An Economic Evaluation of Optimal Intermodal Soybean Flows in Arkansas With Projected Effects of the North American Free Trade Agreement

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The optimal intermodal flow of Arkansas soybeans in 1993 is estimated using both survey data and a linear programming model. Results indicate that both approaches are consistent with each other, suggesting that the linear programming model adequately captures real world behavior and that Arkansas elevators and subterminals are marketing soybeans in an optimal manner. The optimal mode of transporting soybeans from elevators and subterminals to in-state processors is by truck. Rail is found to be the optimal mode of transporting soybeans to Galveston, while barge is optimal for transporting soybeans to New Orleans. The Arkansas soybean marketing and transportation infrastructure as of 1993 is deemed to be adequate to meet any possible increased export demand for soybeans resulting from NAFTA.

1. Introduction

Grain marketing may be defined as "the performance of all business activities that coordinate the flow of goods and services from grain producers to consumers and users." This analysis examines the transportation component of the grain marketing system within Arkansas. Specifically, (1) optimal intermodal flows of soybeans within Arkansas are determined and (2) the effect of the North American Free Trade Agreement (NAFTA) on the Arkansas soybean transportation and marketing system is estimated. The first objective is tackled by using both survey data and a theoretical linear programming model. Simulations which model increased soybean export demand are used to address the second issue.

This study focuses on the Arkansas soybean marketing and transportation system for the 1993 marketing year. Soybeans and rice are the two most important crops grown in Arkansas both in volume and dollar terms. Over the period 1990-96 soybeans and rice accounted for 29.6% and 47.1% of all grain and oilseed production measured in bushels. Over the same period soybeans and rice accounted for 44.4% and 39.1% of the dollar value of all grain and oilseed production. The distribution of Arkansas produced grain and oilseeds begins with transportation from supply points to country elevators, subterminals, millers, processors and other end users such as poultry integrators. Country elevators and subterminals may subsequently ship grain and oilseeds by truck, rail or barge to consumption areas referred to in this paper as final destination points. Truck shipments may be hauled by truck-brokers, by private trucks and by regulated motor carriers. With respect to barge shipments, one barge can typically carry 1,500 tons of goods, which is the equivalent of 60 trucks or 15 rail cars. A typical barge shipment might actually consist of 36 barges controlled by one boat. Although Arkansas has an established rail distribution network not all elevators have rail connections. For example, in 1987, of the 18 waterfront grain elevators located in Arkansas, all received grain by truck for shipment by barge, but only two had facilities for receipt and shipment by rail. The distribution process by which soybeans are transported from elevators and subterminals to final destination points is referred to in this paper as an intermodal flow. The next section of this paper outlines a theoretical linear programming model designed to determine the optimal intermodal flow of Arkansas soybeans from elevators and subterminals to final destination points. The third section discusses data considerations and describes a survey designed to elucidate information about the soybean marketing practices of Arkansas elevators and subterminals during 1993. Estimated model results are presented in Section 4 and are compared to the survey results. Section 5 draws final concluding comments.

2. Model Specification

The optimal intermodal flow of soybeans in Arkansas by transportation mode and facility location is determined by using a modified version of a linear programming model developed by Hilger, McCarl and Uhrig 1977. Specifically, the total cost associated with marketing soybeans from the various production regions of Arkansas to final demand or consumption destinations is minimized, subject to various supply and demand constraints.

The problem is characterized by minimizing the objective function:

(1) $$\text{Minimize TC} = \sum_{t=1}^{12}\left[\sum_{i=1}^{50}\sum_{j=1}^{14} c_{ijt} X_{ijt} + \sum_{i=1}^{50}\sum_{k=1}^{5} d_{ikt} Y_{ikt} + \sum_{j=1}^{14}\sum_{k=1}^{5}\sum_{m=1}^{3} e_{jkmt} Z_{jkmt}\right]$$

Subject to the following constraints:

(2) $$\sum_{j=1}^{14} X_{ijt} + \sum_{k=1}^{5} Y_{ikt} \leq SE_{it} \quad i = 1,...,50;\ t = 1,....,12.$$

(3) $$\sum_{k=1}^{5}\sum_{m=1}^{3} Z_{jkmt} \leq SS_{jt} + \sum_{i=1}^{50} X_{ijt} \quad j = 1,...,14;\ t = 1,...,12.$$

(4) $$\sum_{j=1}^{14} X_{ijt} + \sum_{k=1}^{5} Y_{ikt} \leq SC_{it} \quad i = 1,...,50;\ t = 1,...,12.$$

(5) $$\sum_{k=1}^{5} Z_{jkmt} \leq SC_{jmt} \quad j = 1,...,14;\ t = 1,...,12;\ m = 1,2,3.$$

(6) $$\sum_{i=1}^{50} X_{ijt} \leq RC_{jt} \quad j = 1,...,14;\ t = 1,...,12.$$

(7) $$\sum_{i=1}^{50} Y_{ikt} \geq \sum_{j=1}^{14}\sum_{m=1}^{3} Z_{jkmt} \geq D_{kt} \quad k = 1,...,5;\ t = 1,...,12.$$

where:

i, j, k, m and t index country elevators, subterminals, destinations, transportation modes and moths respectively;

c_{ijt} = Per unit costs of country elevator i soybean shipments to subterminal j in month t;

X_{ijt} = Quantity of soybeans shipped from country elevator i to subterminal j in month t.

d_{ikt} = Per unit costs of country elevator i soybean shipments to destination k in month t;

Y_{ikt} = Quantity of soybeans shipped from country elevator i to destination k in month t;

e_{jkmt} = Per unit costs of subterminal j soybean shipments to destination k, by mode m, in month t.

Z_{jkmt} = Quantity of soybeans shipped from subterminal j to destination k, by mode m, in month t.

SE_{it} = Regional supply of soybeans available to country elevator i at time t.

SS_{jt} = Regional supply of soybeans available to subterminal j.

SC_{it} = Monthly shipping capacity of country elevator i at time t.

SC_{jmt} = Monthly shipping capacity of subterminal j to destination k, by mode m, in month t.

RC_{jt} = Monthly receiving capacity of subterminal j, and

D_{kt} = Final demand for soybeans at destination k in month t.

From the objective function in (1), it can be seen that monthly grain marketing costs are comprised of three terms: (I) $\sum_{i=1}^{50}\sum_{j=1}^{14} c_{ijt}X_{ijt}$, the summation of the total cost associated with shipping a given quantity of soybeans from elevator i to subterminal j;

(ii) $\sum_{i=1}^{50}\sum_{k=1}^{5} d_{ikt}Y_{ikt}$, the summation of the total cost associated with shipping a given quantity of soybeans from elevator i to destination k; and (iii) $\sum_{j=1}^{14}\sum_{k=1}^{5}\sum_{m=1}^{3} e_{jkmt}Z_{jkmt}$, which is the summation of the total cost of shipping a given quantity of soybeans from subterminal j to destination k. Soybean shipments from elevators to either subterminals or final detination points are restricted to truck shipments because as indicated in the survey, which is discussed in the following section, this is the primary mode of transportation available to them. Shipments from subterminals to final destination points may be made by any of the three available modes of transportation – truck, rail or barge.

Turning to the model constraints, equation (2) requires that shipments of soybeans from elevators to subterminals and to final destination points be less than or equal to the regional supply of soybeans available to each elevator. The second constraint specified in equation (3) requires that soybean shipments from subterminals to final destination points be less than or equal to the regional supply of soybeans available to subterminals plus soybean shipments from elevators. Equation (4) limits elevator shipments of soybeans, to both subterminals and final destination points, to be less than or equal to the monthly elevator shipping capacity based on a 25-day work month with 12-hour days. Each elevator's hourly shipping capacity was determined from survey responses. Similarly subterminal shipping capacities are determined from survey results and soybean shipments from subterminals to final destination points are constrained by equation (5) to be less than or equal to the monthly subterminal shipping capacities. The quantity of soybeans that are shipped from elevators to subterminals is constrained to be less than or equal to the receiving capacities of the respective subterminals, as defined by equation (6). The final constraint addressed in equation (7) insures that demand at each final destination is less than or equal to the total supply of soybeans, which consists of the quantity of soybeans shipped from both elevators and subterminals. Demand at each final destination is determined from survey results.

3. Grain Transportation Survey and Data Considerations

The theoretical model outlined above is estimated using both survey and historical data for 1993 on grain transportation and processing in Arkansas. The survey, which consisted of two main sections, was targeted to all grain elevators and subterminals listed in the *1992 Arkansas Directory of Grain Elevators (Cooperative Extension Service).* After two mailings, 64 out of a possible 239 questionnaires were returned in a useable form giving us a 26.7% successful response rate. The first section of the survey was designed to solicit questions as to the likely effect of NAFTA on the various aspects of rice and soybean marketing in Arkansas. The second section was designed to determine the current shipping and receiving capacity of facilities by type of grain, storage capacity of facilities, modes of transportation serving the facilities, the monthly quantity of shipments and the percentage of grain shipped to alternative final destinations. The use of survey data is necessary given the unavailability of documented information relating to soybean storage, shipping and receiving capacities for Arkansas elevators and subterminals during 1993. Figure 1 shows the main grain production regions of Arkansas, the location of the elevators and subterminals surveyed and the location of the final destination points. Three in-state soybean processors located at

Helena, Little Rock and Stuttgart, and the ports of Galveston and New Orleans constitute the final destination points.

With regard to the effect of NAFTA, survey respondents indicated that they strongly believed that rice and soybean exports would increase and that the current Arkansas transportation infrastructure as of 1993 would not limit grain exports to Mexico. Note that data collected on rice from the second section of the questionnaire is not reported as the survey results showed that rough rice was not being shipped for export during the period under analysis. Therefore all subsequent results are reported only with respect to soybeans.

Data on soybean shipping capacities for 50 country elevators and 14 subterminals are reported in Table 1. Elevator rail shipping capacities were lowest, averaging approximately 3,500 bushels per hour (bph). Truck capacities were somewhat higher, averaging almost 5,000 bph for elevators and 13,250 bph for subterminals. Barge capacities had the highest average capacities ranging from 10,000 bph for elevators to 40,000 bph for subterminals.

Soybean receiving capacities for the above elevators and subterminals are presented in Table 2. Elevator rail receiving capacities averaged just over 2,000 bph, while subterminal rail receiving capacities averaged 6,000 bph. Truck receiving capacities were much larger, with the average subterminal capacity reaching 16,000 bph. Only two locations reported barge receiving capacities, an elevator with a capacity of 20,000 bph and a subterminal with a capacity of just 3,800 bph.

The survey respondents also cited their preferred mode of transport. Although 15 of the country elevators were served by a rail line none of them cited rail as their preferred method of shipping soybeans. Reasons given for not shipping by rail included inadequate loading and rail car storage facilities, poor service and high freight rates. Some 58% of elevators cited truck as the preferred method of shipping soybeans and 14% cited barge. Although more than 35% of all subterminals were served by rail line as with elevators none indicated rail as the preferred method of shipping soybeans. The subterminals provided similar reasons to those of the elevators for not using rail. Trucking was again cited by most respondents as the preferred method of shipping soybeans, with 28% preferring barge.

The survey also provided information on monthly storage levels and monthly shipments of soybeans for both elevators and subterminals during 1993. This data is summarized in Table 3. The data on actual shipments and mode of transport used by each facility during 1993 are compared to the estimated optimal intermodal flows from our theoretical model and are discussed in Section 4. The seasonal nature of grain production and marketing is highlighted in the data. Elevators had the largest amount of soybeans in storage during January following the annual harvest. The smallest amount of soybeans in storage occurred in September just prior to the arrival of the new crop. Total soybean shipments for elevators were strongly related to production and storage levels. The largest shipments occurred in February whilst the smallest number were shipped in September. Similarly, subterminals had the largest amount of soybeans in storage in December and the smallest in October. Total shipments of soybeans for subterminals were largest in February and the smallest amount of shipments took place in October.

Highway distances and truck transportation rates are calculated from each elevator to each subterminal and final destination points, and from each subterminal to each final destination. Transportation rates are obtained from telephone surveys and are based on a 25 short ton capacity truck. In-state rates are $6.00 per ton for zero to 50 miles, $8.00 per ton for 51 to 100 miles, $10.00 per ton for 101 to 150 miles and $12.00 per ton for 151 to 200 miles. It is assumed that all in-state transportation is by truck. For truck rates to the final destination points of Galveston and New Orleans, $1.42 per mile is used. Railroad hopper-car rates are obtained from railroad companies and the hopper-car capacity is equal to 80 short tons. Barge rates are obtained from a barge company and the rate is given as $6.50 per short ton from all locations to New Orleans.

Regional supply available to elevators, defined as SE_{it} in equation (2) and regional supply available to subterminals, defined as SS_{jt} in equation (3) is determined by adding published county soybean production data in bushels to monthly soybean storage levels for the various facility locations.

Final soybean demand by the three designated Arkansas soybean processors are determined by telephone contact with one cooperating soybean processor, and estimating the demand at the other two locations using information form industry personnel. Final soybean demand for the final destination points of Galveston and New Orleans are determined by converting the percentage of total shipments from each facility location to each destination into physical bushels and summing the amount shipped from all locations.

The use of survey data provides us with unique insights into the Arkansas soybean marketing system. The survey responses allow us to estimate the theoretical model developed in Section 3 and then to compare the optimal intermodal soybean flows as indicated by our model with the actual flows that occurred in 1993. Estimated results and model comparisons with actual 1993 soybean flows are discussed in the following section.

4. Results

The optimal intermodal flow of soybeans in Arkansas during 1993 is determined by solving the linear programming model developed in Section 3. The model is estimated with respect to 50 elevators and 14 subterminals shipping to five final destinations, which comprise the two export locations of New Orleans and Galveston and the three Arkansas soybean processors located in Helena, Little Rock and Stuttgart. The results presented in Table 4 show the optimal intermodal flow of soybeans in terms of shipment quantities from elevators and subterminals to final destination points by transportation mode.

Given the model assumption that elevators only use trucks to ship soybeans, results indicate that no elevator shipments should be made to New Orleans or Galveston. However, the model places no restrictions as to transportation mode for subterminals. Table 4 shows that with respect to New Orleans all soybean shipments from subterminals should be by barge. In contrast the model determines rail to be the optimal mode of transporting soybeans to Galveston. These results reflect that the dollar per ton transportation cost to ship from subterminals by barge to New Orleans or by rail to Galveston is significantly less than by truck. The optimal mode of transport of soybean shipments to the Arkansas soybean processors was determined to be by truck. Although some subterminals have rail facilities available, the lack of competitive rates resulted in the model predicting no in-state rail shipments assuming optimal behavior.

Table 5 reports both the model-determined optimal shipments and actual shipments determined from the survey data, in terms of quantities and mode of transport. Results indicate that the model determined modes of transportation used by elevators and subterminals and the quantities of soybeans shipped by these modes to final destinations are consistent with the modes and quantities reported in the survey. The results show our theoretical model adequately captures real world behavior and that Arkansas elevators and subterminals are marketing soybeans in an optimal manner.

Survey results for shipments to New Orleans were consistent with the theoretical model with barge being the only mode of transport used. Three subterminals located in Woodruff, Prairie and Monroe counties shipped on the White River and one subterminal located in Jefferson County shipped on the Arkansas River. Both of these waterways flow into the Mississippi River. Two subterminals located in Mississippi County shipped directly on the Mississippi River.

Survey results were also consistent with model estimates for shipments to Galveston. One subterminal located in Desha County shipped all the Arkansas produced soybeans demanded by Galveston. Inland waterways do not exist to ship by barge to Galveston so the next least-cost mode of transport available for shipment to out-of-state destinations, in the form of rail, was used.

Turning to the final in-state destinations, both the theoretical model and survey results showed that all shipments from both elevators and subterminals to the soybean processor located at Helena were by truck. A general southerly flow is evident as this processor draws from two elevators and one subterminal located in Phillips County, facilities located in the surrounding counties of Arkansas, Monroe, Lee, St Francis and facilities located in the more northern counties of Jackson, Poinsett, Crittenden and Craighead. Similarly the model predicted all shipments from both elevators and subterminals to the soybean processor at Little Rock would be made by truck. As expected, general flows of soybeans come from nearby facilities located in Pulaski, Conway, Faulkner, Lonoke and Jefferson counties, and from more distant facilities located in Prairie, White, Woodruff, Jackson, Poinsett and Cross counties to the northeast of Little Rock. As with Helena and Little Rock the third in-state processor, located at Stuttgart received all shipments by truck. It draws from the facilities located in surrounding counties and counties to the northeast, which include Arkansas, Desha, Lincoln, Jefferson, Phillips, Lonoke, Prairie, Monroe, Lee, St. Francis, White, Woodruff, Cross, Crittenden, Jackson and Poinsett.

The model constraints defined in equations (4)-(6) which limit shipments by shipping capacity and receiving capacities respectively were not binding and the destination demand constraint in equation (7) was satisfied.

A secondary issue addressed in this paper relates to the effect of the North American Free Trade Agreement (NAFTA) on the Arkansas soybean transportation system. The theoretical model was re-estimated based on projected increases in the demand for soybeans, which might occur as a result of the free trade agreement. Specifically, increases in the quantities of soybeans being shipped to New Orleans and Galveston, ranging from 10% to 48% are simulated to reflect possible increases in export shipments due to NAFTA. Results show that increases of up to 47.5% do not alter model results, suggesting that the Arkansas soybean infrastructure as of 1993 is capable of meeting any increased demands imposed upon it by NAFTA. An increase of 48%

violates constraints (2) and (3) relating to the available regional supply as of 1993. Of course these results are static in nature and do not take into account any dynamic supply response, which would in turn be endogenous to the model and dependent on the increased demand induced by NAFTA.

5. Conclusions

The optimal intermodal flow of soybeans in Arkansas during 1993 was analyzed using both survey data and a theoretical linear programming model. Both approaches are consistent with each other, suggesting that the model adequately captures real world behavior and that Arkansas elevators and subterminals are marketing soybeans in an optimal manner. The optimal mode of transporting soybeans to in-state soybean processors is found to be by truck. In contrast the optimal method of shipping to the final destinations of Galveston and New Orleans, located out of state is by rail and barge respectively. This is explained by the fact that rail and barge offer lower rates than trucks on longer distances. Simulated increases in the quantity of soybeans shipped to Galveston and New Orleans suggest that soybean marketing infrastructure in Arkansas as of 1993 is adequate to meet any increased demand resulting from NAFTA.

Table 1

Soybean Shipping Capacities for 1993 in (bph)

Item	Number	Average	Std Dev	Min	Max
Elevators					
Truck	37	4,949	3,661	30	14,000
Rail	7	3,500	1,826	1,000	6,000
Barge	6	10,167	6,145	1,000	20,000
Subterminals					
Truck	14	13,250	12,220	2,500	50,000
Rail	5	3,460	508	3,000	4,000
Barge	6	17,550	13,250	1,000	40,000

Table 2

Soybean Receiving Capacities for 1993 in (bph)

Item	Number	Average	Std Dev	Min	Max
Elevators					
Truck	39	7,214	10,817	300	65,000
Rail	2	2,000	1,414	1,000	3,000
Barge	1	20,000	------	20,000	20,000
Subterminals					
Truck	14	16,615	11,778	110	40,000
Rail	2	6,000	------	3,000	9,000
Barge	1	3,800	------	3,800	3,800

Source: 1993 Arkansas grain and oilseed storage and transportation questionnaire.

Table 3

Average Monthly Soybean Storage and Shipments in bushels

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Elevator Storage	191,900	126,821	93,591	65,179	51,001	51,362	37,221	31,229	26,996	39,151	109,291	166,090
Subterminal Storage	1,419,029	1,099,428	777,584	226,825	464,302	429,549	354,209	207,373	82,247	30,232	774,144	1,463,149
Elevator Shipments												
Truck	36,758	33,114	35,203	8,711	19,551	12,121	4,393	1,379	985	48,085	58,204	32,275
Rail	0	0	0	0	0	0	0	0	0	0	0	0
Barge	107,072	240,297	195,519	47,529	12,615	22,175	40,000	40,000	30,000	0	0	162,829
Total	143,830	273,411	230,722	56,240	32,166	34,296	44,393	41,379	30,985	48,085	58,204	195,104
Subterminal Shipments												
Truck	242,766	317,748	415,549	164,405	118,204	189,527	154,216	173,941	142,555	27,768	10,800	43,771
Rail	0	0	0	0	0	0	0	0	0	0	0	0
Barge	369,075	807,145	480,677	65,976	74,289	56,909	93,320	38,471	27,348	68,167	395,663	395,812
Total	611,841	1,124,893	896,226	230,381	192,493	246,436	247,536	212,412	169,903	95,935	406,463	439,583

Table 4

Model Determined Soybean Shipment Quantities from Elevators and Subterminals to Destinations by Mode (000's short tons)

Mode	Elevator					Subterminal				
	New Orleans	Galv	Helena	Little Rock	Stutt	New Orleans	Galv	Helena	Little Rock	Stutt
Truck	0	0	97.19	208.43	166.35	0	0	400.36	312.37	268.48
Rail	0	0	0	0	0	0	2.16	0	0	0
Barge	0	0	0	0	0	772.79	0	0	0	0

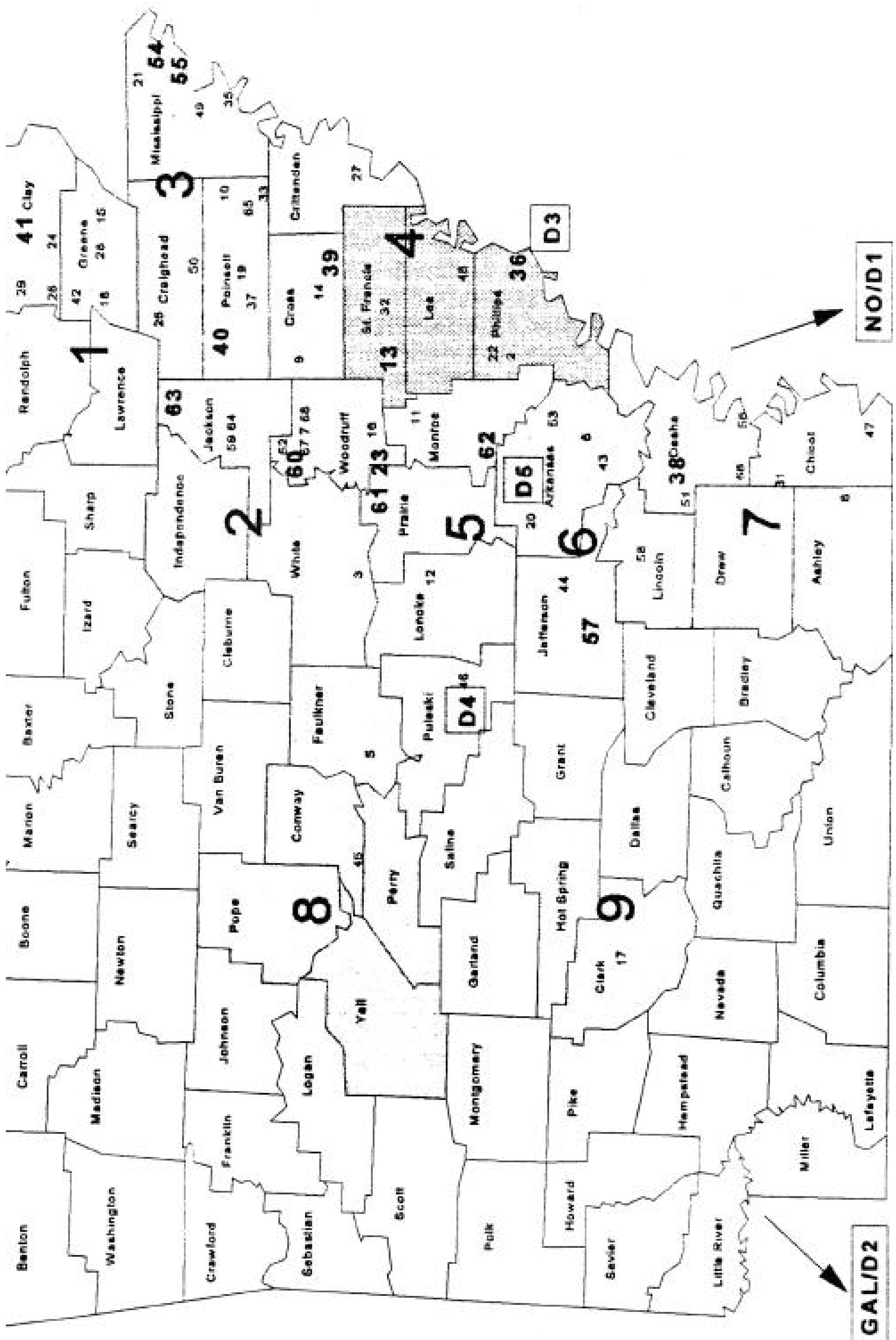
Table 5

Model Determined Soybean Shipment Quantities Compared to Survey Determined Shipment Quantities by Mode (000's short tons)

Mode	Model					Survey				
	New Orleans	Galv	Helena	Little Rock	Stutt	New Orleans	Galv	Helena	Little Rock	Stutt
Truck	0	0	497.55	520.80	434.83	0	0	498	520.80	434.40
Rail	0	2.16	0	0	0	0	2.16	0	0	0
Barge	772.80	0	0	0	0	772.80	0	0	0	0

Figure 1
Location of Arkansas Elevators, Subterminals and Final Destinations

(where small numbers denote elevators, middle sized numbers denote subterminals and large numbers with boxes denote final destinations)



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