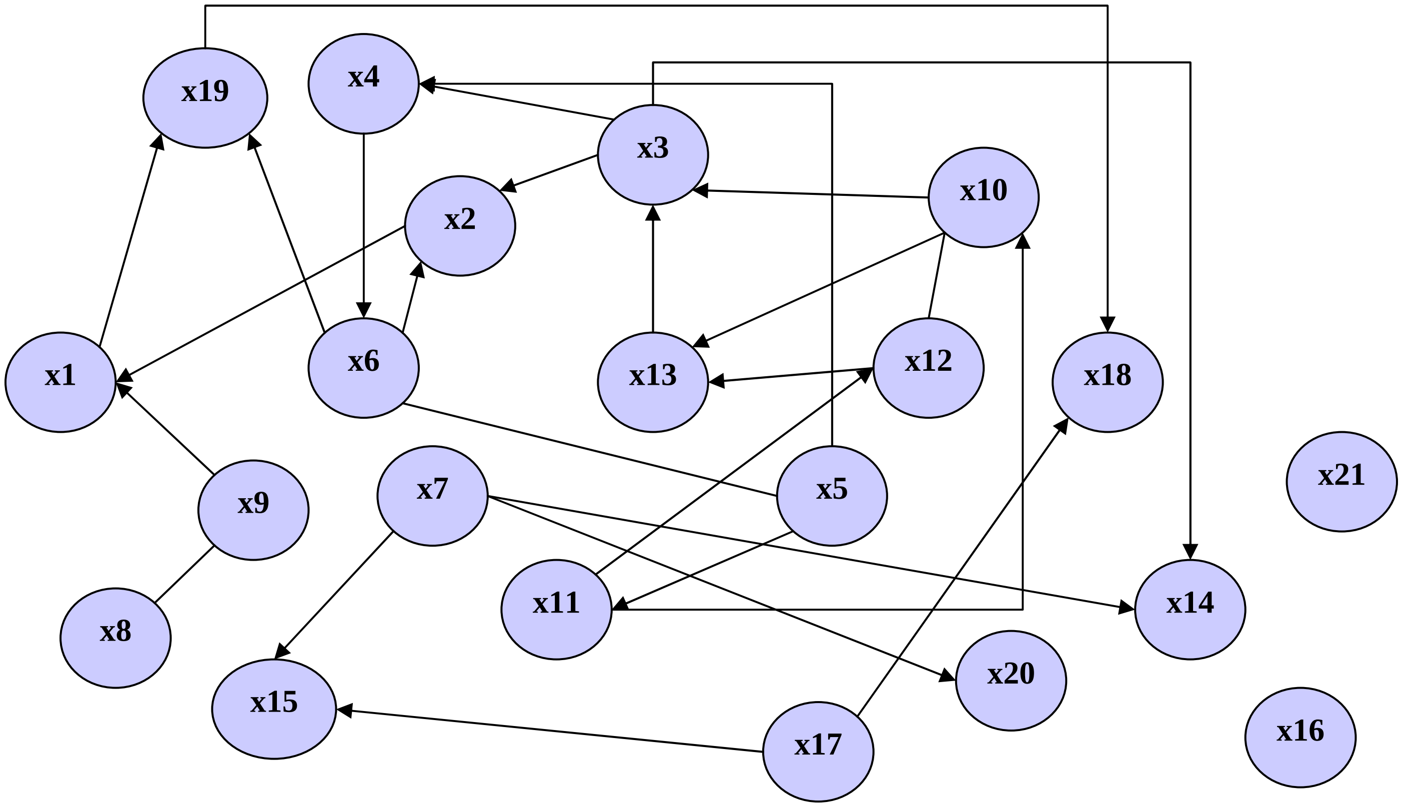


See Table 14 for definition of variables

x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
ADELDV	BRGL	BRGU	COML	RECV	TOTOP	NUMUN	AVGUN	TOTUN	SPRING	SUMMER	FALL	WINTER

x14	x15	x16	x17	x18	x19	x20	x21
L18	L19	L20	L21	L22	L25	L26	L27

Figure 25: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Upper Mississippi River's Lock 25, 5% Significance Level.

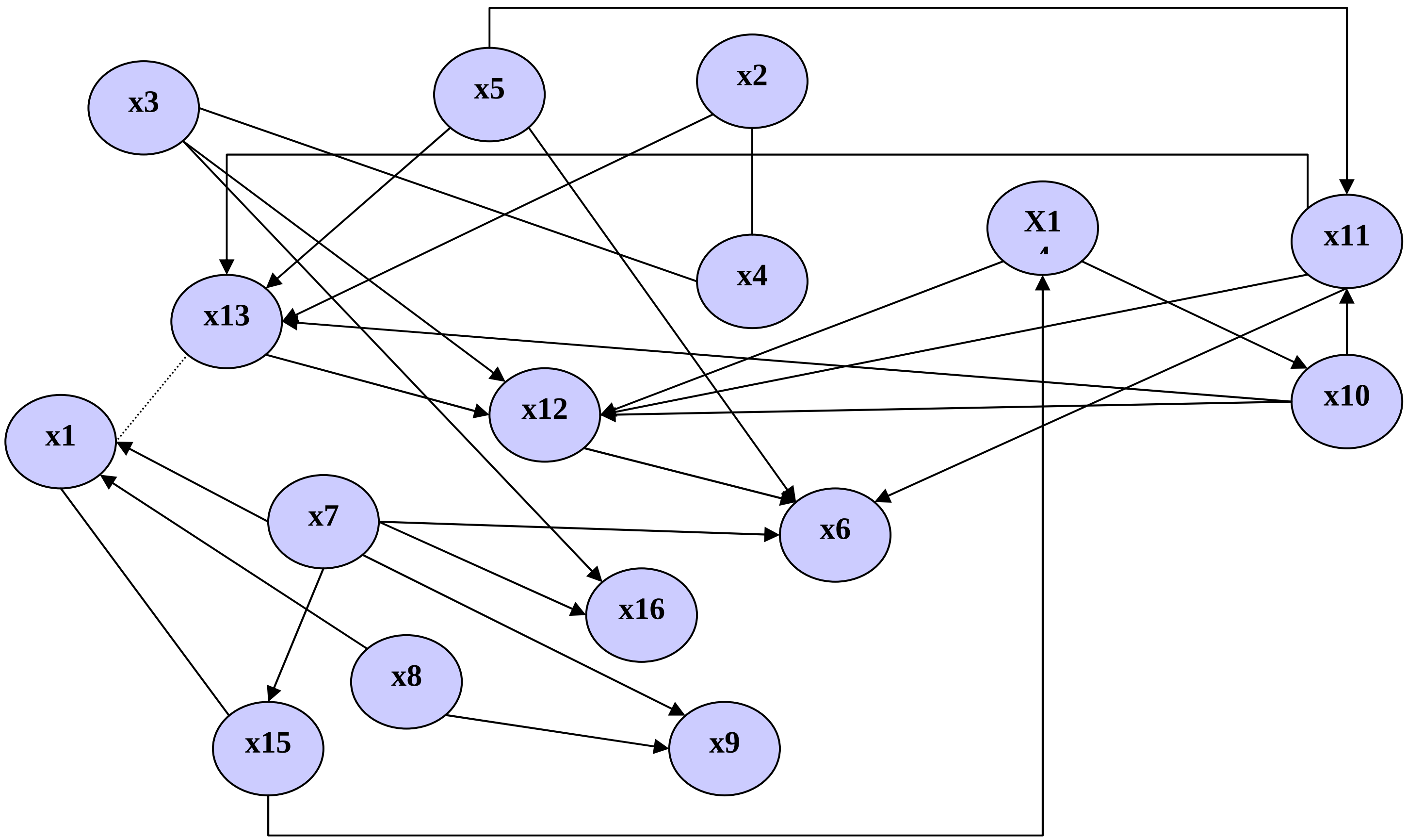


See Table 14 for Definition of Variables

x1	*x2*	*x3*	*x4*	*x5*	*x6*	*x7*	*x8*	*x9*	*x10*	*x11*	*x12*	*x13*
ADELDV	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*

x14	*x15*	*x16*	*x17*	*x18*	*x19*	*x20*	*x21*
L18	*L19*	*L20*	*L21*	*L22*	*L24*	*L26*	*L27*

Figure 26: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Illinois River's Peoria Lock, 5% Significance Level.

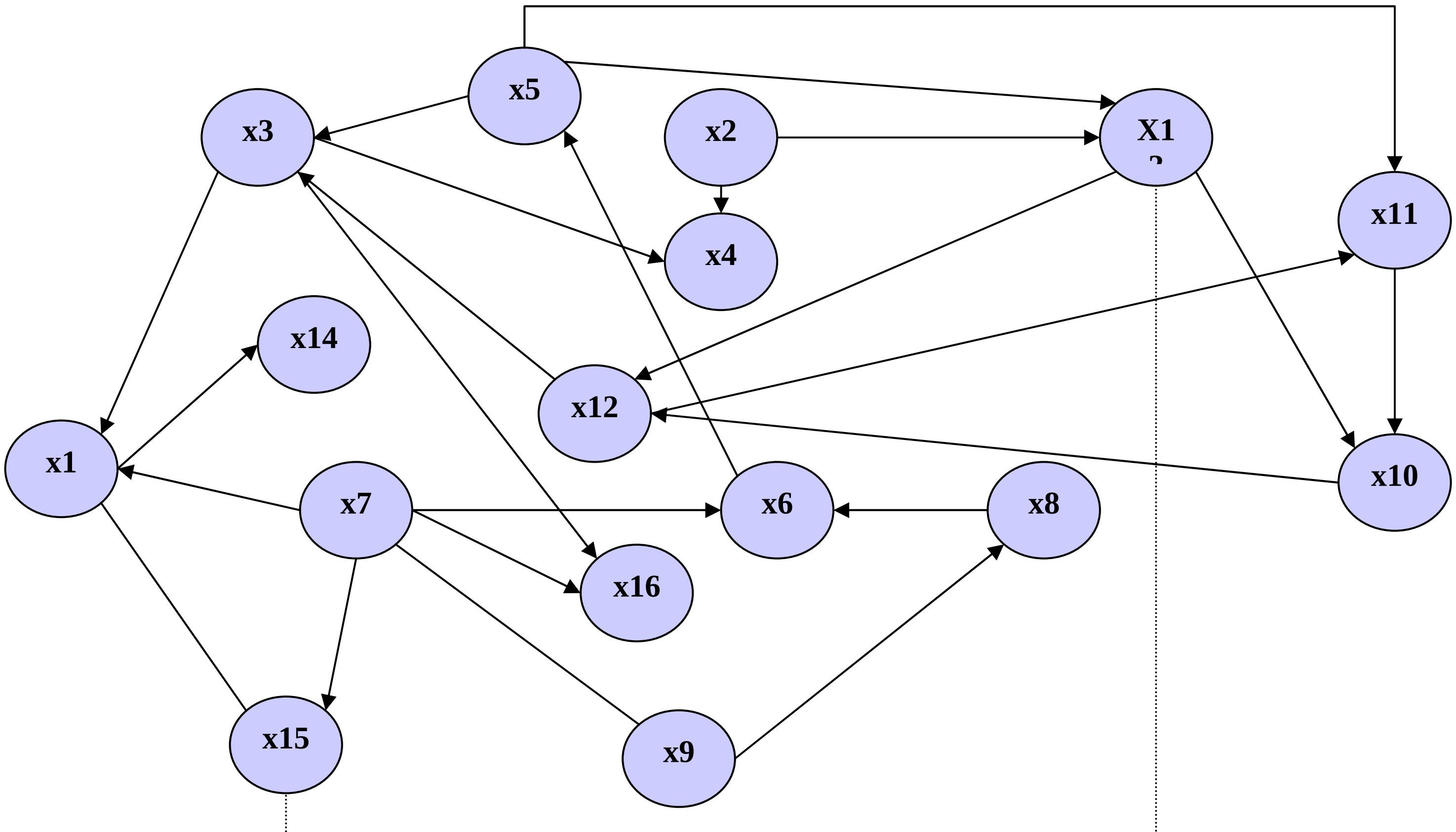


See Table 14 for Definition of Variables

x1	*x2*	*x3*	*x4*	*x5*	*x6*	*x7*	*x8*	*x9*	*x10*	*x11*	*x12*	*x13*
ADELDV	***BRGL***	***BRGU***	***TOWV***	***RECV***	***TOTOP***	***NUMUN***	***AVGUN***	***TOTUN***	***SPRING***	***SUMMER***	***FALL***	***WINTER***

x14	*x15*	*x16*
STARVED ROCK	***LAGRANGE***	***L26***

Figure 27: Directed Graph of Forces That May Cause Delay of Delayed Vessels at Illinois River's LaGrange Lock, 5% Significance Level

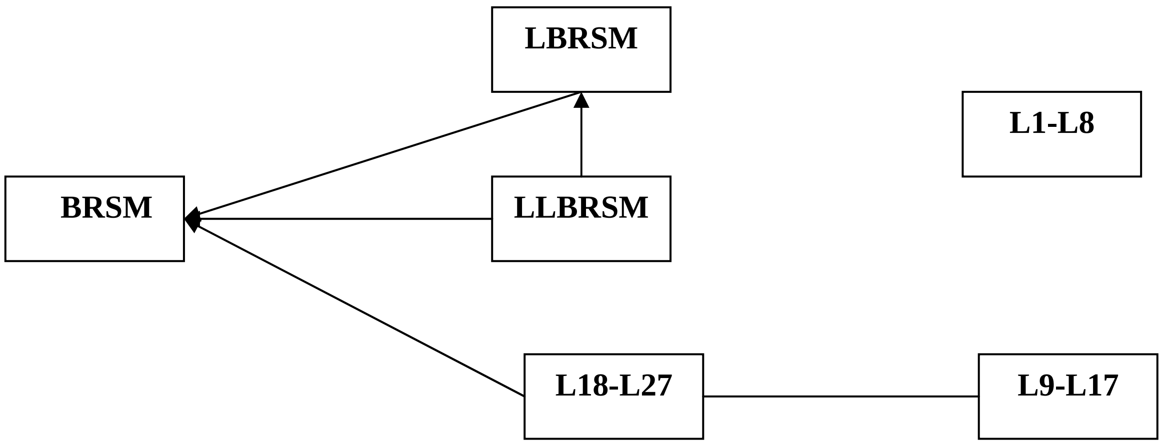


See Table 14 for Definition of Variables

x1	*x2*	*x3*	*x4*	*x5*	*x6*	*x7*	*x8*	*x9*	*x10*	*x11*	*x12*	*x13*
ADELDV	***BRGL***	***BRGU***	***TOWV***	***RECV***	***TOTOP***	***NUMUN***	***AVGUN***	***TOTUN***	***SPRING***	***SUMMER***	***FALL***	***WINTER***

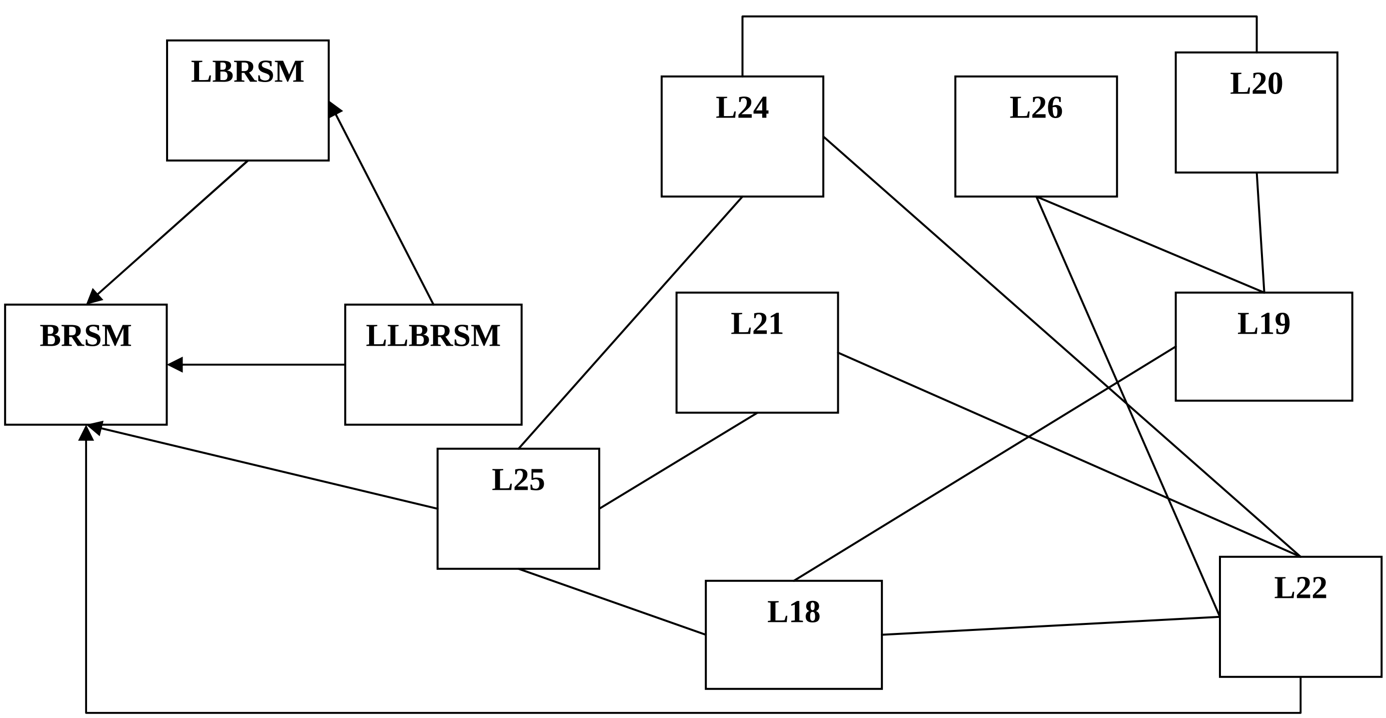
x14	*x15*	*x16*
STARVED ROCK	***PEORIA***	***L26***

Figure 28a: Directed Graph of Forces That May Cause the South Minnesota Barge Rate, Accumulated Lock Delay by River Segment as Causal Forces [1]



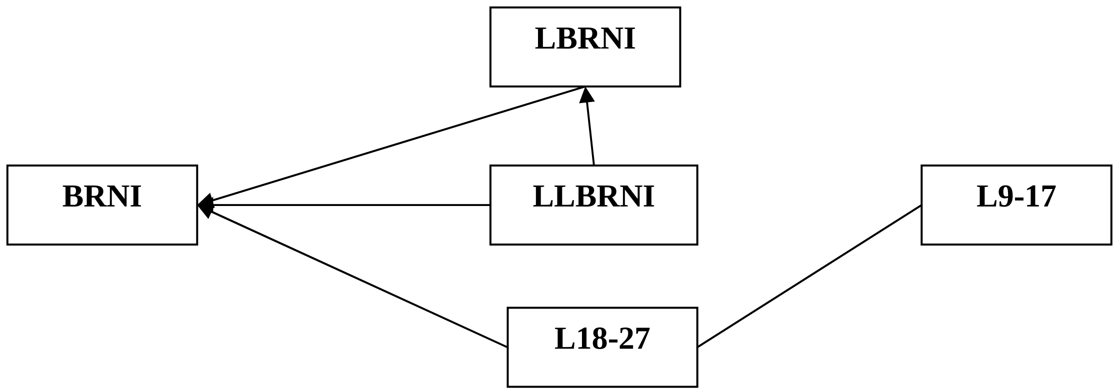
[1] See Table 17 for definition of variables in directed graph.

Figure 28b: Directed Graph of Forces That May Cause the South Minnesota Barge Rate, Individual Lock Delay as Causal Forces [1]



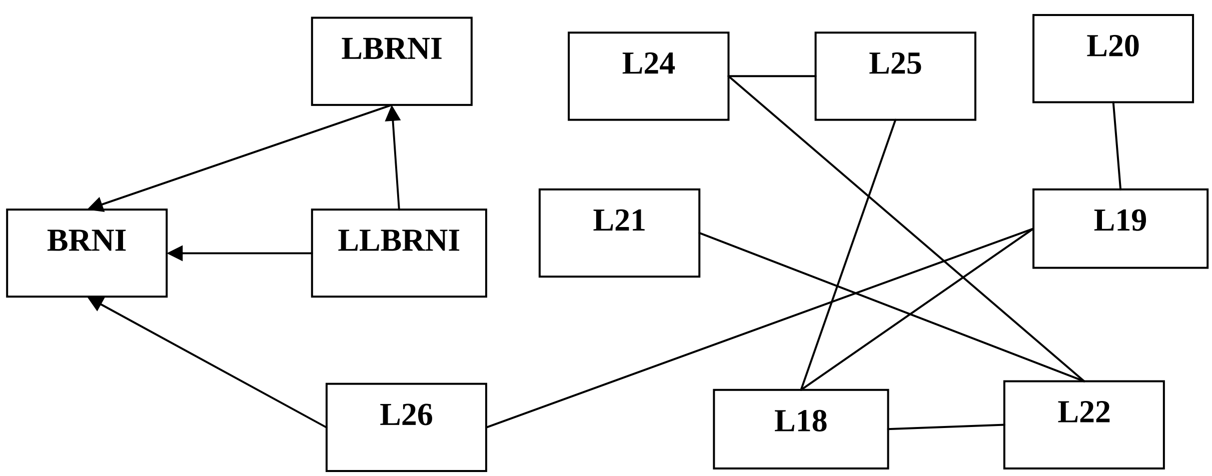
[1] See Table 17 for definition of variables in directed graph.

Figure 29a: Directed Graph of Forces That May Cause the North Iowa Barge Rate, Accumulated Lock Delay by River Segment as Causal Forces [1]



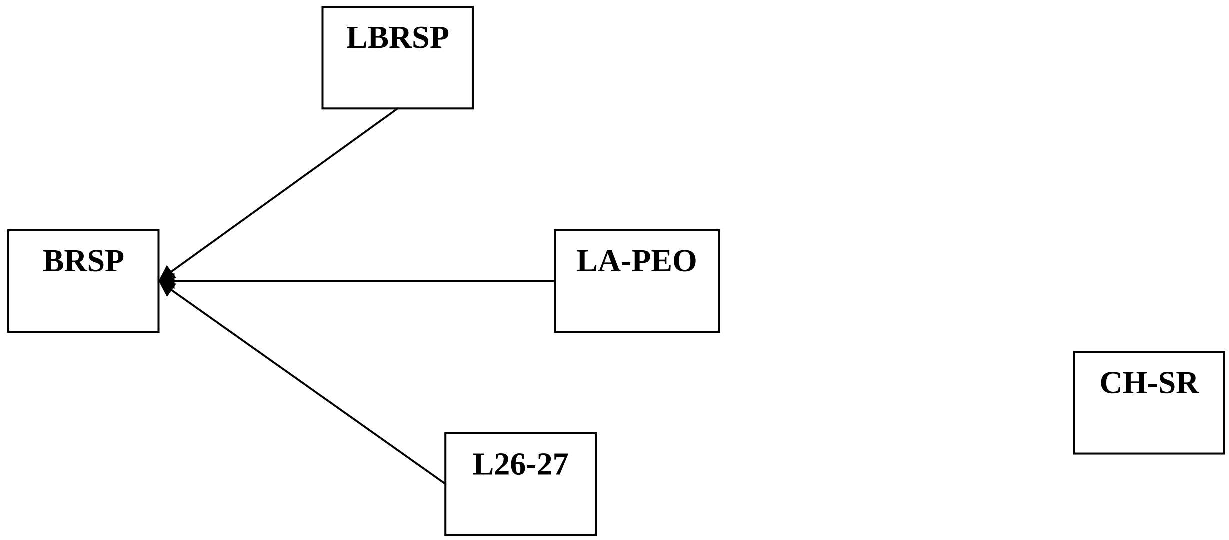
[1] See Table 17 for definition of variables in directed graph.

Figure 29b: Directed Graph of Forces That May Cause the North Iowa Barge Rate, Individual Lock Delay as Causal Forces[1]



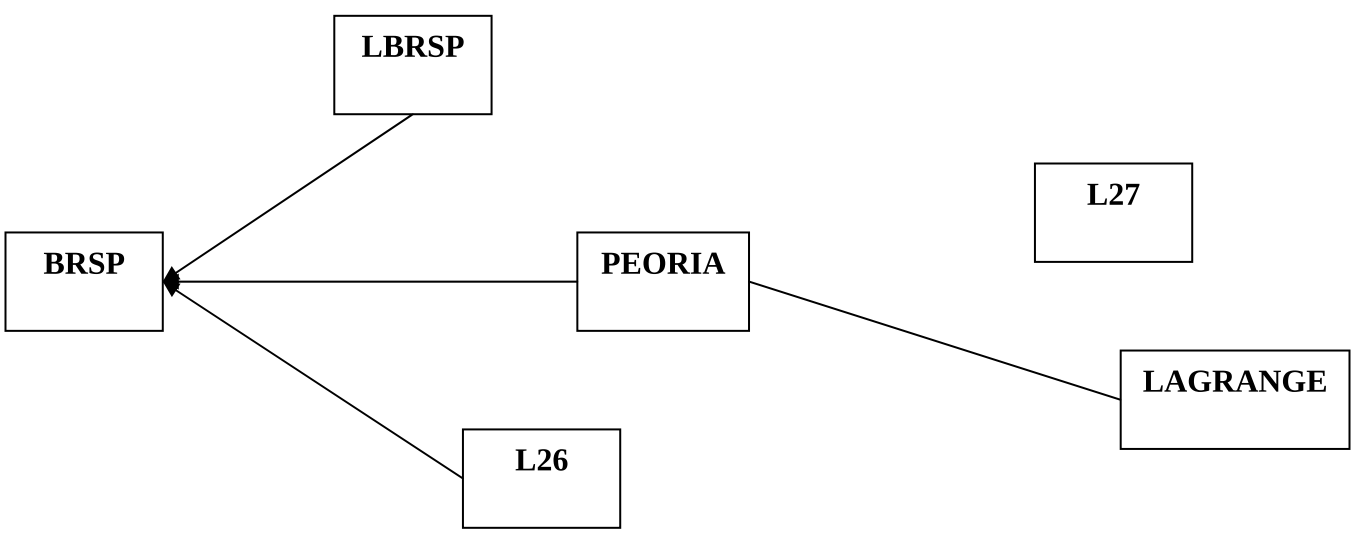
[1] See Table 17 for definition of variables in directed graph.

Figure 30a: Directed Graph of Forces That May Cause the South of Peoria Barge Rate, Accumulated Lock Delay by River Segment as Causal Forces[1]



[1] See Table 17 for definition of variables in directed graph.

Figure 30b: Directed Graph of Forces That May Cause the South of Peoria Barge Rate, Individual Lock Delay as Causal Forces[1]



1 See Table 17 for definition of variables in directed graph.

Appendix List

Table A1. Simple Correlation Matrix of Variables Included in Directed Graph Analysis into Lock Delay at Lock 18 [1]

L18	*ADELDV*	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*	*L19*	*L20*	*L21*	*L22*	*L24*	*L25*	*L26*	*L27*
ADELDV	1.000																				
BRGL	0.027	1.000																			
BRGU	0.081	0.778	1.000																		
COML	0.041	0.955	0.885	1.000																	
RECV	-0.059	0.462	0.272	0.342	1.000																
TOTOP	0.019	0.960	0.860	0.959	0.572	1.000															
NUMUN	0.218	0.213	0.270	0.252	-0.149	0.184	1.000														
AVGUN	0.090	-0.059	0.043	-0.035	0.062	0.002	-0.001	1.000													
TOTUN	0.168	-0.062	0.029	-0.046	-0.017	-0.029	0.170	0.867	1.000												
SPRING	0.033	0.327	0.445	0.342	-0.024	0.331	0.141	-0.051	-0.018	1.000											
SUMMER	-0.011	0.404	0.229	0.318	0.728	0.470	-0.033	0.045	-0.005	-0.366	1.000										
FALL	-0.001	0.184	-0.101	0.160	-0.307	0.019	0.029	-0.045	-0.033	-0.326	-0.323	1.000									
WINTER	0.010	-0.240	0.159	-0.058	-0.245	-0.125	0.112	-0.026	-0.004	-0.186	-0.184	-0.164	1.000								
L19	0.190	-0.195	-0.188	-0.193	-0.138	-0.213	0.095	-0.018	0.017	-0.078	-0.091	0.011	-0.007	1.000							
L20	0.091	0.124	0.134	0.140	0.009	0.131	0.040	0.568	0.456	0.096	0.010	0.012	-0.067	0.275	1.000						
L21	0.461	0.149	0.190	0.195	-0.023	0.156	0.082	0.064	0.048	0.117	-0.034	0.049	-0.017	0.010	0.115	1.000					
L22	0.176	0.461	0.460	0.477	0.110	0.451	0.245	0.007	0.055	0.166	0.187	0.067	-0.143	0.128	0.248	0.349	1.000				
L24	0.102	0.285	0.300	0.285	0.106	0.282	0.134	0.023	0.040	0.038	0.206	-0.009	-0.043	0.009	0.180	0.313	0.488	1.000			
L25	0.101	0.313	0.278	0.288	0.140	0.290	0.094	0.022	0.058	0.102	0.113	0.085	-0.088	-0.022	0.130	0.187	0.323	0.351	1.000		
L26	0.016	0.063	0.083	0.098	-0.071	0.064	0.081	0.009	0.000	-0.044	-0.005	0.112	-0.073	0.065	0.080	0.080	0.169	0.134	0.007	1.000	
L27	-0.029	-0.008	-0.027	-0.021	0.115	0.002	-0.042	-0.019	-0.026	-0.084	0.133	-0.059	-0.003	-0.036	-0.049	-0.027	-0.061	-0.033	0.003	-0.058	1.000

1 See Table 14 for definition of variables

Table A2. Simple Correlation Matrix of Variables Included in Directed Graph Analysis into Lock Delay at Lock 19 [1]

L19	*ADELDV*	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*	*L18*	*L20*	*L21*	*L22*	*L24*	*L25*	*L26*	*L27*
ADELDV	1.000																				
BRGL	-0.205	1.000																			
BRGU	-0.177	0.779	1.000																		
COML	-0.205	0.963	0.880	1.000																	
RECV	-0.129	0.495	0.314	0.409	1.000																
TOTOP	-0.210	0.955	0.826	0.959	0.628	1.000															
NUMUN	0.154	0.166	0.192	0.205	-0.008	0.159	1.000														
AVGUN	0.091	-0.227	-0.178	-0.237	-0.117	-0.239	0.013	1.000													
TOTUN	0.203	-0.059	0.037	-0.033	-0.129	-0.073	0.546	0.416	1.000												
SPRING	-0.080	0.336	0.446	0.365	-0.073	0.296	-0.013	-0.064	0.037	1.000											
SUMMER	-0.090	0.399	0.213	0.316	0.787	0.490	0.078	-0.084	-0.075	-0.351	1.000										
FALL	-0.012	0.205	-0.080	0.173	-0.264	0.065	0.043	-0.049	-0.048	-0.318	-0.315	1.000									
WINTER	0.015	-0.210	0.209	-0.050	-0.239	-0.116	0.061	-0.005	0.068	-0.187	-0.185	-0.168	1.000								
L18	0.110	0.092	0.132	0.112	-0.006	0.085	0.074	0.105	0.074	0.053	0.010	0.017	0.009	1.000							
L20	0.004	-0.127	-0.104	-0.137	-0.049	-0.133	-0.047	-0.012	-0.013	-0.030	-0.038	-0.035	-0.028	-0.056	1.000						
L21	0.635	-0.126	-0.103	-0.132	-0.053	-0.130	-0.035	-0.016	-0.019	-0.034	-0.041	-0.033	-0.010	-0.045	0.006	1.000					
L22	0.592	0.121	0.136	0.118	0.035	0.106	0.041	-0.051	-0.025	0.053	0.067	0.005	-0.080	0.038	-0.014	0.857	1.000				
L24	-0.022	0.307	0.306	0.301	0.146	0.286	0.178	-0.056	0.023	0.050	0.215	0.000	-0.044	0.121	-0.042	-0.039	0.209	1.000			
L25	-0.056	0.166	0.148	0.145	0.086	0.142	-0.009	-0.036	-0.037	0.063	0.070	0.045	-0.081	0.051	-0.041	-0.045	0.055	0.234	1.000		
L26	0.026	0.033	0.049	0.050	-0.064	0.018	0.119	-0.041	0.042	-0.051	-0.013	0.100	-0.067	-0.002	0.058	-0.023	0.071	0.121	-0.033	1.000	
L27	-0.043	-0.017	-0.029	-0.031	0.092	-0.006	0.047	0.172	0.027	-0.083	0.128	-0.060	-0.006	-0.029	-0.027	-0.026	-0.053	-0.033	0.002	-0.055	1.000

1 See Table 14 for definition of variables

Table A3. Simple Correlation Matrix of Variables Included in Directed Graph Analysis into Lock Delay at Lock 20 [1]

L20	*ADELDV*	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*	*L18*	*L19*	*L21*	*L22*	*L24*	*L25*	*L26*	*L27*
ADELDV	1.000																				
BRGL	-0.106	1.000																			
BRGU	-0.088	0.804	1.000																		
COML	-0.117	0.965	0.877	1.000																	
RECV	-0.057	0.506	0.300	0.418	1.000																
TOTOP	-0.106	0.973	0.885	0.981	0.524	1.000															
NUMUN	-0.017	0.218	0.156	0.228	-0.027	0.219	1.000														
AVGUN	-0.001	-0.158	-0.134	-0.174	-0.089	-0.166	-0.060	1.000													
TOTUN	0.014	-0.120	-0.113	-0.130	-0.104	-0.125	0.252	0.734	1.000												
SPRING	-0.026	0.350	0.451	0.349	-0.066	0.348	-0.014	-0.024	0.031	1.000											
SUMMER	-0.034	0.409	0.236	0.336	0.787	0.425	0.020	-0.066	-0.083	-0.331	1.000										
FALL	-0.031	0.234	-0.037	0.225	-0.217	0.141	0.168	-0.043	-0.047	-0.302	-0.299	1.000									
WINTER	-0.025	-0.172	0.220	-0.022	-0.238	-0.051	0.089	-0.039	-0.045	-0.181	-0.179	-0.164	1.000								
L18	-0.050	0.160	0.198	0.183	0.024	0.167	0.124	0.075	0.119	0.077	0.033	0.037	0.016	1.000							
L19	0.006	-0.153	-0.129	-0.122	-0.118	-0.145	0.178	0.004	0.216	-0.069	-0.078	-0.002	0.025	0.125	1.000						
L21	0.006	-0.107	-0.087	-0.109	-0.053	-0.109	-0.066	-0.014	-0.022	-0.031	-0.038	-0.031	-0.004	-0.040	0.634	1.000					
L22	-0.012	0.120	0.133	0.111	0.047	0.116	-0.015	-0.028	0.018	0.056	0.068	0.007	-0.075	0.042	0.583	0.845	1.000				
L24	-0.040	0.304	0.301	0.287	0.182	0.303	0.149	-0.019	0.071	0.057	0.217	0.008	-0.044	0.130	-0.016	-0.036	0.196	1.000			
L25	-0.040	0.375	0.334	0.351	0.184	0.361	0.141	-0.028	0.024	0.138	0.144	0.104	-0.079	0.155	-0.032	-0.046	0.120	0.363	1.000		
L26	0.058	0.045	0.060	0.065	-0.063	0.049	0.061	-0.050	-0.005	-0.046	-0.007	0.101	-0.062	0.006	0.029	-0.022	0.074	0.121	-0.003	1.000	
L27	-0.029	-0.056	-0.057	-0.056	0.096	-0.051	-0.057	0.074	0.104	-0.090	0.105	-0.066	-0.012	-0.048	-0.050	-0.026	-0.060	-0.050	-0.011	-0.063	1.000

1 See Table 14 for definition of variables

Table A4. Simple Correlation Matrix of Variables Included in Directed Graph Analysis into Lock Delay at Lock 21 [1]

L21	*ADELDV*	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*	*L18*	*L19*	*L20*	*L22*	*L24*	*L25*	*L26*	*L27*
ADELDV	1.000																				
BRGL	-0.110	1.000																			
BRGU	-0.088	0.788	1.000																		
COML	-0.116	0.970	0.880	1.000																	
RECV	-0.053	0.497	0.301	0.410	1.000																
TOTOP	-0.114	0.973	0.878	0.983	0.537	1.000															
NUMUN	-0.046	0.040	-0.042	0.029	0.021	0.028	1.000														
AVGUN	-0.013	-0.081	0.007	-0.045	-0.118	-0.058	0.196	1.000													
TOTUN	-0.012	-0.069	0.016	-0.030	-0.097	-0.045	0.281	0.928	1.000												
SPRING	-0.031	0.336	0.437	0.342	-0.029	0.338	-0.017	0.002	-0.028	1.000											
SUMMER	-0.038	0.411	0.228	0.345	0.751	0.442	0.027	-0.099	-0.080	-0.332	1.000										
FALL	-0.031	0.233	-0.046	0.213	-0.235	0.119	0.033	-0.012	0.003	-0.307	-0.303	1.000									
WINTER	0.001	-0.211	0.201	-0.057	-0.257	-0.090	-0.054	0.096	0.111	-0.195	-0.193	-0.178	1.000								
L18	-0.040	0.160	0.203	0.188	0.019	0.173	0.107	-0.045	-0.033	0.076	0.032	0.041	0.001	1.000							
L19	0.634	-0.152	-0.128	-0.136	-0.117	-0.150	0.262	-0.041	-0.016	-0.069	-0.078	0.005	0.021	0.125	1.000						
L20	0.006	-0.109	-0.090	-0.123	-0.049	-0.114	0.027	-0.007	-0.007	-0.026	-0.034	-0.032	-0.022	-0.050	0.006	1.000					
L22	0.845	0.114	0.131	0.110	0.045	0.114	0.011	0.046	0.015	0.054	0.065	0.004	-0.078	0.041	0.583	-0.012	1.000				
L24	-0.037	0.297	0.291	0.286	0.158	0.302	0.086	0.155	0.071	0.054	0.213	0.006	-0.058	0.127	-0.017	-0.041	0.193	1.000			
L25	-0.046	0.367	0.324	0.351	0.189	0.356	0.001	0.001	-0.021	0.133	0.142	0.099	-0.096	0.154	-0.032	-0.040	0.119	0.360	1.000		
L26	-0.023	0.040	0.061	0.060	-0.060	0.046	0.084	0.098	0.058	-0.048	-0.008	0.099	-0.064	0.003	0.028	0.058	0.072	0.117	-0.006	1.000	
L27	-0.026	-0.045	-0.052	-0.056	0.082	-0.046	-0.030	0.200	0.231	-0.089	0.112	-0.065	-0.007	-0.044	-0.048	-0.028	-0.058	-0.047	-0.008	-0.062	1.000

1 See Table 14 for definition of variables

Table A5. Simple Correlation Matrix of Variables Included in Directed Graph Analysis into Lock Delay at Lock 22[1]

L22	*ADELDV*	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*	*L18*	*L19*	*L20*	*L21*	*L24*	*L25*	*L26*	*L27*
ADELDV	1.000																				
BRGL	0.120	1.000																			
BRGU	0.135	0.785	1.000																		
COML	0.115	0.970	0.881	1.000																	
RECV	0.032	0.524	0.304	0.432	1.000																
TOTOP	0.134	0.974	0.880	0.985	0.550	1.000															
NUMUN	0.140	-0.018	-0.067	-0.014	-0.007	-0.021	1.000														
AVGUN	0.353	0.070	0.060	0.081	-0.067	0.075	0.117	1.000													
TOTUN	0.321	0.059	0.026	0.059	-0.054	0.054	0.323	0.895	1.000												
SPRING	0.055	0.334	0.438	0.350	-0.092	0.343	-0.063	0.013	-0.011	1.000											
SUMMER	0.067	0.415	0.231	0.347	0.835	0.445	-0.005	-0.021	-0.046	-0.330	1.000										
FALL	0.005	0.230	-0.056	0.201	-0.232	0.111	0.084	0.089	0.132	-0.308	-0.304	1.000									
WINTER	-0.072	-0.217	0.202	-0.073	-0.272	-0.102	-0.051	-0.049	-0.040	-0.198	-0.195	-0.182	1.000								
L18	0.044	0.164	0.203	0.194	0.009	0.182	0.107	0.060	0.055	0.078	0.032	0.044	-0.004	1.000							
L19	0.584	-0.144	-0.122	-0.126	-0.116	-0.137	0.340	0.141	0.184	-0.068	-0.077	0.009	0.025	0.126	1.000						
L20	-0.012	-0.108	-0.089	-0.114	-0.047	-0.110	-0.036	-0.013	-0.014	-0.026	-0.033	-0.031	-0.022	-0.049	0.006	1.000					
L21	0.845	-0.106	-0.085	-0.114	-0.054	-0.107	0.009	0.173	0.120	-0.031	-0.038	-0.031	0.008	-0.039	0.634	0.006	1.000				
L24	0.194	0.300	0.293	0.283	0.169	0.308	0.041	0.163	0.138	0.054	0.214	0.008	-0.060	0.129	-0.016	-0.040	-0.037	1.000			
L25	0.121	0.371	0.328	0.343	0.143	0.357	-0.006	0.061	0.054	0.136	0.143	0.098	-0.100	0.157	-0.031	-0.039	-0.046	0.362	1.000		
L26	0.073	0.042	0.061	0.076	-0.063	0.047	0.025	0.113	0.084	-0.046	-0.008	0.099	-0.064	0.005	0.029	0.058	-0.022	0.118	-0.004	1.000	
L27	-0.057	-0.044	-0.054	-0.065	0.127	-0.047	0.006	-0.040	-0.033	-0.088	0.113	-0.066	-0.007	-0.044	-0.048	-0.028	-0.026	-0.047	-0.007	-0.061	1.000

1 See Table 14 for definition of variables

Table A6. Simple Correlation Matrix of Variables Included in Directed Graph Analysis into Lock Delay at Lock 24[1]

L24	*ADELDV*	*BRGL*	*BRGU*	*COML*	*RECV*	*TOTOP*	*NUMUN*	*AVGUN*	*TOTUN*	*SPRING*	*SUMMER*	*FALL*	*WINTER*	*L18*	*L19*	*L20*	*L21*	*L22*	*L25*	*L26*	*L27*
ADELDV	1.000																				
BRGL	0.309	1.000																			
BRGU	0.304	0.792	1.000																		
COML	0.288	0.964	0.889	1.000																	
RECV	0.167	0.509	0.279	0.410	1.000																
TOTOP	0.321	0.973	0.886	0.984	0.529	1.000															
NUMUN	0.249	0.120	0.118	0.157	0.028	0.141	1.000														
AVGUN	0.110	-0.109	-0.123	-0.135	-0.100	-0.123	-0.036	1.000													
TOTUN	0.283	-0.116	-0.120	-0.135	-0.107	-0.122	0.158	0.864	1.000												
SPRING	0.057	0.335	0.439	0.363	-0.114	0.348	0.031	-0.017	-0.011	1.000											
SUMMER	0.216	0.416	0.239	0.343	0.866	0.445	0.030	-0.060	-0.059	-0.326	1.000										
FALL	0.014	0.235	-0.051	0.190	-0.259	0.110	0.026	-0.003	-0.026	-0.306	-0.302	1.000									
WINTER	-0.064	-0.226	0.183	-0.080	-0.262	-0.104	0.054	-0.031	-0.014	-0.202	-0.200	-0.187	1.000								
L18	0.138	0.184	0.217	0.212	0.024	0.204	0.165	-0.013	0.013	0.084	0.037	0.052	-0.007	1.000							
L19	-0.011	-0.130	-0.109	-0.099	-0.104	-0.124	0.230	0.013	0.038	-0.065	-0.074	0.017	0.025	0.131	1.000						
L20	-0.038	-0.105	-0.088	-0.103	-0.043	-0.106	-0.040	0.011	0.004	-0.025	-0.033	-0.031	-0.022	-0.047	0.007	1.000					
L21	-0.035	-0.104	-0.083	-0.100	-0.049	-0.102	-0.020	-0.001	-0.003	-0.030	-0.037	-0.030	0.007	-0.038	0.634	0.007	1.000				
L22	0.201	0.129	0.146	0.139	0.040	0.143	0.053	0.006	0.035	0.059	0.070	0.008	-0.073	0.053	0.585	-0.010	0.843	1.000			
L25	0.368	0.380	0.337	0.340	0.148	0.370	0.044	0.045	0.097	0.140	0.147	0.099	-0.104	0.166	-0.026	-0.038	-0.044	0.128	1.000		
L26	0.123	0.053	0.072	0.096	-0.052	0.059	0.031	-0.035	-0.010	-0.042	-0.004	0.101	-0.061	0.010	0.031	0.059	-0.021	0.077	0.001	1.000	
L27	-0.046	-0.043	-0.052	-0.074	0.135	-0.037	-0.100	-0.017	-0.026	-0.088	0.112	-0.065	-0.005	-0.042	-0.047	-0.028	-0.026	-0.056	-0.006	-0.061	1.000

1 See Table 14 for definition of variables

Table A7. Simple Correlation Matrix of Variables Included in Directed Graph Analysis into Lock Delay at Lock 25 [1]

L25	ADELDV	BRGL	BRGU	COML	RECV	TOTOP	NUMUN	AVGUN	TOTUN	SPRING	SUMMER	FALL	WINTER	L18	L19	L20	L21	L22	L24	L26	L27
ADELDV	1.000																				
BRGL	0.207	1.000																			
BRGU	0.188	0.784	1.000																		
COML	0.157	0.960	0.883	1.000																	
RECV	0.079	0.529	0.277	0.418	1.000																
TOTOP	0.190	0.972	0.867	0.976	0.578	1.000															
NUMUN	0.040	0.149	0.182	0.217	-0.052	0.170	1.000														
AVGUN	0.670	-0.155	-0.139	-0.181	-0.071	-0.163	-0.088	1.000													
TOTUN	0.616	-0.148	-0.133	-0.168	-0.091	-0.152	0.012	0.839	1.000												
SPRING	0.084	0.335	0.437	0.356	-0.038	0.342	0.088	-0.044	-0.014	1.000											
SUMMER	0.089	0.421	0.236	0.342	0.807	0.468	0.009	-0.046	-0.053	-0.324	1.000										
FALL	0.052	0.235	-0.052	0.197	-0.254	0.100	0.045	-0.038	-0.044	-0.305	-0.301	1.000									
WINTER	-0.094	-0.226	0.193	-0.068	-0.273	-0.119	-0.017	-0.034	-0.059	-0.202	-0.199	-0.187	1.000								
L18	0.089	0.189	0.218	0.213	0.022	0.198	0.238	-0.075	-0.053	0.085	0.039	0.053	-0.007	1.000							
L19	-0.037	-0.124	-0.106	-0.093	-0.111	-0.123	0.232	-0.029	0.005	-0.064	-0.073	0.019	0.025	0.132	1.000						
L20	-0.035	-0.104	-0.087	-0.115	-0.045	-0.107	-0.012	-0.013	-0.017	-0.025	-0.032	-0.030	-0.021	-0.046	0.007	1.000					
L21	-0.039	-0.102	-0.081	-0.102	-0.051	-0.102	-0.050	-0.011	-0.017	-0.030	-0.036	-0.030	0.007	-0.037	0.634	0.007	1.000				
L22	0.067	0.132	0.150	0.137	0.037	0.138	0.055	-0.056	-0.044	0.059	0.071	0.009	-0.072	0.056	0.585	-0.010	0.842	1.000			
L24	0.245	0.312	0.304	0.291	0.154	0.314	0.102	-0.051	0.027	0.057	0.216	0.016	-0.063	0.142	-0.010	-0.038	-0.034	0.204	1.000		
L26	-0.023	0.057	0.074	0.090	-0.060	0.054	0.149	-0.053	-0.055	-0.041	-0.004	0.103	-0.061	0.012	0.032	0.059	-0.021	0.079	0.125	1.000	
L27	-0.005	-0.042	-0.050	-0.075	0.097	-0.033	-0.101	-0.002	-0.019	-0.087	0.112	-0.065	-0.004	-0.042	-0.047	-0.028	-0.026	-0.056	-0.046	-0.061	1.000

1 See Table 14 for definition of variables