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Economic Implications of Alternative Dry-Bulk Fertilizer Supply Systems: A South-Central Nebraska Case Study

by
Mary Berglund
Dale G. Anderson

TEACHING RESEARCH EXTENSION

Institute of Agriculture and Natural Resources

The Agricultural Experiment Station
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln
H. W. Ottoson, Director
In Cooperation With
Economics, Statistics and Cooperatives Service
U.S. Department of Agriculture
Washington, D.C.

CONTENTS

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ACKNOWLEDGMENTS

Procedures and results reported here are based on a study conducted under Nebraska Agricultural Experiment Station Project 10-60, a contributing project to Western Regional Project WM-61, "Impact of Changes in World Food Supply-Demand Conditions Upon Selected Agricultural Factor Markets." This study is an extension of earlier work done under Nebraska Agricultural Experiment Station Project 10-62, a contribution to North Central Regional Project 112, "Impact of Changing Transportation Systems on Local Grain and Farm Supply Firms" (1, 5). The earlier project in turn was an outgrowth of a study made at Iowa State University (3).

Mr. James Miller, a University of Nebraska College of Law student, developed most of the bulk-blending, warehousing, and trucking cost estimates used in the study. Dr. John I. Bucy, Tennessee Valley Authority, Muscle Shoals, Alabama, provided single-car rail rates for fertilizer shipments. Mr. Wayne Budt, formerly with the Nebraska Public Service Commission, secured most of the multiple-car and other special rates. Mr. James Kramer and Dr. William Sutherland, Tennessee Valley Authority, Lincoln, Nebraska, offered many helpful suggestions. A great many other persons provided data and advice; their collective help was indispensable.

Economics, Statistics and Cooperatives Service, U.S. Department of Agriculture, provided partial financial support for the project; the patience and encouragement of Dr. John O. Gerald, the E.S.C.S. cooperator in Washington, was appreciated.

SUMMARY

This study analyzed the economic implications of alternative patterns of rail service for a case-study area in south-central Nebraska. Special attention was given to effects of branchline abandonments on the delivery system for dry-bulk fertilizer.

The study was an extension of an earlier Nebraska track-abandonment study which focused only on grain traffic (1). Based on the earlier work, the study area should receive net economic benefit from abandonment of one-fourth of the area's branch-line track.

The purpose of the latest study was to establish the effect of including dry-bulk fertilizer, the major commodity moving into the area by rail, on the earlier results.

Five alternative rail-line configurations or options were evaluated:

I. The existing single-car system, with no track abandonment.
II. Multiple-car shipments over a completely upgraded rail system.
III. Abandonment of light-duty rail lines, with multiple-car shipments to a nearby fertilizer warehouse.
IV. Abandonment of light-duty lines, with multiple-car shipments to new warehouses in the area.
V. Abandonment of light-duty track, with fertilizer backhauled in multiple-car lots from new combination grain/fertilizer warehouses in the study area.

The addition of fertilizer to the analysis did not appreciably change the outcome of the earlier grain-oriented study. Although the existing system of single-car rail shipments of fertilizer to blending plants and grain from country elevators to terminal markets (Option I) was less costly and generated more net revenue than Option II requiring the upgrading of all track to multiple-car standards, it was outperformed by each of the other options considered. While the addition of fertilizer traffic to the analysis made track upgrading a more attractive option than in the previous study, upgrading remained the most costly option. Variable costs of fertilizer transportation and handling were minimized by upgrading the track, but higher fixed costs resulting from upgrading more than offset savings in operating costs.

Net revenue to the study area was greatest for Option III, involving abandonment of the poorest one-fourth of the area's track. Grain was consolidated at seven subterminal elevators and shipped to final destinations in 50-car trains; fertilizer moved to a single existing warehouse near the study area in lots of 3-10 cars. Country elevators on abandoned rail lines continued to serve as collection houses for transshipment of grain to the subterminals. Fertilizer blending plants on abandoned track as well as those on remaining lines were supplied by trucks operating out of the warehouse. Most of the savings from track abandonment resulted from improved car utilization, lower up-

grading and track maintenance costs, and the salvage value of the abandoned track.

Implications of rail branch-line abandonment depend on conditions specific to the area at issue. The most important variables include:

1. The condition of the rail line and its volume of traffic.
2. The number, size and location of shippers requiring long-distance bulk freight transfer services.
3. The quality and cost to shippers of existing rail service.
4. Access to water transportation.

The lines considered for abandonment in the present study were incapable of carrying multiple-car lots of covered hopper cars filled with grain or fertilizer. These lines carried little except grain traffic and that could move at lower cost when consolidated into 50-car lots, a move which would make much track redundant.

Warehouse construction costs were too high, dry fertilizer volume too small, and demand too seasonal to justify coordinated multiple-car shipments of grain and fertilizer through a new, combination grain and fertilizer warehouse facility. Costs of such coordinated shipments were lower, however, than costs of uncoordinated shipments through a new warehouse, and lower yet than those of the existing system, suggesting that coordination may be feasible in the long run when facilities must be replaced.

Dry fertilizer tonnage moving into the six-county area was only 2 percent of grain shipments out of the area, an amount far too small to allow continuous shipment of 50-car unit trains. Each of the three major fertilizer nutrients came from a different source, a fact that further diminished prospects for unit-train shipments. Optimal organization of the grain system thus was a far more critical issue than was that of the fertilizer system.

While country elevators bypassed by their railroad appeared likely to be disadvantaged in the long run when facility replacements are required, the lack of rail service should be of less consequence for fertilizer dealers since truck service was less costly than rail shipments. Most fertilizer dealers were too small to accept multiple-car rail shipments. Moreover, the potential for expanded retail trade territories and fertilizer sales volumes is limited by the relatively high costs of farm delivery, costs which increase rapidly with increasing delivery distance.

The existing pattern of fertilizer dealerships in the area appears therefore to be stable. The effects from rail abandonment would depend to a considerable extent, however, on availability of intermediate warehouses and multiple-car rail rates to those warehouses. While there appear to be economic incentives for such adjustments, political and social factors are also important in shaping trends in the transportation industries.

The study area was located too far from the nearest barge terminal for water shipments to have been a competitive alternative. Presence of a nearby barge facility would likely have strengthened the case for intermediate warehousing of fertilizer.

It is unlikely that results from the present study would have differed greatly for any other grain producing area. Fertilizer usage is necessarily but a small proportion of the volume of grain produced. The proportion of fertilizer to grain shipments would be greater in an area where more of the grain is fed to local livestock, but in such areas the case for abandonment might be strengthened by the accordingly smaller amount of outbound grain. Costs of the last leg of the fertilizer delivery system, that of moving the product to the farmer, are likely to be high relative to costs for the rest of the system in other areas of the state and nation. The Nebraska delivery system appears to be as efficient as any.

Considerable savings might be realized from adjustments toward the more efficient system represented in Option III. While the adjustments would be difficult for some of the individual business firms involved, net economic effects for the area would be positive.

ECONOMIC IMPLICATIONS OF ALTERNATIVE DRY-BULK FERTILIZER SUPPLY SYSTEMS: A SOUTH-CENTRAL NEBRASKA CASE STUDY

Mary Berglund
and
Dale G. Anderson[1]

INTRODUCTION

The Problem

Commercial fertilizer use in Nebraska increased 40-fold between 1950 and 1978 (20, p. 72; 25, p. 72) and seems likely to continue to be an important crop production input. Bulk-blending has become the major marketing system for dry fertilizers, replacing the former bag

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handling methods. In 1960, U.S. farmers purchased 90.7 percent of their fertilizer in dry form and 9.3 percent in the liquid form; 85 percent of the dry fertilizer was in bags and only 15 percent in bulk form (25, p. 6). By 1978, 67 percent of the total fertilizer was in dry form; 76 percent of the dry fertilizer moved to farmers in bulk and 24 percent in bags (25, p. 6). Dry forms of fertilizer were relatively less important in Nebraska; 37 percent of purchases in 1978 were dry, 63 percent were liquid. Of the dry materials, only 5 percent was bagged (25, p. 72).

The trend toward bulk forms of fertilizer, coupled with a shorter crop planting season, has had several impacts on fertilizer marketing. Pressure to deliver larger amounts of fertilizer in a much shorter time frame has affected shipping, storage, and handling activities. Large-scale storage facilities are required to coordinate the even tempo of fertilizer production activities with highly seasonal demand patterns. Much of the storage occurs at or near the source of fertilizer manufacture. Bulk blending plants, capable of combining basic fertilizer materials to meet farmers' specific needs, have been built in most rural areas.

Hopper cars of about 100-ton (90.7t)* capacity have become the dominant means for long-distance shipment of dry-bulk fertilizers. Railroads increasingly are giving favorable rate treatment to grain and other bulk commodities shipped in multiple-car lots, with resulting cost savings to qualifying shippers. Railroads are pressing for abandonment of low-density branch-line track, maintaining that continued service over such track is uneconomical and that consolidation of traffic at fewer shipping points will yield cost savings. The economic merits and implications of these developments need study.

Purpose of the Study

The objective of this research was to develop and analyze a series of alternatives for marketing dry-bulk fertilizer in a six-county area in south-central Nebraska. These alternatives included various configurations of fertilizer storage and handling facilities, rail network, and transportation rates. "Optimal" systems were selected from among alternative means for moving the major dry-bulk fertilizer materials from point of manufacture to farms in the study area. Selections were made on the basis of net system costs and benefits accruing to the study area. The purpose of the study was to determine the effect of including dry-bulk fertilizer traffic on the outcome of an earlier analysis which focused only on grain flows (1, 5). Since liquid and gaseous fertilizers can be shipped by rail only in specialized cars and since emphasis of the present study was on potential for coordinated grain and fertilizer shipments, these materials were not included in

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*Figures in parentheses are in metric units.

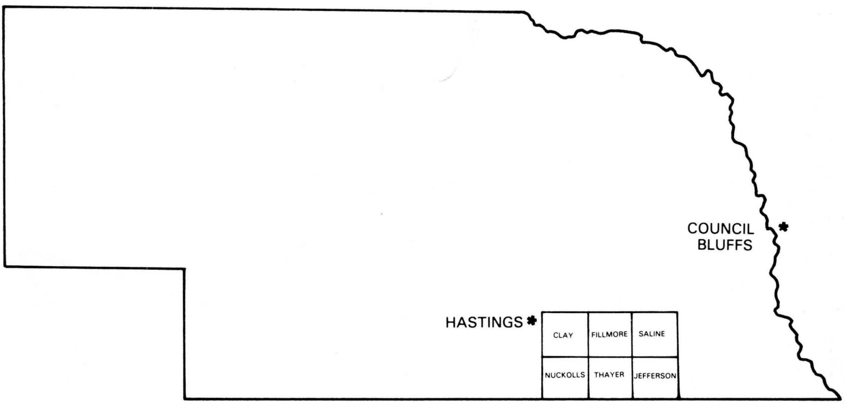

Figure 1. Location of Nebraska branch-line abandonment case study.

the study. Moreover, anhydrous ammonia pipelines have badly eroded the railroads' traffic in that product.

The Study Area

The study area (Figure 1) comprised six counties in south-central Nebraska: Clay, Fillmore, Saline, Nuckolls, Thayer and Jefferson. This area was selected for the earlier grain study because of its large surplus of cash grain and its high proportion of light-duty branch lines. Because a major purpose of the fertilizer project was to explore implications of a coordinated marketing system for grain and fertilizer, this area was also chosen for the fertilizer project.

The area marketed about 40 million bushels (1.02 million t) of feed grain in 1970, with projected marketings of 67 million bushels (1.7 million t) by 1980. There were 84 country elevators at 62 locations. No subterminal facilities existed, although results of the study indicated that savings would be realized from upgrading seven of the elevators to subterminal status. Dry-bulk fertilizer consumption in the area was almost 30 thousand tons (27.2 thousand t) in 1974, or about 20 percent of total fertilizer use. Projected 1980 use is nearly 38 thousand tons (34.5 thousand t). Although significant in absolute terms, projected dry-bulk fertilizer sales are only a little more than 2 percent of projected grain marketings by weight. The study area had 48 dry-bulk fertilizer dealers, 32 with blending plants. There were no large wholesale warehouses, although two such facilities were relatively near the area.

The rail network in the six counties consisted of 603 miles (965 km) of track owned by six railroad companies (Figure 2). Of the total mileage, 24 percent could carry fully loaded hopper cars. Two sections of track in use at the time of the study, one 67.2 miles (112 km)

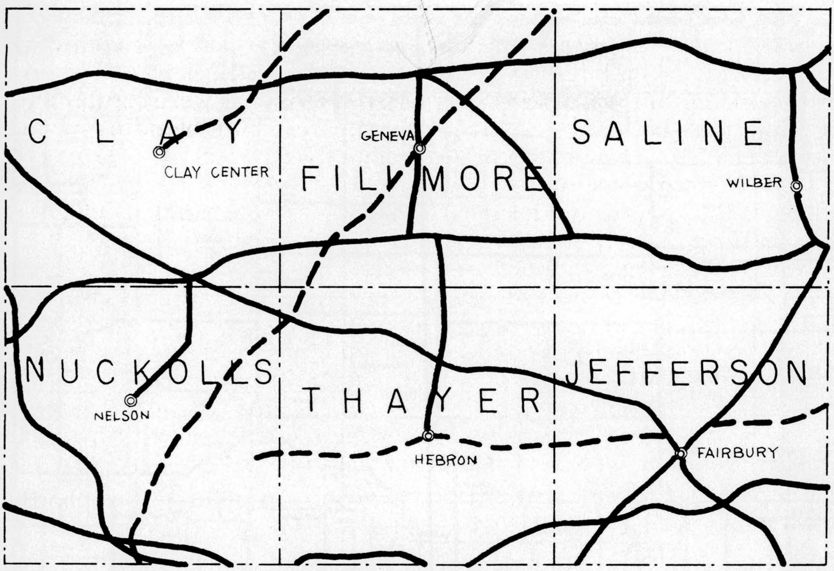

Figure 2. Rail lines in the six-county area, 1974. Heavy lines are rail lines with carrying capacity greater than 263,000 lb. Broken lines have a carrying capacity less than 263,000 lb. Source: Based on map published by the Nebraska Public Service Commission.

long, the other 39.3 miles (65.5 km), have subsequently been abandoned.[2]

The rural highway system (Figure 3) at the time of the study consisted of a total of 4,213 miles (7022 km) of roads of four types: high, intermediate, gravel, and unsurfaced. Classified by surface type, 15 percent of the roads were paved, 85 percent were unpaved.

Previous Work

Rationalization of product assembly and delivery systems is not new. Numerous investigators have employed a variety of analytical approaches in an effort to optimize such systems. Grain marketing, in particular, has received considerable attention (see, for example, 8, 15).

Models used in these studies have typically been highly aggregative and applied to relatively large geographical settings. The present study and its immediate predecessors were unique in the great detail of their modeling, detail which tended to limit their spatial scope. The present study has its roots in work at Iowa State University (3, 4, 14) and in the previously-cited Nebraska study (1, 5, 11) which focused on

[2]The longer track extended from Superior to Seward and was owned by the Great Plains Railway, a short-line carrier which has become bankrupt and its physical facilities liquidated. The shorter track, between Fairbury and Ruskin, was owned by the Rock Island.

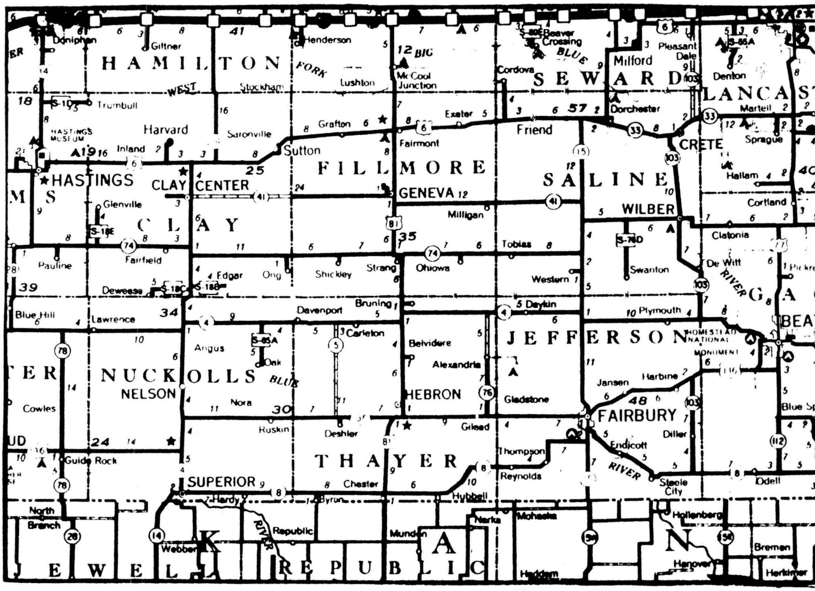

Figure 3. Highway system in the six-county area, 1974. Source: Nebraska Department of Roads.

grain marketing. Results from each of these studies indicated potential for cost savings from abandonment of light-duty branch-line rail track, consolidation of grain at subterminal elevators, and shipment in multiple-car lots to final destinations.

The present study expands and updates the Nebraska grain marketing analysis. Results of that study indicated that savings would be obtained from the reorganization of the existing grain marketing network in a six-county area, the same area on which the present study is focused. Based on projected 1980 grain shipments, extensive branch-line track abandonment and shipments in multiple-car lots through subterminal elevators generated annual net revenue for the study area of $668,000 more than that under the existing system.

The earlier study failed, however, to account for the effects of return-haul rail traffic to the area. Although grain shipments make up the bulk of the area's rail traffic, farm inputs, especially fertilizer, are also significant. Nebraska farmers applied 593,300 tons (538,142 t) of dry-bulk fertilizer materials in 1978 (25, p. 72), much of which was transported from distant points such as Florida, New Mexico, and Texas. Consideration of fertilizer shipments was therefore a logical extension of the grain study. At issue was the question of whether fertilizer backhauls might bolster the case for retention of branch lines or whether a reoriented system of fertilizer delivery might enlarge the savings from abandonment.

It appeared logical to suppose that, since there were economies in consolidating grain shipments in multiple-car lots, savings might result from similar consolidation of fertilizer shipments. It appeared further that multiple-car shipments of fertilizer might provide a backhaul for part of the multiple-car grain shipments.

Building on evidence from the earlier studies and with a view toward evaluating apparent trends toward rail track abandonment and marketing facility consolidations, the present study was aimed at simultaneous rationalization of fertilizer and grain systems for the case-study area. Examination of the sensitivity of final solutions to changes in selected variables may provide a basis for extrapolating results to other geographic areas and other market settings.

RESEARCH PROCEDURES

The Model

A primary requirement of the model used in the study was that it provide a systems approach to the rationalization of the rail network. Consideration of both grain shipments from the study area and dry-bulk fertilizer shipments into the area necessitated the use of a heuristic transportation model whose solution was accomplished in several stages. The basic Stollsteimer model (19) used in the original grain study was adapted for this purpose at Iowa State University (3, 14) and later used to evaluate alternative marketing networks in the six Nebraska counties (1, 5, 6, 11). The systems model used in the present study was developed specifically to evaluate the impact of fertilizer shipments on rationalization of the rail network and other elements of the marketing system in the Nebraska study area. Since the detailed features of the model have been identified in previous studies only a general recapitulation emphasizing features unique to the current study is required.

The basic role of the model was to simulate the most efficient organization of grain marketing and fertilizer distribution activities in the study area. Optimal fertilizer origins, transportation modes, and storage facility size and location were determined endogenously by the model. Fertilizer was assumed to flow from mining or manufacturing origins for each of the three primary nutrients (nitrogen, phosphorous, potassium) through 32 existing bulk-blending plants to 150 farm destinations (areas five miles (8.33 km) square) or from origins through existing or potential storage warehouses to the blending plants and, finally, to the farm destinations. Origin-to-blending plant and origin-to-warehouse shipments could move by rail, barge, or combination barge-rail or barge-truck. Transshipments from warehouses to blending plants moved by rail or truck, while all farm deliveries were made by truck.

Except for one option in which coordinated shipments were examined, grain and fertilizer were assumed to move independently of each other. Dry-bulk fertilizer, however, moved to the same 150 areas from which grain marketings originated. Producers were assumed to purchase dry-bulk material from the nearest bulk-blending plant. Blending plants and their storage facilities were located at 32 of the area's 62 grain elevator sites. The seven subterminal elevator sites selected in the grain model were identified as potential locations for new fertilizer warehouses. The study area had no existing fertilizer warehouses; the nearest ones were at Hastings, Nebraska and Council Bluffs, Iowa (Figure 1). The rail network and rural road system were identical for any given option for both grain and fertilizer movements.

The systems model maximized total joint net revenue to the region from the sale of grain less all costs of handling and transporting projected 1980 grain and fertilizer flows, *i.e.*, gross revenue less transportation, handling, and annual investment costs (new or expanded facilities only) at elevators, subterminals, bulk-blending plants, and fertilizer warehouses:

(1) $\text{Max } \pi = TR - [TTC_g + THC_e + THC_s] - [TTC_f + THC_b + THC_w] - UMC_r$

(1) Where π = annual joint net revenue of grain producers

TR = gross revenue from sale of grain

TTC_g = total transportation costs of grain movement

THC_e = total handling costs at country elevators, including annual costs of expansion

THC_s = total handling costs at subterminal elevators, including annual costs of constructing new facilities

TTC_f = total transportation costs of fertilizer movement

THC_b = total handling costs at blending plants, including annual costs of construction

THC_w = total handling costs at fertilizer warehouses, including annual costs of constructing new facilities

UMC_r = total annual costs of upgrading and maintaining light rail lines

The expression in the first bracket is an abbreviated representation of the grain model. The second bracket constitutes the fertilizer portion of the systems model and the third term represents rail maintenance and upgrading costs. Because costs of transporting and handling dry-bulk fertilizer reduce net revenue from grain sales, optimal organization of the fertilizer distribution subsystem is one in which these costs are minimized:

(2) $\text{Min } TC_f = TTC_f + THC_b + THC_w$

Where TC_f = total cost of transporting and handling fertilizer

The systems model is illustrated in Figure 4.

Sub-optimization procedures were employed to make the problem manageable. These procedures were heuristic in that non-optimal grain marketing and fertilizer distribution options, *including* non-optimal modal choices, were eliminated at an early stage. Three distinct stages were involved.

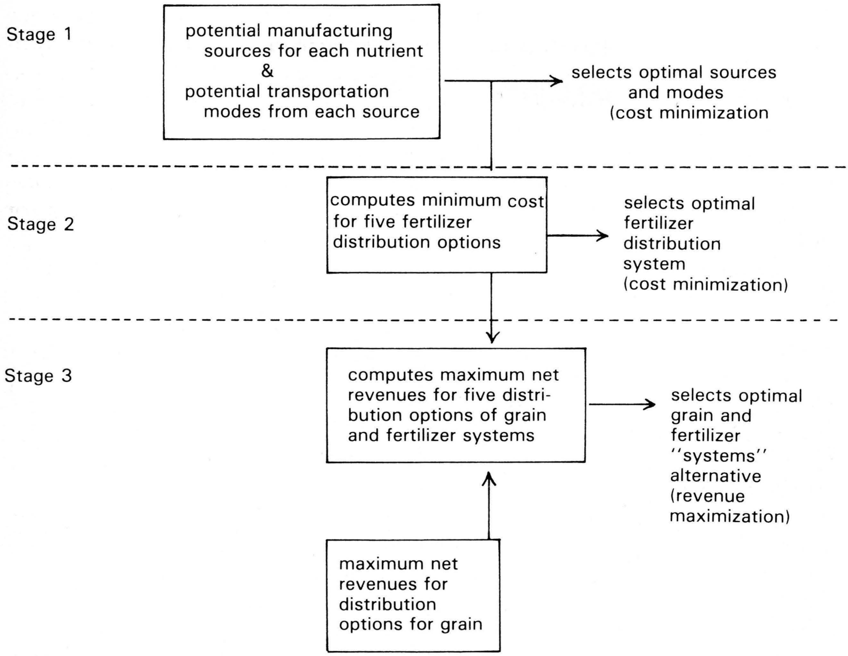

Figure 4. Model of solution stages.

Cost minimization of the fertilizer subsystem (equation 2) occurred in Stages 1 and 2. In Stage 1, cost minimization procedures were employed in selection of optimal manufacturing sources for dry-bulk fertilizer from potential sources and of the least-cost mode(s) for transporting each nutrient from its least-cost source. These sources and the minimum-cost modes of shipping from each source were used in Stage 2 to develop five alternative distribution options for fertilizer. The optimal (least-cost) marketing alternative was then selected from among the five.

In Stage 3, results of the grain model were combined with Stage 2 fertilizer results; five grain and fertilizer shipping and handling options (see Stage 2 Procedures) were evaluated on the basis of maximum net revenue to the study area. In this final stage, the optimal "systems" organization was identified for grain moving from the study area to terminal markets and for fertilizer moving from manufacturing sources to farm destinations.

Stage 1 Procedures

A transportation model with transshipment was used in Stage 1 to determine the least-cost origin and mode for shipments of each fertilizer nutrient from manufacturing origins to blending plants and/or warehouses serving the six counties. The transshipment model was modified so that its solution generated the optimal modal choice, based on minimization of variable transportation and handling costs, for each fertilizer source. Stage 1 decomposition processes simplified comparison of the various distribution networks represented in the five options and assured consistency in option comparisons.

Cost-minimization runs were made with both rates and costs for rail and barge movements and for each of the five options. The rate analysis provided comparisons of net benefits to the study area from alternative systems under existing and expected future rate structures. The cost analysis provided comparisons of net benefits with respect to resources outlays irrespective of who pays the costs and thus yielded results having broader "social" implications. Twelve manufacturing locations were identified as possible nitrogen and phosphate sources, partly for the potential they offered for combining grain shipments to terminal markets with dry fertilizer backhauls. Since sources for potash tended not to be located near major grain terminals and therefore offered limited backhaul possibilities, only two such locations were entered in the model. Potential fertilizer origins are listed in Table 1.

Sensitivity tests were also made at this stage of the model. Sensitivity of fertilizer source and transport mode optima to changes in freight rates and costs was evaluated. Since transportation rates and costs varied by size of shipment (car size as well as number of cars per shipment), type of fertilizer, and specific destination in the study area, each of these variables was standardized for all tests.

Table 1. Potential origins for manufactured fertilizer materials used in six-county Nebraska study area.

Fertilizer material		
Nitrogen	Phosphorous	Potassium
California (El Centro)	California (Fontana)	New Mexico (Carlsbad)
Florida (Tampa)	Florida (Bartow) (Tampa)	Saskatchewan, Canada (Saskatoon)
Iowa (Port Neal)	Idaho (Pocatello)	
Kansas (Lawrence)	Louisiana (Donaldsonville) (New Orleans)	
Louisiana (Donaldsonville) (New Orleans)	Mississippi (Pascagoula)	
North Carolina (Lee Creek)	North Carolina (Lee Creek)	
Oklahoma (Tulsa)	Oklahoma (Tulsa)	
Texas (Beaumont) (Fort Worth) (Houston)	Texas (Beaumont) (Fort Worth) (Houston)	
Wyoming (Cheyenne)		

Source: Selected from a comprehensive list of plants in (23).

Stage 2 Procedures

Stage 2 of the model involved selection of the optimal system of fertilizer distribution from among five distribution options. Fertilizer sources and transportation modes for each option were those previously selected as optimal. Each of the options was structured so as to minimize transportation, handling, and investment costs for the configuration of rail line, transportation rates, and fertilizer facilities unique to that option. Option I was modeled on the existing system of fertilizer distribution in the six counties and provided a benchmark for comparison with the other four options representing various existing or potential conditions in the study area. The five options:

Option I: Single-car Rail Rates with no Rail Abandonment

1. Existing rail lines were maintained at 1974 handling capacities.
2. Fertilizer was shipped from manufacturing sources to blending plants under single-car rail rates.
3. Blended fertilizer was delivered to farm destinations by truck.
4. All blending plants had rail service; no intermediate warehouses existed.

Option II: Multiple-car Rail Rates with Existing Rail Lines Upgraded

1. All rail line was upgraded to handle fully-loaded hopper cars.
2. Fertilizer was shipped from manufacturing sources to blending plants under 3-10-car rates. (Potash moved under single-car rates.)
3. Blended material was delivered to farm destinations by truck.
4. All blending plants had rail service; no intermediate warehouses existed.

Option III: Multiple-car Rates to Existing Warehouse Adjacent to Area with Abandonment of Light-density Lines

1. All light-density branch lines (25% of total) were abandoned, and remaining lines upgraded to handle fully-loaded hopper cars.
2. Fertilizer was shipped from manufacturing sources to an existing warehouse adjacent to the study area under 3-10-car rates.
3. Dry-bulk material was transshipped to blending plants by truck.
4. Blended material was delivered to farm destinations by truck.
5. Six blending plants were without rail service.

Option IV: Multiple-car Rates to New Warehouses with Abandonment of Light-density Lines

1. All light-density branch lines (25% of total) were abandoned, and remaining lines upgraded to handle fully-loaded hopper cars.
2. Fertilizer was shipped from manufacturing sources to new warehouses in the study area under 3-10-car rates.
3. Dry-bulk material was transshipped to blending plants by truck.
4. Blended material was delivered to farm destinations by truck.
5. Six blending plants were without rail service.

Option V: Multiple-car Rates with Backhaul, Abandonment of Light-density Lines

1. All light-density branch lines (25% of total) abandoned, and remaining lines upgraded to handle fully-loaded hopper cars.
2. Fertilizer was shipped as backhaul for grain through new warehouses in the study area under combination multiple-car rates.
3. Dry-bulk material was transshipped to blending plants by truck.
4. Blended material was delivered to farm destinations by truck.
5. Six blending plants were without rail service.

Fertilizer distribution adjustments made necessary by rail-line abandonment were evaluated as a subset of modal choice. Marketing alternatives for options III, IV and V, involving abandonment of light-density lines, were narrowed, in the final stages of the model, by preselecting the optimal method of moving bulk material from warehouses through blending plants and on to farm destinations. Three possibilities were evaluated:

1. Blending facilities on abandoned lines could be supplied by truck shipments from the nearest blending plant on a viable rail line.
2. Blending facilities on abandoned lines could cease operation and farms formerly served by such plants could obtain material directly from the nearest blending plant on a viable line (re-routing of fertilizer through 26 remaining blending plants).
3. Blending facilities on abandoned lines could receive fertilizer transshipped from warehouses in trucks.

The first alternative required either that blending plants on abandoned lines receive material unloaded at a competitor's rail siding (not a likely arrangement) or the use of a portable auger for unloading rail cars on another nearby siding. Material would then move to the plant in semi-trailer trucks for blending and subsequent distribution to farm destinations. The second alternative involved closure of six blending plants. Farmers served by plants on abandoned lines received their fertilizer from other more distant plants. The third alternative allowed all blending operations to remain in business and to receive material from warehouses in large semi-trailer trucks.

A cost-minimizing transshipment model was used in Stage 2 to determine minimum-cost routings and handling arrangements for fertilizer. The model was run five times, once for each option, each time with appropriate data describing the various configurations of rail line, rates and distribution facilities. Finally, the model was rerun for each of the five options with rail cost estimates substituted for rates. The model was modified, for application to Options IV and V, to permit endogenous selection of the optimal number, size, and location of new fertilizer warehouses for the study area. The procedure used was a variant of the modified Stollsteimer model (19) employed in locating subterminal elevators in the earlier grain study (1, 5). The transshipment model minimized marginal transportation and handling costs for each option; annual costs of new investments were added, and the five options ranked from least to highest costs.

Stage 3 Procedures

In the final stage of the model, results of the fertilizer distribution options were combined with results of the grain model as in Equation 1 above.[3] Minimized cost results for the fertilizer portion were subtracted from the maximized revenue results for grain for each of the five options. Options were ranked from highest joint net revenue to lowest. The marketing alternative yielding the maximum net revenue was considered to be "optimal."

Together, results from Stages 1 and 2 provided a picture of the relative costs of alternative dry-bulk fertilizer handling and transportation systems. Stage 3 provided an overall view of the economics of alternative systems of both grain and fertilizer marketing; in some systems the two products moved independently (Options I-IV), in one (Option V) they shared transportation and handling arrangements. Since costs incurred in upgrading and maintenance of light-density lines were included in the previous grain study they were not accounted for in Stage 2 of the present study as that would have involved double counting. Nor was an effort made to establish which proportion of these costs were attributable to fertilizer and which to grain traffic as that would have involved a purely arbitrary allocation. Instead, they were included in Stage 3 as costs of the total grain and fertilizer system. Stage 3 results thus provide the only complete picture of the relative merits of alternative systems.

Data Requirements

Basic data needed for the model, in addition to those employed in the grain rationalization study, included: 1) projections of 1980 dry-bulk fertilizer flows through the distribution network in the study area; 2) potential sources of supply for the primary fertilizer ingredients; 3) location of existing blending and storage facilities in the area; 4) transportation rates and costs from fertilizer sources to blending plants and warehouses, and delivery costs to farm destinations; 5) fertilizer handling costs at blending plants and warehouses; 6) investment costs of new blending and warehouse facilities; and 7) upgrading and maintenance costs of rail lines and of the rural road network.

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[3]The grain model was re-run with updated price data; results, therefore, vary somewhat from those published in the previous study. Adjustments were also necessary under Option V to account for special rates for combination grain and fertilizer movements.

Table 2. Dry-bulk commercial fertilizer sales, by county, Nebraska, study area, July 1, 1973 to June 30, 1974.

County	Material: Ammonium nitrate		Urea		Phosphates		Potash		Dry mixed		Total	
	tons	(t)	tons	(t)	tons	(t)	tons	(t)	tons	(t)	tons	(t)
Clay	3,186	2,890	----		515	467	311	282	2,171	1,969	6,183	5,608
Fillmore	1,985	1,800	158	143	351	318	223	202	2,210	2,005	4,927	4,469
Jefferson	1,600	1,451	----		490	444	314	285	2,097	1,902	4,501	4,083
Nuckolls	1,052	954	12	11	133	121	88	80	605	549	1,890	1,714
Saline	2,243	2,034	28	25	479	434	274	249	4,189	3,800	7,213	6,542
Thayer	1,621	1,470	116	105	9	8	231	210	3,296	2,990	5,273	4,783
Total[a]	11,687	10,600	314	285	1,977	1,793	1,441	1,307	14,568	13,214	29,987	27,199

Source: (16).
[a]**t** detail may not add to totals because of rounding errors.

Table 3. Estimated nutrient composition of "dry-mix" fertilizer for six counties, 1973-74.

Nutrient	Tons	(t)
Nitrogen	7,748	7,028
Phosphate	5,299	4,806
Potash	1,521	1,380
Total	14,568	13,214

Source: Computed from data in (16).

Table 4. Total dry fertilizer use, six counties, 1973-74.

Nutrient	Tons	(t)[a]	Percent
Nitrogen	19,749	17,913	66
Phosphate	7,276	6,600	24
Potash	2,962	2,687	10
Total	29,987	27,199	100

Source: Computed from data in (16).
[a]Detail does not add to total because of rounding errors.

Table 5. Average dry material application rates, six counties, 1973-74.

Nutrient	Rate (lb/acre)	Rate kg/ha
Nitrogen	40	45
Phosphate	15	17
Potash	6	7

Source: Computed from data in (9) and (16).

Projections of 1980 Dry-bulk Fertilizer Flows

Fertilizer use was projected to 1980 by combining projected crop acres with estimates of fertilizer application rates per acre for that year. Application rates were based on 1974 levels adjusted to reflect projected 1980 yields of corn and soybeans used in the grain model.

Total fertilizer sold in the six counties from July, 1973 through June, 1974 (16) was assumed to represent fertilizer shipments for the 1974 crop production year. Data on fertilizer sales by county were available for each fertilizer material so that dry material use could be separated from liquid use (Table 2). Dry material was further separated into three primary nutrients, nitrogen (N), phosphates (P), and potash (K), based on the average analysis of mixtures for 1973-74. Results are in Tables 3 and 4.

Average application rates per fertilized acre for each major nutrient were computed from data on fertilized acres in the six counties (16). These rates are found in Table 5. Since the rates apply only to dry material, they are lower than typical nutrient application rates.

Projected application rates were applied against the 1974 level of fertilized acres. Simplifying assumptions included 1) that the proportion of dry to liquid fertilizer use in the six counties remained constant (1 to 5 or 19.8 percent dry) and 2) the proportion of acres planted in each crop remained constant. For consistency with the grain model, projected grain yields from the previous study were used: 103.3 bushels per acre (6.6t per ha) for corn and 88.8 bushels per acre (5.6 t per ha) for grain sorghum, averaged over irrigated and non-irrigated yields. Fertilizer application rates required to generate these yields were taken from USDA 1980 projections for Nebraska (9). An average increase in fertilizer use of 4.37 percent per year was required.

Sources of Fertilizer Supply

Sources of dry-bulk fertilizer used in the study area varied by type of nutrient. Plant sites were identified from a 1974 Tennessee Valley Authority (TVA) directory (22). Since one aspect of the research involved examination of merits of combined grain-fertilizer movements, production plants in locations facilitating coordination of fertilizer as a backhaul for grain shipments were included as potential sources. In the initial suboptimization process, such diverse sources as Lee Creek, North Carolina and Fontana, California were included for manufactured phosphates and ammonium nitrate. Other phosphate sources included Florida, Louisiana, and Texas. Since 97 percent of the dry-bulk nitrogenous material used in the study area was ammonium nitrate, urea sources were disregarded in order to simplify the analysis. Other nitrogen sources included Louisiana, Texas and Kansas. Possible potash sources were New Mexico and Saskatchewan, Canada.

Location of Blending Plants and Storage Facilities

Existing blending facility and storage sites were identified from information obtained from a questionnaire used in the grain study (5), from a directory of Nebraska fertilizer dealers (17), and from a TVA directory of fertilizer manufacturing firms (23). Thirty-two blending plants and their respective storage capacities were identified in the six-county area; although there were 48 dry-bulk dealers in the study area, 16 sold only preblended materials. Storage capacities at blending plants ranged from 70 to 1,200 tons (63 to 1088 t), with the average capacity being 475 tons (431 t). No large fertilizer warehouses existed in the study area, but material might be routed through facilities in Hastings, Nebraska or Council Bluffs, Iowa (a river terminal), sites which were considered feasible destination points for rail or barge movements, respectively.

Transportation Costs from Fertilizer Sources to Blending Plants or Warehouses

Separate analyses were made using both rates and costs, for barge as well as rail, single-and multiple-car movements of dry fertilizer into the study area. Single-and multiple-car rail rates, reflecting early 1974 tariffs, for each of the nutrients from each source, were obtained from a fertilizer rate generator developed by TVA.[4] Additional multiple-car rates, obtained from the Nebraska Public Service Commission, were inclusive of Ex Parte 318 adjustments. Barge rates generally in effect during the 1974 shipping season came from TVA sources.[5] Rail cost estimates were based on adjustments (6) to ICC *Cost Scales* (13), while barge costs were estimated from previous studies of costs of barging fertilizer (10, 18).

Single-car rates varied by fertilizer material, minimum shipment size, origin and specific destination in the study area. As an example, the rate for fertilizer compounds from Donaldsonville, Alabama to Geneva, Nebraska was $21.91 per ton in 50-ton lots ($24.16 per t in 45-t lots), $18.79 in 100-ton shipments ($20.72 per t in 91-t lots). Corresponding rates to Superior, Nebraska were $21.39 and $18.33 per ton ($23.58 and $20.21 per t). Rates for superphosphate from Donaldsonville to Geneva were $18.77 and $16.06 for 50- and 100-ton shipments ($20.69 and $17.71 per t for 45- and 91-t shipments), respectively. Corresponding rates to Superior were $18.31 and $15.67 ($20.19 and $17.28/t).

Rail rates for combination grain-fertilizer movements were based on adjustments in an existing rate for coordinated hauls. A tariff for

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[4]Rates supplied by Dr. John Bucy, Tennessee Valley Authority, Muscle Shoals, Alabama.

[5]Bucy, *loc. cit.*

corn-superphosphate movements from Hoopeston, Illinois to Tampa, Florida and return, applied to a distance of 1,297 rail-line miles (2,162 rail-line km). Since distances from Nebraska to Louisiana and Texas Gulf markets were comparable (about 1,050 miles or 1750 km), the existing tariff was modified by applying the ton-mile rate for the Illinois-Florida haul to movements to the study area. The fertilizer portion of the estimated combination rate for Texas sources ranged from $8.50 to $9.45 per ton ($9.37 to $10.42 per t), compared with single-car rates of $15 to $18 per ton ($16.54 to $19.85 per t). An actual 3-10-car rate for fertilizer compounds and phosphates moving from Houston, Texas to Omaha, Nebraska was $9.63 per ton ($10.62 per t).

Barge rates are negotiated between shipper and carrier and are subject to variation. Best estimates of prevailing rates for urea and diammonium phosphate from Gulf origins to Missouri River terminals were as follows:

Origin	**Destination**	**Rate**	
		($/ton)	**($/t)**
New Orleans, La.	Brownville, Ne.	8.40	9.26
New Orleans, La.	Council Bluffs, Ia.	9.00	9.92
Galveston, Tx.	Council Bluffs, Ia.	10.50	11.58
Mobile, Al.	Brownville, Ne.	9.20	10.14
Mobile, Al.	Council Bluffs, Ia.	9.80	10.80

Costs of Transporting Fertilizer from Warehouses to Blending Plants and from Plants to Farm Destinations

Dry-bulk fertilizer transshipped from warehouses to blending plants moved in large semi-trailer trucks, while farm delivery was performed by nurse trucks which supplied flotation spreaders.

Trucking cost functions for transshipments from warehouses were based on results of a Nebraska grain-trucking cost study (22) which were adapted for use in the grain model. Costs for an 825-bushel (21-t) semi-trailer grain truck were modified to reflect fertilizer transport conditions. Trucks were assumed to travel 100,000 miles (166,667 km) per year; length of haul ranged from 75 to 300 miles (125 to 500 km). Included in the fixed costs were depreciation, taxes, license and registration fees, insurance, interest, and office overhead costs. Variable cost items included tires, maintenance and repairs, fuel, wages, and miscellaneous expenses. Costs averaged $0.449 per mile ($0.269 per km) or $0.018 per ton-mile ($0.012 per t-km) for one-way hauls averaging 150 miles (250 km). Cost per ton = $1.5425 + $0.0260mi. (Cost per t = $1.701 + $0.016 km.)

Costs of delivery to farms were based on findings of a Nebraska study of the costs of blending and distributing dry-bulk fertilizer (2). Operations of model blending plants were separated into appropriate

Table 6. Plant and delivery. Average variable costs, model blending plant, 720 tons (653 t) storage, use density 8.5 tons per square mile (2.78 t/sq km), Nebraska, 1974.

Item	cost[a]			
Plant	($/ton)		($/t)	
Blend fertilizer and fill truck at plants (labor)	0.24		.26	
Inventory loss	4.00		4.41	
Fertilizer fee	0.04		0.04	
Interest on accounts receivable	1.95		2.15	
Interest on inventory	2.09		2.30	
Interest on working capital	0.11		0.12	
Insurance on inventory	0.12		0.13	
Total plant costs		8.55		9.43
Delivery				
Truck delivery of fertilizer to farm spreader and return	0.48		0.53	
Labor				
Find spreader and unload truck	0.23		0.25	
Deliver spreader from farm to farm (travel time)	0.03		0.03	
Hook and unhook spreader	0.10		0.11	
Delivery truck operation	0.44		0.49	
Interest on working capital	0.03		0.03	
Total delivery costs		1.30[b]		1.43[b]
Total		9.85		10.86

Source: Adapted from (2).
[a]Detail may not add to totals because of rounding errors.
[b]Based on inventory turnover of three times per year.

sub-functions to facilitate estimation of ton-mile delivery costs. Although that study examined three alternative distribution systems, only one was modeled in the present analysis. The selected system consisted of 8-ton (7.26 t) nurse trucks which supplied 8-ton (7.26 t) self-propelled flotation spreaders. It was assumed that farmers purchased material from the nearest blending plant.[6] Average total delivery costs for a fully-utilized plant were estimated at $2.96 per mile ($1.78/km), or $0.740 per ton-mi. ($0.490/t-km).

Cost per ton = $4.05 + $0.1796 mi. (Cost per t = $4.47 + $0.1078 km).

Fertilizer Handling Costs at Blending Plants and Warehouses

Costs of handling dry fertilizer at blending plants were adapted from the same source as those for farm delivery (2). Costs were standardized at 1974 levels; the year of the earlier study. The costs were estimated by economic engineering techniques from data obtained

[6]Although some studies have shown that cost may not always dictate the farmer's choice of dealers (7), the goal of the present study was identification of the least-cost fertilizer delivery system.

Table 7. Total investment costs, model blending plant, 720 tons (653 t) storage, use density 8.5 tons per square mile (2.78 t/sq. km), Nebraska, 1974.

Item	Cost	
	($)	
Land	1,600	
Office building	2,040	
Office equipment	400	
Pay loader	10,000	
Sub total		14,040
Spreaders	24,500	
Trucks	28,950	
Pick-up truck	952	
Sub total		54,402
Total		68,442

Source: Adapted from (2).

Table 8. Total annual fixed costs, model blending plant, 720 tons (653 t) storage, use density 8.5 tons per square mile (2.78 t/sq. km), Nebraska, 1974.

Item	Cost	
	($)	
Plant		
Depreciation:		
Office building	102	
Office equipment	24	
Pay loader	900	
Maintenance and repairs	4,987	
Office overhead	200	
Secretarial labor	2,080	
Management	3,000	
Licensing	20	
Insurance	519	
Total plant costs		11,832 (5.48/ton or 6.04/t)[a]
Delivery		
Depreciation:		
Spreaders	4,410	
Trucks	3,722	
Pick-up truck	122	
Licensing	89	
Insurance	406	
Total delivery costs		8,749 (4.05/ton or 4.47/t)[a]
Total		20,581 (9.53/ton or 10.51/t)[a]

Source: Adapted from (2).
[a]Based on inventory turnover of three times per year.

from Nebraska firms; a blending plant of 720 tons (653 t) storage capacity with three turns of stock per year was representative of actual Nebraska plants and was chosen as the model plant.

Accommodation to the highly seasonal demand for fertilizer was achieved by combining fertilizer sales with other lines of business activity, including grain operations. This combination allowed year-

Table 9. Average costs per ton and metric ton of dry-bulk fertilizer, model blending plant, 720 tons (653 t) storage, use density 8.5 tons square mile (2.78 t/sq. km), Nebraska, 1974.

Plant utilization (percent of capacity)	Plant		Delivery		Total	
	$/ton	($/t)	$/ton	($/t)	$/ton	($/t)
	Average variable cost					
100	8.54	9.42	1.30	1.43	9.84	10.85
75	8.55	9.43	1.19	1.31	9.74	10.74
50	8.55	9.43	1.06	1.17	9.61	10.60
	Average fixed cost[a]					
100	5.48	6.04	4.05	4.47	9.53	10.51
75	7.30	8.05	5.40	5.95	12.70	14.00
50	10.96	12.08	8.10	8.93	19.06	21.01
	Average total cost					
100	14.03	15.47	5.35	5.90	19.38	21.37
75	15.85	17.47	6.59	7.27	22.44	24.74
50	19.51	21.51	9.16	10.10	28.67	31.61

Source: Adapted from (2).
[a]Based on inventory turnover of three times per year.

around use of labor and fixed facilities such as office, scale and rail siding. Variable handling costs included labor, inventory loss, fertilizer tax, insurance, interest on inventory and working capital. Average variable handling costs per ton of fertilizer were $8.55 ($9.43/t) for a plant of 720-tons (653 t) capacity (Table 6). Total investment costs for such a plant are found in Table 7, while Table 8 contains average annual fixed costs. Average variable, fixed and total costs per ton for various levels of plant utilization are shown in Table 9.

Investment and Handling Costs at Fertilizer Warehouses

Because the fertilizer and grain marketing systems were viewed as being interdependent, new fertilizer warehouses were assumed to be expansions of existing facilities or were built at grain-shipping sites; allocated costs of shared rail siding, office, and truck scales were included in the model. Investment costs of new fertilizer storage facilities were estimated for each of the four warehouse sizes, 10-, 20-, 30- and 40,000-ton (9,070, 18,141, 27,211 and 36,281 t) storage capacities. Estimated total installed costs of the various sizes of fertilizer warehouses are contained in Table 10.

The most economical warehouse construction, based on a telephone survey of warehouse managers and contractors, was a wooden building on a concrete foundation and slab. The warehouse had a series of bins to allow for simultaneous storage of several types of dry fertilizer: ammonium nitrate, urea, phosphates, and potash. Land costs were included at $2,500 per acre ($6,250/ha) for five, seven, eight, and ten acres (2, 2.8, 3.2 and 4 ha) for the 10-, 20-, 30-, and

Table 10. Estimated installed costs of model fertilizer warehouses, Nebraska, 1974.

Item	Warehouse capacity; (1 ton = 0.91 t) (thousands of tons) 10	20	30	40
	($)			
Building	350,000	680,000	960,000	1,200,000
Equipment:				
Receiving				
Conveyor	25,000	35,000	38,000	40,000
Dump pit	10,000	10,000	10,000	10,000
Load-out				
Payloaders	30,000	40,000	60,000	80,000
Conveyors	12,000	20,000	24,000	30,000
Land	12,500	17,500	20,000	25,000
Total installed cost	439,500	802,500	1,112,000	1,385,000
Cost per ton of storage space	43.95	40.13	37.07	34.63
Cost per t of storage space	48.45	44.24	40.87	38.18

40,000-ton (9,070, 18,141, 27,211, and 36,281 t) warehouses, respectively.

Receiving and load-out equipment varied with facility size. Increased costs of larger conveyor belts and motors to drive them at a faster speed made installed costs of receiving equipment higher for the larger warehouses.

Economic engineering techniques were used in determining the annual cost of these installed facilities. Costs were based on estimated interest, depreciation, insurance, and tax rates (Table 11). Appropri-

Table 11. Estimated annual fixed costs of model fertilizer warehouses, Nebraska, 1974.

Item	Warehouse capacity; (1 ton = 0.91 t) (thousands of tons) 10	20	30	40
	($)			
Annual equivalent cost of building and equipment (10% interest) (20-year life)	45,457	87,530	121,218	150,348
Payloaders (10-year life)	4,619	6,159	9,238	12,318
Interest on land (10%)	1,250	1,750	2,000	2,500
Taxes and insurance (2% of installed cost)	8,790	16,050	22,240	27,700
Total annual cost	60,116	111,489	154,696	192,866
Annual cost per ton of storage[a]	6.01	5.57	5.16	4.82
Annual cost per t of storage	6.63	6.14	5.69	5.31

[a]Based on one turn of stock per year. Turnover is low since the warehouses serve primarily as a link between relatively continuous production and highly discontinuous use of fertilizer.

Table 12. Estimated variable handling costs at model fertilizer warehouses, Nebraska, 1974.

Item	Warehouse capacity; (1 ton = 0.91 t) (thousands of tons) 10		20		30		40	
	$/ton ($t)							
Labor	2.00	2.21	1.50	1.65	1.25	1.38	1.00	1.10
Fringe benefits	.15	.17	.13	.14	.10	.11	.08	.09
Plant maintenance	.05	.06	.04	.04	.04	.04	.03	.03
Equipment repair	.17	.19	.15	.17	.13	.14	.12	.13
Power	.10	.11	.08	.09	.06	.07	.04	.04
Telephone	.07	.08	.05	.06	.04	.04	.03	.03
Management	1.50	1.65	.90	.99	.70	.77	.60	.66
Miscellaneous	.18	.20	.16	.18	.13	.14	.10	.11
Total[a]	4.22	4.65	3.01	3.32	2.45	2.70	2.00	2.21

[a]t detail may not add to totals because of rounding errors.

ate rates were suggested by representatives of firms owning warehouses. Property taxes and insurance costs were a fixed percentage of initial installed costs. Internal Revenue Service guidelines of 20-year building and equipment life were used for all except the payloader where a 10-year life was assumed.

Estimated variable handling costs for each of the four warehouse sizes are found in Table 12. Average variable handling costs declined with increasing warehouse size owing to greater capital intensity of the larger operations and resultant lower ratio of variable to fixed expenses. Variable costs per ton ranged from a high of $4.22 ($4.65/t) for the smallest warehouse to a low of $2.00 ($2.21/t) for the largest facility. Labor was by far the most significant variable cost item, accounting for about half of average variable costs for each plant size. Management, another major item, was treated as variable since its cost would be avoidable if plant operations were discontinued. Two new facilities selected by the model under Option IV were of 20,000-ton (18,141 t) capacity and had average variable costs of $3.01 per ton ($3.32/t) of dry-bulk material. Variable handling costs for the existing warehouses (Option III) near the study area (Council Bluffs, Iowa and Hastings, Nebraska) were estimated at $2.00 per ton ($2.21/t).[7]

Costs of Upgrading Light-density Rail Lines

Average annual track maintenance and upgrading costs were taken from the earlier grain study (5, p. 30). Average annual maintenance costs were estimated at $2,800 per mile ($1,680/km); these costs were avoided by rail abandonment. Costs of upgrading light lines to accommodate unit trains of hopper cars averaged $49,000 per mile ($29,400/km) or $5,376 per mile ($3,226/km) per year over 25 years at 10 percent interest, assuming a salvage value of $2,181 ($1,309/km). The abandoned 60-pound (27.27 kg) rail had an average net salvage

[7]Based on discussions with warehouse operators.

value of $18,410 per mile ($11,046/km) for an average annual value (over 25 years at 10 percent) of $2,028 ($1,217/km). The latter was an offset against upgrading costs and a net benefit from permanent abandonment.

Highway Resurfacing and Maintenance Costs

Track abandonment resulted in increased use of the rural road system, the need for roads to be resurfaced more frequently, and in a higher level of highway maintenance costs. The marginal costs of the additional highway traffic for each of the various marketing options were calculated previously in the grain study. Tax revenues derived from truck operations were computed to determine whether additional revenues would cover the additional costs. The marginal fuel tax and license revenues in the grain study averaged 5.4 times greater than the marginal costs of the additional truck traffic. Fertilizer tonnage moving over rural roads was only about 2 percent of grain tonnage; it was assumed that additional rural road system costs attributable to fertilizer traffic could also be absorbed by the tax revenues generated by the traffic. No additional estimates of marginal highway maintenance and resurfacing costs were made for the fertilizer distribution network.

RESULTS

The model was structured to allow the ranking of alternative fertilizer and grain-fertilizer marketing systems in the six-county study area according to their relative economic efficiency. The results fell into four categories:

1. Projections of dry-bulk fertilizer use in 1980.
2. Optimal transportation modes and fertilizer origins determined by suboptimization procedures (Stage 1) and sensitivity testing of selected results.
3. Optimal patterns of fertilizer marketing for each of five distribution options (Stage 2).
4. Optimal marketing configuration for the grain and fertilizer system (Stage 3).

Projected Use of Dry-bulk Fertilizer

Dry-bulk fertilizer use in the six-county area was projected to reach 37,860 tons (34,340t) by 1980. Total usage included 24,988 tons (22,665 t) of nitrogenous fertilizer, mostly ammonium nitrate; 9,086 tons (8,241 t) of phosphates; and 3,786 tons (3,434 t) of potash. Fertilizer use increased 4.37 percent per year based on projected grain yields. Actual 1973-74 dry fertilizer use and 1980 projections by county are shown in Table 13. Total fertilizer usage, dry and liquid, for the six counties was 151,155 tons (137,102 t) in 1974. The ratio of dry to liquid fertilizer use in the area was assumed to remain constant at 1 to 5.

Table 13. Dry bulk fertilizer use in the six-county Nebraska area, actual 1973-74 and 1980 projections.

County	1973-74		1980-1981	
	tons	(t)	tons	(t)
Clay	6,183	5,608	7,950	7,211
Fillmore	4,927	4,469	6,058	5,495
Jefferson	4,501	4,083	5,679	5,151
Nuckolls	1,890	1,714	2,272	2,061
Saline	7,213	6,542	9,086	8,241
Thayer	5,273	4,783	6,815	6,181
Total	29,987	27,199	37,860	34,340

Optimal Manufacturing Sources and Transportation Modes (Stage 1)

The first stage of the three-stage model involved determining the least-cost origin and mode for shipments of each fertilizer nutrient from manufacturing origins to blenders and/or warehouses. Twelve potential source locations were evaluated for dry-bulk nitrogen and phosphates, two for manufactured potash. Rail, barge, truck and various combinations of the three modes were considered.

Optimal Sources

The least-cost origin for nitrogen (ammonium nitrate) proved to be Lawrence, Kansas. For manufactured phosphates the choice was Houston, Texas. Carlsbad, New Mexico was the least cost of two potential sources of potash (the other being Saskatchewan, Canada). Average rail rates and costs from optimal origins to the study area for each option appear in Tables 14 and 15.

Sensitivity of these optimal solutions to changes in transportation rates or costs was also examined in Stage 1. Results varied by fertilizer type, shipment size, and specific destination. For example, the least-cost source of phosphates for Fairmont, Nebraska was Texas; freight rates for 50-ton (45-t), single-car shipments would have to change at least $3.50 per ton ($3.86/t) in favor of Florida to make the latter source optimal (assuming other freight rates and costs remained un-

Table 14. Average rail rates[a] from optimal sources to study area blenders or warehouses, 1974.

Source & material	Option I		Option II		Option III		Option IV		Option V	
	$/ton	($/t)	$/ton	($/t)	$/ton	($/t)	$/ton	($/t)	$/ton	($/t)
Nitrogen from Kansas	7.29	8.04	3.82	4.21	3.88	4.28	3.88	4.28	3.81	4.20
Phosphorus from Texas	15.67	17.28	9.63	10.62	*9.65*	*10.64*	*9.65*	*10.64*	*8.15*	*8.99*
Potassium from New Mexico	22.91	25.26	22.91	25.26	9.96	10.98	9.75	10.75	9.75	10.75

[a]Simple average of rates to blending plants in the study area; published rates varied by specific destination.

Table 15. Average rail costs[a] from optimal sources to study area blenders or warehouses.

Source & material	Option									
	I		II		III		IV		V	
	$/ton	($/t)	$/ton	($/t)	$/ton	($/t)	$/ton	($/t)	$/ton	($/t)
Nitrogen from Kansas	3.40	3.75	2.28	2.51	2.33	2.57	2.11	2.33	1.89	2.08
Phosphorus from Texas	7.60	8.38	5.63	6.21	5.79	6.38	5.62	6.20	5.49	6.05
Potassium from New Mexico	7.94	8.75	7.94	8.75	5.34	5.89	5.49	6.05	5.49	6.05

[a]Based on 1973 ICC *Cost Scales* (13); actual rates varied by specific destination.

changed). Freight rates from the Louisiana source would need to be reduced by at least $1.03 per ton ($1.14/t) in order for that location to be chosen. Florida would need a freight rate advantage of at least $4.99 per ton ($5.50/t) and Louisiana an advantage of at least $0.87 per ton ($0.96/t) to make 100-ton (91-t) single-car phosphate shipments from these sources optimal. Since there was greater variation among rates for smaller than for larger shipment sizes, optimal solutions involving the larger shipments tended to be more sensitive to rate changes.

Optimal Modes

Optimal modal choices for shipments of dry bulk fertilizer into the study area were also generated in Stage 1. *A priori,* barge-rail or barge-truck movements, appeared to be likely possibilities for fertilizer coming from Gulf Coast sources. It turned out, however, that shipments in 100-ton (91-t) hopper cars yielded the lowest costs. Two-thirds of the dry bulk material used in the area was ammonium nitrate, a material not suitable for barge shipment.[8] Potash could move from either Canada or New Mexico over routes offering no water transportation alternatives. The only feasible barge movements to the study area were those bringing manufactured phosphates from Louisiana and Florida to an existing warehouse in Council Bluffs, Iowa for reshipment by truck or rail to blenders in the study area. Although the barge-truck alternative was less costly than barge-rail movement, both cost more than the shorter rail movement from Texas sources to an existing warehouse (Hastings, NE) nearer the study area than the one at Council Bluffs.

Truck transshipment from fertilizer warehouses was the least costly way to service blending plants on abandoned rail lines. Abandonment of light-density branch lines, closing the six blending plants they served and re-routing dry-bulk material through the remaining 26 blending plants resulted in 40,384 fewer ton-miles (61,049 t-km) of traffic than under the other two abandonment alternatives. However,

[8]Ammonium nitrate cannot legally be transported by barge unless it has been diluted with a "contaminant" so as to reduce the danger of fire and explosion.

owing to relatively high delivery costs from blending plants to farm destinations, it was not economical to close blending plants on abandoned lines; increased delivery costs resulting from reduced plant numbers more than offset the savings in transport costs from supplying fewer firms. Transportation costs from manufacturing sources to these blending plants were not increased at all in some cases since fertilizer could move to warehouses in multiple-car trains under reduced rates and from there to blenders in large trucks. Additional costs were incurred in every case, however, by the additional handling of the dry-bulk material at warehouses.

The alternative of transshipping fertilizer to blending plants on abandoned lines from an existing warehouse was preferred because the material moved in semi-trailer trucks at a fraction of the plant-to-farm delivery cost. As measured by results of sensitivity tests, delivery costs of re-routing through 26 remaining blenders would need to fall by $0.5040 per ton-mile ($0.3334/t-km) from their estimated actual $0.7642 per ton-mile ($0.5055/t-km) to replace warehouse transshipment as the preferred alternative.

Optimal Organization of Fertilizer Distribution (Stage 2)

Stage 2 of the model involved selection of the least costly organization of the fertilizer distribution system from among the five options discussed previously in "Research Procedures." Manufacturing sources and transportation modes were those selected as optimal in Stage 1.

The purpose of Stage 2 comparisons was to determine the marginal cost effects of including fertilizer distribution activities in the overall transportation and handling picture. Since rail upgrading and maintenance costs occasioned by the various levels of track retention associated with each of the options were included in the earlier grain analysis, they were not considered in Stage 2. The joint use of the track and attendant facilities for grain and fertilizer traffic makes any allocation of costs of these fixed assets a largely arbitrary matter; the costs were included in Stage 3 where the broader grain and fertilizer system was evaluated.

Results from Stage 2 optimization procedures appear in Table 16. Variable transportation and handling costs were minimized for each of the five options. Cost findings were separated into transportation and handling subcomponents to facilitate comparison among options. Total variable costs were estimated two ways for each distribution option, once using estimated rail costs, and once using published rail rates (Table 17). Annual warehouse investment costs were added, where appropriate, as a separate item. The rankings of the options, in order of least to highest cost were:

1. Option II
2. Option III

Table 16. Stage 2 results: annual variable fertilizer transportation, handling and warehouse investment costs, alternative options, Nebraska study area, 1974.

Cost item	Option I single-car shipments and rates to all blend sites	Option II 3-10-car shipments and rates to all blend sites	Option III 3-10-car shipments and rates to existing warehouses	Option IV 3-10-car shipments and rates to existing warehouses	Option V combined haul[a] to new warehouses
Rail:[b]					
to warehouse					
Nitrogen from Kansas			$ 96,951	$ 96,949	$ 95,328
Phosphorus from Texas			87,684	87,502	79,506
Potassium from New Mexico			37,709	36,914	36,913
			222,344	221,365	211,747
to blender					
Nitrogen from Kansas	$182,159	$ 95,528			
Phosphorus from Texas	142,384	87,502			
Potassium from New Mexico	86,738	86,737			
	411,281	269,767			
Truck:					
transshipped to blender			39,222	17,675	17,675
delivery to farms	194,429	194,429	194,428	194,429	194,429
			455,994	433,469	423,851
Total transshipping cost	605,710	464,196			
Handling costs:					
Warehouses					
one 40,000-ton (36,281 t)			73,448	111,687	111,687
two 20,000-ton (18,141 t)					
Blenders	323,324	320,100	323,324	323,324	323,324
Total handling	323,324	320,100	396,772	435,011	435,011
Total transport & handling	929,034	784,296	852,766	868,480	858,862
Warehouse investment	0	0	0	222,977	222,977
Total transport, handling & investment	$929,034	$784,296	$852,766	$1,091,457	$1,081,839

[a]Rail estimates include only the portion of the combined haul attributable to fertilizer movement. The grain portion of the haul is included in Stage 3 results.
[b]Based on railraod rates.

Table 17. Stage 2 results: annual variable fertilizer transportation, handling and warehouse investment costs, rail-cost vs. rail-rate basis, alternative options, Nebraska study area, 1974.

Cost item	Option I single-car shipments to all blend sites	Option II 3-10-car shipments to all blend sites	Option III (rail abandonment) 3-10-car shipments to existing warehouses	Option IV (abandonment) 3-10-car shipments to new warehouses	Option V (abandonment) combined haul to warehouses
Rail rate basis:					
Total variable transport and handling cost	$929,034	$784,296	$852,766	$868,480	$858,862
Warehouse investment	0	0	0	222,977	222,977
Total	929,034	784,296	852,766	1,091,457	1,081,839
Rank	3rd	1st (least cost)	2nd	5th	4th
Rail cost basis:					
Total variable transport and handling cost	716,824	652,749	761,406	771,788	765,011
Warehouse investment	0	0	0	222,977	222,977
Total	716,824	652,749	761,406	994,765	987,988
Rank	2nd	1st (least cost)	3rd	5th	4th

3. Option I
4. Option V
5. Option IV

Of the options involving rail abandonment (III, IV and V), total variable transportation costs were least under Option V in which grain and fertilizer shipments were coordinated through combined fertilizer warehouses and subterminal elevators. Owing to economies of large size warehouses, handling costs were lower for material moving through one larger warehouse (40,000 tons or 36,281 t) than for two or more smaller facilities. Lowest handling costs were incurred under Options I and II where no intermediate warehouse handling was necessary. Inclusion of costs of an extra handling at warehouses and annual investment costs of building the new facilities made Option V suboptimal.

Total variable transportation and handling costs were minimized under Option II in which dry bulk material (except for potash) moved to blending plants in 3-10-car lots. The latter option required upgrading of all light-density branch lines, however, so omission of upgrading costs results in an incomplete picture.

Based on rail rates, Option II cost $68,470 less than the second-best alternative, Option III (rail abandonment with shipments through existing warehouses near the study area); $307,161 less than the Option IV (shipments through new warehouses); and $144,738 less than shipping under the existing system of single-car rates (Option I).

Stage 2 procedures were also performed with rail costs for bulk fertilizer shipments substituted for rail rates in order to give the problem a broader social perspective. (Railroad rates may or may not reflect actual transport costs.) Results are reported in Table 17. Option II, upgrading of all rail lines, rail abandonment and rail shipment of fertilizer to all blenders under multiple-car rates, was least costly as before. The existing system ranked second and shipments through existing warehouses third. The least desirable alternative again was Option IV, shipments through new warehouses in the area. Since costs of track upgrading required to make Option II workable were not considered, the option must be regarded as "optimal" only in the sense of the marginal contribution of fertilizer shipments to an overall grain and fertilizer system.

The relationship between variable transportation and handling costs varied with the type of fertilizer distribution system. Variable transportation costs were reduced by the lower costs and rates associated with multiple-car shipments, but variable handling costs were increased because of the warehouse transshipment occasioned by the multiple-car system. Transportation costs under the existing single-car system (Option I) accounted for two-thirds of total variable costs, with the remainder attributable to handling. More than two-thirds of the variable transportation expenses resulted from long-haul rail movements to blending plants; short-haul delivery expense was less than a third. By contrast, variable transportation costs, including rail upgrading costs, accounted for only 53 percent of total variable costs in Option III. Long-haul rail costs were less than half (49 percent) of the variable transportation costs.

Potential savings from multiple-car shipments of fertilizer were limited by the size of the local market. Total 1980 dry fertilizer needs in the study area were estimated at 37,860 tons (34,340 t). The total quantity of all dry fertilizer materials moved would occupy only 379 100-ton (91-t) rail cars annually or less than eight 50-car unit trains. Projected 1980 grain shipments, by contrast, were more than 1.86 million tons (1.69 million t) and would fill 18,637 100-ton (91-t) cars or 373 50-car unit trains.

Optimal Organization of Grain and Fertilizer System (Stage 3)

In Stage 3 optimal results from the fertilizer distribution system analysis (Stage 2) were superimposed upon the optimal marketing organization of the grain model. Rail upgrading and maintenance expenses (estimated previously for the grain model) were also added at this point. Total net revenues generated in the grain model less total costs of the fertilizer distribution system were estimated for each of the five fertilizer marketing alternatives. The optimal organization was selected from among the five. Results are summarized in Table 18. The rankings, from highest net revenue to lowest, were:

1. *Option III.* Abandonment of 25 percent of the track. Grain moved to terminal markets from seven subterminal elevators under 50-car rail rates. Dry-bulk fertilizer moved to an existing warehouse adjacent to the study area under 3-10-car rail rates and was transshipped by semi-trailer trucks to blending plants in 32 locations for subsequent delivery to farm destinations.

2. *Option V.* Abandonment of 25 percent of the track. Grain was shipped to terminal markets in 50-car lots from seven subterminals in the study area under combined grain-fertilizer rates. Fertilizer provided a back-haul for a small part of the grain moving from these subterminals.

3. *Option IV.* Abandonment of 25 percent of the track. Grain moved to terminal markets from seven subterminal elevators under 50-car rates. Bulk fertilizer moved under 3-10-car rail rates to two new warehouses located in the study area (optimal number and location of warehouses were determined endogenously by the model).

4. *Option I.* The existing single-car system using the entire 1974 network of rail lines at existing capacities. Grain moved directly from country elevators to terminal markets in single-car rail shipments. Fertilizer moved directly to blending plants from manufacturing

Table 18. Stage 3 results: total annual grain and fertilizer revenues and costs of transportation, handling, warehouse investment and rail upgrading maintenance costs; rail cost vs. rail rate basis; alternative options; Nebraska study area, 1974.

Cost/revenue item	Option I single-car shipments to all blend sites	Option II 3-10-car shipments to all blend sites	Option III 3-10-car shipments to existing warehouses (abandonment)	Option IV 3-10-car shipments to new warehouses (abandonment)	Option V combined haul to new warehouses (abandonment)
Rail Rate Analysis					
Net grain revenue	$188,487,248	$188,740,928	$188,711,568	$188,711,568	$188,758,622
Fertilizer transport & handling costs	929,034	784,296	852,766	868,480	858,862
Fertilizer warehouse investment costs	0	0	0	222,977	222,977
Subterminal investment cost	0	532,314	532,314	532,314	532,314
Rail upgrading & maintenance costs	1,688,400	2,351,623	1,119,420	1,119,420	1,119,420
Total net revenue	$185,869,814	$185,072,695	$186,207,068	$185,968,377	$186,025,049
Rank	4th	5th	1st	3rd	2nd
Rail Cost Analysis					
Net grain revenue	$209,471,103	$210,293,536	$210,222,175	$210,222,175	$210,222,175
Fertilizer transport & handling costs	716,824	652,749	761,406	771,788	765,011
Fertilizer warehouse investment costs	0	0	0	222,977	222,977
Subterminal investment costs	0	532,314	532,314	532,314	532,314
Rail upgrading & maintenance costs	1,688,400	2,351,623	1,119,420	1,119,420	1,119,420
Total net revenue	$207,065,879	$206,756,850	$207,809,035	$207,575,676	$207,582,453
Rank	4th	5th	1st	3rd	2nd

sources in single-car shipments without intermediate warehouse stops.

5. *Option II.* Entire rail network upgraded. Shipments of grain in 50-car lots moved to terminal markets from seven subterminal elevators. Most dry-bulk fertilizer moved under 3-10-car rates from manufacturing sources directly to blending plants. Potash moved under single-car rates owing to the small quantities required at each blending site.

Option III, track abandonment, with fertilizer shipped through an existing warehouse, generated $182,019 more net revenue than the second-best alternative, Option V (rail abandonment with combined grain-fertilizer movements), and $238,691 more than Option IV, calling for shipment to new fertilizer warehouses in the study area. Alternative III generated $337,254 more than did the existing system of single-car shipments (Option I), and $1,134,373 more net revenue than Option II, requiring upgrading of all light-density branch lines.

Final results were also obtained using rail costs substituted for rail rates. The findings are reported in Table 18. Ranking of the options did not change from those in the analysis using rail rates.

The addition of fertilizer shipments to the grain marketing model did not change the rankings in the updated original results. Abandonment of light-density rail lines, along with access to multiple-car rail rates, remained preferable to shipping under the existing single-car system over existing rail lines, or to shipping under multiple-car rates over an upgraded rail system.

The inclusion of inbound fertilizer traffic widened the advantage of track abandonment over the existing system as analyzed in the earlier study, but narrowed its advantage over upgrading. While fertilizer provided a modest amount of additional traffic with which costs of track upgrading and maintenance could be shared, total system costs were minimized by moving both grain and fertilizer through intermediate warehouses, taking advantage of multiple-car cost and rate savings.

Dry fertilizer use in the six-county area was not sizable enough to have a significant bearing on optimal system organization. Dry fertilizer tonnage moving into the area was only 2 percent of grain tonnage moving from the area, making optimal organization of the grain system far more critical than that of fertilizer. More importantly, fertilizer volume was too small to benefit from transportation economies realized in 50-car movements of grain. Since each of the three fertilizer nutrients came from a different source, opportunities were further reduced for unit-train movements.

The number and size of fertilizer blending plants in the study area were sufficient to meet expected fertilizer distribution needs in the near future. Relatively high costs of delivery to farms (costs which increased rapidly with size of delivery territory) and modest economies of size at blending plants militate against consolidation of blending operations. Most existing plants were too small to utilize multiple-car rail shipments even if they had access to track capable of supporting such service. Multiple-car rail shipments through an existing warehouse near the area, with truck delivery to blenders, were the least-cost means for bringing fertilizer to the area.

Viewed either in terms of estimated carrier costs or actual and anticipated freight rates, single car rail shipments of dry-bulk fertilizer direct to dealers were not a desirable alternative. It was less costly to move fertilizer by rail in multiple-car lots to warehouses in or near the study area and from there by truck to local dealers. Net system revenues were enhanced by track abandonment and multiple-car shipments even where construction of new warehouse facilities was required.

However, construction of a new warehouse, even if it permitted coordination of fertilizer backhauls in cars used for grain shipments, was a more costly alternative than use of a nearby existing warehouse incapable of providing such coordination.

Although coordination of multiple-car inbound fertilizer shipments as backhauls for outbound grain hauls was more economical than the present system of uncoordinated single-car shipments in both directions, a third alternative of unit-train grain shipments from seven subterminals and 3-10-car shipments of fertilizer through a single warehouse was even less costly. Most of the savings in either case stemmed from improved car utilization, reduced track upgrading and maintenance expenses occasioned by track abandonment, and the salvage value of the abandoned track.

IMPLICATIONS

Fertilizer dealers on abandoned lines may not be disadvantaged relative to those on remaining lines since most existing blending plants were too small to accept multiple-car shipments. The potential for expansion of retailers' trade territories and sales volumes was limited by relatively high costs of farm delivery and by modest economies of size in blending operations. Since rail shipments in single-car lots were more costly than combination rail-truck shipments through an intermediate warehouse, rail service may provide blend plants with no advantage in the future. The existing pattern of fertilizer dealerships in the area is therefore likely to be a stable one.

The effects from abandonment do depend, however, on availability of intermediate warehouses and on multiple-car rail rates to these warehouses. Lacking both rail service and access to a warehouse, blenders would face long-distance truck transport costs which would be higher than present rail rates. Furthermore, there is no guarantee that the optimal system will automatically evolve since neither rail rates nor service characteristics are directly subject to the dictates of competitive pressures. Political and social as well as economic factors will shape the future nature of transportation systems.

In the future, when replacement decisions must be made, location of fertilizer and grain warehouses adjacent to each other would appear to have merit. Prospects for matching shipments of fertilizer with outbound shipments of grain in lots much larger than 3-10 cars do not appear favorable, however. Since grain tonnage far exceeds that of fertilizer, not all grain subterminals should have an associated fertilizer warehouse. Although seven subterminals were optimal for the study area, only two fertilizer warehouses were needed.

Volume of traffic is a key factor in determining the feasibility of line retentions or upgrading. Had all fertilizer used in the study area been in a dry form (four-fifths was either liquid or gas), the feasibility of track upgrading would have been enhanced. There is no reason, however, to anticipate a shift toward dry materials; the trend, in fact, has been in favor of the liquid and gaseous materials. Present potash consumption exceeds levels recommended by some University agronomists. Declining application rates would reduce transportation and storage requirements but only slightly since potash use is small relative to that of other materials.

It seems unlikely that results from the present study would have been greatly different for any other grain farming area. Fertilizer sales volumes inevitably are small relative to volumes of grain produced and marketed. The proportion of fertilizer to grain shipments would be greater in an area where more of the grain is fed to local livestock but in such areas the case for abandonment might be strengthened by the accordingly smaller amount of out-bound grain. Costs of the last leg of the delivery system, that of moving the product to the farmer, are likely to be high relative to costs for the rest of the system in other areas of the state and nation. The Nebraska-delivery system appears to be as efficient as any.

Limited access to a river terminal was not critical to the outcome of the study. Although the case-study area was located too far from a terminal for barge shipments to be competitive with rail hauls, the case for intermediate warehousing might have been even stronger had there been a nearby barge loading facility.

The condition of the rail line and the amount of traffic over the line are critical factors in assessing the merits of any prospective abandonment. It is easier to make an economic case for abandonment of track in poor condition and carrying a small volume of traffic than to make a case for abandonment of a high-quality line carrying a heavier traffic load. The latter factors are probably the most important of all in relating the results of this or any other study to another situation. The lines considered for abandonment in the present study were incapable of carrying multiple-car lots of covered hopper cars filled with grain. These lines carried little except grain traffic and that could move at lower cost when consolidated into 50-car lots, a move which would make much track redundant.

Price inflation since the present study was started has resulted in higher costs of storage, handling and transport of grain and fertilizer. There is no reason to suppose, however, that the basic findings of the study have been affected substantially. If anything, rising costs strengthen the case for improvements in system efficiency. Fuel prices in particular have increased significantly. Increases in energy costs are likely to enhance the cost advantage of pipeline transportation of anhydrous ammonia and might accelerate the trend toward substitution of this product for dry-bulk materials. Such a development would further dissipate rail traffic and add to the vulnerability of branch lines.

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