Location and Efficiency of the Iowa Feed-Manufacturing Industry

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The American commercial mixed-feeds industry has experienced rapid growth, especially since World War II. Changes have occurred in the product produced, in the number, size, location, and technology of plants, and in the number, size, and organization of the purchasers of the industry's products. The purpose of this study was to develop and use an analytical procedure to solve for the efficient number, size, and location of plants in the Iowa feed-manufacturing industry. Such information should assist the industry in adjusting to rapidly changing demand and technology.

The problematical situation out of which the specific objectives emerge is to find the least-cost location and size pattern for feed-manufacturing plants in Iowa. The solution should take account of changing levels of demand, the changing levels of available technology, and the commercialization trends of modern farming. Are the existing feed-manufacturing plants economically efficient in size? Are their locations optimal? Should there be more or fewer of them?

It is probable that many plant managers are unsure of how their costs levels compare with levels that could be attained. This uncertainty might apply to procurement, production, distributing, and selling costs or to some combination of the four. What is the current level of demand and what is a reasonable expectation for the future? The demand problem is compounded when product form and quality subsets are considered. Brand loyalties and services provided can differ as modern farming becomes more commercialized. For example, it is probable that farmers with higher gross farm incomes are more price conscious and demand more services than farmers with lower gross farm incomes.

Objectives

The objectives of our study were:

1. to determine the relationship between processing costs and volume for single-shift operations;
2. to determine the relationship between processing costs and volume for double-shift operations;
3. to determine the relationship between distribution costs and the number of plants;
4. to determine the relationship between processing costs and the number of plants; and
5. to determine the optimum number, size, and location of feed manufacturing plants in Iowa.

To realize these primary objectives, it was necessary to accomplish the following secondary objectives:

1. to derive a manufacturing cost standard that could be used as an industrial benchmark;
2. To develop a road-mileage transportation matrix relating a reference point in each county to each Iowa population center of 5,000 persons or more; and
3. to analyze costs of transporting feeds in Iowa.

This study concerned mixed feeds manufactured by business firms. These feeds are fed to livestock and poultry; the product form may be either supplement or complete feed. The scope of our study was the analysis of costs to process, sell, and distribute feeds to the county or "wholesale" level. That is, the county is considered a trade area, and distribution to the trade area delimits the marketing focus of our study. Problems of within-county or retail handling and distribution were not included in the objectives of this research.

Analytical Procedure

Five basic steps were necessary in reaching the least-cost solution to the problem of optimum number, size, and location of feed manufacturing plants in Iowa. Each involved a number of substeps.

The initial step was to define the spatial area. The state of Iowa was chosen. Each of the 99 counties was taken to be a node of feed demand to be supplied by the feed industry.

Next, potential plant site locations were selected. The choice was based arbitrarily on population figures from the 1960 population census. Only major population centers, defined as 5,000 or more persons, were considered potential plant sites; 51 such population centers were defined for Iowa.

Data inputs were then developed for the model through five substeps. First, feed demand was estimated for each county. The basis for these estimates was livestock numbers by class as reported in the 1964 Census of Agriculture. The initial estimates were disaggregated into supplement- and complete-feed tonnages. Second, several economic-engineering study results were synthesized to extimate a per-ton cost-to-volume relationship in feed manufacturing and thereby ascertain economies of scale. Third, a road-mileage transportation matrix from each potential manufacturing location to each

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county was developed for the state. The result was a 51 x 99 matrix of road mileages. Fourth, costs of transporting feeds in Iowa were determined. Costs per mile in relation to length of haul were obtained for large trucks (about 18 ton load average). Data sources were a survey of Iowa Commerce Commission filings on private operator and contract carrier tariff charges plus an Iowa State University survey of truck costs incurred by Iowa feed manufacturers. Finally, selling costs per ton were estimated in relation to distance.

The fourth step of the research procedure involved calculating transportation and selling costs from each origin to each destination. Then, the relationship between distribution costs (transportation plus selling costs) and number, size, and location of plants was established. The computations involved in this step will be explained in detail later.

The fifth step entailed combining the total distribution cost function and the manufacturing cost function—both with respect to plant numbers. The vertical summation of these two functions resulted in a combined cost function. When the minimum point on the combined cost function is found with respect to plant numbers, the efficient solution is reached. The solution consists of the number of feed manufacturing plants, where each is located, the tonnage size of each plant, which plants should serve which county feed demands, and the cost levels for each plant and the industry under an efficient organization.

LONG-RUN SPATIAL MODEL FOR THE IOWA FEED-MANUFACTURING INDUSTRY

A crucial assumption of our study was that cost minimization is compatible with the fundamental objectives of the firm. That is, the goals of the feed company are furthered by the ability to produce with a low cost structure. A fact of life in the business world is that a relatively low cost structure is the basis for effective competition. A low cost structure also has favorable implications for social welfare. Although cost savings may not be passed along to producers and (or) consumers, it is only feasible to share cost savings if they exist.

Plant location should be planned with great care at the firm level. Location cost advantages may be reaped over a long period. Efficiency, in this context, implies either distributing as much product as possible with given available resources or distributing to a given demand density as inexpensively as possible. Our study is concerned with the latter efficiency criterion.

The general model was developed initially as a raw material assembly model (Stollsteimer, 1963). Its application was to determine the optimum number, size, and location of pear processing plants with respect to assembling pear production. This application was for a small, relatively isolated area. In our study, the model is developed as a distribution model and applied to the feed industry in Iowa. The problem is to determine simultaneously for the entire state the number, size, and location of plants that minimize the total combined manufacturing, distribution, and selling costs. Given a fixed volume of output, the model requires relationship expressions between number of plants and manufacturing costs, distribution costs, and selling costs. In addition, a relationship between manufacturing costs and output volume is needed.

Algebraically, the model is:

$$\underset{(J,L_k)}{\text{MIN}}\ TCC = \sum_{j=1}^{J} P_j F_j \Big| L_J + \sum_{i=1}^{I}\sum_{j=1}^{J} F_{ij} T_{ij} \Big| L_J + \sum_{i=1}^{I}\sum_{j=1}^{J} F_{ij} S_{ij} \Big| L_J \quad [1]$$

with respect to plant numbers ($J \leq L$) and locational pattern $L_k = 1, 2, ..., LC_j$, subject to

$$\sum_{i=1}^{I}\sum_{j=1}^{J} F_{ij} = F$$

$$\sum_{i=1}^{I} F_{ij} = F_j$$

$$\sum_{j=1}^{I} F_{ij} = F_i$$

$$F_{ij} \geq 0,\ T_{ij} \geq 0,\ S_{ij} \geq 0,\ P_j \geq 0$$

where $i = 1, ..., I$ and $j = 1, ..., J$. A verbal description may be helpful. Given I demand nodes (F_i) to be supplied from any one or more of L possible locations, the problem is one of cost minimization. The total quantity of feed demanded is to be manufactured, sold, and transported as inexpensively as possible. The elements of the model are defined as:

- TCC = total combined manufacturing, selling, and distributing cost;
- F = total quantity of product demanded;
- F_i = product demanded at demand node i;
- F_j = product supplied by supply node j;
- P_j = unit plant cost at supply node j;
- T_{ij} = unit cost of transporting the product from j to i;
- S_{ij} = unit cost of selling to demand node i from supply node j;
- L_J = all combinations of locations for J plants;
- L_j = location of plant j;
- L_k = one combination of locations for J plants among the LC_j possible combinations of locations for j plants.

The logic of the model's solution follows from two considerations: (i) the more widely distributed and greater the number of feed manufacturing plants, the lower will be distribution costs; and (ii) in-plant manufacturing costs will increase at a decreasing rate as the number of plants increase (i.e., economies of scale exist). The first factor decreases total combined costs as more plant locations are added. The second factor, however, increases total combined costs as plants are added because more plants imply that each plant must be smaller. The solution is the point at which the two factors just offset one another—the rate at which the distribution factor decreases total combined costs just equals the rate costs are increased by the plant number factor.

APPLICATION TO THE FEED INDUSTRY AND OPERATIONAL SOLUTION PROCEDURE

The feed manufacturing operation might be divided into 12 activity stages. In the following analysis, these stages are assumed sufficiently independent to permit an additive relationship in the calculation of total costs. Consider the following cost expression:

$$\text{TOTC} = (\text{TINGMC} + \text{TINGTC} + \text{TRD} + \text{TINGBC} + \text{TINGHC} + \text{TINGPC} + \text{TMIXC} + \text{TPELC} + \text{TPKGC} + \text{TWHC} + \text{TTRANC} + \text{TSELLC}) \quad [2]$$

where

TOTC = total cost;
TINGMC = total ingredient materials cost (fob);[3]
TINGTC = total ingredient transportation cost;
TINGBC = total ingredient buying cost;
TRD = total research and development costs;
TINGHC = total plant receiving cost;
TINGPC = total plant processing cost;
TMIXC = total plant mixing cost;
TPELC = total plant pelleting cost;
TPKGC = total plant packaging cost;
TWHC = total plant warehousing cost;
TTRANC = total product transportation cost;
TSELLC = total product selling cost.

Dividing each term in equation 2 by volume (V) gives long-run average cost. Equation 2 can be rewritten as

$$\text{AOTC} = \text{AINGMC} + \text{AINGTC} + \text{ARD} + \text{AINGBC} + \text{AINGHC} + \text{AINGPC} + \text{AMIXC} + \text{APELC} + \text{APKGC} + \text{AWHC} + \text{ATRANC} + \text{ASELLC}. \quad [3]$$

The first three terms (AINGMC, AINGTC, ARD) are constant with respect to both volume and distance that the final product must be transported; thus

$$[d(\text{AINGMC})]/dV = [d(\text{AINGTC})]/dV = [d(\text{ARD})]/dV = 0$$

and

$$[d(\text{AINGMC})]/[d(\text{DISTANCE})] = [d(\text{AINGTC})]/[d(\text{DISTANCE})] = [d(\text{ARD})]/[d(\text{DISTANCE})] = 0$$

This study determined the minimum cost locational pattern for the Iowa feed industry to supply a given demand. Since the first three terms will not vary with respect to plant numbers, the three cost sources can be visualized as affecting merely an extension of the dependent axis when plant numbers are plotted against costs. This result reflects an assumption that per weight-unit ingredient costs and average research and development costs are the same for any major population center in Iowa.

The last two terms in equation 2 vary according to distances from market. Their cost magnitudes therefore vary with the number of plants. The remaining seven terms represent components of feed manufacturing *per se*. They are: ingredient procurement, ingredient receiving, processing, mixing, pelleting, packing, and warehousing. These are aggregated and called "plant manufacturing costs." It is assumed that problems of plant harmony have been resolved and that efficient production techniques are being used. This assumption is reasonable since economic-engineering methods utilizing industry-cost standards were used in synthesizing manufacturing costs.

The total cost function can now be written more simply as

$$\text{TOTC} = \text{TMC} + \text{TTRANC} + \text{TSELLC} \quad [4]$$

where each term is affected by the number of plants.

The total manufacturing cost function is:

$$\underset{(J,L_k)}{\text{TMC}} = \sum_{j=1}^{J} P_j F_j \,\big|\, L_J \quad [5]$$

Since unit costs for both transportation and selling vary with distance from market, for computational purposes the last two terms of equation 4 can be combined. Let $D_{ij} = T_{ij} + S_{ij}$, then the total distribution cost function becomes

$$\underset{(J,L_k)}{\text{TDC}} = \sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij} F_{ij} \,\big|\, L_J \quad [6]$$

and the total combined cost function including manufacturing, selling, and distributing can be reduced to

$$\underset{(J,L_k)}{\text{TOTC}} = \underset{(J,L_k)}{\text{TMC}} + \underset{(J,L_k)}{\text{TDC}}$$

$$= \sum_{j=1}^{J} P_j F_j \,\big|\, L_J + \sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij} F_{ij} \,\big|\, L_J \quad [7]$$

Certain assumptions concerning the manufacturing cost function should be emphasized. It is assumed that these costs are independent of plant location and that manufacturing technology remains unchanged.

Many plant-cost empirical studies indicate that the total long-run cost-volume functional relationship is linear with a positive intercept. A linear, nonhomogeneous total cost function implies economies of scale (declining L-shaped average cost function) and constant long-run marginal costs. The empirical results of our study confirm this description. Total manufacturing costs will increase with the number of plants. With constant marginal processing costs and a positive intercept in the plant-cost function, the total cost of processing a fixed quantity of feed will increase by the amount of the intercept for every increase in the number of plants.

[3] Prices at the geographic location where the ingredient originates.

There are I demand nodes to be served from J or fewer of J possible plant locations or supply nodes. The first step in minimizing the combined total cost function with respect to plant number (J) and plant location pattern (L_k) is to obtain a distribution cost function that has been minimized. The procedure is to assign plant numbers j = 1, ..., J and compute the cost for each possible combination of each assigned number of plants. There are ${}_LC_J$ possible combinations of locations $L_k|J$. For example, if there are eight potential plant sites, five plants can be arranged in

$$\frac{8!}{5!3!} = 56 \text{ ways.}$$

There is a (I by J) cost (C) matrix wherein each element represents transportation plus selling costs of each demand node i being supplied by each potential supply node j (plant location). If there are 99 counties and 50 potential plant sites, the C matrix is 99 by 50. For each possible locational pattern, L_k, there is a submatrix $C_{ij}^* | L_k$ of matrix C. The dimensions of this submatrix are I by j), where j is the assigned number of plants. A vector $C_i^{min}|L_k$ is obtained by scanning $C_{ij}^*|L_k$ by rows and selecting the minimum C_{ij} in each. Minimum total distribution costs, with j plants and a fixed locational pattern L_k, are equal to the conformable product of the $C_i^{min}|L_k$ vector and the vector of quantities demanded at each demand node i. The resultant expression is

$(F_i^o)\ C_i^{min}|L_k$

where F_i^o is the vector of fixed quantities demanded.

There are ${}_LC_J$ such values for each value of j. The minimum of these values over L_k is a point on the distribution cost function minimized with respect to plant locations. The result is j values of the function

$$TDC^{min} = L_k^{min}\ (F_i^o)\ C_i^{min}|L_k \qquad [8]$$

where

TDC^{min} = total distribution cost minimized with respect to plant location for each j = 1, 2, ..., J. The shape of the TDC^{min} function is deduced from the expected signs of the first and second differences with respect to varying plant numbers (Stollsteimer, 1963). It is to be expected that both transportation and selling costs will be reduced with the addition of more plants; hence

$$\Delta TDC^{min} / \Delta J \leqslant 0$$

The first difference will be less than zero as long as there exists an element C_{ij}^{**} in C but not in $C_{ij}^{min}|L_k$ such that $C_{ij}^{**} < C_{ij}^{min}$ for some i. The sign of the second difference is less certain but is expected to be positive or zero; hence

$$\Delta^2 TDC^{min} / \Delta J^2 \geqslant 0$$

In brief, a decreasing monotonic convex (to the origin) function is expected. It has been shown that it is possible to construct numerical situations in which the second difference is negative (Hoch, 1965). However, Hoch notes that, if one vector (only) enters, the second difference cannot be negative; therefore, barring special constructions, the nonnegativity condition holds.

After the minimized distribution function has been obtained, the second major computational step is to add manufacturing costs. The total combined cost function

$$\underset{(J)}{TC} = \underset{(J)}{TMC} + \underset{(J)}{TDC^{min}} \qquad [9]$$

is obtained. Recall that the distribution cost function (TDC) has been minimized with respect to locational pattern, L_k, for each number of plants J. The total combined cost is the vertical summation of the manufacturing and minimized distribution cost functions. The minimum point on the total combined cost shows the optimum number of plants. The distribution cost function minimization procedure determined which L_k (locational pattern) of the ${}_LC_J$ possible combinations was optimum for each number of plants. Thus, the location of each of the optimum number of plants is determined. The size of each plant is determined by the magnitude of demand to be served by that plant.

The foregoing procedure requires computation of costs for every conceivable combination of plant numbers, sizes, and locations to minimize cost. If all calculations must be made, however, the model's usefulness is severely restricted because of computational costs. The relation of computations to number of plants considered is roughly exponential. The computational cost burden soon becomes astronomical. For example, it was estimated that computing all combinations of 50 plants would be about a year's work for the computer. Unless the bulk of the computations are circumvented, the model's use is limited to small problems. Therefore suboptimization procedures were developed. These suboptimization procedures widen the possible use of the basic model.

THE COMMERCIAL MIXED-FEEDS INDUSTRY

Perspective

The feed industry ranks among the largest 15 manufacturing industries of the United States and is the largest industry serving the American farmer (Schoeff, 1961, p. 7). From a small beginning, rapid growth was experienced from the turn of the century to the depression—with some decline during the depression (Ralph, 1953, pp. 14-15). Stimulated by increased economic activity, technological, and nutritional programs, the desire for (and incomes to afford) better-balanced diets, higher prices for livestock and livestock products, and relative shortages of many kinds of feeds, the feed industry grew very rapidly in the post-depression period (Askew and Brensike, 1953). Growth of the commercial feed industry has been allied closely with protein nutrition and the introduction of new feed materials. The crucial ingredient in these materials usually has been protein.

The USDA makes annual estimates of total concentrates fed and the number of animal units. An animal unit is defined in terms of the feed consumed by one producing milk cow in 1 year, according to a 1940-45 base period. Conversions for other periods and other livestock classes are made to standard animal units. Table 1 presents the 1950 to 1965 data on total concentrates fed and index of animal units (base period 1957-59 = 100). These data suggest a general pattern of increasing demand for feed concentrates. Comparison of the relative rates of increase indicates that concentrates fed per animal unit increased over the time depicted.

The most recent Census of Agriculture was the first to obtain information on commercially mixed feeds, millfeeds, and supplements purchased by farmers. Purchases reported for the United States amounted to 44.9 million tons, and those in Iowa came to 2.6 million tons (U.S. Bureau of the Census, 1965). The Census reported that the average price per ton of commercial feed purchased in Iowa was $101.12; the corresponding U.S. figure was $83.22. Since the price per ton for supplements is much higher than that for complete feed, it is clear that the proportion of total feed in supplement form is much higher in Iowa than the national average. Indeed, the Iowa price per ton exceeded any other state—the closest was the Illinois price of $96.95 per ton.

Table 1. Total concentrates fed and animal concentrate units index, 1950-1965, United States.

Year	Animal units index (Base: 1957-59=100)	Total concentrates fed (mil. tons)
1950	99	126.1
1951	99	128.6
1952	95	117.6
1953	94	119.9
1954	97	119.8
1955	100	125.6
1956	97	123.6
1957	97	132.1
1958	102	143.1
1959	101	147.9
1960	102	153.1
1961	103	155.2
1962	105	154.1
1963	105	153.3
1964	102	150.4
1965 [a]	103	162.9

[a] Preliminary.

Source: Economic Research Service. 1966. Livestock-feed relationships. U.S. Dept. Agr. Stat. Bul. (Suppl.) 337

Industry Structure and Organization

Concentration refers to ownership or control of a large proportion of some aggregate of economic resources or activity either by a small proportion of the firms or by a small absolute number of such firms (Bain, 1965, p. 85). Degree of concentration frequently is used as an indication of monopoly or oligopoly. Available data suggest a relatively low concentration in the prepared-animal-feeds industry. Table 2 indicates concentration in terms of value of shipments. The data cited are national. At local or regional levels, it seems likely that the feed industry is more concentrated.

The structure of feed industry seems to fit the category of industries having some large firms, but with an extensive competitive fringe of small sellers. Industrial competition includes firms ranging from large, with regional or national distribution, to locally oriented smaller suppliers. Large firms tend to emphasize nonprice competition through product development and quality control (product differentiation) and advertising. The competitive fringe of small firms tries to achieve volumes by price competition and cost reduction. The magnitude and impact of product differentiation seems relatively slight and may be decreasing. One study found that purchasers of local feeds generally were price conscious, had larger operations, were indifferent to advertising claims, were interested in convenient supply location and services, and many purchased directly (Kalb, 1964). As farms become fewer but larger, an increasing emphasis on price competition can be anticipated. Feed manufacturers advertise little in newspapers or network television—probably directing advertising expenditure toward farm magazines, local television, and point-of-purchase media (Padberg and Nelson, 1965).

Table 2. Percentage of value of shipments by the largest feed companies in the USA, 1954 and 1958.

Industry code	Class of product and year	Percentage of value of shipments accounted for by		
		Largest 4	Largest 8	Largest 20
2042	Prepared animal feeds:			
	1954	21	29	43
	1958	22	31	44
20421	Poultry feeds:			
	1954	26	36	52
	1958	26	37	52
20422	Livestock feeds:			
	1954	23	33	48
	1958	26	36	51

Source: U.S. Congress, Senate Subcommittee on Antitrust and Monopoly, Committee on the Judiciary. Concentration ratios in manufacturing industry. Part I, 87th Cong., 2nd Sess., 1962.

The market organization of the industry is depicted in fig. 1. This is a flow chart illustrating the physical movement of materials through production and distribution. The market-organization flow chart could be visualized as a combined assembly-distribution model. The trends discussed in the previous section could result in basic structural changes in the flow chart. Most, however, would affect magnitude of flows within the basic structure. For example, the trend toward direct selling would be represented by a heavier flow along the arrow from "formula feed manufacturers" (complete feeds and [or] concentrates) to "farmers" and (or) "commercial feedlots."

The input market consists of feed grains, animal and plant protein materials, and trace ingredients such as minerals, vitamins, and antibiotics. Product differentiation at the input level is nearly nonexistent; standardized government grades and a high level of market information result in the output of one seller being regarded as very similar to that of any other.

Iowa Agriculture and the Feed Industry

Changes taking place in Iowa agriculture are exemplified by comparing 1959 and 1964 Census of Agriculture data. Several of these changes have an impact upon the commercial mixed-feeds industry in the state. In the 5-year span, Iowa farm numbers continued to decline, while farm size and farm values continued to increase (U.S. Bureau of the Census, 1960 and 1965). Farm numbers fell from 174,707 to 154,162 (12 percent) as size rose from 193.6 to 219.0 acres per farm (13 percent) and value rose from $49,150 to $59,901 per farm (22 percent). Two-thirds of the farm-value increase was due to increased size of farms, with the remainder representing increasing value per acre of land and buildings (Mayer and Howell, 1966). Between 1959 and 1964, the per-farm value of all farm products sold went up from $13,074 to $16,848 (29 percent).

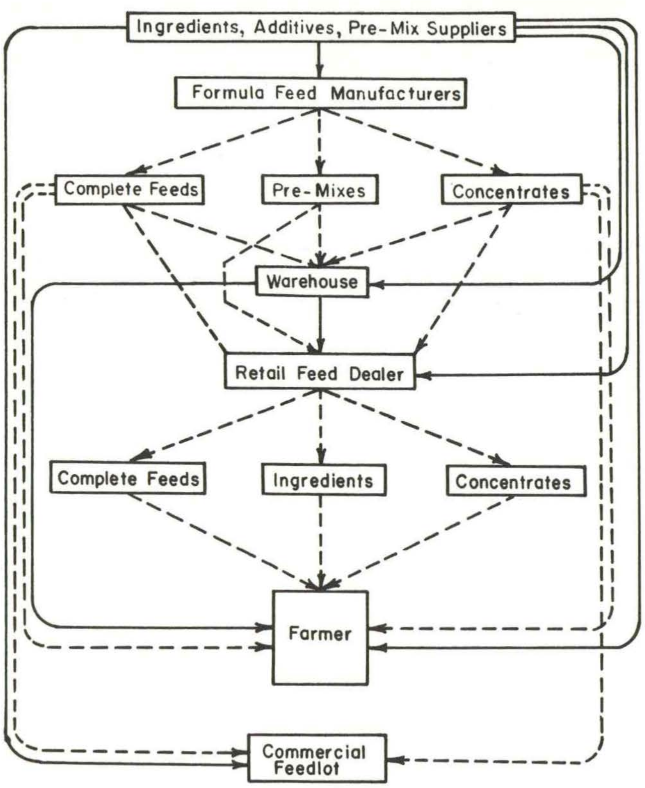


Fig. 1. Market organization of the feed industry.

In the same time, total cropland harvested was off somewhat, while the livestock picture was mixed. Census figures show that corn acreage and production fell considerably, while those of soybeans nearly doubled. Beef cattle and turkey production increased. Other poultry and sheep production decreased. Swine and dairy production remained about steady.

Looking into the future, Iowa's population is not expected to change a great deal, expanding less than 3 percent in the next decade. The rate of increase for the United States, however, is expected to be about 15 percent (U.S. Department of Commerce, 1967). In a projection study for Iowa, W.R. Maki predicted a 1975 population just under 3 million, noting that increases in manufacturing and service industries will be able to do little more than offset employment declines in agricultural production (Maki, 1965). For consumption of livestock products, however, it is national population and preferences that are of primary importance. So it is for the feed industry. U.S. population has been increasing at roughly 2 percent per year. Iowa agricultural output in 1974 was projected to be one-quarter higher than 1964—largely based on population projections. Maki projects production increases for meat animals, feed crops, poultry, eggs, and dairy products.

The Iowa Department of Agriculture, Feeds Division, compiles feed tonnages taxed by an inspection fee. These data show that yearly tonnage has about doubled since 1954—with increases in all feed classes except chicken feed.[4] Turkey and beef tonnages have increased sharply. Feed production for swine and dairy increased strongly up to about 1959-60, whereupon swine tonnage became steady, and dairy feed tonnage continued to increase moderately.

In an industry experiencing demand expansion, a primary manner of adjustment to trends is capacity expansion. *Feed Age* made a survey to ascertain the nature and magnitude of 1963 feed facility expansions in the United States (Karstens, 1964). The expansions were relatively small since fewer than one-third of the 341 expansions recorded involved capital expenditures in excess of $125,000. The significance of the survey to our study is that Iowa accounted for nearly one-fifth of all the expansions. As part of our study, a survey was taken of expansions in the North Central Region reported by trade magazines. Five years—1960 through 1964—were covered. The observations included expan-

[4] Data obtained by visit to Feeds Division, Iowa Department of Agriculture, Des Moines.

sions at all levels—manufacturing and local elevators. Besides new facilities, some expansions were by remodeling, and some were additions to existing facilities. Of the 245 reported expansions, 78, or 32 percent, were in Iowa. Of the Iowa expansions, 36 percent were by cooperatives, and 49 percent by private operators or firms. Large companies expanding by remodeling or new building accounted for the remaining 15 percent. Nearly all (85 percent) were recorded as being new facilities as distinct from remodel-and-expand undertakings. It was not possible to obtain information indicating the magnitude of net expansion. One would likely err to assume all new constructions represent net feed-industry capacity expansions. Often an old facility is abandoned as the new facility becomes operational.

DEVELOPMENT OF DATA INPUTS

Spatial Delineation

The spatial region considered in this study is the State of Iowa. The marketing dimension scope is feed manufacturing and distribution to the wholesale level; that is, to retail outlets and (or) large-volume feeders. Retail distribution has received attention in other studies.

Each of the 99 counties was treated as a demand point. One reference point was chosen for each county. In general, the reference point was the geographic center. Since most counties are rectangular, the geographic center could be determined as the intersection of two corner-to-corner lines traversing the county diagonally. In some instances, the reference point was adjusted slightly from the geographic center. It seemed realistic, from the viewpoint of transporting people or materials, to make the reference point a trade center, major road intersection, or point on a major road if only a small adjustment was required. This minor adjustment is justified because towns and roads have been established to facilitate the needs of people and their economic (and other) activity.

Implicit in the procedure of choosing one reference point in each county is the idea that the reference point represents the average number of miles traveled into the county from any given potential manufacturing plant location distributing to that county. Suppose a manufacturing plant is located in Mason City and the distribution to Hamilton County is considered. If product distribution is to be to (say) 8 random points in the county, the average distance to these points can be approximated by the distance from Mason City to the county's geographic center.

Major population centers, defined as those centers whose population exceeded 5,000, were regarded as potential plant locations. Such a definition is arbitrary. But, in choosing potential plant sites, we thought that centers with 5,000 or more persons could offer minimum facilities and an environment attractive to a company (or cooperative) contemplating the establishment of a manufacturing plant. Facilities include a manufacturing plant's need for water, electricity, financial institutions, communications, and transportation channels. The facilities already present in the previously defined major population centers can likely support an additional plant of at least moderate size. The local labor market is an additional concern. It would be desirable for a plant to be located where the labor pool is large enough to preclude any serious distortion of the local labor market. The term environment considers community living aspects, such as available housing, school, church, and recreation facilities. We believed that adequate provision of such factors would exist for any center of 5,000 or more persons.

When two centers within 10 miles of each other met the specification, they were regarded as one; instances were Des Moines-West Des Moines-Urbandale, Mason City-Clear Lake, Davenport-Bettendorf, Waterloo-Cedar Falls-Evansdale, and Cedar Rapids-Marion. A total of 51 potential plant sites were selected by using the 5,000-population criterion. Their geographic dispersion is illustrated in fig. 2. These centers are well dispersed. If circles were drawn around each center, using a 50-mile radius, the entire state would be contained except for a very small corner of Lyon County.

Demand Analysis

Feed demand estimates were essential inputs to the primary objectives of the research. Estimates were needed for each county. Supplement and complete feed estimates were required for each county; each set of these was for each of 16 livestock classes. Thus, a total of 3,168 demand estimates completed the task. Estimates were based upon livestock numbers reported in the 1964 Census of Agriculture (U.S. Department of Commerce, 1965).

Derivation of Standard Animal Units

The U.S. Department of Agriculture has developed a procedure for converting livestock numbers into "standard animal units" (Economic Research Service, 1963). These animal units are a measure of livestock numbers weighted by feed consumption.

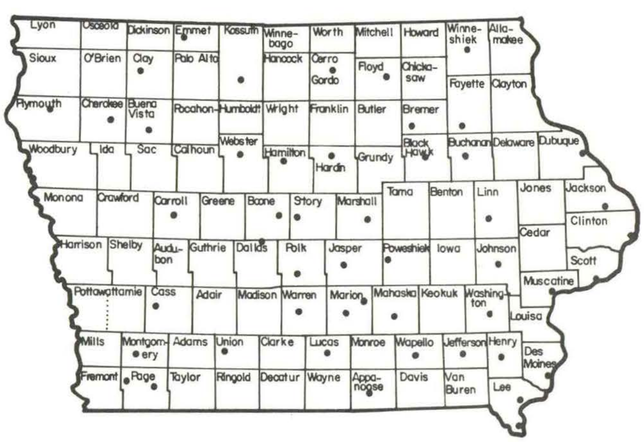


Fig. 2. Geographic dispersion of 51 Iowa centers with 5,000 or more population.

Current feed consumption data are available for various classes of livestock (Hodges, 1964). It is possible to estimate feed requirements from animal unit computations. Feed per animal unit has been estimated in a time series. Feed demand requirements, based on livestock numbers, can be estimated for local, state, regional, or national levels and compared with available supplies at corresponding levels of geographic aggregation. Researchers in Iowa might focus their concern on local (county) and state (Iowa) levels.

An animal unit is defined as the equivalent of one milk cow in terms of feed consumed per year (Economic Research Service, 1961). Numbers of each kind of livestock, including poultry, are converted into animal units by weighting such numbers by a factor. The factor for a particular class of livestock is the ratio of the amount of feed consumed per head per year to that for one milk cow. That is,

$$f_v = \text{factor} = \frac{\text{amt. of feed consumed/v/year}}{\text{amt. of feed consumed/milk cow/year}}$$

where v refers to the class of livestock (table 3). The base period for the computation of the factors is 1940-45 for all classes of livestock except broilers. The base period is 1950-53 for broilers.

Animal units are computed and presented by the USDA in three basic series:

1. concentrate-consuming animal units, or livestock and poultry weighted by consumption of concentrates;[5]
2. roughage-consuming animal units, or livestock numbers weighted by consumption of roughage including pasture; and
3. concentrate- and roughage-consuming animal units, or livestock numbers weighted by all feed.

A subset of the concentrate series, called the high-protein-consuming animal units, is also computed.

Since the objectives of this report are in terms of the demand for livestock feeds of commercial source (that is, manufactured feeds), consideration will henceforth refer only to the first of the three animal-unit series. Concentrate-consuming animal units (grain-consuming in USDA parlance) will hereafter be implied by the term "animal units." The commercial mixed-feeds industry produces mainly concentrates—supplements or complete feeds (supplements plus feed grain).

The USDA calculates animal units for the "feeding year" beginning Oct. 1.[6] There is considerable state and regional variation in the factors for converting livestock numbers into animal units. In addition to national calculations, the USDA computes an animal-units result for each state. The 1959-1964 time series for the U.S. (48 states), the North Central Region, the Corn Belt, and Iowa is presented in table 4.

These USDA data and results are not disaggregated to any substate levels such as counties, and county estimates are needed for our study. The most reliable and complete county-level data sources

[5] The term concentrates includes feed grain, corn hogged-off, oilseed meals, animal proteins, grain proteins, millfeeds, added fats, and miscellaneous low fiber feeds.

[6] Minor adjustments permitted comparing "feeding year" results with calendar year results from census data.

Table 3. Weighting factors for grain-consuming animal units, national[a] and Iowa, 1964.

Type of animal	Weights U.S.	Weights Iowa
1. Milk cows and heifers 2 years old and over	1.03	1.20
2. Heifers and heifer calves kept for milk[b]	0.35	0.50
3. Beef cows 2 years old and over	0.17	0.40
4. Cattle on feed	1.95	2.50
5. All other cattle[b]	0.16	0.30
6. Stock sheep on farms	0.022	0.050
7. Horses and mules 2 years old and over	1.31	1.40
8. Colts	0.15	0.20
9. Hogs fed during feeding year	0.72	0.75
10. Hens and pullets on farms	0.06	0.055
11. Chickens raised during the year	0.017	0.020
12. Turkeys raised during year	0.07	0.07

[a] The base (1.00) for the factors in this table is the average quantity of grain and other concentrates consumed annually by the average milk cow in the U S. during 1940-45. The factor for sheep and lambs on feed is 0.12 and for broilers is 0.0008; they are the same for all states.

[b] The factors for heifer and heifer calves kept for milk include an allowance for dairy bulls; "other cattle" includes an allowance for beef bulls.

Sources: Economic Research Service. 1964. Livestock-feed relationships. U.S. Dept. Agr. Stat. Bull. p.45. 337; and Economic Research Service. 1965. Livestock-feed relationships. U.S. Dept. Agr. Stat. Bull. (Suppl.) 337. p. 17.

Table 4. Concentrate-consuming animal units, US, North Central Region, Corn Belt, and Iowa, 1949-1964.

	Year beginning October 1 (feeding year)[a]					
	1964	1963	1962	1961	1960	1959
	(thousands)					
Iowa	23,710	24,449	24,500	23,868	23,658	23,940
Corn Belt[b]	59,067	62,271	63,041	61,542	61,306	61,401
North Central Region[c]	95,891	100,485	101,223	99,222	98,626	98,043
U.S.[d]	167,664	172,259	172,801	168,986	167,557	165,748

[a] Year of reference relates to Oct. 1; e.g., 1963 here is Oct. 1, 1963, to Sept. 30, 1964.

[b] Corn Belt: Ohio, Indiana, Illinois, Iowa, and Missouri.

[c] N.C.: (Corn Belt, plus Michigan, Wisconsin, Minnesota, North Dakota, South Dakota, Nebraska, and Kansas.

[d] 48 states: data not available for Alaska and Hawaii.

Sources: Economic Research Service. 1964. Livestock-feed relationships. U.S. Dept. Agr. State. Bull. 337; Economic Research Service. 1965. Livestock-feed relationships. U.S. Dept. Agr. Stat. Bull. (Suppl.) 337; and Economic Research Service. 1961. Animal units of livestock fed annually, 1909 to 1960. U.S. Dept. Agr. Stat. Bull. 301.

is the census. Once the Census of Agriculture data format was made comparable to USDA animal unit calculation needs, the USDA calculation procedure could be followed by using census data.

Table 5 illustrates the state-level calculation for 1964, using the census as source data. An entry-by-entry explanation of the calculation elements appears elsewhere (Warrack, 1967, pp. 100-102).

After the number of livestock in each of the various classes have been obtained, they can be converted into numbers of grain- or concentrate-animal units. The factors used for this conversion are those given in table 3. With only three exceptions, Iowa factors were used in the calculations. The factors for "sheep and lambs on feed" and "broilers" are national figures. The refinement step that separated "cattle on feed" and "calves on feed" was undertaken in this research because it was expected that the former class would require more feed than the latter. High-quality steer calves (450 lbs = beginning weight) were estimated to require 53.6 bushels of corn equivalent while being fattened for market; similarly yearlings (675 lbs = beginning weight) were estimated to require 74.1 bushels of corn equivalent. Since the Iowa conversion factor for "cattle on feed" into animal units is 2.5, the conversion factor for "calves on feed" was estimated to be (53.6/74.1) (2.5) = 1.8.

The number of animal units from each of the 16 categories was computed. Then, the 16 animal unit figures were aggregated into an over-all scalar representing Iowa total. This is shown in table 5. The described procedure was also applied at the county level.

Feed Requirements

There are two important aspects of the calculated animal-unit figures. They are a basis for estimating feed required (demand for feed) and a basis for disaggregation of state totals into county estimates.

Table 5. Iowa calculation of animal units, 1964.

Livestock class	Source of calculation	Number of head	Conversion factor	Animal units	Variable name
A. On farms at census					
1. Milk cows	Direct from 1964 census[a]	735.6	1.2	382.8	M1COWS
2. Milk heifers and heifer calves	(212 + 233)/861 736	380.2	0.5	190.1	MH2HC
3. Beef cows	1983 - 736	1,247.1	0.4	498.8	B3COWS
4. Cattle on feed	(1731/7124) (7285) (3154/ (3154 + 387)	1,590.2	2.5	3,975.6	FINV4L
5. Calves on feed	(1731/7124) (7285) (357/ (3154 + 357)	179.9	1.8	323.8	FINV5S
6. Other cattle	Residual from 7285	3,151.9	0.3	945.6	OTH6
7. Horses and mules	Direct from 1959 census	81.1	1.4	113.6	H7M
8. Stock sheep	(900/1312) (1365)	936.3	0.05	46.8	ST8SH
9. Sheep on feed	(412/1312) (1365)	428.6	0.12	51.4	FD9SH
10. Chickens over 4 months	Direct from 1964 census	19,503.6	0.055	1,072.7	C10OLD
11. Turkeys for breeding	Direct from 1964 census	199.5	0.07	14.0	T11BR
12. Swine for breeding	Direct from 1964 census	1,959.0	0.75	1,469.3	SW12BR
B. Sold during year					
13. Broilers	Direct from 1964 census	1,906.4	0.008	15.3	BR13
14. Other chickens for slaughter	Direct from 1964 census	12,822.4	0.02	246.4	OC14SL
15. Turkeys raised	Direct from 1964 census	8,297.2	0.07	580.8	TUR15E
16. Hogs sold	Direct from 1964 census	19,883.0	0.75	14,912.3	HOG16S
TOTAL				25,349.3	TOTAL

[a] U.S. Department of Commerce. Bureau of the Census. 1965. 1964 U.S. Census of Agriculture. U.S. Gov. Print. Off. Washington, D.C.

The USDA annually derives a coefficient relating tons of feed required to animal units. Table 6 traces the magnitude of this coefficient from 1950-1964. Over time, there has been a general tendency to feed more concentrates per animal unit. Multiplying the coefficients by animal-unit calculations yields estimates of feed required. For the State of Iowa we have:

1964 : (25,349) (0.87) = 22,054

1959 : (24,074) (0.85) = 20,462

These figures are in thousands. The estimated Iowa demand for concentrate feeds expanded from nearly 20 1/2 million tons in 1959 to about 22 million tons in 1964. These estimates refer to complete feeds. The Appendix contains results for each livestock variable and each of Iowa's 99 counties.

The feed requirement or tons per animal unit is a USDA calculation based on "national data." The computation is a comparison with supply of feed—called the feed-balance calculation. The supply of concentrate feeds is the sum of quantity of feed grains produced, carryover stocks, quantity of by-product feeds, and feed in parts (Agricultural Research Service, 1957, p. 59). The supply is allocated to quantity fed to livestock, all other uses, and stocks to be carried over into the next year. When compared with supply of feed for livestock (i.e., after subtracting carryover stocks and other uses volume), animal-unit numbers allow calculation of a number-to-supply balance for any year. The feed supply for livestock is divided by the number of animal units to compute the tons-per-animal-unit feed requirements coefficient.

Disaggregation by Product Form

As has been noted previously, our demand estimates for feed in Iowa correspond closely to USDA estimates. These demand magnitudes refer to complete feeds. But, much commercial feed tonnage is in the form of supplements rather than complete feeds. In feed-grain surplus states, such as Iowa, the supplement-form fraction of total feed purchases is high.

Table 6. Concentrate feed fed per animal unit, 1950-64. [a]

Year	Tons per animal unit	Year	Tons per animal unit
1950	0.75	1958	0.83
1951	0.75	1959	0.85
1952	0.77	1960	0.89
1953	0.74	1961	0.91
1954	0.76	1962	0.92
1955	0.74	1963	0.89
1956	0.76	1964	0.87
1957	0.77		

[a] The coefficients are derived for the feeding year (beginning Oct. 1); thus, the calendar year figure cited here is that designated by the previous year's Oct. 1.

Sources: Economic Research Service. 1964. Livestock-feed relationships. U.S. Dept. Agr. Stat. Bull. 337; and Economic Research Service. 1967. Livestock-feed relationships. U.S. Dept. Agr. Stat. Bull. (Suppl.) 337.

Earlier, two product-form conclusions were documented; much of commercial mixed feed is supplement, and the fraction in Iowa is relatively high. The consequence of these conclusions is that some adjustment was imperative if realistic estimates of feed tonnage volumes were to be derived. The actual feed volumes are partly supplement and partly complete feed tonnages. A procedure was needed to disaggregate the previously-derived feed tonnage estimates into supplement feed tonnages and complete feed tonnages.

The commercial feed-tonnage data from the Iowa Department of Agriculture are separated between supplement and complete feeds for most classes of livestock. These data were used as a basis for disaggregating the estimates of our study into tonnages of supplement and complete feeds. The data for 1964 were calculated.

The basic idea was to convert Iowa Department of Agriculture data on supplement tonnages into complete feeds and add the results to complete feed tonnages reported; then, the proportions of this total of supplement "source" and complete feed "source" could be found and applied to the estimates of our study. As a consequence, the feed estimates of our study could be divided into complete feed and supplement "source," and the latter converted from complete to supplement feed tonnages. A major data requirement of this procedure is percentages of supplements in the respective rations of each of the 16 livestock classes for which feed tonnages were derived.

By using the preceding logic, the four basic procedural steps were 1) obtain ration coefficients for each of the 16 livestock classes, indicating the fraction of the total ration that should be supplement; 2) with these coefficients, transform the Iowa Department of Agriculture data into complete-feeds-only estimates; 3) with the derived complete-feed estimates for this Iowa data, disaggregate the estimates of our study into complete-feed and supplement-feed tonnages; and 4) sum the tonnages of these two product forms into one commercial mixed-feed tonnage estimate for our study. The result was a tonnage estimate for each of the 16 livestock classes for each county.

Comparability Adjustments and Final Tonnage Estimates

As a consequence of applying the procedural steps outlined, the state total feed estimate of 4,712,673 tons is separated into 1,422,660 tons of complete feed and 3,290,013 tons of supplement feed. It was noted earlier that the total feed-concentrate requirements estimated for Iowa corresponded very closely with those of the USDA. State-level data on feed requirements and (or) feed production and (or) feed purchases are available from several sources. These figures vary rather widely from one source to another, and attention should be given to reconciliation of the various estimates. The objective of this section is to examine and relate the feed estimates from several sources.

Data sources compared with our study were: 1964 Census of Agriculture figures on Iowa farmer purchases of commercially mixed feeds, millfeeds, and supplements; Current Industrial Reports on Poultry and Livestock Feed Production; and Iowa Department of Agriculture feed tonnage reports. All these sources differ in their estimates.

For two reasons, one can expect that the potential feed demand estimates suggested by our study are not entirely accessible demand for the commercial mixed-feeds industry. There are still livestock that are fed no feed of commercial source; these livestock numbers would enter into our study estimates, but none of the other three estimates. In addition, the rations used (and the supplement component of each ration) were based on recommended nutritional levels. These coefficients should be regarded as upper bounds; few farmers would feed beyond recommended levels, but it is likely that many would feed less. This reasoning would apply to total concentrates fed per animal unit and even more so to the proportion of the total ration that is supplement. It is, however, difficult to know by what magnitude the estimates should be adjusted.

The Census Bureau explicitly recognized that the Current Industrial Report's data should be regarded as low. There are two reasons for this: 1) they feel that it is likely that the coverage of their survey is incomplete and 2) the Standard Industrial Classification of manufacturing establishments is used.[7] (An establishment must be engaged primarily in the feed-manufacturing activity to be included.) Some establishments produce feed even though their primary activity is other than feed manufacturing.

The tonnage data compiled by the Iowa Department of Agriculture relates to taxed feed tonnage; that is, tonnage on which the inspection fee of 10 cents per ton is paid. It seems reasonable to expect a downward bias in these tonnage totals.

Finally, there may be some reason to consider Census of Agriculture data as minimums. It seems likely that a farmer would have a more accurate record of the number and kinds of livestock he has (revenue side) than feed purchases he has made during the year (cost side). It also seems reasonable to suppose that errors in reported livestock numbers might be normally distributed, but those relating to feed purchases might be skewed toward underestimation.

To fulfill the objectives of this research, a realistic set of estimates was needed to describe the feed demand that is accessible market demand for the commercial formula feeds industry. Estimates for each county were required. Qualitatively, it is clear that the feed estimates generated thus far in our study are high and that the estimates from each of the other three sources are low. The real question is "how much."

The problem would best have been resolved by surveying representative farms of representative counties to get more complete and detailed information. But that procedure was beyond the scope of available time and resources, so arbitrary adjustments were made. Complete and supplement feeds were treated separately. The adjusted estimate for complete feeds was taken to be 85 percent and, for supplements, 70 percent of the previously estimated tonnage to be supplied. Two 99 x 16 adjusted tonnage matrices were calculated, one for adjusted complete feed tonnages and the other for adjusted supplement feed tonnages.

The final adjusted matrix of tonnages per livestock class per county is found by summing the complete and supplement tonnage matrices. Table 7 presents the county totals and the state total of animal units, unadjusted complete and supplement feed tonnages, adjusted complete and supplement feed tonnages, and final estimated feed tonnages to be supplied. Table 8 contains state totals by livestock classes for the same six items as in table 7. The names of the 16 livestock variables correspond to those designated in table 5. Tonnages by livestock class for each county are given in the Appendix.

[7] SIC 2042, prepared animal and poultry feeds.

Iowa Transportation Matrix

Development of a road-mileage transportation matrix for Iowa was necessary for the analysis of distribution costs. Since both transportation and selling costs varied with distance, distance relationships were essential ingredients in computing distribution costs.

Between the 51 major population centers and each (of 99) county reference point, the surface distances (air miles) and "angle relationships" were measured. Road miles vary directly with each. It can be demonstrated that the angle relationships will never exceed 45 degrees.

A manipulation of trigonometric functions converts air miles to road miles by using the angle relationships:

$$\sin\theta = a/h;\ \text{so } a = h \sin\theta$$
$$\cos\theta = b/h;\ \text{so } b = h \cos\theta$$

where

a = road miles in one direction
b = road miles in the other
h = air miles
θ = angle

solving,

$$\text{road miles} = a + b = h \sin\theta + h \cos\theta$$

A computer program was written to accomplish the mathematical conversion.

Analysis of Transportation Costs

The Iowa transportation matrix developed contains a road mileage for every combination of potential plant site and node of county feed demand. The requirements of the model are to have every such combination expressed in terms of distribution costs, where distribution costs are transportation costs plus selling costs. Cost per mile times miles will yield the desired transportation dollar figure for each combination.

Table 7. Animal units, unadjusted complete and supplement feed tonnages, adjusted complete and supplement feed tonnages, and estimated tonnages to be supplied; by county and state.

County	Animal Units and Tonnages					
	AN units	UNADJ CF	UNADJ SF	ADJ CF	ADJ SF	Tonnage
Adair	231,209	12,581	29,085	10,694	20,359	31,053
Adams	148,723	8,127	18,533	6,908	12,973	19,881
Allamakee	219,940	12,510	29,473	10,633	20,631	31,265
Appanoose	89,740	4,430	10,813	3,765	7,569	11,335
Audubon	273,330	14,149	34,963	12,027	24,474	36,501
Benton	432,372	22,582	53,972	19,195	37,780	56,975
Black Hawk	287,220	17,024	38,984	14,470	27,289	41,759
Boone	233,698	14,069	31,627	11,959	22,139	34,098
Bremer	208,201	14,307	30,895	12,161	21,626	33,787
Buchanan	278,379	16,363	37,130	13,909	25,991	39,900
Buena Vista	313,608	18,406	41,599	15,645	29,119	44,764
Butler	282,808	17,968	39,235	15,273	27,464	42,737
Calhoun	206,711	11,542	26,889	9,811	18,822	28,633
Carroll	386,473	20,360	49,224	17,306	34,457	51,763
Cass	264,404	12,562	32,584	11,018	22,809	33,826
Cedar	466,301	24,540	57,666	20,859	40,366	61,225
Cerro Gordo	270,294	17,920	37,827	15,232	26,479	41,711
Cherokee	355,608	16,516	43,738	14,040	30,617	44,657
Chickasaw	223,310	14,525	31,589	12,346	22,112	34,459
Clarke	110,355	6,341	14,146	5,390	9,902	15,292
Clay	235,212	11,821	29,367	10,048	20,697	30,745
Clayton	345,961	19,871	46,151	16,890	32,306	49,196
Clinton	486,503	22,811	59,036	19,389	41,325	60,715
Crawford	377,018	20,211	48,329	17,179	33,830	51,010
Dallas	221,184	12,561	28,408	10,677	19,886	30,562
Davis	98,111	5,464	12,227	4,644	8,559	13,203
Decatur	92,873	4,756	11,420	4,043	7,994	12,037
Delaware	402,742	24,516	54,325	20,839	38,027	58,866
Des Moines	154,575	8,674	18,945	7,373	13,261	20,634
Dickinson	131,066	7,370	17,473	6,264	12,231	18,496
Dubuque	354,502	20,364	46,175	17,309	32,322	49,632
Emmet	130,164	6,819	16,676	5,796	11,673	17,469
Fayette	314,182	18,929	43,294	16,090	30,306	46,395
Floyd	209,144	13,483	29,309	11,461	20,516	31,977
Franklin	323,190	18,948	43,141	16,106	30,199	46,304
Fremont	100,982	4,530	12,701	3,850	8,891	12,741
Greene	207,089	10,921	26,052	9,283	18,236	27,519
Grundy	293,882	16,532	38,284	14,052	26,799	40,851
Guthrie	196,346	11,191	25,461	9,512	17,823	27,335
Hamilton	324,977	24,855	50,326	21,127	35,228	46,355
Hancock	275,332	18,306	39,095	15,560	27,366	42,927
Hardin	319,253	18,011	41,646	15,309	29,152	44,462
Harrison	183,113	8,788	22,267	7,470	15,587	23,057
Henry	222,123	15,175	31,210	12,899	21,847	34,746
Howard	179,323	11,909	25,653	10,123	17,957	28,080
Humboldt	172,824	9,760	22,689	8,296	15,882	24,178
Ida	285,760	14,632	36,358	12,437	25,451	37,888
Iowa	340,935	18,595	43,193	15,806	30,235	46,041
Jackson	290,088	14,290	35,840	12,146	25,088	37,234
Jasper	359,886	19,350	45,270	16,447	31,689	48,136
Jefferson	145,960	8,119	18,307	6,901	12,815	19,716
Johnson	371,119	23,308	49,706	19,812	34,794	54,606
Jones	376,063	18,985	46,695	16,137	32,686	48,824
Keokuk	303,480	18,474	39,673	15,703	27,771	43,474
Kossuth	403,134	24,573	54,847	20,887	38,393	59,280
Lee	161,188	9,278	20,609	7,886	14,426	22,313
Linn	307,020	18,065	39,210	15,355	27,447	42,802
Louisa	164,968	9,212	20,698	7,830	14,489	22,319
Lucas	101,807	5,913	13,183	5,026	9,228	14,254
Lyon	305,447	15,860	39,666	13,481	27,766	41,247
Madison	176,828	9,333	21,590	7,933	15,113	23,046
Mahaska	327,275	18,599	41,281	15,809	28,897	44,706
Marion	243,001	13,017	30,346	11,064	21,242	32,307
Marshall	279,712	13,348	34,183	11,346	23,928	35,274
Mills	157,109	6,883	18,754	5,851	13,128	18,978
Mitchell	250,832	15,245	34,707	12,958	24,295	37,253
Monona	172,360	8,760	21,239	7,446	14,867	22,313
Monroe	84,567	4,405	10,304	3,744	7,213	10,957
Montgomery	197,910	9,575	24,070	8,139	16,849	24,988
Muscatine	229,969	12,338	28,666	10,487	20,066	30,553
O'Brien	306,838	17,918	39,797	15,230	27,858	43,088
Osceola	177,197	9,502	23,199	8,077	16,239	24,316
Page	234,225	11,241	28,290	9,555	19,803	29,358
Palo Alto	208,279	11,425	26,937	9,711	18,856	28,567
Plymouth	550,372	30,134	70,830	25,614	49,581	75,195
Pocahontas	243,822	14,362	32,730	12,208	22,911	35,119
Polk	140,807	8,472	18,898	7,201	13,229	20,430
Pottawattamie	493,924	20,335	58,418	17,285	50,893	58,177
Poweshiek	272,300	14,528	34,002	12,349	23,801	36,150
Ringgold	124,949	6,448	15,306	5,481	10,714	16,195
Sac	347,981	17,003	43,320	14,453	30,324	44,777
Scott	311,669	17,246	39,660	14,659	27,762	42,421
Shelby	332,078	16,529	41,756	14,050	29,229	43,279
Sioux	577,225	29,381	73,560	24,974	51,492	76,466
Story	251,481	15,828	34,038	13,454	23,827	37,280
Tama	381,219	20,607	48,269	17,516	33,788	51,304
Taylor	154,969	8,155	19,191	6,932	13,434	20,365
Union	121,303	6,256	14,772	5,318	10,340	15,658
Van Buren	116,119	6,745	14,890	5,733	10,423	16,156
Wapello	107,366	5,890	13,330	5,006	9,331	14,337
Warren	164,287	9,493	21,285	8,069	14,899	22,969
Washington	408,660	27,408	56,502	23,297	29,551	62,848
Wayne	125,172	7,969	17,328	6,774	12,130	18,903
Webster	177,368	11,242	24,502	9,556	17,151	26,707
Winnebago	184,746	13,227	25,383	11,243	17,768	29,011
Winneshiek	332,960	20,702	46,388	17,597	32,472	50,068
Woodbury	377,456	20,953	51,460	17,810	36,022	53,832
Worth	177,162	12,877	24,421	10,945	17,095	28,040
Wright	248,411	16,628	33,327	14,304	23,329	37,633
IOWA TOTAL	25,349,120	1,422,660	3,290,013	1,209,260	2,303,009	3,512,269

Table 8. Animal units, unadjusted complete and supplement feed tonnages, adjusted complete and supplement feed tonnages, and estimated tonnages to be supplied by livestock class, state totals.

Livestock class	Animal units and tonnages					
	AN units	UNADJ CF	UNADJ SF	ADJ CF	ADJ SF	Tonnage
M1COWS[a]	882,776	27,550	148,093	23,417	103,665	127,082
MH2HC	190,106	5,933	17,939	5,043	12,557	17,600
B3COWS	498,840	0	21,700	0	15,190	15,190
FINV4L	3,975,562	48,481	405,480	41,209	283,836	325,045
FINV5S	323,759	3,948	34,799	3,356	24,359	27,715
OTH6	945,554	0	82,263	0	57,584	57,584
H7M	113,574	0	9,881	0	6,917	6,917
ST8SH	46,812	0	3,026	0	2,118	2,118
FD9SH	51,432	0	4,855	0	3,398	3,398
C10DLD	1,072,698	193,796	295,781	164,726	207,046	371,772
T11BR	13,967	2,144	3,502	1,823	2,451	4,274
SW12BR	1,469,264	88,974	209,195	75,628	146,437	222,065
BR13	15,251	13,268	0	11,278	0	11,278
OC14SL	256,447	46,330	70,711	39,381	49,498	88,879
TUR15R	580,806	89,197	145,636	75,818	101,946	177,764
HOG16S	14,912,270	903,037	1,837,151	767,582	1,286,005	2,053,587

[a] Livestock class corresponds to variables in table 5.

Motor transportation was emphasized in our study. Iowa law sets forth the regulatory framework within which trucks must operate. Costs depend upon equipment used, and the equipment alternatives must meet legal stipulations. At the time this research was undertaken the weight limitation was 73,280 pounds maximum. Tractor semitrailers could not exceed 55 feet in over-all length, while double-bottoms could not exceed 60 feet. The Iowa Motor Carrier Law (Iowa State Commerce Commission, 1966), administered by the Iowa State Commerce Commission, provides that motor carriers must obtain a permit to operate, and must file a table of rates (tariffs) to be charged for their services.

Per-Unit Cost Analysis

Two basic approaches are available for truck transportation cost analysis: a "cost" approach and a "revenue" approach. Both were used. The "cost" approach entails analyzing information based on cost surveys of trucking firms and feed companies that distribute their own products by truck. The other approach, where revenue to the carrier is cost to the feed manufacturer or distributor, involves sampling actual tariffs.

The revenue-approach analysis determined actual charges by trucking firms for moving feed. These actual charges were found by sampling tariffs on file with the Iowa State Commerce Commission. A cross-section of common carrier tariffs and contracts was examined. Costs per ton (or per hundredweight) were noted for each mileage category.

A set of 15 tariffs was examined, and data were recorded. Since feed manufacturers generally are large companies, we believed that they would be in a favorable position to bargain with truckers who haul feed. This seemed especially true inasmuch as the feed company is free to operate its own trucks if dissatisfied with the rates they obtain. Therefore, it did not seem reasonable to use simple averages to describe the feed company's available alternatives for transporting feed. The negotiation process was simulated by taking the lowest 20 percent of the tariff; that is, for each mileage category, the three lowest tariffs were selected, and the average was found. The average cost per ton was computed; assuming 18-ton loads, a cents-per-mile figure was computed for each mileage category.

Regressing costs per ton on miles indicated a linear relationship

$$CPT = 1.32 + 8.25 \text{ Miles } (R^2 = 0.989)$$

Cost per mile declined steeply at first, but became very flat after about 95 miles. A slight increase was noted at distances exceeding 360 miles.

A survey of feed companies yielded some truck-cost data for hauling feed. Usable data were obtained from 13 Iowa Companies. Cost and mileage data were obtained for the years 1962-63, 1963-64, and 1964-65. The results are summarized in table 9. For 1964, an average figure of 35.91 cents per mile would be found by

$$(1/2)(35.19) + (1/2)(36.63)$$

USDA truck cost studies have yielded results confirming the Iowa survey figures (Camp, 1964; Wright, 1964).

Determination of Transportation Costs

The procedure followed in determining truck transportation costs relied on results of both the cost- and revenue-approach analysis. The result is a 51 x 99 cost matrix in which each element gives the total transportation cost of a potential plant site serving the feed demand of a county. For example, the transportation cost of a Sioux City plant serving the feed needs of Carroll County would be one element; a similar figure is given in the matrix for each of the other 98 counties, and an analogous cost vector is presented for each of the other 50 potential plant sites.

Following the principle of choosing the least-cost method of moving feed, a cost-per-mile set of relationships was developed. The cost-approach survey of truck costs resulted in calculating an average cents-per-mile cost of 35.91. It seems reasonable to expect the feed company to own and operate trucks as long as ownership costs per mile are less than those available from trucking firms. Conceptually, one can visualize drawing a constant cost per mile line (at 35.91 cents) on a graph and selecting that cost for all mileages whose trucking rates exceed this figure. The lines would cross between 97 and 98 miles.

The resulting transportation cost per mile is 35.91 cents for distances between zero and 98 miles. Costs per mile then declined very slowly with greater distance, reaching 23.50 cents per mile at 360 miles and remaining constant thereafter.

The transportation cost per trip (per load of feed) could then be computed. Each element of the 51 x 99 road-mileage transportation matrix was multiplied by the appropriate cost per mile. The cost per load of feed was calculated for each potential plant location serving each Iowa county, thus:

Cost per mile per load x miles = cost per load.

The number of 18-ton loads necessary to serve each county's feed tonnage demand was then calculated:

Cost per load x no. of loads = total costs.

The final result was a 51 x 99 total transportation cost matrix indicating the total cost of transportation of the feed demand of each county from each potential plant site.

Table 9. Summary of feed company truck costs per mile in cents for Iowa.

	1962-63	1963-64	1964-65
Range	22.00-39.20	25.00-47.40	25.00-47.10
Average	32.51	35.19	36.63

Selling Costs

Very little research on the feed industry has included the analysis of sales expenses, but a recent feed industry cost study did consider sales expenses (Phillips, 1960). This study analyzed one firm size under four types of organization: premix, concentrate, complete, and retail-manufacturer feed production and distribution. A cross section of the last three types would be quite representative of the manufacturing organization for Iowa visualized in our study.

The per-ton sales expenses found in the Phillips' study were grouped into seven categories. The results are given in table 10. The costs are based on 1955 data obtained by survey of actual feed firms in the Midwest. The firm size considered was that of 40,000 tons per year. The respective averages for concentrate, complete, and retail-manufacturing operations were $4.77, $6.16, and $4.59. The average of these three figures is $5.17. Nearly all this feed was distributed to points within 100 miles of the manufacturing plant.

The cost level was adjusted upward to reflect the general pattern of rising costs since 1955. A per-ton sales expense differential of 16 percent was applied on the basis of changes in the consumer price index. With use of the base period 1957-59=100, the consumer price index (all items) rose from 93.3 in 1955 to 108.1 in 1964; the rate of increase was 15.97 percent (U.S. Dept. of Agr., 1966). Hence, it seemed reasonable to take $6.00 per ton as a cost figure for sales expenses. This figure would apply to selling feeds up to about 100 miles from the location of the plant.

The level of selling costs per ton was related to distance. Per-ton sales costs are expected to be higher as selling points are further removed from the feed manufacturing location. Available evidence suggests that some level of sales expense is necessary, however, even if strictly local markets are served. The Phillips' study (1960) showed that retail-manufacturers sold nearly 60 percent of their output within 25 miles of the plant (96 percent within 50 miles) and yet had sales expenses of $4.59 per ton; they spent a much higher percentage on advertising than did concentrate or complete-feed manufacturers. Seemingly, selling expenditures in the feed industry are incurred as follows: a certain cost level for advertising, bad debts, salesmen, telephone, and travel are necessary even though the sales area is small; then, as the sales area expands, heavier expenditures for salesmen (and their expenses) begin to dominate selling costs.

In the absence of detailed selling-cost data, a cost-distance relationship was assumed. A linear relationship between average selling costs per ton and distance was established by using $6.00 per ton at 100 miles distance and assuming the rate of cost change to be $1.00 per ton for each 100-mile change in distance. This placed the intercept at $5.00. Stated as a linear equation

$$Y = ax + b$$

the numerical relation became

$$AC = 0.01\ X + 5.00$$

where AC = sales cost per ton and where X= miles between plant and selling point. For example, the per-ton selling cost 300 miles removed from the plant location would be $8.00.

Table 10. Sales expenses in dollars per ton by type of expense for the feed manufacturing plants, by type of organization, 1955.

Expense item	Concentrate Av.	Concentrate Range	Complete Av.	Complete Range	Retail manufacturing Av.	Retail manufacturing Range
1. Supervision	0.44	0.34-0.62	0.36	0-0.99	0	0-0
2. Salesman	2.44	0.13-4.88	2.71	2.08-3.93	1.73	0.16-4.56
3. Travel and meetings	0.51	0.07-1.12	1.42	1.17-1.82	0.15	0.09-0.19
4. Bad debts	0.20	0-0.60	0.24	0.19-0.27	0.27	0-0.80
5. Telephone	0.09	0.07-0.11	0.13	0-0.21	0.19	0-0.58
6. Advertising	0.95	0.08-1.39	1.08	0.64-1.69	1.83	1.13-3.03
7. All others	0.34	0.09-0.53	0.29	0.11-0.47	0.41	0.02-0.88
Total	4.77		6.16		4.59	

Source: Phillips, Richard. 1960. Costs of procuring, manufacturing, and distributing mixed feeds in the Midwest. U.S. Dept. Agr. Market. Res. Rpt. 388.

FEED-MANUFACTURING COSTS AND COST-VOLUME RELATIONSHIPS

Manufacturing costs represent 6 to 10 percent of total costs of the feed industry (Schoeff, 1961, p. 17). Only ingredient costs and transportation costs are more important. Labor accounts for about half the cost of manufacturing a ton of feed. The feed industry is strongly aware of the importance of cost efficiency in the manufacturing process.

Available feed manufacturing cost studies have followed one of the basic approaches: economic-engineering or statistical. Most have used the former approach. It involves obtaining basic information and coefficients from feed manufacturers and applying industry and engineering standards to "build" a manufacturing unit and compute its costs. The statistical approach analyzes cost data by sample surveying of company cost records. Some of the problems inherent in each approach will be noted as various studies are reviewed. One general distinction is crucial: although the statistical approach seeks a positive description of actual feed-manufacturing costs, the objective of economic-engineering studies is to establish minimum attainable costs.

Long-run average costs for manufacturing feed for both single- and double-shift operations were estimated by using the economic-engineering methods. A range of plant sizes was examined for each. A synthesis of several feed manufacturing cost studies was undertaken. The final result is a long-run average cost function for single-shift operations and another for double-shift operations. The corresponding long-run total cost functions were derived. A 260-day-per-year operation was assumed, which is comparable to other studies of the feed industry.

A comprehensive study on economies of scale in feed manufacturing was undertaken at the University of New Hampshire, with the University of Massachusetts and the USDA cooperating (Burbee *et al.*, 1965). Poultry feeds were emphasized in this economic-engineering cost study. Costs for eight model mills were developed. The mill volumes were: 20.9, 41.8, 62.7, 83.6, 125.4, 174.2, 261.3, and 348.4 tons per day.[8] The yearly volumes range from 5,434 to 90,577 tons. The cost sources were grouped into six classes: labor inputs and cost, investment and costs for feed manufacturing facilities, ownership costs, administrative and supervisory personnel costs, utility costs, and other costs.

Most feed-manufacturing cost studies have tended to emphasize labor costs and compare labor requirements with some standard as a proxy for comparing plant-production efficiency. In the New England study, the labor force consisted of production workers who perform the several manufacturing processes plus maintenance and general repairs. The man-hours per ton ranged from 1.00 to 0.16 between the smallest and largest of the eight model mills. The wage rate per hour for production and maintenance personnel was $1.85 plus 37 cents fringe benefits and $2.00 plus 40 cents fringe benefits, respectively. Combined labor cost per ton, from smallest to largest, ranged from $2.26 to 36 cents. Variable costs, such as equipment repair and service, mill supplies, inventory (interest on investment and insurance), and shrinkage of 1/4 of 1 percent (loss of moisture and losses of ingredients due to unloading, handling, storing, loading, etc.), were charged under "other costs."

Investment for feed manufacturing facilities included equipment and the physical plant (mill and storage building facilities). Equipment items required were synthesized from input-output relationships and manufacturer's equipment specifications. Delivered equipment costs and installation costs were determined. Physical-plant costs were treated similarly. Land-requirement estimates were obtained from physical-layout drawings and charged at $5,000 per acre. Two major ownership costs were depreciation (due to time, wear, and obsolescence on the physical plant and equipment facilities) and interest on investment (6 percent of equipment, buildings, and land values). Other ownership costs were property taxes, insurance, and fixed maintenance costs (to keep buildings, equipment, and facilities in operating condition).

A number of administrative and supervisory functions must be performed to insure accurate records, coordination, and production control. These specific functions include management, ingredient purchasing, nutrition and ration formulation, quality control, bookkeeping, and supervision of personnel. There are some miscellaneous fixed costs accounted for in the study; these costs include registration and analysis fees, audit and legal fees, management travel costs, and so forth.

[8] The uneven tonnage sizes result from coordinating model mill sizes with poultry-processing sizes, thus facilitating the over-all study of integrated operations.

Total cost per ton decreases monotonically from the smallest to the largest model mill. The results of this study were supplemented and modified to represent the Iowa (Midwest) feed manufacturing situation. Specifically, feed-ingredient receiving and packing cost results were added, and warehousing costs were modified.

U.S. Department of Agriculture Studies

The U.S. Department of Agriculture has conducted a series of feed-manufacturing cost analyses on industry-defined cost centers. The industry has delineated seven: ingredient receiving, grain processing, mixing, pelleting, packing, warehousing, and maintenance. The activities conducted in each of these cost centers are detailed elsewhere (Warrack, 1967, pp. 151-2). In a USDA study series, the maintenance cost center was not considered separately. Four of the six reports were based on 80- and 200-ton per day mill sizes. Double shifts also were considered. Each report details labor and equipment requirements, investment and operating costs, and standards for labor and equipment usage. The USDA researchers believed the cost standards used are attainable by nearly all plant managers.

Ingredient-Receiving Costs

Costs of receiving and handling feed ingredients were studied for 80- and 200-ton per day plants (Vosloh, 1965a). It was assumed that 80 percent of incoming ingredients would be bulk, with the remainder in bags.

The receiving center should handle about the same tonnage per day as the quantity of mixed feed manufactured. Labor was classified as production and supervisory, and industry performance standards were assumed. The production-labor wage rate assumed was $2.05 per hour, and $2.50 per hour was used for supervisory labor. For maintenance workers, $2.35 per hour was assumed. An increment of 10 cents per hour was added for all laborers working night shifts. The straight-line method was used for depreciation, and 3-percent interest was charged each year on total capital investment in equipment.

Operating two shifts per day allows fixed costs to be spread over a greater output volume. Variable costs, primarily labor, became a greater part of total costs. By operating two 8-hour shifts, costs per ton are reduced from 64 cents to 50 cents for the smaller plant and from 50 cents to 41 cents in the larger. One recommendation of the study was that plant managers consider operating more than one shift as an alternative to more automation.

Processing Costs

Particle reduction is an important operation. An important assumption was that 60 percent of a feed plant's output is routed through the processing center for grinding, crimping, or cracking before mixing. The respective quantities to be processed are 45 and 120 tons (Vosloh, 1965b).

Day-shift operating costs were handled in a manner exactly analogous to the receiving center. The same wage rates were used. The resulting costs were 85 cents per ton of material processed by the smaller plant and 61 cents for the larger. The second (night) shift was not dealt with specifically. One more adjustment was necessary since it was desired to state cost of processing in terms of the plant's total feed output; the cost per ton of feed output is 60 percent of the cost per ton of ingredient materials actually processed.

Mixing Costs

Industry-established standards for labor and equipment were followed in studying mixing costs (Vosloh, 1962). Wage rates are somewhat low because the study was completed a few years ago. Depreciation and interest were charged as before.

The results show that per-ton mixing costs can be reduced by operating larger plants and (or) more than one shift per day. On a one-shift basis, the 200-ton plant (52,000 tons per year) mixes for 63 cents, and the 80-ton plant (20,800 tons per year) cost is 80 cents per ton. The respective double-shift mixing cost results are 55 cents and 70 cents per ton.

Packing Costs

The fourth USDA report, which followed the 80-ton and 200-ton per day size format, dealt with packing mixed feeds (Vosloh, 1964). An assumption was that plants package 80 percent of the mixed feed production, while the other 20 percent is bulk mixed feed. Labor wage rates used for production, supervisors, and maintenance, respectively, were \$1.86, \$2.50, and \$2.25 per hour for day shift and 10-cent increment for night. Equipment, depreciation, and interest were handled as before.

The daily tonnage packed in the respective model mills would be 64 and 160 tons per shift. The cost results show that it costs less per ton to package feeds in the larger plant as compared with the smaller; moreover, costs per ton are reduced when more than one shift is operated. An adjustment was made to permit stating cost per ton of total feed rather than per ton of feed packaged.

Based on 64 tons per day, the single-shift unit cost was 39.3 cents; the double-shift unit cost was 36.6 cents. In the larger model, these costs per ton packaged were 29.8 and 27.1 cents. Eighty percent of each cost figure would reflect cost per ton of plant feed output. These are 31.5, 29.3, 23.8, and 21.7 cents, respectively.

Pelleting Costs

Pelleting of feed is a process by which premixed dry feeds (mash) are formed into relatively hard pellets of various sizes. The pellet form offers some advantages over mash: increased livestock gains, less farmer labor, less waste, less dust, and greater density, allowing greater tonnage for a given space. The USDA study reviewed here examines a pelleting model for a small feed manufacturing plant and gives cursory consideration to a larger one (Vosloh, 1961).

An annual pelleting capacity of 7,800 tons (30 tons per day) was assumed for detailed cost analysis. Such a size might "harmonize" quite well with an 80-ton feed manufacturing model mill.

Equipment, depreciation, and interest costs were handled as before. Production labor was assumed to be paid \$2.07 per hour, and supervisory labor was charged at \$702 per year or 9 cents per ton. The report concluded that a larger pelleting cost center (say twice as large) would require twice the equipment expenditure but only the same amount of labor. Hence labor costs per ton would be halved.

Only one-shift operations were considered in the report. An adaptation of the cost results allowed an approximation of two-shift costs; labor costs were more than doubled, while depreciation and interest costs were halved. The adapted results are: \$2.32 per ton pelleted (\$0.87 per ton of feed output) in the small single-shift model and \$2.19 and \$0.82, respectively, for small double-shift model; \$2.11 per ton pelleted (\$0.79 per ton of feed output) in the large single-shift model and \$1.96 and \$0.74, respectively, for the large double-shift operation. The two pelleting models are assumed to correspond roughly with the two model mill sizes (80 and 200 ton) studied by USDA researchers. The cost results were based on tonnages pelleted; thus, an adjustment was necessary if costs were to be stated in terms of total plant feed output.

Warehousing Costs

The emphasis in each of the two USDA studies was labor time and costs (Askew *et al.*, 1957; Brensike, 1958). In both, the results represent analysis of a case study of six plants having a daily volume of 100 tons.

USDA researchers found that the total warehouse cost per ton of feed shipped was \$1.58, with 69 percent of total warehouse operating costs accounted for by labor. The cost per ton of feed produced was \$1.47; some feed bypasses the warehouse.

Warehousing cost standards developed by the industry indicate that an 80-ton-per-day plant should need 0.309 man-hours per ton and that a 200-ton plant should require 0.264 hours of labor per ton. At \$2.30 per hour, these respective labor costs would be 71 and 61 cents—far less than the actual cost reported in the USDA studies. If labor costs represent 69 percent of the total warehousing costs, the respective total warehouse costs would be \$1.03 and \$0.88 per ton. A major conclusion of the warehouse cost studies was that labor efficiency generally could be improved by about one-third.

Resume of results

The numerical results of the six USDA cost center studies are reported in table 11. In addition, each column of reported results is updated to 1964.

Table 11. Synthesis of USDA cost results[a] and adjustments to 1964, dollars per ton.

Cost Center	One shift				Two shifts			
	80 ton (20800)		200 ton (52000)		80 ton (41600)		200 ton (104000)	
	USDA	Adjusted to 1964	USDA	Adjusted to 1964	USDA	Adjusted to 1964	USDA	Adjusted to 1964
Ingredient receiving	0.64	0.67	0.50	0.53	0.50	0.53	0.41	0.44
Processing	0.51	0.52	0.37	0.37	0.46	0.46	0.32	0.32
Mining	0.80	0.87	0.63	0.67	0.70	0.77	0.55	0.59
Packing	0.32	0.36	0.26	0.27	0.29	0.34	0.22	0.26
Pelleting	0.87	0.90	0.79	0.81	0.82	0.86	0.74	0.75
Warehousing[b]	1.03	1.03	0.80	0.88	1.03	1.03	0.88	0.88
Total cost		4.35		3.53		3.99		3.24

[a] USDA results were taken from the published reports cited previously: Vosloh (1961, 1962, 1964, 1965a, 1965b), Askew (1957), Brensike (1958).

[b] Constant per-ton costs with increasing shifts implicitly assumes that additional labor costs are exactly offset by decreasing fixed costs per ton.

Labor costs have tended to rise over the years so most of the reports had to be updated with reference to labor costs. Labor costs were adjusted to 1964 wage levels, assumed to be $2.30 per hour for production workers and $2.80 per hour for supervisors in Iowa. A 15-cent increment was assumed for the night shift. All these figures include fringe benefits worth roughly 40 cents per hour.

Single-Shift Cost Synthesis

The Burbee *et al.* (1965) study, reviewed in detail earlier, was used as a benchmark for synthesizing a cost-volume relationship that would represent the Iowa feed-manufacturing situation. Several adjustments were necessary. The study referred to bulk feeds exclusively; since packaged feeds are very important in Iowa, packing costs had to be added. Wage rates had to be adjusted. Supplemental warehouse labor and supervision had to be added under the thesis that bagged feeds require more warehousing labor than bulk feeds. Finally, an ingredient-procurement cost category was developed. A total of 14 manufacturing and manufacturing-related cost categories were developed.

Comparison of synthesized cost results (table 12) with USDA results (table 11) suggests that the cost levels are realistic. A detailed comparison and explanation of adjustments is given by Warrack (1967, pp. 168-170).

Figure 3 illustrates the synthesized long-run average cost function. Eight observations representing the total manufacturing cost function are regressed on volume. The total cost function seemingly can be represented as linear. The linear equation is:

$$\text{Total Costs} = 53202.5 + 4.74084 \text{ Volume}$$
$$(R^2 = 0.994)$$

Economies of scale exist for all sizes of plants, but cost decreases are moderate after a scale of 60,000 tons is reached.

Double-Shift Cost Synthesis

Numerous suggestions that feed manufacturing plants be operated more than one shift per day have been made. These recommendations are based on cost analyses. The synthesized single-shift cost estimates of our study were used as a basis for obtaining double-shift cost estimates. In deriving double-shift estimates, single-shift estimates were handled in four basic ways, depending upon the cost element. As output doubles (per 24-hour day or per year), some per-ton cost elements would remain invariant, while some fixed cost elements would be halved. Other cost elements would increase per ton. Still other costs per ton would decrease, but the decrease would be less than half.

Cost per ton related to utilities, equipment repairs and services, mill supplies, inventory, shrink, and ingredient procurement would not be expected to vary with the number of shifts operated.

The variable costs per ton that would be expected to increase are those related to labor and labor supervision. A 15-cent increment for the night shift was assumed; the respective wage rates for labor and supervision thus became $2.45 and $2.95 per hour. By using procedures analogous to developing single-shift estimates, average costs for the night shift were developed. The next step was to find over-all average costs by averaging the day and night shift results. Take the variable labor cost

Table 12. Single-shift long-run average costs per ton for 8 model plant sizes.

Costs	Model number:	1	2	3	4	5	6	7	8
	Daily tonnage:	20.9	41.8	62.7	83.6	125.4	174.2	261.3	348.4
	Yearly tonnage:	5,434	10,868	16,302	21,739	32,609	45,287	67,993	90,577
A. Variable costs					(dollars per ton)				
1. Labor, production and maintenance		2.26	1.80	1.62	1.05	0.77	0.51	0.40	0.37
2. Utilities		0.82	0.77	0.75	0.73	0.77	0.69	0.70	0.67
3. Equipment repairs and services		0.63	0.51	0.44	0.56	0.43	0.42	0.40	0.36
4. Mill supplies		0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
5. Inventory costs		0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
6. Shrink		0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Variable cost subtotal[a]		4.04	3.42	3.15	2.67	2.32	1.96	1.83	1.74
B. Fixed costs									
1. Ownership costs		2.78	2.18	1.90	2.34	1.85	1.76	1.62	1.50
2. Administrative and supervisory		1.44	1.16	0.98	0.91	0.86	0.76	0.66	0.60
3. Miscellaneous		0.34	0.29	0.26	0.24	0.21	0.19	0.18	0.17
Fixed cost subtotal[a]		4.55	3.62	3.14	3.50	2.91	2.71	2.47	2.27
C. Added costs									
1. Labor cost differential		0.08	0.07	0.06	0.04	0.03	0.02	0.01	0.01
2. Packing costs		0.41	0.39	0.38	0.36	0.33	0.29	0.25	0.18
3. Additional warehouse labor		1.34	1.34	0.98	0.62	0.62	0.58	0.53	0.53
4. Additional warehouse supervision		0.09	0.09	0.07	0.06	0.06	0.06	0.06	0.06
5. Ingredient procurement		0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Added cost subtotal[a]		2.34	2.31	1.91	1.50	1.46	1.37	1.27	1.20
Total costs per ton		10.93	9.36	8.20	7.67	6.69	6.05	5.57	5.21

[a] May not add because of rounding.

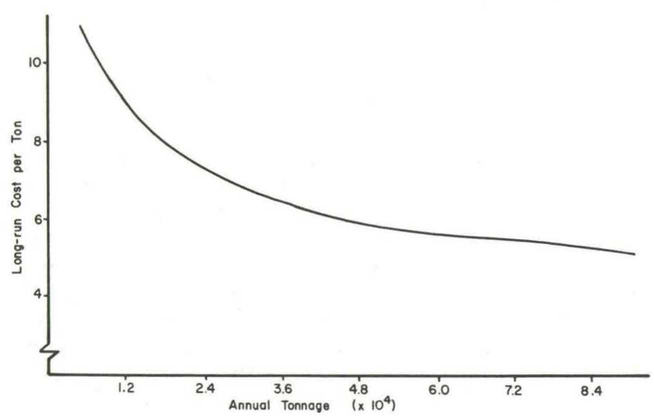


Fig. 3. Long-run average cost function, single-shift synthesis.

of the smallest plant as an example: The single-shift cost was $2.26 per ton, while the double-shift was $2.42; the combined average cost per ton is $2.34. The costs of operating a plant for a day shift and a night shift were obtained in this way.

Table 13 presents the cost results for a two-shift operation for the eight model plants. The cost entries correspond to those of table 12.

Some fixed costs per ton could be halved by operating 16 hours per day instead of 8. These would include such cost sources as mill building, office, land, and executive personnel. But, some costs regarded as fixed for rate of output would not be fixed as hours of operation are varied; these are costs related to ingredient and output materials: warehouse, grain storage, and finished-feed holding facilities. For these three physical-plant facili-

Table 13. Double-shift average costs per ton for 8 model plant sizes.

Costs	Model number:	1	2	3	4	5	6	7	8
	Daily tonnage:	41.8	83.6	125.4	167.2	250.8	348.4	522.6	696.8
	Yearly tonnage:	10,868	21,736	32,604	43,478	65,218	90,577	135,986	181,154
A. Variable costs					(dollars per ton)				
1. Labor, production and maintenance		2.34	1.87	1.67	1.09	0.80	0.53	0.42	0.39
2. Utilities		0.82	0.77	0.75	0.73	0.77	0.69	0.70	0.67
3. Equipment repairs and services		0.63	0.51	0.44	0.56	0.43	0.42	0.40	0.36
4. Mill supplies		0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
5. Inventory costs		0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
6. Shrink		0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Variable cost subtotal		4.13	3.49	3.20	2.72	2.34	1.98	1.86	1.76
B. Fixed costs									
1. Ownership costs		1.61	1.26	1.09	1.35	1.06	1.01	0.94	0.86
2. Administrative and supervisory		0.72	0.58	0.49	0.46	0.43	0.38	0.33	0.30
3. Miscellaneous		0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.09
Fixed cost subtotal		2.50	1.99	1.71	1.93	1.60	1.49	1.36	1.25
C. Added costs									
1. Labor cost differential		0.16	0.13	0.12	0.08	0.06	0.04	0.03	0.03
2. Packing cost center		0.40	0.38	0.37	0.35	0.32	0.28	0.25	0.18
3. Additional warehouse labor		1.43	1.43	1.04	0.66	0.66	0.62	0.56	0.56
4. Additional warehouse supervision		0.10	0.10	0.07	0.06	0.06	0.06	0.06	0.06
5. Ingredient procurement		0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Added cost subtotal		2.51	2.46	2.02	1.57	1.52	1.42	1.32	1.25
Total costs per ton		9.14	7.94	6.93	6.22	5.46	4.89	4.54	4.26

ties, it was assumed that double investment was needed to permit double production through double-shifting.

Depreciation is loss of value due to time, obsolescence, and wear. Although most cost studies halve equipment costs when considering two shifts, it would seem that equipment will wear more when operated 16 rather than 8 hours per day. *A fortiori*, time and obsolescence, relative to wear, would become less important sources of depreciation cost. It was assumed that equipment life was shortened 25 percent by the added stress and wear of the second shift. The computational consequence was that fixed equipment costs per ton of output were cut by one-quarter rather than by half by operating two shifts. This alternative assumption regarding equipment had an important effect on costs since equipment represented over half the total investment in each model plant size.

The composite of these fixed cost considerations is shown as ownership costs in tables 12 and 13. The magnitude of these costs in table 13 exceeds half the magnitude of the corresponding entries in table 12. As before, the over-all average cost figures were obtained by averaging the cost magnitudes of the two shifts.

If the double-shift cost results were graphed, the shape of the cost-volume curve would resemble that of the single-shift synthesis. The total cost function for double-shift synthesis was also linear. The regression equation is

$$\text{Total costs} = 90{,}064.25 + 3.84544 \text{ Volume} \quad (R^2 = 0.995)$$

For volumes exceeding about 50,000 tons annually, lower average costs can be achieved by operating two shifts, but for smaller sizes, single-shift costs per ton are lower. This implication conflicts with blanket recommendations favoring multiple shifts.

MODEL SOLUTION AND APPLICATION

In this section, the long-run spatial model is applied empirically, and the results are presented. The model's major data components were detailed previously. Two basic approaches are followed in the empirical solution: the iterative-expansion approach and the iterative-elimination approach. Each requires the minimization of total distribution costs with respect to location patterns, and both require the computation of total manufacturing costs with respect to number of locations. These two costs are then summed in both approaches to obtain a combined total cost function to be minimized with respect to the number of locations.

The procedure includes minimizing distribution costs with respect to location patterns for each possible number of potential plant locations.[9] With 40 potential plant locations, minimizing distribution costs with respect to location patterns would entail computing

$40C_1, 40C_2, ..., 40C_{39}, 40C_{40}$.

For each, manufacturing costs are added to minimized distribution costs to obtain total combined costs.

Computational cost considerations made it impossible to follow the model's optimization procedure precisely. For example, some experimentation with the model revealed that only two combinations per second could be computed on the "high" end—$40C_{37}$ would take about 85 minutes to compute, and $40C_{36}$ would take about 765 minutes. On the "low" end, about 31 combinations per second could be computed; yet $40C_4$ would take about 50 minutes to compute. Consequently, suboptimization procedures were developed.

Suboptimization Procedures

Iterative-Elimination Approach

This suboptimization procedure involved working from the "high" end; that is, computing $40C_{40}$, $40C_{39}$, $40C_{38}$, etc. If a plant was eliminated by the model on two sucessive runs, it was permanently removed. For example, if Clinton was eliminated by computing $40C_{39}$, and it was one of two sites eliminated in the $40C_{38}$ computation, then Clinton was permanently removed as a production site and the next computing step was based upon 39 potential plant locations. Continuing, if the site removed by $39C_{38}$ was one of two removed by $39C_{37}$, that potential plant location was removed from consideration. In each step, manufacturing costs and total combined costs were computed. The procedure was continued as long as the total combined cost function decreased with each decrease in number of plant locations. Eventually a total combined cost function minimum was reached. Then combined costs rose with further decreases in plant location numbers.

Once total combined costs began to rise, it was not necessary to program further calculations. Actually, three further steps were programmed to check for total combined cost function convexity in the neighborhood of the suboptimization solution. The convexity was confirmed. Three computations on the "low" end were also performed ($40C_1$, $40C_2$, and $40C_3$) because it was relatively inexpensive to obtain this information.

As the number of locations increases, total minimized distribution costs decrease sharply when only a few locations are considered. But as the number of locations considered becomes large, the slope of the total minimized distribution cost function becomes small.

The empirical results confirm two important assumptions of the model. The signs of all first differences were negative.

$\Delta TDC^{min} / \Delta J < 0$

and all second differences were positive

$\Delta^2 TDC^{min} / \Delta J^2 \geqslant 0$

The numerical cost results are presented in table 14. The table also contains the manufacturing and combined cost (minimized distribution plus manufacturing) results for both single- and double-shift applications.

Iterative-Expansion Approach

With one important exception, the basic solution procedure is the same for the iterative-expansion approach as for the iterative-elimination approach. The exception is that the minimized distribution cost calculations are subject to an additional constraint —locations previously selected by the model are

Table 14. Iterative-elimination approach: minimized total distribution costs, single-shift and multi-shift manufacturing costs, and respective total combined costs.

Number of plants	Minimized dist'n costs	Single-shift mfg. costs	Multi-shift mfg. costs	Combined costs (single)	Combined costs (multi)
	(thousands of dollars)				
1	37,323	16,704	13,596	54,028	50,920
2	32,415	16,757	13,686	49,172	46,101
3	30,050	16,811	13,776	46,861	43,827
•	•	•	•	•	•
•	•	•	•	•	•
•	•	•	•	•	•
22	22,074	17,822	15,488	39,895	37,562
23	21,975	17,874	15,578	39,850	37,552
24	21,878	17,928	15,668	39,806	37,546
25	21,788	17,981	15,758	39,769	37,546
26	21,703	18,034	15,848	39,737	37,551
27	21,621	18,088	15,938	39,709	37,559
28	21,545	18,141	16,028	39,686	37,573
29	21,483	18,194	16,118	39,677	37,601
30	21,432	18,247	16,208	39,679	37,640
31	21,383	18,300	16,298	39,683	37,681
32	21,337	18,354	16,388	39,690	37,725
33	21,296	18,407	16,478	39,702	37,774
34	21,255	18,460	16,568	39,715	37,824
35	21,216	18,513	16,658	39,729	37,874
36	21,184	18,566	16,749	39,750	37,932
37	21,157	18,620	16,839	39,776	37,995
38	21,135	18,673	16,929	39,808	38,063
39	21,114	18,726	17,019	39,840	38,132
40	21,102	18,779	17,109	39,881	38,210

[9] Eleven of the original 51 potential plant locations were eliminated: Boone, Independence, Keokuk, Knoxville, Maquoketa, Mt. Pleasant, Pella, Perry, Red Oak, Shenandoah, and Washington.

retained. Additional plants are located as well as possible given that previous locations are retained. Distribution costs were calculated for each number of plants from 1 through 40. Then feed manufacturing costs were added to obtain the total combined cost function.

For a given number of plant locations, the number of location pattern alternatives in the iterative-expansion approach to the long-run spatial model is a fraction of the alternatives in the iterative-elimination approach. Model computing costs are related directly to the number of location pattern alternatives. In the iterative-elimination approach, each conceivable combination represents a possible location pattern—an exceedingly high number in most instances. The number of possible location patterns in the iterative-expansion approach equals only the number of potential plant locations not yet selected. Therefore, the iterative-expansion was relatively inexpensive to compute.

The iterative-expansion approach, like the iterative-elimination process, is a suboptimization procedure. Not all possibilities are computed in the sense of the basic model. This approach was applied empirically to the set of 40 potential plant locations described earlier. The full range of calculations was performed since it was relatively inexpensive to do so. The numerical results are presented in table 15.

Feed-Manufacturing Costs in Relation to Number of Plants

Total manufacturing costs were computed for each number of plant locations considered using both suboptimization procedures. In each approach, the single- and multi-shift manufacturing costs were calculated. The results were obtained by using the estimated cost equations derived earlier.

The nature of the feed-manufacturing cost calculations was established by minimizing the distribution costs with respect to the plant location pattern. For any given number of plant locations, the minimized total distribution cost function established which locations should serve each county's feed demand, giving the tonnage to be manufactured at each location. Then, the linear cost equations were used to estimate total manufacturing costs.

When few locations were considered, application of the estimated manufacturing cost functions involved extrapolating beyond the volume ranges used in the estimations. Extrapolating the linear total cost function implies that economies of scale are never exhausted, but that the rate of decrease in the long-run average cost function becomes very small. The average cost functions become nearly constant at volumes not greatly beyond the maximum volumes used in the regression estimations. Comparing the rate of average cost decrease with the extrapolated rate of plant volume size increase, a 1/2-cent decrease per 1,000-ton size increase is reached at 110,000 tons annually for the single-shift cost function. The 1/4-cent rate of decrease is reached at 150,000 tons. For the multi-shift cost function, a 1/2-cent decrease per 1,000-ton size increase is reached at 140,000 tons annually. At 200,000 tons the 1/4-cent rate of decrease is reached.

The most extreme case possible in the model is for one plant location to serve the entire estimated Iowa feed demand of 3.5 million tons. It seems extreme to visualize a feed manufacturing establishment this large. It is more realistic to suppose that several separate plants would be established. Among single-shift operations, there might be 32 plants (each of 110,000 tons annual capacity) if the 1/2-cent per 1,000 tons rate of average cost decrease is accepted as representing constancy. If the 1/4-cent rate is regarded as average cost constancy, there might be 23 plants with a capacity of 150,000 tons annually. The respective results for multi-shift operations might suggest 25 plants

Table 15. Iterative-expansion approach: minimized total distribution costs, single-shift and multi-shift manufacturing costs, and respective total combined costs.

Number of plants	Minimized distribution costs	Single-shift mfg. costs	Multi-shift mfg. costs	Combined costs (single)	Combined costs (multi)
	(thousands of dollars)				
1	37,323	16,704	13,596	54,028	50,920
2	32,796	16,757	13,686	49,554	46,483
3	30,317	16,811	13,776	47,128	44,094
4	28,836	16,864	13,866	45,700	42,703
5	27,384	16,917	13,957	44,301	41,341
6	26,646	16,970	14,047	43,616	40,693
7	25,988	17,024	14,137	43,011	40,124
8	25,393	17,077	14,227	42,469	39,619
9	24,282	17,130	14,317	41,958	39,145
10	24,469	17,183	14,407	41,652	38,876
11	24,139	17,236	14,497	41,376	38,636
12	23,848	17,290	14,587	41,138	38,435
13	23,570	17,343	14,677	40,912	38,247
14	23,336	17,396	14,767	40,732	38,104
15	23,127	17,449	14,857	40,576	37,984
16	22,923	17,502	14,947	40,425	37,870
17	22,773	17,556	15,037	40,329	37,811
18	22,624	17,609	15,127	40,233	37,752
19	22,478	17,662	15,217	40,140	37,695
20	22,335	17,715	15,308	40,050	37,642
21	22,198	17,768	15,398	39,966	37,595
22	22,091	17,822	15,488	39,912	37,579
23	21,992	17,875	15,578	39,867	37,570
24	21,896	17,928	15,668	39,824	37,564
25	21,806	17,981	15,758	39,787	37,563
26	21,717	18,034	15,848	39,752	37,565
27	21,630	18,088	15,938	39,718	37,568
28	21,545	18,141	16,028	39,686	37,573
29	21,483	18,194	16,118	39,677	37,601
30	21,432	18,247	16,208	39,679	37,740
31	21,383	18,300	16,298	39,683	37,681
32	21,337	18,354	16,388	39,690	37,725
33	21,296	18,407	16,478	39,702	37,774
34	21,255	18,460	16,568	39,715	37,824
35	21,216	18,513	16,658	39,729	37,874
36	21,184	18,566	16,749	39,750	37,932
37	21,157	18,620	16,839	39,776	37,995
38	21,135	18,673	16,929	39,808	38,063
39	21,114	18,726	17,019	39,840	38,132
40	21,102	18,779	17,109	39,881	38,210

of 140,000 tons annual capacity or 18 200,000-ton-plants. Of course, some combination of single- and multi-shift operations would be possible.

Total Combined Costs with Respect to Number of Plants

The total combined cost function was obtained by vertical summation of the minimized total distribution function and the total manufacturing cost function. Each of the three functions varies with number of potential plant locations. The solution for the long-run spatial model is the minimum point on the total combined cost function. The distribution cost function is negatively sloped, while the manufacturing cost function has a positive slope. As long as the absolute value of the slope of the distribution cost function exceeded the slope of the manufacturing cost function, the combined cost function decreased with respect to plant location numbers. The converse is also true. The combined cost function was at a minimum when the absolute values of the two slopes were equal; that is,

$$\beta_D = \beta_M$$

where the betas are the respective slope magnitudes.

Iterative-Elimination Approach Solutions

Figure 4 is a graph of the numerical results in table 14. The table gives a single-shift and multi-shift solution. The solution to the single-shift combinations approach is 29 plant locations. For 29 plants the minimized total distribution costs were $21,483,200, while the accompanying total manufacturing costs were $18,193,952. The total combined costs were $39,677,152. The per-ton combined cost was $11.30 for the single-shift solution to supply the estimated feed tonnage of 3,512,269 tons for Iowa. The breakdown was $6.12 per ton for manufacturing and $5.18 for distribution.

Figure 4 illustrates that the total combined cost function for multi-shift operations lies below that for single-shift operations. Since the total manufacturing cost function slopes differ, the solution differs. The total combined-cost minimum for multi-shift operations was reached at 25 plants. Minimized total distribution costs for the 25-plant solution were $21,788,016. Multi-shift total manufacturing costs were $15,757,821. The total combined costs to manufacture and distribute 3,512,269 tons of feed would be $37,545,824.[10] The average costs per ton were $6.20, $4.49, and $10.69, respectively.

Multi-shift distribution costs are higher because the solution contains fewer locations. Manufacturing costs are considerably lower; thus, average combined costs for the multi-shift combinations approach are lower by 61 cents per ton. These results would suggest that over-all industry costs can be reduced by operating multiple shifts.

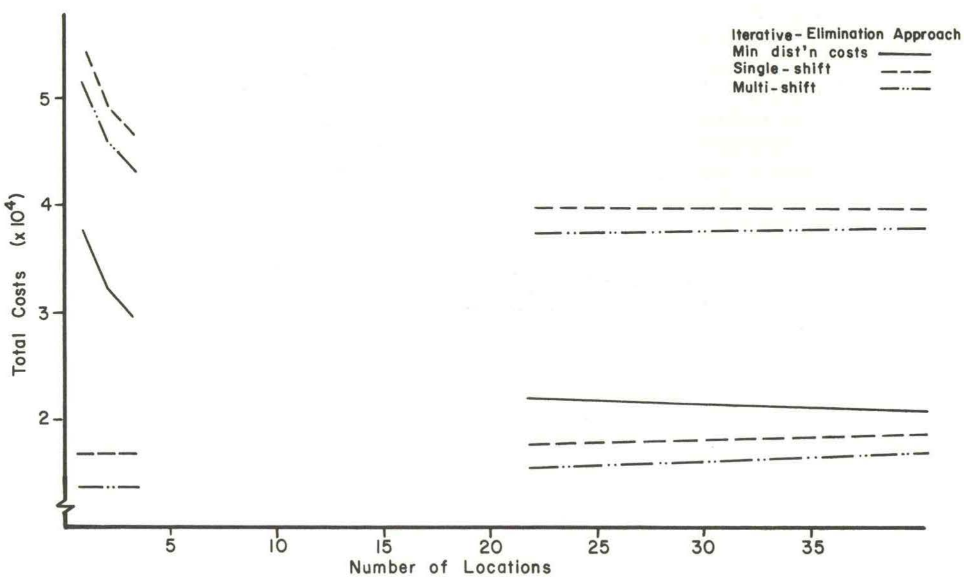
Iterative-Expansion Approach Solutions

The iterative-expansion solution results were presented in table 15 and are shown in fig. 5. The iterative-expansion solutions are remarkably similar to the iterative-elimination approach solutions. Indeed, the single-shift solution is precisely the same; the same number of plant locations is selected by the model, 29, and they are the same locations. As before, the minimized total distribution, total manufacturing, and total combined costs were $21,483,200, $18,193,952, and $39,677,152. The respective average costs were $6.12, $5.18, and $11.30 per ton of estimated feed demand.

The iterative-expansion approach's multi-shift solution did differ from that of the iterative-elimination approach. In each, the solution was composed of 25 plant locations. But some of the locations were different. Two locations included in the iterative-elimination approach solution were excluded

[10] The seventh and eighth digits do not total because of rounding.

Fig. 4. Iterative-elimination approach total combined cost functions, single-shift and multi-shift operations.



from the iterative-expansion approach solution, and two new locations were included.

The multi-shift total manufacturing cost was \$15,757,820 and the total combined cost was \$37,563,472.[11] The combined average cost was \$10.70 per ton—breaking down into \$6.21 for distribution and \$4.49 for manufacturing. The combined average cost for multi-shift was 60 cents per ton lower than the single-shift result.

Comparing the solutions from the two major approaches followed in our study, the iterative-expansion approach has the practical advantage of being much less expensive to compute. The single-shift solution for each approach was precisely the same. The two multi-shift solutions differed little.

IMPLICATIONS OF THE EMPIRICAL RESULTS

The large size of the problem in our study made optimization of the long-run spatial model computationally infeasible. There could have been two fortuitous exceptions. If the solution number of plant locations had been very small or large, optimization could have been achieved. Such was not the case. The single-shift solution was a set of 29 locations, while 25 locations were included in the multi-shift solution. It would have been useful to compute $40C_{29}$ and $40C_{25}$ as a check on the suboptimization results. Unfortunately, even these two computational steps were too expensive to be undertaken. It was estimated that computing $40C_{29}$ would require more than 10,000 hours of of computer time! Computing $40C_{25}$ would cost even more.

The solution procedures used are suboptimizations. The results cannot be regarded as optimums; not all conceivable location patterns were considered.

[11] The seventh and eighth digits do not total because of rounding.

The iterative-expansion approach is a suboptimization procedure because it involves a constraint preventing simultaneous solution of the optimum number of plant locations and the optimum location pattern for each number. The iterative-elimination approach to solving the long-run spatial model does find the optimum location patterns for the computed alternatives. But, computational costs prevent the consideration of all conceivable alternatives.

The cost results for the four solutions are summarized in table 16. Both total and per ton costs are included. Three major Iowa population centers are excluded from all solutions: Des Moines, Waterloo, and Sioux City. There are at least two important reasons that these centers might be included in practical locations for the Iowa feed industry. They are large population centers, which might offer important external economies in financing, sales promotion, and growth opportunities. Ingredient-cost advantages may prevail because of the location of meat packing plants, oilmeal processors, and other ingredient suppliers. The model does not consider these cost economies. As a practical matter, the industry would likely locate in Des Moines, Sioux City, Waterloo, and Council Bluffs as well as in other population centers. The loss in distribution efficiency is relatively slight and might be more than offset by external economies and subjective considerations.

As applied, the model is biased against population centers near Iowa's borders. For example, Sioux City would likely be a feed supply source for some Nebraska and South Dakota livestock. Only Iowa feed demand is considered in our study. As a means of counteracting "border effects," the substitution of Sioux City for Le Mars and Council Bluffs for Atlantic seems even more reasonable. The arbitrary delineation of state boundaries is a limitation of our study.

Fig 5. Iterative-expansion approach total combined cost function, single-shift and multi-shift operations.

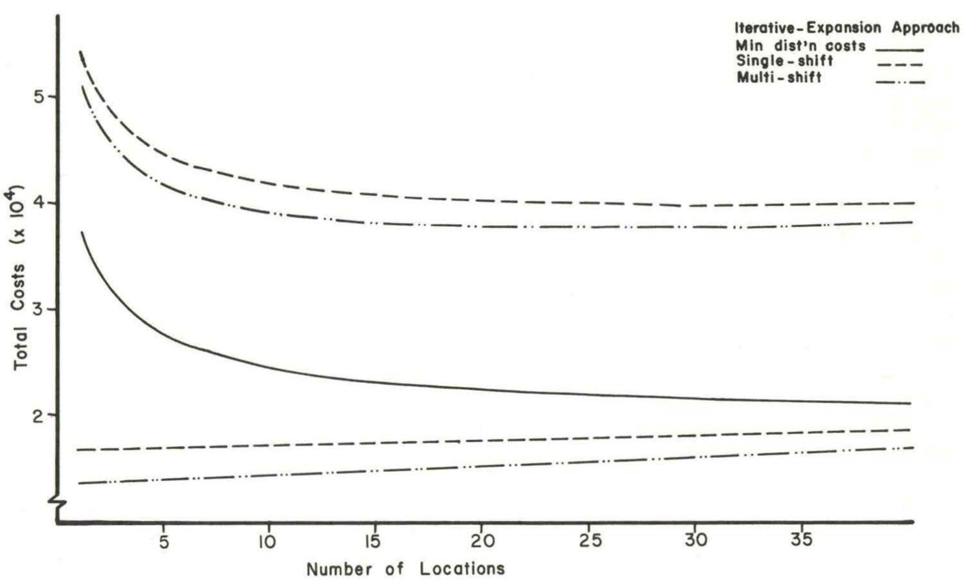


Table 16. Summary of cost results for four empirical solutions to the long-run spatial model.

Solution	Total costs[a] Minimized distribution	Manufacturing	Combined	Per-ton costs Minimized distribution	Manufacturing	Combined
Iterative-Elimination						
Single-shift	$21,483,200	$18,193,952	$39,677,152	$6.12	$5.18	$11.30
Multi-shift...........	21,788,016	15,757,821	37,545,824	6.20	4.49	10.69
Iterative-Expansion						
Single-shift.........	21,483,200	18,193,952	39,677,152	6.12	5.18	11.30
Multi-shift...........	21,805,664	15,757,820	37,563,472	6.21	4.49	10.70

[a] Digits seven and eight may not check because of rounding.

In nearly all instances, the tonnage volumes to be produced at plant locations were less than 200,000 tons annually. Thus, the model results would usually imply that there should be one plant at each location. At three locations—Iowa City, Le Mars (or Sioux City), and Storm Lake—two manufacturing establishments might be more realistic. The tonnage to be supplied from each of these three locations exceeds 200,000 tons yearly.

An important finding of our study is that the results of the two suboptimization procedures are closely parallel. Indeed, in the range of 28 to 40 plant locations, the results are exactly the same. The respective single-shift solutions are equal. The multi-shift solutions are virtually equal. An important difference is that the expansion approach is less expensive to compute; this approach to the long-run spatial model solution appears to have important business applications. Also, the suboptimization procedures can be used to widen the application of the underlying spatial model.

How valid are the suboptimum solutions computed in our study? The questions can be resolved only be computing $40C_{29}$, $40C_{25}$, and other combinations in their respective neighborhoods. The cost burden made these computations infeasible. The shapes of the estimated cost functions, however, suggest that the degree of suboptimization may be slight. In the neighborhood of the solutions, the total combined cost functions are very flat. This means that a small deviation from the solutions, either by the incorrect number of plant locations or incorrect location patterns, will raise costs only modestly. The solutions seem "robust." It appears doubtful that the optimization procedure (if it could be computed) would reach a solution substantially different from the suboptimization solutions.

The flatness of the total combined cost functions has other implications. Since deviation from the solution does not appear to raise costs sharply, factors specific to the location being considered become more important. These factors might be external economies or diseconomies (as discussed earlier), feed-ingredient availability, or purely subjective. The results imply that feed firms might tend to locate plants either in larger population centers or near related operations such as meat packing plants or soybean oilmeal processors.

An additional question was investigated by using the model. How much cost efficiency would be sacrificed if plants were located only in Iowa's larger population centers? Discounting eastern Iowa's river cities somewhat, the 10- and 15-largest population centers were selected as location possibilities. Both single- and double-shift operations were examined. Results indicated that both the 10- and 15-location patterns were importantly less efficient than the model's suboptimization solutions. The set of 15 was more efficient than the 10. Choice of location on the basis of population size would result in cost efficiency sacrifices of important magnitude. A more complex choice criterion is needed.

Major feed-manufacturing plants were found to exist in at least 26 Iowa locations. The number of actual plant locations corresponded closely to the number suggested by model solutions. But the existing location pattern was not optimum. Also, at the 26 locations there are actually 40 plants. Fewer plants would exist if model solution results were implemented. As a consequence of comparing the existential situation with model results, two implications appear to hold. First, the Iowa feed industry may be overbuilt in terms of the number of plant locations. Second, over-all feed industry costs might be lower if there were fewer plants in some locations.

This study's solution results in lower combined costs than can be achieved through a cost-minimizing distribution pattern with the existing situation. For single-shift operations, the potential savings could be about 25 cents per ton; potential savings for the multi-shift alternative could be 24 cents per ton. The magnitude of these potential savings seems important. Expressed in terms of the estimated feed demand for Iowa of 3,512,269 tons, the potential savings could be nearly $1 million. These savings do not include possible reductions in distribution costs which could be made by reorganizing feed distribution as shown in the model solutions.

The translation of model results into individual firm behavior is not clear. Even though the industry as a whole might have excess facilities, the rational expansion of an individual firm is not precluded. Unless an existing facility is very badly located, it will not be eliminated instantaneously. A facility will usually be phased out by "depreciating it out" (economic theory suggests continued operation of a facility as long as returns exceed variable costs). The long-run spatial model assumes that the feed demand of each county is exclusively served by a plant at a given location. In reality, there is competition for markets and distribution by several plants in the same demand area. Individual firms do not have motivation to conform to an industry cost-minimizing locational pattern; profit-maximization objectives, in the context of a competitive framework, may prevent optimum industry location. The reconciliation of profit-maximization and cost-minimization objectives has never yet been fully accomplished in long-run spatial location problems.

Actual number, size, and location of plants and competitive practices would be expected to raise actual industry costs above the levels suggested in the solutions of our study. In general, the results of our study suggest that the Iowa feed industry cost performance is acceptable. Our results do not indicate a need for strong public policy measures to ensure an efficient location pattern for the commercial mixed-feeds industry. On the other hand, public policy objectives could emphasize the provision of information and projections to encourage the consolidation and construction of new feed-manufacturing plants in locations more consistent with over-all efficiency in the industry. This is particularly true in terms of adjusting the industry in the future to changes in the level and location of demand for mixed feeds. Further research is needed to project these changes and to analyze industry adjustments in terms of number, size and location of plants required to maintain acceptable levels of efficiency in the Iowa feed industry.

SUMMARY

Changes in the feed industry have occurred as a consequence of scientific nutritional advances and changes in agriculture. The feed industry, formerly expected to supply only protein supplements, has become a supplier of services, technical knowledge, and complete feeds as well. The demand for commercial mixed feeds has risen more rapidly than the aggregate demand for livestock feed. The feed industry has expanded both its volume and the number and variety of its products. As farms have grown fewer, larger, and more specialized, more inputs, including feed, are purchased. Returns to farmers have become more dependent on the prices of purchased inputs and the services provided with their purchases.

A general objective of this study was to supply information and methods by which the economic efficiency of the Iowa feed industry could be improved. The primary focus was on efficiency with respect to location. It was hypothesized that overall Iowa feed-industry costs could be reduced. Possibilities for cost reduction would be tested by solving a long-run spatial model for an *efficient locational configuration* involving the optimum number and size of plants. To test the hypothesis, the data requirements of a long-run spatial model were developed; as a by-product of the primary research objective, information was obtained on feed demand, feed manufacturing costs, selling costs, truck transportation costs for moving feed, and the existing pattern of production and distribution in the industry.

A feed tonnage estimate was made for each of Iowa's 99 counties. The 1964 Census of Agriculture was the basis for these estimates. For Iowa, it was estimated that about 3.5 million tons of feed were supplied by the commercial mixed-feeds industry. Within each county, the feed tonnage estimates were disaggregated into estimates for each of 16 major livestock classes. Furthermore, each estimate was separated into supplement and complete feed tonnages. A road-mileage transportation matrix for Iowa was developed and used, in conjunction with transportation-cost and selling-cost analysis, to obtain a distribution-cost matrix. Finally, feed manufacturing costs representative of Iowa were estimated. Single-shift and double-shift (a special case of multi-shift) operations were analyzed. Economies of scale were determined for each type of operation.

The long-run spatial model was solved in accordance with county demand estimates and a set of potential plant locations in Iowa. For each given number of plants, total distribution costs were minimized with respect to plant location. Volumes at included locations were used to estimate total manufacturing costs. The sum of manufacturing and distribution costs formed total combined costs. The minimum point on the total combined cost function was the model's solution. Operationally, the optimization could not be calculated directly because the computational cost burden would have been excessive. Two suboptimal solution procedures were developed and programmed on the IBM 360/50 computer: an iterative-elimination procedure and an iterative-expansion procedure. The solutions for single- and double-shift operations were 29 and 25 plants, respectively.

The solutions were compared with the current production and distribution pattern of the Iowa feed industry. Close correspondence indicated that the industry is located relatively well. But cost-savings possibilities of about 25 cents per ton were detected, which could arise by adjusting the number, size, and location of existing plants. The savings from improved efficiency could represent nearly $1 million annually.

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APPENDIX

Table A-1 Estimated tons of feed to be supplied to each county, by each livestock class.

	Livestock class															
County	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH	FD9SH	C10OLD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
Adair	812	112	309	1,993	237	734	76	26	42	3,786	0	2,133	0	747	44	19,991
Adams	472	65	216	761	328	438	46	9	14	1,919	0	1,468	0	412	2	13,730
Allamakee	4,106	569	203	586	60	613	63	9	14	2,648	0	1,846	24	580	1,790	18,155
Appanoose	671	93	230	254	116	377	90	40	63	1,012	0	804	0	173	3	7,409
Audubon	1,023	142	126	5,105	675	900	44	13	21	5,686	2	2,044	18	1,289	133	19,278
Benton	1,273	176	258	6,389	411	1,004	68	22	35	5,214	0	3,786	25	1,328	236	36,750
Black Hawk	2,269	314	86	3,712	145	482	82	64	103	5,029	120	2.100	8	1,246	3,827	22,172
Boone	463	64	107	3,889	203	494	80	20	33	6,691	4	1,728	112	1,515	1,414	17,381
Bremer	3,617	501	40	817	85	316	60	7	11	6,377	65	1,650	13	1,415	2,849	15,966
Buchanan	2,527	350	107	2,249	216	493	157	13	21	5,115	23	2,390	7	1,049	1,087	24,095
Buena Vista	612	85	92	4,664	232	526	39	44	71	4,255	157	2,664	0	895	4,913	25,516
Butler	2,612	362	113	1,785	380	546	76	10	16	7,396	22	2,620	45	1,790	1,297	23,667
Calhoun	472	62	131	2,901	614	448	74	21	33	3,332	113	1,755	13	801	1,850	16,010
Carroll	1,124	156	181	6,907	466	1,010	55	15	24	5,822	0	3,364	14	1,393	1,739	29,494
Cass	650	90	233	4,740	521	842	81	14	22	3,630	0	2,159	0	983	170	19,753
Cedar	1,433	198	177	5,610	318	771	69	30	48	3,285	0	4,415	0	815	14	44,042
Cerro Gordo	876	121	108	2,385	197	434	76	23	37	5,953	272	2,708	59	1,359	4,594	22,509
Cherokee	839	116	98	9,402	158	1,072	61	20	31	3,034	96	2,513	51	804	2,643	23,718
Chickasaw	2,441	338	113	1,518	118	480	78	8	13	6,461	90	1,707	53	1,165	2,121	17,754
Clarke	508	70	230	261	188	377	54	10	15	869	0	999	6	150	1,969	9,585
Clay	737	102	107	4,831	290	599	57	37	59	3,880	0	1,821	9	1,059	97	17,058
Clayton	6,011	833	165	1,008	81	611	69	12	19	4,695	32	3,481	27	978	283	30,892
Clinton	1,876	260	147	10,176	188	1,223	83	11	18	3,705	4	3,722	0	786	13	38,503
Crawford	1,606	222	243	5,520	512	1,123	80	23	36	6,465	0	3,493	0	1,704	805	29,176
Dallas	493	68	148	2,344	296	460	69	16	25	3,202	7	2,001	16	953	816	19,648
Davis	925	128	184	236	109	325	72	93	148	1,379	5	885	303	467	1	7,943
Decatur	687	95	236	234	143	470	75	14	22	753	0	755	0	71	943	7,539
Delaware	4,719	654	66	1,669	135	475	55	5	9	7,417	11	4,372	0	1,324	2	37,952
Des Moines	354	49	127	1,442	356	298	58	13	21	1,301	0	1,456	491	290	32	14,345
Dickinson	703	97	73	2,101	243	385	32	32	52	3,142	64	1,041	0	1,019	580	8,931
Dubuque	5,147	713	153	2,696	133	472	54	5	8	4,192	0	3,417	813	946	38	30,845
Emmet	534	74	74	2,412	320	349	35	14	23	2,180	47	975	59	661	598	9,116
Fayette	5,006	693	124	1,972	118	650	75	9	14	7,072	41	2,529	44	1,674	909	25,464
Floyd	1,126	156	97	2,752	146	427	56	13	22	4,901	100	1,453	143	1,347	3,858	15,400
Franklin	1,346	186	104	4,423	446	584	71	64	103	6,722	35	2,981	36	1,652	2,191	25,361
Fremont	187	26	114	2,644	192	387	40	7	11	620	0	778	0	116	215	7,404
Greene	404	56	133	3,016	438	489	56	20	33	2,421	4	1,783	0	580	1,100	16,987
Grundy	1,350	187	114	3,898	328	564	57	29	47	4,764	51	2,411	0	975	1.588	24,488
Guthrie	796	110	250	1,577	495	591	74	17	28	4,407	0	1,710	6	1,112	0	16,161
Hamilton	394	55	67	4,095	241	443	85	16	26	2,880	221	2,174	23	792	23,594	21,251
Hancock	1,204	167	89	3,339	97	442	53	21	34	8,751	97	2,430	25	2,364	2,567	21,246
Hardin	998	138	117	4,564	359	650	73	29	47	4,631	20	2,926	0	1,151	2,806	25,952
Harrison	718	100	157	2,776	320	655	62	6	9	1,685	1	1,593	0	450	2	14,524
Henry	411	57	137	863	447	315	87	21	34	1,386	256	2,006	39	354	8,541	19,792
Howard	2,553	354	124	734	118	411	45	9	15	6,133	4	1,448	121	1,381	561	14,070
Humboldt	581	80	51	2,750	165	362	35	21	34	3,467	0	1,655	0	1,177	344	13,455
Ida	568	79	109	6,181	344	860	41	11	18	3,609	303	2,260	0	733	2,852	19,920
Iowa	1,122	155	310	3,819	241	862	67	24	39	2,764	106	3,151	0	659	3,328	29,394
Jackson	2,824	391	264	3,268	253	785	84	7	12	2,230	9	2,462	0	381	3	24,263
Jasper	1,495	207	271	3,840	651	758	87	23	36	4,357	0	3,186	37	1,082	273	31,833
Jefferson	474	66	134	783	237	303	62	26	42	1,412	2	1,342	0	325	311	14,197
Johnson	852	118	236	2,069	334	614	139	30	49	2,968	117	3,538	0	588	8,206	34,746
Jones	2,210	306	156	5,560	207	797	90	19	30	3,356	0	3,448	0	710	4	31,929
Keokuk	751	104	216	1,234	310	504	103	30	47	2,061	31	3,008	0	586	4,528	29,961
Kossuth	1,820	252	150	5,176	417	785	79	45	73	10,455	0	3,656	0	2,986	1,758	31,629
Lee	893	124	133	1,400	254	330	72	25	41	1,935	31	1,410	311	368	973	14.014
Linn	2,038	282	180	3,134	166	615	103	33	53	3,649	0	2,781	1,068	911	1,124	26,666
Louisa	200	28	109	1,170	345	278	44	11	18	729	21	1,744	0	141	1,378	16,102
Lucas	446	62	202	198	156	376	109	31	50	1,493	0	993	0	334	1,320	8,483
Lyon	2,133	295	91	6,484	149	751	61	36	58	6,829	0	2,241	0	1,542	1	20,576
Madison	491	68	296	874	311	590	82	21	33	1,685	0	1,680	0	406	92	16,418
Mahaska	1,101	153	168	3,327	408	536	80	34	54	3,118	0	3,148	558	690	1,191	30,140
Marion	1,066	148	176	2,134	404	441	61	47	75	2,489	0	2,275	0	502	3	22,487
Marshall	886	123	199	5,244	525	759	82	25	40	2,391	39	2,306	0	525	1.012	21,118

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Table A-1 (Cont'd)

	Livestock Class															
County	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH	FD9SH	C10OLD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
Mills	300	42	81	4,148	110	374	40	6	10	772	0	1,297	0	150	752	10,896
Mitchell	1,680	233	62	3,891	423	407	50	11	18	5,685	237	1,758	24	1,407	3,510	17,858
Monona	566	78	108	2,297	136	483	58	16	26	1,554	3	1,786	0	452	4	14,744
Monroe	439	61	191	172	73	336	104	28	44	1,032	1	765	0	205	1	7,507
Montgomery	580	80	137	3,166	340	604	49	9	15	1,693	1	1,845	0	459	2	16,008
Muscatine	889	123	123	2,286	231	368	54	11	17	1,312	86	2,153	0	267	773	21,860
O'Brien	1,288	178	67	5,970	245	629	59	29	47	6,054	48	2,461	1,173	1,456	1,072	22,313
Osceola	1,196	166	51	3,326	171	453	19	20	32	4,030	0	1,300	0	1,045	1	12,509
Page	543	75	193	3,946	315	689	68	10	16	2,125	0	1,911	0	382	0	19,084
Palo Alto	762	106	84	3,207	311	460	45	17	27	3,650	47	1,740	0	868	690	16,553
Plymouth	1,192	165	196	10,536	356	1,194	80	23	38	6,813	0	4,968	432	1,612	6,129	41,462
Pocahontas	604	84	76	4,150	229	492	43	22	35	5,586	146	1,898	0	1,498	1,894	18,363
Polk	607	84	108	1,444	253	328	87	16	25	3,920	5	1,113	8	1,120	25	11,286
Pottawattamie	993	137	185	15,326	357	1,289	145	26	41	4,265	0	3,614	12	885	15	30,888
Poweshiek	1,095	152	270	2,402	585	702	67	19	30	3,142	56	2,368	7	704	190	24,363
Ringgold	710	98	269	599	151	527	65	11	17	1,214	0	1,105	0	200	527	10,702
Sac	965	134	163	7,595	481	936	50	22	36	4,995	0	2,930	0	1,272	424	24,774
Scott	1,353	187	100	3,414	176	519	83	11	18	3,924	0	2,898	6	819	21	28,891
Shelby	1,203	167	149	6,656	649	986	68	9	14	4,861	1	2,769	0	1,542	560	23,646
Sioux	3,391	470	65	13,010	455	1,259	65	37	60	9,944	0	4,706	408	2,135	446	40,014
Story	650	90	95	3,914	172	464	81	22	35	4,447	85	1,995	564	1,310	4,362	18,995
Tama	1,126	156	284	5,010	415	994	62	21	34	6,337	0	3,352	18	1,314	5	32,175
Taylor	717	99	269	874	341	542	99	21	34	1,882	27	1,469	0	430	259	13,303
Union	471	665	235	681	186	484	70	10	16	1,386	0	1,093	0	280	12	10,668
Van Buren	564	78	181	235	97	293	83	53	85	927	44	3,074	185	178	1,085	8,995
Wapello	484	67	142	529	131	287	77	25	40	1,162	0	883	76	212	162	10,059
Warren	891	123	225	483	445	454	81	13	21	1,772	45	1,694	0	338	1,886	14,499
Washington	531	74	150	2,138	284	426	75	24	39	1,714	396	4,027	27	464	13,747	38,732
Wayne	906	125	272	452	189	474	87	18	29	1,580	107	868	47	237	4,685	8,828
Webster	471	65	121	1,757	420	358	93	14	22	2,777	21	1,540	0	677	4,663	13,708
Winnebago	1,067	148	56	1,254	58	261	34	9	14	5,154	0	1,815	1,079	1,346	247	16,469
Winneshiek	5,342	740	206	1,029	113	756	78	13	20	6,716	67	3,004	12	1,603	2,933	27,439
Woodbury	893	124	169	8,917	275	1,002	94	28	45	3,656	143	3,026	0	788	8,085	26,587
Worth	867	120	66	1,829	86	268	37	14	22	4,065	83	1,548	1,328	1,238	2,138	14,330
Wright	716	99	83	2,508	359	425	85	28	45	4,431	0	2,512	1,396	1,217	3,005	20,724