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An analysis of the domestic and foreign distribution of US heavy grains under alternative assumptions regarding possible future supply, demand, and transport costs

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An analysis of the domestic and foreign distribution of U.S. heavy grains under alternative assumptions regarding possible future supply, demand, and transport costs

by

Dennis Merriam Conley

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
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DOCTOR OF PHILOSOPHY

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INTRODUCTION

In the past few years, there has been an increased importance in the international trade of all types of goods and commodities. One major comparative advantage in trade for the U.S. has been in heavy grains.[1] This trade advantage allowed grains to significantly contribute to the U.S. economy. They have contributed to easing balance of payments problems. They have been the initial commodity in the development of new markets, particularly the Soviet Union and mainland China, thus paving the way for potential trade in other U.S. goods and commodities. The increased trade has added to the income for producers. And, it has provided a basis for the reduction and possible elimination of subsidies to farmers, allowing agriculture to become a free and self-sustaining industry.

The years 1972 and 1973 will long be remembered as being unique in the history of U.S. grain marketing. Some events that occurred during these two years are given as follows.

The major event was when the U.S. sold relatively large amounts of wheat and other grains to the Soviet Union and mainland China. This sale resulted from a poor harvest in the Soviet Union and China due to adverse weather conditions. Compounding the lack of supply was the adverse weather in Argentina, Australia, and Southeast Asia. The Russian purchase took place with two processes going on simultaneously. They negotiated publicly with government officials in Washington to obtain

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[1] Heavy grains: feed grains, wheat, and soybeans.

a line of credit for the purchase. And, they negotiated secretly with officials of private grain companies settling on the cash terms for the purchase.

The wheat sale was particularly interesting. The world price for wheat was used as a basis for the negotiated sale price. This price was below the U.S. wheat price and under an existing agriculture program the U.S. government agreed to pay a subsidy to the private grain companies. The subsidy was to make up the difference in prices and induce the sale to the Soviet Union. And, even though the U.S. paid no direct subsidy for feed grains, they did subsidize U.S. flag ocean vessels so they would be competitive with foreign flag vessels. The unexpected surprise was the Soviet Union buying much more wheat than had been anticipated. This drove the price to new highs and resulted in substantial subsidy payments. Many farmers did not benefit from the price rise though, since they had already sold their grain for much lower prices. They had no prior knowledge of the potential foreign sales and expected a grain surplus.

A second event was the increased demand for soybeans based on an increased consumer demand for higher protein foods throughout the world. This increased demand for soybeans was partly due to the unavailability of fish off the Peruvian coast and a reduced peanut meal supply as a source of protein. An early snowstorm and unusually wet field conditions during the soybean harvest season also limited potential supplies and thus provided another factor in driving the price to previously unheard of levels.

Third, there were two devaluations of the dollar. This caused U.S. commodities to be cheaper in terms of foreign currencies providing an impetus for foreign demand to increase and drive the prices even higher. The foreign buyers could get more grain after the devaluation for the same amount of money than they could before it. This event had a greater impact on soybean demand than on feed grain demand.

A fourth event was a straining of the transportation and handling capacities of the marketing system in order to move the grain and meet the new foreign demand requirements. This was evidenced by the increase in spread between the central Iowa price for grain and the Rotterdam price. See Table 1. The spread for corn on January 26, 1973, was more than double the spread considered normal of a year earlier, and the spread for soybeans was more than triple a year earlier. The wheat sale added to the shortage of railcars for other grains, and ultimately some ports of export were placed under embargo. During this period a number of grain industry people attributed the high price of grain as being a function of the excess demand in the transportation market.

A fifth event was the embargo of soybean and soybean meal exports in June, 1973, essentially until the new crop was to be harvested in the fall. This was done to meet U.S. needs for feed used in the production of livestock. With an adequate feed supply it was hoped that cattle and poultry producers would increase output and that meat and poultry prices would decline.

It is expected that the U.S. will continue to produce large quantities of feed grains, wheat, and soybeans relative to the rest of the

Table 1. Grain prices, Iowa to Rotterdam

	Corn		Soybeans	
	Jan. 28, 1972	Jan. 26, 1973	Jan. 28, 1972	Jan. 26, 1973
Rotterdam price[a]	\$1.45[b]	\$2.23[b]	\$3.43[b]	\$6.11[b]
Price paid at Gulf by foreign buyers	1.29	2.08	3.30	5.52
Price received at Gulf by domestic shippers	1.27½	1.68½	n.a.	5.10
Central Iowa price	1.04	1.28	2.95½	4.52
Spread, central Iowa to Rotterdam	.41	.95	.47½	1.59

[a] The Rotterdam and central Iowa prices differ by a few days, but this does not significantly affect the spread.

[b] Per bushel.

world and that it will continue to market a significant portion of that production. Examination of Table 2 places the magnitude of U.S. exports marketed in perspective. Of the 62.5 million metric tons (a metric ton equals 2,204.6 pounds) of agricultural products exported in fiscal year 1972, 50.1 million metric tons consisted of feed grains, wheat, and soybeans. Based on projections for fiscal 1973, wheat exports will increase by 77.9 percent to 30.6 million metric tons, feed grain exports will increase by 27.5 percent to 26.9 million metric tons, and soybeans will increase 12.8 percent to 13.2 million metric tons. The total export increase of heavy grains will be 33.2 percent, not counting rice.

Russian grain purchases in the United States for delivery in fiscal 1973 consist of about 10.9 million metric tons of wheat, 7.0 million metric tons of corn, and 1.1 million metric tons of soybeans. Thus, U.S. sales to Russia account for 19 million metric tons of exports out of a projected 72.6 million metric tons of U.S. grain exports for fiscal 1973.

In the previous eight years, the exports of wheat and primary wheat products, rye, rice, corn, oats, barley, sorghum grain, soybeans and primary soybean products have ranged from a low of 44 million metric tons in fiscal 1969 to a high of 61 million metric tons in fiscal 1966. These exports during fiscal 1973 are projected at 76.5 million metric tons, well above recent years.

Purpose

Since the North Central Marketing Area (NCMA) of the U.S. produces a large percentage of the heavy grains, then a new event or a change in policy is going to have a pronounced effect on the marketing of grain

Table 2. U.S. agricultural exports by commodity, fiscal years 1972 and 1973

	Fiscal years		Change	
Commodity	1972	1973[a]	1972 to	1973
Wheat and products of wheat	17.2[b]	30.6[b]	13.4[b]	77.9%
Rye	--[c]	--[c]	--[c]	--
Rice	1.7	1.8	.1	7.0%
Feed grains	21.1	26.9	5.8	27.5%
Soybeans	11.7	13.2	1.5	12.8%
Subtotal	51.8	72.6	20.8	40.2%
Oil, cake, and meal	4.0	3.9	-.1	-2.5%
Other	6.7	7.0	.3	4.5%
Total	62.5	83.4	20.9	33.5%

[a] Projected.

[b] Million metric tons.

[c] 0.05 or less.

from that area. The purpose of this study is to use a transshipment model to identify 1) the domestic and foreign movements of heavy grain, and 2) the implied price surface under various conditions (events and policies). In addition, the purpose is to do a sensitivity analysis of the grain movements and price surfaces when these conditions are changed.

Assumptions are used which reflect current conditions for the 1972-73 crop year. Then assumptions are specified which reflect possible future conditions regarding the marketing of grain. Grain movements and price surfaces are identified under these assumptions:

1. Those reflecting current conditions for the 1972-73 crop year for feed grains, wheat, and soybeans. These conditions are used in deriving three basic solutions.
2. A 20 percent decrease in 1972-73 demand for feed grains by western Europe.
3. A 20 percent increase in 1972-73 demand for soybeans by western Europe.
4. A 20 percent increase in 1972-73 demand for all three grains by Japan.
5. The results derived under the above conditions are analyzed to see if a reduction or subsidy of rail rates from the midwest to the west coast may encourage use of those ports as major export outlets for grain.

The possible future conditions listed above are derived from various sources. The majority of the sources are United States Department of Agriculture (USDA) publications about future market opportunities for U.S. grain. Other sources include newspapers, periodicals, government officials, industry spokesmen, and other grain marketing researchers. The Japanese and western European markets are considered as being among the most important U.S. foreign markets, and the traditional ones also. This type of analysis provides a basis for evaluating the impact of various events or policies on the nation's heavy grain economy. Intelligent policy action concerning grain marketing requires knowledge of district, regional, and national effects on the movement of grain. Similarly, with a change in policy, the intelligent adjustment by individual grain and livestock producers depends on their ability to predict the effects on prices.

Method of Analysis

The method of analysis is first to develop and solve a transshipment model for the base period, 1972-73. Second, different solutions are derived based on assumptions which reflect possible future conditions.

In the computer runs for the base period, three transshipment models are developed; one each for feed grains, wheat, and soybeans. Additional constraints are included to represent the throughput capacity at the ports for the three grains.

The base period computer runs include the following:

1. Construction of a constrained transshipment model with routing patterns for heavy grains from U.S. surplus regions to U.S.

deficit regions and ports, and from ports to foreign deficit regions.

a. Delineation of U.S. and foreign regions.

b. Estimation of the surplus and deficit quantities of grain for the U.S. and foreign regions.

c. Estimation of the cost of transporting grain from surplus regions to U.S. deficit regions and ports, and from ports to foreign deficit regions.

d. Estimation of the grain throughput capacities for the ports of export.

2. Solutions to the basic models.

Once the models have been developed and solutions found which may replicate reality, hypothesized alternative situations are analyzed to determine: 1) the optimal routing patterns, 2) the implied price surfaces, 3) the opportunity costs of shipping over unused routes under various future conditions, and 4) the sensitivity of solutions to changes in conditions.

Related Studies

There has been a considerable amount of research done using linear programming, transportation models, and transshipment models. A few references on this type of work are Heady and Candler (15), Dantzig (8), and Hadley (14). References on marketing and interregional trade are USDA (26), and Bressler and King (4).

In the field of international grain trade Moore, et al. (19) reported the findings of a study on the least cost world trade patterns for selected grains and meats in 1965-66. World trade patterns were defined as those routes from U.S. and foreign exporting countries to other foreign importing countries and to the U.S. The study examined the actual trade patterns for specific grains and meats in 1965-66 and compared them with the least cost patterns as determined by linear programming. Savings from using the least cost patterns were shown by commodity. The model was also used to show the impact of a 10 percent reduction in United States outgoing freight rates on world trade patterns for selected grains and meats. The actual and least cost world trade patterns were expected to deviate from each other due to export subsidies, trade barriers, lack of homogeneity among products and imperfect knowledge.

Sharp and McDonald (24) considered both U.S. domestic and U.S. to foreign region trade of individual grains for 1966-67. The objectives of the study were to determine the impact of ocean vessel size on 1) the transportation cost of United States exports of heavy grain, and 2) upon U.S. grain export facility requirements. Additionally, they evaluated the impact of reduced barge rates for transporting grain to ports of export. They used a linear programming formulation of the transshipment model and solved for the least cost trade patterns for each of three grains under various assumptions. The assumptions specified that a certain percentage of U.S. grain had to be exported by a certain size of ship. Various percentage combinations were assumed. Their results included the total and segmented transportation costs (optimal) under the various assumptions, and diagrams of the optimal domestic movements of grain. Also, their model solutions provided estimates of the combined volume of grain that should flow through a port. This estimated volume was used as a basis to determine if there was a surplus or deficit of storage capacity at the ports.

Leath and Blakley (18) did an interregional analysis of the U.S. grain marketing industry for the 1966-67 marketing year. The overall objective was to determine simultaneously the geographical flows of wheat, feed grain, soybeans, and wheat flour that minimizes the total cost of storage, assembly, milling, and distribution for the grain marketing industry. Transshipment models were formulated using the linear programming framework. They were domestic in scope with final foreign demand occurring at the ports of export. The models included several, but by no means all, important spatial interrelationships involved in grain marketing; one model incorporated the time dimension of the marketing process. There were four variations of the basic transshipment model. The first variant simultaneously determined 1) the least cost flow patterns and intermarket and shipping point price relationships, and 2) the optimum level of regional milling activities, given 1967 regional milling capacities. The second variant determined the optimum location of flour milling, given 1967 regional wheat supplies and flour requirements. The third variant determined least cost flow patterns when minimum inventory levels were maintained at all grain destinations. The fourth variant, or time-staged model, determined the optimum utilization of regional storage capacity and the least cost flows of each grain simultaneously for the four quarters of the marketing year.

Driscoll and Leath (10) used an updated version of the last analysis discussed to estimate optimum flows for wheat, feed grains, and soybeans in fiscal year 1973. The purpose of the study was based on the heavy activity in grain and soybean exports for the fiscal year 1973. The activity was expected to produce severe strains in the domestic transportation system and in the handling capacities of the ports. Again a multi-commodity, multi-regional model was formulated and optimized with a linear programming algorithm. No transportation capacity constraints were placed on any route included in the model. This implicitly assumed that transportation equipment would be available to move the required volumes. The objectives were to 1) determine the least cost flow patterns of grains to satisfy export as well as domestic demands for grains, and 2) determine optimum ports of exit for grains given transportation costs and handling capacities at ports.

The research being done for this study is a continuation of work done by Davis (9), Cayemberg (5), and Conley (7). Davis and Cayemberg worked on the Phase I project for the North Central Regional Marketing Committee (NCM-42), "Impact of Changing International Trade in Grain (Including Soybeans and Soybean Products) on Marketing of United States Grain." Davis' contribution was the development of shipping costs on the ocean for U.S. grain exports, and initial development of the ocean grain movements. Cayemberg did an analysis of freight rates and ocean shipping of U.S. grain exports.

Conley continued the work and developed Phase II for the NCM-42 project where domestic and ocean shipments were integrated for a model that was international in scope. In Phase II the three commodities were considered individually and model solutions were derived based on 1966-67 data. This study is a continuation and updating of the Phase II work now under the project NC-104, "Systems Analysis of the Economics of Grain Marketing."

MARKETING FOUNDATIONS

This chapter covers some of the economic theory and concepts underlying marketing. In addition, a discussion of methodology and possible extensions for marketing research is given. This foundation is for grain commodities but also applies, in general, to other agricultural and industrial commodities. The discussion begins with the efficiency of marketing systems and the perfect market concepts. Next, interregional competition and prices are explored with respect to the various marketing utilities, for example, space, form, and time. Third, the reason why the objective of transportation models is cost minimization is discussed. Fourth, extensions of methodology to include dynamics, stochastics, and verification procedures are given. Finally, there is a discussion of simulation.

Efficiency of Marketing Systems

The efficiency of marketing systems and how to evaluate it is a continuing question in economics. A number of economic authors have presented similar and contrasting approaches in attempts to answer the question. My purpose is to review three existing approaches to the question, not to develop a new one.

Sosnick

In the first, Sosnick (25) uses an industrial organization approach to discuss the concept of effective competition. That is, of a socially desirable state of affairs in an industry or a market. The article implies that effective competition results in the efficiency of a marketing system. Sosnick points out that a score of economists have sought a standard against which functioning markets could be judged. They have tried to specify a realistic ideal; a market situation that, unlike perfect competition, is both desirable and attainable. Sosnick states, by reference to George Stigler, the concepts of effective competition have not provided "operational criteria capable of being applied concretely...." He then proceeds to contribute his list of "meaningful and manageable criteria."

Sosnick does this in two parts. First, he presents principles a writer should follow in defining effective competition. A writer should be specific, definite, explicit, realistic, discriminating, comprehensive, and stringent. Sosnick discusses each of the principles in detail. Secondly, he presents his list of meaningful and manageable criteria. His position is that a market is effectively competitive if and only if it is free of twenty-five flaws. A few are: unsatisfactory products, inefficient production, bad externalities, spoliation, exploitation, unfair tactics, wasteful advertising, undue profits or losses, inadequate research, undesirable discrimination, misallocation of risk, misinformation, and inefficient rules of trading. He then discusses each flaw in detail.

There appears to be some disparity between his definitions and his principles of defining. The ambiguities that remain make it difficult to concretely apply the list as operational criteria. There is some value to the list though. It provides attributes to recognize when a marketing system is being investigated. It provides a set of subjective criteria to use in evaluating the efficiency of the marketing system.

Preston and Collins

The second approach to efficiency of marketing systems is from Preston and Collins (21). It is derived from the results of a simulation study. They state that a principal criterion for appraising the efficiency of marketing activities appears to be the minimizing of measured costs per unit of marketing work over calendar time periods. And they state that the cost standard has been the primary focus of major empirical studies of marketing activity on an economy-wide basis. However, critics of the cost standard stress the importance of the qualitative dimension, the scope for variety and adaptation in the system, and the standard of living delivered, as being the ultimate appraisal criteria.

Preston and Collins suggest extending the criteria for analyzing market efficiency beyond the cost standard but stopping short of the qualitative dimension. They argue there are too many cost dimensions. These include incurred versus opportunity costs, the timing and incidence of expenditures, and the special market costs associated with communication and risk reduction. Thus, any attempt to develop a single composite cost figure is subject to overwhelming conceptual and statistical limitations.

Preston and Collins propose the following criteria for evaluating the efficiency of marketing systems: 1) viability-stability, 2) number of units traded and amount of market effort, 3) revenues of market participants, and 4) realization of potential transactions. They discuss these criteria in some detail, but presented here is a brief summary of each.

Viability is the continued existence of a market. Stability refers to a market situation when cost changes are readily reflected in price changes, demand changes reflected in volume changes, and random instability not associated with fundamental readjustments is at a minimum.

Number of units traded and amount of market effort uses the engineering approach to estimate output/input efficiency measures. Number of units traded would be an output, and amount of market effort, like communication activity, would be an input.

The total net revenues of all market participants is another criterion. Comparison of this criterion with gross measures of trading volume and price levels helps determine trade-offs in the choice of market organization.

In a centralized market all potential transactions are realized by those willing to buy and sell at the market price. In a decentralized market all potential transactions may not occur due to absence of full communication and information. One indicator of market inefficiency is the number of potential transactions not realized, and why.

Preston and Collins present an application of their criteria derived from simulation results. They conclude that a single criteria or indicator of efficiency is unacceptable, and the appraising of changes in marketing systems is more complicated than supposed.

Bressler and King

Bressler and King (4) present a broader view of the efficiency of marketing systems. The conceptual basis relies heavily on productive efficiency. They state,

> "...the creation of marketing services does not differ from other productive processes which, given the efficient operation of the

> pricing mechanism, bring about the economical allocation of resources. The direct objective of the marketing system, therefore, can be described as providing for and participating in price formation with the understanding that the pricing system has as its prime function the guiding of the flow of resources into production (including marketing) and of goods and services into consumption. It will be convenient to consider separately the productive efficiency aspect and the pricing efficiency aspect of marketing systems."

It is apparent the marketing services include transportation, storage, and processing, and these services may occur in the marketing system as "productive processes". The productive efficiency aspect applies to these services. The pricing system determines which of these services receive resources along with the allocation of goods and services into consumption.

Productive efficiency in the creation of marketing services includes: 1) the extent firms utilize capacity, or the "load" factor--the amount of unutilized capacity, and 2) the extent firms are organized to take full advantage of economics of scale--the "scale" factor. This approach to efficiency in marketing allows one to determine optimum number, size, and location of marketing (processing) firms with the inclusion of assembly and processing costs. The comparison of this optimum with the existing marketing organization provides for: 1) an appraisal of existing scale and load efficiency, 2) planning for the future, and 3) an estimate of cost savings possible.

Pricing efficiency studies attempt to explain what happens to prices in a marketing system under various circumstances. These studies contrast actual prices with those generated by some type of "efficiency" model, usually related to or identical with competitive models. These models are based largely on the theory of the perfect market in space, form, and time. It is expected that a perfect market will result in prices that are related through space by transportation costs, through form by processing costs, and through time by storage costs. Although a model of a perfect market, or an efficiency model are abstractions of reality it is hoped they can identify distortions in pricing performance.

The concept of "perfect" markets remains to be defined according to Bressler and King. The essential conditions of a perfect market are: 1) perfect knowledge by all buyers and sellers, 2) each buyer and seller acts in an economically "rational" way (maximize profits), disregarding any influence of his actions on price, and 3) free entry in all directions. These conditions are less restrictive than those of perfect competition: 1) perfect knowledge of all economic agents, 2) each economic agent is so small relative to the market that it can exert no perceptible influence on price, 3) free mobility of all resources, including free and easy entry and exit of business firms into and out of an industry, and 4) the product is homogeneous (12).

Marketing Utility Dimensions of Price

There are three basic marketing utility dimensions of price. They are space, form, and time. They represent the marketing utilities of transportation, processing, and storage, respectively. The perfect market models, efficiency models, transportation and transshipment models, etc., are designed to include at least one of these utilities. The purpose of this section is to show the economic basis of the marketing utilities and how they affect the trade of commodities. This approach in this section is oriented heavily toward point-trading type of models. Much of this material is from Bressler and King (4).

Transportation utility

The economic basis of the transportation (sometimes called spatial) utility representing the space dimension of price will be given first. Figure 1 shows markets in Region 1 and Region 2. In Region 1 the vertical distance OB = T_{12} is the unit transport cost from Region 1 to 2. BH (single market equilibrium price in Region 1) + OB = OH $<$ OJ (single market equilibrium price in Region 2); thus interregional trade will occur from Region 1 to 2 given adequate communication. This interregional trade has the effect of combining the demand and supply relationships into a single market shown in the third section of Figure 1. The final prices for the two regions are determined by the combined equilibrium price OF. The price in Region 1 is BC, and the price in Region 2 is OA = OB (transport cost) + BC. The volume traded is represented by the quantity E_{12}. It is the amount received in Region 2 and shipped by Region 1.

In general, given n regions, interregional trade will occur only if the prices in each market differ by more than transport costs, and there is communication. This analysis provides the economic basis for the transportation and transshipment models with the objective of minimizing total transportation cost. The primal solution to such models gives the volume of interregional trade. The dual solution gives a set of interregional price differences that are less than or equal to transport costs. That is, the set of equilibrium regional prices with interregional trade that

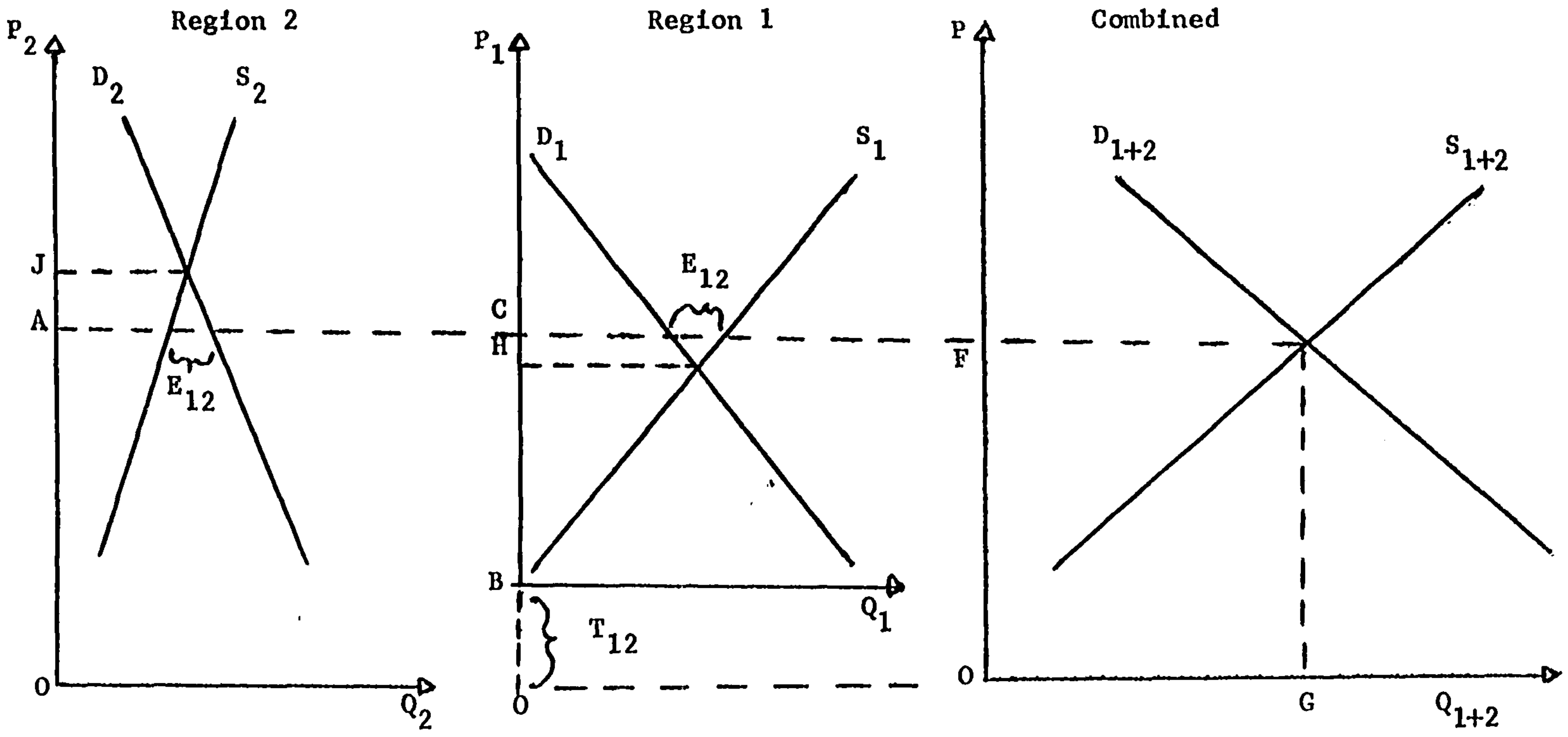

Figure 1. The effects of transport costs T_{12} on price and trade

minimizes total transportation cost.

Processing utility

The economic basis of the processing utility representing the form dimension of price is similar to the basis for spatial dimension of price. As shown in the previous analysis a single market can extend over a large geographic area with a market-wide structure of prices interrelated through transport costs. In a similar way, a market can extend through alternative product forms with a consistent structure of prices interrelated through processing costs.

For example, let a finished product be produced from some raw material, and this process occurs at one geographic location. Assume it is economical to produce the finished product. Also, assume there is a perfect market, as previously defined, with competition. Let,

n = units of finished product/unit of raw material

c = processing cost/unit of finished product

p = price of the finished product

R = price of the raw material

Then the following equality will be true in a perfect market.

1 $R = n\,(p-c)$

The competition in the perfect market will cause the price of the finished product p and of the raw material R to stay in balance so the net value of the finished product less processing cost will equal the price of the raw material. If p is lower than equation 1 specifies, then processors will incur losses and the product will not be produced. If p is higher than equation 1 specifies, then abnormal profits will attract competition until equilibrium is restored.

The equilibrium relationships for a number of finished products m from a given raw material s are:

2 $R_s = n_1(p_1-c_1)$

$R_s = n_2(p_2-c_2)$

......

$R_s = n_m(p_m-c_m)$

In equilibrium, all net values will equal the price of the raw material R_s, thus:

3 $n_1(p_1-c_1) = n_2(p_2-c_2) = \cdot \cdot \cdot = n_m(p_m-c_m)$.

The allocation of raw material into a certain finished product can be seen by the following argument. If the net value of the raw material in finished product 1 is higher than in any other product, then the material goes to the factor market of product 1. If the net value of the raw material is lower, then the material goes to the factor market of some other finished product. If the net value of the raw material is equal for two finished products, then the material falls on an "indifference boundary" between the two factor markets. For an example of the form dimension of market price, see Bressler and King (4), pages 164-165.

Storage utility

The economic basis of the storage utility representing time dimension of price is exactly the same as for transportation utility. Production and consumption may be separated in time similar to the separation of markets in space. The creation of time utility to bridge the time lag between production and consumption is a productive activity, storage, requiring a cost in terms of resources.

The illustration of temporal price relationships and commodity allocation is accomplished by using Figure 2. Assume the commodity is produced in period 1, the harvest period, and can be consumed in either period 1 or 2. No production occurs in period 2. Assume the supply is perfectly inelastic, although this is not necessary. When there is no storage from period 1 to period 2, the intersection of D_1 and S show the quantity OJ is available for consumption in period 1 at price P_o.

The lines ES_1 and ES_2 represent excess supply curves; the quantity of supply that exceeds demand for different price levels. Since there is no supply in period 2 then ES_2 equals $-D_2$. ES_1 is the quantity available at different price levels after demand has been satisfied in period 1. Thus, it is available to satisfy demand in period 2.

In the hypothetical case when storage is available from period 1 to 2 at no cost, then equilibrium is at the intersection of curves ES_1 and ES_2. The equilibrium price P_n, up from P_o in period 1 only, is the same for both periods. The equilibrium quantities consumed are OF for period 1 and OI' for period 2, and OF plus OI' (or OI) equals OJ the total supply. Note, the consumption in period 1 is less than in period 2.

The equilibrium price with no storage cost is P_n for both periods; where ES_1 and ES_2 intersect. The inclusion of storage cost will cause the prices in the two periods to differ. The curve ES_2 - ES_1 measures the vertical price differences between ES_2 and ES_1. SC measures the unit storage cost from period 1 to 2. The intersection of SC with curve ES_2 - ES_1 projected upward to ES_1 and ES_2 gives the set of equilibrium prices for the

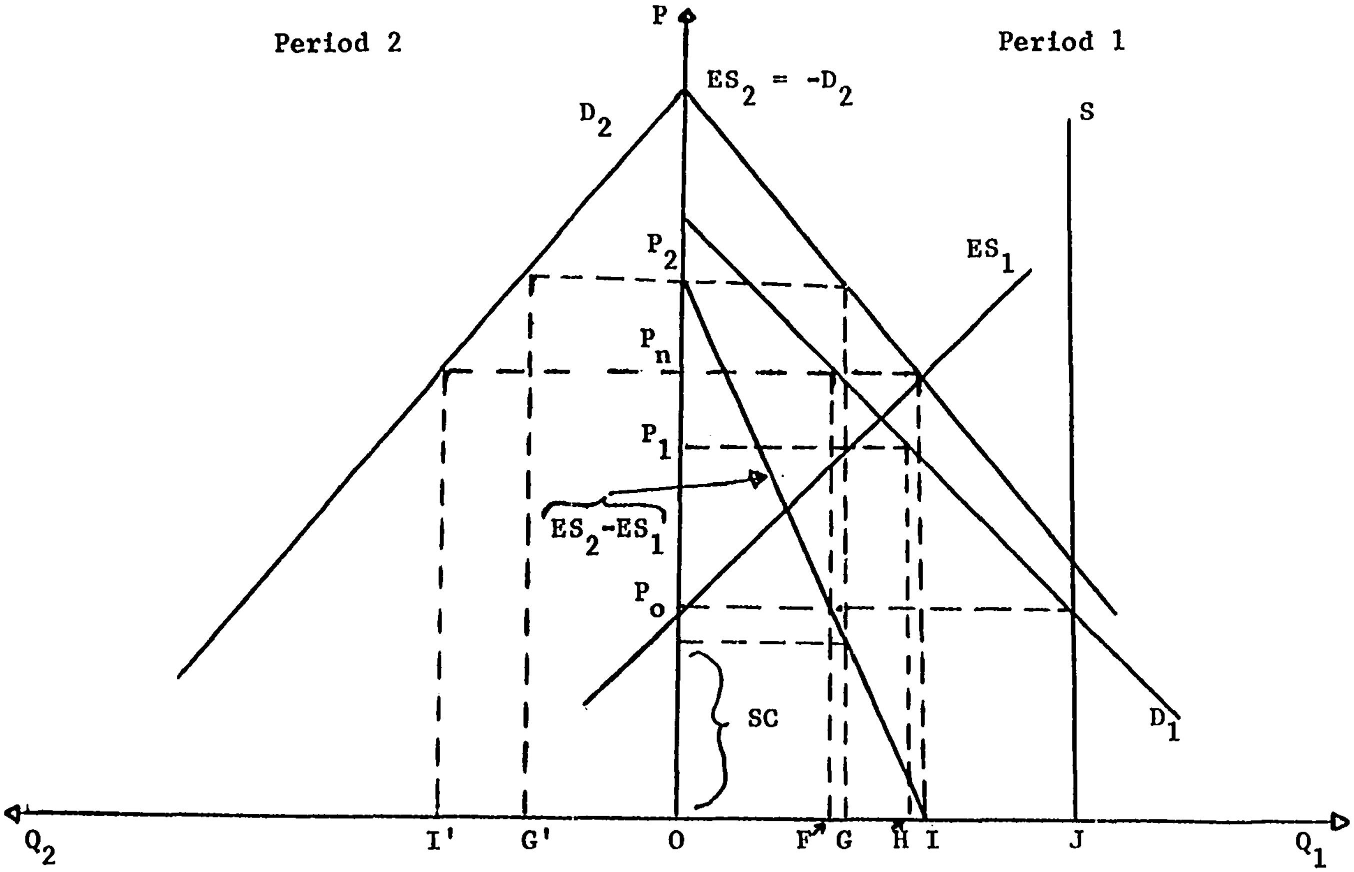

Figure 2. Two-period equilibrium with storage costs included

two periods, and they differ by exactly storage cost. The price in period 1 is P_1 down from P_n but still up from P_o. The quantity available for consumption in period 1 is OH; from P_1 projected down off D_1. This is an amount FH greater than OF with no storage cost. The price in period 2 is P_2 up from P_n. The quantity available for consumption is now OG', an amount I'G less than OI' with no storage cost. Note, in this case, the consumption in period 1 greater than in period 2. This demonstrates how the market mechanism arrives at a temporal price relationship and commodity allocation when the storage utility and its associated costs are considered. Bressler and King (4) on pages 209-211 give an example of how to analyze the temporal dimension of market price by using a modification of the transportation model.

A final note should be made about the unit cost functions used in the three analyses. It is assumed that these functions are known or can be estimated relatively well. Variances in the cost functions do occur. Factors such as various transportation modes and length of haul affect transport costs. Utilization of plant capacity affects processing costs. And, storage may enhance or deteriorate commodity values causing the costs to vary. Thus, the estimation of the cost functions can be difficult and is an integral part of marketing studies.

Transportation Cost Minimization

One question that needs to be asked is: Why, in studies using transportation or transshipment models, is the objective to minimize transportation costs? Why not use the foundation of economic theory of the firm and seek to maximize profit? One answer to these questions is that interregional competition usually includes multiple firms and though each seeks to maximize profit individually, the greatest benefit to society occurs when there are not excessive costs. In a perfectly competitive market the long-run equilibrium condition for each firm is when price equals the minimum long-run average cost. This causes every firm to operate at its optimum size. If they are not, then resources are wasted causing an excessive cost to society.

More specifically, interregional competition keeps interregional prices in line so the differences are equal to costs of transport. Ideally, the costs are minimized through competition. If one of the firms has higher costs than necessary, the competition not being effective enough, then there is an extra cost to society. First, the inefficiency of the operation costs in terms of resources. Secondly, it costs society through higher prices.

The estimation of unit cost is another major question. One approach is to do engineering cost studies using assumptions reflecting the best economies of scale and capacity utilization, along with other factors. Another approach is to fit the lower envelope curve or the average curve to the per unit operating costs of the firms in the industry, then use the minimum point on the curve. At least this captures the least cost available in the industry, but not necessarily for society since the industry may be an imperfect competitor.

Samuelson (23) presents a more rigorous analysis in answering the above questions. He relates the maximizing of "net social pay-off" to minimizing total transportation costs and to solving the transportation problem using linear programming. Net social pay-off = social pay-off in region 1 + social pay-off in region 2 - transport cost from region 1 to 2. The social pay-off of any region is defined as the algebraic area under its excess demand curve; excess demand = demand - supply for various price levels. He shows how to maximize the net social pay-off in a two-region case and then generalizes to a n-region case. The n-region case is set up as a transportation model. He then shows that the maximizing of net social pay-off is impossible unless an optimal solution to the transportation model is obtained, and it is optimal when total transportation cost is minimized. The finding of the above optimal solution is precisely the Koopmans-Hitchcock (transportation) problem in linear programming.

Extensions

One of the major real world factors affecting all types of activity, including economic, is time. As has been said by many, "The only thing constant is change." Economic activity is always changing with time; it is dynamic. It is not static except for an instant in time. One important consideration in almost any economic activity is when should the activity occur? Should it take place now, or be delayed until the future?

This question leads to another factor that characterizes most of economic activity. What about the impact of uncertainty on this activity? Uncertainty includes the effect of incomplete and imperfect information. For example, perfect knowledge about future sales is not available. The levels of regional demand, supply, or prices may not be available for the immediate future. The purpose of this section is to analyze the impact time and uncertainty have on transshipment model solutions, and to suggest other methods that incorporate these elements into the analysis.

Time and uncertainty

It is common in studies of interregional trade to compare the solution of a transshipment model with the corresponding real world information. And in many cases the two are different. Some authors claim this disparity is due to the inefficiency of the real world. And some go so far as to suggest, either directly or subtly, the real world should adjust itself in direction and magnitude until it coincides with the model solution. Looking at both sides of the analysis, the question to ask is: Is the disparity due to inefficiency in the real world, or the inability of the model to reflect an efficient system? The efficient system may exist in the real world, or it may not exist. In either case the solution and real world are different.

Typically, these models are based on annual data and solved for an annual solution versus say a multiperiod quarterly solution. Intra-year variability of prices, costs, supplies, demand and other factors, say weather, can cause the real world annual flows to be very different from a model solution. In addition, the variability of these factors causes the estimation of annual parameters, say representing costs, demands or supplies, to have some uncertainty associated with them. The model may not capture the timeliness and uncertainty of these factors since they are constantly changing. The annual model structure is too rigid to allow a wide degree of variation, except through parametric programming. As a result, the annual model solution and real world flows differ for perfectly good reasons, and neither one can be judged as the efficient system.

Model purpose

The intention of the above discussion is not to put the whole of transshipment models and the like asunder, but to discuss how real world systems can be evaluated. Two major components of the purpose behind a model need consideration. First, the time horizon for planning or policy considerations is important. Second, model design is important.

When the time horizon for planning is relatively long term, say three to ten years, then the use of an annual base model to estimate inter-year flows, under various assumptions, is perfectly valid. For example, capital investment to increase port capacity has multiple-year effects. Parameters can be varied to reflect different levels of investment and thus different capacity levels. Similarly, supply and demand can be varied on an inter-year basis. The annual base model should be fairly recent to the time horizon. And, the base model should explicitly measure the factors being analyzed. If increased port capacity is being analyzed for the future, then the base model should explicitly include and measure the port capacity component.

This does not preclude an annual model being used for a short term horizon. For example, an estimate of the flows for the future year 1974 can provide useful information. The annual base model could be for the past year 1972. Parameters are changed to reflect estimated 1974 levels. The structural components of the marketing system, like port capacity or transportation capacity, may either change or remain the same. The solution is a conditional estimate of the annual flows for the year 1974. Its usefulness depends on the stability of real world factors reflected by the model parameters.

Implicit in this discussion is the approach that an annual base model is developed and then used to estimate some future real world system behavior. Specifically, the annual base model is designed to historically reflect the real world. This leads to the second major consideration; model design. The designing of a model should include those real world components which significantly constrain the system. For example, port and transportation capacities constrain the grain marketing system. Without this type of constraint in the model, the model solution and real world will differ, and its usefulness in estimating the future is reduced. It appears model design can go in two directions: 1) a model designed to reflect a perfect market, or 2) a model designed to reflect reality. In the first, the model does not include those components reflecting imperfections in the market, say incomplete mobility of resources. It is an "efficiency" model, and its purpose is to provide a norm to compare with the real world. The second type of model includes constraints reflecting market imperfections, and its purpose is to replicate the real world.

The two types of model design approaches are significantly different. Yet, the results of each are useful. Starting with the real world model and relaxing constraints the impact of imperfections can be seen. Or, one can start with an efficiency model and add constraints. Of particular interest in the results would be the cost (to society) of the imperfections, and whether or not it is worth the investment to eliminate them.

Verification

The purpose here is to briefly mention the importance of verification. It is important in the development of a real world type of model. Verification of the base model lends credibility to the methodology and assumptions used. And, it adds credibility to the future projections. The failure to verify a model can result in policy recommendations that are misleading or hard to achieve.

There are a number of statistical techniques available for comparing model solutions with real world data. Some are: 1) regression, 2) correlation, 3) coefficient of determination, 4) hypothesis testing, 5) Theil's inequality coefficient, 6) Chi-square, and 7) Kolmogorov-Smirnov. The application of these techniques increases the model builders' information, but ultimately the user must decide whether or not to accept or reject it.

Additional material and references on verification are in Conley (7).

Simulation

The previous discussion of time and uncertainty and their impact on annual type models requires some additional comments. First, the uncertainty factor in model input can be represented by chance-constrained or stochastic programming. The cost, supply, demand, etc., parameters can be assumed to come from a probability density function. The solution to this type of problem has additional qualifying statements about the confidence intervals of the parameters. Second, the dynamic factor of model input can be represented by time-staged, or dynamic programming.

If one does not constrain himself to mathematical programming type models, then another feasible methodology for marketing research is systems simulation. Systems simulation is becoming more useful with the development of advanced computer languages based on elements of systems analysis. Systems simulation is basically divided into two types; discrete and continuous. Also, some simulations can be done on analog computers and other simulations on digital computers. The purpose here is to briefly discuss three system simulation approaches all using computers.

The first approach is a discrete simulation method based on the IBM General Purpose Simulation System (GPSS) language (16). The basic elements in GPSS are transactions which are created and move from one operational block to another. A few operations represented by the blocks are conditional transfers, delays, queues, seizing and releasing of facilities, and the termination of transactions. GPSS has the capability to easily handle both the time and uncertainty dimensions of models. However, it does not optimize like a linear programming problem, although system parameters can be varied to try to find an optimum. GPSS is well suited to handle queueing-inventory or scheduling problems.

The second approach to system simulation is a continuous method based on Forrester's Industrial Dynamics (13). The basic elements are the flows of orders, money, people, information, capital equipment and material. Operational blocks include levels (stocks in economics), decision functions (rate equations), information take-offs, auxiliary variables to connect information flows, delays and constants. These blocks are interconnected by the flows, and information feedback loops may result. The simple economic model showing the multiplier effect is an information feedback system. Industrial dynamics easily handles the dynamics of a system and can be described as a recursively dynamic system. Uncertainty is generated with a noise function, or from some given density function. The major purpose of industrial dynamics is system design; to evaluate the impact of existing or additional elements on a system, particularly the dynamic impact on the system. Information may be distorted, decision functions changed, or some operations added or deleted. Industrial dynamics is not an optimization technique, but describes system behavior and indicates what can be done to improve the system.

The third approach to system simulation of grain marketing is futuristic, and involves the use of an analog computer. The flows of grain through a marketing network would be analogous to electricity flowing through various circuits. The factors controlling the grain flows could be represented by potentiometers, and capacitors would serve as storage. The supplies are determined by various inputs of voltage, and demands by negative capacitor charges. If such a system were developed, I believe it's possible today, then a "hands-on" capability to analyzing a marketing system is possible. Many assumptions could be tried in a short time period and the results immediately seen. It would truly be a space age approach to marketing research.

METHODOLOGY

The purpose of this chapter is to describe the transshipment models developed for this study. Included are the assumptions of a transshipment model, the mathematical formulation, and the regional delineation. Also given are procedures to estimate surplus and deficit requirements, as well as the transport costs by various modes.

Description of the Various Models

There are three transshipment models developed in this study; one for feed grains, one for wheat, and one for soybeans. A tree diagram showing the general routing patterns for the grains is given in Figure 3. The flow from top to bottom indicates the shipments from surplus regions to deficit regions where the foreign deficit regions are supplied through intermediate ports. There are 93 surplus regions for feed grains, 90 for wheat, and 92 for soybeans. There are 21 domestic deficit regions for feed grains, 24 for wheat, and 22 for soybeans. There are 9 port of export regions and 44 foreign deficit regions for the three types of grain. The surplus regions produce, consume, and ship out grain but do not receive any grain. The domestic deficit regions ship grain in, produce, and consume, but they do not ship any out. The ports ship grain in and out but neither produce nor consume. The foreign deficit regions receive grain from the ports and consume it. Foreign region demand is assumed equal to United States' exports.

Assumptions of the model

The transshipment model is a linear programming model with some

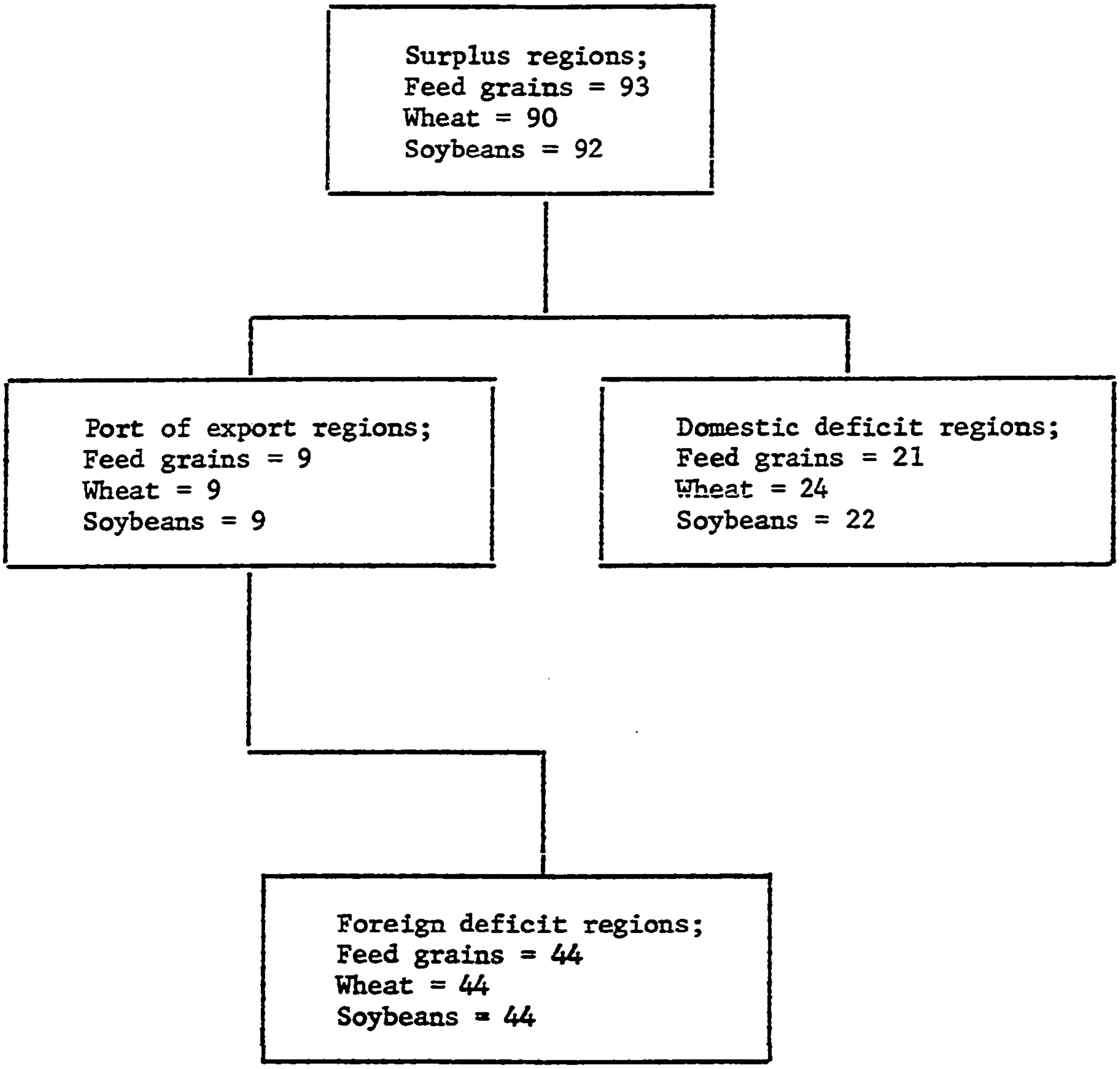

Figure 3. General flow of grain from surplus regions to deficit regions

additional assumptions. Those necessary for this application of the transshipment model are:

1. The product shipped is homogeneous. That is, the supply of grain at any region or origin serves equally well to satisfy the demands at any destination or deficit region.
2. The net supply of grain available at the various origins and the net demand at the various destinations are known, and total net demand is equal to total net supply.
3. Transshipment through intermediate ports of export is permitted. The amount shipped in minus the amount shipped out for each port is equal to zero.
4. The cost per ton of transporting the grain from origins to destinations is known and is independent of the number of units to be transported.
5. The objective is to minimize total cost of transportation.
6. Flows of grain from origins to destinations can occur only at non-negative levels.
7. An entire region is represented by a point in that region. There are no additional costs in collecting surplus grain at a point of origin, or in distributing grain from a point of destination.

Mathematical formulation of the model

The parameters and variables for the three transshipment models are described in general as follows:

S_i	known net surplus quantity in domestic region i.
D_j	known net deficit quantity in domestic region j.
E_f	known exports from United States to foreign region f.
K_p^c	known throughput capacity at port p by type of grain c.
B_{ijt}	known cost/ton of shipping from region i to region j by transport mode t.
G_{ipt}	known cost/ton of shipping from region i to port p by mode t.
H_{pfm}	known cost/ton of marine shipping from port p to foreign region f by mode m, where m refers to ships of different size and flag.
X_{ijt}	quantity shipped from region i to region j by mode t (to be determined).
Y_{ipt}	quantity shipped from region i to port p by mode t (to be determined).
Z_{pfm}	quantity shipped from port p to foreign region f by mode m (to be determined).

The objective function is as follows:

Minimize

4 $$TC = \sum_i \sum_j \sum_t B_{ijt} X_{ijt} + \sum_i \sum_p \sum_t G_{ipt} Y_{ipt} + \sum_p \sum_f \sum_m H_{pfm} Z_{pfm}$$

where TC is total transportation cost. The first term on the right of the equality is the total cost of shipping from domestic surplus regions to domestic deficit regions. The second term is the total cost of shipping from domestic surplus regions to ports. The last term is the total cost of shipping from ports to foreign deficit regions.

The objective function is subject to the following constraints:

5 $$\sum_j \sum_t X_{ijt} + \sum_p \sum_t Y_{ipt} = S_i \qquad i = 1, 2, \ldots, I.$$

6 $$\sum_i \sum_t X_{ijt} = D_j \qquad j = 1, 2, \ldots, J.$$

7 $$-\sum_i \sum_t Y_{ipt} + \sum_f \sum_m Z_{pfm} = 0 \qquad p = 1, 2, \ldots, P.$$

8 $$-\sum_p \sum_m Z_{pfm} = -E_f \qquad f = 1, 2, \ldots, F.$$

9 $$\sum_i \sum_t Y_{ipt} \leq K_p^c \qquad p = 1, 2, \ldots, P.$$

10 All the X_{ijt}, Y_{ipt}, and Z_{pfm} are non-negative.

Chicago becomes the base point for the price levels. That is, all prices are relative to the base point Chicago.

The levels of S_i, D_j, and E_f are set so that:

11 $$\sum_i S_i - \sum_j D_j - \sum_f E_f = 0$$

Region delineation

United States regions and basing points The construction of the transshipment model requires specification of region sizes and ports. Figure 4 shows how the North Central Marketing area is divided into crop-reporting districts. The number inside the circle indicates the district number, and the point indicates the basing point (city) within that district. The points outside the North Central Marketing Area are representative of the basing points in other United States

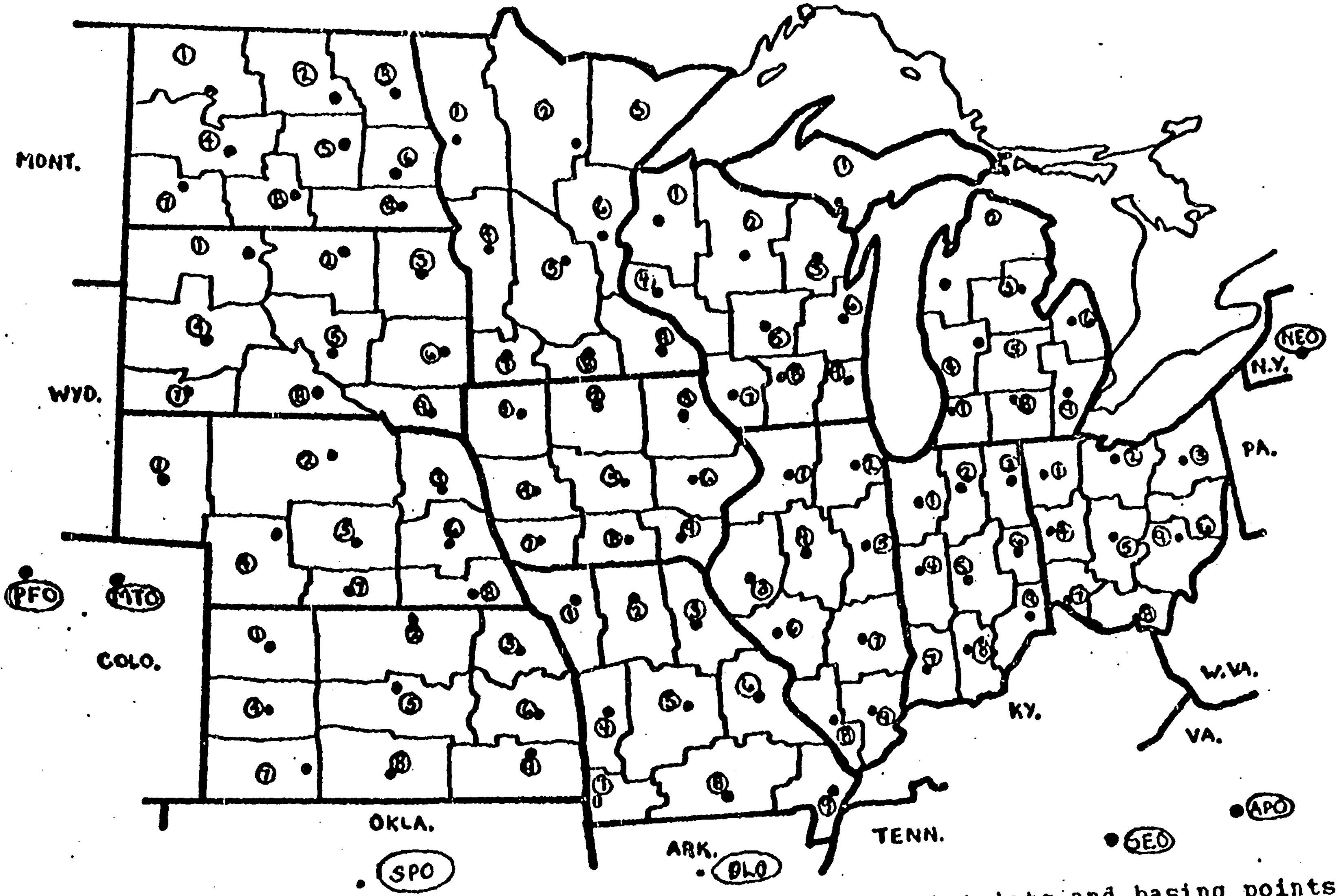

Figure 4. North Central Marketing Area, crop-reporting districts and basing points

regions. The district numbers and basing points are given by commodities in Appendix A. Figure 5 shows the location and size of the regions outside the North Central Marketing Area.

United States ports of export The United States sector of the model has been constructed with crop-reporting districts and regions of states which included a basing point within each one. The ports of exports are also specified on the criterion that they represent a certain export region of the United States. The basing port region of export and the headquarter ports represented in the port region are given in Table 3.

Foreign regions and ports of import The United States exported grains to 145 countries during 1972-73, of which 44 countries were major importers in terms of the volume of grains under study. A port in each of these 44 countries is chosen as a shipment point. Exports to the remaining 101 countries are added to the exports of the selected 44 countries on the basis of geographical location and ocean proximity existing between the 44 shipment points and the other 101 countries. Thus these 44 regions cover all the exports to the 145 countries. The 44 regions are shown in Figure 6.

In selecting the shipment points of the 44 foreign regions, the following criteria were used: 1) the size of the port, 2) draught, 3) facilities available, 4) and above all, the purpose for which the ports are primarily used and employed. The port of import and the countries included in each of the 44 foreign regions are given by commodity in Appendix B.

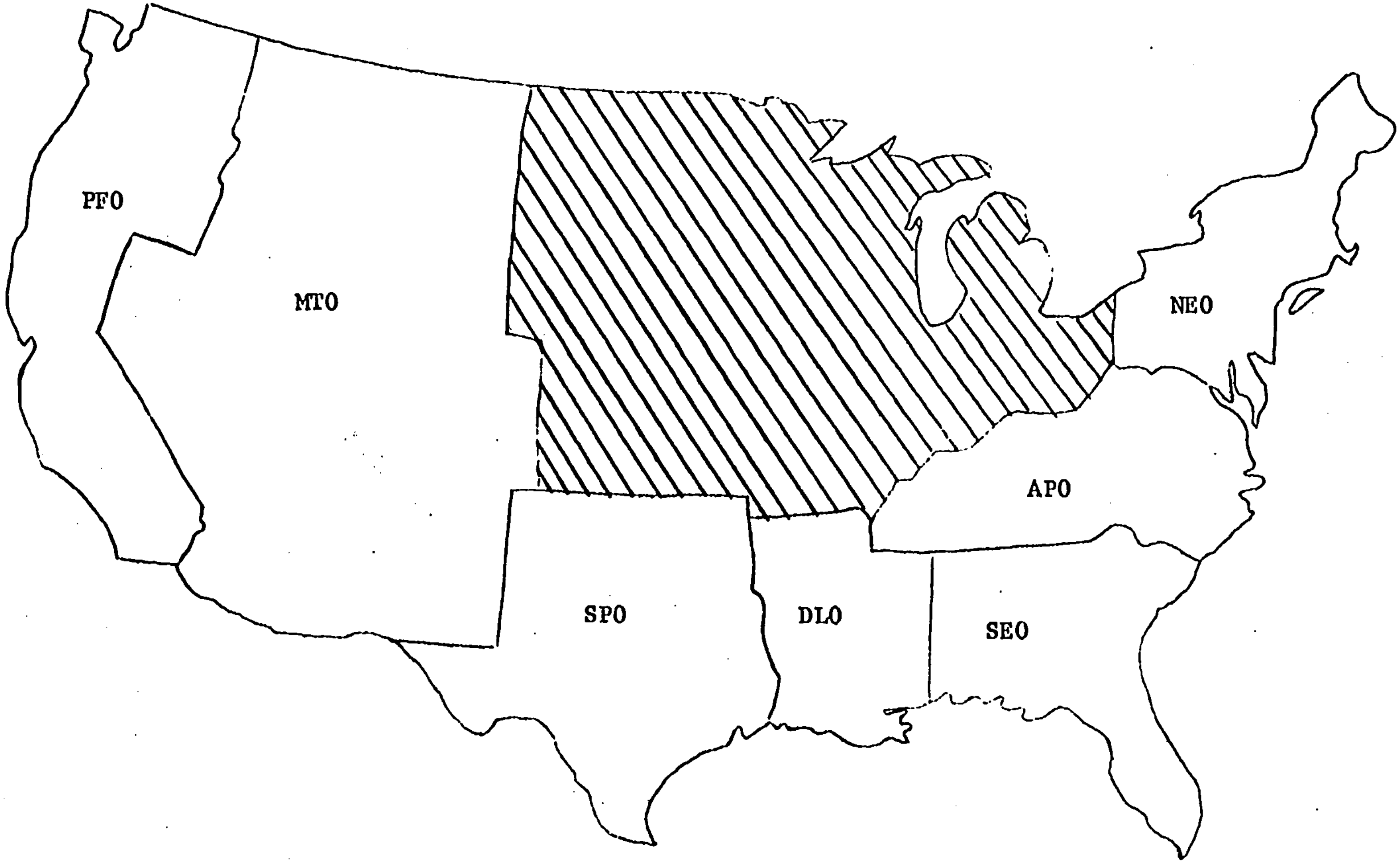

Figure 5. Regions outside the NCMA

Figure 6. Region sizes in the foreign sector

Table 3. United States ports of export and headquarter ports in each port region[a]

Port region	Headquarter ports included in the region	Computer code
Duluth	Pembina, N. D. Minneapolis, Minn. Duluth, Minn.	DUO
Chicago	Milwaukee, Wis. Chicago, Ill.	CHO
Toledo	Detroit, Mich. Cleveland, Ohio	TOO
Philadelphia	Portland, Me. St. Albans, Vt. Boston, Mass Providence, R. I. Bridgeport, Conn. Ogdensburg, N. Y. Buffalo, N. Y. New York City, N. Y. Philadelphia, Penn. Baltimore, Md. Norfolk, Va.	PHO
Charleston	Wilmington, N. C. Charleston, S. C. Savannah, Ga. Miami, Fla.	CSO
New Orleans	Tampa, Fla. Mobile, Ala. New Orleans, La. St. Louis, Mo.	NOO
Galveston	Port Arthur, Tex. Galveston, Tex. Laredo, Tex. El Paso, Tex. Houston, Tex.	GVO

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[a] Source: See reference (37).

Table 3. (Continued)

Port region	Headquarter ports included in the region	Computer code
Los Angeles	San Diego, Calif. Nogales, Ariz. Los Angeles, Calif. San Francisco, Calif.	LAO
Seattle	Portland, Oreg. Seattle, Wash. Juneau, Alaska Honolulu, Hawaii	SLO

Domestic Surpluses and Deficits

Data requirements for the models include net surplus quantities of grain available at the origin, and net deficit quantities required at the destinations. A net surplus for a region results when the supply level exceeds the demand level, and vice versa for a deficit. The procedure for estimating the supply and demand levels, and subsequently surpluses and deficits, is quite intricate. All estimates are for an annual basis and cover the appropriate crop year depending on the type of grain. The crop year for feed grains is October 1 to September 30; for wheat is June 1 to May 31; and for soybeans is September 1 to August 31. Feed grains include corn, oats, barley, and grain sorghum. Wheat includes all wheat, and rye. Soybeans include soybeans.

The components of supply are the production and beginning stock (inventory) levels minus the ending stock levels. The components of demand are seed, feed, and industrial use plus exports. Thus, the equation to estimate a surplus or deficit for a district or region (groups of states not in the NCMA) is:

12 Net balance = production + beginning stocks - ending
stocks - seed use - feed use - industrial use

The total net balance, net balance summed over regions and districts, is expected to cover export demand. Later on, a procedure is given showing how total net balance is adjusted to exactly cover exports.

Supply estimates

Production and stocks data are collected for each crop reporting district and region from the twelve north central states' agricultural statistical services, and the USDA. The production information is available by district and state while stocks information is only available by state. Stocks are divided into two parts; on-farm and off-farm. On-farm stocks are allocated to districts in proportion to production. Off-farm stocks are allocated equally among districts. Regions need only use total stocks, both on-farm and off-farm, by states for estimates.

Demand estimates

The estimates of demand levels for each district and region requires estimates of seed, feed, and industrial use. Estimation of the latter two is somewhat complex.

Seed use

Seed use is approximated as being proportional to production uniformly for all districts and regions. This assumes production is uniformly proportional to plantings.

Feed grain demand

Feed grain demand is comprised of four parts. They are 1) livestock feed, 2) industrial use, 3) seed use, and 4) exports. Seed use has been covered, export demand is in the "Foreign demand" section to be discussed later.

Livestock feed

Feed use of feed grains is based on grain-consuming animal units estimated for each district and region. Livestock numbers, including cattle on feed, are collected from the twelve north central states' agricultural statistical services, and USDA. The livestock numbers are then converted to grain-consuming animal units (29). The amount each unit consumes per year is estimated to be 1.33 tons (22).

Industrial use These uses are not a large percentage of the total feed grain demanded, unlike livestock feed and exports. But they are included since they represent important components of feed grain demand. The industrial uses of feed grains include 1) wet processing, 2) dry-corn milling, 3) cereal manufacture, 4) malting, and 5) brewing and distilling. It was necessary to find the location of these activities and to estimate their capacity. The state location and capacities were available from some current research being done by Fedeler, et al. (11). The district location and capacities were obtained from a corn-milling industry directory (20) and Bureau of Census data (34). The state and district capacities were based on plant employment levels in a region.

Wheat demand Wheat demand consists of 1) processed for food, 2) seed, 3) livestock feed, 4) industrial use, and 5) exports.

Processed for food Wheat processed for food demand is basically flour milling demand. The demand for wheat is a derived demand associated with demands for the various types of flour. The flour milling location and capacities by state were available from Fedeler, et al. (11). The district location and capacities were obtained from an industry directory (20).

Livestock feed Livestock feed demand for wheat is assumed to be distributed as wheat fed on farms where produced. The wheat fed on farms is available by state from USDA (33). In the north central states, the ratio of district production to state production is equated to district feed use over state feed use. This determines the wheat feed use in a district.

Industrial use Industrial use is negligible and considered a part of livestock feed. This is in line with the USDA practice in situation reports.

Soybean demand Soybean demand is comprised of 1) industrial use, 2) seed, and 3) export. The industrial use of soybeans is for crushing. The soybean crushing capacity was obtained from Fedeler, et al. (11). Fedeler obtained the crushing capacity by state and city through private communication or census data on employment levels, and it is for the year 1972.

Allocation procedure

Recall that it is necessary to meet export demand with the total net U.S. balance. That is, once all domestic deficits have been satisfied, the remaining surplus needs to cover export demand. The following procedure is used to assure export demand is adequately met.

Equation 13 gives the balance (surplus or deficit) in the n^{th} region (including districts).

$$13 \qquad BAL_n = PD_n + BS_n - ES_n - SU_n - FU_n - IU_n \qquad n = 1, 2, \ldots, I + J.$$

where:

PD_n is production in the n^{th} region.

BS_n is beginning stocks in the n^{th} region.

ES_n is ending stocks in the n^{th} region.

SU_n is seed use in the n^{th} region.

FU_n is feed use in the n^{th} region.

IU_n is industrial use in the n^{th} region.

Each of these components are summed over the n regions (including districts). Then, for each component, the relative proportion the n^{th} region contributes to the total is estimated. For example, the relative proportion the n^{th} region contributes to total production is:

14 $$RPD_n = PD_n / \sum_n PD_n \qquad n = 1, 2, \ldots, I + J.$$

Next, the national estimates of production, beginning and ending stocks, seed use, feed use, and industrial use were collected for the three grains from situation reports (27, 28, 32). Total balance at the national level, that left to satisfy export demand, is:

15 $$TBAL = USPD + USBS - USES - USSU - USFU - USIU$$

where the following are defined at the national level.

TBAL is total balance.

USPD is U.S. production.

USBS is U.S. beginning stocks.

USES is U.S. ending stocks.

USSU is U.S. seed use.

USFU is U.S. feed use.

USIU is U.S. industrial use.

The levels of U.S. exports to the various foreign countries are summed over the countries to give U.S. exports.

16 $$USEX = \sum_f EX_f \qquad f = 1, 2, \ldots, 44.$$

The new level of U.S. production required to meet all requirements is:

17 $NUSPD = USPD + (USEX - TBAL)$.

If there is a difference between total exports and total balance, then the current level of production is adjusted to absorb the difference. Since the purpose of this study is to identify grain movements under various levels of foreign demand, the USEX figure will change. Note, only production is adjusted since domestic disappearance (TBAL - USPD) is left unchanged. This procedure assures equality between total production and total utilization plus exports.

The new level of U.S. production, NUSPD, is then allocated to the n regions based on the RPD_n figure. This gives a new PD_n for equation 13. The other elements of equation 13 are estimated by multiplying the relative proportion the n^{th} region contributes to the total component times the national figure for the component. For example,

18 $FU_n = RFU_n\ (USFU)$ $n = 1, 2, \ldots, I + J$.

Equation 13 is then recalculated with BAL_n being the new level of surplus or deficit in the n^{th} region. This procedure also assures that the national levels of feed use, industrial use, etc., are completely accounted for.

The surpluses and deficits in the n regions are given in Appendix A for the three grains. A table gives the city basing point of the region, the computer code for the solution tables, and the surplus or deficit level of grain for the region.

Foreign demand

The demand for grains by the foreign sector are the amounts exported from the U.S. to the 145 countries from June, 1972, through May, 1973. The 145 countries are represented by 44 regions which cover all the exports to the 145 countries (35, 36). Appendix B gives the basing point, the countries included in the region, the computer code, and the demand for the three grains. These are the export levels that are varied under the different alternatives considered in this study.

Port capacities

A set of constraints are included in the model which can limit the throughput capacities of the ports. The levels of these capacities are estimated as the inspections for export at the various ports. They are only an approximate estimate since over a given period of time, new capacity throughput levels may be set. The purpose of the constraints are to not allow excessive amounts of grain to flow through a port, and to keep the model in line with the real world. Additionally, the total transport cost when the system is constrained in this manner versus when it is not provides interesting information. Currently, the solutions are derived with port capacities being non-constraining. The purpose of this being to look at grain movements when the system adapts to reflect transport costs and not present rates, and when potential capital investments in port handling facilities may be realized to meet changes in foreign demand for U.S. grains.

Development of Transportation Costs

The total per ton transportation cost between a surplus region and a deficit region is developed in two segments. The first segment is the cost of shipping from U.S. surplus regions to U.S. deficit regions and to ports of export. The second segment is the cost of shipping from the ports of export to the foreign destinations.

Domestic transportation costs

The costs of shipping grain over land from the surplus regions to deficit regions and ports are developed for three modes of transport. They are rail, truck, and truck-barge combinations.

Rail costs The cost of shipping grain by rail was estimated from the latest Interstate Commerce Commission publication (17). Cost functions for the year 1970 are estimated using simple linear regression. The data are the fully allocated costs per hundred-weight for a covered hopper car loaded to 190,000 pounds. The territories considered are the Official and Western. This cost information is for the year 1970. Once the cost functions are estimated they are adjusted to reflect costs for the 1972-73 crop year as closely as possible. The adjustment factor is taken from a railroad industry publication (2). It is the ratio of the 1970 index of charge-out prices and wage rates to the estimated mid-year 1973 index. The mid-year 1973 index was extrapolated from the inter-year change for the previous three years. The adjustment factor is 150/123, or a little over 20 percent increase. The rail cost functions are:

19 Official Territory: $C = (150/123)\ (1.73 + 0.0101 * D_a)$ with $R^2 = 0.9998$

20 Western Territory: $C = (150/123)\ (1.72 + 0.0086 * D_a)$ with $R^2 = 0.9998$

where:

C is cost in dollars per ton.

D_a is air distance.

In the model, rail routes are allowed to exist from all surplus regions to all domestic deficit regions and ports.

Truck costs The estimation of truck costs is difficult since a variety of truck types and hauling distances exist. To resolve the problem a number of existing studies were analyzed (3, 11). They are recent and all use an engineering cost study approach. The total cost of hauling grain by truck ranges from 25.6 cents per mile to 47.2 cents per mile depending on the length of trip and size of truck used. An 850 bushel (23.8 ton) semi-truck making 30 mile trips had costs of 47.2 cents per mile, while a 525 bushel (14.7 ton) truck for trips of 180 miles had costs of 29.7 cents per mile. The Fedeler study (11) estimated total trucking costs to be 33 cents per mile. Based on these studies and the estimates they derived the following truck cost function is used.

21 $C = 0.02 * D_r$

where:

C is cost in dollars per ton.

D_r is rectangular distance.

In the construction of the model truck routes of length greater than 400 miles are not allowed to exist. Based on statements by grain company and trucking industry spokesmen, this is reasonable.

Truck-barge costs The cost of shipping grain by barge is estimated by using actual published barge rates (1). This assumes the cost of transporting grain is equivalent to the published rates. That is, published rates are not superficial and the published rate is the cost to the merchandiser. The competitive nature of the industry is reflected in the wide fluctuation of rates as barge companies bid for business. Rates are low in times of ample capacity, and are high when capacity is scarce. The truck-barge cost is calculated when a surplus region is within 200 trucking miles of a barge port. If there is more than one barge port meeting this criteria, then the truck-barge cost is calculated by adding:

1. the computed trucking cost from the surplus region to the port,
2. the elevating charge; assumed to be $1.00 per ton,
3. and the barge rate.

Then the least cost truck-barge route is selected for inclusion in the program.

Ocean transportation costs

The second segment of the cost derivation is the shipping on the ocean from United States ports of export to the 44 foreign destination ports.[1] Ocean freight rates for grains are extremely variable because

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[1] The derivation of ocean shipping costs is mainly from Davis (9) and Cayemberg (5), with additions by Medappa Chottepanda and the author, both in the Economics Department, Iowa State University, Ames, Iowa 1970.

of the short run relationship between the supply of shipping and the demand for such shipping. The difficulty of obtaining actual rates, along with the variability of the rates, led to the use of marine cost functions to estimate ocean shipping costs.

The use of an engineering cost study is justified since most ships are under long term charter, say 10 years. While year to year rates may fluctuate, the long term charter rates are close to the cost figures including a return on investment. Another factor to consider in using cost figures is the increased ownership of tonnage by grain exporting companies. They are moving more of their own grain in their own ships, and the appropriate figure is cost.

Since the original cost study was done for the years 1966-67, the cost figures were compared to actual rates for 1971. It was considered by a USDA industry economist[1] as a year when rates and costs were very close. The comparison showed the ocean cost figures were within 10 percent of the rates. Thus, no adjustment in costs were made.

There are three main factors that go into the derivation of the marine cost functions. These three factors are:

1. ocean distances and speed of the vessel
2. port days
3. canal days

Ocean distances Ocean distances are derived using the nautical mile (6080 feet) as the unit of measure for the distances

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[1] T. Q. Hutchinson, Industry Economist, Marketing Economics Division, Economic Research Service, United States Department of Agriculture; private communication.

between each of the 9 United States ports and each of the 44 foreign ports. The shortest navigational distances between the United States and foreign ports are considered. The Suez Canal is assumed to be closed, hence ships bound for Eastern Africa and Western Asia have to sail via another route. The distances between United States ports and all foreign ports, except Luanda, are computed based on published references. The distance between the United States ports and Luanda are approximated. The speed of the vessel is assumed to be 14 knots.

Port days   The number of days a ship spends in port has a large effect on the total cost of a voyage. The number of days spent in port is the sum of three parts: 1) loading days, 2) discharge days, 3) idle days. The number of port days is primarily a function of the port facilities available, particularly the number of cranes and their capacity to load and discharge cargos. The dock facilities and the amount of ocean traffic account for the number of idle days the vessels are kept waiting to unload cargo. There is no standard number of days that a particular type of bulk grain vessel spends in a particular port. However, the number of port days with respect to the 9 United States ports and the 44 foreign ports indicates some consistency in the loading, discharge, and idle days required for the various sizes of ship. The number of port days for United States ports are given in Table 4.

The 44 foreign ports are classified into four groups, each representing those ports which have consistency in port accommodation as well as observed data relating to port days. The list of groups and ports are given as follows:

Table 4. Average number of days for loading a certain size of ship[a]

U.S. Port	15,000 DWT	30,000 DWT	80,000 DWT[b]
Duluth	5	x[c]	x
Chicago	5	x	x
Toledo	5	x	x
Philadelphia	5	7	x
Charleston	5	7	x
New Orleans	5	7	x
Galveston	4	7	x
Los Angeles	7	10	15
Seattle	5	7	10

[a] M. LeRoy Davis thesis (9).

[b] DWT is deadweight ton.

[c] The x indicates that the harbor is too shallow to accommodate that size of ship.

Group A: All ports of Asia and Africa except Japan, South Africa, and United Arab Republic.

Group B: Japan, Italy, Poland, South Africa, Israel, East Germany, United Arab Republic, Portugal, Spain, and South America.

Group C: The rest of Europe except the ports in Group D.

Group D: Netherlands, Belgium, and West Germany.

The idle days are constant for the three sizes of ship under study. The actual days spent in discharge of 30,000 DWT[1] ships at all the ports capable of handling this size is assumed to be 1½ times the number of discharge days for a 15,000 DWT ship. The actual days taken to discharge an 80,000 DWT ship in the ports capable of handling this size is assumed to be 1¼ times the discharge days for a 30,000 DWT ship. Table 5 gives the number of discharge days and idle days for the 44 foreign ports.

Canal days Ships sailing through the Saint Lawrence Seaway or the Panama Canal are assumed to have delays that add to the voyage time. Thus the marine costs are increased. It is assumed that ships going from any United States port to any foreign port via either one of these canals will require one extra voyage day.

Marine cost functions After specifying the ocean distances, port days, and canal days, a marine cost function is used which was developed by M. LeRoy Davis (9). There are six different marine cost functions, three for United States flag ships based on the size of

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[1] Dead weight tons.

Table 5. The average number of days at discharge and idle days at the foreign ports by size of ship

	15,000 DWT[a]		30,000 DWT		80,000 DWT	
Foreign port	Days at discharge	Idle days	Days at discharge	Idle days	Days at discharge	Idle days
Veracruz, Mexico	8	2	12	2	x	x
Cristobal, Panama	8	2	12	2	x	x
Kingston, Jamaica	8	2	12	2	x	x
Port of Spain, Trinidad	8	2	12	2	x	x
LaQuira, Venezuela	8	2	12	2	15	2
Rio De Janeiro, Brazil	8	2	12	2	15	2
Montevideo, Uruguay	8	2	12	2	x	x
Callao, Peru	8	2	12	2	x	x
Valparaiso, Chile	8	2	12	2	15	2
Gothenburg, Sweden	6	1	9	1	x	x
Oslo, Norway	6	1	9	1	x	x
Helsinki, Finland	6	1	9	1	x	x
Copenhagen, Denmark	6	1	9	1	x	x
Liverpool, United Kingdom	6	1	9	1	11	1
Dublin, Ireland	6	1	9	1	x	x
Rotterdam, Netherland	4	1	6	1	6	1
Antwerp, Belgium	4	1	6	1	6	1
Marseille, France	6	1	9	1	x	x
Hamburg, W. Germany	4	1	6	1	6	1
Rostock, E. Germany	6	1	x[b]	x	x	x
Gdansk, Poland	8	2	12	2	x	x
Barcelona, Spain	8	2	12	2	x	x
Lisbon, Portugal	8	2	12	2	15	2

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[a] DWT is deadweight ton.

[b] The x indicates that the harbor is too shallow to accommodate that size ship.

Table 5. (Continued)

Foreign port	15,000 DWT[a]		30,000 DWT		80,000 DWT	
	Days at discharge	Idle days	Days at discharge	Idle days	Days at discharge	Idle days
Genoa, Italy	8	2	12	2	15	2
Istanbul, Turkey	8	2	12	2	15	2
Casablanca, Morocco	10	3	15	3	19	3
Tunis, Tunisia	10	3	x	x	x	x
Alexandria, U.A.R.	8	2	12	2	x	x
Tel Aviv, Israel	8	2	12	2	15	2
Dakar, Senegal	10	3	15	3	x	x
Lagos, Nigeria	10	3	x	x	x	x
Capetown, S. Africa	8	2	12	2	15	2
Mombasa, Kenya	10	3	15	3	x	x
Bombay, India	10	3	15	3	x	x
Karachi, Pakistan	10	3	15	3	x	x
Saigon, Vietnam	10	3	15	3	x	x
Manila, Philippines	10	3	15	3	x	x
Hong Kong, Hong Kong	10	3	15	3	x	x
Yokohama, Japan	8	2	12	2	15	2
Montreal, Canada	6	1	9	1	x	x
Luanda, Angola	10	3	x	x	x	x
Sydney, Australia	6	1	9	1	11	1
Odessa, U.S.S.R.	8	2	12	2	x	x
Shanghai, M. China	10	3	15	3	x	x

ship. They are as follows:

22 Total cost per ton;[1] 15,000 DWT U.S. flag ship

= 0.889 (days in port) + 0.937 (at-sea days) + 0.055

23 Total cost per ton; 15,000 DWT foreign flag ship

= 0.317 (days in port) + 0.351 (at-sea days) + 0.055

24 Total cost per ton; 30,000 DWT U.S. flag ship

= 0.528 (days in port) + 0.563 (at-sea days) + 0.035

25 Total cost per ton; 30,000 DWT foreign flag ship

= 0.194 (days in port) + 0.216 (at-sea days) + 0.035

26 Total cost per ton; 80,000 DWT U.S. flag ship

= 0.331 (days in port) + 0.349 (at-sea days) + 0.028

27 Total cost per ton; 80,000 DWT foreign flag ship

= 0.127 (days in port) + 0.135 (at-sea days) + 0.028

where:

at-sea days = ocean distance/(speed × 24) + canal days

where:

One day is assumed to be 24 hours. Distance is measured in nautical miles. Speed is 14 nautical miles per hour.

These marine cost functions assume the following:

1. A 15,000 DWT ship utilized 90 percent cargo space outbound, while 30,000 and 80,000 DWT ships utilize 95 percent of cargo space outbound.
2. There is 60 percent of a normal full load on the return trip.
3. There is no shortage of ships at ports where they are needed.

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[1] In dollars per short ton (2000 pounds).

4. Only those ports that have harbors deep enough can accommodate the larger sizes of ship. See Table 5.

The marine assumptions allow a total of six possible cost per ton rates for each ocean route, that is, three sizes of ship with two different types of flag for each route on the ocean. In the models that allow the six modes for each route, some of them are not used because a certain size of ship cannot be accommodated in the United States or foreign harbor needing the service. A particular harbor may not be deep enough to allow a larger ship to enter it so this possible mode-route is not allowed to exist. Other harbors may be deep enough to accommodate the largest size of ship so all six mode-routes are allowed.

Routes

The computer codes given in Appendix A are used in constructing the variable names for the domestic routes. If a region is a surplus area, its computer code forms the first half of a variable name, say MC5... A deficit region's computer code forms the second half, say ...MC8. The seventh element of the code represents the type of grain: F for feed grains, W for wheat, and S for soybeans. The eighth element indicates the mode of transport. R is for rail, T is for truck, and B is for truck-barge. A complete route code is thus MC5MC8FR.

Shipping on the ocean is made up of routes from United States ports to foreign regions. They are constructed in a similar manner as before. The computer code for the United States ports of export, Table 3, forms the first part of a variable name, say DUO... The computer code for the foreign regions, Appendix B, forms the second part, say ...UKO... The seventh element indicates type of grain as before. The mode, size of ship and flag combination, forms the last part, say ...1. The mode is a number from 1 to 6 and corresponds to the cost functions given by equations 22-27. A resultant mode-route is, for example, DUOUKOF1.

The variable names representing routes are given in Appendix C along with the solutions to the models.

RESULTS AND INTERPRETATIONS

Definitions

The presentation of results and interpretations requires that two definitions be understood. These definitions are of an optimal solution, and an implied price surface.

Optimal solution

An optimal solution gives a set of values for the variables so that they meet the requirements of the constraints and also are the set of values that optimize the objective function. The transshipment model determines a set of values subject to the constraints that the surplus supplies at different origins meet the deficit demands at different destinations. Ports are treated as intermediate shipping points to final destinations. The objective function requires that the total transportation cost be a minimum subject to the constraints.

Implied price surface

The solution to the transshipment model yields shadow prices which can be interpreted as the <u>value</u> of the commodity at an origin and a destination. The difference between the two being less than or equal to the transportation cost.

In the model, commodities at Chicago have a per unit value of zero and it serves as the base for determining all other prices relative to the price at Chicago. For example, the solution to the model may indicate that IA5 has a per ton value of -$3.80 relative to a base price of zero at Chicago. If the price (soybeans) at Chicago is $50 per ton or

$1.50 per bushel, then the price that is implied at IA5 is $46.20 (50.-3.80) or $1.38 3/5 per bushel. This is how the solution to the model results in an implied price surface relative to some base.

The price that is implied at a particular region, say IA5, may change from one solution to another. If IA5 ships grain to a different destination, there is usually a change in the cost coefficient associated with the new route. It should be noted that these are not market prices but values, determined by the model, that imply certain prices for a commodity.

Presentation of Results

There are eight different solutions presented; three for feed grains, two for wheat, and three for soybeans. Each solution is discussed with reference to: 1) movements to domestic deficit regions, 2) movements to ports of export, 3) movements to foreign regions, and 4) the implied price surface. Each solution has a table giving the following information: 1) optimal quantity of grain that moves both to domestic and foreign destinations, 2) percentage of total exports that pass through a port region, and 3) the total transportation cost.

Recall the assumptions under which each of the alternative computer runs are made. They are as follows:

1. Those reflecting current conditions for the 1972-73 crop year for feed grains, wheat, and soybeans. These conditions are used in deriving three basic solutions.
2. A 20 percent increase in demand for all three types of grain by Japan. The 1972-73 crop year for exports is the

base year. These conditions result in three solutions.

3. A 20 percent decrease in demand for feed grains by western Europe; one solution.
4. A 20 percent increase in demand for soybeans by western Europe; one solution.

Optimal Distributions for 1972-73

The three solutions presented, one each for feed grains, wheat, and soybeans, are based on current conditions for the 1972-73 crop year. They are considered the three basic solutions. Referring to the tables in Appendices C and D will give the numerical information on optimal movements and the implied price surfaces, respectively.

Solution 1: feed grains

Solution number 1 is for the optimal distribution of feed grains based on the 1972-73 crop year. Supply and demand estimates of grain are made for the domestic sector and demand estimates are made for the foreign sector. Subsequently, surpluses and deficits are assigned to regions, and transport costs from the surplus to the deficit regions are estimated. The movements which minimize total transportation costs are shown in Figures 7 and 8. The iso-price lines are given in Figure 9. The numerical values are given in Appendices C and D.

Domestic shipments The map for domestic shipments, Figure 7, shows the Southeast pulling feed grains from as far away as Iowa and similarly for the Delta. They are the two largest deficit areas, respectively, with the Northeast being next closest. Iowa supplies 32 percent of the

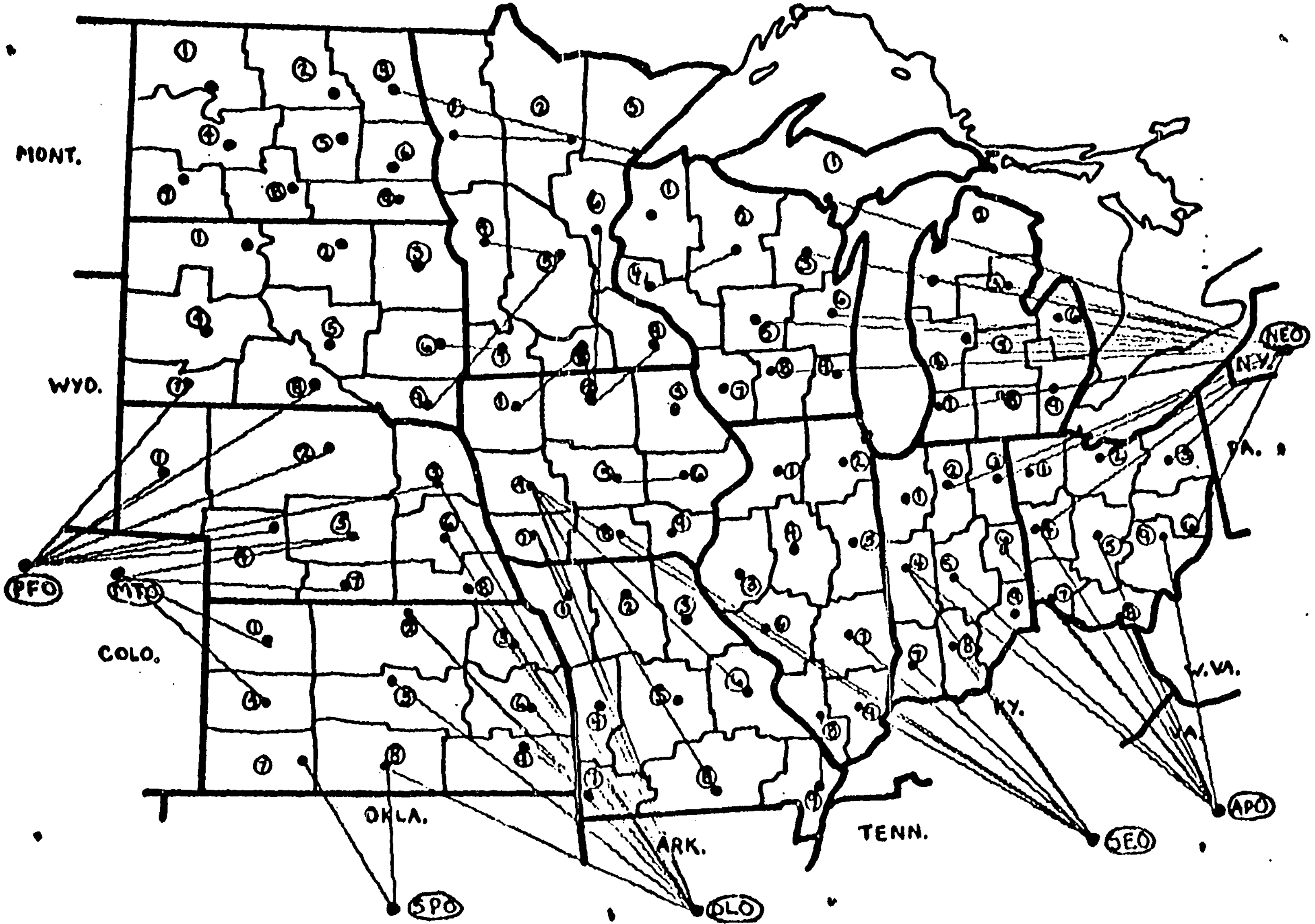

Figure 7. Solution 1, feed grain movements to domestic deficit regions

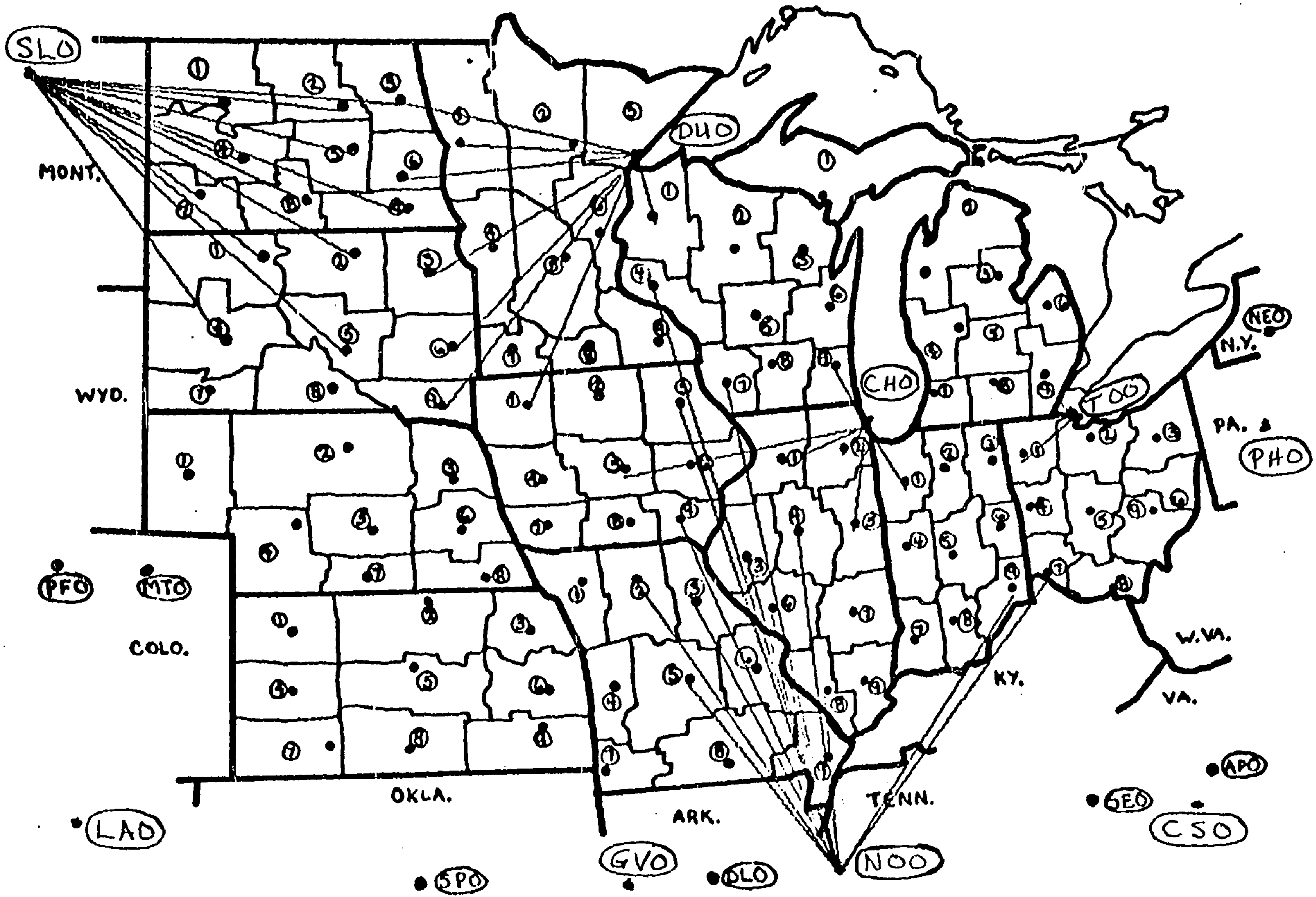

Figure 8. Solution 1, feed grain movements to ports

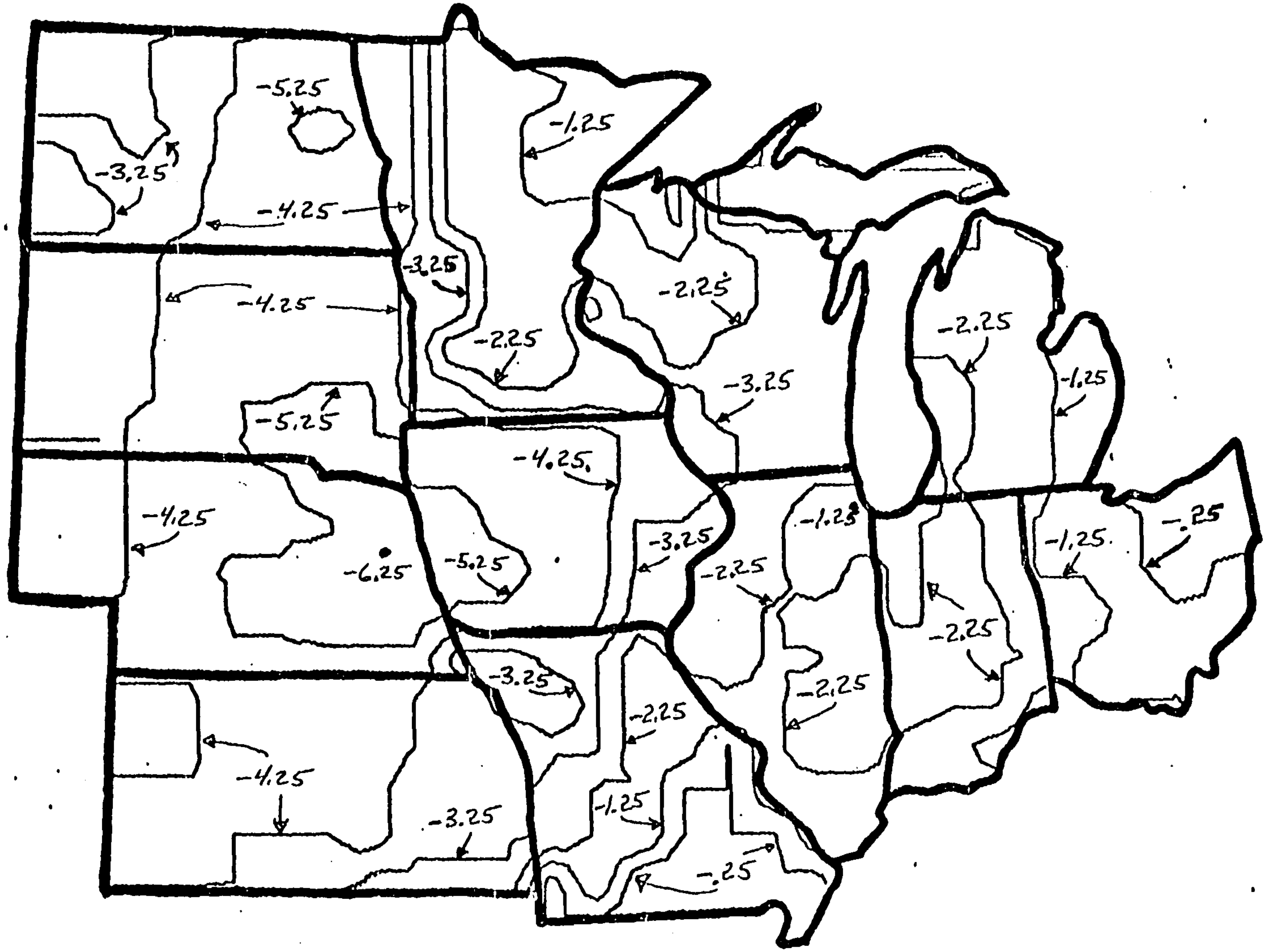

Figure 9. Solution 1, iso-price differences for feed grains relative to Chicago

Southeast deficit, with IA4 supplying 23 percent of it. The Delta pulls 24 percent of its feed grains from Iowa and 46 percent from Nebraska; NB8 supplying 31 percent. The Northeast pulls 22 percent from Wisconsin.

These figures imply that when demands are large, and competing with large demand regions nearby, then to satisfy the needs long shipments are necessary. For example, the Southeast and Delta require large amounts and are competitive with each other, thus having to pull from longer distances to meet their needs. Similarly for the Northeast and Appalachia regions. The other movements appear to be consistent with minimizing distance shipped and still satisfying requirements from nearby sources.

Shipments to ports The map for shipments to ports is given in Figure 8. The majority of the feed grains go through Chicago, followed by New Orleans and then Duluth. See Table 6. The Great Lakes handle 60.5 percent of all feed grain exports, the Gulf 25.2 percent, and Seattle 14.2 percent. The high percentage going out of the Lakes results because no port throughput capacity is binding, say due to weather or facilities.

If throughput capacity were binding based on June, 1972, through May, 1973, inspections for export, then the throughput at Duluth would be 6.0 percent versus 20.2 percent non-constrained. The throughput at Chicago would be 5.0 percent versus 35.3 non-constrained. The throughput at Toledo would be 4.0 percent versus 5.1 percent. New Orleans would have an additional 24.6 percent capacity available. Philadelphia would have additional capacity of 6.1 percent, Charleston:

Table 6. Percent of total feed grains exports passing through a port region, Solution 1 and inspections; June, 1972-May, 1973

Port region	Solution 1	Inspections
Duluth	20.2	6.0
Chicago	35.3	5.0
Toledo	5.1	4.0
Philadelphia	--	6.1
Charleston	--	10.9
New Orleans	25.2	49.8
Galveston	--	15.6
Los Angeles	--	0.6
Seattle	14.2	2.0

10.9 percent, Galveston: 15.6 percent, and Los Angeles: 0.6 percent. Seattle throughput would be 2.0 percent versus 14.2 percent non-constrained. The implications of these figures are that feed grain movements based on costs, and not being constrained at ports are significantly different than when approximated real world constraints are allowed.

An important implication of these results is shown in the movements from the Dakotas to Seattle. The pull from foreign regions, notably Japan, combined with the largest size of ocean vessel is causing this pattern to occur. The patter occurs even though the Great Lakes' ports can be much more competitive than the actual 1972-73 situation since they are not constrained in the model. If the foreign demand in Japan and other Asian countries continues or increases, then, based on costs, the northwestern states of the NCMA can be major suppliers of feed grains. Also, the movements of feed grains would go through the Seattle port region (including Portland and Tacoma) if port facilities were available. This would justify the building of port handling facilities at those locations. Based on the competitive solution which specifies a throughput of 5,271,000 tons of feed grains, and a conservative turnover ratio of 10 to 1, then storage capacity of 527,100 tons or 18,822,741 bushels would be necessary. If the turnover ratio of 12 to 1 is possible, then storage for 15,685,617 bushels would be needed. These figures are for feed grain movements only, more storage may be necessary depending on the levels of wheat and soybean movements.

Another important implication is the amount the transport costs would have to be reduced to encourage movements from Iowa to Seattle. The rail cost of $16.25 per ton from IA1 (Iowa district 1) to Seattle would need to be reduced or subsidized by $2.28 per ton, or about 6.4¢ a bushel. From IA2 to Seattle a reduction of $3.60 per ton or 10¢ per bushel would be necessary. From IA4 to Seattle a reduction of $2.16 per ton, 6¢ per bushel, would be necessary from a rail cost of $16.70 per ton, or 46.8¢ per bushel. The rail cost from IA5 to Seattle is $17.66 per ton, or 49.4¢ per bushel, and the reduction necessary would be $3.93 per ton, or 11¢ a bushel. These figures show that the transportation costs from northwest and central Iowa are very high, and substantial subsidies or reductions in costs would be necessary to encourage any flow at all. If costs were reduced by these amounts the flow may be minimal. Greater reductions in costs or other factors (e.g., preference for west coast delivery) may be required to achieve a higher volume.

Price surface The map showing the iso-price lines which describe an implied price surface is given in Figure 9. All prices are in dollars per ton and are relative to a Chicago price of zero. For purposes of plotting the iso-price lines the zero base is at the lower end of Lake Michigan. The exact prices for each district and region are in Appendix D. The conversion factors from dollars per ton to cents per bushel are given in Table 7. The interpretation of the implied price surface is fairly general in nature. The closer a surplus region is to a port or deficit area, the higher the implied price; that is, base price at Chicago minus dual solution value. The further

Table 7. Conversion of \$/ton to ¢/bushel

\$/ton	¢/bushel
-\$0.25	- 0.7¢
-\$1.25	- 3.5¢
-\$2.25	- 6.3¢
-\$3.25	- 9.1¢
-\$4.25	-11.9¢
-\$5.25	-14.7¢
-\$6.25	-17.5¢

away from a deficit area a surplus region is, the lower the price with more going to transportation costs. Take, for example, a shipment from IA4 (Iowa district 4) to MO1 (Missouri district 1); then relative to a Chicago price say of $1.60 per bushel, the value of the feed grain at IA4 is $1.44 ($1.60 - $0.16). Where -$0.16 per bushel is -$5.74 per ton given in Appendix D, Table D-1, for the IA4 location. Also note the IA4 location on the implied price surface. The value of the feed grain at MO1 is $1.522 ($1.60 - $0.078), where -$0.078 per bushel is -$2.79 per ton given in Appendix D, Table D-1. Thus, the iso-price lines describe an implied price surface which is shown in Figure 9.

Solution 2: wheat

Solution number 2 is for the optimal distribution of wheat based on the 1972-73 crop year for wheat. All types of wheat are considered as one grain. The movements which minimize total transportation costs are shown in Figures 10 and 11. The iso-price lines are shown in Figure 12. The numerical values are in Appendices C and D.

Domestic shipments The map for domestic shipments, Figure 10, shows a dramatic movement of wheat from Nebraska all the way to the Northeast. Nebraska supplies 77 percent of the requirements in the Northeast. Kansas supplies 20 percent. Another long movement is Kansas and Missouri to Appalachia. Kansas supplies 15 percent of the requirements, and Missouri 13 percent. This shows that when the three regions, Northeast, Appalachia, and Southeast, have large demands and because of location are competing for the same sources of supply, then some longer movements occur. Otherwise, deficit areas are supplied

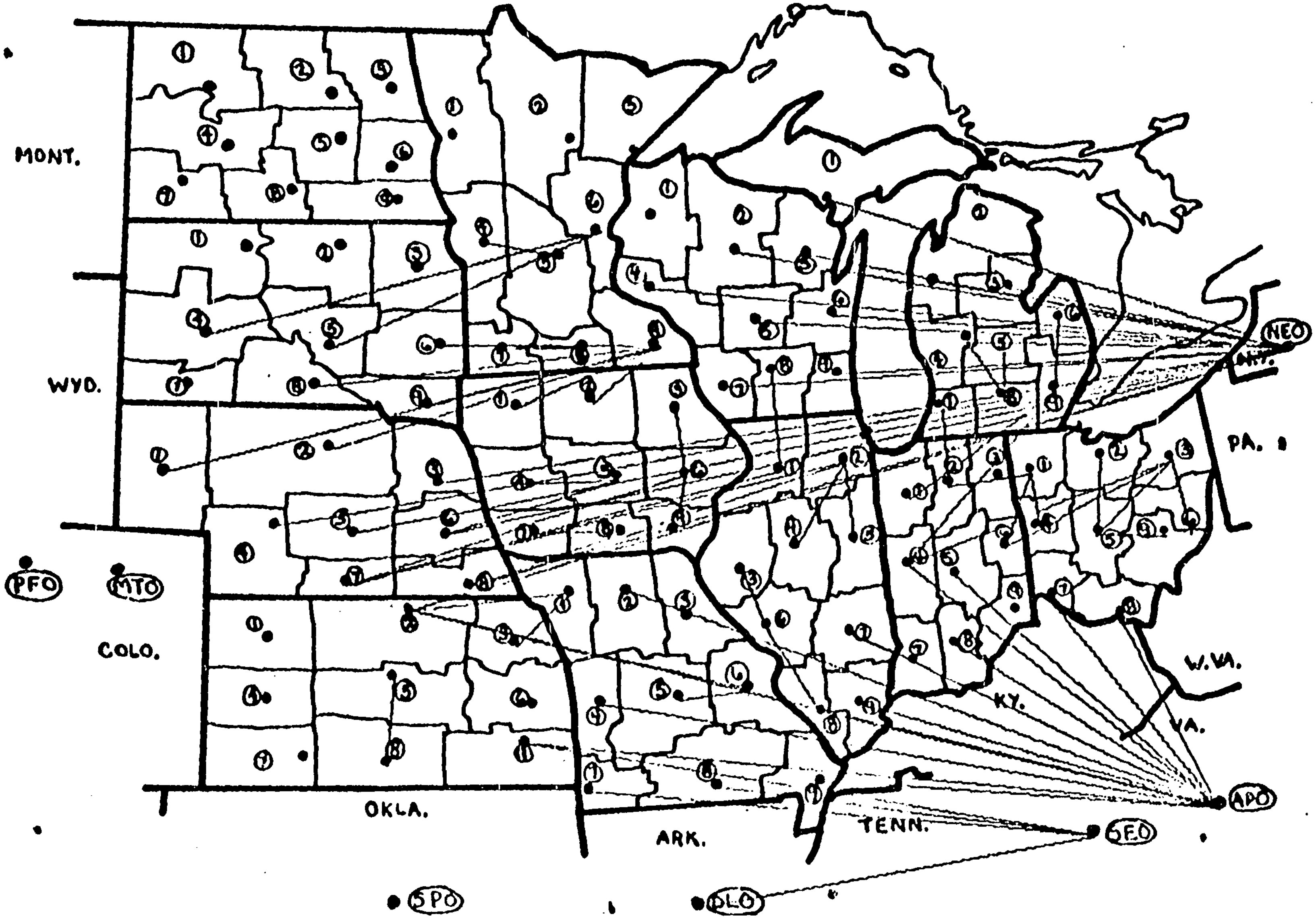

Figure 10. Solution 2, wheat movements to domestic deficit regions

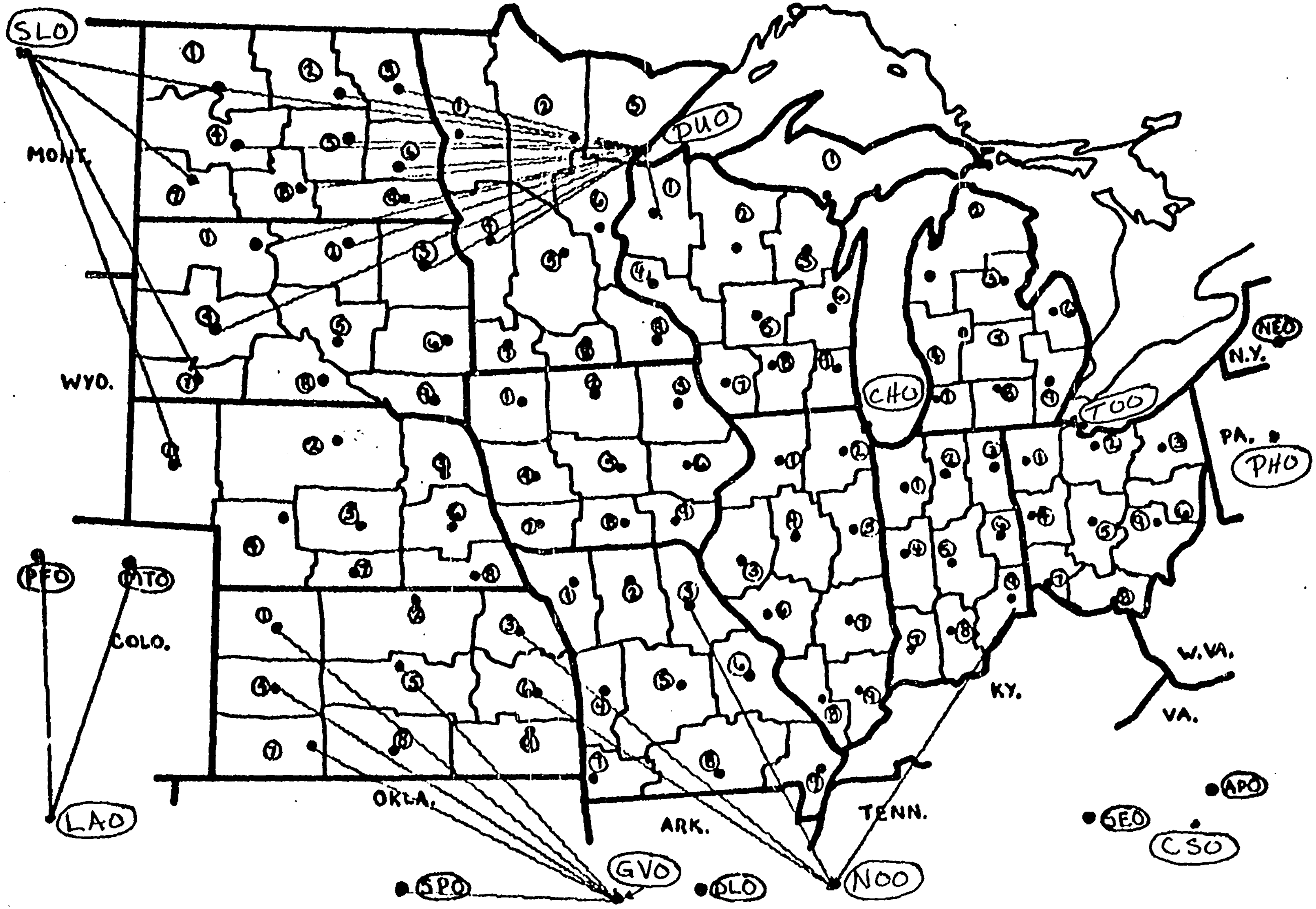

Figure 11. Solution 2, wheat movements to ports

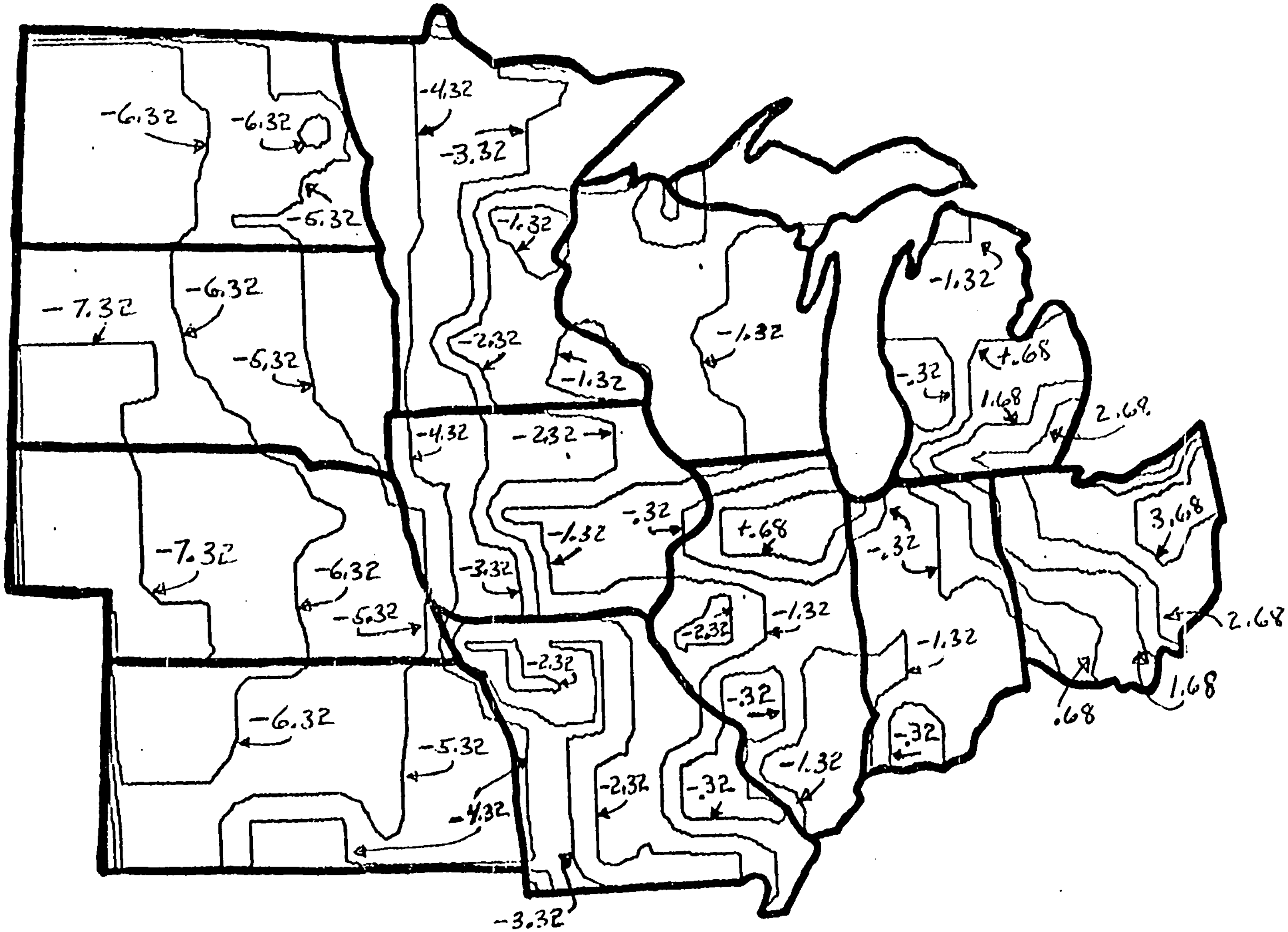

Figure 12. Solution 2, iso-price differences for wheat relative to Chicago

from relatively nearby sources.

Shipments to ports The shipments to ports are shown in Figure 11. Duluth handles 32.7 percent of all wheat exports with Los Angeles next at 31.6 percent. See Table 8. Based on inspections for export Duluth in the real world could handle 8.8 percent versus 32.7 percent non-constrained, and Los Angeles could handle 0.2 of a percent versus 31.6 percent. Galveston has 23.9 percent extra capacity, New Orleans has 6.1 percent extra, and Seattle has 18.1 percent extra.

The movements in Figure 11 are based on costs, and when ports are non-constrained. The implications are that Duluth could be a major port for wheat export if facilities were available, and if the winter closing did not affect annual volume too much. But, the flow through Duluth is also based on location of foreign demand. The majority of Duluth's exports go to western Europe, along with 35 percent to the Soviet Union, and some to north and east Africa. It is likely both the western European and Soviet Union markets may decrease demand. Also, possible are lower barge rates or new unit trains to the Gulf which could negate a need for additional facilities at Duluth.

Another port to consider improving is Los Angeles, which includes Long Beach and Stockton. In this solution, 79 percent of Los Angeles' exports go to Viet Nam, Philippines, Japan, and mainland China. Regions that could be reasonably supplied via Seattle and Galveston. Based on inspections, Los Angeles would need extra annual handling capacity of 9.866 million tons. Based on a 10 to 1 turnover ratio that would require storage capacity of 32.9 million bushels. But at the same time, Galveston

Table 8. Percent of total wheat exports passing through a port region, Solution 2 and inspections; June, 1972-May, 1973

Port region	Solution 2	Inspections
Duluth	32.7	8.8
Chicago	--	0.2
Toledo	--	0.3
Philadelphia	--	2.1
Charleston	--	4.6
New Orleans	8.2	14.3
Galveston	19.9	43.8
Los Angeles	31.6	0.2
Seattle	7.6	25.7

would already have 7.476 million tons excess capacity, and Seattle would have 5.692 million tons excess. The latter two are the nearest ports and would more than cover the extra needed at Los Angeles. But there would be additional costs of transportation to ship say from PFO or MTO to Seattle or Galveston. The opportunity costs derived in the model solution provides information on the additional minimal costs necessary. The additional minimal cost by rail from PFO to Seattle would be $1.47 per ton, or 4.1¢ per bushel. The additional cost from MTO would be $0.82 per ton, or 2.3¢ per bushel. The additional minimal cost from PFO to Galveston would be $13.38 per ton, or 37.5¢ per bushel. And from MTO to Galveston the additional cost would be $0.94 per ton, or 2.6¢ per bushel. The supply of 6.221 million tons at MTO would about fill Galveston's excess of 7.476 million tons. The additional total transportation cost at the minimal $0.94 per ton from MTO to Galveston would be about $5.85 millions. If the 3.695 million tons at PFO went to Seattles' 5.692 million tons excess at the minimal $1.47 per ton, the cost would be $5.41 millions. The combined cost being about $11.3 millions; hardly enough to cover the investment that would be needed at Los Angeles to increase capacity. There would also be excess capacity at Seattle and Galveston, if the Los Angeles port region facilities were built.

Price surface The map showing the iso-price lines which describe an implied price surface is given in Figure 12. The highest iso-price lines start in Ohio with them decreasing all the way to the western NCMA. There are a few pockets of higher prices scattered in various states. The far left iso-price of -\$7.32 per ton under Chicago price is equal to 22¢ per bushel under Chicago price. The iso-price increments of \$1. per ton are equivalent to 3¢ per bushel. The iso-price of \$0.68 per ton above Chicago price is equal to 2¢ per bushel. And the far right iso-price in Ohio of \$3.68 per ton is equal to 11¢ per bushel above Chicago.

Solution 3: soybeans

Solution 3 is for soybeans based on the 1972-73 crop year. Figures 13, 14, and 15 show the movements and the implied price surface. The numerical values are in Appendicies C and D.

Domestic shipments The domestic shipments are shown in Figure 13. There is only one long distance movement from Nebraska and Kansas to the Pacific, PFO, region. All other movements are from nearby surplus regions. The movements indicate soybean production is well dispersed, and deficit regions can be adequately supplied from close surplus regions. This implies domestic soybean needs do not require a substantial amount of transportation.

Shipments to ports Figure 14 shows the shipments of soybeans to the ports. First, the movement to Seattle is negligible. It amounts to 340 tons or 11,332 bushels. New Orleans had the majority of exports, almost equal Chicago and Duluth combined. See Table 9. Duluth handles 20.4 percent of all soybean exports non-constrained, but based on inspections, it could only handle 0.6 of one percent. Chicago handles 22.6 percent non-constrained, the constrained level is 6 percent. Toledo handles 11.2 percent non-constrained, and 8 percent constrained. This is fairly close.

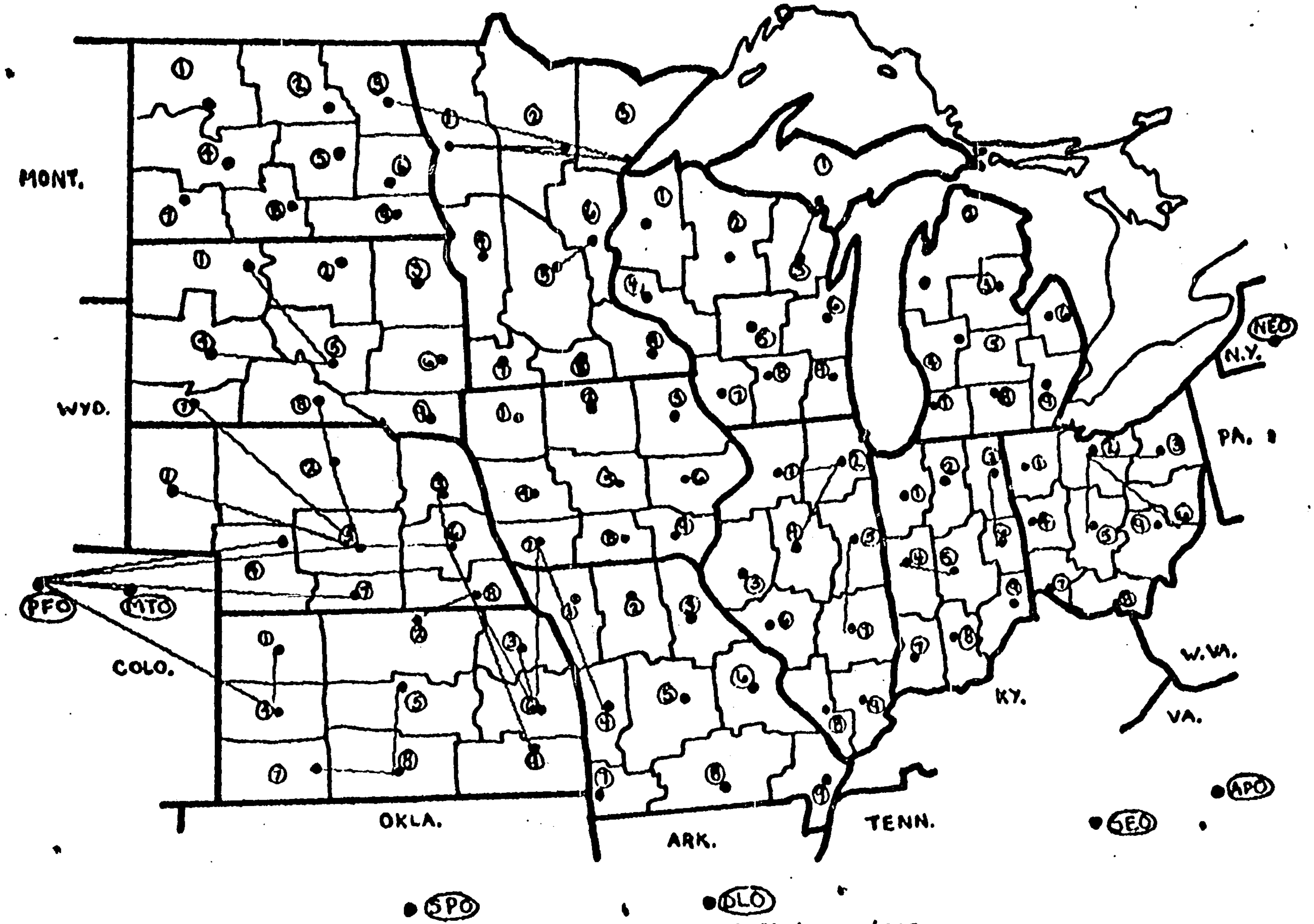

Figure 13. Solution 3, soybean movements to domestic deficit regions

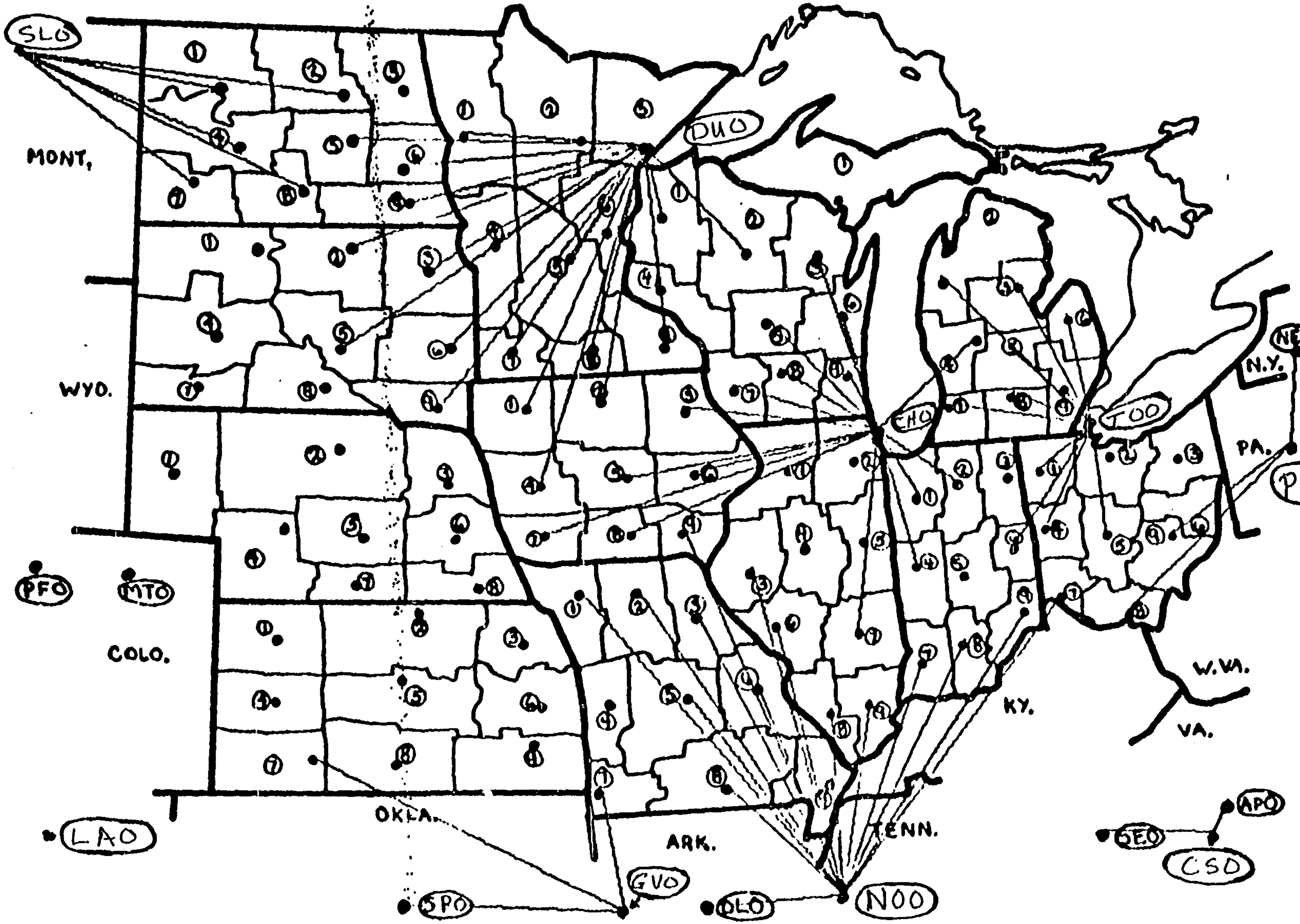

Figure 14. Solution 3; soybean movements to ports

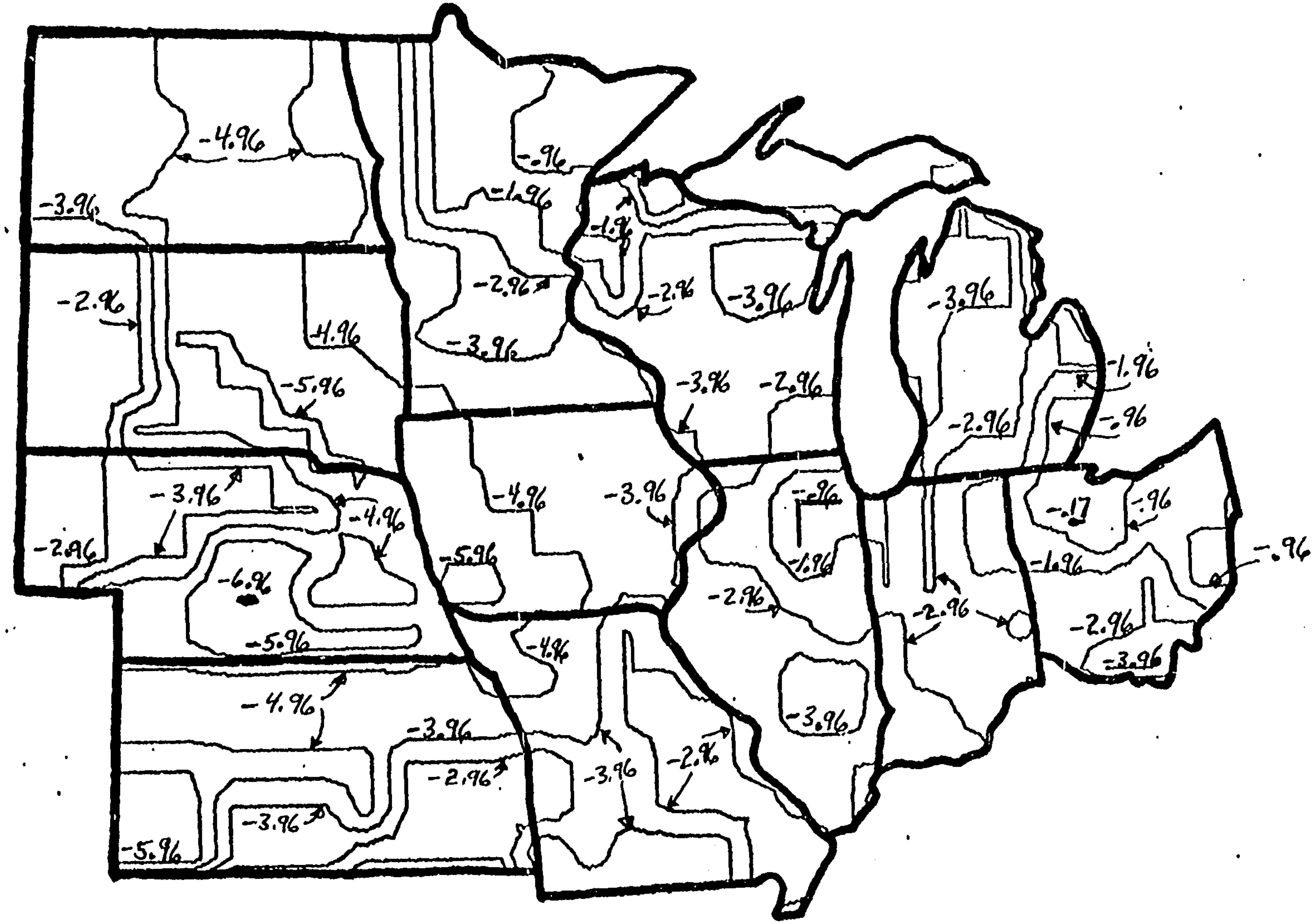

Figure 15. Solution 3, iso-price differences for soybeans relative to Chicago

Table 9. Percent of total soybean exports passing through a port region, Solution 3 and inspections; June, 1972-May, 1973

Port region	Solution 3	Inspections
Duluth	20.4	0.6
Chicago	22.6	6.0
Toledo	11.2	8.0
Philadelphia	1.2	2.0
Charleston	1.5	7.3
New Orleans	41.6	69.1
Galveston	1.5	7.0

Philadelphia and Charleston handle 2.7 percent non-constrained but could handle 9.3 percent. New Orleans and Galveston handle 43.1 percent in the solution but could handle 76.1 percent.

What are the implications? The Great Lakes' ports are supplying the majority of the demand in the northern, western, and southern European countries. These countries demand 63 percent of U.S. soybean exports. For the future, soybean demand experts expect this demand to continue or increase. Given the configuration of soybean surpluses, the domestic demands, and the world demands, it appears the ports of Duluth and Chicago could become major ports for soybean exports if throughput facilities were available. The additional throughput facilities are based on the non-constrained flow that is in excess of inspections. If Duluth were capable of handling the non-constrained flow resulting from this solution, it would require additional storage facilities of 10.6 million bushels at a 12 to 1 turnover ratio. For Chicago the additional storage would be 8.9 million bushels at a 12 to 1 turnover ratio. Note, though, the Great Lakes' ports are shipping most of the soybeans to Europe. They are competing with New Orleans and Galveston as ports for export. These latter two ports have excess capacity and would be able to handle 90 percent of the exports Duluth and Chicago cannot handle in the real world. If transportation rates, notably barge rates on the Mississippi River, were reduced then the excess capacity at the Gulf would probably be utilized. Given the nature of barge rates, such a reduction is possible from one year to the next. The Gulf would probably compete the grain away from Duluth and Chicago. Thus, additional facilities at Duluth and Chicago would be an uncertain investment.

Another implication comes out for the port of Toledo. It would require a minimal amount of increase in storage capacity, based on inspections, to accommodate potential flow through it. Additional storage of 2.07 million bushels would be necessary for a turnover ratio of 10 to 1. Or 1.7 million tons storage based on a turnover of 12 to 1. However, the moderate increase in throughput could be handled with a higher turnover ratio. If the current ratio is 10 to 1, an increase to 14 to 1 would allow Toledo to handle the exports specified in the solution. If the current ratio is 12 to 1, an increase to 17 to 1 would do it. These increases would be a result of investment in handling equipment or design to expedite the soybean flow.

Based on the opportunity costs in the solution, implications are also available for the reduction or subsidy in transportation costs necessary to encourage some flow of grain from Iowa to Seattle. To encourage the movement of soybeans from IA1 to Seattle would require the cost to be reduced a minimum of $3.51 per ton, or 10.5¢ per bushel, out of a cost of $16.25 per ton. This would be a reduction of 21.6 percent. From IA4 the reduction required would be $3.28 per ton, 9.8¢ per bushel, out of a cost of $16.70 per ton, a reduction of 19.6 percent. The reduction or subsidy necessary from central Iowa, IA5, would be $5.16 per ton, 15.5¢ per bushel, out of a cost of $17.66 per ton. This would be a 29.2 percent reduction. IA7 would require a reduction of $3.05 per ton, 9.2¢ per bushel, out of $16.87 per ton.

This is an 18 percent reduction. These figures show the minimum reduction or subsidy in rail costs from western Iowa to Seattle to be 18 to 22 percent. From central Iowa the reduction would be 29.2 percent. This would encourage some flow to Seattle. An additional reduction in costs or other factors (e.g., preference for west coast delivery) may be required to achieve a reasonable volume.

Price surface The iso-price lines for soybeans are given in Figure 15. Two areas in Ohio, one continuing into southeast Michigan, one area in Illinois, and one in northern Minnesota are the high prices on the surface. The low prices are in southwest Iowa and Kansas, central and southern Nebraska, and central to southeast South Dakota. From Ohio west to Illinois the prices do not decline very much. This is compared to the declines from Illinois west into Nebraska and Kansas, and from northern Minnesota southwest into those same areas. The implied price of -\$0.96 per ton below Chicago price is 2.9¢ per bushel. Each \$1. increment is 3¢ per bushel. Central Iowa would have a price, based on transportation costs only, of about 15¢ per bushel below Chicago price. While the price in southwest Iowa would be 18¢ below Chicago price.

Alternative Optimal Distributions

There are five alternative solutions presented, two for feed grains, one for wheat, and two for soybeans. They are based on 1972-73 crop year conditions with all the same assumptions except the following:

1. Japan's demand for feed grains, wheat, and soybeans increases by 20 percent; three alternative solutions, one for each grain.

2. Western European demand for feed grains decreases by 20 percent, and the demand for soybeans increases by 20 percent; two alternative solutions.

Referring to the tables in Appendices C and D will give the numerical information on optimal movements and the implied price surfaces, respectively.

Solution 4: feed grains

Solution 4 is for feed grains and has the same assumptions as Solution 1, except the demand for feed grains by Japan is 20 percent higher than for the 1972-73 export year. This alternative is considered because Japan imports a significant amount of U.S. feed grains. Japan is expected to continue or increase the demand in the future (30).

> "...Imports of corn and sorghum for feed are free of duty and are not subject to import quotas. The quantities imported depend mainly on the growth of the livestock sector...Because of increasing demand for livestock products, imports of feedstuffs [corn and sorghum] are expected to expand substantially in 1973--coarse grains by 7 percent. ...The U.S. share of grain imports will probably increase because of decreased supplies in other major grain exporting countries."

This is the outlook for 1973 and the demand is expected to continue to increase in subsequent years.

Domestic shipments The domestic shipments for Solution 4 are given in Figure 16. When compared to Solution 1 the routing patterns change very little if any. IA4 no longer supplies the Delta (DLO). It supplies more to the Southeast in Solution 4 than in Solution 1. IA4 also supplies a little less to each of the other deficit regions.

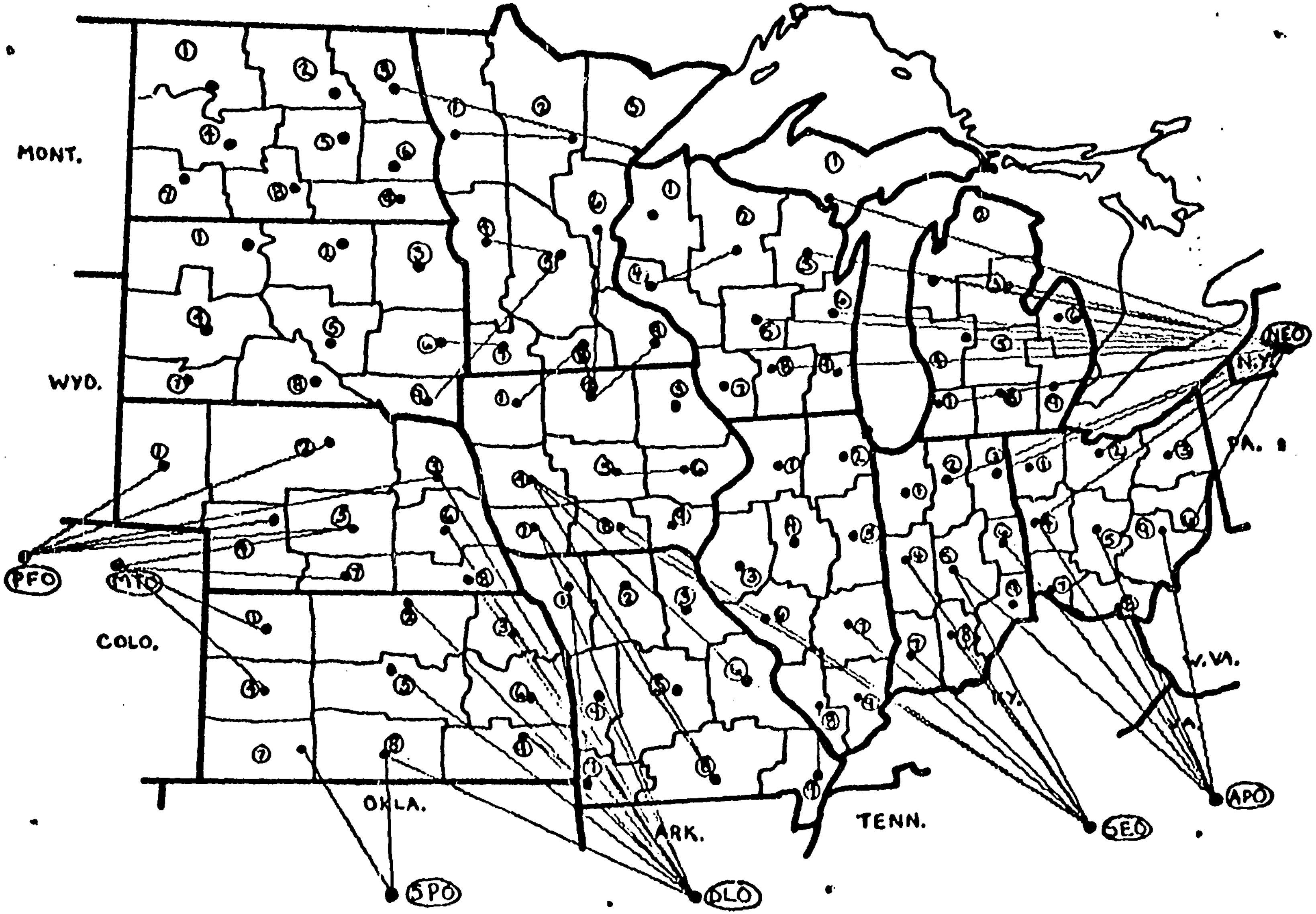

Figure 16. Solution 4, feed grain movements to domestic deficit regions

This is reasonable since the local supply in deficit regions has been increased along with supply increases in surplus regions so the total net surplus for the U.S. can meet the increased export demand.

Iowa supplies 35.7 percent of the requirements for the Southeast, up 3.7 percent from Solution 1. IA4 supplies 26.8 percent of it, up 3.8 percent from Solution 1. The Delta pulls 20 percent of its feed grains from Iowa, down 4 percent, and 47.3 percent from Nebraska; NB8 supplying 31 percent. These percentages are close to Solution 1.

Shipments to ports The map for shipments to ports is given in Figure 17. Again, the routing patterns change little from Solution 1. IA7 now supplies New Orleans, and SD7 and SD8 supply Seattle. The New Orleans level of exports to Japan increases by 30 percent. Seattle's level of exports to Japan increases by 13 percent. The comparison of export levels passing through a port region is given in Table 10. The effect can be seen that the Great Lakes' relative levels of exports have decreased while New Orleans' and Seattle's shares have gone up. The magnitude of the export going out of the Lakes has decreased also.

The implication given in Solution 1 is enforced from the results of Solution 4. The Dakotas still supply Seattle with the Japanese demand reaching further into South Dakota. Also, note the shipments from ND3 to both Duluth and Seattle. A shipment prevalent in both solutions. In Solution 1, Duluth receives 1,036,810 tons from ND3, while in Solution 4 it receives 588,840 tons. Seattle receives 11,840 tons from ND3 in Solution 1, and 469,420 tons in Solution 4. This shows the competition occurring between Seattle and the Great Lakes

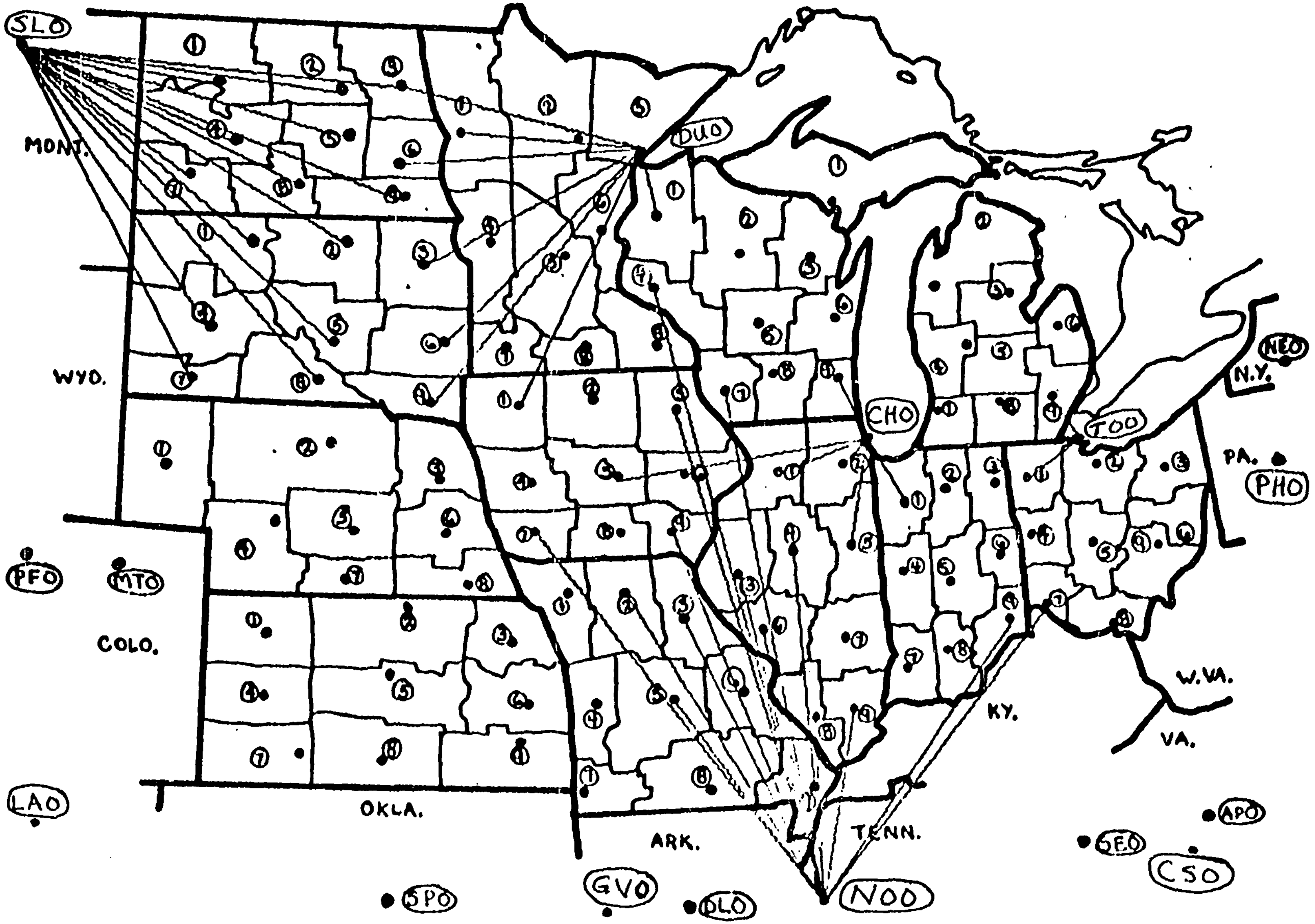

Figure 17. Sōlution 4, feed grain movements to ports

Table 10. Percent of total feed grain exports passing through a port region, Solution 4, Solution 1, and inspections; June, 1972-May, 1973

Port region	Solution 4	Solution 1	Inspections
Duluth	18.6	20.2	6.0
Chicago	34.4	35.3	5.0
Toledo	4.9	5.1	4.0
Philadelphia	--	--	6.1
Charleston	--	--	10.9
New Orleans	26.8	25.2	49.8
Galveston	--	--	15.6
Los Angeles	--	--	0.6
Seattle	15.3	14.2	2.0

when eastern Asian demand increases by a small amount. All this further supports the building of additional handling facilities at Seattle.

Another implication evident is that Seattle pulls deeper into South Dakota. But it does not yet pull into Nebraska, Iowa, or Minnesota. However, New Orleans does pull into southwest Iowa. With the Great Lakes and Seattle ports non-constrained in throughput capacity, the band where movements go in opposite directions would appear to run northeast from NB5 to MN8. This is if Asian demand continued to increase. Considering the alternative with the Lakes ports being constrained, but Seattle having adequate capacity, it appears New Orleans would pull further into Iowa and Minnesota to satisfy the European demand. That demand was satisfied by the Lakes ports when they were not constrained. The conclusion from this is, given the location of world demand for feed grains, their relative levels, and an increase in Asian demand, then it is more likely New Orleans will pull from Iowa, or central NCMA, before Seattle. Seattle would probably pull further into Minnesota, and possibly Nebraska.

Price surface The iso-price lines representing the price surface are given in Figure 18. There is very little change in the iso-price line patterns compared to Solution 1, Figure 9. The surface through central Illinois expands a little, and northwest North Dakota has two areas combined. The implied price surface in Solution 4 is a little lower than the surface in Solution 1. But, since the iso-price line patterns did not change much, the interregional price differences remain almost the same. The value \$-6.38 per ton for the lowest point is equal to -17.9¢ per bushel below Chicago price. The increment of \$1.

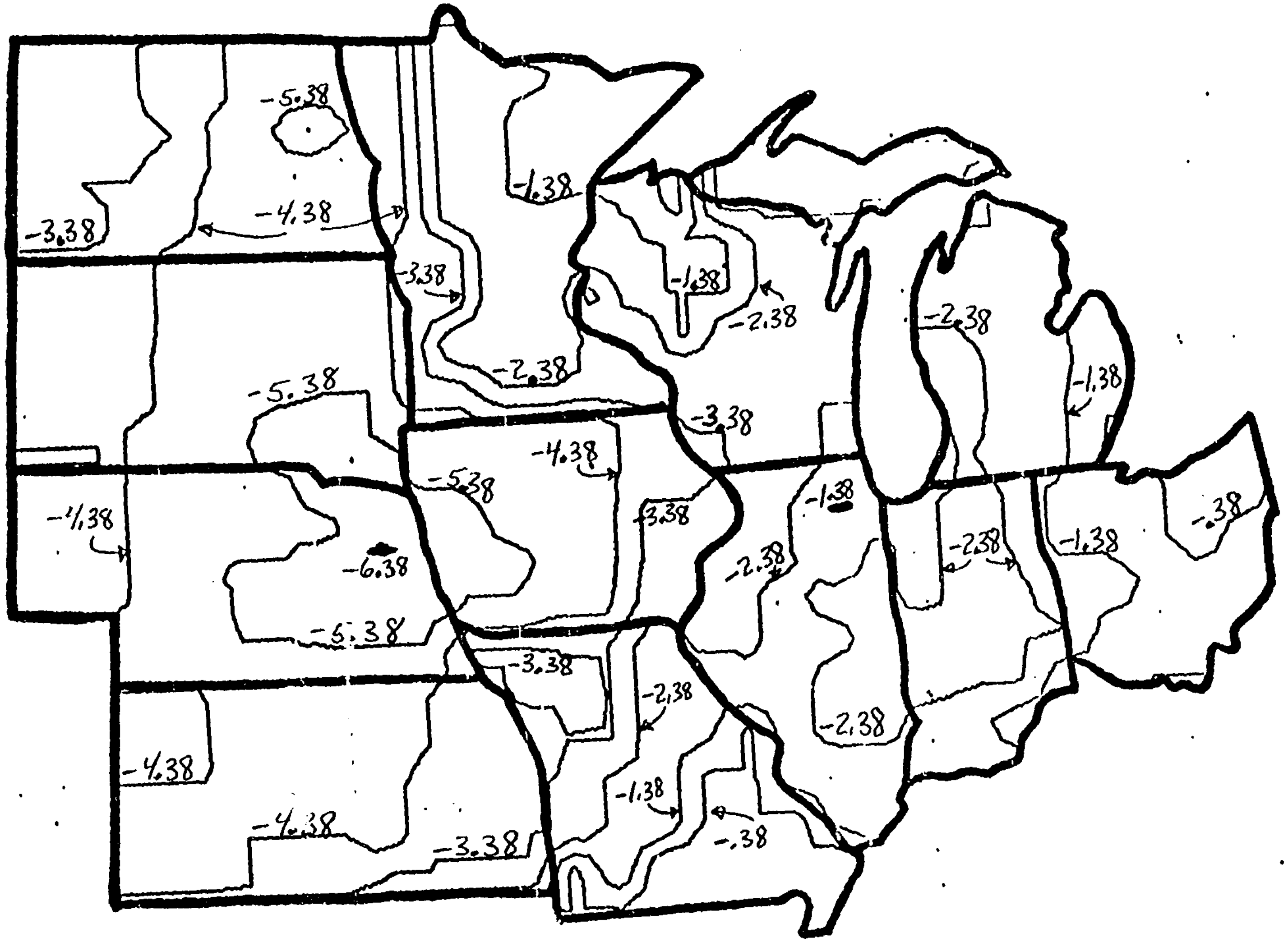

Figure 18. Solution 4, iso-price differences for feed grains relative to Chicago

per ton is equal to 2.8¢ per bushel.

Solution 5: feed grains

Solution 5 is for the optimal distribution of feed grains based on the 1972-73 crop year, except the western European demand has decreased by 20 percent. Otherwise the assumptions are the same as Solution 1 for feed grains. This alternative is considered because it is expected that western European demand for feed grains will decline due to the United Kingdom joining the Common Market (31).

> "However, as a member of EC, the United Kingdom will have to raise agricultural support prices substantially as well as institute the EC's variable-levy system for most major farm products... ."
>
> The picture looks especially bleak for U.S. grain exports to the United Kingdom."

The movements which minimize total transportation costs are shown in Figures 19 and 20. The numerical values are in Appendices C and D.

Domestic shipments The map for domestic shipments, Figure 19, shows very little change in the pattern of movements. IA1 supplies MN7, and IA5 supplies the Northeast and Southeast regions. KA5 also supplies the Southern Plains region (SPO). Otherwise the patterns are similar. The actual quantities moving over the routes changes some from Solution 1 to Solution 5. Some routes carry more and some less but the magnitudes do not seem to vary much from Solution 1.

Shipments to ports Figure 20 shows the shipments to the ports. When Solution 5 is compared to Solution 1, IA7 supplies New Orleans, and SD7 and SD8 supply Seattle in Solution 5. Table 11 shows the exports going through the Great Lakes declines with the decline in European de-

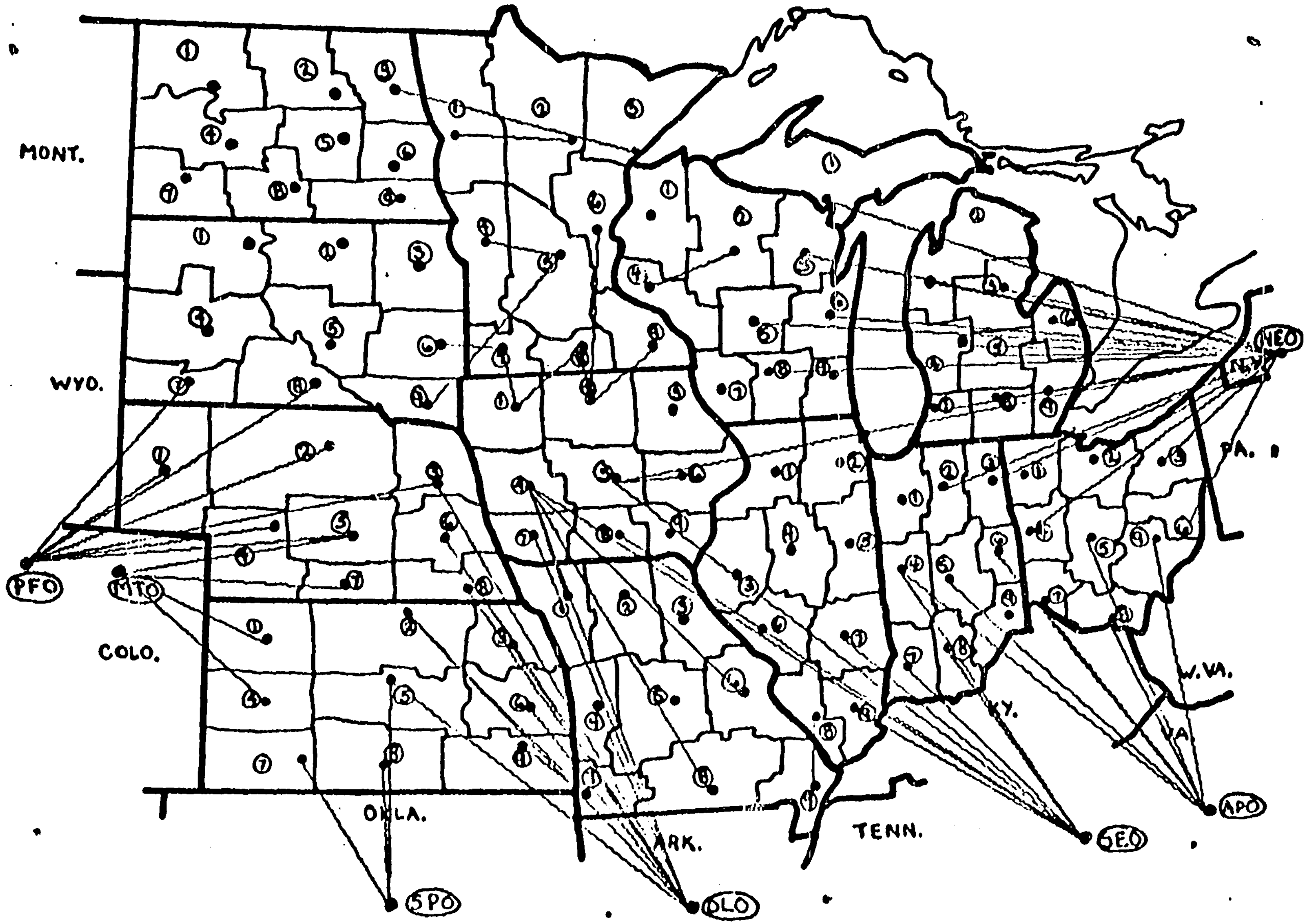

Figure 19. Solution 5, feed grain movements to domestic deficit regions

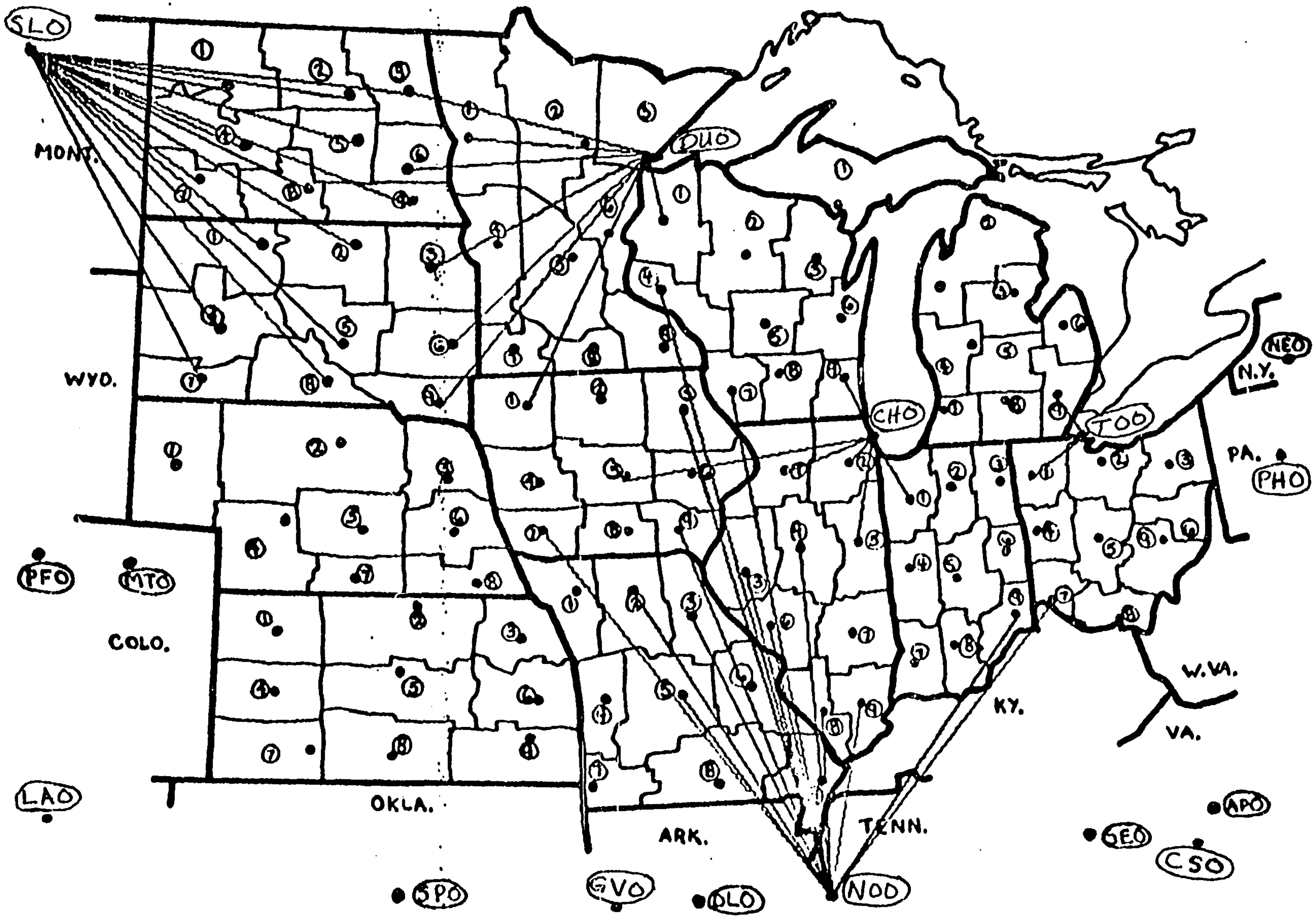

Figure 20. Solution 5, feed grain movements to ports

Table 11. Percent of total feed grain exports passing through a port region, Solution 5, Solution 1, and inspections; June, 1972-May, 1973

Port region	Solution 5	Solution 1	Inspections
Duluth	18.6	20.2	6.0
Chicago	34.4	35.3	5.0
Toledo	4.9	5.1	4.0
Philadelphia	--	--	6.1
Charleston	--	--	10.9
New Orleans	26.8	25.2	49.8
Galveston	--	--	15.6
Los Angeles	--	--	0.6
Seattle	15.3	14.2	2.0

mand. New Orleans and Seattle increase slightly.

The implications in Solution 5 enforce those in Solutions 1 and 4. Seattle still has substantial throughput. It is capable of competing with New Orleans, given adequate facilities. Also, Seattle will have additional supplies available in the Dakotas if European demand declines and Asian demand increases, as in Solution 4. This supports additional handling facilities for Seattle, but not necessarily for the Great Lakes since lower barge rates or more unit train shipments to the Gulf, to use its excess capacity, would compete the grain away from the Lakes.

Total transportation cost

The total transportation costs for the three feed grain solutions, Solutions 1, 4, and 5, are given in Table 12.

Table 12. Total transportation costs, feed grain solutions

Solution	Transportation Cost
1	$892,424,328.
4	$921,122,547.
5	$861,754,932.

Solution 1 is the solution based on 1972-73 crop year conditions. Solution 4 has the same assumptions as Solution 1, except Japanese demand increases by 20 percent. Similarly for Solution 5, except western European demand decreases by 20 percent. The total cost figure for Solution 1 is the estimated transportation bill under non-constrained, or most efficient conditions. When Japanese demand increases by 20 percent, the cost increases by 3.2 percent or $28.7 millions. When western European demand decreases by 20 percent, the cost decreases by 3.4 percent or $30.7 millions. The implications are that, based on the 20 percent changes, if Japan and western Europe balance each other out on demand changes, then the transportation bill will remain fairly unchanged.

Solution 6: wheat

Solution 6 is for the distribution of wheat based on the 1972-73 crop year, except the Japanese demand has increased by 20 percent. Otherwise the assumptions are the same as Solution 2 for wheat. The reason for considering this alternative is the same as for Solution 4. There are no maps to show the flow patterns for this solution. By comparison of the tabular output the patterns change very little if any from those for Solution 2. The tabular information for optimal flows and shadow prices is given in Appendices C and D. The primary interest in this solution is the effect on quantities going through ports of export. See Table 13.

One implication is the increase in wheat going through Seattle. The percentage of total wheat exports going through Seattle changes from 7.6 to 9.0 percent. But the increase in volume going through Seattle is 18.4 percent. Seattle still has excess capacity to supply Asian markets. Looking at the real world inspections and markets, it appears Galveston and Seattle could still easily handle what Los Angeles cannot in order to supply the Asian markets of Viet Nam, Philippines, Japan, and mainland China even with the increased demand. The implications for Solution 2 are enforced by those for Solution 6. No new port facilities at Los Angeles are necessary.

Table 13. Percent of total wheat exports passing through a port region, Solution 6, Solution 2, and inspections; June, 1972-May, 1973

Port regions	Solution 6	Solution 2	Inspections
Duluth	30.9	32.7	8.8
Chicago	--	--	0.2
Toledo	--	--	0.3
Philadelphia	--	--	2.1
Charleston	--	--	4.6
New Orleans	8.7	8.2	14.3
Galveston	19.8	19.9	43.8
Los Angeles	31.6	31.6	0.2
Seattle	9.0	7.6	25.7

Total transportation cost

The total transportation costs for wheat in Solution 2 and 6 are given in Table 14. Solution 2 is based on 1972-73 crop year conditions. Solution 6 has the same assumptions as 2 except Japanese demand increases by 20 percent. The increase in transportation cost is $9.6 millions, or 1.6 percent when the demand increases.

Table 14. Total transportation costs, wheat solutions

Solution	Transportation Cost
2	$586,505,627.
6	$596,104,872.

Solution 7: soybeans

Solution 7 is for the distribution of soybeans based on the 1972-73 crop year, except the Japanese demand has increased by 20 percent. Otherwise the assumptions are the same as Solution 3 for soybeans. This alternative is considered because Japan imports a significant amount of U.S. soybeans. Japan is expected to continue or increase the demand in the future (30).

> "...imports of feedstuffs are expected to expand substantially in 1973...soybeans by 3 percent. The U.S. share of the grain imports will probably increase because of decreased supplies in other major grain exporting countries. For soybeans...the U.S. will probably maintain its already high share--92 percent...."

This is the outlook for 1973 and demand is expected to continue or increase in the future.

There are no maps to show the flow patterns, but by comparing the tabular output given in Appendix C, the patterns remain very similar to those for Solution 3. Appendix D contains shadow price information. The primary interest in this solution is the effect on quantities going through ports of export. See Table 15.

The implications derived in Solution 3 are still valid in Solution 7. Given the configuration of soybean surpluses, the domestic demands, and the world demands, Duluth and Chicago could become major ports for soybean exports. But, they supply most of the European markets and are competing with the Gulf for it. The chance of barge rate reductions, or implementation of more unit trains to the Gulf could compete the grain away from Duluth and Chicago, negating a need for additional facilities.

One important implication is for the port of Seattle. Even with the increase in Japanese demand, there is no throughput of soybeans at Seattle. The addition of facilities at the Seattle port region for the handling of soybeans appears to be unnecessary.

Solution 8: soybeans

Solution 8 is for the distribution of soybeans based on the 1972-73 crop year, except the western European demand has increased by 20 percent. Otherwise the assumptions are the same as Solution 3 for soybeans. This alternative is considered because western Europe has a very high demand for soybeans. Western Europe is expected to continue or increase the demand in the future (31).

Table 15. Percent of total soybean exports passing through a port region, Solution 7, Solution 3, and inspections; June, 1972-May, 1973

Port region	Solution 7	Solution 3	Inspections
Duluth	20.2	20.4	0.6
Chicago	21.0	22.6	6.0
Toledo	11.1	11.2	8.0
Philadelphia	1.3	1.2	2.0
Charleston	1.7	1.5	7.3
New Orleans	43.2	41.6	69.1
Galveston	1.5	1.5	7.0

> "...U.S. exports of soybeans and soybean products and certain nongrain feeds are expected to increase, as there will be a tendency to substitute these feeds for higher cost grain. Soybeans and soybean meal enter the EC Common Market duty free,...."

This is the outlook for 1973 and demand is expected to continue or increase in the future.

There are no maps to show the flow patterns but comparison of the tabular output for Solution 8 and 3 shows little change in patterns. One change is IL4 shipping to New Orleans in Solution 8. Appendices C and D have the optimal flows and shadow prices, respectively. The effect on quantities going through ports of export is shown in Table 16.

The results are almost the same as for Solution 3. The important implication is the increased European demand does not cause the Great Lakes ports to either dominate or even shift the flow away from the Gulf. Otherwise the implications given in Solution 3 hold for Solution 8.

Total transportation cost

The total transportation costs for soybeans in Solutions 3, 7, and 8 are given in Table 17.

Table 17. Total transportation costs, soybean solutions

Solution	Transportation Cost
3	$266,479,282.
7	$278,997,168.
8	$295,968,000.

Solution 3 is based on 1972-73 crop year conditions. Solution 7 has the same assumptions, except Japanese demand increases by 20 percent. Similarly for Solution 8, except western European demand increases by 20

Table 16. Percent of total soybean exports passing through a port region, Solution 8, Solution 3, and inspections; June, 1972-May, 1973

Port region	Solution 8	Solution 3	Inspections
Duluth	19.9	20.4	0.6
Chicago	23.2	22.6	6.0
Toledo	11.3	11.2	8.0
Philadelphia	0.8	1.2	2.0
Charleston	2.5	1.5	7.3
New Orleans	40.6	41.6	69.1
Galveston	1.7	1.5	7.0

percent. The added Japanese demand increases the transportation cost by \$12.5 millions or 4.6 percent. The added western Europe demand increases cost by \$29.5 millions or 11 percent.

SUMMARY AND RECOMMENDATIONS

Summary

Since the North Central Marketing Area (NCMA) of the U.S. produces a large percentage of the heavy grains in the U.S., then a new event or a change in policy is going to have a pronounced effect on the marketing of grain from that area. This study uses a transshipment model to identify 1) the domestic and foreign movements of heavy grain, and 2) the implied price surface under various conditions. In addition, a sensitivity analysis of the grain movements and price surfaces when these conditions are changed is included.

Assumptions are used which reflect current conditions for the 1972-73 crop year. Then assumptions are specified which reflect possible future conditions regarding the marketing of grain. Grain movements and price surfaces are identified under these assumptions:

1. Those reflecting current conditions for the 1972-73 crop year for feed grains, wheat, and soybeans. These conditions are used in deriving three basic solutions.
2. A 20 percent decrease in demand for feed grains by western Europe.
3. A 20 percent increase in demand for soybeans by western Europe.
4. A 20 percent increase in demand for all three grains by Japan.
5. The results derived under the above conditions are analyzed to see if a reduction or subsidy of rail rates from the mid-

west to the west coast may encourage use of those ports as major export outlets for grain.

The possible future conditions listed above are derived from various sources. The majority of the sources are United States Department of Agriculture (USDA) publications about future market opportunities for U.S. grain. Other sources include newspapers, periodicals, government officials, industry spokesmen, and other grain marketing researchers. The Japanese and western European markets are considered as being among the most important U.S. foreign markets, and the traditional ones also. This type of analysis provides a basis for evaluating the impact of various events or policies on the nation's heavy grain economy. Intelligent policy action concerning grain marketing requires knowledge of district, regional, and national effects on the movement of grain. Similarly, with a change in policy, the intelligent adjustment of individual grain and livestock producers depends on the ability to predict the effects on prices.

The important implications of the study center on the movements of heavy grains to the ports of export, and the possible needs of expanding port handling facilities.

Based on feed grain movements and port inspection levels, the port region of Seattle including Portland and Tacoma, should increase its handling and storage facilities. If a turnover ratio of 12 to 1 is possible then storage for 15.7 million bushels would be needed. The pull from foreign regions, notably Japan, combined with the largest size of ocean vessel is causing about 5.3 million tons of feed grains to go through Seattle.

This occurs even though the Great Lakes ports can be much more competitive in the model than in the real world since they are not constrained in the model. Also, if the Japanese and Asian demand continues, then, based on costs, the northwestern states of the NCMA can be major suppliers of feed grains. But, in order for central Iowa to supply Seattle a minimal reduction or subsidy of 20 percent in rail costs would be necessary. Greater reductions may be required to achieve a higher volume.

Based on wheat movements, it appears Seattle has adequate capacity to handle movements from the western U.S. and northern NCMA. Soybean movements out of Seattle are negligible. To encourage any movement of soybeans to Seattle from central Iowa would require a minimal reduction in costs of 29 percent. Additional reductions may be necessary for a higher volume.

The ports of Duluth and Chicago should not consider any substantial expansion in throughput capacity. Based on the model solutions, the Great Lakes ports could supply the majority of heavy grain demand to northern, western, and southern European countries if they had adequate facilities. These countries demand 63 percent of U.S. soybean exports. But, the Great Lakes ports are competing with New Orleans and Galveston as ports for the European demand. The latter two ports have much excess capacity in the non-constrained solutions and they would be able to handle a majority of the exports the Great Lakes ports cannot in the real world. If barge rates on the Mississippi River were reduced or more unit trains go to the Gulf, then the Gulf would compete the grain away from the Great Lakes. Given the nature of barge rates, and the current increase in implementing unit trains to the Gulf, additional facilities at the Great Lakes would be an uncertain investment.

Los Angeles, in the non-constrained solution, only handles a substantial volume for wheat movements. Based on inspections, Los Angeles would require storage capacity of 32.9 million bushels with a 10 to 1 turnover ratio. In the non-constrained solution, 79 percent of Los Angeles exports go to Viet Nam, Philipines, Japan, and mainland China. Galveston and Seattle both had excess capacity that more than covered the Los Angeles exports, and they could supply the same markets. Based on opportunity costs derived in the solution, the ports of Seattle and Galveston could receive the wheat flowing to Los Angeles at an additional transportation cost of about $11.3 millions. The investment at Los Angeles for facilities to handle 32.9 million bushels would be much greater.

Recommendations

The scope of this study should be expanded to include all three grains into a single model. Additionally, constraints to represent transportation capacity by modes should be included. With all three grains being analyzed in one model, the possibility exists for port throughput capacity constraints for the grains combined. Also, the recent USDA projections of supply and disappearance one and two years into the future should be used in the model to estimate distribution patterns for the short-run.

The foreign supply of grains is a significant factor in the marketing of U.S. grains overseas. This component should be included in an advanced model to reflect foreign competition to the U.S.

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APPENDIX A. SURPLUS AND DEFICIT REGIONS FOR FEED GRAINS, WHEAT, AND SOYBEANS IN THE UNITED STATES

Table A-1. Surplus and deficit regions for heavy grains in the United States, 1972-73 crop year

Basing point	Computer code[a]	Feed grains[b]	Wheat	Soybeans
Ohio				
Defiance	OH1	1590.891	-255.536	795.655
Norwalk	OH2	792.341	-47.693	-192.119
Kent	OH3	127.489	-138.215	16.476
Sidney	OH4	968.415	150.014	528.558
Columbus	OH5	955.128	163.920	268.784
New Philadelphia	OH6	75.439	12.427	4.956
Cincinnati	OH7	360.478	8.962	186.757
Portsmouth	OH8	103.601	21.579	84.417
McConnelsville	OH9	54.110	-20.099	5.781
Indiana				
Rensselaer	IN1	1529.896	64.924	541.373
Rochester	IN2	1301.407	92.400	371.405
Fort Wayne	IN3	1585.925	24.552	-10.855
Crawfordsville	IN4	1619.398	104.802	313.415
Indianapolis	IN5	2708.118	65.699	-1.603
Muncie	IN6	1033.448	62.373	317.030
Washington	IN7	1231.067	-90.959	362.778
Bedford	IN8	302.219	29.374	95.967
North Vernon	IN9	169.641	31.455	118.952
Illinois				
Dixon	IL1	3237.274	-45.806	615.511
Plano	IL2	1557.811	-317.954	-282.616
Macomb	IL3	1863.868	37.092	308.330
Bloomington	IL4	2859.736	50.482	175.863
Paxton	IL5	3979.267	39.745	-110.315
Girard	IL6	1562.315	-251.090	740.171
Effingham	IL7	2351.320	330.437	1299.527
Pickneyville	IL8	302.820	226.745	469.695
McLeansboro	IL9	574.060	217.724	490.712
Michigan				
Powers	MC1	15.114	3.074	-0.035
Manton	MC2	34.452	4.311	0.246
West Branch	MC3	40.409	6.909	0.215

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[a] The last digit of the computer code refers to the crop reporting district.

[b] All amounts are in 1000 short tons, and a minus sign indicates a deficit while no sign indicates a surplus.

Table A-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Hart	MC4	80.119	8.130	0.152
Mt. Pleasant	MC5	287.996	34.741	26.838
Caro	MC6	298.141	54.064	44.847
Allegan	MC7	233.547	-70.218	26.838
Charlotte	MC8	54.452	-40.401	117.664
Ann Arbor	MC9	309.991	-122.800	208.147
Wisconsin				
Spooner	WI1	53.012	2.670	4.222
Wausau	WI2	-76.546	3.688	0.549
Shawano	WI3	12.458	4.004	0.359
Osseo	WI4	343.679	3.322	25.402
Wautoma	WI5	212.063	5.564	4.697
Chilton	WI6	352.940	7.888	8.464
Muscoda	WI7	240.651	1.014	5.393
Madison	WI8	887.595	3.930	41.106
Waukesha	WI9	93.879	14.861	39.871
Minnesota				
Crookston	MN1	1596.320	1268.355	46.316
Bemidji	MN2	-72.652	25.733	-1.505
Two Harbors	MN3	-76.342	15.569	-1.600
Morris	MN4	285.987	351.206	27.865
St. Cloud	MN5	-1190.864	-36.930	334.669
Cambridge	MN6	-466.823	-450.695	-115.215
Slayton	MN7	-1149.106	31.901	725.249
Mankato	MN8	-1371.224	-66.100	433.918
Rochester	MN9	-891.234	-550.665	250.188
Iowa				
Spencer	IA1	2920.164	3.293	833.705
Mason City	IA2	2558.297	3.569	413.844
West Union	IA3	1252.179	3.222	419.218
Carroll	IA4	3223.652	9.802	605.910
Marshalltown	IA5	3062.785	-106.940	214.378
Cedar Rapids	IA6	-260.078	-115.418	70.281
Red Oak	IA7	1580.448	14.496	549.665
Chariton	IA8	767.045	-62.994	413.579
Fairfield	IA9	538.734	15.072	492.574
Missouri				
King City	MO1	-2.942	-950.623	332.503
Bucklin	MO2	127.981	7.627	504.087
Monroe	MO3	38.961	24.881	365.034

Table A-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Clinton	M04	216.464	67.681	-58.858
Jefferson City	M05	19.401	49.763	239.480
Pacific	M06	-494.747	-183.649	142.457
Carthage	M07	-193.628	13.652	115.996
West Plains	M08	-417.755	15.661	33.086
Sikeston	M09	-20.322	324.394	1011.251
North Dakota				
Stanley	ND1	564.406	1469.204	0.078
Rugby	ND2	679.824	964.978	0.046
Park River	ND3	1124.987	1660.782	0.078
Beulah	ND4	381.782	727.235	0.078
Carrington	ND5	596.799	928.148	0.046
Valley City	ND6	959.322	955.905	59.754
Dickinson	ND7	407.325	690.516	0.078
Bismarck	ND8	280.211	428.750	0.046
LaMoure	ND9	920.608	692.369	63.498
South Dakota				
Isabel	SD1	158.490	271.793	-0.123
Ipswich	SD2	803.916	653.440	0.320
Summit	SD3	692.001	359.412	16.872
Phillip	SD4	44.167	247.908	-0.123
Miller	SD5	421.996	321.401	0.415
Madison	SD6	1181.238	41.681	50.228
Hot Springs	SD7	5.905	151.048	-0.123
Winner	SD8	177.472	316.367	0.067
Scotland	SD9	1391.820	22.693	163.526
Nebraska				
Alliance	NB1	119.893	1054.075	-1.050
Ainsworth	NB2	173.305	100.698	-0.642
Norfolk	NB3	1781.851	41.686	247.137
N. Platte	NB4	1137.288	155.662	12.886
Loup City	NB5	3443.159	319.043	337.548
David City	NB6	573.865	379.698	-476.478
Holdrege	NB7	1466.199	441.280	5.353
Beatrice	NB8	2325.403	528.538	133.379
Kansas				
Colby	KA1	181.726	1166.509	-0.140
Belleville	KA2	280.003	1128.974	-0.203
Holton	KA3	1017.418	1265.106	3.122
Scott City	KA4	521.675	1202.690	8.347

Table A-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Ellsworth	KA5	358.283	1336.749	5.528
Ottawa	KA6	250.481	2072.083	-316.027
Dodge City	KA7	569.887	384.642	146.946
Kingman	KA8	345.840	-416.885	-20.399
Chanute	KA9	185.011	238.373	-58.691
Pa., Md., and states N.E. thereof: Northeast Region Albany, N.Y.	NE0	-7159.434	-2053.580	161.109
Ky., Tenn., Va. W. Va., and N.C. Appalachia Region Greensboro, N.C.	AP0	-5281.512	-1525.410	93.631
S.C., Ga., Fla. and Ala. Southeast Region Atlanta, Ga.	SE0	-8861.777	-381.679	178.535
Miss., Ark., and La. Delta Region Little Rock, Ark	DL0	-7580.230	334.388	2169.466
Tex. and Okla. Southern Plains Region Fort Worth, Tex.	SP0	-765.417	2553.319	53.516
Mont., Colo., Id., Wyo., N.M., Ariz., Utah, and Nev. Mountain Region Denver, Colo.	MT0	-2347.961	6221.754	2.490
Wash., Ore., and Calif. Pacific Region Sacramento, Calif.	PF0	-6079.234	3695.859	-151.116

APPENDIX B. 1972-73 UNITED STATES EXPORTS OF FEED GRAINS, WHEAT, AND SOYBEANS

Table B-1. United States exports of feed grains, wheat and soybeans to foreign regions: June, 1972 - May, 1973[a]

Basing point	Computer code	Feed grains[b]	Wheat	Soybeans
Veracruz, Mexico Mexico Guatemala British Honduras Honduras	MXO	650.7	735.2	40.3
Cristobal, Panama Panama El Salvador Nicaragua Costa Rica Columbia	PAO	246.8	603.6	15.8
Kingston, Jamaica Jamaica Bahamas Haiti Dominican Republic Leeward and Windward Islands	JMO	166.5	135.5	11.1
Port of Spain, Trinidad Trinidad Bermudas Barbados Northern Antilles French West Indies Guyana Surinam	TRO	116.3	164.3	7.8
La Guaira, Venezuela Venezuela	VZO	588.5	683.8	80.3
Rio De Janeiro, Brazil Brazil Paraguay	BZO	7.6	1279.3	7.8
Montevideo, Uruguay Uruguay	URO	48.4	170.2	7.8

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[a] See references (35, 36).

[b] All amounts are in 1000 short tons.

Table B-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Callao, Peru	PUO	286.9	830.3	112.7
Peru				
Ecuador				
Bolivia				
Valparaiso, Chile	CLO	233.2	31.4	7.9
Chile				
Argentina				
Gothenburg, Sweden	SWO	24.2	7.3	0.0
Sweden				
Oslo, Norway	NWO	185.0	124.2	249.9
Norway				
Helsinki, Finland	FNO	6.0	27.8	7.8
Finland				
Latvia				
Copenhagen, Denmark	DNO	1.0	31.4	562.6
Denmark				
Liverpool, United Kingdom	UKO	2356.2	641.4	406.7
United Kingdom				
Dublin, Ireland	IRO	160.8	41.4	7.8
Ireland				
Iceland				
Rotterdam, Netherland	NHO	3605.6	1034.2	2695.8
Netherland				
Antwerp, Belgium	BLO	3040.1	107.3	252.1
Belgium				
Marseille, France	FRO	9.4	357.0	412.8
France				
Switzerland				
Hamburg, West Germany	WGO	1941.3	402.8	5666.7
West Germany				
Rostock, East Germany	EGO	18.7	76.6	7.8
East Germany				

Table B-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Gdansk, Poland Poland Czechoslovakia Hungary	POO	675.3	707.5	142.9
Barcelona, Spain Spain	SI0	2206.9	31.4	1245.6
Lisbon, Portugal Portugal Azores	PG0	593.2	125.1	12.5
Genoa, Italy Italy Austria	IT0	283.4	159.4	693.1
Istanbul, Turkey Turkey Yugoslavia Greece Bulgaria Cyprus Syria Albania	TK0	878.6	486.1	0.4
Casablanca, Morocco Morocco Algeria Canary Island Madeira Island	MR0	157.2	806.4	7.8
Tunis, Tunisia Tunisia Malta Libya	TU0	35.1	103.7	7.8
Alexandria, U.A.R. United Arab Republic Lebanon Iraq Iran Jordan Kuwait Saudi Arabia	UA0	280.5	755.2	33.3

Table B-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Arabia				
Aden				
Bahrain				
A. Yemen				
S. Yemen				
Tel Aviv, Israel	ISO	734.9	185.3	357.5
Israel				
Dakar, Senegal	SNO	64.8	40.8	7.8
Senegal				
Guinea				
Sierra Leone				
Gambia				
Liberia				
Mali				
Mauritania				
Lagos, Nigeria	NGO	29.3	412.4	7.8
Nigeria				
Cameroon				
Ivory Coast				
Ghana				
Togo				
Gahon				
Niger				
Upper Volta				
Dahomey				
Other West Africa				
Capetown, South Africa	SAO	19.7	31.4	7.8
South Africa				
Other South Africa				
Mombasa, Kenya	KNO	1.5	153.6	7.8
Kenya				
Sudan				
Somali Republic				
Ethiopia				
Uganda				
Zambia				
Tanzania				
Mauritius				
Mozambique				
Malawi				

Table B-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Bombay, India	IDO	448.3	1381.0	7.8
India				
Bangladesh				
Nepal				
Ceylon				
Burma				
Karachi, Pakistan	PKO	18.7	1017.7	7.8
Pakistan				
Afghanistan				
Saigon, Vietnam	VNO	1705.8	2673.0	714.1
South Vietnam				
Laos				
Cambodia				
Thailand				
South Korea				
Taiwan				
Manila, Philippines	PPO	361.1	1032.4	57.4
Philippines				
Malaysia				
Singapore				
Indonesia				
Other Southern Asia				
Hong Kong, British Crown Colony	HKO	0.2	53.3	7.8
British Crown Colony				
Macao				
Yokohama, Japan	JPO	8966.2	3502.7	3878.2
Japan				
Montreal, Canada	CNO	1309.0	690.6	631.7
Canada				
Luanda, Angola	AGO	2.7	31.5	7.8
Angola				
Other Western Portuguese Africa				
Congo				
Zaire				
Burundi				
Rwanda				

Table B-1. (Continued)

Basing point	Computer code	Feed grains	Wheat	Soybeans
Sydney, Australia Australia Nansei Island New Zealand British Western Pacific Island Trust Territory of Pacific Island	AUO	20.2	30.2	7.8
Odessa, U.S.S.R. Union of Soviet Socialist Republic Romania	SUO	4037.4	8868.2	942.7
Shanghai, Peoples Republic of China Peoples Republic of China	CMO	778.7	597.7	0.0

APPENDIX C. OPTIMAL SOLUTIONS FOR FEED GRAINS, WHEAT, AND SOYBEAN MODELS

Table C-1. Solution 1, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
OH1TOOFT	1590.89	WI8NEOFR	887.60	NB1PFOFR	119.89
OH2NEOFR	792.34	WI9CHOFT	93.88	NB2PFOFR	173.31
OH3NEOFR	127.49	MN1DUOFR	1523.67	NB3DLOFR	581.28
OH4NEOFR	767.54	MN1MN2FT	72.65	NB3PFOFR	1200.57
OH4APOFR	200.88	MN4MN5FT	285.99	NB4PFOFR	1137.29
OH5APOFR	955.13	IA1DUOFR	2749.19	NB5MTOFR	178.36
OH6NEOFR	75.44	IA1MN8FT	170.97	NB5PFOFR	3264.80
OH7NOOFB	170.90	IA2MN6FT	466.82	NB6DLOFR	573.87
OH7APOFR	189.58	IA2MN8FT	1200.25	NB7MTOFR	1466.20
OH8APOFR	103.60	IA2MN9FT	891.23	NB8DLOFR	2325.40
OH9APOFR	54.11	IA3NOOFB	1252.18	KA1MTOFR	181.73
IN1CHOFT	1529.90	IA4SEOFR	2053.30	KA2DLOFR	271.38
IN2NEOFR	1301.41	IA4DLOFR	257.84	KA2MO7FR	8.62
IN3NEOFR	1585.92	IA4MO6FR	494.75	KA3DLOFR	1017.42
IN4APOFR	36.64	IA4MO8FR	417.76	KA4MTOFR	521.67
IN4SEOFR	1582.76	IA5CHOFR	2802.70	KA5DLOFR	358.28
IN5APOFR	2708.12	IA5IA6FT	260.08	KA6DLOFR	250.48
IN6APOFR	1033.45	IA7DLOFR	1577.51	KA7SPOFR	569.89
IN7SEOFR	1231.07	IA7MO1FT	2.94	KA8DLOFR	150.31
IN8SEOFR	302.22	IA8SEOFR	767.05	KA8SPOFR	195.53
IN9NOOFB	169.64	IA9NOOFB	538.73	KA9MO7FT	185.01
IL1CHOFT	3237.27	MO2NOOFB	127.98	DUOSWOF2	24.18
IL2CHOFT	1557.81	MO3NOOFB	38.96	DUOUKOF2	2356.22
IL3NOOFB	1863.87	MO4DLOFR	216.46	DUOIROF2	160.81
IL4NOOFB	2859.74	MO5NOOFB	19.40	DUOWGOF2	1941.32
IL5CHOFT	3979.27	ND1SLOFR	564.41	DUOEGOF2	18.69
IL6NOOFB	1562.32	ND2SLOFR	679.82	DUOPOOF2	675.28
IL7SEOFR	2351.32	ND3DUOFR	1036.81	DUOSIOF2	1047.56
IL8NOOFB	282.50	ND3SLOFR	11.84	DUOCNOF2	1309.02
IL8MO9FT	20.32	ND3MN3FR	76.34	CHOFNOF2	5.96
IL9SEOFR	574.06	ND4SLOFR	381.78	CHODNOF2	1.03
MC1NEOFR	15.11	ND5SLOFR	596.80	CHONHOF2	3605.61
MC2NEOFR	34.45	ND6DUOFR	959.32	CHOBLOF2	3040.10
MC3NEOFR	40.41	ND7SLOFR	407.32	CHOFROF2	9.37
MC4NEOFR	80.12	ND8SLOFR	280.21	CHOSIOF2	1159.37
MC5NEOFR	288.00	ND9SLOFR	920.61	CHOTKOF2	878.59
MC6NEOFR	298.14	SD1SLOFR	158.49	CHOTUOF2	35.11
MC7NEOFR	233.55	SD2SLOFR	803.92	CHOUAOF2	280.46
MC8NEOFR	54.45	SD3DUOFR	692.00	CHOISOF2	734.85
MC9TOOFT	309.99	SD4SLOFR	44.17	CHOSNOF2	64.85
WI1DUOFT	53.01	SD5SLOFR	422.00	CHOSUOF2	3387.25
WI3NEOFR	12.46	SD6DUOFR	32.13	TOONWOF2	185.04
WI4NOOFB	267.13	SD6MN7FT	1149.11	TOOPGOF2	593.17
WI4WI2FT	76.55	SD7PFOFR	5.90	TOOITOF2	283.41
WI5NEOFR	212.06	SD8PFOFR	177.47	TOOMROF2	157.15
WI6NEOFR	352.94	SD9DUOFR	486.95	TOONGOF2	29.30
WI7NOOFB	240.65	SD9MN5FR	904.87	TOOAGOF2	2.69

Table C-1. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
TOOSUOF2	650.12	NOOVZOF4	588.51	NOOIDOF4	448.29
PHOISOF4	0.00	NOOBZOF4	7.56	NOOPKOF4	18.69
CSOBZOF4	0.00	NOOUROF4	48.39	NOOVNOF4	1705.83
NOOMXOF4	650.68	NOOPUOF4	286.94	NOOPPOF4	361.11
NOOPAOF4	246.82	NOOCLOF4	233.19		
NOOJMOF4	166.49	NOOSAOF4	19.73		
NOOTROF4	116.26	NOOKNOF4	1.54		

Table C-2. Solution 2, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
DL0SE0WR	334.39	MN1DU0WR	1268.36	NB6IA5WR	97.14
SP0GV0WR	2553.32	MN2DU0WR	25.73	NB7NE0WR	302.27
MT0LA0WR	6221.75	MN3DU0WT	15.57	NB7IL1WR	41.88
PF0LA0WR	3695.86	MN4DU0WR	314.28	NB7IA6WR	97.13
OH4OH1WT	150.01	MN4MN5WT	36.93	NB8NE0WR	480.05
OH5OH2WT	47.69	MN7MN8WT	31.90	NB8IA3WR	48.49
OH5OH3WR	96.13	IA1MN9WR	3.29	KA1GV0WR	1166.51
OH5OH9WT	20.10	IA2MN9WT	3.57	KA2NE0WR	415.22
OH6OH3WT	12.43	IA3IA6WT	3.22	KA2AP0WR	234.87
OH7AP0WR	8.96	IA4IA5WT	9.80	KA2IL2WR	227.72
OH8AP0WR	21.58	IA7IA8WT	14.50	KA2MO1WR	117.27
IN1MC9WR	64.92	IA9IA6WT	15.07	KA2MO6WR	133.89
IN2OH1WT	22.18	MO2AP0WR	7.63	KA3NO0WB	431.76
IN2MC7WT	70.22	MO3NO0WB	24.88	KA3MO1WT	833.35
IN3OH1WT	24.55	MO4AP0WR	67.68	KA4GV0WR	1202.69
IN4AP0WR	74.90	MO5MO6WT	49.76	KA5GV0WR	919.86
IN4OH3WR	26.08	MO7SE0WR	13.65	KA5KA8WT	416.89
IN4MC9WR	3.82	MO8SE0WR	15.66	KA6NO0WB	2072.08
IN5AP0WR	65.70	MO9AP0WR	324.39	KA7GV0WR	384.64
IN6OH1WT	58.80	ND1DU0WR	884.52	KA9AP0WR	220.39
IN6OH3WR	3.57	ND1SL0WR	584.68	KA9SE0WR	17.98
IN8AP0WR	29.37	ND2DU0WR	964.98	DU0SW0W2	7.33
IN9NO0WB	31.45	ND3DU0WR	1660.78	DU0NW0W2	124.20
IL3IL6WT	37.09	ND4DU0WR	727.23	DU0FN0W2	27.76
IL4IL2WT	50.48	ND5DU0WR	928.15	DU0DN0W2	31.39
IL5IL2WT	39.75	ND6DU0WR	955.90	DU0UK0W2	641.36
IL7AP0WR	239.48	ND7SL0WR	690.52	DU0IR0W2	41.44
IL7IN7WT	90.96	ND8DU0WR	428.75	DU0NH0W2	1034.25
IL8AP0WR	12.74	ND9DU0WR	692.37	DU0BL0W2	107.02
IL8IL6WT	214.00	SD1DU0WR	271.79	DU0FR0W2	356.98
IL9AP0WR	217.72	SD2DU0WR	653.44	DU0WG0W2	402.79
MC1NE0WR	3.07	SD3DU0WR	359.41	DU0EG0W2	76.60
MC2NE0WR	4.31	SD4DU0WR	118.62	DU0PO0W2	707.54
MC3NE0WR	6.91	SD4MN6WR	129.29	DU0SI0W2	31.39
MC4NE0WR	2.47	SD5MN6WR	321.40	DU0PG0W2	125.05
MC4MC8WR	5.66	SD6MN8WR	34.20	DU0IT0W2	159.41
MC5MC8WT	34.74	SD6MN9WR	7.48	DU0MR0W2	806.36
MC6MC9WT	54.06	SD7SL0WR	151.05	DU0TU0W2	103.74
WI1DU0WT	2.67	SD8MN9WR	316.37	DU0UA0W2	755.24
WI2NE0WR	3.69	SD9MN9WR	22.69	DU0SN0W2	40.81
WI3NE0WR	4.00	NB1SL0WR	957.50	DU0NG0W2	412.44
WI4NE0WR	3.32	NB1MN9WR	96.57	DU0CN0W2	690.61
WI5NE0WR	5.56	NB2MN9WR	100.70	DU0AG0W2	31.49
WI6NE0WR	7.89	NB3NE0WR	41.69	DU0SU0W2	3557.35
WI7NE0WR	1.01	NB4NE0WR	155.66	CH0BL0W2	0.24
WI8IL1WT	3.93	NB5NE0WR	319.04	TO0IT0W2	0.00
WI9NE0WR	14.86	NB6NE0WR	282.56	PH0SU0W4	0.00

Table C-2. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
CSOSUOW4	0.00	GVOVZOW4	683.78	LAOISOW6	185.33
NOOUROW4	170.16	GVOPUOW4	830.30	LAOSAOW6	31.39
NOOSUOW4	2390.01	GVOKNOW4	153.61	LAOIDOW4	14.93
GVOMXOW4	735.18	GVOSUOW4	2920.84	LAOVNOW4	2673.01
GVOPAOW4	603.55	LAOBZOW6	1279.32		
GVOJMOW4	135.49	LAOCLOW6	31.39		
GVOTROW4	164.27	LAOTKOW6	486.05		

Table C-3. Solution 3, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
NEOPHOSR	161.11	WI6CHOST	8.46	SD8NB2ST	0.07
APOCSOSR	93.63	WI7CHOSR	5.39	SD9DUOSR	163.53
SEOCSOSR	178.53	WI8CHOSR	41.11	NB3NB6ST	247.14
DLONOOSR	2169.47	WI9CHOST	39.87	NB4PFOSR	12.89
SPOGVOSR	53.51	MN1DUOSR	43.30	NB5PFOSR	122.18
MTOPFOSR	2.49	MN1MN2ST	1.50	NB5SD7SR	0.12
OH1TOOST	795.65	MN1MN3SR	1.52	NB5NB1SR	1.05
OH3OH2ST	16.48	MN4DUOSR	27.87	NB5NB2ST	0.57
OH4TOOST	528.56	MN5DUOSR	219.46	NB5NB6ST	213.63
OH5TOOST	98.10	MN5MN6ST	115.21	NB7PFOSR	5.35
OH5OH2ST	170.68	MN7DUOSR	725.25	NB8NB6ST	15.71
OH6OH2ST	4.96	MN8DUOSR	433.92	NB8KA2ST	0.20
OH7NOOSB	186.76	MN9DUOSR	250.19	NB8KA6SR	58.78
OH8PHOSR	84.42	IA1DUOSR	833.70	NB8KA9SR	58.69
OH9PHOSR	5.78	IA2DUOSR	413.84	KA3KA6ST	3.12
IN1CHOST	541.37	IA3CHOSR	419.22	KA4PFOSR	8.21
IN2CHOST	371.40	IA4DUOSR	605.91	KA4KA1ST	0.14
IN4CHOST	311.82	IA5CHOSR	214.38	KA5KA8ST	5.53
IN4IN5ST	1.60	IA6CHOSR	70.28	KA7GVOSR	132.08
IN6TOOSR	306.17	IA7CHOSR	236.68	KA7KA8ST	14.87
IN6IN3ST	10.86	IA7MO4SR	58.86	DUOSWOS2	0.05
IN7NOOSB	362.78	IA7KA6ST	254.13	DUOUKOS2	406.73
IN8NOOSB	95.97	IA8CHOSR	413.58	DUOIROS2	7.81
IN9NOOSB	118.95	IA9NOOSB	492.57	DUOWGOS2	3515.63
IL1CHOST	508.75	MO1NOOSB	332.50	DUOEGOS2	7.81
IL1IL2ST	106.76	MO2NOOSB	504.09	CHONWOS2	200.98
IL3NOOSB	308.33	MO3NOOSB	365.03	CHODNOS2	562.57
IL4IL2ST	175.86	MO5NOOSB	239.48	CHONHOS2	570.60
IL6NOOSB	740.17	MO6NOOSB	142.46	CHOBLOS2	252.08
IL7CHOSR	1189.21	MO7GVOSR	116.00	CHOWGOS2	2151.03
IL7IL5ST	110.32	MO8NOOSR	33.09	CHONGOS2	7.81
IL8NOOSB	469.70	MO9NOOSB	1011.25	CHOCNOS2	631.68
IL9NOOSB	490.71	ND1SLOSR	0.08	TOONHOS2	2125.15
MC2TOOSR	0.25	ND2SLOSR	0.05	TOOPGOS2	12.51
MC3TOOSR	0.21	ND3MN3SR	0.08	TOOTUOS2	7.81
MC4CHOSR	0.15	ND4SLOSR	0.08	TOOAGOS2	7.81
MC5TOOSR	26.84	ND5DUOSR	0.05	PHOSIOS4	251.31
MC6TOOST	44.85	ND6DUOSR	59.75	CSOSIOS4	238.89
MC7TOOSR	26.84	ND7SLOSR	0.08	CSOUAOS4	33.27
MC8TOOST	117.66	ND8SLOSR	0.05	NOOPAOS4	15.79
MC9TOOST	208.15	ND9DUOSR	63.50	NOOJMOS4	11.07
WI1DUOST	4.22	SD2DUOSR	0.32	NOOTROS4	7.81
WI2DUOSR	0.55	SD3DUOSR	16.87	NOOVZOS4	80.35
WI3CHOSR	0.32	SD5DUOSR	0.17	NOOBZOS4	7.81
WI3MC1ST	0.04	SD5SD1SR	0.12	NOOUROS4	7.81
WI4DUOSR	25.40	SD5SD4SR	0.12	NOOPUOS4	112.69
WI5CHOSR	4.70	SD6DUOSR	50.23	NOOCLOS4	7.92

Table C-3. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
NOOFROS4	412.82	NOOISOS4	357.48	NOOVNOS4	525.11
NOOPOOS4	142.90	NOOSNOS4	7.81	NOOPPOS4	57.37
NOOSIOS4	755.39	NOOSAOS4	7.81	NOOJPOS4	3877.90
NOOITOS4	693.13	NOOKNOS4	7.81	NOOSUOS4	942.72
NOOTKOS4	0.33	NOOIDOS4	7.81	GVOMXOS4	40.25
NOOMROS4	7.81	NOOPKOS4	7.81	GVONWOS4	48.89

Table C-4. Solution 4, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
OH1TOOFT	1609.74	WI9CHOFT	100.12	NB1PFOFR	123.31
OH2NEOFR	802.58	MN1DUOFR	1540.38	NB2PFOFR	178.99
OH3NEOFR	132.49	MN1MN2FT	72.05	NB3DLOFR	644.07
OH4NEOFR	595.94	MN4MN5FT	296.75	NB3PFOFR	1173.99
OH4APOFR	387.68	IA1DUOFR	2844.91	NB4PFOFR	1156.39
OH5APOFR	969.34	IA1MN8FT	123.44	NB5MTOFR	80.37
OH6NEOFR	77.70	IA2MN6FT	465.93	NB5PFOFR	3412.37
OH7NOOFB	367.76	IA2MN8FT	1245.20	NB6DLOFR	583.40
OH8APOFR	106.09	IA2MN9FT	887.76	NB7MTOFR	1484.58
OH9APOFR	55.65	IA3NOOFB	1286.09	NB8DLOFR	2355.70
IN1CHOFT	1555.16	IA4SEOFR	2368.98	KA1MTOFR	187.38
IN2NEOFR	1322.73	IA4MO6FR	488.99	KA2DLOFR	286.27
IN3NEOFR	1605.16	IA4MO8FR	416.53	KA3DLOFR	1035.20
IN4SEOFR	1637.46	IA5CHOFR	2886.06	KA4MTOFR	532.87
IN5APOFR	2642.34	IA5IA6FT	224.22	KA5DLOFR	364.49
IN5SEOFR	99.83	IA7NOOFB	82.18	KA6DLOFR	256.64
IN6APOFR	1046.40	IA7DLOFR	1523.59	KA7SPOFR	585.52
IN7SEOFR	1249.00	IA7MO8FR	0.55	KA8DLOFR	282.39
IN8SEOFR	307.00	IA8SEOFR	783.28	KA8SPOFR	74.58
IN9NOOFB	173.50	IA9NOOFB	563.09	KA9DLOFR	14.72
IL1CHOFT	3283.31	MO1MO7FR	13.72	KA9MO7FT	177.48
IL2CHOFT	1586.18	MO2NOOFB	136.92	DUOSWOF2	24.18
IL3NOOFB	1892.10	MO3NOOFB	48.69	DUOUKOF2	2356.22
IL4NOOFB	2904.54	MO4DLOFR	225.21	DUOIROF2	160.81
IL5CHOFT	4019.02	MO5NOOFB	28.98	DUOWGOF2	1941.32
IL6NOOFB	1592.35	ND1SLOFR	569.43	DUOEGOF2	18.69
IL7SEOFR	2378.59	ND2SLOFR	685.82	DUOPOOF2	675.28
IL8NOOFB	292.58	ND3DUOFR	588.84	DUOSIOF2	791.67
IL8MO9FT	17.14	ND3SLOFR	469.42	DUOCNOF2	1309.02
IL9NOOFB	582.23	ND3MN3FR	76.29	CHOFNOF2	5.96
MC1NEOFR	15.66	ND4SLOFR	385.75	CHODNOF2	1.03
MC2NEOFR	35.27	ND5SLOFR	602.45	CHONHOF2	3605.61
MC3NEOFR	41.12	ND6DUOFR	967.85	CHOBLOF2	3040.10
MC4NEOFR	81.47	ND7SLOFR	411.39	CHOFROF2	9.37
MC5NEOFR	292.87	ND8SLOFR	283.63	CHOSIOF2	1415.26
MC6NEOFR	304.79	ND9SLOFR	930.39	CHOTKOF2	878.59
MC7NEOFR	239.16	SD1SLOFR	160.67	CHOTUOF2	35.11
MC8NEOFR	66.60	SD2SLOFR	814.18	CHOUAOF2	280.46
MC9TOOFT	317.89	SD3DUOFR	701.49	CHOISOF2	734.85
WI1DUOFT	56.78	SD4SLOFR	45.23	CHOSNOF2	64.85
WI3NEOFR	14.51	SD5SLOFR	428.82	CHOSUOF2	3360.50
WI4NOOFB	279.95	SD6DUOFR	52.88	TOONWOF2	185.04
WI4WI2FT	73.54	SD6MN7FT	1145.84	TOOPGOF2	593.17
WI5NEOFR	217.03	SD7SLOFR	6.43	TOOITOF2	263.41
WI6NEOFR	363.09	SD8SLOFR	180.91	TOOHROF2	157.15
WI7NOOFB	253.13	SD9DUOFR	524.06	TOONGOF2	29.30
WI8NEOFR	905.20	SD9MN5FR	888.35	TOOAGOF2	2.69

Table C-4. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
TOOSUOF2	676.87	NOOVZOF4	588.51	NOOIDOF4	448.29
PHOISOF4	0.00	NOOBZOF4	7.56	NOOPKOF4	18.69
CSOBZOF4	0.00	NOOUROF4	48.39	NOOVNOF4	1705.83
NOOMXOF4	650.68	NOOPUOF4	286.94	NOOPPOF4	361.11
NOOPAOF4	246.82	NOOCLOF4	233.19		
NOOJMOF4	166.49	NOOSAOF4	19.73		
NOOTROF4	116.26	NOOKNOF4	1.54		

Table C-5. Solution 5, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
OH1TOOFT	1560.58	MN1DUOFR	1496.81	NB1PFOFR	114.40
OH2NEOFR	775.88	MN1MN2FT	73.61	NB2PFOFR	164.17
OH3NEOFR	119.44	MN4MN5FT	268.69	NB3DLOFR	179.18
OH4NEOFR	943.98	IA1DUOFR	2594.07	NB3PFOFR	1544.47
OH5APOFR	932.28	IA1MN7FT	1.22	NB4PFOFR	1106.57
OH6NEOFR	71.81	IA1MN8FT	247.41	NB5MTOFR	335.89
OH7APOFR	348.77	IA2MN6FT	468.26	NB5PFOFR	3027.56
OH8APOFR	99.59	IA2MN8FT	1127.97	NB6DLOFR	558.53
OH9APOFR	51.64	IA2MN9FT	896.81	NB7MTOFR	1436.65
IN1CHOFT	1489.28	IA3NOOFB	1197.66	NB8DLOFR	2276.70
IN2NEOFR	1267.13	IA4SEOFR	1112.57	KA1MTOFR	172.64
IN3NEOFR	1555.00	IA4DLOFR	1076.77	KA2DLOFR	245.85
IN4APOFR	302.21	IA4MO1FT	29.73	KA2MO7FR	24.08
IN4SEOFR	1288.16	IA4MO6FR	504.00	KA3DLOFR	988.84
IN5APOFR	2653.37	IA4MO8FR	418.83	KA4MTOFR	503.67
IN6APOFR	1012.62	IA5CHOFR	1153.83	KA5DLOFR	286.28
IN7SEOFR	1202.24	IA5NEOFR	99.46	KA5SPOFR	62.02
IN8SEOFR	294.54	IA5SEOFR	1415.42	KA6DLOFR	240.57
IN9NOOFB	163.43	IA5IA6FT	317.72	KA7SPOFR	544.76
IL1CHOFT	3163.26	IA7DLOFR	1538.86	KA8SPOFR	327.95
IL2CHOFT	1512.21	IA8SEOFR	740.95	KA9MO7FT	173.45
IL3NOOFB	1818.49	IA9NOOFB	499.58	DUOSWOF2	19.34
IL4NOOFB	2787.71	MO2NOOFB	113.62	DUOUKOF2	1884.97
IL5CHOFT	3915.37	MO3NOOFB	23.32	DUOIROF2	128.65
IL6NOOFB	1514.03	MO4DLOFR	202.40	DUOWGOF2	1553.06
IL7SEOFR	2307.47	MO5NOOFB	3.99	DUOEGOF2	18.69
IL8NOOFB	266.28	ND1SLOFR	556.34	DUOPOOF2	675.28
IL8MO9FT	25.44	ND2SLOFR	670.19	DUOSIOF2	987.43
IL9SEOFR	560.92	ND3DUOFR	388.95	DUOCNOF2	1309.02
MC1NEOFR	14.23	ND3SLOFR	644.24	CHOFNOF2	4.77
MC2NEOFR	33.14	ND3MN3FR	76.43	CHODNOF2	0.82
MC3NEOFR	39.27	ND4SLOFR	375.40	CHONHOF2	2884.49
MC4NEOFR	77.94	ND5SLOFR	587.71	CHOBLOF2	2432.08
MC5NEOFR	280.16	ND6DUOFR	945.61	CHOFROF2	7.49
MC6NEOFR	287.45	ND7SLOFR	400.78	CHOSIOF2	778.11
MC7NEOFR	224.52	ND8SLOFR	274.72	CHOTKOF2	878.59
MC8NEOFR	34.92	ND9SLOFR	904.89	CHOTUOF2	35.11
MC9TOOFT	297.29	SD1SLOFR	154.99	CHOUAOF2	280.46
WI1DUOFT	46.96	SD2SLOFR	787.42	CHOISOF2	734.85
WI3NEOFR	9.16	SD3DUOFR	676.75	CHOSNOF2	64.85
WI4NOOFB	246.52	SD4SLOFR	42.45	CHOSUOF2	3217.93
WI4WI2FT	81.38	SD5SLOFR	411.02	TOONWOF2	148.03
WI5NEOFR	204.08	SD6MN7FT	1153.14	TOOPGOF2	474.54
WI6NEOFR	336.62	SD7PFOFR	5.07	TOOITOF2	226.72
WI7NOOFB	220.59	SD8PFOFR	171.94	TOOMROF2	157.15
WI8NEOFR	859.30	SD9DUOFR	427.29	TOONGOF2	29.30
WI9CHOFT	83.84	SD9MN5FR	931.43	TOOAGOF2	2.69

Table C-5. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
TOOSUOF2	819.44	NOOVZOF4	588.51	NOOIDOF4	448.29
PHOISOF4	0.00	NOOBZOF4	7.56	NOOPKOF4	18.69
CSOBZOF4	0.00	NOOUROF4	48.39	NOOVNOF4	1705.83
NOOMXOF4	650.68	NOOPUOF4	286.94	NOOPPOF4	361.11
NOOPAOF4	246.82	NOOCLOF4	233.19		
NOOJMOF4	166.49	NOOSAOF4	19.73		
NOOTROF4	116.26	NOOKNOF4	1.54		

Table C-6. Solution 6, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
DLCSE0WR	341.78	MN1DU0WR	1285.02	NB6IA5WR	97.00
SP0GV0WR	2613.67	MN2DU0WR	25.88	NB7NE0WR	307.95
MT0LA0WR	6322.30	MN3DU0WT	15.57	NB7IL1WR	41.63
PF0LA0WR	3777.29	MN4DU0WR	320.06	NB7IA6WR	96.88
OH4OH1WT	153.77	MN4MN5WT	36.34	NB8NE0WR	535.39
OH5NE0WR	0.01	MN7MN8WT	32.20	KA1GV0WR	1181.76
OH5OH2WT	44.29	IA1MN9WR	3.31	KA2NE0WR	320.78
OH5OH3WR	103.44	IA2MN9WT	3.58	KA2AP0WR	128.52
OH5OH9WT	19.86	IA3IA6WT	3.24	KA2IL2WR	225.23
OH6OH3WT	12.77	IA4IA5WT	9.92	KA2IA8WR	48.28
OH7AP0WR	10.48	IA7IA8WT	14.68	KA2MO1WR	290.58
OH8AP0WR	22.07	IA9IA6WT	15.27	KA2MO6WR	130.19
IN1MC9WR	66.31	MO2AP0WR	8.39	KA3NO0WB	629.87
IN2OH1WT	25.55	MO3NO0WB	26.15	KA3MO1WT	658.93
IN2MC7WT	69.07	MO4AP0WR	69.29	KA4GV0WR	1218.89
IN3OH1WT	27.17	MO5MO6WT	51.45	KA5GV0WR	945.79
IN4AP0WR	106.88	MO7SE0WR	15.49	KA5KA8WT	412.91
IN5AP0WR	69.20	MO8SE0WR	16.03	KA6NO0WB	2105.21
IN6OH1WT	42.69	MO9AP0WR	329.79	KA7GV0WR	388.34
IN6OH3WR	21.18	ND1DU0WR	411.26	KA9AP0WR	242.44
IN8AP0WR	30.00	ND1SL0WR	1074.87	KA9SE0WR	3.81
IN9NO0WB	32.09	ND2DU0WR	976.00	DU0SW0W2	7.33
IL3IL6WT	38.35	ND3DU0WR	1680.96	DU0NW0W2	124.20
IL4IL2WT	51.70	ND4DU0WR	735.50	DU0FN0W2	27.76
IL5IL2WT	40.64	ND5DU0WR	938.77	DU0DN0W2	31.39
IL7AP0WR	249.27	ND6DU0WR	966.84	DU0UK0W2	641.36
IL7IN7WT	87.87	ND7SL0WR	698.35	DU0IR0W2	41.44
IL8AP0WR	23.77	ND8DU0WR	433.54	DU0NH0W2	1034.25
IL8IL6WT	208.23	ND9DU0WR	700.34	DU0BL0W2	107.26
IL9AP0WR	221.54	SD1DU0WR	274.84	DU0FR0W2	356.98
MC1NE0WR	3.12	SD2DU0WR	661.28	DU0WG0W2	402.79
MC2NE0WR	4.39	SD3DU0WR	363.64	DU0EG0W2	76.60
MC3NE0WR	7.01	SD4DU0WR	125.83	DU0PO0W2	707.54
MC4NE0WR	6.72	SD4MN6WR	125.46	DU0SI0W2	31.39
MC4MC8WR	1.57	SD5MN6WR	325.14	DU0PG0W2	125.05
MC5MC8WT	35.59	SD6MN8WR	33.71	DU0IT0W2	159.22
MC6NE0WR	1.83	SD6MN9WR	8.42	DU0MR0W2	806.36
MC6MC9WT	54.09	SD7SL0WR	152.59	DU0TU0W2	103.74
WI1DU0WT	2.69	SD8MN9WR	320.00	DU0UA0W2	755.24
WI2NE0WR	3.70	SD9MN9WR	22.96	DU0SN0W2	40.81
WI3NE0WR	4.01	NB1SL0WR	976.49	DU0NG0W2	412.44
WI4NE0WR	3.35	NB1MN9WR	91.29	DU0CN0W2	690.61
WI5NE0WR	5.61	NB2MN9WR	100.93	DU0AG0W2	31.49
WI6NE0WR	7.98	NB3NE0WR	42.10	DU0SU0W2	3202.77
WI7NE0WR	1.02	NB4NE0WR	156.99	CH0IT0W2	0.19
WI8IL1WT	3.98	NB5NE0WR	323.29	TO0BL0W2	0.00
WI9NE0WR	15.04	NB6NE0WR	293.64	PH0SU0W4	0.00

Table C-6. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
CS0SU0W4	0.00	GV0VZ0W4	683.78	LA0IS0W6	185.33
NO0UR0W4	170.16	GV0PU0W4	830.30	LA0SA0W6	31.39
NO0SU0W4	2623.16	GV0KN0W4	153.61	LA0VN0W4	2673.01
GV0MX0W4	735.18	GV0SU0W4	3042.27	LA0PP0W4	1032.38
GV0PA0W4	603.55	LA0BZ0W6	1279.32		
GV0JM0W4	135.49	LA0CL0W6	31.39		
GV0TR0W4	164.27	LA0TK0W6	486.05		

Table C-7. Solution 7, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
NE0PH0SR	168.99	WI5CH0SR	4.78	SD6DU0SR	51.19
AP0CS0SR	147.61	WI6CH0ST	8.62	SD8NB2ST	0.07
SE0CS0SR	209.78	WI7CH0SR	5.49	SD9DU0SR	166.65
DL0NO0SR	2271.39	WI8CH0SR	41.89	NB3NB6ST	252.50
SP0GV0SR	58.97	WI9CH0ST	40.63	NB4PF0SR	13.15
MT0PF0SR	2.49	MN1DU0SR	44.21	NB5PF0SR	121.61
OH1TO0ST	811.64	MN1MN2ST	1.50	NB5SD7SR	0.12
OH3OH2ST	16.77	MN1MN3SR	1.52	NB5NB1SR	1.05
OH4TO0ST	538.60	MN4DU0SR	35.53	NB5NB2ST	0.56
OH5TO0ST	116.00	MN5DU0SR	227.71	NB5NB6ST	220.73
OH5OH2ST	162.63	MN5MN6ST	114.77	NB7PF0SR	5.48
OH6OH2ST	5.03	MN7DU0SR	739.07	NB8NB6ST	3.24
OH7NO0SB	190.29	MN8DU0SR	453.33	NB8KA2ST	0.19
OH8PH0SR	86.00	MN9DU0SR	256.40	NB8KA6SR	79.24
OH9PH0SR	5.87	IA1DU0SR	855.08	NB8KA9SR	53.30
IN1CH0ST	551.58	IA2DU0SR	435.51	KA3KA6ST	3.19
IN2CH0ST	378.38	IA3CH0SR	427.22	KA4PF0SR	8.39
IN4CH0ST	322.46	IA4DU0SR	621.86	KA4KA1ST	0.13
IN5IL5SR	13.87	IA5CH0SR	238.86	KA5KA8ST	5.65
IN6TO0SR	319.49	IA6CH0SR	80.47	KA7GV0SR	140.94
IN6IN3ST	3.48	IA7CH0SR	273.91	KA7KA8ST	8.82
IN7NO0SB	369.59	IA7MO4SR	52.93	DU0SW0S2	0.05
IN8NO0SB	97.71	IA7KA6ST	233.31	DU0UK0S2	406.73
IN9NO0SB	121.14	IA8CH0SR	421.48	DU0IR0S2	7.81
IL1CH0ST	558.02	IA9NO0SB	504.17	DU0WG0S2	3638.25
IL1IL2ST	69.08	MO1NO0SB	343.42	DU0EG0S2	7.81
IL3NO0SB	323.84	MO2NO0SB	513.73	CH0NW0S2	249.87
IL4IL2ST	199.49	MO3NO0SB	376.10	CH0DN0S2	562.57
IL6NO0SB	763.88	MO5NO0SB	244.05	CH0NH0S2	497.31
IL7CH0SR	883.21	MO6NO0SB	145.17	CH0BL0S2	252.08
IL7NO0SB	371.51	MO7GV0SR	118.20	CH0WG0S2	2028.41
IL7IL5ST	69.38	MO8NO0SR	33.70	CH0TU0S2	7.81
IL8NO0SB	478.52	MO9NO0SB	1030.63	CH0NG0S2	7.81
IL9NO0SB	499.93	ND1SL0SR	0.08	CH0CN0S2	631.68
MC2TO0SR	0.25	ND2SL0SR	0.05	TO0NH0S2	2198.44
MC3TO0SR	0.22	ND3MN3SR	0.08	TO0PG0S2	12.51
MC4CH0SR	0.16	ND4SL0SR	0.08	TO0AG0S2	7.81
MC5TO0SR	27.36	ND5DU0SR	0.05	PH0SI0S4	260.86
MC6TO0ST	45.72	ND6DU0SR	60.89	CS0SI0S4	324.12
MC7TO0SR	27.36	ND7SL0SR	0.08	CS0UA0S4	33.27
MC8TO0ST	119.94	ND8SL0SR	0.05	NO0PA0S4	15.79
MC9TO0ST	212.18	ND9DU0SR	64.71	NO0JM0S4	11.07
WI1DU0ST	4.30	SD2DU0SR	0.33	NO0TR0S4	7.81
WI2DU0SR	0.56	SD3DU0SR	17.20	NO0VZ0S4	80.35
WI3CH0SR	0.32	SD5DU0SR	0.19	NO0BZ0S4	7.81
WI3MC1ST	0.04	SD5SD1SR	0.12	NO0UR0S4	7.81
WI4DU0SR	25.88	SD5SD4SR	0.12	NO0PU0S4	112.69

Table C-7. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
NOOFROS4	412.82	NOOISOS4	357.48	NOOVNOS4	467.62
NOOPOOS4	142.90	NOOSNOS4	7.81	NOOPPOS4	57.37
NOOSIOS4	660.61	NOOSAOS4	7.81	NOOJPOS4	4653.55
NOOITOS4	693.13	NOOKNOS4	7.81	NOOSUOS4	942.72
NOOTKOS4	0.38	NOOIDOS4	7.81	GVOMXOS4	40.25
NOOMROS4	7.81	NOOPKOS4	7.81	GVOCLOS4	7.92

Table C-8. Solution 8, optimal flows

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
NEOPHOSR	185.92	WI6CHOST	8.96	SD9DUOSR	173.37
APOCSOSR	263.63	WI7CHOSR	5.71	NB3NB6ST	264.03
SEOCSOSR	276.93	WI8CHOSR	43.57	NB4PFOSR	13.73
DLONOOSR	2490.45	WI9CHOST	42.26	NB5DUOSR	14.66
SPOGVOSR	70.70	MN1DUOSR	46.16	NB5PFOSR	129.16
MTOPFOSR	2.49	MN1MN2ST	1.50	NB5SD4SR	0.12
OH1TOOST	845.98	MN1MN3SR	1.52	NB5SD7SR	0.12
OH3OH2ST	17.39	MN4DUOSR	52.01	NB5NB1SR	1.05
OH4TOOST	560.19	MN5DUOSR	245.47	NB5NB2ST	0.54
OH5TOOST	166.85	MN5MN6ST	113.81	NB5NB6ST	212.43
OH5OH2ST	132.95	MN7DUOSR	768.77	NB7PFOSR	5.74
OH6OH2ST	5.18	MN8DUOSR	495.05	NB8KA2ST	0.18
OH7NOOSB	197.88	MN9DUOSR	269.74	NB8KA6SR	103.82
OH8TOOSR	89.40	IA1DUOSR	901.02	NB8KA9SR	37.53
OH9PHOSR	6.05	IA2DUOSR	482.07	KA3KA6ST	3.35
IN1CHOST	573.51	IA3CHOSR	444.43	KA4LAOSR	8.78
IN2CHOST	393.38	IA4DUOSR	656.15	KA4KA1ST	0.11
IN4CHOST	341.90	IA5CHOSR	291.48	KA5KA8ST	1.72
IN3OH2SR	12.38	IA6CHOSR	102.38	KA5KA9SR	4.18
IN5IL2SR	22.04	IA7CHOSR	334.52	KA7GVOSR	155.82
IN5IL5ST	25.09	IA7MO4SR	40.20	DUOSWOS2	0.06
IN6TOOSR	335.75	IA7KA6ST	207.95	DUOUKOS2	488.07
IN7NOOSB	384.23	IA8CHOSR	438.46	DUOIROS2	9.37
IN8NOOSB	101.47	IA9NOOSB	529.10	DUOWGOS2	3833.65
IN9NOOSB	125.83	MO1NOOSB	366.88	DUOEGOS2	7.81
IL1CHOST	652.00	MO2NOOSB	534.47	CHONWOS2	7.82
IL3NOOSB	357.17	MO3NOOSB	399.89	CHODNOS2	529.20
IL4NOOSB	33.92	MO5NOOSB	253.87	CHONHOS2	801.65
IL4IL2ST	216.36	MO6NOOSB	150.99	CHOBLOS2	302.50
IL6NOOSB	814.82	MO7GVOSR	122.93	CHOWGOS2	2774.37
IL7CHOSR	1376.91	MO8NOOSR	35.00	CHONGOS2	7.81
IL8NOOSB	497.47	MO9NOOSB	1072.28	CHOCNOS2	631.68
IL9NOOSB	519.74	ND1SLOSR	0.08	TOONHOS2	2433.26
MC2TOOSR	0.26	ND2SLOSR	0.05	TOOTUOS2	7.81
MC3TOOSR	0.23	ND3MN3SR	0.08	TOOAGOS2	7.81
MC4CHOSR	0.16	ND4SLOSR	0.08	PHOWGOS4	191.97
MC5TOOSR	28.48	ND5DUOSR	0.05	CSODNOS4	145.89
MC6TOOST	47.58	ND6DUOSR	63.34	CSOSIOS4	361.40
MC7TOOSR	28.48	ND7SLOSR	0.08	CSOUAOS4	33.27
MC8TOOST	124.84	ND8SLOSR	0.05	NOOPAOS4	15.79
MC9TOOST	220.84	ND9DUOSR	67.31	NOOJMOS4	11.07
WI1DUOST	4.47	SD2DUOSR	0.35	NOOTROS4	7.81
WI2DUOSR	0.57	SD3DUOSR	17.89	NOOVZOS4	80.35
WI3CHOSR	0.33	SD5DUOSR	0.33	NOOBZOS4	7.81
WI3MC1ST	0.04	SD5SD1SR	0.12	NOOUROS4	7.81
WI4DUOSR	26.92	SD6DUOSR	53.26	NOOPUOS4	112.69
WI5CHOSR	4.97	SD8NB2ST	0.08	NOOCLOS4	7.92

Table C-8. (Continued)

Route	Optimal Flow	Route	Optimal Flow	Route	Optimal Flow
NOOFR0S4	495.38	NOOMR0S4	7.81	NOOPK0S4	7.81
NOOPO0S4	142.90	NOOIS0S4	357.48	NOOVN0S4	714.13
NOOSI0S4	1133.30	NOOSN0S4	7.81	NOOPP0S4	57.37
NOOPG0S4	15.01	NOOSA0S4	7.81	NOOHK0S4	7.81
NOOIT0S4	831.75	NOOKN0S4	7.81	NOOJP0S4	3869.12
NOOTK0S4	0.38	NOOID0S4	7.81	NOOSU0S4	942.72

APPENDIX D. SHADOW PRICES FOR FEED GRAINS, WHEAT, AND SOYBEAN MODELS

Table D-1. Solution 1, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DU0F	-0.08	MC1F	-3.55	MO7F	0.02	VZ0F	8.93
TO0F	0.58	MC2F	-2.06	MO8F	0.56	BZ0F	11.22
PH0F	4.22	MC3F	-1.34	MO9F	-0.01	UR0F	11.86
CS0F	4.09	MC4F	-3.03	ND1F	-3.02	PU0F	9.90
NO0F	3.78	MC5F	-1.63	ND2F	-4.14	CL0F	10.72
GV0F	4.07	MC6F	-0.79	ND3F	-5.19	SW0F	9.27
LA0F	7.76	MC7F	-2.32	ND4F	-3.38	NW0F	9.30
SL0F	8.80	MC8F	-1.69	ND5F	-4.63	FN0F	10.08
NE0F	7.33	MC9F	-0.44	ND6F	-5.10	DN0F	9.38
AP0F	5.17	WI1F	-1.62	ND7F	-2.90	UK0F	8.48
SE0F	4.82	WI2F	-1.27	ND8F	-3.91	IR0F	8.30
DL0F	1.83	WI3F	-2.63	ND9F	-5.20	NH0F	8.14
SP0F	1.47	WI4F	-3.62	SD1F	-3.87	BL0F	8.14
MT0F	0.19	WI5F	-2.84	SD2F	-5.01	FR0F	9.47
PF0F	9.31	WI6F	-2.36	SD3F	-4.87	WG0F	8.42
OH1F	-1.15	WI7F	-3.31	SD4F	-4.03	EG0F	9.51
OH2F	-0.44	WI8F	-3.09	SD5F	-5.18	PO0F	10.73
OH3F	0.23	WI9F	-2.30	SD6F	-5.39	SI0F	10.24
OH4F	-1.66	MN1F	-4.50	SD7F	-3.25	PG0F	9.37
OH5F	-1.00	MN2F	-1.72	SD8F	-5.08	IT0F	10.59
OH6F	-0.34	MN3F	-0.81	SD9F	-6.09	TK0F	11.60
OH7F	-1.16	MN4F	-4.01	NB1F	-3.35	MR0F	10.61
OH8F	-0.23	MN5F	-1.44	NB2F	-4.98	TU0F	11.48
OH9F	-0.39	MN6F	-1.44	NB3F	-6.25	UA0F	11.58
IN1F	-1.95	MN7F	-3.70	NB4F	-4.40	IS0F	11.72
IN2F	-2.72	MN8F	-2.33	NB5F	-5.41	SN0F	11.02
IN3F	-2.06	MN9F	-2.59	NB6F	-5.73	NG0F	12.71
IN4F	-2.91	IA1F	-5.17	NB7F	-5.04	SA0F	12.58
IN5F	-2.37	IA2F	-4.79	NB8F	-5.01	KN0F	14.97
IN6F	-2.17	IA3F	-3.93	KA1F	-4.10	ID0F	16.32
IN7F	-1.86	IA4F	-5.74	KA2F	-5.04	PK0F	16.36
IN8F	-1.57	IA5F	-4.93	KA3F	-4.20	VN0F	16.36
IN9F	-0.90	IA6F	-3.16	KA4F	-4.35	PP0F	15.82
IL1F	-2.55	IA7F	-5.07	KA5F	-4.71	HK0F	15.79
IL2F	-1.42	IA8F	-4.62	KA6F	-3.52	JP0F	13.97
IL3F	-2.50	IA9F	-2.83	KA7F	-4.58	CN0F	5.34
IL4F	-2.19	MO1F	-2.79	KA8F	-4.21	AG0F	13.37
IL5F	-2.66	MO2F	-3.40	KA9F	-2.99	AU0F	13.56
IL6F	-2.14	MO3F	-1.66	MX0F	8.40	SU0F	11.72
IL7F	[illegible].65	MO4F	-3.01	PA0F	8.79	CM0F	15.79
IL8F	-2.09	MO5F	-2.16	JM0F	8.61		
IL9F	-1.97	MO6F	-0.22	TR0F	9.21		

Table D-2. Solution 2, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DUOW	-0.09	MC1W	-1.70	MO7W	-3.77	VZOW	8.55
TOOW	0.58	MC2W	-0.21	MO8W	-2.44	BZOW	10.61
PHOW	4.22	MC3W	0.51	MO9W	-1.22	UROW	11.53
CSOW	4.04	MC4W	-1.18	ND1W	-7.30	PUOW	9.50
NOOW	3.45	MC5W	1.38	ND2W	-6.21	CLOW	9.45
GVOW	3.32	MC6W	1.17	ND3W	-5.20	SWOW	9.26
LAOW	3.43	MC7W	2.21	ND4W	-6.96	NWOW	9.30
SLOW	4.52	MC8W	2.90	ND5W	-5.69	FNOW	10.08
NEOW	9.18	MC9W	3.48	ND6W	-5.11	DNOW	9.38
APOW	6.72	WI1W	-1.63	ND7W	-7.18	UKOW	8.47
SEOW	4.59	WI2W	-1.50	ND8W	-6.48	IROW	8.29
DLOW	-2.35	WI3W	-0.78	ND9W	-5.26	NHOW	8.14
SPOW	-1.72	WI4W	-2.17	SD1W	-6.93	BLOW	8.14
MTOW	-7.47	WI5W	-0.99	SD2W	-5.78	FROW	9.47
PFOW	-2.66	WI6W	-0.51	SD3W	-4.88	WGOW	8.41
OH1W	2.63	WI7W	-1.73	SD4W	-7.42	EGOW	9.50
OH2W	3.16	WI8W	-0.95	SD5W	-6.00	POOW	10.72
OH3W	4.40	WI9W	-0.56	SD6W	-5.05	SIOW	10.23
OH4W	0.96	MN1W	-4.51	SD7W	-7.62	PGOW	9.37
OH5W	0.90	MN2W	-3.65	SD8W	-6.53	ITOW	10.59
OH6W	2.97	MN3W	-3.22	SD9W	-5.48	TKOW	11.32
OH7W	0.39	MN4W	-4.29	NB1W	-8.32	MROW	10.61
OH8W	1.32	MN5W	-1.72	NB2W	-6.69	TUOW	11.48
OH9W	2.97	MN6W	-0.83	NB3W	-5.53	UAOW	11.58
IN1W	-1.03	MN7W	-4.10	NB4W	-7.45	ISOW	11.35
IN2W	-0.23	MN8W	-1.35	NB5W	-6.44	SNOW	11.02
IN3W	1.24	MN9W	-0.56	NB6W	-5.50	NGOW	12.71
IN4W	-1.36	IA1W	-4.16	NB7W	-6.83	SAOW	10.63
IN5W	-0.82	IA2W	-2.76	NB8W	-5.46	KNOW	14.62
IN6W	-0.38	IA3W	-1.96	KA1W	-6.97	IDOW	15.52
IN7W	0.58	IA4W	-3.78	KA2W	-6.02	PKOW	15.80
IN8W	-0.49	IA5W	-1.03	KA3W	-4.75	VNOW	13.32
IN9W	-1.23	IA6W	-0.37	KA4W	-6.35	PPOW	13.09
IL1W	0.78	IA7W	-4.06	KA5W	-5.87	HKOW	12.79
IL2W	1.28	IA8W	-1.38	KA6W	-4.53	JPOW	9.64
IL3W	-2.42	IA9W	-2.15	KA7W	-5.64	CNOW	5.33
IL4W	-1.12	MO1W	-2.17	KA8W	-4.23	AGOW	13.37
IL5W	-0.88	MO2W	-3.43	KA9W	-4.64	AUOW	9.48
IL6W	0.14	MO3W	-1.99	MXOW	7.83	SUOW	11.72
IL7W	-1.94	MO4W	-3.71	PAOW	8.39	CHOW	12.79
IL8W	-2.24	MO5W	-2.05	JMOW	8.23		
IL9W	-1.69	MO6W	0.06	TROW	8.85		

Table D-3. Solution 3, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DUOS	-0.08	MC1S	-1.58	MO7S	-4.92	VZOS	7.70
TOOS	0.58	MC2S	-4.12	MO8S	-4.55	BZOS	9.99
PHOS	3.37	MC3S	-3.79	MO9S	-2.40	UROS	10.63
CSOS	3.19	MC4S	-4.26	ND1S	-4.25	PUOS	8.67
NOOS	2.55	MC5S	-3.37	ND2S	-5.37	CLOS	9.49
GVOS	2.50	MC6S	-2.07	ND3S	-5.07	SWOS	9.27
LAOS	6.53	MC7S	-3.20	ND4S	-4.61	NWOS	9.30
SLOS	7.57	MC8S	-2.61	ND5S	-5.68	FNOS	9.65
NEOS	-0.78	MC9S	-0.44	ND6S	-5.10	DNOS	9.38
APOS	-1.23	WI1S	-1.62	ND7S	-4.13	UKOS	8.48
SEOS	-1.65	WI2S	-3.88	ND8S	-5.14	IROS	8.30
DLOS	-3.27	WI3S	-4.26	ND9S	-5.25	NHOS	8.14
SPOS	-2.54	WI4S	-3.78	SD1S	-2.59	BLOS	8.14
MTOS	-3.62	WI5S	-3.86	SD2S	-5.77	FROS	9.25
PFOS	7.76	WI6S	-3.62	SD3S	-4.87	WGOS	8.42
OH1S	-1.15	WI7S	-3.87	SD4S	-2.51	EGOS	9.51
OH2S	-0.17	WI8S	-3.41	SD5S	-6.02	POOS	10.39
OH3S	-1.80	WI9S	-2.30	SD6S	-5.39	SIOS	9.95
OH4S	-2.30	MN1S	-4.50	SD7S	-1.99	PGOS	9.37
OH5S	-2.43	MN2S	-1.72	SD8S	-5.09	ITOS	10.14
OH6S	-0.86	MN3S	-0.69	SD9S	-6.09	TKOS	10.77
OH7S	-2.39	MN4S	-4.28	NB1S	-2.66	MROS	10.32
OH8S	-3.97	MN5S	-3.54	NB2S	-3.89	TUOS	11.48
OH9S	-3.05	MN6S	-2.12	NB3S	-5.83	UAOS	10.74
IN1S	-1.95	MN7S	-4.93	NB4S	-5.95	ISOS	10.82
IN2S	-3.09	MN8S	-4.29	NB5S	-6.96	SNOS	10.18
IN3S	-1.69	MN9S	-4.15	NB6S	-4.47	NGOS	12.71
IN4S	-3.48	IA1S	-5.17	NB7S	-6.71	SAOS	11.35
IN5S	-2.06	IA2S	-4.83	NB8S	-6.36	KNOS	13.74
IN6S	-3.31	IA3S	-4.47	KA1S	-4.48	IDOS	15.09
IN7S	-3.16	IA4S	-5.85	KA2S	-4.53	PKOS	15.13
IN8S	-3.91	IA5S	-4.93	KA3S	-4.63	VNOS	15.13
IN9S	-2.13	IA6S	-4.26	KA4S	-5.95	PPOS	14.59
IL1S	-2.55	IA7S	-6.25	KA5S	-5.31	HKOS	14.50
IL2S	-0.94	IA8S	-5.22	KA6S	-2.77	JPOS	12.74
IL3S	-3.73	IA9S	-4.06	KA7S	-6.46	CNOS	5.34
IL4S	-3.34	MO1S	-5.20	KA8S	-3.67	AGOS	13.37
IL5S	-2.15	MO2S	-4.63	KA9S	-2.25	AUOS	11.99
IL6S	-3.37	MO3S	-2.89	MXOS	7.01	SUOS	10.82
IL7S	-4.51	MO4S	-2.09	PAOS	7.56		
IL8S	-3.32	MO5S	-3.39	JMOS	7.38		
IL9S	-3.24	MO6S	-2.70	TROS	7.98		

Table D-4. Solution 4, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DUOF	-0.08	MC1F	-3.78	MO7F	-0.20	VZOF	8.93
TOOF	0.58	MC2F	-2.29	MO8F	0.52	BZOF	11.22
PHOF	4.22	MC3F	-1.57	MO9F	-0.01	UROF	11.86
CSOF	4.09	MC4F	-3.26	ND1F	-3.02	PUOF	9.90
NOOF	3.78	MC5F	-1.86	ND2F	-4.14	CLOF	10.72
GVOF	4.07	MC6F	-1.02	ND3F	-5.19	SWOF	9.27
LAOF	7.76	MC7F	-2.55	ND4F	-3.38	NWOF	9.30
SLOF	8.80	MC8F	-1.92	ND5F	-4.63	FNOF	10.08
NEOF	7.10	MC9F	-0.44	ND6F	-5.10	DNOF	9.33
APOF	4.94	WI1F	-1.62	ND7F	-2.90	UKOF	8.46
SEOF	4.78	WI2F	-1.27	ND8F	-3.91	IROF	8.30
DLOF	1.70	WI3F	-2.86	ND9F	-5.20	NHOF	8.14
SPOF	1.34	WI4F	-3.62	SD1F	-3.87	BLOF	8.14
MTOF	0.06	WI5F	-3.07	SD2F	-5.01	FROF	9.47
PFOF	9.18	WI6F	-2.59	SD3F	-4.87	WGOF	8.42
OH1F	-1.15	WI7F	-3.31	SD4F	-4.03	EGOF	9.51
OH2F	-0.67	WI8F	-3.32	SD5F	-5.18	POOF	10.73
OH3F	0.0	WI9F	-2.30	SD6F	-5.39	SIOF	10.24
OH4F	-1.89	MN1F	-4.50	SD7F	-3.34	PGOF	9.37
OH5F	-1.23	MN2F	-1.72	SD8F	-5.09	ITOF	10.59
OH6F	-0.57	MN3F	-0.81	SD9F	-6.09	TKOF	11.60
OH7F	-1.16	MN4F	-4.01	NB1F	-3.48	MROF	10.61
OH8F	-0.46	MN5F	-1.44	NB2F	-5.11	TUOF	11.48
OH9F	-0.62	MN6F	-1.44	NB3F	-6.38	UAOF	11.58
IN1F	-1.95	MN7F	-3.70	NB4F	-4.53	ISOF	11.72
IN2F	-2.95	MN8F	-2.33	NB5F	-5.54	SNOF	11.02
IN3F	-2.29	MN9F	-2.59	NB6F	-5.86	NGOF	12.71
IN4F	-2.95	IA1F	-5.17	NB7F	-5.17	SAOF	12.58
IN5F	-2.60	IA2F	-4.79	NB8F	-5.14	KNOF	14.97
IN6F	-2.40	IA3F	-3.93	KA1F	-4.23	IDOF	16.32
IN7F	-1.90	IA4F	-5.78	KA2F	-5.17	PKOF	16.36
IN8F	-1.61	IA5F	-4.93	KA3F	-4.33	VNOF	16.36
IN9F	-0.90	IA6F	-3.16	KA4F	-4.48	PPOF	15.82
IL1F	-2.55	IA7F	-5.20	KA5F	-4.84	HKOF	15.79
IL2F	-1.42	IA8F	-4.66	KA6F	-3.65	JPOF	13.97
IL3F	-2.50	IA9F	-2.83	KA7F	-4.71	CNOF	5.34
IL4F	-2.19	MO1F	-3.20	KA8F	-4.34	AGOF	13.37
IL5F	-2.66	MO2F	-3.40	KA9F	-3.21	AUOF	13.56
IL6F	-2.14	MO3F	-1.66	MXOF	8.40	SUOF	11.72
IL7F	-2.69	MO4F	-3.14	PAOF	8.79	CMOF	15.79
IL8F	-2.09	MO5F	-2.16	JMOF	8.61		
IL9F	-2.01	MO6F	-0.26	TROF	9.21		

Table D-5. Solution 5, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DUOF	-0.08	MC1F	-3.50	MO7F	0.07	VZOF	8.93
TOOF	0.58	MC2F	-2.01	MO8F	0.61	BZOF	11.22
PHOF	4.22	MC3F	-1.29	MO9F	-0.01	UROF	11.86
CSOF	4.09	MC4F	-2.98	ND1F	-3.02	PUOF	9.90
NOOF	3.78	MC5F	-1.58	ND2F	-4.14	CLOF	10.72
GVOF	4.07	MC6F	-0.74	ND3F	-5.19	SWOF	9.27
LAOF	7.76	MC7F	-2.27	ND4F	-3.38	NWOF	9.30
SLOF	8.80	MC8F	-1.64	ND5F	-4.63	FNOF	10.08
NEOF	7.38	MC9F	-0.44	ND6F	-5.10	DNOF	9.38
APOF	5.22	WI1F	-1.62	ND7F	-2.90	UKOF	8.48
SEOF	4.87	WI2F	-1.27	ND8F	-3.91	IROF	8.30
DLOF	1.88	WI3F	-2.58	ND9F	-5.20	NHOF	8.14
SPOF	1.79	WI4F	-3.62	SD1F	-3.87	BLOF	8.14
MTOF	0.24	WI5F	-2.79	SD2F	-5.01	FROF	9.47
PFOF	9.36	WI6F	-2.31	SD3F	-4.87	WGOF	8.42
OH1F	-1.15	WI7F	-3.31	SD4F	-4.03	EGOF	9.51
OH2F	-0.39	WI8F	-3.04	SD5F	-5.18	POOF	10.73
OH3F	0.28	WI9F	-2.30	SD6F	-4.72	SIOF	10.24
OH4F	-1.61	MN1F	-4.50	SD7F	-3.20	PGOF	9.37
OH5F	-0.95	MN2F	-1.72	SD8F	-5.03	ITOF	10.59
OH6F	-0.29	MN3F	-0.81	SD9F	-6.09	TKOF	11.60
OH7F	-1.11	MN4F	-4.01	NB1F	-3.30	MROF	10.61
OH8F	-0.18	MN5F	-1.44	NB2F	-4.93	TUOF	11.48
OH9F	-0.34	MN6F	-1.44	NB3F	-6.20	UAOF	11.58
IN1F	-1.95	MN7F	-3.03	NB4F	-4.35	ISOF	11.72
IN2F	-2.67	MN8F	-2.33	NB5F	-5.36	SNOF	11.02
IN3F	-2.01	MN9F	-2.59	NB6F	-5.68	NGOF	12.71
IN4F	-2.86	IA1F	-5.17	NB7F	-4.99	SAOF	12.58
IN5F	-2.32	IA2F	-4.79	NB8F	-4.96	KNOF	14.97
IN6F	-2.12	IA3F	-3.93	KA1F	-4.05	IDOF	16.32
IN7F	-1.81	IA4F	-5.69	KA2F	-4.99	PKOF	16.36
IN8F	-1.52	IA5F	-4.93	KA3F	-4.15	VNOF	16.36
IN9F	-0.90	IA6F	-3.16	KA4F	-4.30	PPOF	15.82
IL1F	-2.55	IA7F	-5.02	KA5F	-4.66	HKOF	15.79
IL2F	-1.42	IA8F	-4.57	KA6F	-3.47	JPOF	13.97
IL3F	-2.50	IA9F	-2.83	KA7F	-4.26	CNOF	5.34
IL4F	-2.19	MO1F	-2.45	KA8F	-3.89	AGOF	13.37
IL5F	-2.66	MO2F	-3.40	KA9F	-2.94	AUOF	13.56
IL6F	-2.14	MO3F	-1.66	MXOF	8.40	SUOF	11.72
IL7F	-2.60	MO4F	-2.96	PAOF	8.79	CHOF	15.79
IL8F	-2.09	MO5F	-2.16	JMOF	8.61		
IL9F	-1.92	MO6F	-0.17	TROF	9.21		

Table D-6. Solution 6, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DU0W	-0.09	MC1W	-1.70	MO7W	-3.77	VZ0W	8.55
TO0W	0.58	MC2W	-0.21	MO8W	-2.44	BZ0W	10.66
PH0W	4.22	MC3W	0.51	MO9W	-1.22	UR0W	11.53
CS0W	4.04	MC4W	-1.18	ND1W	-7.30	PU0W	9.50
NO0W	3.45	MC5W	1.38	ND2W	-6.21	CL0W	9.50
GV0W	3.32	MC6W	1.06	ND3W	-5.20	SW0W	9.26
LA0W	3.48	MC7W	2.12	ND4W	-6.96	NW0W	9.30
SL0W	4.52	MC8W	2.90	ND5W	-5.69	FN0W	10.08
NE0W	9.18	MC9W	3.37	ND6W	-5.11	DN0W	9.38
AP0W	6.72	WI1W	-1.63	ND7W	-7.18	UK0W	8.47
SE0W	4.59	WI2W	-1.50	ND8W	-6.48	IR0W	8.29
DL0W	-2.35	WI3W	-0.78	ND9W	-5.26	NH0W	8.14
SP0W	-1.72	WI4W	-2.17	SD1W	-6.93	BL0W	8.14
MT0W	-7.42	WI5W	-0.99	SD2W	-5.78	FR0W	9.47
PF0W	-2.61	WI6W	-0.51	SD3W	-4.88	WG0W	8.41
OH1W	2.54	WI7W	-1.73	SD4W	-7.42	EG0W	9.50
OH2W	3.07	WI8W	-0.95	SD5W	-6.00	PO0W	10.72
OH3W	4.31	WI9W	-0.56	SD6W	-5.05	SI0W	10.23
OH4W	0.87	MN1W	-4.51	SD7W	-7.62	PG0W	9.37
OH5W	0.81	MN2W	-3.65	SD8W	-6.53	IT0W	10.59
OH6W	2.88	MN3W	-3.22	SD9W	-5.48	TK0W	11.37
OH7W	0.39	MN4W	-4.29	NB1W	-8.32	MR0W	10.61
OH8W	1.32	MN5W	-1.72	NB2W	-6.69	TU0W	11.48
OH9W	2.88	MN6W	-0.83	NB3W	-5.53	UA0W	11.58
IN1W	-1.14	MN7W	-4.10	NB4W	-7.45	IS0W	11.40
IN2W	-0.32	MN8W	-1.35	NB5W	-6.44	SN0W	11.02
IN3W	1.15	MN9W	-0.56	NB6W	-5.50	NG0W	12.71
IN4W	-1.36	IA1W	-4.16	NB7W	-6.83	SA0W	10.68
IN5W	-0.82	IA2W	-2.76	NB8W	-5.46	KN0W	14.62
IN6W	-0.47	IA3W	-1.96	KA1W	-6.97	ID0W	15.52
IN7W	0.58	IA4W	-3.78	KA2W	-6.02	PK0W	15.80
IN8W	-0.49	IA5W	-1.03	KA3W	-4.75	VN0W	13.37
IN9W	-1.23	IA6W	-0.37	KA4W	-6.35	PP0W	13.14
IL1W	0.78	IA7W	-4.06	KA5W	-5.87	HK0W	12.84
IL2W	1.28	IA8W	-1.38	KA6W	-4.53	JP0W	9.69
IL3W	-2.42	IA9W	-2.15	KA7W	-5.64	CN0W	5.33
IL4W	-1.12	MO1W	-2.17	KA8W	-4.23	AG0W	13.37
IL5W	-0.88	MO2W	-3.43	KA9W	-4.64	AU0W	9.53
IL6W	0.14	MO3W	-1.99	MX0W	7.83	SU0W	11.72
IL7W	-1.94	MO4W	-3.71	PA0W	8.39	CH0W	12.84
IL8W	-2.24	MO5W	-2.05	JM0W	8.23		
IL9W	-1.69	MO6W	0.06	TR0W	8.85		

Table D-7. Solution 7, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DU0S	-0.08	MC1S	-1.58	MO7S	-4.84	VZ0S	7.78
TO0S	0.58	MC2S	-4.12	MO8S	-4.47	BZ0S	10.07
PH0S	3.45	MC3S	-3.79	MO9S	-2.32	UR0S	10.71
CS0S	3.27	MC4S	-4.26	ND1S	-4.17	PU0S	8.75
NO0S	2.63	MC5S	-3.37	ND2S	-5.29	CL0S	9.57
GV0S	2.58	MC6S	-2.07	ND3S	-5.07	SW0S	9.27
LA0S	6.61	MC7S	-3.20	ND4S	-4.53	NW0S	9.30
SL0S	7.65	MC8S	-2.61	ND5S	-5.68	FN0S	9.73
NE0S	-0.70	MC9S	-0.44	ND6S	-5.10	DN0S	9.38
AP0S	-1.15	WI1S	-1.62	ND7S	-4.05	UK0S	8.48
SE0S	-1.57	WI2S	-3.88	ND8S	-5.06	IR0S	8.30
DL0S	-3.19	WI3S	-4.26	ND9S	-5.25	NH0S	8.14
SP0S	-2.46	WI4S	-3.78	SD1S	-2.59	BL0S	8.14
MT0S	-3.62	WI5S	-3.86	SD2S	-5.77	FR0S	9.33
PF0S	7.76	WI6S	-3.62	SD3S	-4.87	WG0S	8.42
OH1S	-1.15	WI7S	-3.87	SD4S	-2.51	EG0S	9.51
OH2S	-0.17	WI8S	-3.41	SD5S	-6.02	PO0S	10.47
OH3S	-1.80	WI9S	-2.30	SD6S	-5.39	SI0S	10.03
OH4S	-2.30	MN1S	-4.50	SD7S	-1.99	PG0S	9.37
OH5S	-2.43	MN2S	-1.72	SD8S	-5.09	IT0S	10.22
OH6S	-0.86	MN3S	-0.69	SD9S	-6.09	TK0S	10.85
OH7S	-2.31	MN4S	-4.28	NB1S	-2.66	MR0S	10.40
OH8S	-3.89	MN5S	-3.54	NB2S	-3.89	TU0S	11.48
OH9S	-2.97	MN6S	-2.12	NB3S	-5.83	UA0S	10.82
IN1S	-1.95	MN7S	-4.93	NB4S	-5.95	IS0S	10.90
IN2S	-3.09	MN8S	-4.29	NB5S	-6.96	SN0S	10.26
IN3S	-1.69	MN9S	-4.15	NB6S	-4.47	NG0S	12.71
IN4S	-3.48	IA1S	-5.17	NB7S	-6.71	SA0S	11.43
IN5S	-5.84	IA2S	-4.83	NB8S	-6.36	KN0S	13.82
IN6S	-3.31	IA3S	-4.47	KA1S	-4.48	ID0S	15.17
IN7S	-3.08	IA4S	-5.85	KA2S	-4.53	PK0S	15.21
IN8S	-3.83	IA5S	-4.93	KA3S	-4.63	VN0S	15.21
IN9S	-2.05	IA6S	-4.26	KA4S	-5.95	PP0S	14.67
IL1S	-2.55	IA7S	-6.25	KA5S	-5.23	HK0S	14.58
IL2S	-0.94	IA8S	-5.22	KA6S	-2.77	JP0S	12.82
IL3S	-3.65	IA9S	-3.98	KA7S	-6.38	CN0S	5.34
IL4S	-3.34	MO1S	-5.12	KA8S	-3.59	AG0S	13.37
IL5S	-2.15	MO2S	-4.55	KA9S	-2.25	AU0S	12.07
IL6S	-3.29	MO3S	-2.81	MX0S	7.09	SU0S	10.90
IL7S	-4.51	MO4S	-2.09	PA0S	7.64		
IL8S	-3.24	MO5S	-3.31	JM0S	7.46		
IL9S	-3.16	MO6S	-2.62	TR0S	8.06		

Table D-8. Solution 8, shadow prices

Region	Shadow Price	Region	Shadow Price	Region	Shadow Price	Region	Shadow Price
DUOS	-0.08	MC1S	-1.58	MO7S	-4.92	VZOS	7.61
TOOS	0.58	MC2S	-4.12	MO8S	-4.64	BZOS	9.90
PHOS	3.28	MC3S	-3.79	MO9S	-2.49	UROS	10.54
CSOS	3.10	MC4S	-4.26	ND1S	-4.34	PUOS	8.58
NOOS	2.46	MC5S	-3.37	ND2S	-5.46	CLOS	9.40
GVOS	2.50	MC6S	-2.07	ND3S	-5.07	SWOS	9.27
LAOS	6.44	MC7S	-3.20	ND4S	-4.70	NWOS	9.30
SLOS	7.48	MC8S	-2.61	ND5S	-5.68	FNOS	9.65
NEOS	-0.87	MC9S	-0.44	ND6S	-5.10	DNOS	9.38
APOS	-1.32	WI1S	-1.62	ND7S	-4.22	UKOS	8.48
SEOS	-1.74	WI2S	-3.88	ND8S	-5.23	IROS	8.30
DLOS	-3.36	WI3S	-4.26	ND9S	-5.25	NHOS	8.14
SPOS	-2.54	WI4S	-3.78	SD1S	-2.59	BLOS	8.14
MTOS	-4.16	WI5S	-3.86	SD2S	-5.77	FROS	9.16
PFOS	7.22	WI6S	-3.62	SD3S	-4.87	WGOS	8.42
OH1S	-1.15	WI7S	-3.87	SD4S	-2.93	EGOS	9.51
OH2S	-0.17	WI8S	-3.41	SD5S	-6.02	POOS	10.30
OH3S	-1.80	WI9S	-2.30	SD6S	-5.39	SIOS	9.86
OH4S	-2.30	MN1S	-4.50	SD7S	-2.53	PGOS	9.36
OH5S	-2.43	MN2S	-1.72	SD8S	-5.63	ITOS	10.05
OH6S	-0.86	MN3S	-0.69	SD9S	-6.09	TKOS	10.68
OH7S	-2.48	MN4S	-4.28	NB1S	-3.20	MROS	10.23
OH8S	-4.00	MN5S	-3.54	NB2S	-4.43	TUOS	11.48
OH9S	-3.14	MN6S	-2.12	NB3S	-6.37	UAOS	10.65
IN1S	-1.95	MN7S	-4.93	NB4S	-6.49	ISOS	10.73
IN2S	-3.09	MN8S	-4.29	NB5S	-7.50	SNOS	10.09
IN3S	-2.57	MN9S	-4.15	NB6S	-5.01	NGOS	12.71
IN4S	-3.48	IA1S	-5.17	NB7S	-7.25	SAOS	11.26
IN5S	-5.41	IA2S	-4.83	NB8S	-6.36	KNOS	13.65
IN6S	-3.31	IA3S	-4.47	KA1S	-4.86	IDOS	15.00
IN7S	-3.25	IA4S	-5.85	KA2S	-4.53	PKOS	15.04
IN8S	-4.00	IA5S	-4.93	KA3S	-4.63	VNOS	15.04
IN9S	-2.22	IA6S	-4.26	KA4S	-6.33	PPOS	14.50
IL1S	-2.55	IA7S	-6.25	KA5S	-6.06	HKOS	14.47
IL2S	-1.11	IA8S	-5.22	KA6S	-2.77	JPOS	12.65
IL3S	-3.82	IA9S	-4.15	KA7S	-6.46	CNOS	5.34
IL4S	-3.51	MO1S	-5.29	KA8S	-4.42	AGOS	13.37
IL5S	-3.01	MO2S	-4.72	KA9S	-2.25	AUOS	11.99
IL6S	-3.46	MO3S	-2.98	MXOS	7.01	SUOS	10.73
IL7S	-4.51	MO4S	-2.09	PAOS	7.47		
IL8S	-3.41	MO5S	-3.48	JMOS	7.29		
IL9S	-3.33	MO6S	-2.79	TROS	7.89		