APPLICATION OF SPATIAL MODELS TO IMPROVING THE EFFICIENCY OF A COUNTRY HOG MARKETING SYSTEM

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Most spatial equilibrium studies done in the past have focused on macro problems of an industry or a commodity. There are, however, important applications for spatial models in analyses of efficient resource use on the micro or firm level.

One important area of application is in analysis of the efficiency of single-firm marketing systems. Many cooperatives and other agribusiness firms have developed systems for marketing agricultural commodities or distributing farm supplies. These systems involve multiple assembly and distribution points, and often some processing function is performed between the points of origin and final destination.

Firms operating these systems have the opportunity to efficiently allocate resources since they have centralized control over the system. But, they also have the difficult problems of determining the allocation of resources that will achieve an optimum configuration and product allocation for the system. These problems readily lend themselves to solution through the application of spatial equilibrium analysis.

This paper presents an example of the application of spatial models in an analysis of the efficiency of resource use in an existing country hog marketing system [2]. It also discusses the magnitude of potential efficiencies to be gained from optimizing such a system.

The country hog marketing system studied was operated by a large livestock marketing cooperative. It was comprised of 42 country markets that bought hogs daily from producers. These markets' operations were coordinated by a central sales office that also sold the hogs to slaughterers and controlled the allocation of hogs from the country markets to buyers' slaughter plants. During the study year this system shipped 3.9 million hundredweight of hogs to 56 slaughter plants located in 14 states.

OBJECTIVES

The study had dual objectives. The first was to determine if the cooperative was optimizing its daily allocation of hogs. An optimum allocation was assumed to be one that minimized the total cost of transporting hogs from country markets to slaughter plants. Other optimizing goals could have been used, such as maximizing total net revenue to the system. This goal might be appropriate for a firm that sells all its hogs on a delivered price basis.

The second objective was to determine if the number, size, and location of country markets in the cooperative's system was optimum. In other words, does the present market structure result in minimum total transfer costs (total transportation plus market operating costs)?

PROCEDURES

The study was conducted in two phases paralleling the dual objectives. These were (1) an optimum allocation analysis and (2) an optimum market structure analysis.

The optimum allocation analysis was based on the cooperative's hog supplies and demands for an "average day." These were derived from actual shipments on 24 randomly selected days during the study year. Transportation rates for each possible shipping route were estimated with a linear regression equation based on actual trucking rates charged for the routes used by the cooperative. Shipments were precluded along a third of the possible routes since transit time would not allow certain packers' kill

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schedules to be met or certain packers would not accept hogs from the markets involved.

A computerized linear programming transportation model was then applied to determine an optimum allocation of hogs for the cooperative's country marketing system on the "average day." The model was adapted from Dantzig's [1] linear programming formulation of the well-known transportation problem. It was designed to allocate hogs by weight, grade, and market class and to equate existing supplies with packer purchases. This model was stated mathematically as follows:

(1) Minimize: $TTC = \sum_i \sum_j c_{ij} X_{ij} \mid W_k$

Subject to:

$$\sum_j X_{ij} = S_i$$

$$\sum_i X_{ij} = D_j$$

$$\sum_i S_i = \sum_j D_j$$

$$X_{ij} \geqslant 0$$

Where:

TTC = total transportation costs,

c_{ij} = the cost per cwt. of shipping hogs from market i to slaughter plant j,

X_{ij} = cwt. of hogs shipped from market i to slaughter plant j,

S_i = supply of hogs at market i (cwt.),

D_j = demand for hogs by slaughter plant j (cwt.), and

W_k = one weight-grade-market class combination of hogs.

The model provided a separate solution for each weight-grade-market class combination. Since the fixed supplies and demands were specified by weight, grade, and market class, the model could be applied to each combination independently and the solution results summed over all combinations to obtain an optimum allocation.

The optimum market structure analysis was based on the cooperative's annual hog sales from its markets and the annual purchases of its slaughter plant customers during the study year. Hog supplies and demands were specified only by market class. The transportation cost matrix and shipping route restrictions used in the optimum allocation analysis also were used in this phase of the study.

A regression equation based on the cooperative's actual costs at its 42 country markets was used to estimate operating costs for markets of various sizes up to a maximum annual volume of 300,000 hundredweight. This equation is as follows:

(2) $\text{Log } \hat{Y} = 1.29902 - 0.34779 \cdot \text{Log } x$

Where:

Y is the estimated market operating cost in dollars per hundredweight corresponding to a given annual market volume, and

X is the annual volume of hogs handled by a market in hundredweight (market size).

The resulting average market operating cost curve is shown in Figure 1.

The optimum market structure analysis was based on several important assumptions: (1) Existing market locations represent the potential market locations in an optimum system; (2) all production occurs at existing market locations, so present farm-to-market transportation costs are assumed to be zero; (3) producers will not ship hogs further than 50 miles to a country market, and (4) the cooperative would continue to market the same total volume of hogs if some of its markets were eliminated in an optimum system.

A computerized transshipment model with economies of scale in market operations was employed to determine an optimum number, size and location of markets for the cooperative's system. The model is an adaption of the formulation used by King and Logan [3], with modifications to handle multiple product types. It may be stated mathematically as follows:

(3) Minimize: $TC = \sum_i \sum_j \sum_k t_{ij} H_{ijk} + \sum_i \sum_k c_i M_{ik} + \sum_i \sum_j \sum_k T_{ij} X_{ijk}$

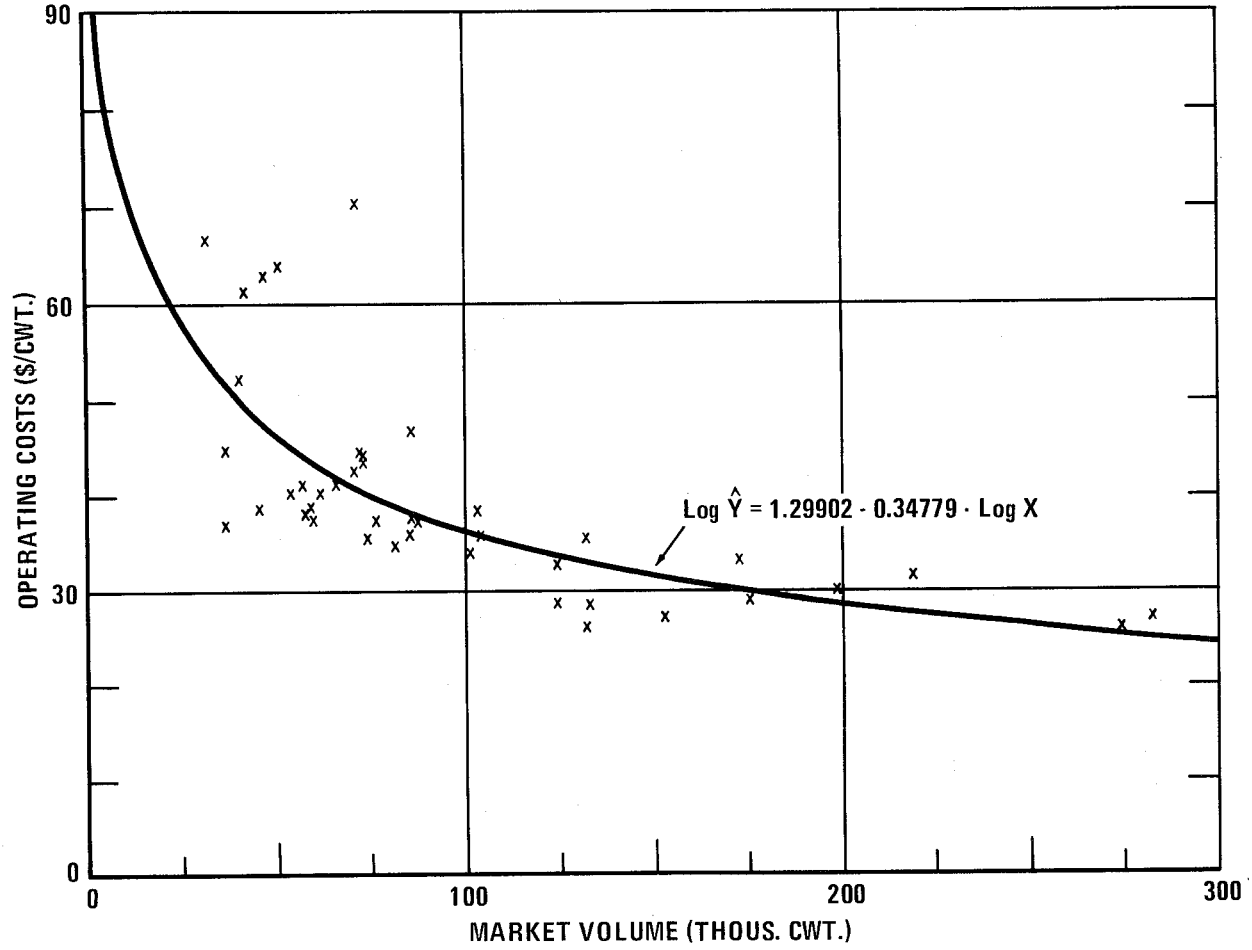
Subject to:

$$\sum_j X_{ijk} = M_{ik}$$

$$M_{ik} = S_{ik} - \sum_j (H_{ijk} - H_{jik})$$

$$\sum_i X_{ijk} = D_{jk}$$

Figure 1. RELATIONSHIP OF AVERAGE MARKET OPERATING COSTS TO ANNUAL MARKET VOLUME



$H_{ijk}, M_{ijk}, X_{ijk} \geqslant O$

Where:

TC = total transportation plus market operating costs,

H_{ijk} = cwt. of k type hogs shipped from production area i to market j,

M_{ik} = cwt. of k type hogs marketed by market i,

X_{ijk} = cwt. of k type hogs shipped from market i to slaughter plant j,

t_{ij} = cost per cwt. of shipping hogs from production area i to market j,

c_i = market operating cost per cwt. at market i,

T_{ij} = cost per cwt. of shipping hogs from market i to slaughter plant j,

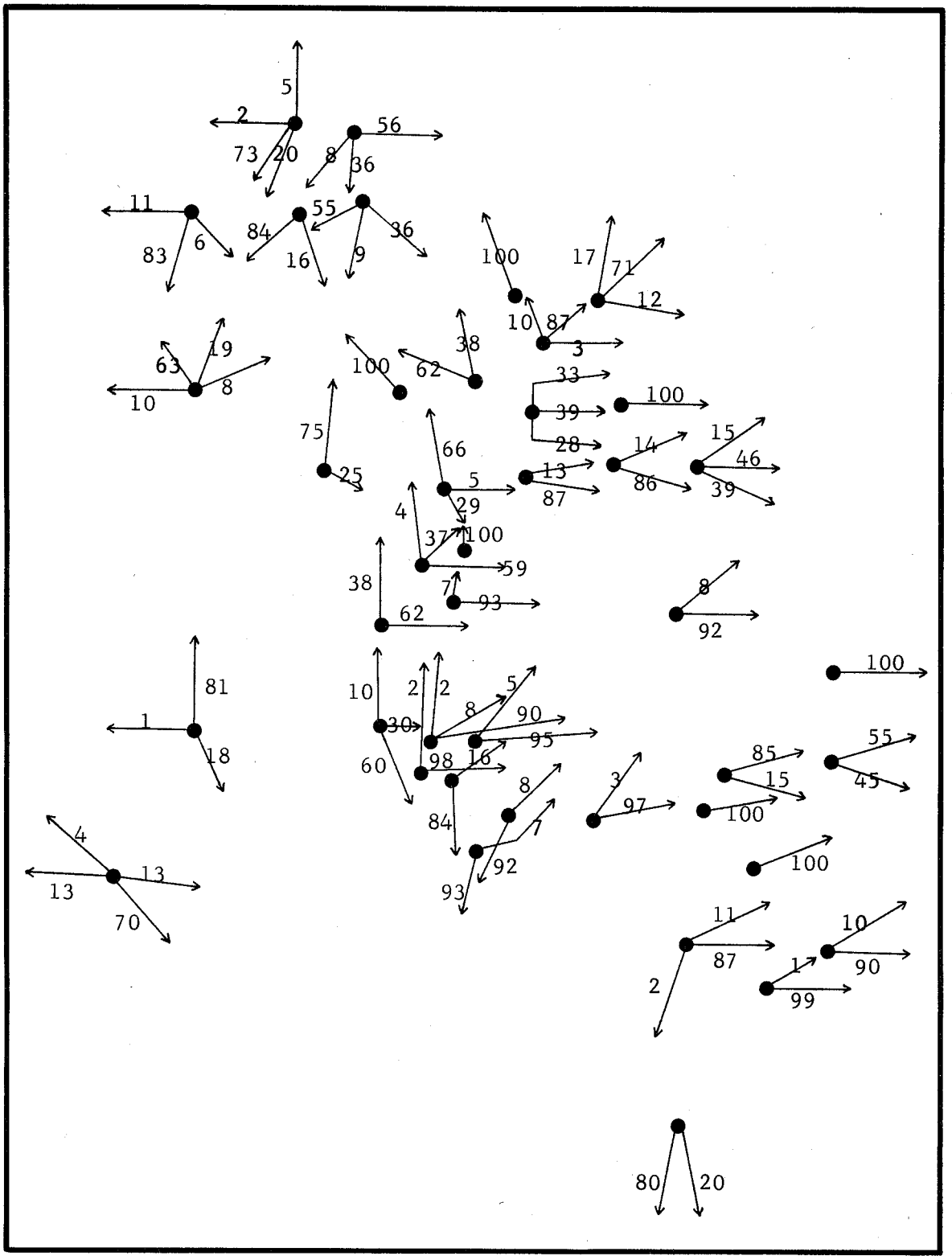
S_{ik} = supply of k type hogs in production area i (cwt.), and

D_{jk} = demand for k type hogs by slaughter plant j (cwt.).

An iterative procedure was used to solve the transshipment model. The initial iteration contained all the existing markets and a "drop" routine was used in subsequent iterations to reduce the number of markets. The iterative procedure was continued as long as successively lower cost solutions were obtained. Economies of scale were incorporated by adjusting each market's operating cost based on its volume specified in the previous iteration solution.

In the first iteration, all markets were assigned an operating cost associated with a market large enough to handle the country marketing systems' total annual volume. The solution provided insight into the influence of transportation costs alone on the allocation of hogs from the existing country markets (Figure 2). For the second iteration each market was assigned a cost based on the volume of hogs it actually handled during the study year. The solution

Figure 2. DIRECTION OF OUTBOUND HOG SHIPMENTS FROM EXISTING MARKETS WITH THE ALLOCATION OPTIMIZED AND CONSTANT OPERATING COSTS AT ALL MARKETS



Legend

● - Country hog market

Numbers indicate percent of market's volume shipped.

showed the influence of total transfer costs on inbound shipments, market volume, and outbound shipments.

With the results of the first two iterations as background, 13 possible market consolidations were enumerated based on the distance between markets, maximum market size, and the influence of transportation costs on the direction of hog movements. A budgeting process then was used to estimate the probable effects of these consolidations on total transfer costs. Based on these estimates, the possible consolidations were ranked in order of their contribution to reduced total transfer costs, from largest to smallest.

In the third and subsequent iterations, the appropriate markets were dropped from the model matrix to effect the desired market consolidations and generate improved solutions. For each iteration the surviving consolidated market was assigned an operating cost consistent with its volume plus the volume of the closed market(s) as specified in the previous iteration solution.

Each market consolidation and resulting reduction in market numbers produced an improved market structure until the level of 26 markets was reached in iteration 11. With the further consolidation of markets in iteration 12, the increase in total transportation costs exceeded the decrease in total market operating costs, with the result that total transfer costs increased. Thus, the number, size, and location of markets given in the iteration 11 solution represented an optimum market structure, but not necessarily a unique optimum (Figure 3).

EMPIRICAL RESULTS

Results of the first phase analysis indicated that the use of transportation resources could be reduced substantially by optimizing the cooperative's daily hog allocation. If hogs had been allocated optimally on the "average day," they would have been shipped an average of 26 fewer miles than they actually were shipped, and total transportation costs would be reduced by an estimated $538, or 4.1 cents a hundredweight (Table 1). Based on the cooperative's sales volume for the study year, total annual transportation costs would have been reduced by an estimated $161,000 if daily hog shipments had been allocated optimally throughout the year.

Optimization also would substantially alter the pattern of shipments from country markets to slaughter plants. Most importantly, the average market would ship hogs to fewer slaughter plants and would ship a larger proportion of its hog supplies to its four largest slaughter plant customers. This would reduce the effort expended by the markets in billing packers and arranging transportation and enable them to concentrate on meeting the buying specifications of fewer plants.

Table 1. ESTIMATED TOTAL AND PER HUNDREDWEIGHT TRANSPORTATION COSTS FOR THE "AVERAGE DAY" UNDER ACTUAL AND OPTIMUM ALLOCATIONS

Allocation	Transportation Cost	
	Total	Per hundredweight
	-----Dollars-----	
Actual	6,156	0.469
Optimum	5,618	0.428
Difference	-538	-0.041

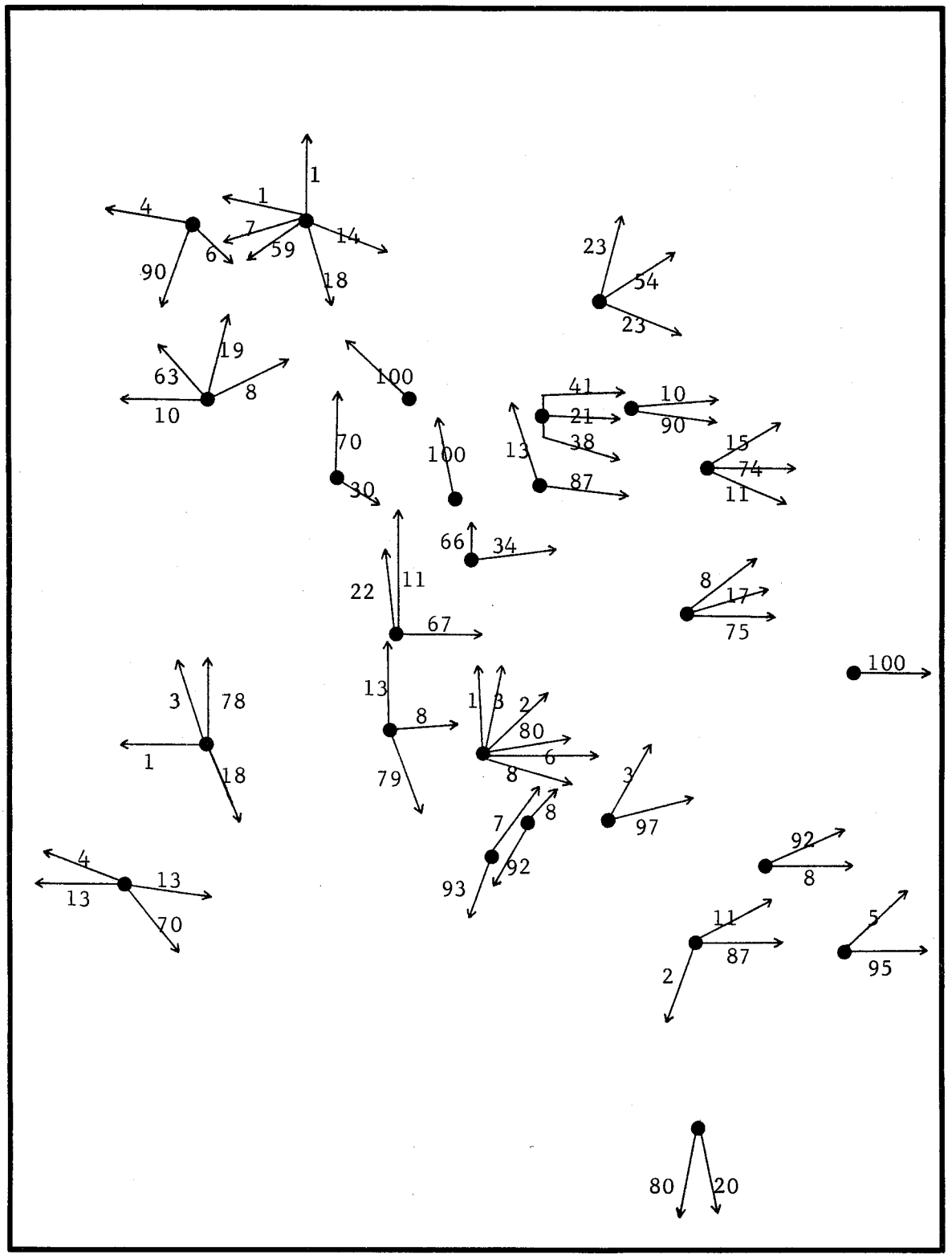
The second phase analysis showed that under the optimum structure the cooperative would operate only 26 of the 42 markets in the existing system. Average market size would increase from 98,000 hundredweight annually to over 158,000 hundredweight, an increase of 62 percent (Table 2). Accompanying the increased market size would be a reduction in average market operating costs estimated at 5.4 cents a hundredweight, a decline of 15 percent.

Table 2. EFFECTS OF NUMBER OF MARKETS AND AVERAGE MARKET SIZE ON AVERAGE MARKET OPERATING COST

Number of markets	Average Market size	Average market operating cost per hundredweight
	Hundredweight	Cents
42	98,016	35.3
39	105,555	34.4
35	117,619	33.5
34	121,078	32.7
32	128,646	32.0
31	132,795	31.6
30	137,222	31.2
29	141,954	30.8
28	147,024	30.5
27	152,469	30.2
26	158,333	29.9

Table 3 shows that optimizing the cooperative's market structure would reduce total transfer costs by an estimated $221,000 annually. Essentially all of these cost savings would result from economies of scale in market operations, with total operating costs being reduced by an estimated $220,000. Total

Figure 3. **DIRECTION OF OUTBOUND HOG SHIPMENTS FROM MARKETS IN THE OPTIMUM MARKET STRUCTURE**



Legend

● - Country hog market

Numbers indicate percent of market's volume shipped.

Table 3. **ESTIMATED TOTAL ANNUAL TRANSFER COSTS FOR THE EXISTING AND OPTIMUM MARKET STRUCTURES, BY TYPE OF COSTS**

Type of costs	Existing structure	Optimum structure	Increase (+) or decrease (-)
	Dollars		
Inbound transportation	0	51,847	+ 51,847
Market operating	1,451,761	1,231,592	- 220,169
Outbound transportation	1,828,712	1,775,906	- 52,806
Total	3,280,473	3,059,345	- 221,128

transportation costs from the closed market locations to the optimum markets (inbound transportation costs) would increase by an estimated $51,800. However, this would be more than offset by an estimated $52,800-reduction in total transportation costs between the markets and slaughter plants.

Total inbound transportation costs would be higher because hogs would have to be shipped from production areas where markets were closed to remaining markets in other production areas. But, these shipments would move in the direction of final slaughter plant destination so that total outbound transportation costs would be lower.

CONCLUSIONS

The results of the analyses indicate that the resources of the swine industry were not being used in the most efficient manner by one country hog marketing system. Both the short-run allocation of hogs from country markets to slaughter plants and the long-run structure of the country marketing system could be more efficient. What are the implications for the cooperative and other firms operating similar marketing systems?

The results of the study suggest that from an industry efficiency standpoint, the cooperative should adopt an optimum allocating procedure and structure its country marketing system in an optimum configuration. However, an industry objective of achieving maximum efficiency may conflict with the cooperative's objective of maximizing net returns to its member-patrons.

While a potential exists for generating substantial industry savings by optimizing the cooperative's daily hog allocation, no one firm or segment of the industry would necessarily capture all or any part of the savings. Since many plants buy hogs f.o.b. the country market and pay the trucking cost, the distribution of savings would be determined by the relative bargaining strength of the cooperative and the slaughter plants.

The majority of the cooperative's hogs would be shipped at a lower cost if allocated optimally. But, some slaughter plants would incur higher trucking costs and no doubt would attempt to lower their purchase prices so their net delivered cost would not increase. To recoup these losses, the cooperative would have to bargain for higher prices from those plants that would realize lower trucking costs. The cooperative would, therefore, participate in the potential industry savings only to the extent it could bargain for increased prices at a high enough level to more than offset any reduced prices.

The cooperative or any other firm could not justify adopting an optimum allocation procedure without being reasonably sure it could recover enough of the potential savings to at least compensate for any added costs. Additional costs would be incurred for development and operation of the computer system, and for formal grading of hogs at the country markets. It is possible that these added costs could exceed the total potential industry savings, in which case optimization would make both the cooperative and the industry less efficient than at present. However, if computerized distribution is more efficient, then competitive pressures may eventually force the cooperative and other firms to adopt such a procedure.

In view of these possibilities, the cooperative and other firms should work to develop marketing strategies that would permit them to capture the benefits of optimum allocation. One possible strategy would be to sell all hogs on a delivered price basis so the potential savings would accrue to the marketing firm as the buyer of transportation services. Even then, competitive forces might erode away some of the savings since the country marketing system is only a subset of the industry.

The cooperative and other firms also should take a long-range look at the future structure of the swine industry. The industry appears to be headed toward an integrated structure in which hogs will move directly from farms to slaughter plants under the

centralized control of individual firms. An optimum allocation procedure would be extremely important to an integrated firm in achieving all the potential benefits of this kind of a coordinated system.

Nearly all the potential savings from optimizing the structure of the country marketing system would accrue to the cooperative. The magnitude of the projected savings in market operating costs would appear to provide sufficient economic incentive for the cooperative to move toward the optimum market structure. But, before accepting this conclusion, the cooperative should evaluate the consequences of at least two potential problem areas. These are (1) the effect of optimization on producers' marketing costs and (2) the effect of competition on the volume of the markets in the optimum system.

Under the optimum market structure, inbound transportation costs would increase by nearly $52,000 annually. This would represent an additional marketing cost of 4.6 cents a hundredweight to producers in those areas where existing markets would be closed. The possibility then exists that these "injured" producers might not continue to ship their hogs to the cooperative's markets.

The cooperative, however, would realize operating cost savings estimated to exceed $220,000. Since a cooperative provides its services at cost and any net savings accrue to member-patrons, all hog producer-patrons would realize a reduction in their marketing costs of an estimated 5.4 cents a hundredweight. If the cooperative adopted a marketing strategy of selling on a delivered price basis and captured the estimated $53,000 annual savings in outbound transportation costs, it could reduce all producers' marketing costs by a total of $273,000, or 6.6 cents a hundredweight. Even those "injured" producers would be slightly better off because the 5.4 cents a hundredweight reduction in market operating costs alone would more than compensate for their increased trucking costs of 4.6 cents a hundredweight.

Closing 16 country markets to achieve the optimum structure could result in the cooperative's losing some of its volume to competing markets. Producers in areas where markets would be closed likely would have access to a competing market closer to their farms than the cooperative's consolidated market in another area. Some producers might not be willing to pass up competing markets and haul their hogs a substantially greater distance to the cooperative market unless they had some economic incentive to do so.

These problems should not be insurmountable, since there would be a slight economic incentive for producers to ship their hogs to the cooperative's markets in the optimum system. The cooperative, however, would need to conduct a well-developed member education program to inform producers of the potential cost savings. In addition, it may need to devise some means of compensating "injured" producers for at least part of their extra trucking costs if the reduction in market operating costs is not enough incentive to insure their continued patronage.

The cooperative might find that the larger, more efficient markets in the optimum system would attract an increased share of the available hog supplies in their operating areas. The increased efficiencies, if reflected in producers' prices, could even stimulate additional hog production in close proximity to these markets.

This study was based on the operations of only one country marketing system, but it provides an example of the potential efficiencies to be gained from optimizing a single-firm marketing system. The study suggests that other firms operating similarly need to evaluate the efficiency of resource use in their country hog marketing systems. The models and techniques used in this study provide a basis for making such analyses. With appropriate modifications, these models also can be applied to problems of efficient product allocation and optimum number, size and location of marketing facilities for other agricultural commodities.

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