B-1331

Alternative Export-Wheat Distribution Systems for the Texas-Oklahoma Panhandle

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Contents

Summary

The foci of this study were the economic feasibility and potential cost savings of operating wheat-carrying unit trains between a six-county area in the Texas-Oklahoma Panhandle and Texas Gulf ports. Costs of the current system are estimated and then contrasted with three alternative organizations that include operation of 20-, 50-, and 80-car trains from study-area origins. The current system involves single-car movements and transit privileges at existing inland-terminal locations. The following three alternative distribution systems are studied:

1) a system involving the operation of 80-car unit trains between area inland-terminal locations and Texas ports (referred to as the 80-car system);
2) a system of 80-car unit trains operating from area inland-terminal locations and of potential subterminals served by 50-car unit trains for delivery of wheat to Texas ports (referred to as the 50-, 80-car system); and
3) a system of 80-car unit trains operating from area inland-terminal locations and of potential subterminals served by either 20-, 50-, or 80-car unit trains for delivery of wheat to Texas ports (referred to as the 20-, 50-, 80-car system).

This research indicates that subterminals served by 50-car trains (50-, 80-car system) would be feasible at five of the study area's 10 potential locations and would be responsible for handling 49 percent of the wheat destined for Texas ports. In addition, the analysis shows that either a 20-, 50-, or 80-car-train operation would be feasible at all 10 potential subterminal locations. Within the 20-, 50-, 80-car system, subterminals would capture 75 percent of the wheat moving to Texas port areas.

The model analysis shows the 20-, 50-, 80-car system to be the most efficient of the export-wheat distribution systems. For the six-county area, this would annually generate marketing-system savings of $2.49 million or 12.2 cents per bushel. The 50-, 80-car system was the second-most efficient system with expected annual savings of $2.08 million or 10.2 cents per bushel. Although the 80-car system ranked third in terms of potential efficiency gains, the analysis indicated this system would yield savings of 8.1 cents per bushel or $1.65 million.

The principal source of marketing-system savings was found to lie in the efficiency of the unit-train concept. The per-ton-mile cost savings to the railroads range from 23 percent for the 80-car system to 41 percent for the 20-, 50-, 80-car organization.

Energy savings are also indicated within the alternative distribution systems. The current system consumes an estimated 399 billion BTU's (British Thermal Units of energy). The most energy efficient system is the 80-car-train organization which consumes approximately 297 billion BTU's — an energy savings of 26 percent. The 50-, 80-car and the 20-, 50-, 80-car systems have estimated energy savings of 25 and 24 percent, respectively.

Several conclusions may arise from this research. First, the unit-train concept is a feasible means of improving the export-wheat marketing system efficiency in the Plains study area, and cost savings are large enough that similar results may be concluded for other Plains areas. Second, a subterminal organization served by unit trains is feasible and cost reducing as compared to an organization of unit trains operating from only inland-terminal locations. Although the greatest opportunity for cost reduction and increased efficiency includes a subterminal organization (50-, 80-car and 20-, 50-, 80-car systems), this organization requires simultaneous development of several system components. Consequently, this would be the most difficult alternative to implement.

Keywords: Unit train/transportation economics/grain transportation/grain exports.

Alternative Export-Wheat Distribution Systems for the Texas-Oklahoma Panhandle

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Hard Red Winter wheat is a major source of income for U.S. and South Plains grain producers. Historically, wheat has ranked as one of the most valuable crops in Texas and Oklahoma, states that are major producers of the annual Hard Red Winter wheat national output and that are located in the southern portion of this grain's production area (Figure 1).

Exports are a significant outlet for the national annual wheat production and hold promise of becoming even more important in the future. On a national basis, exports of Hard Red Winter wheat generally comprise from 43 to 75 percent of the annual production, except in the unusual market conditions of 1972 and 1973 when exports exceeded 75 percent of the current crop (Table 1). Exports of Hard Red Winter wheat increased from 336 million bushels in 1969 to 775 million bushels in 1973. Since 1973, Hard Red Winter wheat export volume has fluctuated between 418 and 625 million bushels.[1]

During the 1970's, Gulf ports were responsible for 50 to 62 percent of the Nation's total wheat exports and from 76 to 86 percent of the Hard Red Winter wheat exports (Table 2). Texas Gulf ports, particularly the North Texas Gulf ports (Beaumont, Port Arthur, Houston, and Galveston), are the principal Hard Red Winter wheat export locations. In 1977 and 1978, North Texas Gulf ports were responsible for 70 and 68 percent of the respective Hard Red Winter wheat exports in the United States. In the same time periods, South Texas Gulf ports (Corpus Christi and Brownsville) exported 8 and 12 percent of the respective U.S. foreign sales of this wheat class.

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[1] Hard Red Winter wheat typically constitutes about 50 percent of total wheat exports.

South Plains Export-Wheat Transportation/Marketing System and Potential Efficiencies

The country elevator represents the first marketing agent in the South Plains export wheat marketing system. Wheat assembled to country elevators by producers will generally move to inland terminals which, in turn, distribute grain to Gulf ports as warranted by demand. The region's single-car rate structure allows for transit at the inland-terminal locations.

The substantial capacity of the South Plains inland-terminal industry is, in part, a product of the railroad's rail rate structure — the railroad's transit privilege. This privilege permits wheat to be shipped from country elevators to Gulf ports on a single-car-through rate with intermediate stops for inland-terminal storage. In essence, the rate on a direct shipment from country elevator to Gulf port is equal to the sum of the rates from country elevator to inland terminal and from inland terminal to Gulf port. If follows that a grain shipper's transportation charge on export-destined wheat is not unfavorably affected by transshipment at inland-terminal locations. A second important aspect of the current rate structure involves equalized rail rates to Gulf port locations. This rate structure allows grain handlers to ship to most of the Gulf ports at the same rate.

The export rate structure can be more easily understood through consideration of a specific example. Assume a country elevator located at Perryton, Texas has a Gulf export rate of 50.7 cents per bushel (Ex Parte 343). Because of the transit privilege and equalized Gulf rates, this grain may move at the 50.7-cents-per-bushel rate to any regional inland-terminal location for storage prior to its final movement to the Gulf port areas. Accordingly, up to 90

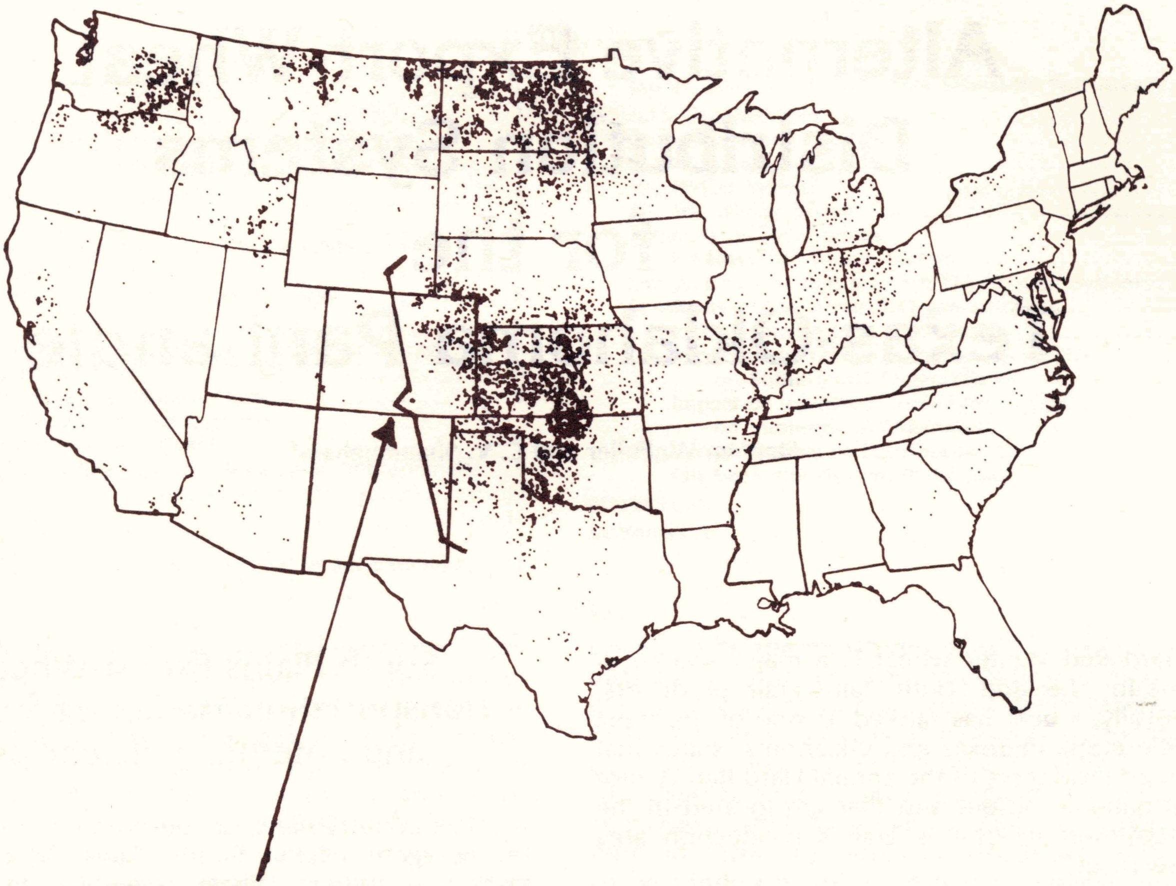

Figure 1. Location of the Hard Red Winter wheat production area in the United States (one dot equals 10,000 harvested acres). Source: *U.S. Wheat Industry*, Economics, Statistics, and Cooperative Service, U.S. Department of Agriculture, Agricultural Economic Report No. 432, August 1979.

percent of the wheat produced in the South Plains moves through inland terminals.

Recently, railroads have initiated truck-substitution and truck-allowance tariffs. The truck allowance or substitution allows for the transit privilege as if grain were being moved by rail to the inland terminals. With truck substitution, railroads pay the trucking cost and bill the elevator for the flat rail rate to the terminal. Truck allowance is handled by the elevator which pays for trucking to the inland terminal with the railroad deducting a predetermined amount from the rail rate.

Transportation activities comprise about 75 percent of export-wheat marketing costs in the South Plains and thus represent one of the most critical and costly links in the system. On-going research at several Midwestern institutions has revealed the unit train to be a more efficient means of long-distance grain transportation. In general, Midwestern researchers have been investigating means of maintaining the efficiency of a grain transportation system that would abandon a major portion of the region's branchline segments. Researchers at Iowa State University investigated the practicality of restructuring the country elevator industry to include subterminals located on retained railroad mainlines [1]. In this reorganization scheme, the subterminal received grain from producers and country elevators and shipped on unit trains destined for port locations. Their study revealed the cost savings of the unit train to more than offset other cost increases resulting from reorganization. Studies of analogous situations in the Corn Belt regions of Indiana and Ohio have reached similar conclusions [3,4]. Although previous studies contain some parallel aspects with the South Plains wheat-producing region, there are important marketing-system differences that keep their results from being useful to this major wheat-producing area.

In contrast to the Midwestern situation, rail abandonment is not a serious threat in the South Plains, except on a few branchline segments. It follows that the region's country elevators and subterminals alike would have rail service, thus a subterminal's cost superiority and feasibility are less apparent here than in the Midwest where some country elevators are left without rail service. Another contrasting characteristic is the substantial

TABLE 1. HARD RED WINTER WHEAT: MARKETING YEAR, SUPPLY, AND DISAPPEARANCE, 1969-78

Year beginning June 1	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
					(000,000 bu.)					
Beginning stocks	475	574	492	471	287	169	224	377	603	631
Production	785	755	747	761	957	879	1,053	968	997	834
TOTAL	1,260	1,329	1,239	1,232	1,244	1,048	1,277	1,345	1,600	1,465
Domestic Use	350	387	432	326	300	314	314	324	443	426
Exports	336	450	337	704	775	510	581	418	565	625
TOTAL	686	837	769	1,030	1,075	824	895	742	1,008	1,051
Ending Stocks May 31	574	492	470	202	169	224	382	603	592	414

Source: *Wheat Situation*, Economic, Statistics and Cooperative Service, U.S. Department of Agriculture, issues WS-219 through WS-244.

TABLE 2. PERCENT OF HARD RED WINTER WHEAT EXPORTS THROUGH VARIOUS COASTAL PORT AREAS

Port Areas	1970	1971	1972	1973	1974	1975	1976	1977	1978
					Percent				
Great Lakes	0.5	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0
Atlantic	0.2	0.2	0.0	4.1	0.4	0.0	0.0	0.0	0.0
Gulf	77.9	86.4	87.1	85.4	81.6	79.9	76.4	84.7	83.1
Pacific	21.4	13.4	12.9	10.2	17.8	20.1	23.6	15.3	16.9
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: *Grain Market News*, Agricultural Marketing Service, U.S. Department of Agriculture, various issues, 1970-78.

inland-terminal industry located throughout the South Plains wheat-producing area. Because of existing inland terminal's substantial grain handling and storage capacity, no new plant investment would be necessary to accommodate unit trains; however, substantial investment would be necessary to upgrade country elevators into subterminals. In which case, a potential subterminal organization would be at a relative cost disadvantage when compared to the Midwest. An additional factor is the region's relatively low density of grain production, which is about one-fourth of that in the Midwest. Assembling large volumes to potential subterminal locations would involve larger market areas and increased assembly cost. Clearly, a subterminal organization in the South Plains appears to be at a relative disadvantage.

To determine the economic feasibility and potential cost savings of unit-train operation in the South Plains, the Texas Agricultural Experiment Station in cooperation with the U.S. Department of Transportation, Texas Transportation Institute, Oklahoma Agricultural Experiment Station, and Kansas Agricultural Experiment Station, has initiated a multistate research project. The principal analysis centers on a contiguous 27-county area located in Southcentral Kansas, Northcentral and Panhandle areas of Oklahoma, and the northern-most counties in the Texas Panhandle. This report focuses on findings associated with a six-county area in the Texas and Oklahoma Panhandles (Figure 2). Because of the unique characteristics of this six-county area, particularly its very low density of wheat production and lack of an inland-terminal industry within the region, this report focuses on this area.

Objectives and Procedures

Objectives

Focusing on the comparative efficiency of alternative distribution systems for marketing Hard Red Winter wheat from the Texas-Oklahoma Panhandle region, this research had as its objectives to determine 1) the economic feasibility of renovating selected country elevators into subterminals and operating unit trains between these facilities and Texas Gulf ports, 2) the economic feasibility of operating unit trains between inland terminals and Texas Gulf ports, and 3) the effect of these organizations on the cost of handling export wheat. The alternative organizations involve various combination of 20-, 50-, and 80-car shipments from potential subterminal locations and 80-car shipments from existing inland-terminal facilities. The following alternative distribution systems were studied:

1) a system involving the operation of 80-car unit trains between area inland-terminal locations and Texas ports (referred to as the 80-car system);
2) a system of 80-car unit trains operating from area inland-terminal locations and of poten-

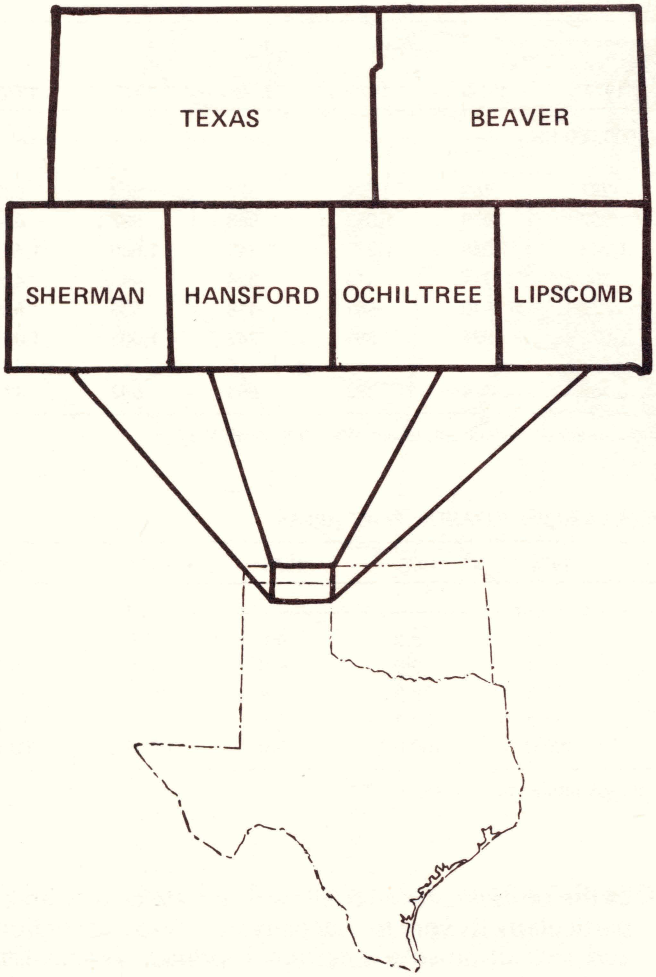

Figure 2. Study-area counties in the Texas-Oklahoma Panhandle.

tial subterminals served by 50-car unit trains for delivery of wheat to Texas ports (referred to as the 50-, 80-car system); and

3) a system of 80-car unit trains operating from area inland-terminal locations and of potential subterminals served by either 20-, 50-, or 80-car unit trains for delivery of wheat to Texas ports (referred to as the 20-, 50-, 80-car system).

Secondary objectives of this study were to

1) determine the differences in energy consumption for the current and alternative distribution systems, and
2) determine the sensitivity of a subterminal organization to unfavorable movements in system cost parameters.

Figure 3 illustrates the grain handling and storage system elements and their involvement in the current and alternative distribution systems. The current system is characterized by flows from farms to country elevators with subsequent flows to inland terminals and ports. Most of the commercial transportation in this system is via single-car rail shipments. The 80-car system would include the grain handling and storage elements of the current system and 80-car train shipments between inland and port terminals. The 50-, 80-car and the 20-, 50-, 80-car systems would involve the introduction of a new marketing system element, the subterminal, which is served by either 20-, 50-, or 80-car trains. Both of these systems would include 80-car trains operating from inland terminals.

Structure and Assumptions of the Analytical Model

Improving marketing efficiency is a goal that cannot be pursued in isolation. Because of the high degree of interdependence among the elements of this area's export-wheat marketing system, a cost-minimizing model of the entire system was constructed. The following are the principal cost elements of the model: 1) farm storage costs, 2) farm assembly costs, 3) truck, rail, and barge transportation costs that link country elevators, potential subterminals, inland terminals, and port terminals, and 4) all facilities' grain handling and storage costs.

The system model represents a wheat crop year (June 1 - May 30) subdivided into three time periods to facilitate a temporal analysis. The first time period includes the first 21 days of the wheat crop year, when harvest is carried out and the annual wheat supply generated. The following 45 days constitute the second time period which represents post-harvest activity, while the final or third period consists of the remaining 299 days of the crop year.

The six-county region was subdivided into 3 × 3-mile areas (9 square miles), which resulted in 825 production origins. The harvest-time supply of wheat and available wheat storage at each production origin were predetermined. The predetermined wheat production reflected 1985 production, and the portion destined for export (84 percent) was based on historical data. Producers may store their annual wheat production at farms (production origins) or ship directly by farm truck to country elevators or subterminals. As farmers appeared reluctant to deliver grain in excess of 30 miles, only those country elevators or subterminals within 30 miles of a farm represented a potential delivery point. If wheat is farm-stored, producers deliver to country elevators or subterminals in later time periods. Since most wheat enters the marketing system via the country elevator, the model was structured so that wheat must be assembled to country elevators or subterminals prior to further movement through the system.

The model includes 58 country elevators located at 36 locations. Country elevators and potential subterminals have predetermined amounts of storage capacity available for area wheat production. All subterminals are renovated country elevators. Country elevators may ship to subterminals, inland

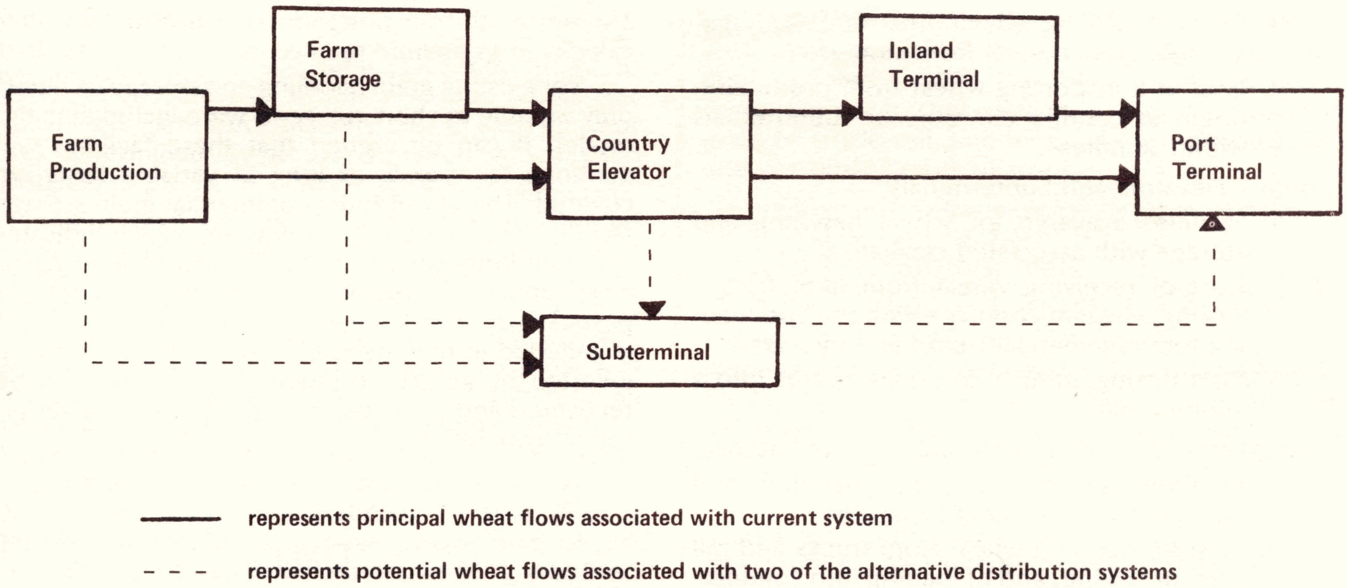

Figure 3. Wheat-flow patterns among marketing-system elements for the current and alternative export-wheat distribution systems.

terminals (Enid, Fort Worth, Amarillo), Gulf port terminals (Houston, Galveston, Beaumont, Port Arthur, Corpus Christi, Mississippi River ports), and a river elevator on the Arkansas River (Catoosa, Oklahoma). The river elevator is linked to all Gulf ports via barge transportation. In the model all movement from country elevator to subterminal is restricted to 75 miles. Truck and rail modes are available for all country elevator shipments except those to subterminals and the river elevator; in which case, only truck carriage is available. All country elevator rail shipments are represented as single-car movements in the cost-minimizing model.

The predetermined subterminal locations require upgrading or investment costs in order to accommodate unit trains. Subterminals are renovated to accommodate 20-, 50-, or 80-car shipments. The level of investment is related to the size of unit train to be accommodated. Inland terminals, port terminals, and the river elevator have predetermined wheat storage capacities available for study-area wheat marketings. Inland terminals may ship by either truck or single-car movement to other inland terminals, by truck to the river elevator, or by 80-car shipments to port elevators. When estimating costs of the current system, rail movement from inland terminals was via single-car shipments. No investment is required at inland terminals for loading of the 80-car unit trains. Port terminals may receive truck-, rail-, or barge-delivered grain which may be stored for short periods of time prior to loading aboard ship. Wheat demand per port and time period was predetermined and based on historical flows to port areas.

To estimate the grain-handling and transportation costs associated with marketing the region's export-destined wheat supply under the current system, shippers faced with the current single-car, transit rate structure were assumed to continue to route wheat as historically practiced. Therefore, wheat flows in the cost-minimizing model followed the historic pattern to allow for the calculation of current-system costs. An estimate of current-system costs represented a benchmark against which alternative distribution-system costs were compared. When calculating the latter, grain was not forced to follow an historic flow pattern except as dictated by past export demands at the various port areas. Rather, wheat was allowed to flow through least-cost channels in order to meet the predetermined export demands.

Because of the need to include substantial details of the transportation and marketing system as well as a spatial and temporal dimension, the resulting model became very large. For this reason, a network-flow model was developed. Previous studies revealed network-flow models to be computationally more efficient than linear-programming codes and capable of accommodating the system characteristics [2]. (See Appendix A for a full description of the model.)

System Data Requirements

To construct the system model, substantial data were required. The following is a list of the model's data needs by marketing-system element.

Production Origin

1. Quantity of wheat harvested on each production origin (3×3-mile area)
2. Wheat storage capacity of each production origin

3. Cost of placing wheat into farm storage, storage, and removal from storage
4. Cost of transporting wheat from production origin to country elevators or subterminals within 30 miles

Country Elevators and Subterminals

1. Facilities available for wheat handling and storage with associated capacities
2. Cost of receiving wheat from farm trucks, storing wheat at country elevators, and loading into commercial trucks and rail cars
3. Cost of upgrading a country elevator into a subterminal

Inland Terminals and River Elevator (Port of Catoosa)

1. Facilities available for wheat handling and storage with associated capacities
2. Cost of receiving wheat from trucks and rail cars, of storing, and of loading into commercial trucks, barges, and rail cars
3. Cost of loading barges at the Port of Catoosa (terminal on the navigable portion of the Arkansas River)

Transportation

1. Cost of transporting wheat by commercial truck from country elevators to subterminals, inland terminals, port terminals, and the Port of Catoosa
2. Cost of single-car rail movement from country elevators to inland terminals and port terminals
3. Cost of barging wheat from Port of Catoosa to Gulf ports
4. Cost of transporting wheat by commercial truck from inland terminals to other inland terminals and port terminals
5. Cost of single-car rail movement from inland terminals to other inland terminals and port terminals
6. Cost of unit-train operation from subterminals and inland terminals to Texas Gulf ports

Port Terminals

1. Facilities available for wheat handling and storage with associated capacities
2. Cost of receiving wheat from trucks, rail cars, and barges and cost of loading grain into ocean-going vessels
3. Demand for study-area wheat at each Gulf port

Time Frame of Costs Included in Model

As the focus of this study was the comparable efficiency of the alternative distribution systems, emphasis was directed at estimating comparable transportation cost parameters for each mode. Therefore, all transportation cost parameters were calculated to include total costs.

For existing grain handling and storage facilities, only variable or short-run costs were included in the model. It can be argued that these facilities will continue to operate as long as variable costs are covered. The life of most commercial grain storage facilities ranges from 25 to 30 years, which indicates that their long-run time frame is considerable. When new capital is invested in a country elevator for purposes of renovating into a subterminal, total cost is included in the analysis. New capital will only be invested by an entrepreneur if the capital can be recovered and a comparable return on the invested capital generated.

Data

The following section relates parameter values entered into the study-region model. For a detailed description of the data and methodology employed to estimate model parameters, *Rail Based Transportation of Export Destined Wheat: An Efficiency Study* (Department of Transportation, Federal Railroad Administration, 1980) should be consulted.

Wheat Supply, Farm, and Country Elevator Storage

Based on historical production trends, the estimated 1985 wheat output for the six-county area was 24.2 million bushels. Based on historical grain flows 84 percent of total production (20.4 million bushels) was estimated to be destined for Gulf ports, the remaining wheat would move into domestic markets. A county's estimated production was distributed among its production origins (3×3-mile areas) to agree with the portion of the county's cultivated land area in each production origin.

To estimate existing on-farm storage in the study area, a mail questionnaire was distributed to a 10-percent random sample of farmers. Based on this survey, the Texas and Oklahoma counties were estimated to include 12.187 and 8.183 million bushels of on-farm storage, respectively. Approximately two-thirds of this capacity was available for wheat storage. On-farm storage estimates were allocated among farms (3×3-mile areas) to agree with each farm's expected grain production.

Storage capacity for each of the region's 58 country elevators was obtained from an on-site visit, secondary sources, or a telephone interview. Storage capacity available for export-destined wheat was calculated by subtracting from each elevator's storage capacity that storage necessary for 1) working space, 2) domestically consumed wheat, and 3) carryover of wheat and other grains. Storage capacity for export-destined grain was estimated at 21.3 million bushels.

Farm Assembly Cost

Distance from each farm (3×3-mile areas) to each country elevator within a 30-mile radius was calculated. Farm truck-delivery cost to each elevator was determined by a cost function which used distance to predict per-bushel assembly cost.

Farm truck costs were determined for a 2.5-ton tandem, tag-axle straight truck; a 2-ton straight truck; and a 1.5-ton straight truck. A survey of elevator receipts indicated that these truck sizes were most commonly employed in farm-to-country elevator delivery. The largest truck (2.5 tons) was assumed to carry 500 bushels and to assemble 35 percent of the country elevator's receipts. The 2-ton truck was assumed to assemble 50 percent of elevator receipts and have a load size of 300 bushels. The 1.5-ton truck was assumed to assemble 15 percent of receipts and have a load size of 250 bushels. Based on these assumptions, a weighted average assembly cost was estimated for alternative distances (Table 3).

Farm Handling and Storage Costs

Farm storage cost includes three cost items: 1) cost of placing wheat into storage, 2) cost of wheat storage, and 3) cost of removing wheat from storage. A survey of wheat producers provided information on sizes and characteristics of existing farm storage. With this information cost parameters were calculated using the economic-engineering estimation technique.

The analysis revealed the per-bushel variable cost of placing wheat into storage to be 2.19 cents, while the per-bushel removal cost was estimated at 1.5 cents. Per-bushel variable cost of storing wheat for 12 months was calculated at 8.3 cents. These costs are for steel bins of 10,000-bushel storage capacity.

Country Elevator, Inland-Terminal, and Port-Terminal Costs

The Economic Research Service (U.S. Department of Agriculture) has conducted a series of studies on cost of grain handling and storage in country elevators, inland terminals, and port terminals. With use of regression analysis, these costs were updated to 1977-78 (Table 4). The parameters reveal the per-bushel costs of receiving and loading grain by truck, rail, and barge at each elevator type and per-bushel costs of storage.

TABLE 3. ESTIMATED FARM TO COUNTRY ELEVATOR ASSEMBLY COST IN CENTS PER BUSHEL, 1977-78

Distance of haul	Assembly cost
(miles)	(¢/bu)
5	6.86
10	7.73
15	8.60
20	9.46
25	10.33
30	11.19

Cost of Upgrading Country Elevators to Subterminals

To determine the feasibility of unit-train shipments from country origins, an assessment was made of the investment needed to modify elevators for this purpose. Analysis revealed that, in general, the level of investment was closely related to the storage capacity of the elevator to be upgraded, the

TABLE 4. ESTIMATED COST IN CENTS PER BUSHEL OF RECEIVING, STORING, AND LOADING GRAIN BY ELEVATOR TYPE, 1977-78

Function	Country elevators	Inland terminals[1]	Port terminals
		(¢/bu.)	
Receiving Grain			
Truck			
Fixed Cost	.373	1.013	1.958
Variable Cost	1.934	1.650	1.309
Total Cost	2.307	2.663	3.267
Rail			
Fixed Cost	-----	1.396	1.265
Variable Cost	-----	2.002	1.317
Total Cost	-----	3.398	2.582
Barge			
Fixed Cost	-----	1.182	.532
Variable Cost	-----	3.938	1.685
Total Cost	-----	5.120	2.217
Loading Grain			
Truck			
Fixed Cost	.565	1.395	5.251
Variable Cost	2.065	1.058	2.089
Total Cost	2.630	2.453	7.340
Rail			
Fixed Cost	.579	1.171	1.640
Variable Cost	2.011	1.514	1.497
Total Cost	2.590	2.685	3.137
Ship/Barge			
Fixed Cost	.096	.348	.498
Variable Cost	.974	.758	.772
Total Cost	1.070	1.106	1.270
Storage (annual cost)			
Fixed Cost	16.212	14.635	26.986
Variable Cost	5.545	4.144	5.131
Total Cost	21.757	18.779	32.117

[1]The river elevator was assumed to have the same cost structure as the inland terminal.

Source: *Costs of Storing and Handling Grain in Commercial Elevators, 1970-71, and Projections for 1972-74,* Economic Research Service, U.S. Department of Agriculture, ERS-501, March 1972. (The tabulated, updated parameters were based on costs taken from the referenced study.)

size of multicar shipment to be handled by the renovated elevator, and expected volume of grain to be handled by the subterminal. The investment associated with the smaller elevators (300,000-750,000 bushels of storage capacity) was greater than that of the larger elevators (over 750,000 bushels of storage capacity). Accordingly, two levels of upgrading costs were estimated (one for each elevator-size category). In addition, the level of investment was dependent on the size of unit train serving the elevator. Since the analysis included three train sizes (20-car, 50-car, and 80-car), three upgrading costs were estimated for each elevator-size category. Existing unit-train rates from Corn Belt origins allow 24 hours for loading; thus, all unit trains were assumed to load within a 24-hour period. It follows that greater elevator upgrading investment was required to accommodate the larger train sizes. In addition, elevator-renovation cost was found to be affected by the annual volume to be handled by the subterminal: the larger the subterminal's annual volume, the greater was the grain-handling capacity and corresponding investment. Investment cost was estimated for annual volumes less than 1.5 million bushels, from 1.5 to 5.0 million bushels, and greater than 5.0 million bushels.

Estimated investment and annual costs of upgrading each elevator-size category are shown in Tables 5 and 6. Investment costs include elevator-equipment costs and rail-equipment costs. Elevator-equipment costs include reclaiming belts, altering spouts, increasing leg capacity, and installing automatic samplers and scales. Rail-equipment costs include additional rail siding, a switch, and a trackmobile. Investment costs range from $48,350 (necessary for upgrading a large elevator to accommodate 20-car trains) to $872,700 (required of a small elevator to accommodate 80-car trains). Annual fixed costs for these respective elevator types are $5,004 and $124,212.

Commercial Truck Transportation Cost

Truck movement of wheat among and within all elevator categories is assumed to be by commercial truckers. The types of vehicles operated by grain truckers vary; the most common types among interviewed firms were diesel-powered, cab-over, twinscrew, tractor-trailer rigs. Analysis revealed that a truck's per-mile cost was influenced by distance of trip. For this reason, two cost functions were calculated — one function for trip distances less than 350 miles, another for distances equal to or in excess of 350 miles. Hauls of less than 350 miles were assumed to have no backhauls, while the longer distances (specifically from the study area to Gulf ports) were assumed to have backhauls one out of every five trips. All loads were assumed to be 860 bushels, except when sensitivity of subterminal organization was tested; in which case, loads were assumed to be 1,100 bushels.

Tables 7 and 8 show the calculated costs for the short- and long-distance hauls, respectively.

Railroad Costs

For purposes of this study, it was necessary to estimate costs of single-car movement from country elevators to inland terminals and port terminals, and from inland terminals to Gulf ports. In addition, the study required cost estimates of 80-car unit trains operating between inland terminals and Gulf ports, as well as 20-car-, 50-car-, and 80-car-train costs of

TABLE 5. ESTIMATED INVESTMENT AND ANNUAL COST OF UPGRADING A 300,000 — 750,000-BUSHEL ELEVATOR TO ACCOMMODATE 20-CAR, 50-CAR, and 80-CAR UNIT TRAINS, 1977-78

	--- 20-Car-Train Annual Volume ---			--- 50-Car-Train Annual Volume ---			--- 80-Car-Train Annual Volume ---		
	Over 5.0 million bushels	1.5 to 5.0 million bushels	Up to 1.5 million bushels	Over 5.0 million bushels	1.5 to 5.0 million bushels	Up to 1.5 million bushels	Over 5.0 million bushels	1.5 to 5.0 million bushels	Up to 1.5 million bushels
Investment cost	$247,250	$162,150	$121,250	$560,500	$418,500	$518,500	$872,700	$702,250	$560,250
Annual cost	$ 36,400	$ 21,088	$ 14,054	$ 82,150	$ 51,287	$ 51,287	$124,212	$ 95,655	$ 64,792

TABLE 6. ESTIMATED INVESTMENT AND ANNUAL COST OF UPGRADING A GREATER THAN 750,000-BUSHEL ELEVATOR TO ACCOMMODATE 20-CAR, 50-CAR, AND 80-CAR UNIT TRAINS, 1977-78

	--- 20-Car-Train Annual Volume ---			--- 50-Car-Train Annual Volume ---			--- 80-Car-Train Annual Volume ---		
	Over 5.0 million bushels	1.5 to 5.0 million bushels	Up to 1.5 million bushels	Over 5.0 million bushels	1.5 to 5.0 million bushels	Up to 1.5 million bushels	Over 5.0 million bushels	1.5 to 5.0 million bushels	Up to 1.5 million bushels
Investment cost	$55,850	$48,350	$ 48,350	$513,250	$375,750	$375,750	$825,850	$655,000	$517,500
Annual cost	$ 6,028	$ 5,004	$ 5,004	$ 77,768	$ 50,721	$ 50,721	$119,770	$ 91,163	$ 59,724

TABLE 7. ESTIMATED COST IN CENTS PER BUSHEL OF COMMERCIAL TRUCK HAULS FOR DISTANCES LESS THAN 350 MILES[1], 1977-78

Miles of haul	Per-Bushel cost
(miles)	(¢/bu)
50	11.10
75	13.3
100	15.5
125	17.7
150	19.9
175	22.1
200	24.3
225	26.5
250	28.7
275	30.9
300	33.1

[1]Assumes no backhaul.

TABLE 8. ESTIMATED COST IN CENTS PER BUSHEL OF COMMERCIAL TRUCK HAULS FOR DISTANCES EQUAL TO OR IN EXCESS OF 350 MILES[1], 1977-78

Miles of haul	Per-Bushel cost
(miles)	(¢/bu)
350	37.3
400	42.2
450	47.1
500	52.0
550	56.8
600	61.7
650	66.6
700	71.5

[1]Assumes a backhaul on 20 percent of the trips.

operating between potential subterminals and Gulf ports.

Railroad costs were estimated by reconstructing the formulae of the ICC cost scales (according to instructions for adjusting cost estimates in *Rail Carload Cost Scales 1974*, Interstate Commerce Commission, 1976). The railroad freight-rate index (Bureau of Labor Statistics, U.S. Department of Labor) was used to convert 1974 cost estimates to 1977-78 estimates. For ease in estimating the cost of point-to-point movements, a computerized rail-cost program was developed. With use of the cost algorithm, the per-bushel variable cost associated with single-car and multicar movements was calculated. To estimate the variable cost for each rail movement, the values for 21 variables were specified, including: number of cars in shipment, origin, destination, routing, way-train and through-train mileage, number of intra- and inter-company switches, gross tons in way and through train, value of grain loss and damage, car days in movement, and switch-engine minutes per car. To make rail costs comparable to the total-cost parameters of the other transportation modes, the variable-cost parameter was multiplied by 1.35. This total-cost parameter was entered into the model for purposes of determining least-cost routings. However, because of the study's focus on the potential operating efficiency of unit trains, the "Results" section reports only railroad's variable cost.

The analysis revealed savings for multicar shipments of 8 to 13 cents per bushel relative to single-car movements. This represented per-bushel savings of 23 to 37 percent relative to the current system.

Barge Costs

Barge transportation of study-area wheat to Gulf port destinations may occur by way of the Port of Catoosa on the Arkansas River. Estimated barge rates are used in this study as a proxy of barge costs. Barge transportation is a highly competitive industry since the rate on bulk shipment of grain is unregulated. Under these circumstances, rates over a period of time should approach long-run costs.

Waterway-transportation rates for bulk grain are closely tied to the Waterways Freight Bureau, Freight Tariff No. 7. Rates for this study were estimated by using the *Guide to Published Barge Rates on Bulk Grain, Schedule No. 8.* and checking these values against the results of a previous cost study [1]. Table 9 indicates values entered into the model to represent costs for barging grain from Catoosa to alternative Gulf ports.

Grain Inspection and Grading Costs at Subterminals

The necessary grain inspection of unit trains at subterminals was found to be more expensive than the current system where official grades are determined at inland-terminal locations. The additional cost at subterminals was associated with a courier service which traveled between subterminals and inland-terminal locations, or the site of official graders. Estimated cost of this service was .1 cent per bushel for 50-and 80-car trains and .2 cent per bushel for 20-car trains.

TABLE 9. ESTIMATED COST IN CENTS PER BUSHEL OF BARGING WHEAT FROM CATOOSA, OKLAHOMA, TO ALTERNATIVE GULF PORTS, 1977-78

From Catoosa, Oklahoma to	Cents Per bushel
	(¢/bu.)
Mississippi River Ports[1]	16.92
Houston, Galveston, Beaumont, Port Arthur	26.82
Corpus Christi	37.26

[1]Includes Ama, Baton Rouge, Destrehan, Myrtle Grove, New Orleans, Reserve and Westwego, Louisiana.

Export Demand of Study-Area Wheat by Port Area

Export demand for the study region's exportable wheat production was estimated for each port area and by time period. These estimates were based on the study area's historical grain-flow patterns. Table 10 indicates the results of these predictions.

Results of Analysis

This section reports the results associated with the current system; the 80-car system; the 50-, 80-car system; and the 20-, 50-, 80-car system. The current-system solution represents a benchmark to which the costs of alternative organizations may be compared.

Current System

To estimate the grain handling and transportation costs of the current system, duplication of the existing system's wheat-flow patterns was necessary. This was accomplished with flow data gathered for the 1976-77 crop year. Table 11 shows the six-county study area's estimated truck and rail flows through the various inland-terminal locations. The structure of the cost-minimizing model forced grain to be moved through these locations in the indicated quantities (Table 11).

TABLE 10. ESTIMATED 1985 EXPORT DEMAND FOR STUDY-AREA WHEAT PRODUCTION BY TIME PERIOD

	Port Areas				
Time period[1]	Houston	Galveston	Beaumont — Port Arthur	Corpus Christi	New Orleans
	(000,000 bu.)				
1	.62	.17	.13	.08	.03
2	1.67	.52	.27	.30	.04
3	10.96	1.62	1.12	2.53	.34
TOTAL	13.25	2.31	1.52	2.91	.41

[1]As indicated in an earlier section, the model includes a crop year which has been divided into three time periods. The first time period includes the 21 days associated with harvest, while the second is a 45-day period following harvest. The final period represents the remainder of the crop year, a 299-day period.

TABLE 11. THE STUDY AREA'S ESTIMATED 1985 WHEAT RECEIPTS AT INLAND TERMINALS UNDER THE CURRENT SYSTEM BY MODE OF TRANSPORT[1]

Inland terminal location	Mode: Truck	Mode: Rail
	(000 bu.)	
Enid	1898	11361
Fort Worth	0	2534
Amarillo	1183	2842

[1]Flow pattern based on 1976-77 crop-year data.

Based on predetermined export demands (Table 10) and 1976-77 flow patterns through the inland-terminal organization (Table 11), costs were calculated. Table 12 shows the estimated grain handling and storage costs and associated truck and rail costs for the six-county area. This solution's grain handling and storage costs include those incurred at country elevators, inland terminals, and port terminals. Truck-shipping costs include farm-to-elevator costs, and country elevator-to-inland terminal costs. Rail-shipping costs include the variable costs associated with assembling wheat from country elevator to inland terminal, shipping wheat from country elevator to Gulf port, and rail transportation from inland terminal to Gulf port. Tabled rail costs represent single-car movements (Table 12). Based on the 1976-77 flow patterns, the estimated grain handling, storage, and transportation cost for the study region is 56.4 cents per bushel.

80-Car System

This alternative involves the operation of 80-car unit trains between inland and port terminals, the only modification relative to the current system. Here, country elevators have the option to ship by the least-cost mode, either by commercial truck or by rail (single-car costs), to inland terminals for subsequent movement on 80-car trains to Gulf ports. In addition, the country elevator may ship directly by truck or rail (single-car costs) to port terminals or ship by truck to the Port of Catoosa for purposes of barging to port terminals. In contrast to the current-system solution, wheat is not forced through the inland-terminal organization (i.e., a historic flow pattern is not being duplicated), but grain is allowed to flow through those channels that are least costly.

Information in Table 13 shows estimated 80-car-train costs associated with transporting wheat between the inland-terminal locations and Texas Gulf ports. For these rail movements, the 80-car-train average variable costs were approximately 8 cents per bushel less than single-car costs. All other costs within the model were unchanged from the current system. Existing inland-terminal facilities were as-

TABLE 12. THE STUDY AREA'S ESTIMATED COSTS FOR MARKETING 1985 EXPORT WHEAT UNDER THE CURRENT SYSTEM BY TYPE OF COST, 1977-78[1]

Type of Cost	Cost
	($)
Total Variable Grain-Handling and -Storage Cost	2,381,334
Total Truck-Shipping Cost	2,345,652
Total Variable Rail-Shipping Cost[2]	6,771,248
Total Cost	11,498,234
Per-Bushel Cost	.564

[1]Costs are associated with marketing 20.4 million bushels.
[2]Total Rail-Shipping cost may be estimated by multiplying the total variable cost by 1.35.

TABLE 13. ESTIMATED TOTAL COST FOR 80-CAR TRAIN OPERATING BETWEEN INLAND TERMINALS AND TEXAS GULF PORTS IN CENTS PER BUSHEL, 1977-78[1]

Inland terminal	Texas Gulf Ports[2] Houston	Galveston	Beaumont — Port Arthur	Corpus Christi
	(¢/bu.)			
Enid	19.58	20.51	21.55	24.85
Fort Worth	12.04	12.97	14.00	17.04
Amarillo	21.01	21.92	21.97	25.83

[1]Costs are calculated by multiplying variable costs with the 1.35 ratio.

[2]The analysis did not include unit-train movement to New Orleans. Given the current rail system's regional configuration, the study region is most efficiently served by Texas Gulf ports. Historically, only a small quantity of the study region's production has moved through the Port of New Orleans.

sumed capable of loading unit trains, and the existing grain inspection and grading costs associated with loading these trains were unchanged relative to the current system.

Based on the model's least-cost solution all wheat (except that demanded at New Orleans) is estimated to flow through the inland-terminal system prior to shipment to Texas Gulf ports (Table 14). Grain would move through the inland-terminal system in order to capture the substantial cost savings associated with the 80-car-train shipments. In the model, unit-train costs were not included to New Orleans; consequently, the least-cost means of filling this demand would be direct single-car shipments from country elevators.

Based on the analysis, the volume flowing to the various inland-terminal locations would be substantially altered relative to that observed with the current system. In particular, flows from the six-county area to Amarillo would be significantly increased, while the quantity transported to Enid would be markedly reduced. Also, no grain would flow to Fort Worth inland-terminal locations.

TABLE 14. ESTIMATED 1985 WHEAT FLOWS FROM STUDY-REGION COUNTIES TO INLAND TERMINALS BY MODE OF TRANSPORT UNDER THE 80-CAR-TRAIN SOLUTION IN THOUSANDS OF BUSHELS[1]

County	Enid Truck	Enid Rail	Fort Worth Truck	Fort Worth Rail	Amarillo Truck	Amarillo Rail
	(000 bu.)					
Beaver, OK	1122	0	0	0	0	0
Texas, OK	0	0	0	0	1680	4659
Sherman, TX	0	0	0	0	292	2981
Hansford, TX	0	0	0	0	151	7000
Ochiltree, TX	675	0	0	0	982	846
Lipscomb, TX	549	0	0	0	0	1280
TOTAL	2346	0	0	0	3105	16766

[1]Grain flows through inland terminals exceed study-area production because country elevators along borders receive grain from adjacent counties, in particular, Ellis and Harper Counties, Oklahoma, and Seward and Meade Counties, Kansas.

The analysis indicates that about 75 percent of the movement from country elevator to inland terminal would be by rail (Table 14). All counties would ship grain by rail to Amarillo except Beaver, Oklahoma (the only county not serviced by a railroad). Country elevators in all counties would truck some wheat either to Amarillo or Enid.

The system costs of this solution are shown in Table 15. Estimated per-bushel cost is 48.3 cents per bushel, compared to an estimated current per-bushel system cost of 56.4 cents, which results in a cost savings of 8.1 cents per bushel.

50-, 80-Car System

This organization is analogous to the 80-car system with the exception that selected country elevators are upgraded to subterminals capable of loading a 50-car train. Ten country elevator sites were identified as potential subterminal locations for wheat produced in the six counties. Five of these locations were within the six-county area; remaining sites were located in adjacent counties (Figure 4). The largest elevator at each location was assumed to be upgraded, and the subterminal was allowed to receive wheat directly from producers located within 30 miles (the same potential market area as a country elevator) and from country elevators located within 75 miles.

Fifty-car, unit-train costs to Texas Gulf ports are substantially less than the single-car cost (10.8 cents less when only variable rail costs are included) (Table 16). However, the opportunity to move grain to inland terminals for shipment on the 80-car train creates a very cost-competitive situation between subterminal and inland-terminal organizations. In order for a subterminal to exist, its associated upgrading, handling, storage, and transportation costs must be less than those similar costs incurred when assembling wheat to inland terminals for shipment on 80-car trains.

The analysis revealed that five of the potential 10 subterminals would be economically feasible. Table 17 identifies these locations, the expected annual volume for each subterminal, and their estimated annual upgrading costs. The model's solution indi-

TABLE 15. THE STUDY AREA'S ESTIMATED COSTS FOR MARKETING 1985 EXPORT WHEAT UNDER THE 80-CAR SYSTEM BY TYPE OF COST, 1977-78[1]

Type of Cost	Cost
	($)
Total Variable Grain-Handling and -Storage Cost	2,621,856
Total Truck-Shipping Cost	2,918,558
Total Variable Rail-Shipping Cost[2]	5,386,071
Total Cost	10,926,485
Per-Bushel Cost	.483

[1]Costs are associated with marketing 22.611 million bushels.

[2]Total Rail-Shipping Cost may be estimated by multiplying the total variable cost by 1.35.

TABLE 16. ESTIMATED TOTAL COST FOR THE 50-CAR TRAINS OPERATING BETWEEN SUBTERMINALS AND TEXAS GULF PORTS IN CENTS PER BUSHEL[1], 1977-78

Subterminal location	Texas Gulf Ports[2] Houston	Galveston	Beaumont — Port Arthur	Corpus Christi
	(¢/bu.)			
Buffalo, OK[3]	28.67	28.50	29.82	36.94
Ashland, KS	30.81	30.58	32.40	35.18
Meade, KS[3]	32.85	33.84	35.07	40.12
Liberal, KS[3]	31.77	32.99	34.70	38.11
Shattuck, OK[3]	28.80	28.57	29.79	33.60
Guymon, OK	32.82	34.09	35.76	39.18
Perryton, TX	30.40	30.12	31.37	35.17
Gruver, TX	30.05	31.31	32.99	35.94
Spearman, TX	31.08	30.85	32.08	35.88
Stratford, TX	27.46	27.28	30.08	31.94

[1]Costs are calculated by multiplying variable costs with the 1.35 ratio.
[2]The analysis did not include unit-train movement to New Orleans. Given the current rail system's regional configuration, the study region is most efficiently served by Texas Gulf ports. Historically, only a small quantity of the study region's production has moved through the Port of New Orleans.
[3]Subterminals located outside the six-county study area but who may receive wheat from the study area.

cates that subterminal annual volumes would range from 1.625 million bushels at Meade, Kansas, to 5.562 million bushels at Perryton, Texas. All or nearly all of Perryton, Stratford, and Liberal subterminal receipts would originate from the six-county area, whereas only a fraction of the Meade and Buffalo subterminal receipts would originate from the study area.

TABLE 17. SUBTERMINAL LOCATIONS THAT WOULD BE SERVED BY 50-CAR TRAINS WITH ESTIMATED UPGRADING COSTS AND BUSHELS OF WHEAT SHIPPED UNDER THE 50-, 80-CAR SYSTEM, 1977-78[1]

Feasible subterminal locations	Necessary annualized upgrading cost	Total volume/ subterminal	Volume to subterminal from study area
	($)	(000 bu.)	
Meade, KS	51,287	1625	586
Liberal, KS	50,721	2714	2464
Buffalo, OK	51,287	2564	398
Perryton, TX	77,768	5562	5562
Stratford, TX	50,721	2756	2756

[1]In this subterminal analysis, Seward County, Kansas, was included. Liberal, Kansas, is located in the southern portion of Seward County, which is adjacent to Beaver and Texas Counties, Oklahoma, and received substantial quantities from the six-county area.

The solution revealed that 49 percent of the wheat destined for Texas Gulf ports would move through the subterminal organizations. Conversely, only 51 percent of the export-destined wheat would move through inland terminals — a substantial decrease relative to the current and 80-car systems. As with the 80-car solution, the distribution of wheat among inland-terminal locations would be altered. In particular, Fort Worth would receive no study-area wheat, while the volume moving to Amarillo would be substantially increased and the flow to Enid substantially reduced. Seventy-two percent of inland-terminal receipts from country elevators would be rail transported (Table 18).

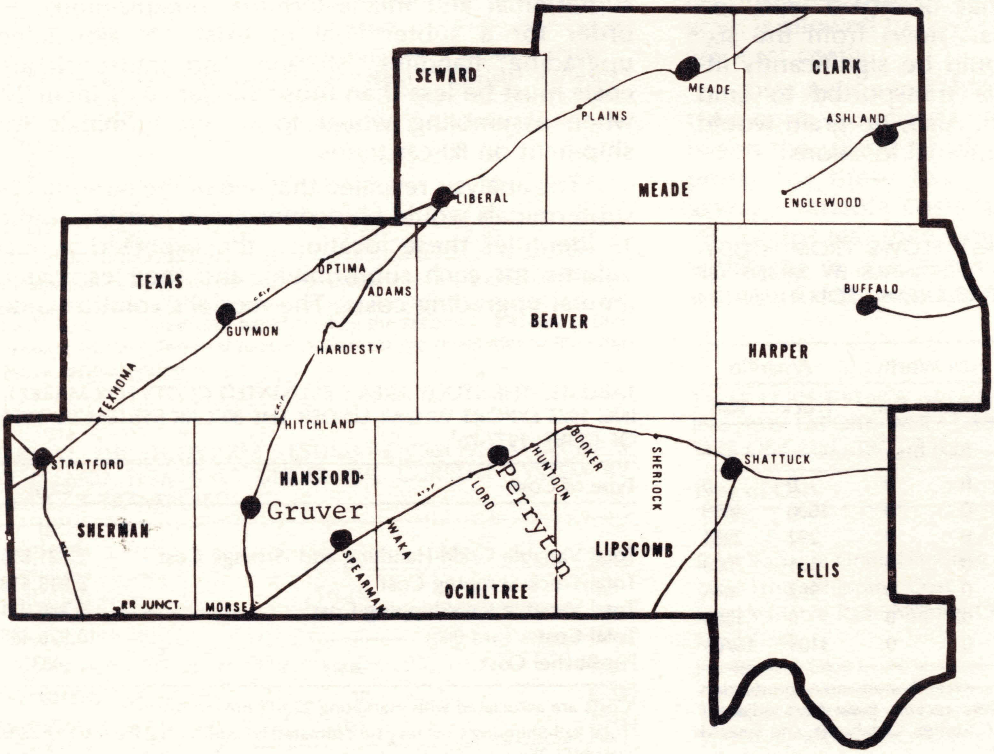

Figure 4. Potential subterminal locations for receipt of study-area wheat production.

TABLE 18. ESTIMATED 1985 WHEAT FLOWS FROM STUDY-REGION COUNTIES TO INLAND TERMINALS BY MODE OF TRANSPORT UNDER THE 50-, 80-CAR SOLUTION IN THOUSANDS OF BUSHELS[1]

County	Enid Truck	Enid Rail	Fort Worth Truck	Fort Worth Rail	Amarillo Truck	Amarillo Rail
	(000 bu.)					
Beaver, OK	434	0	0	0	0	0
Texas, OK	0	0	0	0	1546	2104
Sherman, TX	0	0	0	0	212	572
Hansford, TX	0	0	0	0	0	4828
Ochiltree, TX	355	0	0	0	144	18
Lipscomb, TX	448	0	0	0	0	640
TOTAL	1237	0	0	0	1902	8162

[1]Grain flows through subterminals and inland terminals exceed study-area production because country elevators along borders receive grain from adjacent counties, in particular, Ellis and Harper Counties, Oklahoma, and Seward and Meade Counties, Kansas.

TABLE 19. THE STUDY AREA'S ESTIMATED COSTS FOR MARKETING 1985 EXPORT WHEAT UNDER THE 50-, 80-CAR SYSTEM BY TYPE OF COST, 1977-78[1]

Type of Cost	Cost
	($)
Total Variable Grain-Handling and -Storage Cost	2,571,305
Total Truck-Shipping Cost	2,717,617
Annualized Subterminal-Upgrading Cost	203,492
Additional Grain-Grading Cost at Subterminals	11,766
Total Variable Rail-Shipping Cost[2]	5,354,113
Total Cost	10,858,293
Per-Bushel Cost	.462

[1]Costs include six-county area and Seward County, Kansas. Costs are for marketing 23.497 million bushels.

[2]Total Rail-Shipping Cost may be estimated by multiplying the total variable cost by 1.35.

Results from the model indicate that it would not be a least-cost alternative for area country elevators to ship to subterminals as subterminals would receive all grain from farmers rather than from country elevators because of the keen cost competition between subterminal and inland-terminal organizations. That is, when all costs are considered, it would be more efficient for a country elevator to ship grain to an inland terminal for movement on an 80-car train rather than to ship to a nearby subterminal for movement on a 50-car train.

On-farm storage would be an integral part of the 50-, 80-car organization. The analysis indicates that subterminals would fill their storage at harvest time, and these receipts would represent about 20-33 percent of the subterminal's annual volume. After harvest, farmers would deliver farm-stored wheat to subterminals where storage would be available. In the model, approximately 35 percent of the available on-farm storage was filled for delivery to subterminals at later time periods.

Costs of the 50-, 80-car solution are shown in Table 19. The solution indicates total system costs to average 46.2 cents per bushel, 2.1 cents per bushel less than the 80-car system and 10.2 cents per bushel less than the current system.

20-, 50-, 80-Car System

This organization involves 80-car unit trains operating from inland terminals and either 20-, 50-, or 80-car trains operating from selected subterminal locations. The 50-, 80-car solution served as a guide for deciding which subterminal locations would be served by the alternative-size unit trains. From this solution, the low volume and impractical locations were determined to be partially the results of subterminal-upgrading costs necessary to accommodate a 50-car train. If a subterminal in the 50-car organization had an annual volume less than 1.67 million bushels (the volume carried by 10 trains of 50 cars), it was designated a 20-car-train cost. Those subterminal locations receiving in excess of 2.67 million bushels (the volume carried by 10 trains of 80 cars) appeared to have cost attributes that would support larger unit trains; these locations were then designated 80-car-train locations and given the corresponding rail rates (Table 20).

The 80-car trains operating between subterminals and Texas Gulf port locations had, on the average, variable-cost savings of 12.8 cents per bushel relative to single-car movements. The variable rail-cost savings of the 20-car train relative to the single-car movement was estimated at 9.9 cents per bushel.

As indicated in the analysis, all of the potential subterminals would be feasible and would receive study-area wheat production. Five of these subterminals are located within the six-county region, while the remaining are in adjacent counties. Table 21 shows the activated subterminal locations, annualized upgrading costs, total volume received per subterminal, and volume received at each subterminal from study-area origins. The model analysis indicates volume per subterminal would range from 483,000 bushels at Spearman, Texas (20-car train), to 5.8 million bushels at Perryton, Texas (80-car train). Subterminals would receive 75 percent of the study area's volume destined for Texas Gulf ports. Conversely, only 25 percent of the export-destined wheat would move through inland terminals. Table 22 identifies the expected wheat flows from study-region counties to inland terminals by truck and rail. As with the previous alternative distribution-system solutions, the distribution of receipts at inland-terminal locations were substantially altered relative to the current system. Approximately 69 percent of the inland terminal's receipts would be rail-delivered.

As with the 50-, 80-car system, subterminals in the 20-, 50-, 80-car system would depend on producers to store wheat for later delivery. Approximately 46 percent of the available on-farm storage would be

TABLE 20. ESTIMATED TOTAL COSTS FOR EITHER 20-, 50-, or 80-CAR TRAINS OPERATING BETWEEN SUBTERMINALS AND TEXAS GULF PORTS IN CENTS PER BUSHEL, 1977-78[1]

Subterminal location	Size of train	Texas Gulf Ports[2] Houston	Galveston	Beaumont — Port Arthur	Corpus Christi
	(cars)	(¢/bu.)			
Buffalo, OK[3]	50	27.67	28.50	29.82	36.94
Ashland, KS[3]	20	32.25	32.72	33.86	36.54
Meade, KS[3]	50	32.85	33.84	35.07	40.12
Liberal, KS[3]	80	28.57	29.67	31.17	34.30
Shattuck, OK[3]	20	30.28	30.04	31.27	35.03
Guymon, OK	20	33.62	34.90	36.61	40.07
Perryton, TX	80	27.38	27.15	28.26	31.67
Gruver, TX	20	30.79	32.08	33.82	36.76
Spearman, TX	20	32.62	32.36	33.59	37.37
Stratford, TX	80	24.80	24.66	27.11	28.84

[1]Costs are calculated by multiplying variable costs with the 1.35 ratio.
[2]The analysis did not include unit-train movement to New Orleans. Given the current rail system's regional configuration, the study region is most efficiently served by Texas Gulf ports. Historically, only a small quanitity of the study region's production has moved through the Port of New Orleans.
[3]Subterminals located outside the six-county study area but who may receive wheat from the study area.

TABLE 21. SUBTERMINAL LOCATIONS THAT WOULD BE SERVED BY EITHER 20-, 50-, or 80-CAR TRAINS WITH ESTIMATED UPGRADING COSTS AND BUSHELS OF WHEAT SHIPPED UNDER THE 20-, 50-, 80-CAR SOLUTION IN THOUSANDS OF BUSHELS, 1977-78[1]

Feasible subterminal locations	Necessary annualized upgrading cost	Total volume/ subterminal	Volume to subterminal from study area
	($)	(000 bu.)	
Buffalo, OK	51,287	2194	369
Ashland, KS	14,054	1223	29
Meade, KS	51,287	1090	504
Liberal, KS	91,163	3142	2892
Shattuck, OK	14,054	1149	57
Guymon, OK	5,004	1680	1680
Perryton, TX	119,770	5787	5787
Gruver, TX	5,004	2155	2155
Spearman, TX	14,054	483	483
Stratford, TX	91,163	3053	3053

[1]In this subterminal analysis, Seward County, Kansas, was included. Liberal, Kansas, is located in the southern portion of Seward County, which is adjacent to Beaver and Texas Counties, Oklahoma, and received substantial quantities from the six-county area.

used for this purpose. The analysis indicated no wheat flow from country elevators to subterminals.

The estimated cost of this organization would be 44.2 cents per bushel (Table 23). When compared to the current, 80-car, and 50-, 80-car systems, the respective per-bushel savings of the 20-, 50-, 80-car system are 12.2 cents, 4.1 cents, and 2.0 cents.

Summary of Cost Savings for Each Distribution System

Each of the distribution systems exhibited substantial savings relative to the current system (Table 24). The smallest savings was associated with the 80-car system, the system most analogous to the current one. Based on model results, the estimated per-bushel cost of this organization would be 48.3 cents, a cost savings of 8.1 cents per bushel relative to the current system or an annual cost savings of $1.642 million. With the second alternative distribution system, existing country elevators are upgraded to accommodate 50-car trains. This system had estimated costs of 46.2 cents per bushel, representing a 10.2-cents-per-bushel savings relative to the current system. Based on study-region production, this system would yield an annual savings of $2.081 million. Based on model results the cost of the final alternative system (20-, 50-, 80-car system) would be 44.2 cents per bushel, a savings of 12.2 cents per bushel relative to the current system. This is the most efficient of the analyzed systems and would

TABLE 22. ESTIMATED 1985 WHEAT FLOWS FROM STUDY-REGION COUNTIES TO INLAND TERMINALS BY MODE OF TRANSPORT UNDER THE 20-, 50-, 80-CAR SOLUTION IN THOUSANDS OF BUSHELS[1]

County	Enid Truck	Enid Rail	Fort Worth Truck	Fort Worth Rail	Amarillo Truck	Amarillo Rail
	(000 bu.)					
Beaver, Ok	241	0	0	0	0	0
Texas, OK	0	0	0	0	891	1389
Sherman, TX	0	0	0	0	120	275
Hansford, TX	0	0	0	0	0	1897
Ochiltree, TX	139	0	0	0	0	18
Lipscomb, TX	303	0	0	0	0	261
TOTAL	683	0	0	0	1011	3840

[1]Grain flows through subterminals and inland terminals exceed study-area production because country elevators along borders receive grain from adjacent counties, in particular, Ellis and Harper Counties, Oklahoma, and Seward and Meade Counties, Kansas.

TABLE 23. THE STUDY AREA'S ESTIMATED COSTS FOR MARKETING 1985 EXPORT WHEAT UNDER THE 20-, 50-, 80-CAR SYSTEM BY TYPE OF COST, 1977-78[1]

Type of Cost	Cost
	($)
Total Variable Grain-Handling and -Storage Cost	2,428,949
Total Truck-Shipping Cost	2,360,088
Annualized Subterminal-Upgrading Cost	352,219
Additional Grain-Grading Cost at Subterminals	21,012
Total Variable Rail-Shipping Cost[2]	4,996,861
Total Barge-Shipping Cost	30,456
Total Cost	10,189,586
Per-Bushel Cost	.442

[1]Costs include the six-county area and Seward County, Kansas. Costs are for marketing 23.063 million bushels.

[2]Total Rail-Shipping Cost may be estimated by multiplying the total variable cost by 1.35.

TABLE 24. THE STUDY AREA'S ESTIMATED COST SAVINGS ASSOCIATED WITH THE ALTERNATIVE DISTRIBUTION SYSTEMS, 1985 EXPORTS AND 1977-78 COSTS

System	Per-Bushel cost	Per-Bushel cost savings relative to current system	Annual saving[1]
	(¢/bu.)		($)
Current	56.4		
80-Car	48.3	8.1	1,652,400
50-, 80-Car	46.2	10.2	2,080,800
20-, 50-, 80-Car	44.2	12.2	2,488,800

[1]Calculated by multiplying per-bushel savings (column 3) by the study area's expected 1985 volume entering export channels, 20.4 million bushels.

yield annual marketing-system savings of $2.489 million.

The principal source of savings for each of the three alternative distribution systems is reduced railroad-shipping costs. Variable rail cost for the current system is estimated at 33.2 cents per bushel, whereas the 80-car-train system had an estimated variable rail cost of 23.9 cents per bushel, which results in a cost savings to the railroad of 9.3 cents per bushel. The estimated rail costs of the 50-, 80-car and the 20-, 50-, 80-car systems were 22.8 cents and 21.9 cents per bushel, respectively. This represents respective variable-cost savings to the railroads of 10.4 cents and 11.2 cents per bushel. Rail cost per-ton-mile was calculated for each system to gain additional insight into potential railroad efficiency. With the current system, variable rail cost per-ton-mile was estimated at 1.398 cents. The estimated variable rail costs per-ton-mile for the 80-car, 50- 80-car, and 20-, 50-, 80-car solutions were 1.084 cents, .897 cent, and .818 cent, respectively. The railroad's ton-mile cost savings ranged from 23 percent for the 80-car system to 41 percent for the 20-, 50-, 80-car solution.

Energy Consumption for Each Distribution System

Due to the decrease in available energy supplies and the associated increase in energy's value, research was carried out to estimate energy consumption by the current system and the three alternative systems. This was accomplished by aggregating ton-miles generated by a particular mode in a specific movement and multiplying this value by an appropriate parameter reflecting BTU (British Thermal Units) consumption per ton-mile. The BTU consumption parameters were taken from secondary sources (Table 25). The three alternative systems show energy savings relative to the current system, with the most efficient system being the 80-car solution which displayed energy savings of 26 percent. The least efficient of the alternatives was the 20-, 50-, 80-car solution which consumed 24 percent less energy than the current system.

Sensitivity of Subterminal Organization to Unfavorable Cost Movements

Impact of Increased Farm Storage Cost on Subterminal Organizations

The subterminal system requires substantial farm storage in order for it to be a feasible organization. Some producers may lack facilities or management skill to maintain grain quality relative to other storage facilities; thus, the impact of increased farm storage costs on the viability of the subterminal organization and the impact of these increased costs on the 50-, 80-car system were determined. The annual variable costs of storing wheat on farms is currently estimated at 8.32 cents per bushel. In the model, cost is assigned to the three time periods by duration of each period. The most critical farm storage period was determined to be the first 66 days, which includes a 21-day harvest and a 45-day period following harvest. Based on earlier analysis of the 50-, 80-car solution, grain was found to be farm-stored during these time periods and then shipped to the subterminals as storage space became available. Increased farm storage costs were therefore assigned only to the 21-day harvest period and the following 45 days. Because of possible additional increases in grain shrinkage, farm storage cost was increased by .25 cent per bushel in the first period and .50 cent per bushel in the second period; thus, annual variable farm storage cost increased to 9.07 cents per bushel.

In general, the results of this analysis were as anticipated. Increasing farm storage cost reduces the volume handled by subterminals or, conversely, increases the volume moving to inland terminals (Table 26). With the original 50-, 80-car solution, about 49 percent of the wheat destined for the Texas Gulf ports was handled by subterminals; with in-

TABLE 25. ESTIMATED ENERGY CONSUMPTION OF THE FOUR SOLUTIONS BY MODE OF TRANSPORT IN MILLIONS OF BTU'S[1]

System	1 Car to inland terminals[2]	1 Car to Gulf ports[3]	20-, 50-, and 80-car unit trains to Gulf ports[4]	Commercial truck[5]	Barge[6]	Farm assembly[7]	Total energy consumption
	000,000 BTU's						
Current	95,991	242,888	0	27,539	0	32,140	398,558
80-Car	43,019	7,207	168,414	45,331	0	32,826	296,797
50-, 80-Car	15,904	6,824	207,730	25,944	0	42,233	298,635
20-, 50-, 80-Car	8,458	3,891	223,287	16,242	2,565	47,052	301,495

[1]Energy consumption estimated for marketing 21.59 million bushels.
[2]Based on estimate of 890 BTU's/ton-mile.
[3]Based on estimate of 600 BTU's/ton-mile.
[4]Based on estimate of 400 BTU's/ton-mile.
[5]Based on estimate of 2323.26 BTU's/ton-mile.
[6]Based on estimate of 500 BTU's/ton-mile.
[7]Based on estimate of 4195.62 BTU's/ton-mile.

Sources of Rail and Barge BTU consumption were: *The Replacement of Alton Lock and Dam 26*, September 1979, An Advisory Report of the DOT to the Senate Commerce Committee, and a paper authored by John B. Hopkins, A. T. Newfall, and Martin Hazel, *Fuel Consumption in Rail Freight Service: Theory and Practice*, DOT, Transportation Systems Center, Cambridge, Massachusetts. The paper was presented at the 56th Annual Meeting of the Transportation Research Board, January 1977.

TABLE 26. ESTIMATED QUANTITIES OF 1985 EXPORT WHEAT HANDLED BY SUBTERMINALS BEFORE AND AFTER INCREASED FARM STORAGE COST UNDER THE 50-, 80-CAR SOLUTION[1]

Feasible subterminal locations	Necessary annualized upgrading costs	Total volume/subterminal prior to increasing farm-storage costs	Total volume/subterminal after increasing farm-storage costs	Volume to subterminals from study area
	($)	(000 bu.)		
Meade, KS	51,287	1625	1556	586
Liberal, KS	50,721	2714	2596	2346
Buffalo, OK	51,287	2564	2541	398
Perryton, TX	77,768	5562	5244	5244
Stratford, TX	50,721	2756	2160	2160

[1]In this subterminal analysis, Seward County, Kansas, was included. Liberal, Kansas, is located in the southern portion of Seward County, which is adjacent to, Beaver and Texas Counties, Oklahoma, and received substantial quantities from the six-county area.

creased farm storage cost, this portion is reduced to approximately 44 percent. Aggregate volume handled by subterminals decreased 9 percent. Volume per subterminal did not decrease uniformly. For example, the Stratford subterminal location had a volume decrease of 22 percent, while the Buffalo subterminal location had volume reduced less than 1 percent. Subterminals which are relatively accessible to inland terminals appeared to lose greatest volume. Those having relatively small costs in moving grain to inland terminals are particularly vulnerable to unfavorable cost changes.

As expected, the costs of this solution (46.3 cents per bushel) are increased slightly relative to the original 50-, 80-car solution which had an expected total per-bushel cost of 46.2 cents (Table 27).

Impact of Increased Truck-Weight Limit on Subterminal Organization

Increasing the truck-weight limit reduces per-bushel transportation cost. For example, increasing the load limit from 860 bushels to 1,100 bushels on a 100-mile haul will reduce per-bushel cost from 15.5 cents to 12.3 cents, or by 20 percent. The purpose of this section of the study was to determine the impact

TABLE 27. THE STUDY AREA'S ESTIMATED COSTS FOR MARKETING 1985 EXPORT WHEAT UNDER THE 50-, 80-CAR SOLUTION WITH INCREASED FARM STORAGE COSTS BY TYPE OF COST, 1977-78[1]

Type of Cost	Cost
	($)
Total Variable Grain-Handling and -Storage Cost	2,584,866
Total Truck-Shipping Cost	2,603,281
Annualized Subterminal-Upgrading Cost	206,741
Additional Grain-Grading Cost at Subterminals	10,734
Total Variable Rail-Shipping Cost[2]	5,499,484
Total Cost	10,905,106
Per-Bushel Cost	.463

[1]Costs include the six-county area and Seward County, Kansas. Costs are for marketing 23.577 million bushels.
[2]Total Rail-Shipping Cost may be estimated by multiplying the total variable cost by 1.35.

of increased truck-load limits on the 50-, 80-car subterminal organization.

A priori, several effects may be hypothesized to result from lowered trucking cost: 1) Reduced trucking cost may increase the use of trucks in the assembly of grain to inland terminals for movement on 80-car trains. In which case, subterminals may receive reduced volumes. 2) Lowered trucking cost may make it practical to truck-transport additional wheat directly to Gulf ports and bypass the subterminal and inland-terminal organization. 3) Transportation of wheat from country elevator to subterminal may become more economical; in which case, the volume flowing through the subterminal system would be increased.

For purposes of this analysis, truck-weight limit was assumed to increase from 860 bushels to 1,100 bushels, and backhauls were assumed available for all truck movements.

Increasing the truck-weight limit from 860 bushels to 1,100 bushels adversely affects the subterminal organization. Because of the reduced truck cost, wheat was increasingly shipped by truck to inland terminals. Study-area wheat production destined for subterminals decreased 13 percent. Similarly, the portion of study-area wheat handled by subterminals decreased from 49 percent (original 50-, 80-car solution) to 43 percent. As in the previous solution involving increased farm storage cost, the subterminals are affected unevenly (Table 28). Volume at all facilities decreased relative to the original solution, except for the Meade, Kansas, subterminal location where expected volume increased from 1.625 to 1.994 million bushels. With increased truck-weight limits, a subterminal adjacent to Meade lost its comparative advantage to that facility, and grain was diverted away from the neighboring plant.

Truck was the least-cost assembly mode for 71 percent of the wheat flowing to inland terminals. With the original 50-, 80-car solution, this mode assembled approximately 28 percent of the inland-terminal receipts. The analysis revealed that no wheat would move by truck from country elevator to subterminal or to Texas Gulf port terminal. However, the analysis did indicate that grain would be trucked to the Port of Catoosa for barging to Mississippi River ports. This flow was to meet the predetermined demand at this location which, in the original 50-, 80-car solution, was met by single-car haulage.

Table 29 identifies the costs associated with this organization. As expected, the solution's total per-bushel cost (46.1 cents) is less than that expected for the original 50-, 80-car solution (46.2 cents) with 860-bushel truck-weight limits.

Impacts of Alternative Distribution Systems on Marketing-System Participants

If implemented, each of the three studied grain transportation organizations would affect the marketing-system participants differently. With the 80-car solution, farmers and country elevator managers would not be forced to act in a manner that differs substantially from the current system. Country

TABLE 29. THE STUDY AREA'S ESTIMATED COSTS FOR MARKETING 1985 EXPORT WHEAT UNDER THE 50-, 80-CAR SOLUTION WITH INCREASED TRUCK-WEIGHT LIMITS BY TYPE OF COSTS, 1977-78[1]

Type of Cost	Cost
	($)
Total Variable Grain-Handling and -Storage Cost	2,536,669
Total Truck-Shipping Cost	3,248,912
Annualized Subterminal-Upgrading Cost	180,840
Additional Grain-Grading Cost at Subterminal	10,254
Total Variable Rail-Shipping Cost[2]	4,541,122
Total Barge-Shipping Cost	72,756
Total Cost	10,590,553
Per-Bushel Cost	.461

[1]Costs include the six-county area and Seward County, Kansas. Costs are for marketing 22.973 million bushels.

[2]Total Rail-Shipping Cost may be estimated by multiplying the total variable cost by 1.35.

TABLE 28. ESTIMATED QUANTITIES OF 1985 EXPORT WHEAT HANDLED BY SUBTERMINALS BEFORE AND AFTER INCREASED TRUCK-WEIGHT LIMITS UNDER THE 50-, 80-CAR SOLUTION[1]

Feasible subterminal location	Necessary annualized upgrading costs	Total volume/subterminal prior to increasing truck-load limit	Total volume/subterminal after increasing truck-load limit	Volume to subterminals from study area[1]
	($)	(000 bu.)		
Meade, KS	51,287	1625	1994	586
Liberal, KS	50,721	2714	2596	2346
Buffalo, OK	51,287	2564	1568	293
Perryton, TX	50,721[2]	5562	5130	5130
Stratford, TX	50,721	2756	1899	1899

[1]In this subterminal analysis, Seward County, Kansas, was included. Liberal, Kansas, is located in the southern portion of Seward County, which is adjacent to Beaver and Texas Counties, Oklahoma, and received substantial quantities from the six-county area.

[2]It was not feasible for Perryton to upgrade into a facility capable of handling an annual volume in excess of 5.0 million bushels. The associated upgrading cost would have been $77,768.

elevators would ship a slightly greater percent of their export-destined wheat volume to inland terminals. All wheat destined for the Texas Gulf ports would move through inland terminals for purposes of capturing the more efficient 80-car trains. Although the quantity of wheat moving to inland terminals would tend to increase with the 80-car system, the portion handled by the various inland-terminal locations would be substantially altered. In particular, the six-county study area would ship no wheat to Fort Worth, whereas shipments to Amarillo would increase and those to Enid would decrease. Within the current system, about 15 percent of the flow from country elevators to inland terminals is estimated to be truck-transported. If the cost-based, 80-car solution were implemented, trucks would have to haul 25 percent of the country elevator-to-inland terminal flow for optimum efficiency. Percent total ton-miles generated by railroads would then be reduced from 96.5 in the current system to 96 in the 80-car system.

Both the 50-, 80-car and the 20-, 50-, 80-car solutions would, in general, affect farmers, country elevators, and inland terminals more so than the 80-car solution. Since these distribution systems involve subterminals which receive much of their supply from farm storage, farmers will be required to store their own grain. In addition, farmers would need to assemble grain over greater distances to participate in the subterminal's cost-saving advantage made possible by the operation of unit trains. In general, the average distance of farmer assembly increases 2 to 4 miles relative to the current and 80-car-train solutions. Country elevators located near subterminals may be forced to exit the industry, since farmers would likely bypass them in favor of subterminal facilities. Within the current and 80-car systems, 56 country elevators are involved in receiving producer's export-destined wheat. The 50-, 80-car-train solution includes 30 country elevators and five subterminals while the 20-, 50-, 80-car solution includes 21 country elevators and 10 subterminals. Therefore, the number of initial assemblers is reduced in both of these alternatives. The analysis shows that the volume of wheat received by the inland-terminal industry would be reduced within the subterminal organization, and the portion moving to various inland-terminal locations would be altered relative to the current system. Within the 50-, 80-car and the 20-, 50-, 80-car systems, only 51 and 25 percent of the respective export-destined wheat is estimated to move through inland terminals. Within the subterminal organization, the amount of grain hauled from country elevators to inland terminals by truck would be greater than within the current system but less than within the 80-car system.

The analysis indicates that the current grain-handling industry (country elevator and inland terminal) could be seriously affected with the adoption of a subterminal organization. Reduced volumes of export-destined grain at country elevators and inland terminals could jeopardize the value of these facilities unless alternative income sources were found. In this study, analysis focused on export-destined grain flows or about 84 percent of production and does not indicate least-cost flow patterns for domestically consumed wheat. Perhaps those country elevators not necessary for the handling of export-destined wheat would specialize in the handling and blending of domestically consumed grain. However, it seems likely that some country elevators and most inland terminals would lose in an organization that includes subterminals.

To some extent, the grain-merchandizing practices of subterminal management may need to be altered relative to those necessary for country elevator management. The current single-car rate allows management to merchandize wheat as it is purchased from producers and, therefore, purchased inventory is not great. In contrast, subterminal management would be required to accumulate the purchased inventory to meet the multicar shipment requirements of the unit train. In which case, purchased inventory levels would become substantial, and the risk associated with change in value of inventory would increase relative to the current situation. This risk would likely need to be reduced through acquired futures-hedging skills.

For a subterminal system to evolve, the country elevator industry will need to make substantial capital investment to upgrade facilities. The analysis indicated an incentive for this investment; however, it further revealed that the subterminal system would be in strong competition with the inland-terminal industry. Therefore, an unfavorable movement in a cost parameter (increased farm storage cost, change in trucking costs) can neutralize the subterminal's cost advantage and create an additional investment risk. It would seem that some form of rate assurance by railroads would need to be provided to potential subterminal investors for this system to evolve.

Railroads are the principal source of potential system efficiency and therefore are the most critical marketing agents for the remodelling of the current system. Their potential actions can have significant impacts on other system participants, in particular, the grain-handling industry. It would appear that system changes must be initiated by railroads with the understanding that the grain-handling industry must be provided a financial incentive to modify activity and to invest new capital; that is, available savings to the railroads must, in part, be passed on to grain handlers and, in turn, to farmers in order to obtain system changes. The extent that savings will be passed on to other system participants depends on the level of competition between railroads and other transportation modes and requires further study, which is beyond the scope of this analysis.

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Appendix A

To provide additional insight into the structure of the network-flow model, a prototype is presented. A network model is constructed of nodes representing elements comprising the system — including production origins, country elevators, subterminals, inland terminals, the river elevator, and port terminals — and arcs, which connect nodes and include information regarding lower and upper bounds on the arc flow and, in addition, the unit cost of this flow.

The prototype model includes two production origins (P=2), one country elevator (C=1), one subterminal (S=1), one inland terminal (I=1), one river elevator (R=1), and one port terminal (E=1). It also includes two time periods (T=2) (Figure A1) which are represented through three points in time. Grain stored from point 1 in time to point 2 will have been stored through the first time period. Grain stored from point 2 in time to point 3 will have been carried through the second period. The nodes of the network are defined as follows:

P_{ik}: represents production location i at point k in time
$i = 1, 2, \ldots, P$
$k = 1, 2, \ldots, T+1$

C_{ik}: represents country elevator i at point k in time
$i = 1, 2, \ldots, C$
$k = 1, 2, \ldots, T+1$

S_{ik}: represents subterminal i at point k in time
$i = 1, 2, \ldots, S$
$k = 1, 2, \ldots, T+1$

I_{ik}: represents inland terminal i at point k in time
$i = 1, 2, \ldots, I$
$k = 1, 2, \ldots, T+1$

R_{ik}: represents river elevator i at point k in time
$i = 1, 2, \ldots, R$
$k = 1, 2, \ldots, T+1$

E_{ik}: represents port elevator i at point k in time
$i = 1, 2, \ldots, P$
$k = 1, 2, \ldots, T+1$

The quantity of grain which may be shipped from a country elevator in the first time period is constrained to available transportation. Accordingly, a set of artificial nodes are created. These are represented in Figure A1 as A_i^t and A_i^r, where:

A_i^t: represents the truck node associated with country elevator i during harvest, and

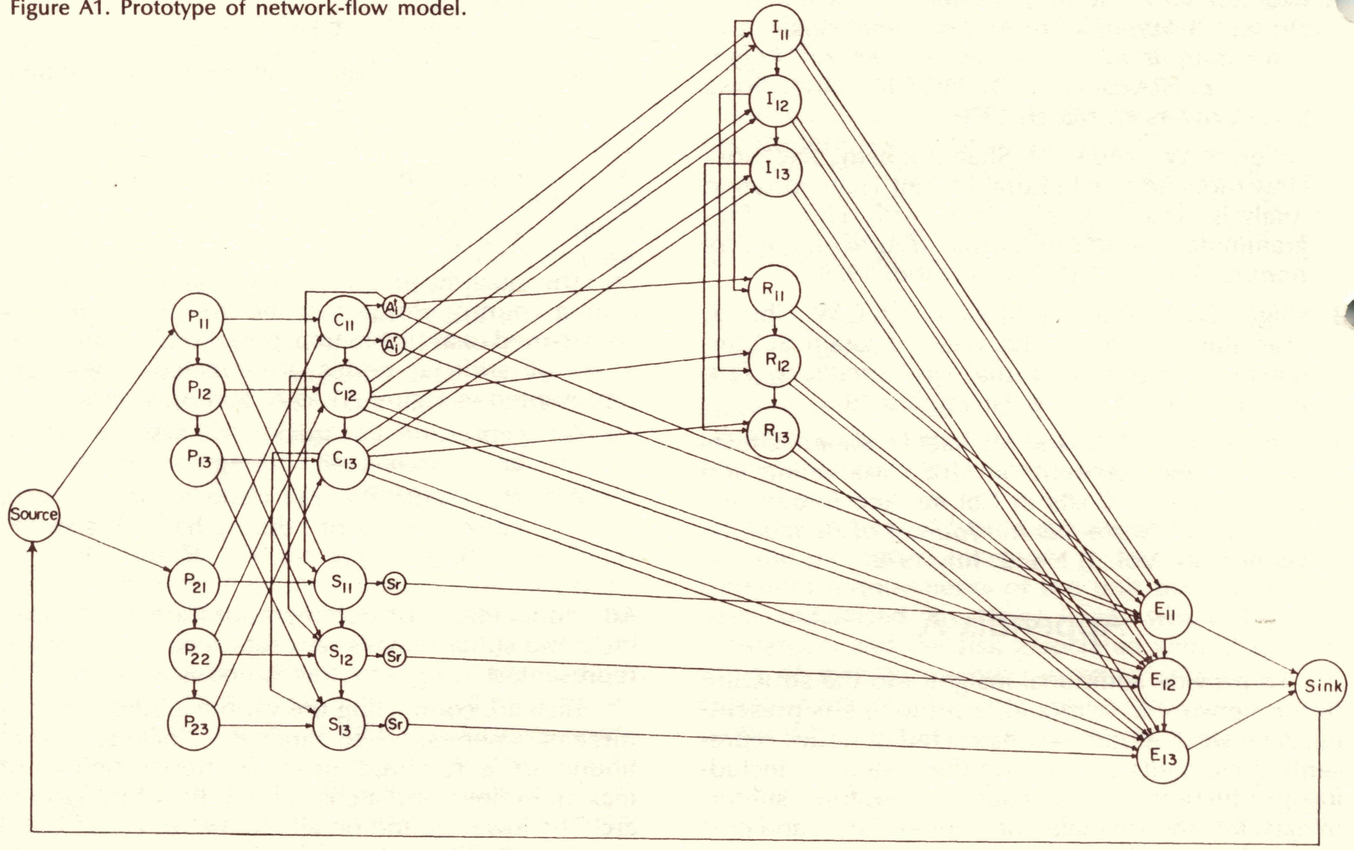
A_i^r: represents the rail node associated with country elevator i during harvest, and
$i = 1, 2, \ldots, C.$

An additional set of dummy nodes are required to include a subterminal's renovation costs. These are represented in Figure A1 as S_r nodes.

Each arc connecting the various nodes includes three parameters. These parameters include a lower bound or a required flow, an upper bound or maximum flow, and a cost of unit flow through the arc. The lower bound on all arcs has been set equal to zero except for those linking the source node with the production origin nodes and the port terminal nodes with the sink node (Figure A1). The lower and upper bounds on the arcs terminating at the production origin node (P_{11} and P_{12}) are set equal to the quantity of harvested wheat at each production origin which is export-destined. The arcs connecting the port elevator with the sink node have their lower and upper bounds set equal to the exogenously estimated foreign wheat demand at the port elevator. Arcs connecting the C_{ik} nodes with the A_i^t and A_i^r nodes have their upper bounds set equal to the respective quantity of truck and rail service available at harvest. All remaining arcs have their upper bounds set equal to infinity, except for those arcs representing wheat storage activities.

Many arcs include costs of either grain receiving, storage, loading, and/or transportation. The multiperiod or storage characteristics of the model are introduced through the use of storage arcs which link a storage facility through points in time. For example, the vertical arc connecting P_{11} (production origin 1, time frame 1) and P_{12} (production origin 1, time frame 2) represents the first time period and includes the farm storage cost associated with production origin 1. The upper bound on this vertical arc reflects the wheat storage available at this production origin. The vertical storage arcs linking the subterminal, inland terminal, river elevator, and port terminal through alternative time

Figure A1. Prototype of network-flow model.



frames include similar types of cost and upper-bound information.

If wheat is not farm-stored at harvest-time, it must move to a country elevator or subterminal. For production origin 1, this will involve flow over the arc linking P_{11} and C_{11} or over the arc linking P_{11} with S_{12}. These arcs include farm assembly cost and unloading costs at these respective facilities. Arcs linking the country elevator with the subterminal, inland terminal, and river elevator include the unit loading cost of the appropriate mode, transportation cost, and the unloading cost at the respective facilities. Similar types of costs are included on those arcs which connect the inland terminal, river elevator, and port terminal. To estimate the costs of the current system, rail arcs included only single-car movement. When the feasibility of multicar shipments are examined, the rail arcs connecting the inland terminal with the port terminal include 80-car costs, whereas the arcs linking the subterminal with the port elevator include either 20-, 50-, or 80-car cost. Arcs connecting the S_{ik} node (subterminal) and the S_r nodes include estimated subterminal unit fixed renovation cost.

To include the annual fixed cost associated with renovating a country elevator into a subterminal, a procedure involving a series of iterative computer solutions of the model was carried out. The initial solution of the model included no subterminal renovation costs (i.e., costs on the arcs connecting the S_{ik} with the S_r level nodes were set equal to zero). The initial solution provided necessary input to the subsequent computer solution, in particular, the subterminal's annual fixed renovation cost was divided by the subterminal's annual volume as determined by the initial solution. The resulting unit cost parameter was entered on the arc connecting the S_{ik} with the S_r nodes, and a solution was again obtained. Again, the annualized cost was divided by the resulting subterminal volume, yielding a new and larger cost parameter, etc. This procedure was carried out until the volume of the potential subterminal stabilized or was changed from solution to solution. The iterative procedure was internalized and typically five or six solutions were required prior to stabilization. The feasible subterminal's stabilized volume was one where the unit fixed renovation costs multiplied by the associated volume yielded the total fixed cost. For the unfeasible subterminals, the stabilized volumes were zero.

The network solution technique requires that a return arc be created, originating at the sink node and terminating at the source node (Figure A1). The lower and upper bounds on this arc are set equal to the total wheat supply which is identical to wheat demand. After construction of the network-flow model, a network algorithm is applied to resolve the least-cost solution.

Any network-flow model can be formulated as a linear-programming model. In a linear-programming model, each node is represented by a row (constraint) and each arc by a column (activity). The direction of flow on an arc linking node *i* to node *j* is indicated in the linear-programming table as a +1 coefficient in the row for node *i* and a −1 coefficient in the row for node *j*. Linear-programming and network-flow models yield identical least-cost solutions.

Acknowledgments

Several individuals made substantial contributions to this research effort. These include Orlo Sorenson (Kansas State University), who estimated grain handling and storage cost parameters, and Jack Lamkin (Texas Transportation Institute), who estimated rail cost parameters. Others making significant contributions were Sadler Bridges (Texas Transportation Institute), Robert Oehrtman (Oklahoma State University), C. Phillip Baumel (Iowa State University), Lowell Hill (University of Illinois), Frank Hardesty (Federal Railroad Administration), and Jack Dezik and Darrell Fannin (Texas A&M University).

Appreciation is expressed to Donald Farris, John Nichols, and Roland Smith for review of the manuscript.

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2M — 11-80