Agribusiness & Applied Economics Report No. 605 July 2007

Grain Shipments on the Mississippi River System: A Long-Term Projection

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Acknowledgments

Our thanks go to Jeremy Mattson and Bob Hearne for reviewing this manuscript and to Edie Nelson for help in preparing the manuscript.

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Abstract

The costs of delays for shipping commodities on the Mississippi River are important and adversely impact growth in shipments. Lock and dam expansion requires substantial capital investment and an extended time period to complete. This study analyzes delay costs and the competitive position of grain shipments on the Mississippi River system. A spatial optimization model of the world grain trade was developed. Results indicated that without expansion in barge capacity, delay costs in 2020 would increase on each reach, with some up to $1.08/mt. Expansion results in reduced delay costs. Barge demand is also impacted by rail capacity. Finally, expanding the locks would result in a re-allocation of shipments among modes, reaches, and ports, notwithstanding minor adjustments in production.

Key Words: Logistics, spatial optimization models in grain, barges, delay costs

Highlights

The locks and dams on the Mississippi River System are an integral part of one of the most important logistical channels for grain shipments in the world. Currently, the cost of delays for shipping on the river adversely impact future growth of shipments on the river. Plans have been made to expand the locks, which would decrease delay costs and allow for further increased traffic.

The lock and dam system is divided into 6 Reaches with individual capacities. Reach 1, St. Louis; Reach 2, Davenport; Reach 3, Minneapolis; Reach 4, Peoria; Reach 5, Louisville; and Reach 6, Cincinnati. The flows from Reach 3 passes through Reach 2 and Reach 1. The flows from Reach 2 passes through Reach 3. Grain from Reach 4 enters the system below the congestion point on the Mississippi, which therefore does not add to delay costs at Reach 4. Reaches 5 and 6 also enter below any congestion points.

A spatial optimization model was developed to minimize production cost of grain and oilseeds in major producing countries and the marketing costs from producing country/regions to consuming country/regions. The model included corn, wheat, and soybeans.

Delay costs are experienced when a lock approaches capacity and the “wait time” increases. Delay costs are typically near zero except for periods of heavy traffic flows. The costs were estimated by the Army Corp of Engineers using historical data. As traffic flow increases, delay cost remains constant until a “critical level” is reached, where they increase rapidly.

The base case was defined and used for comparison with results from the scenarios. The base case represents conditions from 2000 through 2004. Reach shipments were projected to 51 mmt in the base case. Projections were made for 2010, 2020, and 2030. Reach shipments increased to about 65 mmt in 2020 before decreasing to 60 mmt in 2030. The reason for the decrease was that while soybean export continued to increase, corn shipments decreased by 6 mmt between 2020 and 2030 and wheat shipment decreased by over 3 mmt.

Scenarios were run with expanded lock capacities at Reaches 1, 2, and 4. The increased lock capacities (lower delay costs) increased Reach shipments by 2 mmt to 3 mmt, mainly soybeans. The increased capacities of the upper Reaches lowered shipping levels on the lower Reaches indicating that inter-reach competition is important.

Increases in non-grain traffic would decrease shipment of grain in the Mississippi River System. The results showed that a 50% increase in non-grain traffic would reduce grain shipments by about 7 mmt per year.

Railroads are a direct competitor of the barge system. In the base case model, the railroads were constrained at 131 mmt. Sensitivities were run which raised that constraint incrementally to 201 mmt. Effects were small until the level reached 161 mmt. At that point, railroads replaced some of the barge shipments. Reach shipments fell to 48 mmt from 51 mmt at the 161 mmt constraint. When the railroad constraint was raised to 201 mmt, barge traffic fell to about 36 mmt, indicating that improvements in the rail system would pressure barge transportation.

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Introduction

The Mississippi River System is one of the most important logistical channels for grain shipments in the world. However, its locks are old and in need of replacement. Currently, the cost of delays for shipping on the river adversely impact growth in shipments on that mode. Delay costs consists of congestions at locks when barge traffic approaches the capacity of an individual lock. There are plans and pressures for expanding the locks, which would have the impact of decreasing the costs of delay and increase the competitiveness of barge shipping. The locks are divided into reaches. These reaches are defined as: Reach 1, Cairo to LaGrange (St. Louis); Reach 2, LaGrange to McGregor (Davenport); Reach 3, McGregor to Minneapolis (Mpls); Reach 4, Illinois River (Peoria); Reach 5, Cairo to Louisville (Louisville); and Reach 6, Cincinnati (Cincinnati) (Figure1). However, expansion requires a substantial capital investment and an extended time period to complete. Hence, any economic assessment of the value of expanded locks requires estimates of current delay costs and reduced delay costs as a result of the expansion.

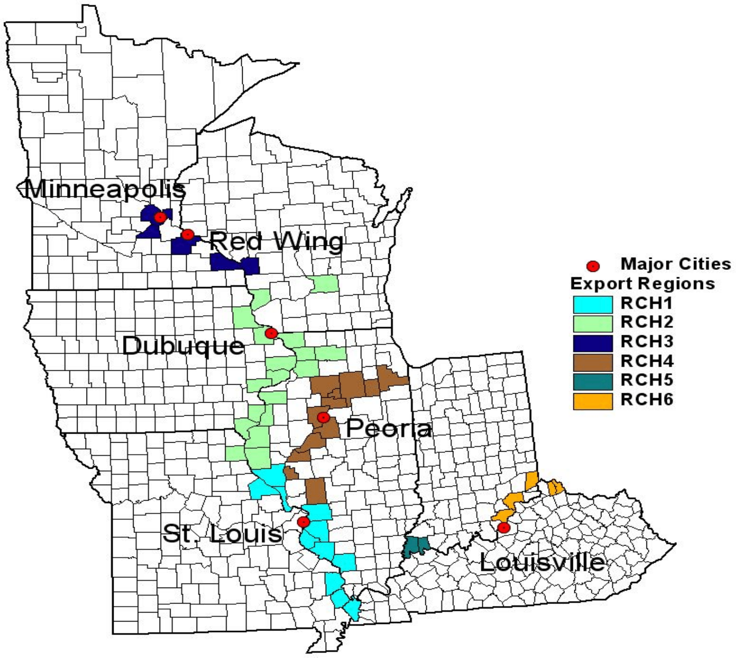

Figure 1. Barge Reach Definitions.

The purpose of this study is to analyze current delay costs and the competitive position of grain shipments (corn, soybeans, and wheat) on the Mississippi River System. The focus is on the world grain trade, expected changes in response to a multitude of evolving competitive pressures and structural changes, and impacts on delay costs. A spatial optimization model of the world grain trade was developed. Parameters for the model are forecasted and used to evaluate future delay costs and changes in flows through targeted logistical channels. Projected import demands are based on consumption functions estimated using income and population and accounting for inter-country differences in consumption dependent on economic development. Each of the competing supply regions and countries were represented by yields, area potential that could be used in production of each grain, production costs, and interior shipping costs. Crucial in this analysis is inter-reach and spatial competition between the U.S. Pacific Northwest and shipments through the U.S. Gulf.

This paper is derived and condensed from the research presented in Wilson et al. (2006, 2007).

Empirical Model

A large-scale, non-linear spatial optimization model is used to make projections and analyze delay costs. This is a very detailed and comprehensive model. This section provides an overview of the procedures and the specification of the analytical model. Agronomic variables and consumption were estimated econometrically and are described first. Then, we describe the spatial optimization model and data sources.

Spatial Optimization Model

The objective of the model is to minimize production costs of grain and oilseeds in major producing countries and marketing costs from producing regions to consuming regions, subject to meeting import demands of importing countries and regions, available supplies and production potential in each of the exporting countries and regions and currently available shipping costs and technologies. The model includes agricultural production and export subsidies commonly used as production enhancements in exporting countries, import tariffs as trade impediments in importing countries, and other trade relations that may affect international competition.

The logic to the objective function is that it reflects what would be considered a longer term competitive equilibrium whereby spatial flows are determined by costs, technical restrictions, and other relationships. Under these conditions, trade flows of agricultural commodities would be determined by demand, production costs in producing countries, marketing costs from exporting countries, and trade interventions. In addition, yields in producing regions are included to measure efficiency in crop and oilseed production. Consumption is projected and the least cost means of satisfying these demands is derived.

The model is solved jointly for corn, soybeans, and wheat. Costs included in the model are direct production costs for each grain in each exporting country and region less production subsidies and interior shipping and handling costs for each grain in each exporting region, less export subsidies and ocean shipping costs and import tariffs. The model contains 16 exporting countries and 16 importing countries with each type of grain and oilseed having different sets of exporting and importing countries. Some exporting countries are further divided into producing and consuming regions to capture the interdependency between the transportation system and agricultural production.

Transportation modes include truck, rail, and barges for inland transportation and ocean vessel for ocean transportation. The model includes six reaches in the United States defined below. Barge rates are represented as a supply function. Four of the six reaches have delay functions which reflect the river congestion costs that could delay flows and increase costs. The function is non-linear which is nearly flat until flows increase to a critical level. At the point the delay costs increase sharply, the model is then forced to shift shipments to either other reaches or other modes at other export ports. The rail system is subjected to a car loading capacity constraint, applied to all U.S. origins. Details of these relationships are described below.

The objective of the model is to minimize production costs in producing regions in exporting countries and shipping costs from producing regions in exporting countries to their consuming regions and importing countries. This objective function is defined as:

$$W = \sum_{c}\sum_{i}(PC_{ci} - s_i)A_{ci} + \sum_{c}\sum_{i}\sum_{j} t_{cij} Q^{T}{}_{ci}$$

$$+ \sum_{c}\sum_{i}\sum_{w} t^{R}{}_{cij} Q^{R}{}_{cij} + \sum_{c}\sum_{i}\sum_{w} t^{T}{}_{ciw} Q^{T}{}_{ciw}$$

$$\sum_{c}\sum_{i}\sum_{p} t_{cip} Q^{R}{}_{cip} + \sum_{i}\sum_{w}\sum_{p} (t_{cwp} + D_p) Q^{B}_{cw}$$

$$+ \sum_{c}\sum_{p}\sum_{q} (t_{cpq} + r_q) Q_{cpq}$$

where *i*=index for producing regions, *j*=index for consuming regions, *p*=index for ports in exporting countries, *q*=index for ports in importing countries, *w*=index for river access point on the Mississippi River System, *B*=barge, *R*=rail, *T*=truck, PC_{ci}=production cost of crop *c* in producing region *i*, A_{ci}=area used to produce crop *c* in producing region *i*, *t*=transportation cost per ton, *Q*=quantity of grains and oilseed shipped, *s*=production subsidies in the exporting country; *r*=import tariffs in the importing country; D=delay costs associated with barge shipments on each of four reaches on the Mississippi River.

The first term on the right-hand side represents production costs in producing regions in exporting countries; the next two terms represent transportation costs from producing regions to domestic consuming regions for domestic consumption by truck and rail. The fourth and fifth terms represent transportation cost from producing regions to river access points and ports for exports, respectively. The sixth term represents barge transportation costs and delay costs from river access points to ports for exports. The last term represents ocean shipping from ports in exporting countries to ports in importing countries. Production and export subsidies (s_i) were deducted from production costs and import tariffs (r_q) were added to ocean shipping costs and to rail shipping costs in the case of Mexico.

The objective function is optimized subject to a set of constraints. Some of these are arable land constraints in exporting countries and demand constraints for each type of grain and oilseed in consuming regions in both exporting and importing countries. This objective function is optimized subject to the following constraints:

1) $$Y_{ci}\ A_{ci} \geq \sum_{j} Q_{cij} + \sum_{P} Q^{R}_{cip} + \sum_{w} Q^{t}_{ciw}$$

2) $$\sum_{c} A_{ci} \leq TA_i$$

3) $$A_{ci} \geq MA_{ci}$$

4) $$\sum_{i} Q_{cij} \geq D_{cj}$$

5) $$\sum_{p} Q_{cpq} \geq MD_{cq}$$

6) $$\sum_{c} \sum_{i} Q_{ciw} \leq LD_{w}$$

7) $$\sum_{c}\sum_{i}\sum_{p} Q^{R}_{cip} + \sum_{c}\sum_{i}\sum_{j} Q^{R}_{cij} \leq MR^{U}$$

8) $$\sum_{i} Q^{R}_{cip} + \sum_{w} Q^{B}_{cwp} = \sum_{q} Q_{cpq}$$

9) $$\sum_{i} \sum_{c} Q^{t}_{ciw} = \sum_{c} \sum_{p} Q^{B}_{cwp}$$

where Y=yield per hectare in each country, TA=total arable land in each producing region, MA=minimum land used for each crop in each producing region, D=forecasted domestic demand in consuming regions, MD=forecasted import demand in importing countries, LD_w = throughput capacity for grains and oilseeds at river access point W, Q^R is quantity shipped by direct rail, Q^B is quantity shipped by barge, and MR^{US} is rail capacity for grains and oilseed shipments.

Equation 1 indicates that total grains and oilseeds produced in each producing region in exporting countries should be equal to or larger than the quantities of grains and oilseeds shipped to domestic consuming regions, river access points, and export ports. Exportable surplus is total domestic production of each type of grain and oilseed minus domestic consumption of the individual crops and moved to ports by rail directly and river access points for shipments by barge to ports. Equation 2 is the physical constraint of arable land in each producing region. The next constraint represents characteristics of production activities in each producing region in exporting countries. Producers tend to produce certain crops due to their experience in production practices and because certain segments of land are more suited to producing one crop over others and switching to other crops raises costs. Equation 4 represents the domestic demand constraints in consuming regions in exporting countries. The total quantity of grains and oilseeds shipped from producing regions to consuming regions should be larger than or equal to the total quantities needed. Equations 5, 6, and 7 represent capacity in handling and shipping in export ports, river access points, and the U.S. rail system, respectively. The last constraint represents inventory clearing at river access points. Equation 8 is for inventory clearing at ports in exporting countries.

The model was calibrated to reflect the flows that occurred during the early 2000s. In addition to the restrictions above, selected restrictions were imposed on the model to calibrate it to current world trade patterns and to U.S. domestic flows. The software GAMS by GAMS Development Corporation was used to solve the spacial optimization model based on a quadratic programming algorithm. These selected restrictions were applied in order to capture some of the peculiarities associated with world grain shipments.

Data Sources and Transformations

Production Costs, Harvest Areas, Yields and Consumption

Production costs were from Global Insight, Inc. (2004b). Harvested area which was used as a constraint, was obtained for each crop in 44 countries/regions and 27 regions within North America. The maximum area was specified as a function of a trend which represents longer term changes in arable land for each grain in individual countries and regions. Changes in arable land are due to changes in economic conditions, policies, and availability of water for agricultural production and trade environments. Harvested area is specified as: $HA_{cit} = a_{0cit} + a_{1cit}\mathrm{Trend} + e_{cit}$ where HA is harvested area, Trend is time trend commencing from 1980, i = 1 to 44 and represents producing regions, and c = 1 to 3 and represents crop. The model is estimated with time series data of HA from 1980 to 2004 and the estimated model is used to forecast HA for the projection period. The estimated value was posed as maximum available land for crop production in each country and region.

Yield for each crop in individual countries/regions is specified as a function of trend which represents advancement in farming technology. The yield equation is specified as: $\ln \mathrm{YLD}_{cit} = b_{0cit} + b_{1ci} \ln \mathrm{Trend} + e_{cit}$ where YLD is the yield in metric tons/hectare, Trend is a time trend commencing from 1980, i = 1 to 44, c = 1 to 3, Trend = 1 to 25 beginning in 1980. Annual data for harvested area (*HA*) and yield (*YLD*) for the years 1980- 2004 were obtained from the *PS&D Data Base* (USDA, Foreign Agricultural Service). The estimated model was used to forecast yields of each crop for the projection period.

Consumption functions were estimated for the three crops for each country and region and used to make projections. Import demand (*MD*) for each crop in the countries/regions were defined as $MD_{cq} = DD_{cq} - DP_{cq}$ where DP is total production and DD is domestic consumption. The model determines the level of import demand. If MD is positive, the country is an importing country, otherwise it is an exporting country.

Modal Shipping Costs and Restrictions

Shipping costs were defined for each mode and route. Ocean rates for ocean shipping were taken from Maritime Research, Inc., for the period 1994 to 2004. Truck rates were defined from Dager (2007) for shipments to the river and from data reported by the USDA, Agricultural Marketing Service (AMS) (2001-2002) for domestic shipments. Rate functions were estimated and combined with distances to define truck rate estimates for each origin and destination in the United States. Rail rates were derived from the Surface Transportation Board waybill data set. Average rates were derived for each year, origin, and destination, including barge reaches. Separate rate matrixes were derived for domestic and export shipments. Shipments to reaches and export ports were not allowed for those movements in which rail rates were not observed (which would be due to rail being non-competitive on that route) and/or where observed rail shipments were zero.

A rail capacity restriction was imposed and was derived from data reported in USDA-AMS. Finally, a set of restrictions was applied to rail movements that, for varying reasons, are virtually zero. These were discovered through the calibration process by comparing model results with observed flows and then verifying reasons for differences.

Barge shipping costs were derived for origins on the Mississippi River System and encompassed all origins within that geographic region. The barge shipping cost was defined as $B=B_r + D_r$, where B_r is the barge rate defined above which is a function of volume shipped from Reach r, and D is a "delay cost" for Reach r. Barge rates were defined as estimated barge rate functions for each reach (Table 1). Reaches 5 to 6 had the steepest slope indicating a higher rate sensitivity to volume shipped. Reach 4 had the flattest slope, followed by Reach 2, 1, and 3.

Table 1. Parameters for Estimated Barge Rate Functions

	Intercept	Slope	R-square
Reach 1	3.84	0.00061	.91
	(15.29)	(10.75)	
Reach 2	7.55	0.00059	.90
	(20.47)	(9.95)	
Reach 3	11.45	0.00071	.95
	(56.20)	(13.83)	
Reach 4	6.95	0.00038	.97
	(42.05)	(19.48)	
Reach 5	4.64	0.00126	.92
	(19.43)	(11.48)	
Reach 6	5.55	0.00240	.91
	(18.81)	(10.86)	

Values in ( ) are t-statistics.

A delay cost was defined for each of the reaches by the U.S. Army Corps of Engineers (ACE) following the procedures defined in Oak Ridge National Laboratory (2004). For Reaches 1 to 4, the delay costs were derived using simulation procedures. For Reaches 5 and 6, it was assumed that the delay costs would be so inconsequential they were not derived.

To derive the delay costs, a barge capacity-volume relationship was estimated for each lock within the reach and then aggregated. Then, a model was developed where Average wait time = *f*(volume); and Cost = *f*(wait time) and results in hyperbolic function. Factors impacting the cost include value of grain, equipment, and labor costs. These were defined relative to "normal traffic" assumed for other commodities, both upstream and downstream traffic, and they reflect the incremental impact on cost for an assumed change in grain traffic. The delay costs for each reach represent the sum of the delay curves at individual locks within the reach. The values were annualized using procedures in Oak Ridge National Laboratory (2004). The delay costs were measured with assumptions regarding improvements. The first assumes existing capacity and operating infrastructure during the base period, 2000 to 2004. The second assumed that capacity is expanded.

Delay costs reflect the cumulative impact of grains originating on that reach. Shipments originating upstream and going through a reach are added to this total. There is an additional critical relationship between grain coming in from the Illinois River (Reach 4) and Reach 1 of the Mississippi River. The capacities of the 600-foot locks at Locks 21 to 25 are restrictive. For traffic coming onto the Mississippi River below St. Louis (Lock 27), there is no lock and therefore no lock delays. Reach 4 traffic enters below the point of congestion.

These delay costs reflect the relationship between total tonnage moving over the reach and expected delay costs. Grain originated on Reach 3 contributes to the traffic and delay in Reach 2 and in Reach 1. Shipments on Reach 1 would not contribute to delays on Reach 2 or 3. Traffic levels for grain and non-grain during the base period (2000-2004) were used to calibrate the delay curves. The base assumption is for zero growth in non-grain traffic, and a sensitivity is used to illustrate the impacts of this assumption. Finally, the delay costs were derived for both the existing capacity, as well as for an expanded lock system. It is anticipated that any expansion would take 13 to 14 years, so the impact of an expansion is expected in 2020.

These results are shown in Figure 2 for each reach for grain volumes only. As movements increase, the delay costs increase and become exponential at different levels for each reach. The results illustrate the impact of the proposed improvements. Specifically, the proposed improvements would have the impact of shifting the delay function rightwards, meaning that near-zero delay costs would exist for a broader range of shipments. For most reaches, current volume is less than the level at which delay costs would begin to escalate sharply. In addition, in some cases there is a very slight negative delay cost.

For Reach 2, the increased costs associated with delay for traffic, less than about 28 mmt of grain traffic, is near zero. Costs increase very sharply for traffic greater than about 30 mmt. In addition, there are slight negative delay costs for volumes less than about 18 mmt. For Reach 1, which reflects the cumulative traffic of grain entering in either Reach 1 (above lock 27) Reach 2, or Reach 3, costs begin to increase for volumes greater than about 38 mmt. Finally, at Reach 4, delay costs are near nil up to about 28 mmt and then increase sharply. For movements greater than these values, the delay costs increase and become exponential at different levels for each reach.

The delay curves change if there were an expansion, as proposed. Improvements would have the impact of shifting the delay function rightwards, meaning that near-zero delay costs would exist for a broader range of shipments. In addition, the value of the negative delay costs for lower volumes is slightly greater than in the previous case.

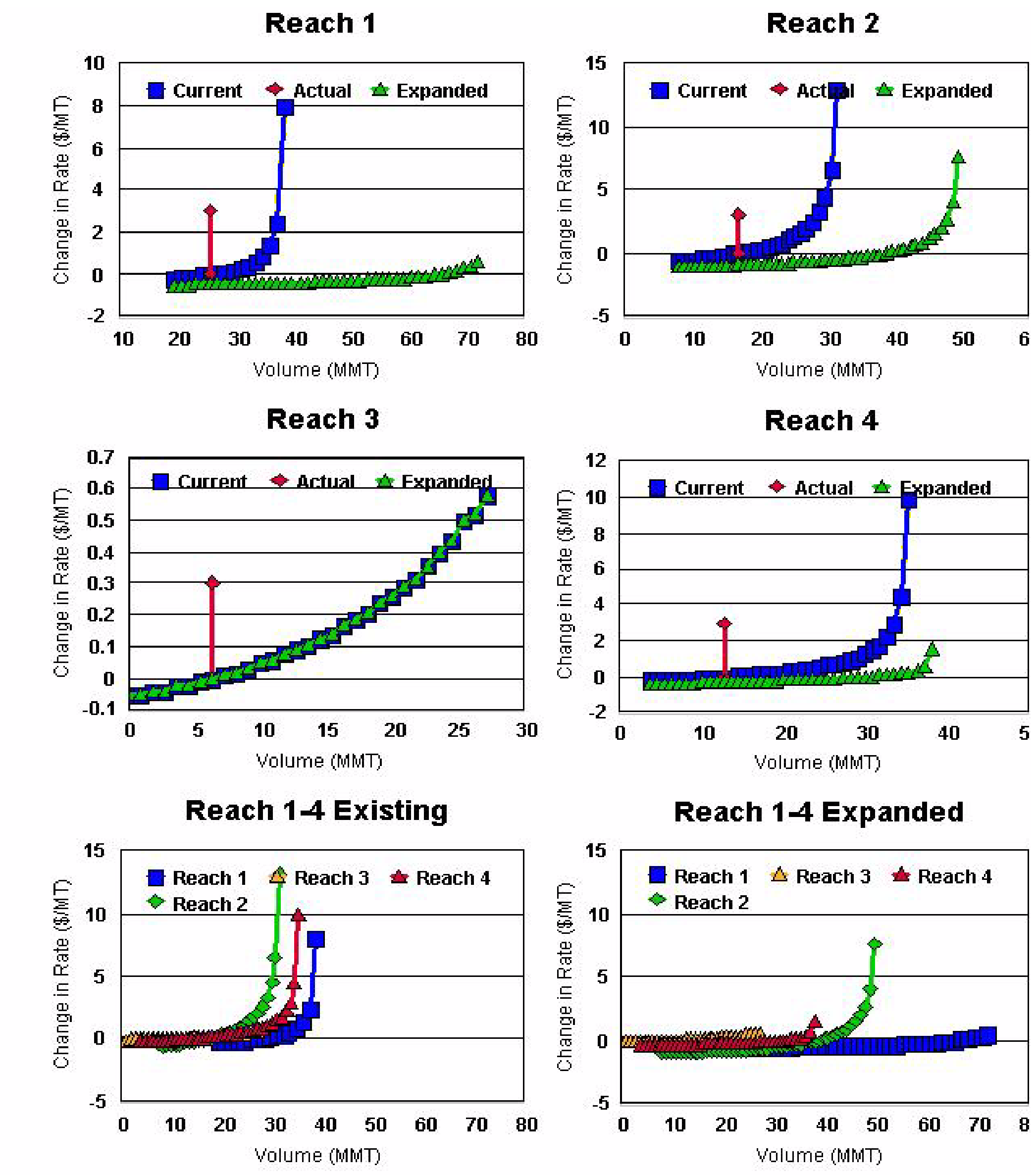

Figure 2. Delay Costs and Actual Volumes, Existing and Expanded Capacity: Grain Volumes Only

Base Case Definition and Projection Methodology

A base case is defined and used for comparison with results from the scenarios. The base case uses data for the period 2000 to 2004. The following logic was used to make projections: 1) Demand is projected for each country and region based on income and population projections from Global Insight, Inc. (2004a); 2) Yield and production costs for each producing region are derived; 3) Production potential is determined in each country/region subject to the area restriction; 4) U.S. modal rates were derived for the period 2000 to 2004, and it was assumed that their spatial relationship was the same during the projection period; and 5) Ocean shipping costs were projected based on oil costs, distances, ship size, trend, etc. Using these, the model was solved for each year in the projection horizon which was defined in 10-year increments.

Table 2 defines the major assumptions for the base period and projection period. The model was estimated with and without expansion of the barge system. Restrictions were imposed on railcar loading capacity. Modal rates were assumed at the 2000 to 2004 average values, and barge rates were represented as a supply relation and subject to delay costs. Area for crop area in the United States was restricted to the historical area harvested and yields were based on longer term trends. These were retained in the projection period, but both were relaxed as sensitivities. Ethanol use of corn in the United States was assumed at the Energy Information Administration projections (EIA 2005).

Due to a cumulation of peculiarities on wheat trade and marketing, mostly due to cost differentials and quality demands, we imposed a set of restrictions. These were intended to ensure that countries' trade patterns were represented and to allow some inter-port area shifts in flows within North America. These primarily relate to costs and quality differences between suppliers and importers. The purpose of these restrictions are due, in part, to the fact that there are numerous suppliers that are lower cost than North America. However, some importers have product demands and product requirements that require purchasing and importing from these regions, despite the higher cost. Australia and Argentina are lower cost producers than North America in many regions. To capture these factors, we imposed restrictions of varying types to calibrate historical trade flows. The restrictions applied for a group of countries include 1) X% of their imports must originate from the hard red spring wheat producing regions of North America; 2) Y% of their imports must originate from the soft white wheat producing regions of North America; and 3) Max Z% of their imports could originate from Canada. Values for X, Y, and Z were derived from actual shipments for the period 1995 to 2004.

Model results were evaluated relative to domestic flows during the base period 2000 to 2004. Data on actual rail and barge flows during the base period were used to compare to model results. If there was a substantial difference, we investigated as to the reason for the difference and made adjustments. Generally, these involved making a series of restrictions on flows so as to not restrict those to or from the river system. These adjustments were made to the model to more accurately reflect these flows.

Table 2. Base Case Assumptions

Model Assumption	Base Period 2000-2004	Projection Period	Sensitivities During Projection Period
Non-grain Barge Traffic	2000-2004 average levels	Assumed same as in base case	
U.S. Rail Capacity	Restricted capacity to recent maximum shipments		Relaxed
Modal Rates	Rail from 2000-2004 average; barge rates represented as supply functions by reach; ocean rates derived from a regression	Retained as in base case	

U.S. Area Restrictions	3 restrictions imposed:
	minimum total area=100% of recent 3-year average;
	maximum total area=100% of base;
	maximum area that can be switched among crops was 7% from the base period.
		Maximum changed to 107% in 2010 forward	

Rest of World (ROW) Area Restrictions	3 restrictions imposed:
	minimum total area=100% of recent 3-year average;
	maximum total area=107% of base;
	maximum area that can be switched among crops was 7% from the base period.
		Maximum changed to 107% in 2010 forward	

Ethanol Production	EIA 2005 projections	EIA 2005 projections	
Other Trade Policies	Retained	Retained	

Results

The base case model was calibrated relative to the average of flows during the base period 2000 to 2004. The model replicates the total quantity of exports from the United States, as well as most competitor countries. Results from the model are very comparable to actual shipments. Export volumes from the United States are comparable by grain type, as are inter-port exports. Reach shipments also compare. Actual shipments were 47 mmt, and varied from 43 to 51 mmt, with sharp declines commencing from 2002. Shipments decreased from 51 mmt to 43 mmt over this period. Reach shipments are also reflective of historical shipments during the base period. The model results compare very favorably with a total of 51 mmt.

Base Case Projections

The model was used to analyze delay costs and to make projections for shipments through the river system. The model was first simulated assuming existing capacity on the barge system, then with expanded capacities. In some cases, it was necessary to make adjustments to maximum area allowed to be planted in order get a solution, i.e., so supplies exceeded demand on a world level. To do this, we retained the base case assumptions as much as possible and then made adjustments for this purpose. For some countries, there have been gradual reductions in area planted (e.g., United States, European Union, and China), whereas in others, there have been increases (e.g., Argentina and Brazil). The percentage adjustment was made relative to that projected area and in all cases was treated as a maximum restriction. The interpretation of this is that in order to produce adequate supplies to meet demand, the area devoted to these crops would have to increase by 7%.

The model was first solved assuming existing capacity. Exports from the United States increase from the base period to 2010, in part due to the assumption that the maximum area for plantings would increase to 107% of forecasted area and in part due to the assumption that China's corn exports fall from 8 mmt to zero in 2010. Thereafter, China exports stay at zero. This implies a relaxed CRP (as represented by the 7% increase) and/or planting area shift from other crops (soybeans, and wheat). The decline that occurs after 2010 is in part due to increasing competitiveness of other exporting countries and increased domestic use of these crops (notably for ethanol). U.S. corn exports decline the most, from a peak of 62 mmt to 42 mmt. Wheat exports decline substantially due to a shift in areas away from wheat, but soybean exports increase, falling only in 2060. Exports from the United States are concentrated in the U.S. Gulf (including Texas Gulf) and decline from 101 to 76 mmt after reaching a peak in 2010. Exports from the PNW decline from 25 mmt to 9 mmt in 2060. Again, the reason for this is the increased domestic use and shifting among crops.

Reach shipments are shown in Figure 3. Reach volume increases from the base period at 51 mmt to 65 mmt in 2020. Thereafter, shipments decline to a longer term level at about 57 mmt. The reduced volume comes from both reduced wheat shipments, which declines drastically (from 3 mmt to zero).

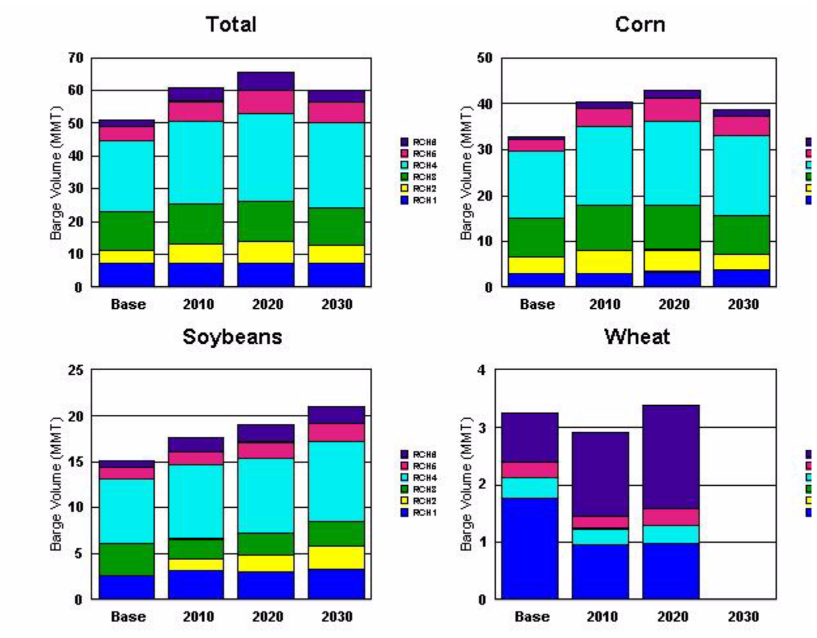

Figure 3. Base Case Projections: Barge Reach Volumes

Expanded Lock System

The model was run assuming the capacities at each of Reaches 1, 2, and 4 were expanded, which would change the delay costs. The upward-sloping delay functions were changed to reflect that of an expanded lock capacity. The changes would occur and, in these estimates, would be completed by 2020. Results are shown in Figure 4 and changes are summarized in Table 3.

The results indicate an increase in barge shipments by 4 mmt by 2020, nearly all of which would be for corn and soybeans in equal amounts (Figure 4). Thereafter, the increase in barge shipments would be about 1 mmt to 2.5 mmt, with most of it being soybeans. Changes would also occur in reach shipments. In 2020, there would be increases in shipments on Reach 1, 2, and 4, but decreases in Reach 5 and 6. These results suggest that inter-reach competition is important. As delay costs decrease in the upper reaches, shipments from the lower reaches decline.

Delay costs were quantified for each simulation on each reach. Technically, the delay costs are the “lock-processing time” including the added queuing time for going through the locks. As barge volumes increase, there is an increase in barge rates. As barge rates increase, there are slight shifts to other modes, routes, or potentially crops. As barge shipping costs increase further due to delay costs, some barge shipments may continue despite the higher costs. It is these additional delay costs that are quantified. These are shown in Table 3 for the base case without expansion and then for the expanded barge capacity. The implicit assumption here is that there is zero growth in non-grain traffic (relaxed below).

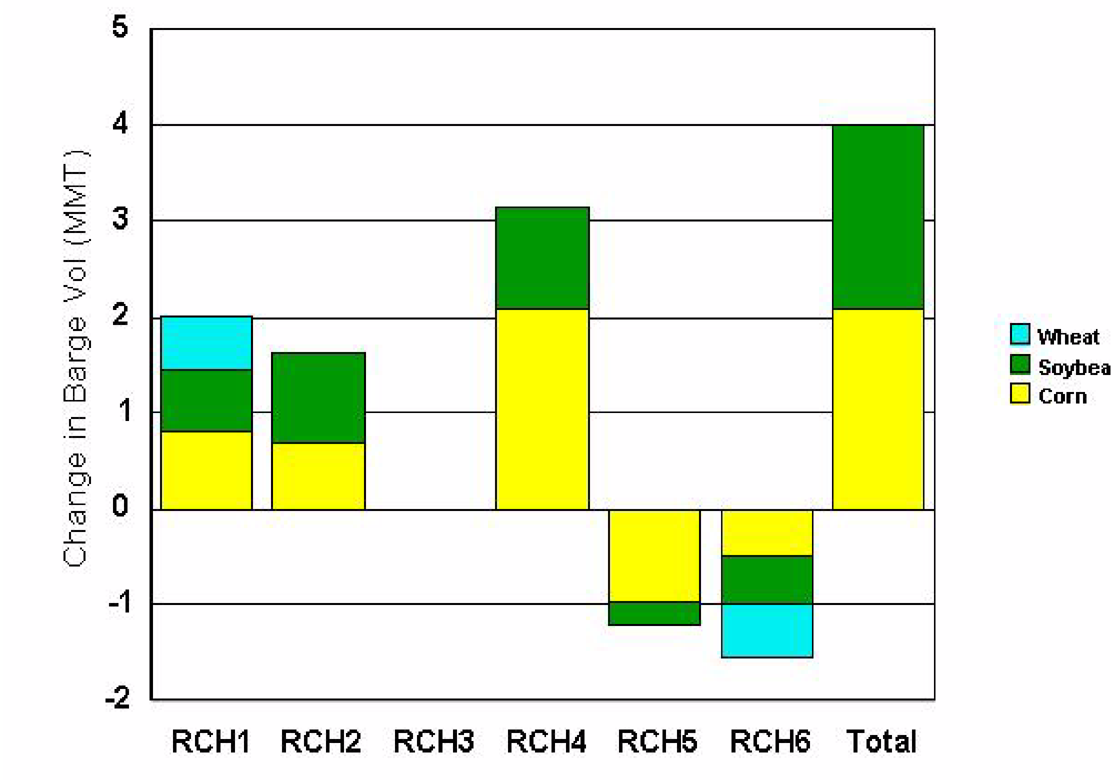

Figure 4. Change in Barge Shipping Volume, Expanded - Current Capacity, 2020.

In the base case, without expansion, negative delay costs are accrued for shipments on Reach 1 and 2, and positive delay costs occur on Reach 3 and 4. The negative delay costs are slight and are reflective of shipments being slightly less than normal during the base period, resulting in a cost savings. These values are relatively small. The delay costs that occur on Reach 4 are more substantive at $0.45/mt. As barge shipments increase on Reach 4, barge rates increase, and when shipments begin to approach about 32 mmt, delay costs are accrued without any traffic diversion. The amount of this added cost due to delay is the delay cost reported in Table 3. Through time, without expansion, the delay cost on Reach 4 increases to $1.08/mt in 2020.

Expanding lock capacity has the effect of reducing delay costs and increasing capacity. The delay costs associated with these scenarios are shown in the middle-panel of Table 3, and changes versus the base case are shown in the lower panel. An expanded lock system would result in lower delay costs at each reach. Those at Reach 4 decline by about $1.01/mt. Similar declines occur at Reach 2 ($1.04/mt) and those at Reach 1 are about $0.44/mt.

Table 3. Comparison of Delay Costs ($/MT) by Reach for Current Barge Capacity, Expanded Barge Capacity and Change

Delay Costs: Current Barge Capacity ($/MT Barge Volume (Grain + Non-Grain))			
	Base Year	2020	2030
Reach 1	-0.12	-0.02	-0.09
Reach 2	-0.19	0.14	-0.08
Reach 3	0.10	0.10	0.08
Reach 4	0.45	1.08	0.94
Delay Costs: Expanded Barge Capacity ($/MT Barge Volume (Grain + Non-Grain))			
		Exp 2020	Exp 2030
Reach 1		-0.46	-0.47
Reach 2		-0.90	-0.94
Reach 3		0.10	0.09
Reach 4		0.06	0.00
Delay Costs: Change from Current Capacity to Expanded Barge Capacity			
		2020	2030
Reach 1		-0.44	-0.39
Reach 2		-1.04	-0.86
Reach 3		0.00	0.01
Reach 4		-1.01	-0.93

Evaluation of the change in delay costs includes both a price and substitution effect, as illustrated in Figure 5. The price effect is the impact of switching to the lower delay cost function which results in lower total barge shipping costs due to the lower delay costs for any given volume. Here the price effect is calculated as the reduction in barge shipping costs at Q_1 and the reduction in costs is equivalent to the shift in delay costs from D_1 to D_2. In addition to this, there is a substitution effect which is the result of substituting increased barge shipments, due to the now lower barge shipping costs, for alternative modes and routes. This is shown by the movement from Q_1 to Q_3 along the new expanded capacity delay cost function which also reflects a movement along the total barge cost function. Here, due to the reduced delay costs (and subsequent lowering of total barge shipping cost), there is a shift from other transit modes to barge, which we refer to as the substitution effect.

These impacts were each evaluated and summarized below. The direct impacts on barge volumes are explained first and shown in Table 4. The first panel shows the delay costs accrued by reach with current barge capacity. These are largest for Reach 4 and slightly negative in Reach 1. Panel 2 reflects the delay costs estimated with the expanded barge capacity delay function at Q_1. Here, the delay costs are about $-29.9 million and are largely a result of reduced delay costs at Reaches 1, 2, and 4. The total effect on delay costs is shown in Panel 3. The lower portion of Table 4 shows the effects on barge delay-costs for the price effect, Panel 4, the substitution effect in Panel 5, and the total effect in Panel 6. As shown in Panel 6, the impact of expansions on delay costs are in the area of $61 million, inclusive of both the price and substitution effects. Most of this is accrued on Reach 4, followed by Reach 2 and 1.

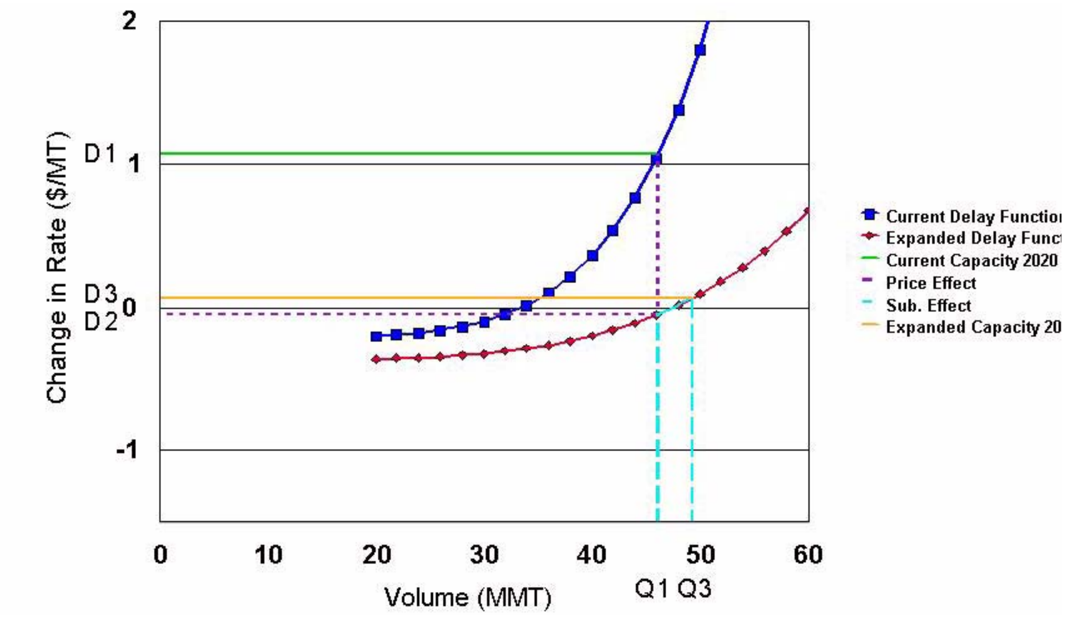

Figure 5. Price, Substitution, and Total Effects on Barge Reach Volume of Shift from Current to Expanded Barge Capacity, Reach 4, 2020

In addition to the price and substitution effects on barge volumes, there is an impact on other modes, routes, and production and shipping of other commodities. This can be evaluated by comparing the equilibrium solution from the model without the expansion, to a model equilibrium including the expansion. The impact of the expanded barge capacity is for increased barge shipments (as described above), which has the impact of reducing rail shipments, potentially changing the composition of port area shipments (e.g., from the PNW to the U.S. Gulf) and potentially causing a slight shift in the composition of production and shipments amongst commodities.

The effect of the expansion on the change in equilibrium between the base case without expansion in 2020 and that with an expansion was evaluated and summarized in Table 5. The expansion results in reduced delay costs of $61 million (about $1.02/mt), which includes the effect of a shift to a delay curve with slightly greater negative costs. As a result, there is an increase in quantity shipped by barge, resulting in a slightly higher barge rate, i.e., a movement along the barge rate function. This is an increase in cost of about $50 million or $0.84/mt. In total, barge shipping costs including delay costs are reduced by $11 million or $0.18/mt. Other impacts are for reduced shipping costs by rail to ports and reaches of about $59 million, increased rail shipments to domestic and slightly greater ocean shipping costs, $10.4 million, due to an increase in shipping from the U.S. Gulf. Taken together, the effect of the expansion is to reduce these costs by $52 million.

Table 4. Total Delay Costs by Reach, Current Capacity, Expanded Costs for Current Capacity Volumes, Expanded Costs for Expanded Volumes, and Differences, by Reach and Year

	Base	2010	2020	2030	2040	2060
1) Delay Costs: Current Capacity ($ 000)						
Reach 1	-2672	-1133	-394	-2072	-1125	-3015
Reach 2	-2983	1488	2631	-1338	619	11519
Reach 3	1222	1176	1222	937	1126	1222
Reach 4	9795	21967	28989	24298	27904	19841
Total	5361	23498	32448	21825	28524	29567
2) Delay Costs: Expanded Costs at Current Capacity Volumes ($ 000)						
Reach 1	-2672	-1133	-12243	-11492	-11974	-10588
Reach 2	-2983	1488	-17533	-16457	-17077	-18597
Reach 3	1222	1176	1222	937	1126	1222
Reach 4	9795	21967	-1313	-2013	-1476	-2659
Total	5361	23498	-29868	-29026	-29401	-30622
3) Delay Costs: Expanded Costs at Expanded Capacity Volumes ($ 000)						
Reach 1	-2672	-1133	-13642	-11798	-12413	-11471
Reach 2	-2983	1488	-18355	-17474	-18007	-19112
Reach 3	1222	1176	1222	1060	1222	1222
Reach 4	9795	21967	1896	10	1564	-826
Total	5361	23498	-28879	-28201	-27633	-30187
4) Change in Delay Costs: Expansion Effect (2-1)						
Reach 1	0	0	-11849	-9420	-10849	-7573
Reach 2	0	0	-20164	-15119	-17696	-30116
Reach 3	0	0	0	0	0	0
Reach 4	0	0	-30302	-26311	-29380	-22500
Total	0	0	-62316	-50851	-57925	-60189
5) Change in Delay Costs: Change in Volume Effect (3-2)						
Reach 1	0	0	-1399	-306	-439	-883
Reach 2	0	0	-822	-1017	-930	-515
Reach 3	0	0	0	123	96	0
Reach 4	0	0	3209	2023	3040	1833
Total	0	0	989	825	1768	435
6) Change in Delay Costs: Total Effect (3-1)						
Reach 1	0	0	-13248	-9726	-11288	-8456
Reach 2	0	0	-20986	-16136	-18626	-30631
Reach 3	0	0	0	123	96	0
Reach 4	0	0	-27093	-24288	-26340	-20667
Total	0	0	-61327	-50026	-56157	-59754

Table 5. Summary: Delay Cost Impacts and Expansion

Impact	$million	$/mt
Reduced delay costs	61	1.02
Increase barge shipments (higher barge rates)	50	.84
Total	-11	-.18
Reduced shipping costs by rail to ports and reaches	59	
Slightly greater ocean shipping costs (more U.S. Gulf shipments)	10.4	
Total	-52	

The model was also simulated assuming increases in non-grain traffic on the river. Increases in non-grain traffic shift delay costs upward along the curve for total barge volume and reduces the volumes of grain that can be shipped at a given delay cost. It is not clear the extent of potential increase in non-grain traffic. Consequently to give a range, we simulated different percentage changes in non-grain traffic. The results show that if the non-grain traffic grows by 50%, (i.e., cumulatively over the base period to 2020), then delay costs increase and grain traffic would decrease by about 7 mmt (Table 6). At this growth rate and without any expansion, the delay costs in 2020 would increase on each reach. Those on Reach 4 would increase from $1.08 to $2.15/mt. With an expanded barge capacity, these delay costs would increase to $0.54/mt. Expansion would result in reduced delay costs on each reach. Delay costs would decrease by $61 to $76 million, depending on the percentage increase in non-grain traffic with most of the delay cost reductions occurring in Reach 4, followed by Reach 2 and 1.

Table 6. Sensitivity of Delay Costs to Changes in Non-Grain Barge Traffic, 2020

Delay Costs: Current Barge Capacity 2020 [$/MT Barge Volume (Grain + Non-Grain)]

	2020	+10%	+20%	+30%	+40%	+50%
Reach 1	-394	-15	676	1,752	2,932	4,560
Reach 2	2,631	2,804	3,970	6,027	8,618	11,651
Reach 3	1,222	1,251	1,363	1,529	1,700	1,876
Reach 4	28,989	31,148	33,737	37,544	42,725	48,561
Total 1-4	32,448	35,188	39,746	46,852	55,976	66,648

Delay Costs: Expanded Barge Capacity 2020 [$/MT Barge Volume (Grain + Non-Grain)]

	Exp 2020	+10%	+20%	+30%	+40%	+50%
Reach 1	-13,642	-13,486	-13,313	-13,122	-12,911	-12,678
Reach 2	-18,355	-17,784	-17,134	-16,397	-15,567	-14,636
Reach 3	1,222	1,394	1,571	1,753	1,940	2,132
Reach 4	1,896	4,148	6,658	9,433	12,490	15,807
Total 1-4	-28,880	-25,728	-22,218	-18,334	-14,048	-9,375

Delay Costs: Change 2020 (Expanded - Current Capacity)

	2020	+10%	+20%	+30%	+40%	+50%
Reach 1	-13,248	-13,471	-13,990	-14,875	-15,843	-17,238
Reach 2	-20,987	-20,588	-21,103	-22,424	-24,185	-26,287
Reach 3	0	143	208	224	240	256
Reach 4	-27,093	-27,000	-27,079	-28,111	-30,235	-32,754
Total 1-4	-61,327	-60,916	-61,964	-65,186	-70,024	-76,022

Sensitivities: Rail Restrictions

As specified, the model included a rail capacity restriction. Capacity could be due to having enough cars, track space, crew, or locomotives, or some combination thereof. The base case assumed rail capacity at the maximum of the observed shipments during the base period. Such a restriction impacts the ability of rail to compete with barges, even though in some cases rail rates are less. In fact, this is a very critical variable, particularly in light of some of the rate relations that exist and that there has been a general increase in rail capacity over time.

As example, a recent survey indicated that each of the major railroads [Burlington Northern Sante Fe (BNSF); Canadian Pacific Rail; Dakota, Minnesota, and Eastern; Norfolk Southern; and the Union Pacific] were expanding their grain car fleets and/or locomotives (*Grain Journal* 2006). The BNSF in particular indicated “Right now, we’re the only railroad that continues to add aggressively to its agricultural fleet....This year, we’ll add another 2,500 cars.” This is in addition to an expansion in use of shuttle trains which has the impact of increasing grain shipping capacity.

To evaluate the impact of this restriction on barge flows, the model was solved assuming rail capacity at the equivalent of 131 mmt up to 201 mmt to evaluate how expanded rail capacity would impact shipments through the barge system. Results are shown in Figure 6. Increases in rail capacity have an inverse impact on barge shipments. Notably, increases in rail capacity, holding rates, and everything else constant, reduces equilibrium barge shipments. This effect is not very great until capacity reaches about 161 mmt. Increases beyond this level reduce barge shipments. The results are important, particularly as rail capacity has been increasing during the past decade, as well as car turnaround which effectively increases capacity.

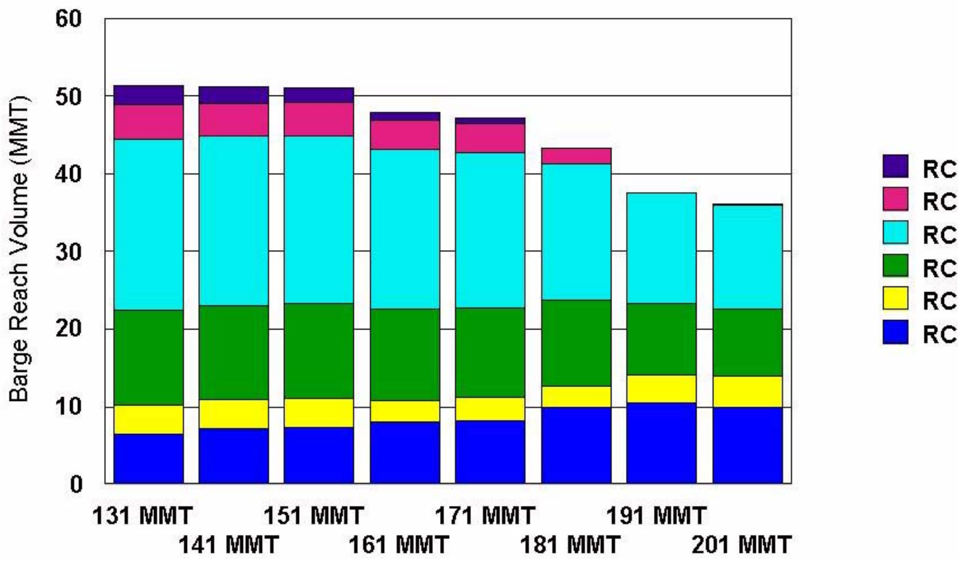

Figure 6. Sensitivity of Barge Reach Volume to Rail Capacity

Summary

The purpose of this study was to develop a methodology and analytical model to forecast grain and oilseed shipments through the Mississippi River System and to analyze delay costs. The model is a spatial optimization model of the world grain trade with a high degree of detail about the U.S. grain logistical system. Important variables are forecasted and used to evaluate changes in flows through specific logistical channels. Projected import demands are based on consumption functions estimated using income and population and accounting for inter-country differences in consumption dependent on economic development. Each of the competing supply regions and countries were represented by yields, area potential that could be used in production of each grain, costs of production, and interior shipping costs, where relevant. Crucial in this model is the inter-reach competition as well as interior spatial competition between the U.S. Pacific Northwest and shipments through the U.S. Gulf.

This model is a longer run model and allows for numerous longer run adjustments. For example, changes in barge rates or capacities have the impact of simultaneously affecting barge shipping costs including delay costs, as well as barge movements on particular reaches, rail rates, as well as marginal changes in production and exports from the United States and other countries. Thus, the comparative statics capture the impact of longer run adjustments. Second, the model has very extensive inter-modal competition which affects inter-port, inter-reach, and inter-modal, as well as inter-regional, competition.

Delay costs are the additional costs associated with shipping on the barge system and result from queuing and the added costs for shipments that are delayed. These are an important feature of barge shipping, particularly when shipment volumes are greater. In several of the reaches, grain flows are near the point at which positive delay costs are accrued. At higher volumes, delay costs escalate and ultimately become nearly vertical. The proposed improvements would have the impact of shifting the delay function rightwards, meaning that near-nil delay costs exist for a broader range of shipments. In addition, the value of the negative delay costs for lower volumes are slightly greater than in the previous case.

As volumes increase, costs of shipping by barge increase, some shipments are diverted to different modes and/or routes, and delay costs accrue to shippers. Without the expansion in barge capacity, the delay costs in 2020 would increase on each reach. Those on Reach 4 would increase to $1.08/mt. Expansion would result in reduced delay costs on each or Reaches 1, 2, and 4 by about $0.44/mt, 1.04/mt, and $1.01/mt, respectively. Expanding lock capacity reduces delay costs, increases capacity, and shipments by barge. Barge shipments increase by about 4 mmt by 2020. There is substantive inter-reach competition and by 2020, shipments on Reach 1, 2, and 4 increase, but shipments on Reach 5 and 6 would decrease. The impact of expansions on delay costs are in the area of $61 million, inclusive of both direct effects. Expansion results in an increase in barge shipping, a decrease in rail shipping cost, and a slight increase in ocean shipping costs. In total, the impact of expanding locks is a decrease in costs by about $52 million.

The results were analyzed assuming a long-term capacity restriction on rail shipping. At least in the shorter term, such a restriction impacts the ability of rail to compete with barges, even though in some critical cases rail rates are less. Sensitivity analysis shows that increases in rail capacity has an inverse impact on barge shipments. Increases in rail capacity, holding rates, and everything else constant, reduce equilibrium barge shipments.

These results have both public and private sector policy implications. The private sector implications are all about factors impacting the competitiveness of the barge system. These are impacted primarily by rail rates to targeted routes, rail capacities, and volumes, determined by the multitude of factors impacting spatial allocation of production and distributions. Public policy implications revolve around delay costs and the impact of expansion on these delay costs. These results indicate the delay costs are important. Expanding the locks would result in a re-allocation of shipments among modes, reaches, and ports, notwithstanding minor adjustments in production. Taken together, the expansion would result in reduced delay costs and growth in non-grain traffic would increase the amount of reduced costs associated with delay. These are important considerations, amongst others, in evaluating the economic and social benefits and costs of expanding these locks on the Mississippi River System.

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