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ECONOMIC ANALYSIS OF DOMESTIC AND OCEAN TRANSPORTATION FOR U.S. GRAIN SHIPMENTS

By

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FOREWORD

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Highlights

This study evaluates the interdependency between domestic and ocean transportation systems with changes in ocean freight rates and identifies impacts of the existing port capacity on the domestic and ocean shipments of grain.

The method used for this study is a mathematical programming model based on a linear programming algorithm. The model has 88 producing regions, 24 domestic consuming regions, 13 export ports, 9 commercial storage locations, and 11 foreign import regions. Three time periods and three different crops (wheat, soybeans, feed grains) are also defined in the model.

Total quantity of grain moved from producing regions to domestic and export markets in the base model is 8,493 million bushels. Approximately 39 percent of the grain goes to domestic consuming regions and the remainder to export markets. Shipments by rail, barge, and truck are 60, 5, and 34 percent of grain shipped to domestic consuming regions, respectively, under the cost-base rate structure. They are 90, 7.5, and 2.5 percent for export shipments. Average transportation costs are 36.99 cents per bushel for all domestic shipments and 60.40 cents per bushel for ocean shipments.

This study indicates that $280 million could be saved by optimizing grain flows and handling facilities at U.S. export ports. Under the cost-base rate structure, much more grain should move to Houston and the Atlantic Coast for export in order to minimize total transportation costs. This study further indicates that optimizing grain flows and handling facilities at export ports is more beneficial for soybean shipments than for shipments of other grains.

Changes in ocean freight rates at the Gulf, West Coast, Great Lakes, or Atlantic Coast significantly change domestic and ocean transportation costs, quantities, and physical flows. Domestic transportation costs are most greatly influenced with a 30 percent increase in ocean freight rates at the Great Lakes. Ocean transportation costs are largest with a 30 percent increase in ocean freight rates at the Gulf. Wheat shipments are most costly with a 30 percent increase in ocean freight rates at the Great Lakes. Soybean and feed grain shipments are most costly when ocean freight rates are changed at the Gulf ports.

ECONOMIC ANALYSIS OF DOMESTIC AND OCEAN TRANSPORTATION FOR U.S. GRAIN SHIPMENTS

by

Won W. Koo

Grain is one of the largest export items in the United States; in 1979, the United States exported 130 million metric tons of grain (Table 1). Exports are dependent upon economic and noneconomic factors such as foreign production, changes in consumers' preference, foreign trade policies, exchange rates and transportation costs. Most of these factors except transportation costs are not domestically controllable.

TABLE 1. U.S. GRAIN EXPORTS IN 1977, 1978, AND 1979

Grain	1977	1978	1979
		(1,000 metric tons)	
Wheat	31,538	32,311	37,198
Soybeans	19,061	20,117	23,818
Feed Grains	55,659	59,200	69,774
Total	106,258	111,628	130,790

SOURCE: USDA, Agricultural Statistics, 1979 and 1981.

An efficient transportation system is essential for the United States to be price competitive with other major grain exporting countries such as Canada, Argentina, and Australia. The existing grain transportation system could be improved through cooperation between the transportation and grain marketing industries.

Modes of transportation available for shipping grain are rail, truck, barge, and ocean vessels. Rail transportation is the most common mode of transporation for domestic grain shipments in the United States. The reasons are: 1) rail has a cost advantage over trucks in a long distance haul, and 2) barge transportation is cheaper than rail for trip distances greater than 900 miles but is limited to areas near waterways. In 1977, more than 60 percent of the total grain shipped to markets was moved by rail and about 25 percent by barge. The remainder was shipped by truck. The modal share is also related to changes in ocean transportation activities.

For example, an increase in ocean shipping rates between gulf ports and major importing countries results in changes in domestic flows of grain to ports and also causes changes in modal share in the U.S. transportation industry. New Orleans and Portland can receive grain by truck, rail, and barge, but other ports (Seattle, the Great Lakes, and Atlantic Coast) can receive grain only by truck and rail. Consequently, changes in flow pattern to the ports will result in changes in modal share in the grain transportation industry.

Although interdependency between domestic and ocean transportation is highly important, research has not been directed toward developing a model which contains domestic and ocean transportation activities. Most studies have focused on domestic grain transportation under an assumption that ocean transportation is exogeneous (Leath and Blakely; Schnake and Franzmann; Fedeler et al. and Binkley et al.). Therefore, these studies have not captured interdependencies between domestic and ocean transportation. Consequently, the optimal grain flows provided by these studies are a conditional optimal subject to the given ocean transportation activities in shipping grain from U.S. ports to foreign import regions.

I. Objective of the Study

Grain transportation is much more than the mere flow of grain between points. Understanding the grain transportation system requires knowing not only how much grain is to be shipped, but also how the grain is to be shipped to minimize transportation costs from producing regions in the United States to both domestic consuming regions and foreign importing countries. This information is essential for formulating transportation policy to improve the grain transportation system. In this study, the U.S. grain transportation system is optimized by endogenizing ocean transportation activities.

Specific objectives are:

1) to examine the U.S. port capacity for grain exports, and
2) to evaluate impacts of changes in ocean freight rates on the grain distribution and transportation system in the United States.

II. Methodology

The model used in this study is a spatial equilibrium model based on a linear programming algorithm. The model is similar to one developed by Koo and Bredvold. The model includes ocean transportation activities between U.S. export ports and foreign import regions in addition to domestic transportation activities specified in Koo and Bredvold.

General Description of the Base Model

The model incorporates transportation and storage activities in marketing grain from each producing area to each consuming area. The transportation activities are subject to various constraints associated with regional demands for grain, regional supplies of grain, storage capacities in commercial storage locations, port capacity, and foreign import demands for grain. The model contains 88 grain producing regions, 24 domestic grain consuming regions, 13 export locations, 9 commercial storage locations, and 11 foreign import regions.

Figure 1 shows the locations of supply origins which are based on grain production patterns in 1977. Figure 2 shows domestic grain consuming regions and export locations. Delineation of domestic consuming regions is based on the locations of grain processing plants.

The nine major commercial grain storage locations are Columbus, Ohio; Memphis, Tennessee; Peoria, Illinois; Kansas City, Missouri; St Paul, Minnesota; North Platte, Nebraska; Dallas, Texas; Lubbock, Texas; and Boise, Idaho. The 11 foreign import regions are Western Europe, Eastern Europe, Middle East, Africa, South Asia, East Asia, Japan, Brazil, U.S.S.R., South America, and Central America.

The model specifies three grain crops: wheat, soybeans, and feed grains. Feed grains include barley, corn, oats, and grain sorghum. Three time periods allowed in the model are: 1) period 1, August through November; 2) period 2, December through March; and 3) period 3, April through July.

Transportation activities specified in the model are: 1) shipments of grain from each producing region to each domestic consuming region; 2) shipments from each producing region to import regions directly; and 3) shipments from producing regions to import regions through commercial storage locations. It is assumed that commercial storage facilities receive grain during the harvest period (period 1) and transport the grain to export ports during the other periods (December through July). These commercial storage areas receive grain by truck and rail, and ship out by rail, truck, and barge.

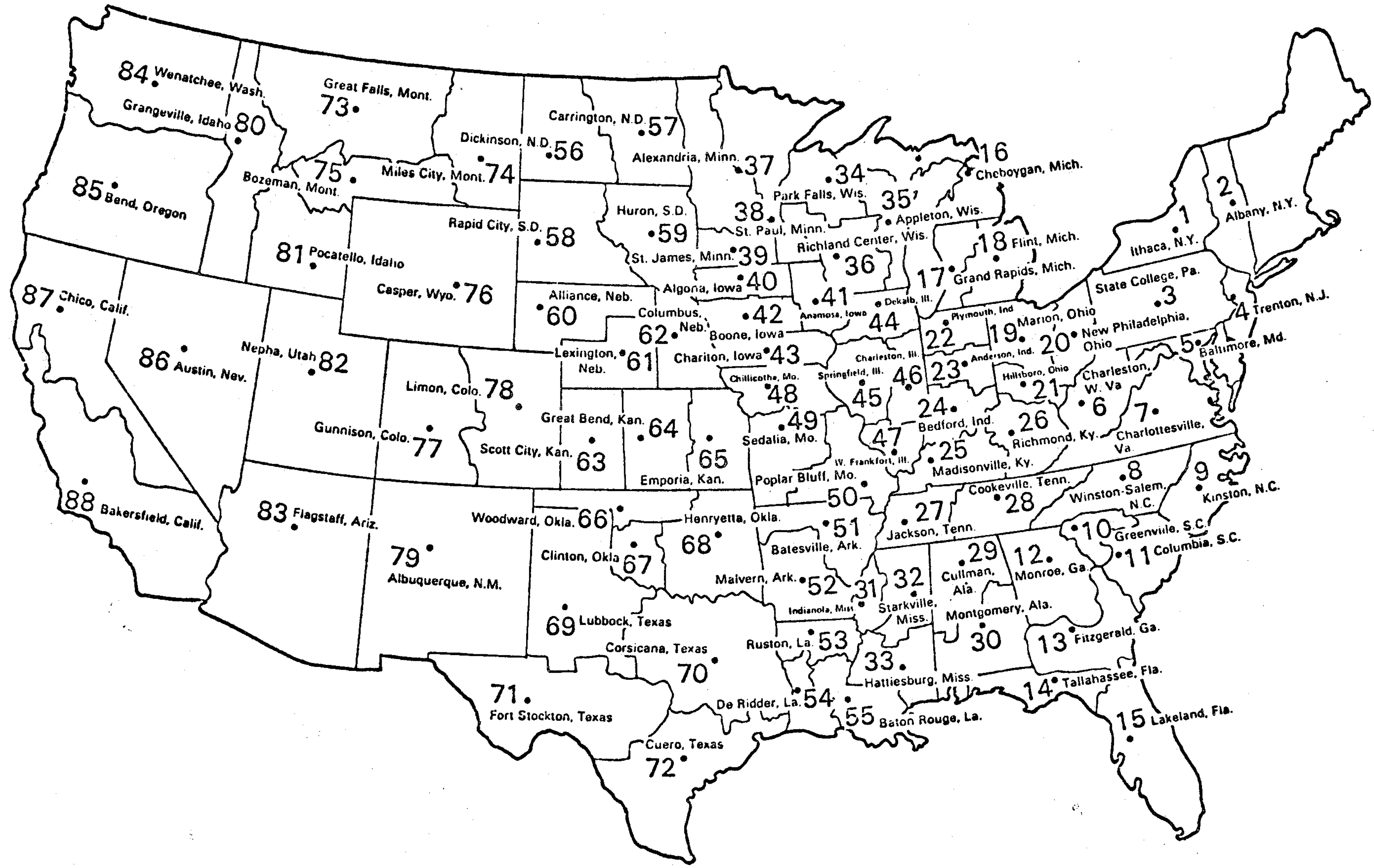

Figure 1. Producing Regions

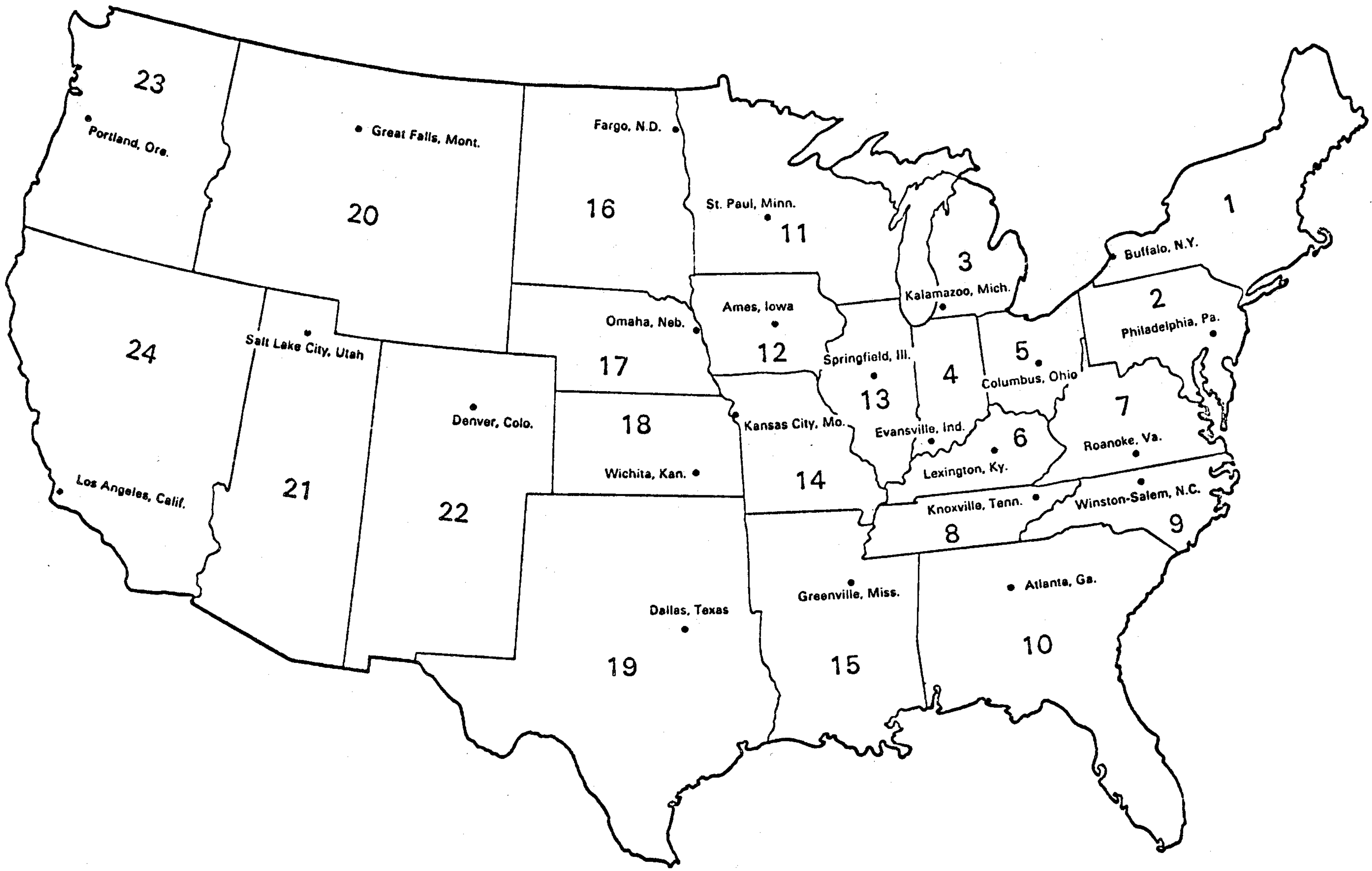

Figure 2. Consuming Regions

Barge transportation activities are coordinated with rail and truck transportation through inland water ports on the Mississippi and Columbia-Snake River system. The study includes 40 water access points as inland water ports on the river systems. Minimum distance water access points are assigned for each producing and consuming region. Minimum transportation costs are calculated for transportation activities between producing regions and water access points, and between water access points and consuming regions. Figure 3 displays the water access points used in the model.

Transportation costs are calculated on the basis of carriers' operating costs. The use of carriers' costs in the mathematical optimization model is justified under the assumption that prices of transportation services will be equal to their average cost under deregulation of grain rail rates in a competitive market system. The base model is developed under the institutional constraints imposed on U.S. grain marketing and transportation sectors. Alternative models are developed to evaluate the economic effects of changes in ocean freight rates and import demands for U.S. grain. The models specified in the study are as follows:

Model 1 - Base model with no port capacity constraints

Model 2 - Model with port capacity constraints

Model 3 - 30 percent increase in ocean freight rates between gulf ports and import regions

Model 4 - 30 percent increase in ocean freight rates between the West Coast and import regions

Model 5 - 30 percent increase in ocean freight rates between the Great Lakes and import regions

Model 6 - 30 percent increase in ocean freight rates between the Atlantic ports and import regions

A Mathematical Explanation of the Base Model

The model used for this study is developed on the basis of a mathematical programming algorithm. The model forms a system of linear equations representing constraints, with one equation designed as the objective function that is to be optimized over those constraints.

The Objective Function

The objective function of the base model is defined to minimize domestic and ocean transportation costs associated with the various transportation activities in the model. The objective function is as follows:

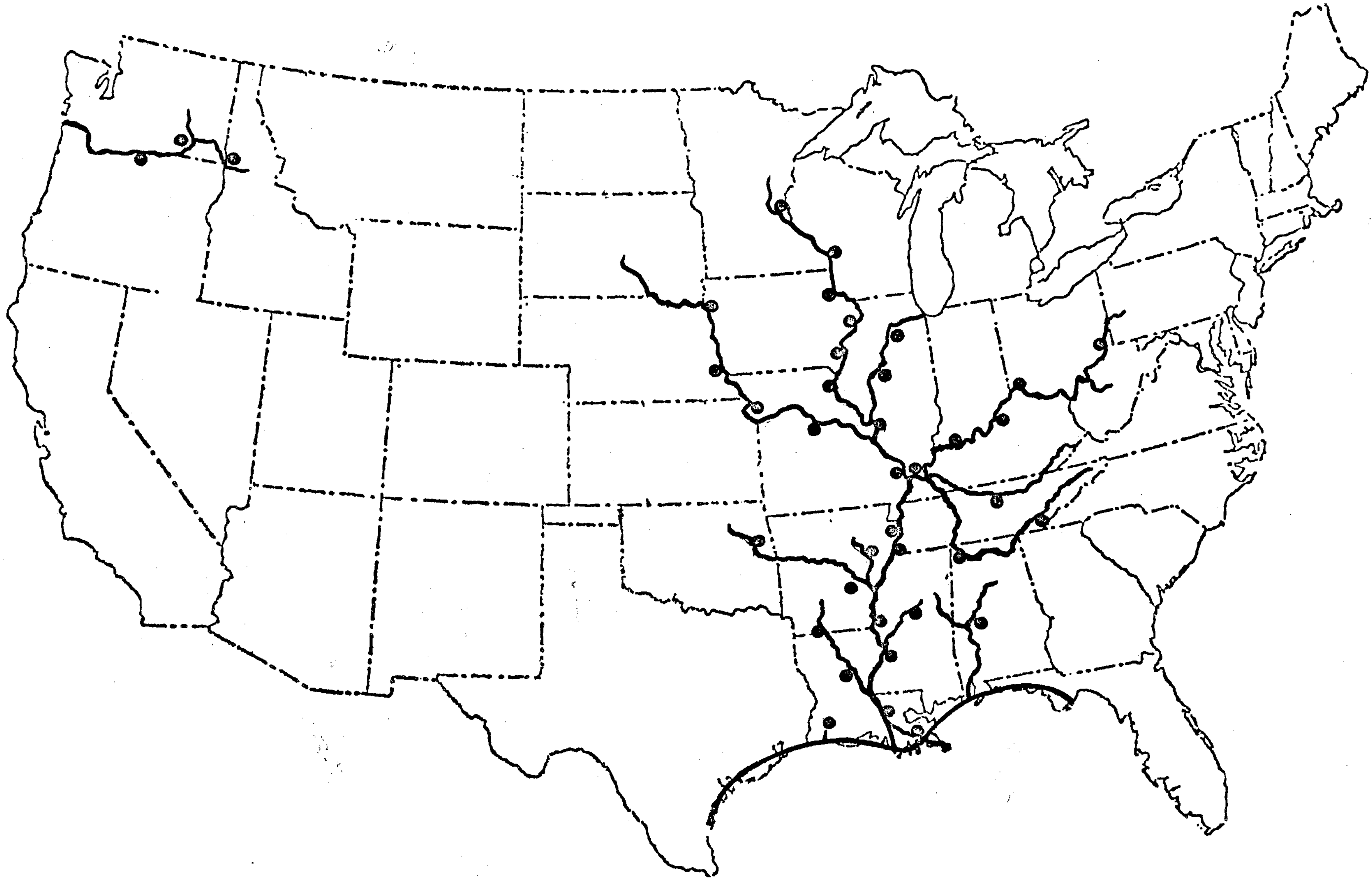

Figure 3. Location of Water Access Points

$$\text{Min } Z = \sum_{t=1}^{3} \sum_{m=1}^{3} \sum_{c=1}^{3} \sum_{i=1}^{88} \sum_{j=1}^{24} DC_{tmcij}\, DX_{tmcij}$$

$$+ \sum_{t=1}^{3} \sum_{m=1}^{3} \sum_{c=1}^{3} \sum_{i=1}^{88} \sum_{n=1}^{13} EC_{tmcin}\, EX_{tmcin}$$

$$+ \sum_{m=1}^{3} \sum_{c=1}^{3} \sum_{i=1}^{88} \sum_{s=1}^{9} SC_{mcis}\, SX_{mcis}$$

$$+ \sum_{t=2}^{3} \sum_{m=1}^{3} \sum_{c=1}^{3} \sum_{s=1}^{9} \sum_{n=1}^{13} SNC_{tmcsn}\, SNX_{tmcsn}$$

$$+ \sum_{t=1}^{3} \sum_{c=1}^{3} \sum_{n=1}^{13} \sum_{f=1}^{11} OC_{tcnf}\, OX_{tcnf}$$

where: t = index for time period

m = index for mode of transportation

c = index for grain type

i = index for producing region

j = index for consuming region

n = index for export port

s = index for commercial storage location

f = index for foreign import region

DC_{tmcij} = transportation and handling costs in shipping crop c from producing region i to domestic consuming region j by mode of transportation m in time period t.

DX_{tmcij} = quantity of crop c shipped from producing region i to consuming region j by mode of transportation m in the time period t.

EC_{tmcin} = transportation and private storage costs in shipping crop c from producing region i to export port n by mode of transportation m in time period t.

EX_{tmcin} = quantity of crop c shipped from producing region i to consuming region j by mode of transportation m in time period t.

SC_{1mcis} = transportation and storage costs in shipping crop c from producing region i to commercial storage location s by mode of transportation m in the time period t.

SX_{1mcis} = quantity of crop c shipped from producing region i to commercial storage location s by mode of transportation m in time period t.

SNC_{tmcsn} = transportation and handling costs in shipping crop c from commercial storage location s to export port n by mode of transportation m in the time period t.

SNX_{tmcsn} = quantity of crop c shipped from storage location s to port n by mode of transportation m in time period t.

OC_{tcnf} = ocean transportation costs in shipping crop c from export port n to import region f in time period t.

OX_{tcnf} = quantity of crop c shipped from export port n to import region f in time period t.

DX and EX are direct transportation activities in shipping grain from producing regions to domestic and export regions. SX includes transportation activities from producing regions to commercial storage locations in the harvest period (period 1). SNX includes transportation activities from commercial storage locations to export locations in the second and third time period. Transportation activities, SX and SNX, are based on an assumption that the commercial storage locations identified in the model receive grain once a year up to their capacity and ship the grain received in the harvest period to export ports in the second and third periods.

Constraints for the Base Model

The objective function for the base model is optimized subject to the following constraints:

1. Total available grain in each producing region must be greater than or equal to the quantity of grain shipped from each producing region to the consuming regions.

$$S_{ci} \geq \sum_{t=1}^{3} \sum_{m=1}^{3} \sum_{j=1}^{24} DX_{tmcij}$$

$$+ \sum_{t=1}^{3} \sum_{m=1}^{3} \sum_{n=1}^{13} EX_{tmcin} + \sum_{m=1}^{3} \sum_{s=1}^{9} SX_{1mcis}$$

$c = 1, 2, 3$
$i = 1, 2, \ldots 88$

where: S_{ci} = quantity of grain available in producing region i
DX, EX, and SX are as previously defined.

2. Total quantity of grain received by each domestic consuming region must be greater than or equal to the quantity of grain required in each consuming region in each time period.

$$D_{tcj} \leq \sum_{m=1}^{3} \sum_{i-1}^{88} DX_{tmcij}$$

t = 1, 2, 3
c = 1, 2, 3
i = 1, 2, . . . 24

where: D_{tcj} = quantity of grain c required in consuming region j in time period t.

DX is as previously defined.

3. Total quantity of grain received by each export port must be less than or equal to the grain handling capacity available in each port in each time period. Each port can receive grain from producing regions and commercial storage locations in the second and third time periods.

$$ED_{1cn} \leq \sum_{m=1}^{3} \sum_{i=1}^{88} a\ EX_{1mcin}$$

$$ED_{tcn} \leq \sum_{m=1}^{3} \sum_{i=1}^{88} a\ EX_{tmcin}$$

$$+ \sum_{m=1}^{3} \sum_{s=1}^{9} a\ SNX_{tmcsn}$$

t = 2, 3
c = 1, 2, 3
n = 1, 2, . . ., 13

where: ED_{1cn} = quantity of grain c required in the export port n in time period 1.

ED_{tcn} = quantity of grain c required in export port n in time period t.

EX and SNX are as previously defined.

4. Quantity of grain received by each commercial storage location must be equal to the total grain shipped from each commercial storage location to export locations.

$$\sum_{m=1}^{3} \sum_{i=1}^{88} SX_{1mcis} = \sum_{t=2}^{3} \sum_{m=1}^{3} \sum_{n=1}^{13} SNX_{tmcsn}$$

c = 1, 2, 3
s = 1, 2, . . . 9

where: SX and SNX are as previously defined.

5. The total storage capacity in each commercial storage location must be greater than or equal to the quantity of grain shipped to that storage location from the producing regions.

$$CS_S \geq \sum_{m=1}^{3} \sum_{c=1}^{3} \sum_{i=1}^{88} SX_{1mcis}$$

$s = 1, 2, \ldots, 9$

6. Total quantity of grain received by foreign import region must be greater than or equal to the quantity of grain required in each import region in each time period.

$$ID_{tcf} \leq \sum_{n=1}^{13} OX_{tcnf}$$

where: ID_{tcf} = quantity of grain c required in import region f in time period t.

7. The quantity of grain received by each export port must be equal to the total quantity of grain shipped from that export port to import regions.

$$\sum_{m=1}^{3} \sum_{i=1}^{88} EX_{tmcin} + \sum_{m=1}^{3} \sum_{s=1}^{9} SNX_{tmcsn} = \sum_{n=1}^{11} OX_{tcnf}$$

$t = 1, 2, 3$
$c = 1, 2, 3$
$f = 1, 2, \ldots 11$

Data Collection

Data needed for this study are demand for and supply of each grain in each consuming and producing region, grain handling capacity at each port and commercial storage location, and transportation costs based on estimated average costs for each transportation activity. The supply and demand for grain are estimated for 1990. Input data such as rail, barge, and trucking costs are estimated on the basis of the 1979 dollars.

Supply and Demand

This study uses the 1990 state surplus grain projections calculated by NC-137 and S-115 regional committee members. The surplus state grain production projection is calculated by subtracting quantities of grain consumed by livestock in each state from the state production projection.

For the states that do not have representation on the NC-137 and S-115 regional committees, the state surplus projection is estimated on the basis of the 1990 state production projection by the United States Department of Agriculture (NIRAP projection). The quantities of each grain consumed are subtracted from the USDA projection for grain production to estimate the surplus grain in each state. The aggregate consumption projection of each grain for livestock is obtained from USDA (NIRAP projection). The aggregate consumption projection for feed grains is allocated to each state on the basis of grain-consuming animal units, and that for wheat is allocated on the basis of the quantities of wheat fed to livestock. The final adjustments for the state surplus projection for each grain are made by adding carryover stock to the estimated state surplus projection. The carryover stocks used for this study are the last five years' average carryover stock for each grain in the United States. The national carryover stocks for each grain are allocated to each state on the basis of the state storage capacity (obtained from Inventory Management Division, ASCS). The projected surplus of wheat, soybeans, and feed grains is shown in Table 2. The state surplus projections for each grain are subdivided into each producing region according to the ratio of grain production in each producing region to that in the corresponding state.

Demand for grain is divided into two categories: domestic and foreign import. Domestic demand for each grain includes only demand for food and excludes demand for feed since it is subtracted from the supply of grain. Domestic demand for each grain is estimated on the basis of the 1990 national demand for industrial and food uses of grain projected by USDA. The national demand for each grain is allocated to each consuming region in proportion to grain processing capacities for each grain. The seasonal demand for grain for food and industrial needs is assumed to be uniform over time periods of the year. Projected annual demand is shown in Table 3. Foreign import demands for grain also are estimated on the basis of the 1990 USDA projection. The national projections are allocated to each import region on the basis of average quantities of grain imported in each region. The annual import projection for each region is reallocated for three time periods on the basis of the quantities of grain imported in each time period.

TABLE 2. STATE SURPLUS PROJECTIONS FOR WHEAT, SOYBEANS, AND FEED GRAINS, 1990

State	Wheat	Soybeans	Feed Grains
		(1,000 bushels)	
Alabama	1,306	71,158	-0-
Arizona	48,706	-0-	-0-
Arkansas	25,650	157,294	-0-
California	77,915	-0-	-0-
Colorado	87,712	-0-	-0-
Connecticut	-0-	-0-	-0-
Delaware	-0-	-0-	-0-
Florida	-0-	16,972	-0-
Georgia	1,576	71,904	-0-
Idaho	53,057	-0-	30,880
Illinois	45,570	376,437	1,255,854
Indiana	62,493	188,938	566,611
Iowa	587	399,232	1,148,186
Kansas	463,377	34,840	306,265
Kentucky	12,089	67,926	52,193
Louisiana	729	108,701	-0-
Maine	-0-	-0-	-0-
Maryland	5,019	19,414	31,942
Massachusetts	-0-	-0-	-0-
Michigan	38,596	20,091	89,923
Minnesota	182,947	125,066	391,031
Mississippi	4,784	106,534	-0-
Missouri	72,663	196,082	178,856
Montana	198,043	-0-	59,172
Nebraska	171,113	53,099	1,027,184
Nevada	1,213	-0-	-0-
New Hampshire	-0-	-0-	-0-
New Jersey	1,558	3,121	2,831
New Mexico	7,794	-0-	1,310
New York	3,361	739	7,061
North Carolina	1,813	62,542	38,623
North Dakota	416,746	4,634	162,250
Ohio	80,461	206,939	395,279
Oklahoma	229,289	8,545	-0-
Oregon	63,517	-0-	-0-
Pennsylvania	-0-	3,226	45,246
Rhode Island	-0-	-0-	-0-
South Carolina	5,397	51,245	11,345
South Dakota	97,873	13,929	99,863
Tennessee	15,426	70,374	-0-
Texas	148,902	18,134	378,379
Utah	4,658	-0-	-0-
Vermont	-0-	-0-	-0-
Virginia	4,885	15,009	24,704
Washington	165,893	-0-	-0-
West Virginia	92	-0-	-0-
Wisconsin	1,823	7,770	181,746
Wyoming	8,128	-0-	10,620

TABLE 3. PROJECTED ANNUAL DEMAND FOR WHEAT, SOYBEANS, AND FEED GRAINS, 1990

Domestic Consuming Region	Wheat	Soybeans	Feed Grains
		(1,000 bushels)	
Buffalo, NY	61,814.22	0	108,459.27
Philadelphia, PA	25,875.72	4,583.28	100,386.54
Kalamazoo, MI	13,417.05	0	6,329.54
Evansville, IN	16,591.62	45,639.24	48,973.02
Columbus, OH	44,024.67	29,113.59	26,295.00
Lexington, KY	2,455.80	14,524.50	138,083.25
Roanoke, VA	12,398.79	9,876.66	35,602.41
Knoxville, TN	21,623.01	40,991.40	103,177.56
Winston-Salem, NC	14,315.49	18,462.27	38,334.36
Atlanta, GA	21,443.31	60,099.21	183,984.18
St. Paul, MN	49,834.71	41,636.94	179,554.17
Ames, IA	6,648.63	96,120.00	42,988.68
Springfield, IL	37,136.46	143,114.88	97,645.83
Kansas City, MO	49,655.04	17,493.96	32,767.77
Greenville, MI	5,989.74	75,333.81	239,151.66
Fargo, ND	4,791.81	0	0
Omaha, NE	17,490.06	25,111.26	8,747.58
Wichita, KS	70,559.25	21,108.96	11,566.26
Dallas, TX	32,644.14	7,229.97	65,652.36
Great Falls, MT	8,146.05	0	0
Salt Lake City, UT	18,927.60	0	15,501.00
Denver, CO	10,661.76	0	5,550.99
Portland, OR	27,912.24	0	10,297.71
Los Angeles, CA	28,151.82	0	162,771.09

Domestic Transportation Costs

The model optimizes transportation and storage activities based on transportation costs between producing and consuming regions by crop and time period. Transportation costs used in the model are for rail movements in single- and multiple-car shipments; highway movements in either five axle tractor-semitrailer trucks or tandem trucks; and barge movements in 195' X 35' covered hopper barges in the Mississippi River system and 250' X 42' barges in the Columbia-Snake River system.

The rail costs for shipping grain from origins in the western territory to the various markets were calculated for 23 heavily traveled rail routes on the basis of a procedure developed by Narigon and Baumel. The estimated costs per cwt. from these 23 cases were regressed against the independent variable, one-way travel distance in miles. The rail cost functions are as follows:

$$RC\ (single) = 14.1049 + 0.04668M$$
$$RC\ (50\text{-}car) = 8.1561 + 0.04506M$$
$$RC\ (75\text{-}car) = 8.0849 + 0.04141M$$

The rail cost functions are adjusted by the carload mileage cost scale published in 1976 to estimate rail cost functions in other territories (official southern and mountain pacific). The rail cost estimation procedure is in the study by Koo and Bredvold.

Trucking costs are estimated for a tractor semi-trailer capable of hauling 850 bushels of grain and a tandem truck capable of hauling 600 bushels of grain. The three components used to estimate trucking costs are fixed, variable, and transfer costs. Fixed costs are independent of the travel distance. Variable costs depend directly on the distance. Transfer costs are not directly associated with the truck operation, but are incurred when a trucker is loading, unloading, or waiting.

Average costs per cwt. based on the cost components are:

$$AC^s = 2.224 + 0.240d$$
$$AC^t = 1.119 + 0.265d$$

where: AC^s is average cost for semi-tractor-trailer; AC^t is average cost for tandem truck; and d represents one-way travel distance. A tandem truck has a cost advantage over tractor semi-trailer for distances less than 44 miles. Hence, this study uses tandem truck for travel distances less than 44 miles and semi-trailer for distances greater than or equal to 44 miles.

Costs of transporting grain by barge are not the same on the Columbia-Snake River system as they are on the Mississippi River system. Barging costs also differ by river section within the Mississippi system. This is due to the peculiar cost characteristics of each river section. To develop barge cost estimates, it is necessary to identify barging costs along individual river systems. The Mississippi River system consists of 12 river sections and the Columbia-Snake River system, 2 river sections (Koo and Bredvold).

Barging grain from one point to another entails a number of activities besides towing a barge up or down river. Barging costs are comprised of many interdependent costs and can be divided roughly into two categories. The first category includes fixed costs associated with the barge operation. Fixed costs are assigned to any particular barge trip on the basis of the number of days in transit. The second category includes those costs associated with variable barging activities. These activities include towing, switching, fleeting, and cleaning the barge during the round trip between origin and destination. The number of these activities required for any particular barge trip, the length of the round trip in miles, and the number of delays expected on any particular river section traveled determines the length of each barge trip in days. The fixed costs per barge trip depend on the length of the trip in question as well as the other barging activities associated with barge movement along individual river sections.

Total barging costs on the Mississippi River system were calculated for 37 barge routes over the more heavily traveled river sections (i.e., those whose barging costs are not quoted as flat rates) on the basis of the above information. Cost per ton from these 37 cases was regressed against the following independent variables: mileage (M), barge capacity (C), and dummy variables for individual river sections.

The regression equation chosen to estimate barging costs on the heavily traveled river sections in the Mississippi River system is as follows:

$$BC_{ij}^{ml} = 17.89 + \underset{(18.41)}{0.005579}\, M_{ij} + \underset{(2.254)}{0.6967}\, D1 + \underset{(5.166)}{1.610}\, D2 + \underset{(8.856)}{2.006}\, D3 + \underset{(5.758)}{0.9690}\, D4 - \underset{(8.725)}{0.009818}\, C \qquad R^2 = 0.9835 \quad s = .4441$$

Where: BC^{m1}_{ij} represents total barging cost in shipping grain from water access point i to water access point j in the main river sections in the Mississippi River system; M_{ij}, one-way water mileage between water access point i and water access point j; D1, dummy variable identifying the Lower Mississippi and Tennessee River sections; D2, dummy variable identifying the Missouri River section; D3, dummy variable identifying the Upper Mississippi River section; D4, dummy variable identifying the Ohio and Illinois River sections; and C, barge capacity. The number in parentheses represents the t-value of the corresponding independent variable.

Likewise, a regression equation was determined for barge trips containing movement on the smaller "flat rate" river sections (Quachita, Yazoo, and White) in the Mississippi River system based on eight cost engineered cases. The equation for barging costs on routes containing "flat rate" river sections is as follows:

$$BC^{m2}_{ij} = 1.216 + \underset{(11.34)}{.008347}\, M_{ij}$$

$$R^2 = .9554 \quad s = .6058$$

Where: BC^{m2}_{ij} = total barging cost in shipping grain from water access point i to water access point j over routes containing mileage in the small river sections in the Mississippi River system.

Total barging costs also were calculated for seven representative routes on the Columbia-Snake system. Cost per ton from these routes was regressed against one-way mileage. The following relationship was estimated:

$$BC^{c}_{ij} = .4512 + \underset{(89.09)}{.0051}\, M_{ij}$$

$$R^2 = .9999 \quad s = .0055$$

Where: BC^{c}_{ij} = total barging cost in shipping grain from water access point i to water access point j in the Columbia-Snake River system.

Ocean Freight Rates

Ocean freight rates between U.S. export ports and foreign import regions were obtained from Chartering Annual, 1979 published by Maritime Research, Inc. Ocean freight rates vary over time, depending upon travel distance, volume shipped, size of ship, and characteristics associated with origin and destination. The ocean rates used in this study are average rates of all shipment rates in 1979 for wheat and soybeans (or feed grains) from U.S. export ports to foreign import regions. Table 4 shows the calculated average ocean freight rates between U.S. export ports and foreign import regions. All U.S. export ports are categorized into four areas: Atlantic, Gulf, West Coast, and Great Lakes. All export ports in the same area have the same rates.

TABLE 4. AVERAGE OCEAN FREIGHT RATES, 1979

Import Region	Atlantic	Gulf	West Coast	Great Lakes
		(dollars/ton)		
Feed Grains				
Western Europe	16.96	17.33	--	36.74
Middle East	34.99	33.68	--	36.66
Africa	25.52	36.72	--	42.83
South Asia	--	34.54	33.52	--
East Asia	--	34.39	35.04	--
Japan & Korea	35.66	20.89	23.68	--
Brazil & Venezuela	--	20.98	32.49	40.79
Eastern Europe	17.71	37.49	--	33.85
U.S.S.R.	29.70	30.68	--	36.41
Other South America	--	29.16	--	--
Central America	--	18.50	23.60	--
Wheat				
Western Europe	18.48	21.08	--	42.95
Middle East	38.14	36.72	--	39.95
Africa	33.33	28.39	40.76	46.68
South Asia	--	37.64	36.54	--
East Asia	--	37.49	38.18	--
Japan & Korea	--	29.16	25.15	--
Brazil & Venezuela	--	26.04	35.41	37.55
Eastern Europe	19.31	40.87	--	36.89
U.S.S.R.	32.37	33.45	--	39.68
Other South America	--	27.60	--	--
Central America	--	23.50	25.73	--

SOURCE: Maritime Research, Inc.

III. Empirical Results

Recall the models have 88 producing regions, 24 domestic consuming regions, 13 export ports, 9 commercial storage locations, and 11 foreign import regions. This section presents results from six different models, one base and five alternative models. Model 1 serves as the base model which contains all transportation activities in shipping grains from producing regions in the United States to domestic and foreign import regions. This model is based on the 1979 cost-base transportation rate structure. Constraints imposed in this model are grain handling capacity at commercial storage locations, projected supply of wheat, soybeans, and feed grains in 1990, and projected demand for these grains in 1990. Model 2 contains the constraints of grain handling capacity at U.S. export ports in addition to those constraints imposed in Model 1. Models 3, 4, 5, and 6 are the same as Model 1, except ocean freight rates are increased 30 percent from the Gulf ports, West Coast ports, Great Lakes ports, and Atlantic ports to foreign import regions, respectively.

Total and Average Transportation Costs in Shipping Grains

Total Transportation Costs

Estimated total and average transportation costs for all grain shipments are shown in Tables 5 and 6. In Model 1, the total transportation costs are $3,142 million for domestic shipments and $3,144 million for ocean shipments, leading to a total transportation cost of $6,285 million. The total transportation costs in Model 2 are $6,553 million which is $260 million larger than Model 1; $3,382 million in ocean transportation costs and $3,171 million in domestic transportation costs. This indicates that a substantial amount of the total transportation costs can be saved by optimizing grain flows to export markets and handling facilities. It should be noted that this analysis is based on transportation costs and does not include the cost of increasing port capacity.

TABLE 5. ESTIMATED TOTAL DOMESTIC TRANSPORTATION AND OCEAN SHIPPING COSTS

Model	Domestic	Ocean	Total
		($1,000)	
1. No port capacity	3,141,564	3,143,599	6,285,123
2. Port Capacity	3,171,191	3,382,155	6,553,346
3. 30% in Gulf	3,226,716	3,495,742	6,722,458
4. 30% in West	3,156,945	3,210,795	6,367,740
5. 30% in Lakes	3,231,417	3,113,598	6,345,015
6. 30% in Atlantic	3,033,596	3,404,988	6,438,584

TABLE 6. ESTIMATED AVERAGE DOMESTIC AND OCEAN TRANSPORTATION COSTS

Model	Domestic	Ocean	Total
		($/1,000 bushels)	
1. No port capacity	369.89	604.02	740.01
2. Port Capacity	371.50	644.55	767.72
3. 30% in Gulf	378.92	668.83	789.43
4. 30% in West	371.70	616.94	749.74
5. 30% in Lakes	380.47	598.26	747.06
6. 30% in Atlantic	357.18	654.25	758.08

Changes in ocean freight rates have significant impacts on domestic transportation as well as ocean transportation. The total transportation cost is largest with a 30 percent increase in ocean freight rates from the Gulf ports to foreign import regions (Model 3). Domestic transportation costs are greatly influenced with a 30 percent increase in ocean freight rates between the Great Lakes and foreign import regions. On the other hand, a 30 percent increase in ocean freight rates between the Gulf ports and foreign import regions results in the largest increase in ocean transportation costs.

Average Transportation Costs

Table 6 shows average transportation costs for domestic and ocean shipments. The average costs are calculated by dividing the total transportation costs by the total quantity shipped. Consequently, the average transportation costs shown in Table 6 are interpreted as transportation costs per 1,000 bushels of grain for shipments of average travel distance. Since average transportation costs do not account for the volume of grain shipped, changes in transportation costs are seen more clearly with alternative models. In Model 1, average domestic transportation cost is 37.0 cents per bushel ($370 per 1,000 bushels), average ocean transportation cost is 60.4 cents per bushel and average total transportation cost is 74 cents per bushel. The average total transportation cost is not necessarily the sum of average domestic and ocean transportation costs because the quantities shipped to domestic and export markets are greater than those shipped to foreign importing regions.

In Model 2, there are substantial increases in average transportation costs compared to Model 1. Average costs in Model 2 are increased by 4 cents per bushel for ocean shipments while average costs for domestic shipments remain nearly the same. These results are consistent with those for total transportation costs in Table 5. This reveals that optimizing grain flows and handling facilities at export markets results in greater reductions in ocean shipping costs than in domestic transportation costs. It further indicates that the present flow pattern of grain between U.S. ports and foreign import regions is constrained by the existing grain handling capacities and is not optimal in terms of overall least-cost.

Changes in ocean freight rates have significant impacts on average domestic transportation costs. The impacts are largest when ocean freight rates between the Gulf ports and import regions are increased in Model 3. Average total transportation cost in Model 3 is 78.9 cents per bushel, 3.9 cents larger than in Model 1. On the other hand, the impacts of changes in ocean freight rates on total transportation costs are the smallest in Model 5 where average total transportation cost is 74.7 cents per bushel, only 0.7 cents larger than in Model 1.

Interdependency Between Domestic and Ocean Transportation Costs

Impacts of changes in ocean freight rates on domestic transportation are different from those on ocean transportation costs. In Models 3 and 4, changes in ocean freight rates result in increases in both domestic and ocean transportation costs. However, increases in average ocean transportation costs are much greater than those in average domestic transportation costs in both models. The impacts are quite different in Models 5 and 6. Changes in ocean freight rates increase average domestic transportation costs and reduce average ocean transportation costs in Model 5, and vice versa in Model 6. This is mainly due to geographic characteristics associated with the Great Lakes and the Atlantic ports. The Atlantic ports have easier access to foreign import regions such as Eastern Asia, Europe, and U.S.S.R. than do the Great Lakes ports. However, the Great Lakes ports are closer to major grain producing regions than the Atlantic ports. For example, a 30 percent increase in ocean freight rates at the Great Lakes (Model 5) results in increases in grain flows from the Great Plains states to the Gulf ports and the West Coast. The changes in grain flow increase total domestic transportation costs because distances from producing regions to the Gulf and West Coast ports are greater than from the producing regions to the Great Lakes. On the other hand, the reduced volume shipped from Great Lakes ports results in lower total ocean cost. This is mainly due to lower rates from other ports. When ocean freight rates are increased at Atlantic ports, reduction in grain flow to the ports is relatively small compared to the rate increase. Hence, total ocean transportation cost rises with an increase in ocean freight rates. However, domestic transportation cost declines in Model 6 because a large amount of grain moved from the eastern producing regions to export ports is shipped to domestic mills with a 30 percent increase in ocean freight rates.

Transportation Costs by Grains

Estimated total domestic transportation costs by grain are shown in Table 7. The domestic transportation costs are divided into two components: domestic transportation costs between producing regions and domestic consuming regions (Table 8) and domestic transportation costs between producing regions

TABLE 7. ESTIMATED TOTAL DOMESTIC TRANSPORTATION COSTS BY GRAINS

Model	Wheat	Soybeans	Feed Grains
		($1,000)	
1. No port capacity	737,075	648,490	1,755,999
2. Port capacity	737,671	685,934	1,747,585
3. 30% in Gulf	729,494	668,386	1,828,835
4. 30% in West	757,044	648,490	1,751,409
5. 30% in Lakes	803,190	665,659	1,762,567
6. 30% in Atlantic	727,330	667,592	1,638,674

TABLE 8. ESTIMATED TOTAL DOMESTIC TRANSPORTATION COSTS FROM PRODUCING REGIONS TO DOMESTIC CONSUMING REGIONS BY GRAINS

Model	Wheat	Soybeans	Feed Grains
		($1,000)	
1. No port capacity	181,716	238,796	646,019
2. Port capacity	183,902	249,264	635,793
3. 30% in Gulf	184,134	241,519	645,850
4. 30% in West	186,183	238,796	646,019
5. 30% in Lakes	185,679	238,796	646,019
6. 30% in Atlantic	179,897	248,040	615,351

and U.S. export ports (Table 9). Total domestic transportation costs in Model 1 are $737 million for wheat shipments, $648 million for soybean shipments and $1,756 million for feed grain shipments. Optimizing grain flows and handling facilities at export ports does not affect the total domestic transportation costs for wheat and feed grain shipments. However, transportation costs to domestic consuming regions and export markets do change. Model 2 has higher transportation costs to domestic consuming regions for wheat shipments and lower transportation costs to export markets than Model 1.

TABLE 9. ESTIMATED TOTAL DOMESTIC TRANSPORTATION COSTS FROM PRODUCING REGIONS TO EXPORT PORTS BY GRAIN

Model	Wheat	Soybeans	Feed Grains
		($1,000)	
1. No port capacity	555,358	409,693	1,109,979
2. Port capacity	553,768	436,670	1,111,791
3. 30% in Gulf	545,359	426,866	1,182,984
4. 30% in West	570,860	409,693	1,105,390
5. 30% in Lakes	617,510	426,862	1,116,548
6. 30% in Atlantic	547,432	419,552	1,023,322

For feed grain, Model 2 results in slightly lower transportation costs to domestic consuming regions and higher transportation costs to export markets compared to Model 1. This indicates that optimizing feed grain distribution could result in shifts of domestic transportation costs from domestic consumers to exporters, and vice versa for wheat. This is mainly due to interdependency between production location and export markets. For soybean shipments, total domestic transportation costs in Model 1 are considerably smaller to domestic and export markets compared to Model 2. This further indicates that opimizing grain flows and handling facilities at export ports is more beneficial for soybean shipments than for shipments of other grains.

Wheat shipments are most costly when ocean freight rates are increased at the Great Lakes (Model 5). Soybean and feed grain shipments are most costly when ocean freight rates are increased at the Gulf ports (Model 3). This is mainly due to production location of wheat, soybeans, and feed grains. While wheat production is concentrated in the upper Great Plains, production of soybeans and feed grains is concentrated in the Corn Belt and Southern states. Impacts of changes in ocean freight rates for domestic consumers are different from those for exporters. Wheat shipments to domestic consuming regions are most costly with increases in ocean freight rates at the West Coast ports, but those to export markets are most costly with increases in ocean freight rates at the Great Lakes. Unlike wheat shipments, soybean shipments to domestic consuming regions and export markets are most expensive when ocean freight rates at the Gulf ports are increased. For feed grain, shipments to domestic consuming regions are unchanged from Model 1 with increases in ocean freight rates at U.S. export ports except that they are less with increases at the Atlantic Coast ports. Domestic transportation costs for feed grain exports are largest with increases in ocean freight rates at the Gulf ports.

Table 10 shows the total ocean transportation costs for wheat, soybeans, and feed grains. The total ocean transportation costs in Model 1 are $1,227 million for wheat shipments, $585 million for soybean shipments, and $1,331 million for feed grain shipments in Model 1. The ocean transportation cost for feed grain shipments in Model 2 is about 14 percent larger than Model 1, and for wheat and soybean shipments, about 3 percent and 0.5 percent larger, respectively. This indicates that feed grain shippers get the largest reduction in ocean transportation costs in shipping grain from U.S. ports to foreign import regions with optimal grain handling facilities at U.S. ports.

TABLE 10. ESTIMATED OCEAN SHIPPING COSTS FOR EACH GRAIN

Model	Wheat	Soybeans	Feed Grains
		($1,000)	
1. No port capacity	1,227,005	585,158	1,331,397
2. Port capacity	1,272,689	587,993	1,521,475
3. 30% in Gulf	1,384,354	654,080	1,457,311
4. 30% in West	1,294,066	585,158	1,331,573
5. 30% in Lakes	1,206,168	578,661	1,328,770
6. 30% in Atlantic	1,255,830	607,459	1,541,703

Increases in ocean freight rates at the Gulf ports influence most significantly the ocean transportation costs for wheat and soybean shipments, and those at the Atlantic ports have the most significant influence for feed grain shipments. On the other hand, changes in ocean freight rates at the Great Lakes have the least influence for shipments of wheat, soybeans, and feed grains.

Quantities of Grain Shipped Under Alternative Models

Table 11 shows the total quantities of grain shipped by modes of transportation. In Model 1, railroads ship 79 percent of grain shipped to markets, barges ship 7 percent, and trucks ship 14 percent. Ocean vessels are used to ship grains from U.S. export ports to foreign import regions. A total of 4,995 million bushels of grain is shipped by ocean vessels in Model 1. Since no alternative modes of transportation are available in ocean transportation, the total quantities of grain shipped are constant, given no changes in the quantities of grain exported. Our main concern is, therefore, changes in modal share in domestic shipments of grain under alternative models. Optimizing grain flows and handling facilities at U.S. export ports has little effect on rail movements but does increase barge movements and decrease truck movements.

TABLE 11. TOTAL QUANTITIES OF GRAIN SHIPPED BY MODES OF TRANSPORTATION

Model	Rail	Barge	Truck
		(1,000 bu.)	
1. No port capacity	6,697,628	575,028	1,220,629
2. Port capacity	6,747,421	525,973	1,262,742
3. 30% in Gulf	6,691,439	468,803	1,355,305
4. 30% in West	6,728,326	575,027	1,189,933
5. 30% in Lakes	6,463,984	665,154	1,364,148
6. 30% in Atlantic	6,824,254	414,050	1,254,982

Modal share is not sensitive to changes in ocean freight rates. Since the Great Lakes and Atlantic ports receive grain largely by railroads, increases in ocean freight rates at one of those ports would change modal share because the increase in ocean freight rates produces more barge traffic to the Gulf and Pacific Northwest ports. However, in the cost-base rate structure, unit-car shipments have a cost advantage in shipping grains to the Gulf over barge. Consequently, shifts of grain from producing regions to the Gulf port will not necessarily increase barge traffic.

Impacts of alternative models on the marketing system of wheat, soybeans, and feed grains are summarized in Tables 12, 13, and 14, respectively. Total quantities of wheat shipped in Model 1 are 2,191 million bushels; 1,073 million bushels for domestic market; and 1,118 million bushels for export markets. The quantities of wheat shipped by rail, barge, and truck are 1,885 million, 18 million, and 268 million bushels, respectively. The proportion of wheat

TABLE 12. TOTAL QUANTITIES OF WHEAT SHIPPED BY MODES OF TRANSPORTATION

Model	Rail	Barge	Truck
		(1,000 bu.)	
1. No port capacity	1,885,063	18,083	267,876
2. Port capacity	1,906,560	18,142	182,936
3. 30% in Gulf	1,891,422	18,584	180,521
4. 30% in West	1,892,071	18,083	183,719
5. 30% in Lakes	1,885,604	22,907	159,755
6. 30% in Atlantic	2,005,317	18,083	154,497

shipments by rail is greater than that for all grain shipments in Model 1. About 87 percent of wheat marketed is shipped by railroads. More wheat is moved by railroads in Model 2 than in Model 1 because Houston and Seattle have a cost advantage for wheat shipments over other ports such as New Orleans and Portland in Model 2.

Railroads also play a dominant role in shipping soybeans from producing regions to both domestic and export markets. However, the proportion of soybean shipments by rail is much smaller than that for wheat shipments. The total quantity of soybeans shipped in Model 1 is about 2,170 million bushels, 602 million bushels for domestic markets and 1,568 million bushels for export markets. The proportion of the total quantity of soybeans shipped by rail, barge, and truck is 64 percent, 8 percent, and 28 percent, respectively (Table 13). More soybeans are shipped by barge in Model 2 than in Model 1

TABLE 13. TOTAL QUANTITIES OF SOYBEANS SHIPPED BY MODES OF TRANSPORTATION

Model	Rail	Barge	Truck
		(1,000 bu.)	
1. No port capacity	1,386,586	171,419	636,033
2. Port capacity	1,279,402	219,857	742,582
3. 30% in Gulf	1,315,001	70,743	775,736
4. 30% in West	1,329,328	171,419	693,291
5. 30% in Lakes	1,272,390	164,483	784,623
6. 30% in Atlantic	1,316,731	164,483	763,746

because: 1) production of soybeans is concentrated in areas near the Mississippi River system; and 2) barge has a cost advantage for soybean shipments over rail.

The total quantity of feed grain marketed in Model 1 is about 4,128 million bushels, 1,611 million bushels to domestic markets, and 2,516 million bushels to export markets (Table 14). Like wheat shipments, railroads play a dominant role for feed grain shipments. About 83 percent of the feed grain marketed is shipped by railroads and the remainder is shared about equally by barge and truck.

Changes in ocean freight rates are less sensitive to wheat distribution than to soybean and feed grain distribution. Changes in ocean freight rates vary the optimal flows of soybeans and consequently change modal share. Feed grain movements are not sensitive to changes in ocean freight rates at the Gulf and Western ports but are sensitive to changes at the Great Lakes and the Atlantic ports. This is mainly due to production location of feed grains.

TABLE 14. TOTAL QUANTITIES OF FEED GRAINS SHIPPED BY MODES OF TRANSPORTATION

Model	Rail	Barge	Truck
		(1,000 bu.)	
1. No port capacity	3,425,979	385,525	316,720
2. Port capacity	3,561,458	287,973	337,223
3. 30% in Gulf	3,485,014	379,475	419,048
4. 30% in West	3,506,925	385,525	312,922
5. 30% in Lakes	3,305,989	477,763	419,769
6. 30% in Atlantic	3,502,206	231,483	336,738

Optimal Grain Handling Facilities in Export Ports

This study evaluates optimal flows of grain from producing regions to domestic consuming regions and to foreign import regions through U.S. export ports. The quantities of grain received by U.S. ports are dependent upon the interdependency between domestic and ocean transportation rate structures.

Table 15 shows the quantities of grain handled by U.S. export ports. While Model 1 does not have grain handling capacity constraints at the 1980 level in the Gulf and Atlantic ports, Model 2 does have the constraints. Quantities of grain received by each port differ between Models 1 and 2. This implies that the existing port facilities are not optimal and could be adjusted to minimize transportation costs in shipping grains from producing regions to foreign import regions. The total transportation cost saving is approximately $268 million annually or about 2.7 cents per bushel (Tables 1 and 2). There are substantial increases in the quantities of grain shipped to the Atlantic ports with no port capacity constraints and substantial reductions in the quantities of grain shipped to other ports (Model 1).

TABLE 15. TOTAL QUANTITY OF GRAIN RECEIVED BY EACH EXPORT PORTS

Model	Atlantic	Gulf	West	Lakes
		(million bushels)		
1. No port capacity	1,363	2,902	469	279
2. Port capacity	704	2,982	718	557
3. 30% in Gulf	2,311	1,570	698	434
4. 30% in West	1,363	3,078	279	293
5. 30% in Lakes	1,363	3,024	469	157
6. 30% in Atlantic	758	3,169	469	617

The changes in ocean freight rates affect grain flows from producing regions to export ports. An increase in ocean freight rates at the Gulf ports (Model 3) increases grain flows to the east (Philadelphia), Pacific Northwest and Great Lakes (Duluth and Chicago) and reduces grain flows to the Gulf ports. The increases in grain flows are much larger at the Atlantic ports than at the other ports. Increases in ocean freight rates at the West Coast (Model 4) result in a moderate reduction in quantity of grain handled at the West Coast and some increases in the Gulf ports while other ports remain unchanged. Increases in ocean freight rates at the Great Lakes do not change grain flows to the West Coast but they result in some increase in grain flows to the Gulf and Atlantic ports. Increases in ocean freight rates at the Atlantic ports result in some increases in grain flows in the Gulf ports and Great Lakes but no changes at the West Coast.

Optimal Flows of Grain

The general pattern of grain flows from producing regions to both domestic consuming and foreign import regions is described in this section. Although volume shipped to domestic and export markets is different, domestic flows of grain follow similar patterns throughout models. Therefore, optimal flows of grain from producing regions to domestic and export markets are presented for only Models 1 and 2. However, optimal flows of grain from U.S. export ports to foreign import regions are presented for all models.

Flows of Grain Without Export Capacity Constraints (Model 1)

Wheat

Domestic demand for wheat is satisfied by wheat produced near consumption centers (Figure 4). Wheat from Kansas and the Southern Plains is shipped to Southeast and Gulf ports (Figure 5). Wheat produced in North and South Dakota is shipped to Minneapolis, Duluth, and nearby domestic consuming centers. North and South Dakota shippers face a cost disadvantage in shipping to Gulf and Eastern consuming regions compared to other Plains states and also face a cost disadvantage in shipping grain to the West Coast for exports compared to Montana, Idaho, Washington, and Oregon shippers. Wheat produced in the Northwestern and Mountain states meets export demand at Seattle and Portland as well as local processing demand (Figure 5). While rail and trucks are mainly used to ship wheat to domestic consuming regions, rail and barge are used to ship to export markets. Since unit-car shipments have a cost advantage over barge shipments, only a small quantity of wheat is shipped by water in Model 1.

Soybeans

Nearly all soybean flows are oriented toward the export demand at Gulf and Atlantic ports (Figure 7). The demand for soybeans by processors is satisfied by local production in most states east of the Rocky Mountains (Figure 6). In most cases, soybeans are moved to domestic markets by truck because of the relatively short distance to market. Soybeans produced in Illinois is moved to New Orleans by barge.

Feed Grains

Feed grain flows from the Corn Belt where production is concentrated to the East and South (Figure 8). Feed grain from the Southern Plains is shipped to domestic consuming regions in California. Small amounts of feed grains produced in Idaho and Wyoming are also moved to meet domestic demand in California. Gulf ports receive most of the feed grains from the Corn Belt (Figure 9). Some feed grains produced in Illinois, Indiana, and Ohio are shipped to Eastern ports. Unlike soybean shipments to domestic markets, most feed grains are moved to domestic markets by rail. Some feed grains produced in the Corn Belt are moved to the Gulf ports by barge.

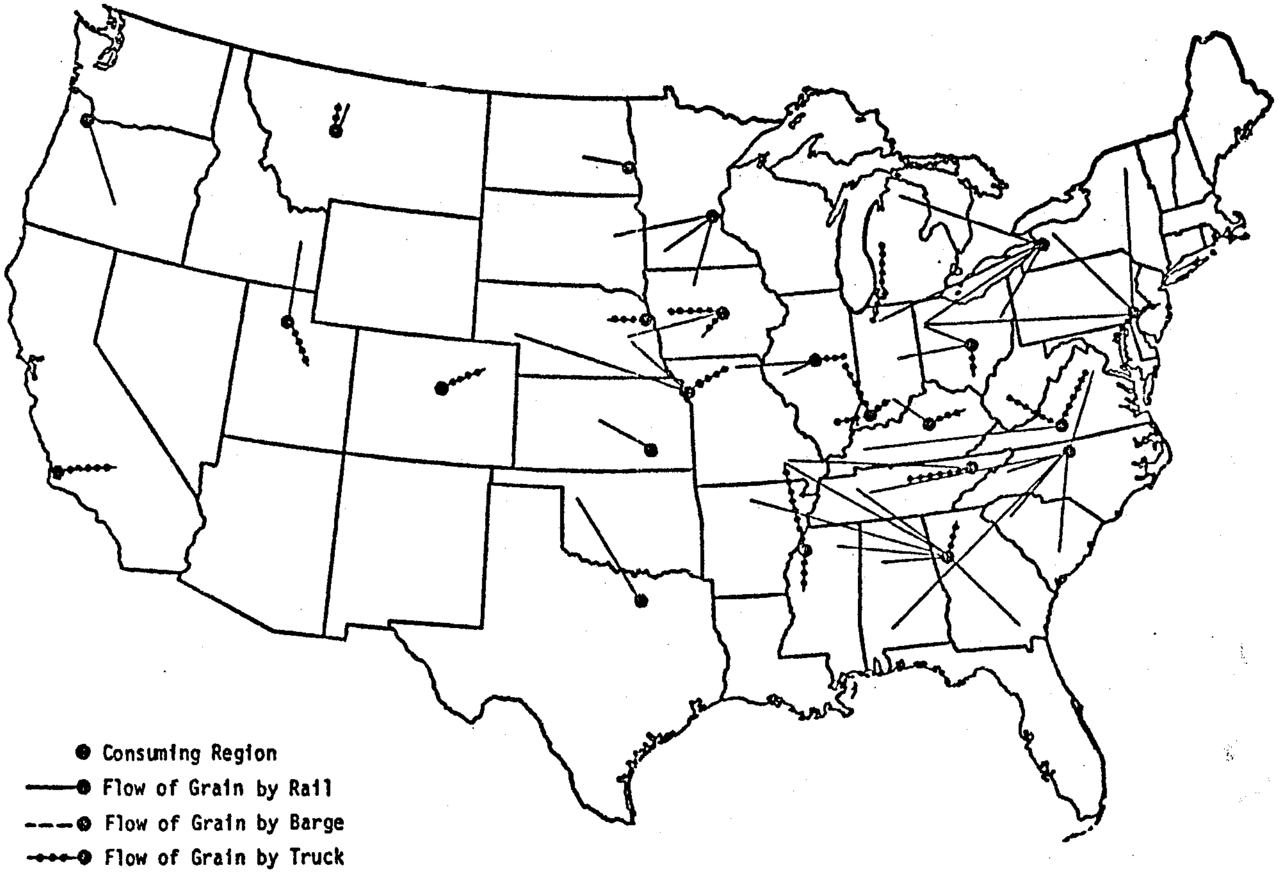

Figure 4. Flows of Wheat from Producing Regions to Domestic Consuming Règions in Model 1

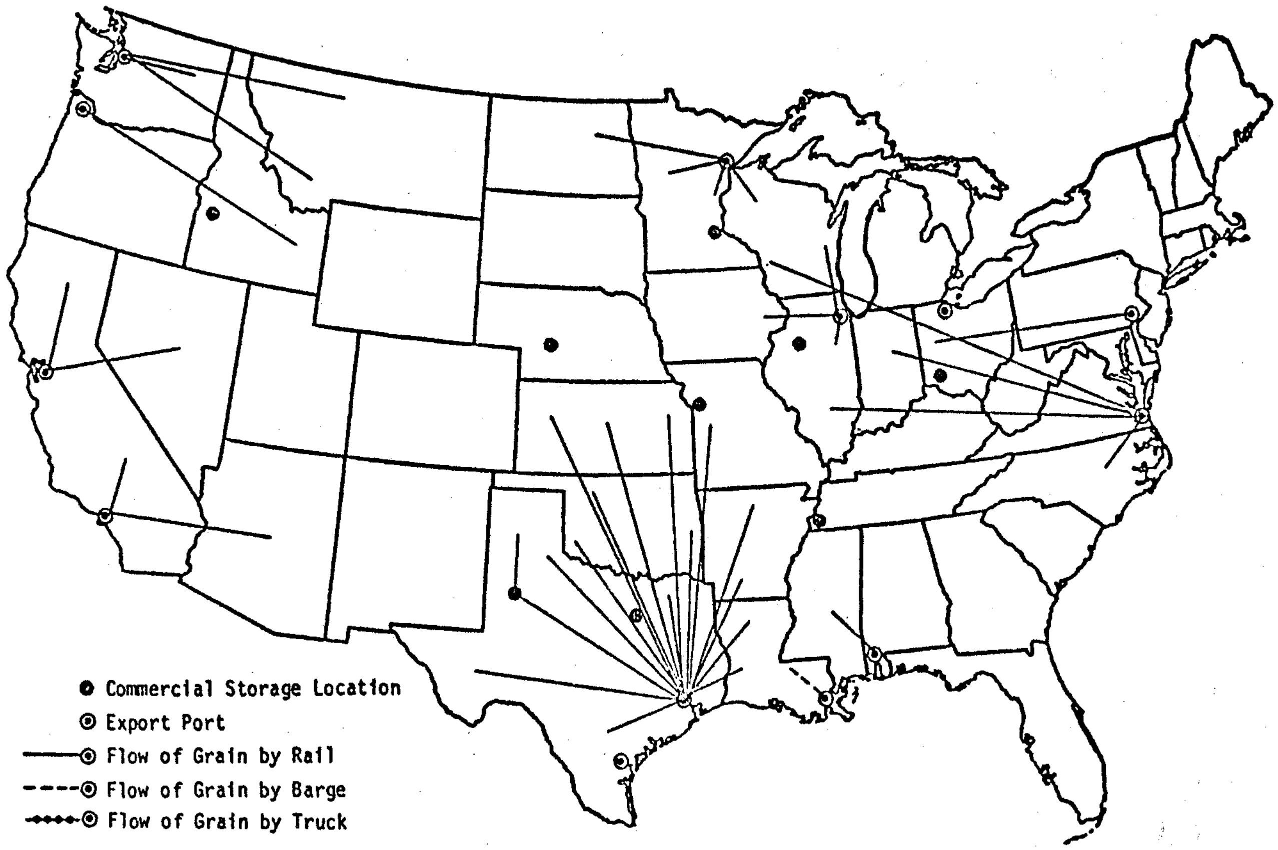

Figure 5. Flows of Wheat from Producing Regions to Export Markets in Model 1

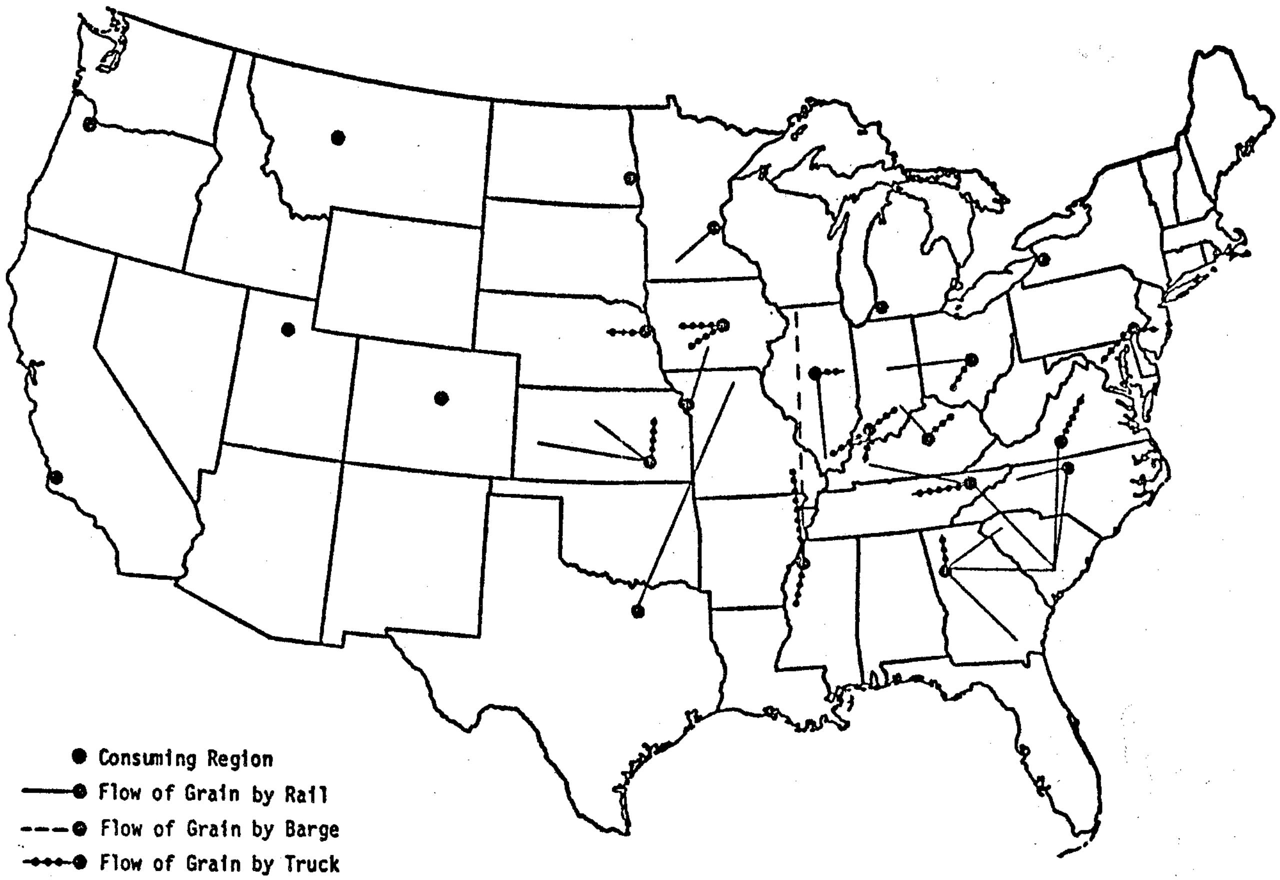

Figure 6. Flows of Soybeans from Producing Regions to Domestic Consuming Regions in Model 1

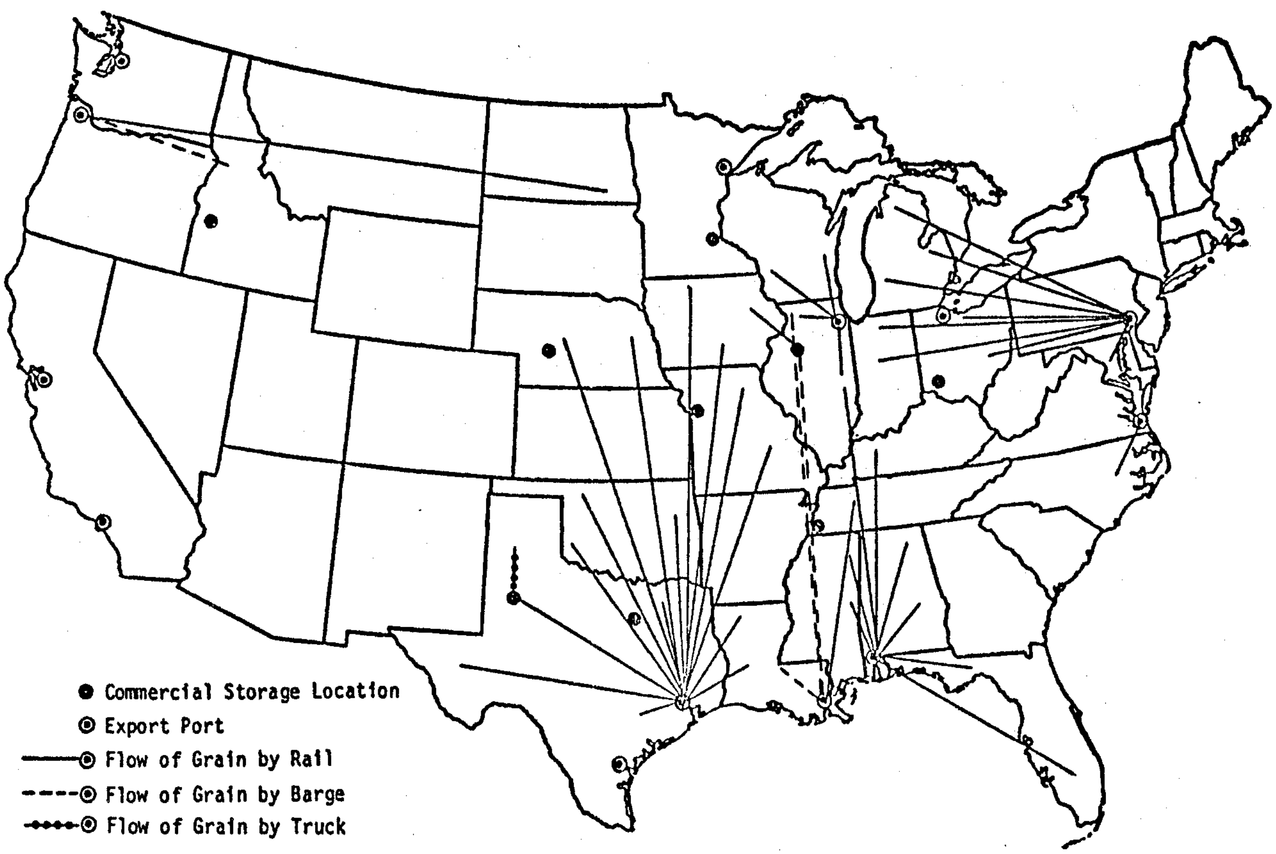

Figure 7. Flows of Soybeans from Producing Regions to Export Markets in Model 1

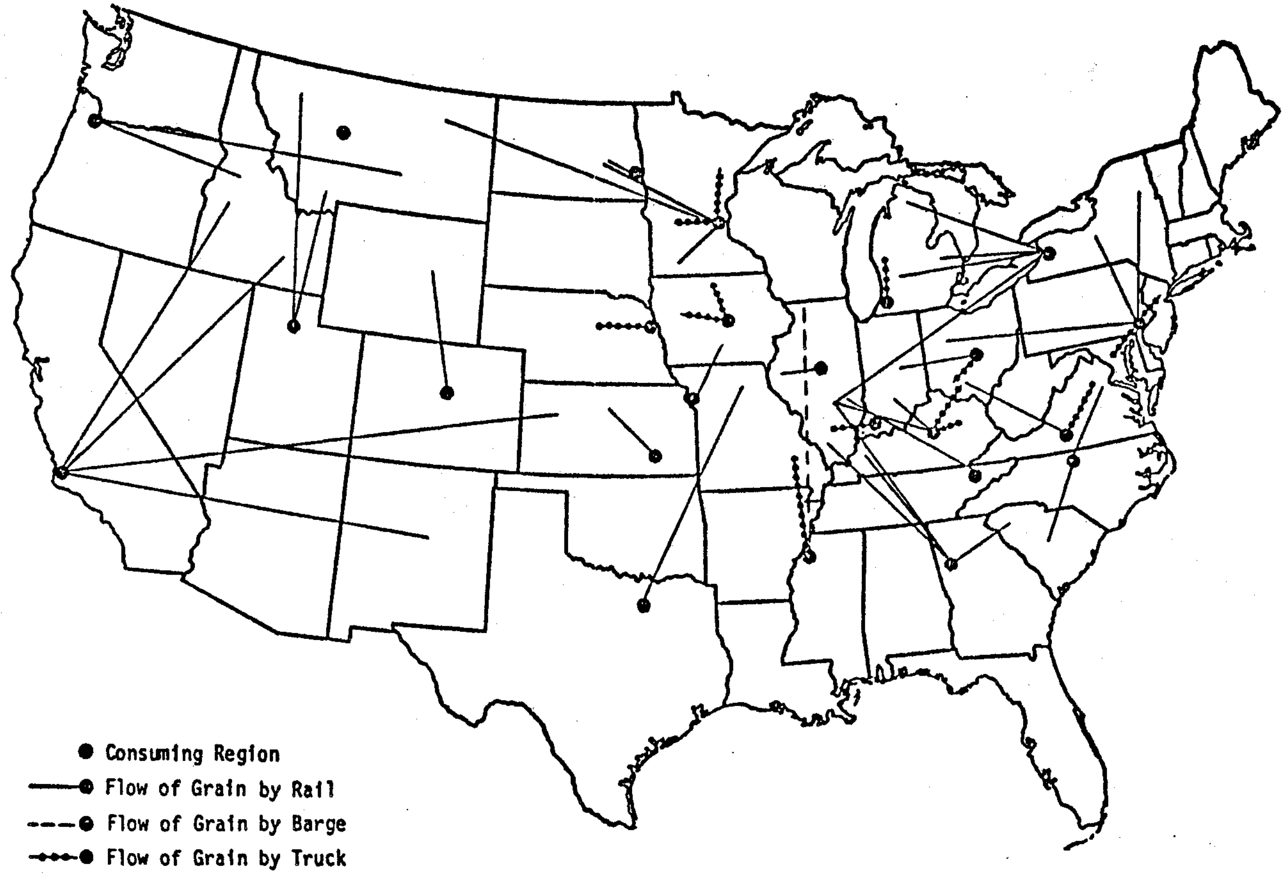

Figure 8. Flows of Feed Grains from Producing Regions to Domestic Consuming Regions in Model 1

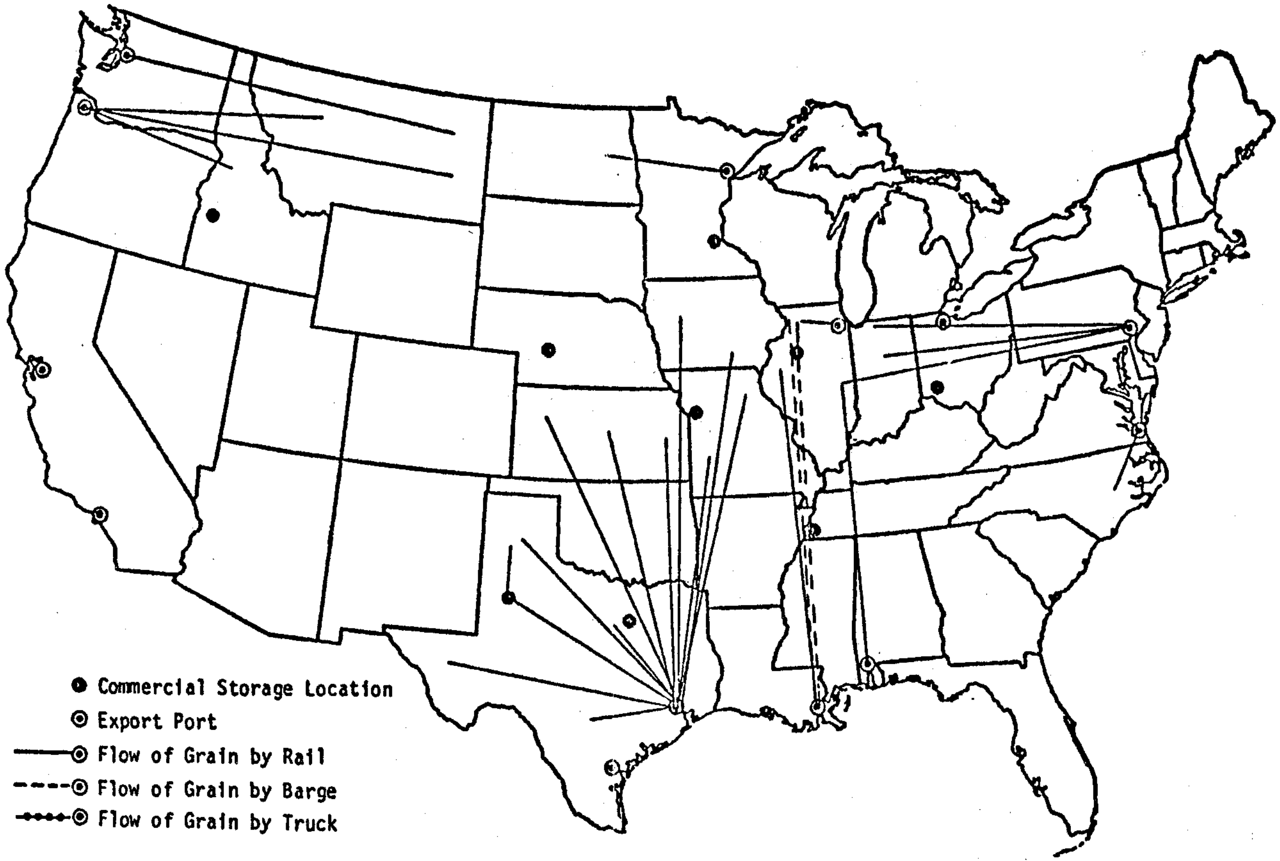

Figure 9. Flows of Feed Grains from Producing Regions to Export Markets in Model 1

Ocean Shipments of Grain

Most grain produced in the United States is moved to foreign importing regions through the Gulf ports in the base model. The Gulf ports handle approximately 65 percent of the total grain exported in the base model. Houston has a cost advantage in receiving grain from producing regions compared to New Orleans under the cost-base rate structure. New Orleans received 969 million bushels of grain and Houston received about 1,740 million bushels in the base model. The West Coast, Atlantic, and Great Lake ports received 469, 1,363, and 273 million bushels of grain, respectively. Seattle has a cost advantage for receiving grain over Portland, San Francisco, and Los Angeles. Duluth receives 80 percent of the grain handled at Great Lakes ports from Minnesota, North Dakota, and South Dakota. Philadelphia received the most grain from the Corn Belt and other Northeastern states in the Atlantic Coast. The advantage some ports have in receiving grain is dependent upon distance from producing regions and to major import regions.

Western Europe receives most of its grain from the Atlantic and Gulf ports. Asia imports grains through the Gulf and West Coast ports. Although ocean freight rates from the West Coast to Asia are lower than those from the Gulf, grains produced in the Southern Plains are moved to Asia through the Gulf ports because savings in ocean transportation costs from the West Coast to the import regions are smaller than the savings in domestic transportation costs to the Gulf ports. Atlantic Coast, Gulf and Great Lakes ports are used to ship grains to USSR, Middle East, and Africa. South and Central America receive grain from the Atlantic and Gulf ports.

Flows of Grain With Export Capacity Constraints (Model 2)

Flows of grain from producing regions to domestic consuming and export markets are shown in Figures 10 through 15. There are substantial reductions in grain flows from producing regions to the Gulf and Atlantic ports with port capacity constraints at the 1980 level. Some export movements are shifted from the Atlantic Coast to the Great Lakes.

With export capacity constraints at the Atlantic and the Gulf ports at the 1980 level, a substantial amount of grain is shipped to foreign import regions through the West Coast ports, mainly Seattle. In Model 2, Seattle ships grain to Africa. Seattle also ships more grain to Asia in Model 2 than in Model 1. In Model 2, approximately 56 percent of the total grain exported is handled through Gulf ports. More grain is handled

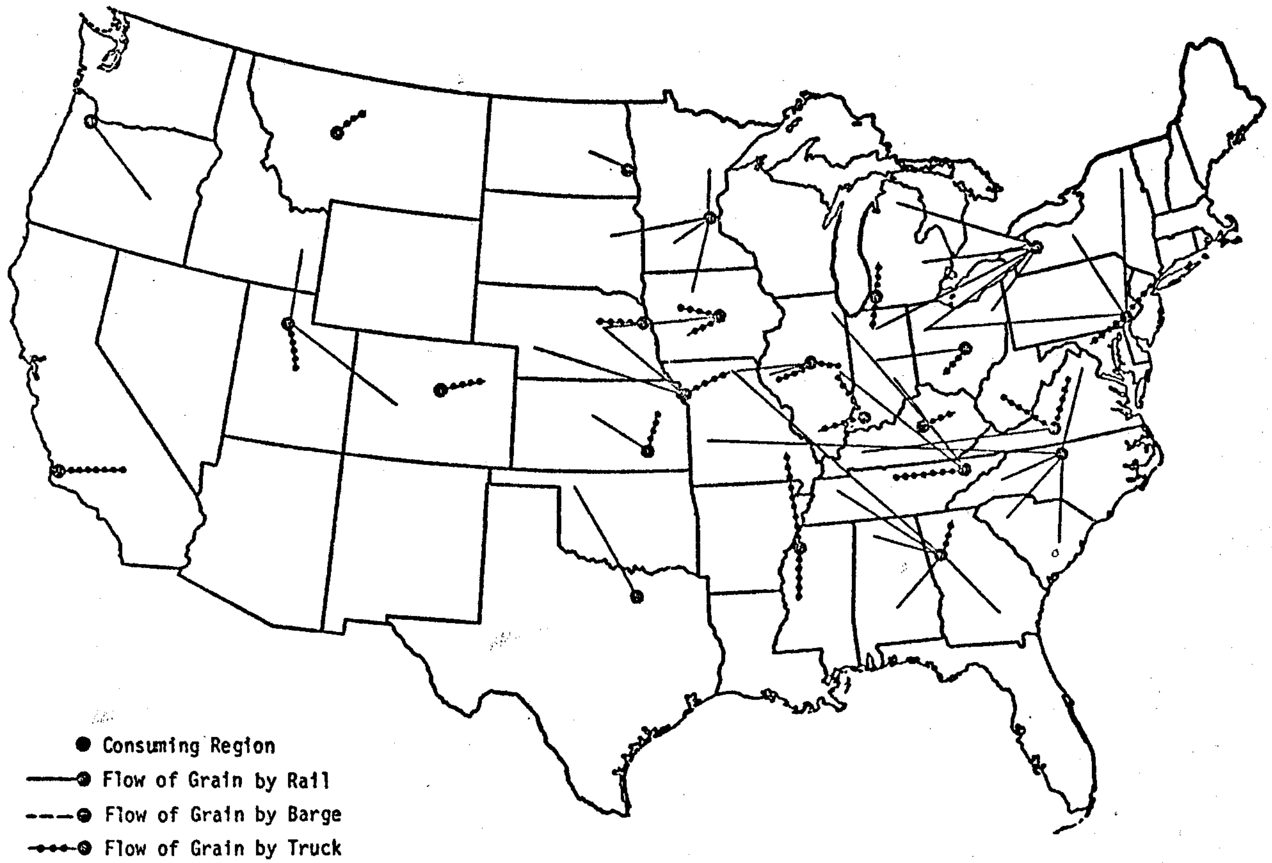

Figure 10. Flows of Wheat from Producing Regions to Domestic Consuming Regions in Model 2

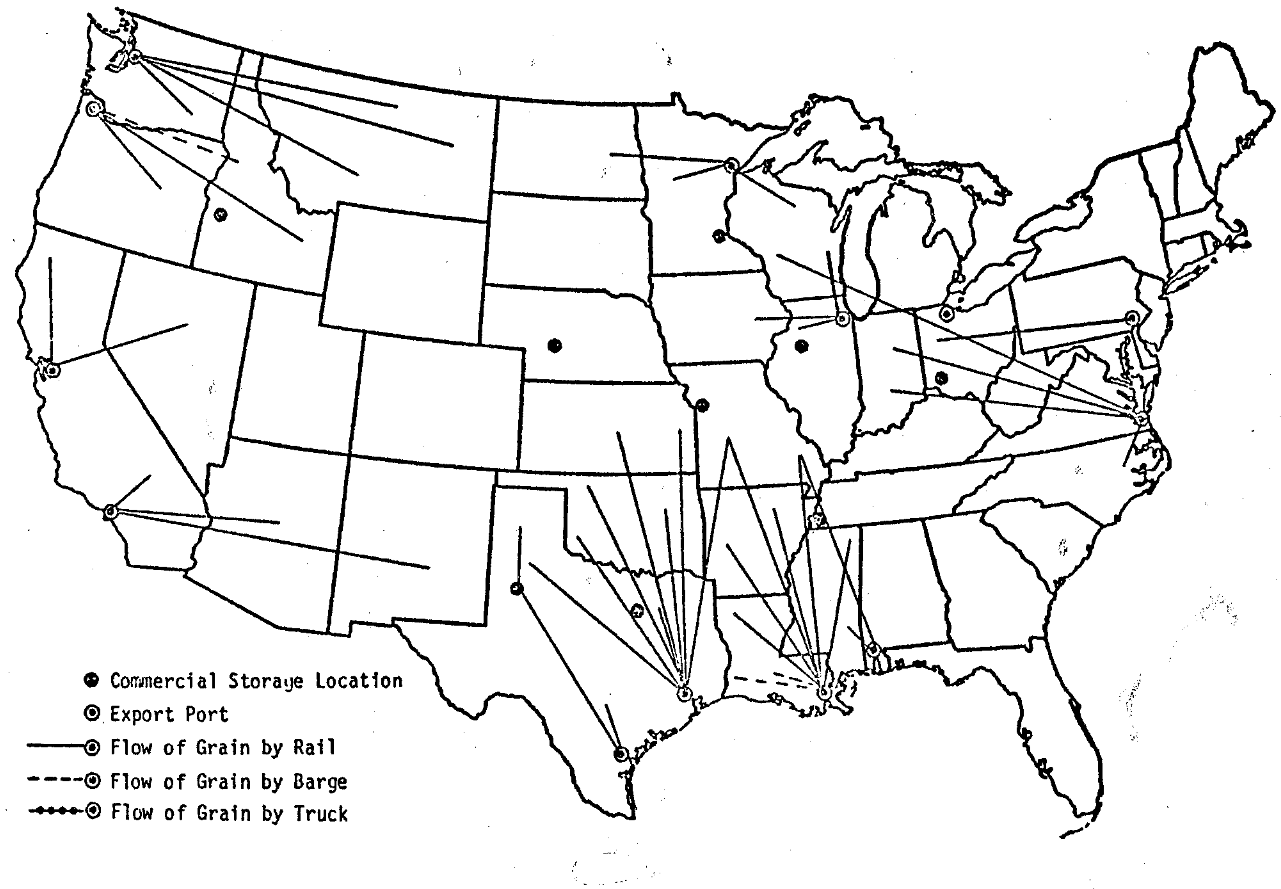

Figure 11. Flows of Wheat from Producing Regions to Export Markets in Model 2

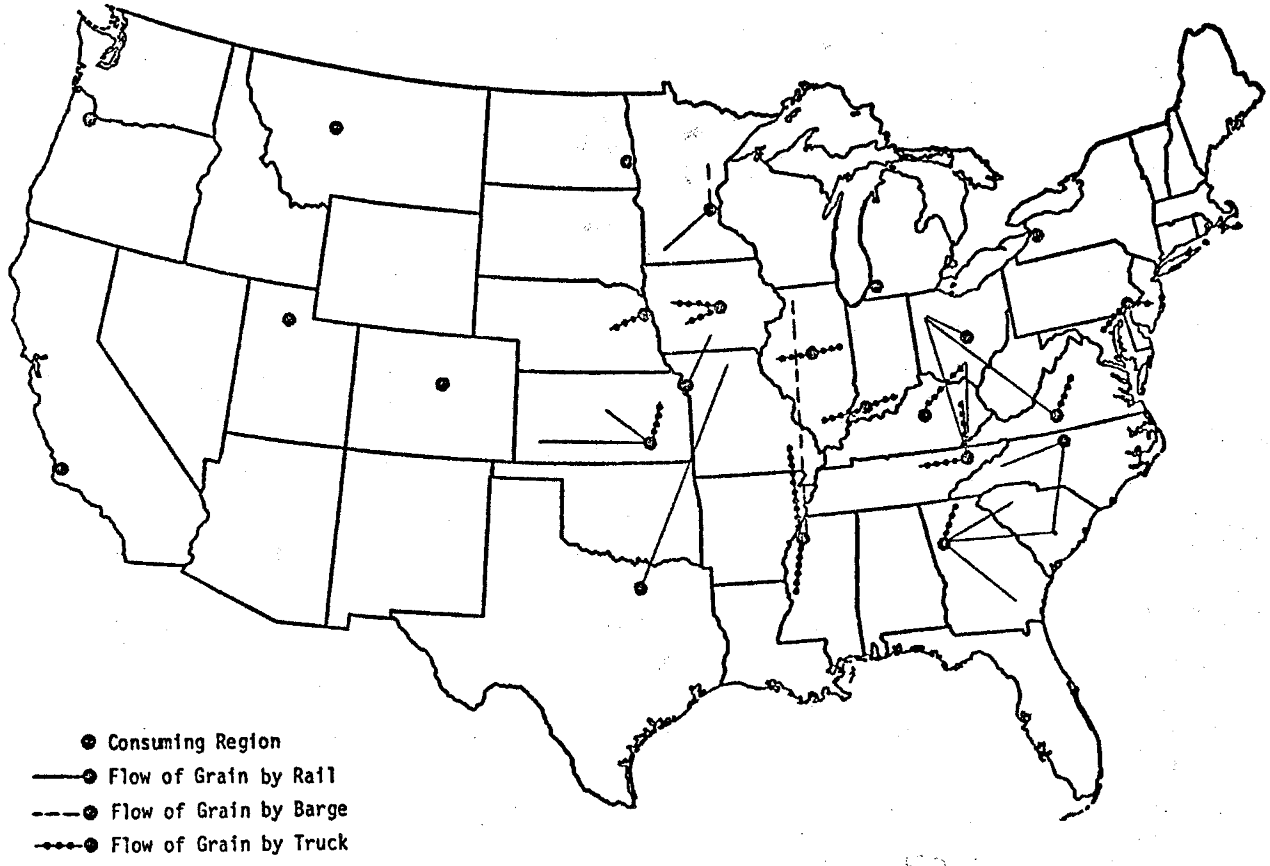

Figure 12. Flows of Soybeans from Producing Regions to Domestic Consuming Regions in Model 2

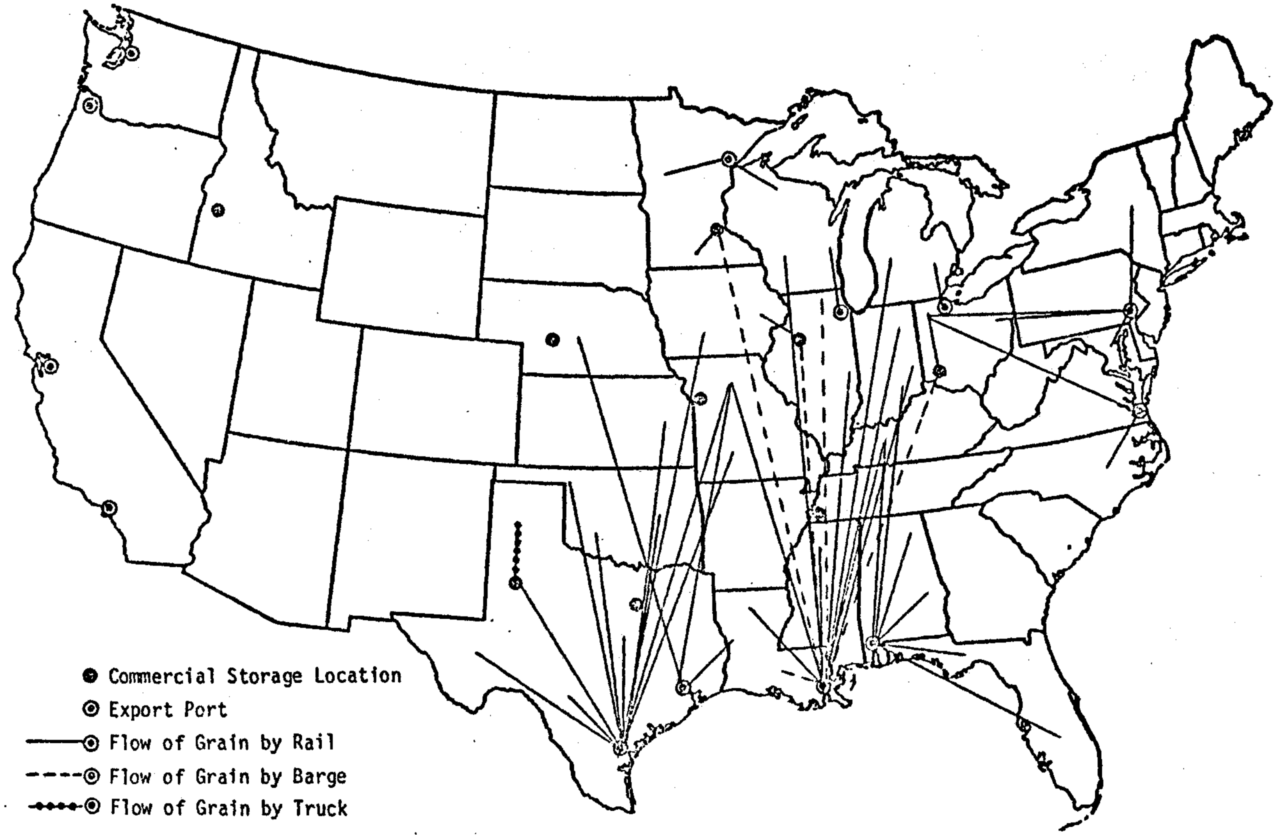

Figure 13. Flows of Soybeans from Producing Regions to Export Markets in Model 2

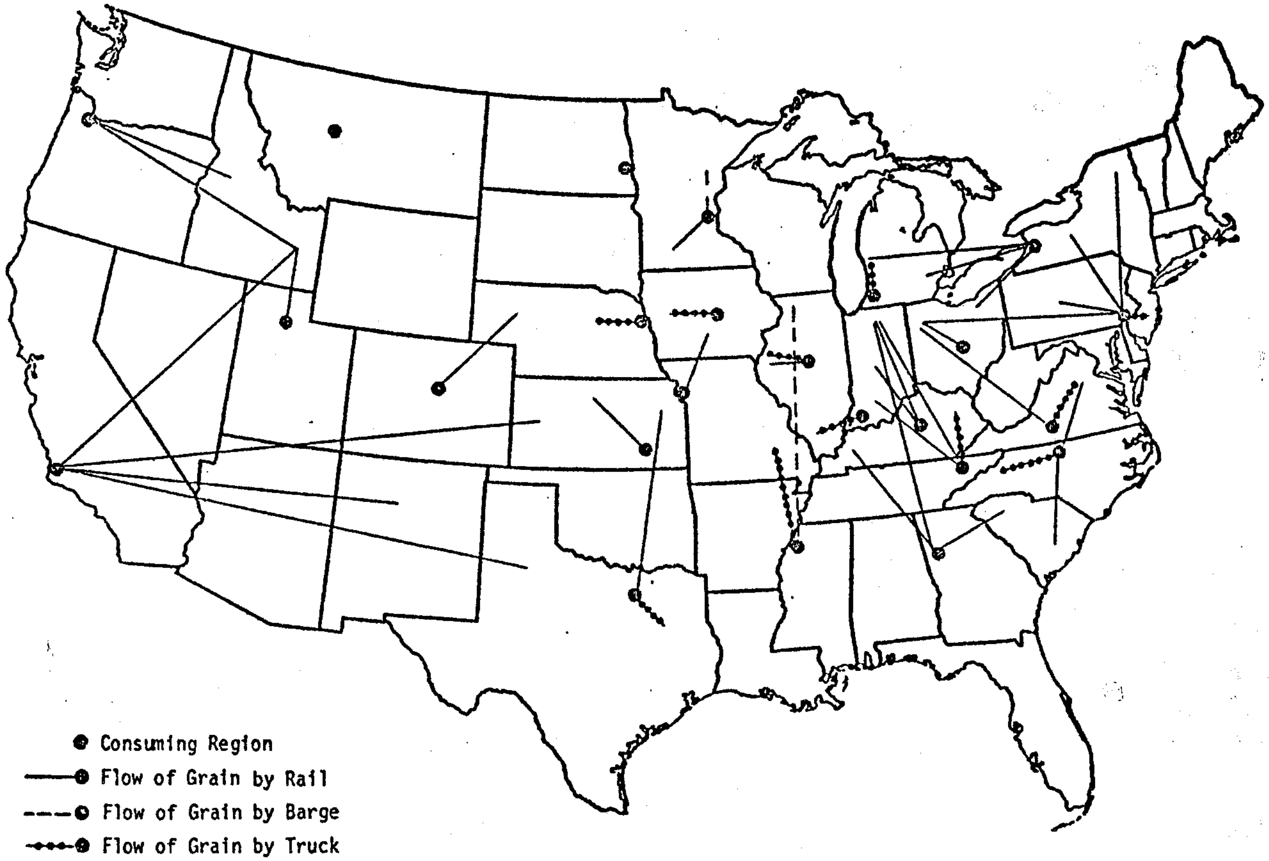

Figure 14. Flows of Feed Grains from Producing Regions to Domestic Consuming Regions in Model 2

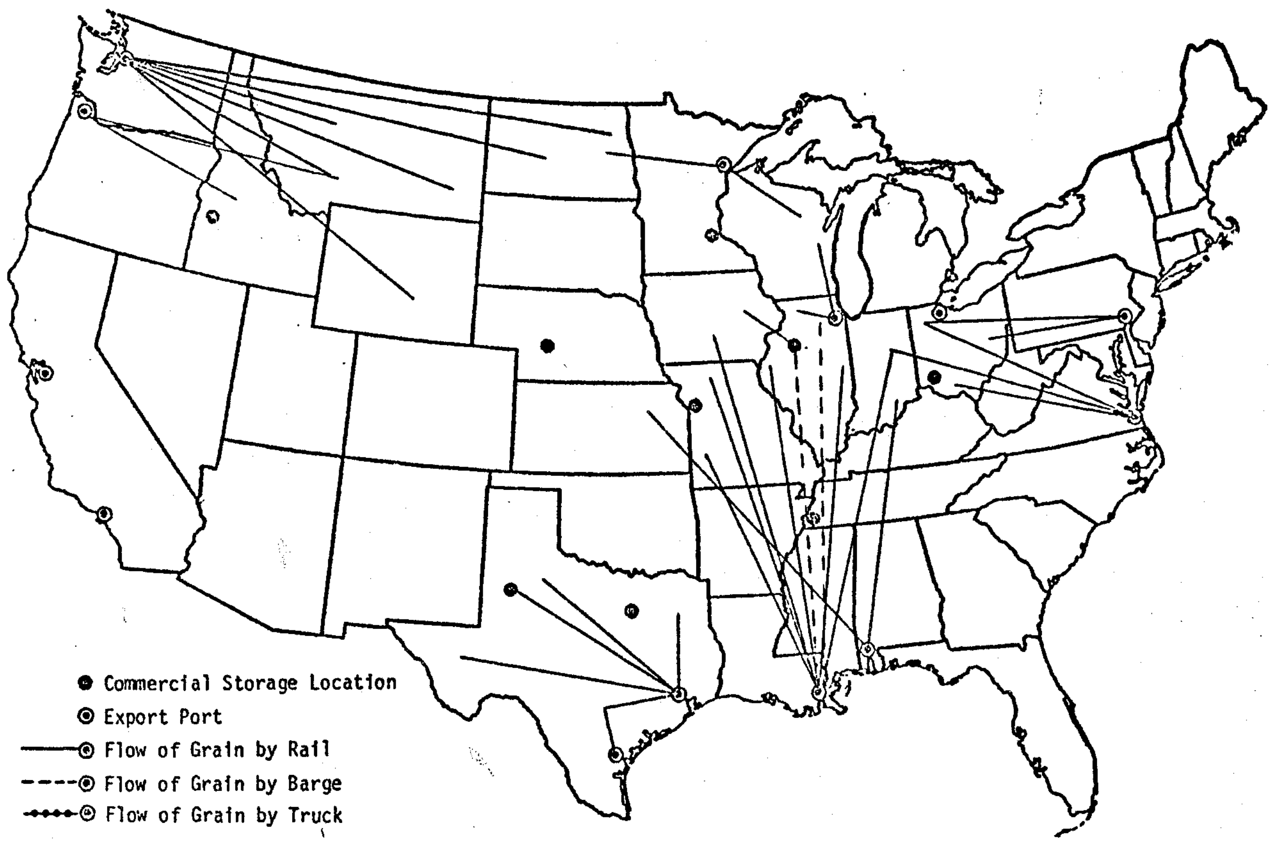

Figure 15. Flows of Feed Grains from Producing Regions to Export Markets in Model 2

at New Orleans in Model 2 than at Houston, which is different from Model 1. Atlantic, West Coast, and Great Lakes ports receive 705, 717, and 565 million bushels of grain, respectively. Atlantic ports receive much less grain in Model 2 than in Model 1. This indicates that grain handling facilities in Houston and Philadelphia should be able to handle more grain to minimize the total transportation costs in shipping grain from producing regions to foreign import regions.

Flows of Grain With Changes in Ocean Freight Rates (Models 3 Through 6)

Increases in ocean freight rates at Gulf ports result in increases in quantities of grain handled at Seattle and Duluth. The extra grain received by Seattle and Duluth is shipped to Western Europe and Asia. The quantities of grain shipped to Eastern Asia and Japan are substantially increased in Model 3 compared to Model 1. In addition, grains are moved from Duluth to Brazil, Eastern Europe, and U.S.S.R. in Model 3. Increases in ocean freight rates at the West Coast ports (Model 4) create some changes in grain flows between U.S. ports and foreign import regions. In Model 4, quantities of grain handled at Seattle and Portland are substantially reduced. Approximately 200 million bushels of grain are shifted from Seattle and Portland to Duluth and the Gulf due to increases in ocean freight rates at the West Coast ports. However, domestic and ocean shipment patterns associated with the Atlantic ports do not change when ocean freight rates are increased at the West Coast.

Increases in ocean freight rates at the Great Lakes (Model 5) reduce grain flow to those Great Lakes ports. Most of the grains are exported through the West Coast and Gulf. This indicates that increases in ocean freight rates at the Great Lakes change domestic flows to the Gulf and West Coast, as well as ocean shipments from those ports to foreign import regions. Domestic and ocean shipments associated with Atlantic ports are not changed with increases in ocean freight rates at the Great Lakes. However, changes in ocean freight rates at the Atlantic ports affect the quantities of grain handled at the Great Lakes as well as those handled at the Gulf. In Model 6, the Great Lakes ports ship grain to the Middle East, Africa, Eastern Europe, and U.S.S.R.

IV. Summary and Conclusions

The model used in this study is a spatial equilibrium model based on a linear programming algorithm. The model determines optimal flows of grain from producing regions in the United States to domestic consuming and foreign import regions. Modes of transportation used in the model are rail, truck, and barge for domestic transportation and ocean vessels for international shipments from U.S. ports to foreign import regions. The purposes of this study were to evaluate interdependency between domestic and ocean transportation systems with changes in ocean freight rates, and to identify impacts of the existing port capacity on the domestic and ocean shipments of grain.

Total quantity of grain moved from producing regions to domestic and export markets in Model 1 is 8,493 million bushels. Approximately 39 percent of the grain goes to domestic consuming regions and the remainder to export markets. Shipments by rail, barge, and truck are 60 percent, 5 percent, and 34 percent of the quantity of grain shipped to domestic consuming regions, respectively under the cost-base rate structure. They are 90 percent, 7.5 percent, and 2.5 percent for export shipments. The total transportation cost in shipping all grains from producing regions to domestic and export markets is estimated at $3,142 million--$1,066 million for grain shipments to domestic consuming regions and $2,075 million for grain shipments to export markets. In addition, the total ocean transportation cost of shipping grain from U.S. export ports to foreign import regions is $3,144 million in Model 1. Average transportation costs are 36.99 cents per bushel for all domestic shipments and 60.40 cents per bushel for ocean shipments.

Quantities of grains received by each U.S. export port are dependent upon domestic transportation costs from producing regions to the ports, ocean transportation costs from the ports to foreign import regions and characteristics associated with the ports. New Orleans, Louisiana and Portland, Oregon have access to inland river systems and can receive grains by barge in addition to rail and truck. Other ports in the U.S. receive grains by rail and truck. Consequently, river ports such as New Orleans and Portland could have a cost advantage over other ports if barge rates are relatively cheaper than rail rates and vice versa. The total transportation cost in Model 2 is $280 million larger than that in Model 1. This indicates that $280 million could be saved by optimizing grain flows and handling facilities at U.S. export ports. Under the cost-base rate structure, Houston and Philadelphia have an advantage as transshipment locations in shipping grains to foreign import regions compared to other U.S. ports such as New Orleans and Portland. The optimal quantities of grain handled in the Gulf, West Coast, Great Lakes, and Atlantic Coast are 2,902, 469, 273, and 1,363 million bushels, respectively. However, those optimal quantities are 2,903 million bushels at the Gulf; 717 million bushels at the West Coast; 556 million bushels at the Great Lakes; and 705 million bushels at the Atlantic ports when grain handling capacities at the Gulf and Atlantic ports are imposed in Model 2. This indicates that much more grain should be moved to the Atlantic Coast for shipments of grain to foreign import regions in order to minimize total transportation costs under the cost-base rate structure.

Changes in ocean freight rates at the Gulf, West Coast, Great Lakes, or Atlantic Coast significantly change domestic and ocean transportation costs, quantities, and physical flows. Domestic transportation costs are most greatly influenced with a 30 percent increase in ocean freight rates at the Great Lakes. On the other hand, ocean transportation costs are largest with a 30 percent increase in ocean freight rates at the Gulf. Changes in total transportation cost are largest when ocean freight rates are increased at the Gulf ports.

Because of production locations, the impacts of changes in ocean freight rates on total transportation costs are different for each grain. Wheat shipments are most costly with a 30 percent increase in ocean freight rates at the Great Lakes. However, soybean and feed grain shipments are most costly when ocean freight rates are changed at the Gulf ports.

Modal share is not sensitive to changes in ocean freight rates. The quantities of grain shipped by barge are not reduced with increases in ocean freight rates at New Orleans and Portland where grains could be received by barge. Similarly, the quantities of grain shipped by rail are not reduced with increases in ocean freight rates at those ports where grains are mainly received by railroads. However, grain flows from producing regions to export ports are sensitive to changes in ocean freight rates. Changes in ocean freight rates at the Gulf ports influence flows of grains from producing regions to all export ports. However, changes in ocean freight rates at the West Coast do not affect flows of grain from producing regions to the Atlantic ports and vice versa. Changes in ocean freight rates at the Great Lakes do not influence flows of grain from producing regions to the Atlantic ports, but those at the Atlantic ports do result in increases in flows of grain to the Great Lakes.

Domestic flows of grain are limited to travel distances shorter than 350 miles. Average travel distance for soybean shipments is shorter than for shipments of wheat and feed grains. Movements of grain to export markets are concentrated as follows: 1) wheat movements from the plains states to the Pacific Northwest, Great Lakes, and Gulf ports; 2) soybean movements from the Corn Belt and southeastern states to the Gulf and Atlantic ports; and 3) feed grain movements from the Corn Belt to the Gulf ports. There are some feed grain and soybean movements to the West Coast, but the quantity shipped is small.

The Northern Plains have a cost disadvantage compared to Minnesota in shipping grain to the Great Lakes and also have a cost disadvantage compared to Montana, Idaho, Washington, and Oregon in shipping grains to the Pacific Northwest ports. The considerable amount of wheat produced in the Northern Plains is moved to the Pacific Northwest and Duluth to meet import demand for wheat. Increases in ocean freight rates at the Pacific Northwest and Great Lakes result in substantial reductions in grain flows from the Northern Plains to the Pacific Northwest and Great Lakes. This indicates that marketing of grains produced in the Northern Plains is not only influenced by domestic transportation rates but also by ocean freight rates at the Pacific Northwest and Great Lakes.

Western Europe receives most of its grain from Gulf and Atlantic ports. Asia imports grain through the Gulf and West Coast ports. Although ocean freight rates from the West Coast to Asia are lower than those from the Gulf, grains produced in the Southern Plains are moved to Asia through the Gulf. This is because savings in ocean transportation costs using the West Coast are smaller than savings in domestic transportation costs using the Gulf. The Gulf, Great Lakes, and Atlantic ports are used to ship grain to the U.S.S.R., Middle East, and Africa. South and Central America receive most of their grain through the Atlantic and Gulf ports.

Changes in flows of grain between U.S. ports and foreign import regions are substantial with increases in ocean freight rates at the Gulf, West Coast, Great Lakes, or Atlantic Coast ports. Ocean freight rates at the Gulf and Great Lakes are highly related to quantities of grain handled at the West Coast and Atlantic Coast ports. Ocean freight rates at the West Coast ports do not affect quantities of grain received and shipped at Atlantic ports but do influence those at the Gulf and Great Lakes. Similarly, ocean freight rates at Atlantic ports do not affect the quantities of grain handled at the West Coast, but do change quantities of grain handled at the Gulf and Great Lakes.

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