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Quantitative model for location of a dairy products plant

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QUANTITATIVE MODEL FOR LOCATION OF A
DAIRY PRODUCTS PLANT

by

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INTRODUCTION

A manager of economic resources constantly faces the problem of making decisions under conditions which are highly dynamic. Incorrect evaluation of future conditions can result in heavy financial loss from unwise investment in new plant and facilities. The manager of economic resources has to find ways of gathering and analyzing information which will help him make decisions under uncertain conditions.

Highly dynamic conditions are found in demand, supply, transportation, and manufacturing sectors of the milk industry.

Demand for milk is influenced by several factors. In the short run, demand may be influenced by tastes of consumers, price of milk, prices of substitutes and complements, and income. In the long run, other variables become important; among these are demographic variables such as place and rate of population growth, growth within age groups, and sex. Region of the country and institutional factors such as school lunch programs also affect the demand for milk.

Conditions in transportation of milk have changed greatly. Examples of changing conditions are a switch from hauling milk in cans to hauling milk in bulk and improved refrigeration techniques. Other factors, such as better roads, improved trucks, and larger truck tank size are reflected in lowered costs per mile of over-the-road tankers. These modern transportation techniques have greatly increased the marketable range of milk.

Factors influencing the supply of milk are the price of milk, opportunity cost to the farmer, and technology.

Milk manufacturing processes have been improved and labor requirements reduced due to new manufacturing techniques and developments in equipment.

The manager of resources makes his decisions in the light of present conditions which are dynamic, causing him to face uncertainty and risk in the future. The problem becomes one of making present decisions under uncertain future conditions.

In making decisions under constantly changing (dynamic) conditions, the manager needs a body of accurate, relevant, organized knowledge upon which his decisions can be based and the consequences of his decisions anticipated. One thing a manager can do to organize his body of knowledge for decision making purposes is to understand the present situation and the underlying variables. To do this, the manager can use an analytic framework that will relate the variables of the situation, giving the manager a framework within which to organize his knowledge and to understand the relationships between variables.

To anticipate the consequences of his decisions, the manager needs knowledge of possible future conditions. A logical procedure for anticipating future conditions is to make projections based on present and past conditions. If the manager has any additional information or insights, these too can be incorporated into the projections. The analytical framework used in analyzing the present situation can then be applied to the future. The manager then makes his decision with a better understanding of the present and an insight into the future.

The problem of this thesis is to show the use of a quantitative model or framework under present and anticipated future conditions to analyze a decision situation using a specific goal. The author will use the transportation model of linear programming to determine the optimum (minimum cost) location of a milk surplus manufacturing plant as a basis for a management investment decision. The specific goal will be the minimization of milk transportation costs from production source to market or destination.

Specific Situation and Problem

This study was initiated when a private firm approached Iowa State University for the purpose of obtaining assistance in their study of the location of a surplus milk processing plant. The problem was formulated and appropriate arrangements were made between the University and the firm for undertaking the project.

The firm is a dairy cooperative with members located in sixty-one Iowa counties. Members elect a board of directors which makes policy decisions and oversees the operation of a surplus plant and related activities.

The normal daily operation of the Cooperative is as follows. Milk procured includes the grades A bulk, B bulk and B can. The milk is hauled by private haulers from farms directly to handlers (bottlers) or to the surplus plant, or else the milk is hauled to receiving stations and reloaded onto Cooperative-owned tankers for shipment to handlers or surplus plant. The private hauler negotiates with the farmers on his route for hauling rates and is paid by the Cooperative. Each producer then authorizes the Cooperative to deduct hauling costs from his check for payment to the hauler. All grade A milk goes to handlers located in six Iowa cities with the surplus grade A milk going to the surplus manufacturing plant. All B bulk and B can milk is shipped directly to the surplus plant. The two main outputs from the plant operation are skim milk powder and butter. Other outputs and products of lesser importance are condensed skim milk, skim milk for cottage cheese, ice cream base mix, whole milk powder, and spot deliveries of grade A milk.

There were several reasons which prompted the Cooperative to consider investment in a new plant. The first was the merger with another dairy cooperative which resulted in a broadened scale of operation for the new organization. The second reason is the present state of the surplus plant. It is a high-cost operation when compared to other plants with similar operations. The plant is located in an old building not originally designed for the present operations. The present equipment within the plant is in various states of technology which results in less than optimum operation for any given piece of equipment. Labor costs are large relative to other costs because the present surplus plant is located in a high-wage area and a high labor input is required in plant operations.

All these factors result in less than optimum cost of operation for the Cooperative. One solution to this situation is the investment in a new surplus plant. What is the optimum location for a new surplus plant?

Objectives of the Study

The objectives of this study were:

1. To illustrate the application of linear programming theory to spatial problems encountered by dairy product firms.
2. To solve for the Cooperative the optimal flow patterns of milk from production areas or origins to markets or destinations using linear programming techniques.
3. To determine the optimum location of the surplus milk manufacturing plant using linear programming techniques.
4. To make the analysis one of comparative statics by projecting supply and demand data to 1975 and solving for optimum flows and location.
5. To create new uses and applications of developed mathematical tools and computational methods so that they can be applied to dairy management problems.
6. To show the use of quantitative tools in analyzing a management decision situation.

Scope of the Study

This study is concerned with the application of linear programming techniques, especially the transportation model, to a specific dairy organization's problem. The assumed behavioral motive involves the efficient use of Cooperative resources and increasing income to Cooperative members.

LITERATURE REVIEW

Weber is credited with being the first to attempt the analysis of the choice of industrial location (4, p. 2). Weber's site of lowest cost is determined by considering weight reduction processes, weight increasing processes, freight rates, insurance, labor costs and transfer costs (6, p. 1547). Weberian analysis can be useful in solving actual industrial location problems, but the analysis is limited in the complexity of problems that can be considered.

The formulation of the transportation model of linear programming and computer techniques has made possible the solution of complex location problems.

The transportation model of linear programming is applicable to a subset of general linear programming problems due to the more restrictive assumptions of the transportation model. Heady and Chandler (2, pp. 339-40) formulate the assumptions of the transportation model as follows:

1. Products are homogeneous. The supply of any origin can fulfill the demand of any destination.
2. Supplies of origins and the demands of destinations are known. If supply is greater than demand, dummy cells or destinations can be introduced to represent surpluses which move into inventories, storage, or other alternatives. (In this study, the surplus manufacturing plant can be thought of as an added destination.)
3. Transportation coefficients from origins to destinations are known and are independent of the amount hauled.

4. There is an objective function to be maximized or minimized.

5. Transportation from origins to destinations can be carried on only at non-negative levels.

The algebraic representation of the assumptions would look like (2, pp. 340-342):

$$\min.\ Z = \sum_i \sum_j C_{ij} X_{ij} \text{ (Objective function)}$$

Subject to:

$$\sum_i X_{ij} = Y_j \text{ (Demand of } j^{th} \text{ destination)}$$

$$\sum_j X_{ij} = B_i \text{ (Supply of } i^{th} \text{ origin)}$$

$$\sum_j Y_j = \sum_i B_i \text{ (Total demand equals total supply)}$$

$$X_{ij} \geq 0 \text{ (Non-negative shipments)}$$

where

$i = 1$ to m origins,

$j = 1$ to n destinations,

C_{ij} = cost coefficient from i^{th} origin to j^{th} destination,

X_{ij} = the amount transferred from the i^{th} origin to the j^{th} destination,

Y_j = the demand of the j^{th} destination, and

B_i = the supply of the i^{th} origin.

The transportation model has been useful in solving various kinds of spatial problems. An early application of the transportation model to a spatial agricultural problem was that of Snodgrass (8). The contributions of the study were (1) the application of linear programming theory to spatial problems as a means of evaluating its usefulness in agricultural interregional trade analysis, and (2) using linear programming to show the optimal resource use pattern (minimum cost) for movement of dairy products from surplus to deficit areas in the United States. The findings of optimum pattern flows were limited by inadequate data for solving pattern flows and inadequate data pertaining to actual movement of products.

Padgett (7) used the same basic analytical tool and techniques as Snodgrass to (1) determine the optimal flow patterns in Indiana for milk and dairy products to minimize transportation costs, and to (2) determine the optimal seasonal utilization of milk and dairy products. Padgett concluded that from the solution of the transportation models and according to location theory, manufactured dairy products should be manufactured near the raw material source and not within large consumption centers.

King and Logan (3) used the transhipment model of linear programming to determine the location and size of California cattle slaughtering plants given the location and quantity of slaughter animals and the final product demand by minimizing the costs of shipping raw materials, processing, and shipping final product. The transhipment model or something equivalent was not used because variations in transportation costs of surplus plant products between various alternative locations are nearly negligible. The operation of a milk surplus plant is a weight-reducing manufacturing process. Also milk powder, a large portion of final product, is priced F.O.B. factory.

Applications of linear programming to optimum flow patterns and location of production and manufacturing facilities have been concerned with flow patterns from one region to another or with production and manufacturing facilities located within one region or another. To be studied is the problem of flow patterns and location of facilities within a region. "In a limited local or regional development program...the locations of consumption are usually known in advance. They would lie, of course, in the neighborhood of existing or planned transport routes, deposits of raw materials, labor pools, harbors, nodal points, etc." (4, p. 110).

The above quotation suggests a procedure for the solution of an optimum location for the surplus manufacturing plant. Discrete locations are selected as possible sites for the plant. Supply, demand, and transportation data are computed. With the necessary data, the transportation model is used to solve for overall transportation costs and optimum pattern flows for each discrete surplus plant location chosen. The optimum plant location will be the one with minimum transportation costs.

The above procedure roughly outlined solves the plant location problem by minimizing transportation costs. It ignores the profit potentiality of the surplus manufacturing plant at any given site. The plant profitability at any given location will depend upon opportunity costs of the site and plant operation costs peculiar to that site. If it is assumed that plant profitabilities are equal at all sites, then the transportation model gives an optimum location.

In reality, the profitability of possible plant locations is not equal. In some of the locations considered, there exist dairy surplus plants which could easily be expanded to accommodate the Cooperative. In making its location decision, the Cooperative will have to consider the transportation costs and site profitability associated with each location. The site profitability of each location will have to be determined by another study before a final decision can be reached by the Cooperative. From the viewpoint of this thesis, all plant sites are assumed to be of equal profitability.

MODEL AND PROCEDURE

The specific problem is: given (1) transportation costs between counties and markets (surplus plant is considered as an extra market or destination), (2) production for each county, (3) and milk requirements by each market, find the optimum location for the surplus plant and resulting optimum flow of milk which will satisfy market consumption requirements supplied from given production units in such a way that total transportation costs are a minimum. Transportation costs for intra-county shipment to markets were considered in setting up the problem.

The mathematical representation of the actual model used is as follows:

i = 1 to n markets or destinations whose demand for fluid A is to be filled,

j = 1 to m production units (origins) or counties supplying A milk to i markets,

X_{ij} = amount of grade A milk going to i^{th} market from j^{th} county,

T_{ij} = transportation coefficient for shipping A milk to i^{th} market from the j^{th} county,

D_i = the demand for milk by the i^{th} market, and

S_j = the supply of A milk by the j^{th} county.

$$\text{min. } Z = \sum_i \sum_j T_{ij} X_{ij} \text{ (Objective function)}$$

Subject to:

$$\sum_j X_{ij} = D_i \text{ (Demand of } i^{th} \text{ market)}$$

$$\sum_i X_{ij} \geq S_j \text{ (Supply of } j_{th} \text{ county)}$$

$$\sum_i D_i = \sum_j S_j \text{ (Equilibrium condition)}$$

$$X_{ij} \geq 0 \text{ (Non-negative shipments)}$$

D_i, S_j, and T_{ij} are constants.

The above model is solved for each discrete surplus plant location considered with appropriate changes made in the T_{ij} for each plant location. Known are the demands, supplies, and transportation coefficients.

The introduction of inequalities into the supply equation reduces the number of artificial vectors needed for solution to the number of demand equations. This considerably reduces the computor time, and hence the cost, of obtaining a solution.

1963 Situation

Production data

Production data was taken from Cooperative records of milk producers and of the volumes of milk they produced for the period October, 1962, to September, 1963. It was assumed that all milk from a specific county originates from one central point within that county and is shipped from that point to a destination. The volume produced by each county was found by adding the volumes of milk produced by Cooperative members within a county for the given period.

There were two reasons for using counties rather than actual milk pick-up routes for milk origins. First, production projections could not be made by routes because the composition of farmers on routes was constantly changing over time. Secondly, it was easier in formulating an analytical framework to abstract from reality and assume that milk originated at several points and was consumed at other points.

Consumption data

Consumption data was taken from Cooperative records of milk sales to handlers for the period October, 1962, to September, 1963. It was assumed that handlers within a localized area constituted a market or destination and that the market was located at one specific point. This assumption only affects local areas or cities with more than one handler. The demand or milk requirement for each market or destination was found by adding together Cooperative sales to handlers within a market for the specific period.

Transportation coefficients

Transportation costs were determined for shipping the milk produced in any county to any one of seven markets or destinations. The surplus plant was considered a variable, in the sense of location, market or destination.

The possible surplus plant locations considered were Des Moines, Marshalltown, Brooklyn, Marion, Hudson, Maquoketa Valley near Arlington, Coggon, and Jessup. Their locations are shown on Figure 1.

The calculation of actual transportation costs used required several steps. First, the distance in miles from a central point within each county to each market or destination was determined. It was assumed that

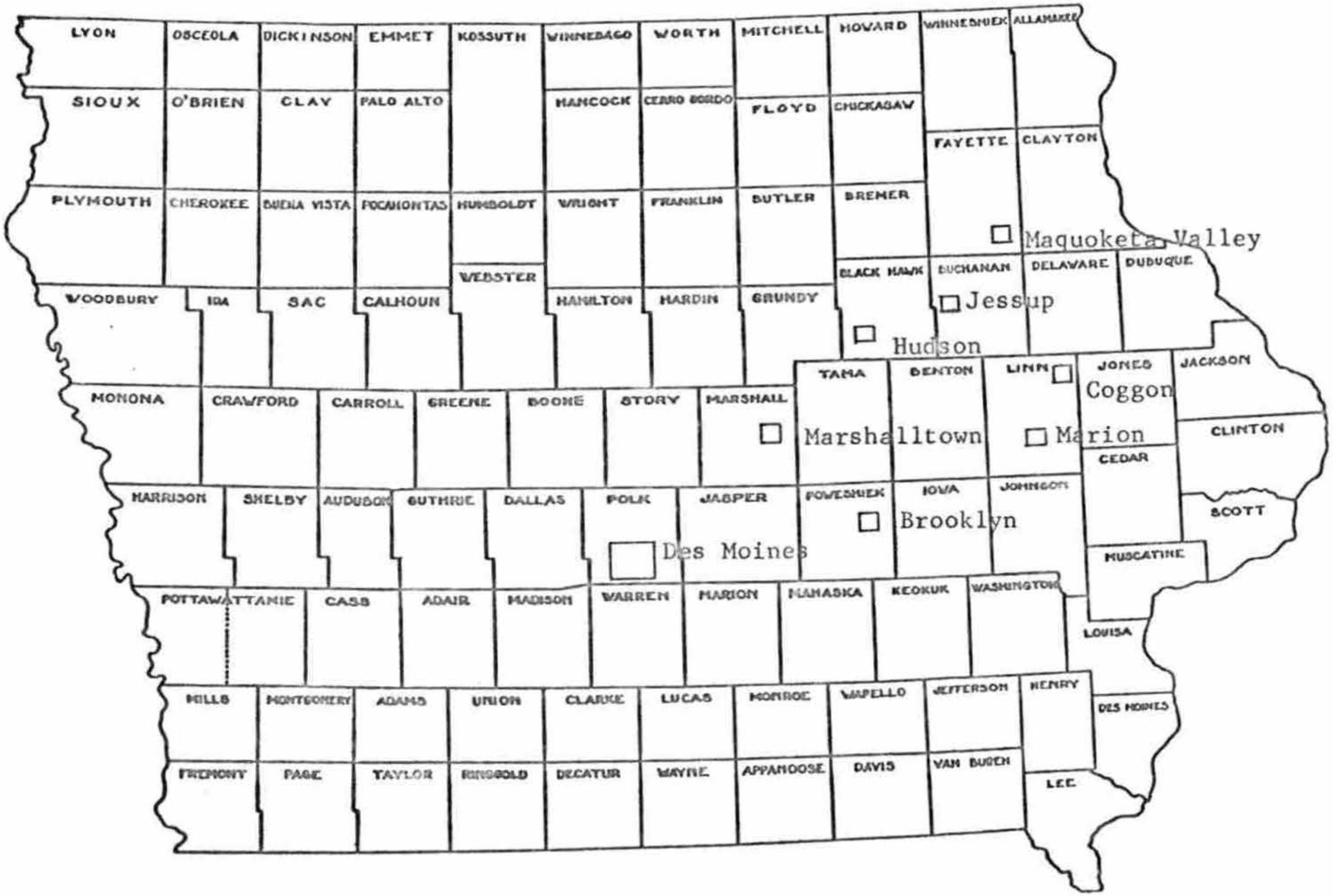

Figure 1. Selected surplus plant locations

there were a number of ways of shipping milk from a given county to a given location. The milk could be hauled directly by farm pick-up tanker from a given county to a given market. Or, the milk could be hauled by farm pick-up tanker from a county to a receiving station where the milk would be reloaded onto over-the-road tanker for shipment to a given market. The location of receiving stations through which milk from a given county could be shipped was predetermined. Receiving stations through which milk was allowed to flow were Marion, Des Moines, Exira, and Brooklyn. Their locations are shown on Figure 2. Milk from any county could be shipped to any market either directly or through a receiving station.

Transportation rates or "standard" transportation rates were determined for grade A and B bulk farm pick-up tanker, grade B can farm pick-up truck, and over-the-road tanker. The farm pick-up tanker "standard" rates were determined by taking the average standard rate per hundredweight and dividing by the average total length of farm pick-up route. The standard rate per hundredweight is the rate the hauler charges the farmer for milk pick-up. The "standard" rate for over-the-road tanker was determined by taking tanker cost per hundredweight and dividing by the miles traveled one way; i.e., from receiving station to destination. The cost per hundredweight was calculated from Cooperative records of volumes of milk hauled and the costs involved for alternative over-the-road tanker routes. The "standard" rates calculated from Cooperative data for the period October, 1962, to September, 1963, are:

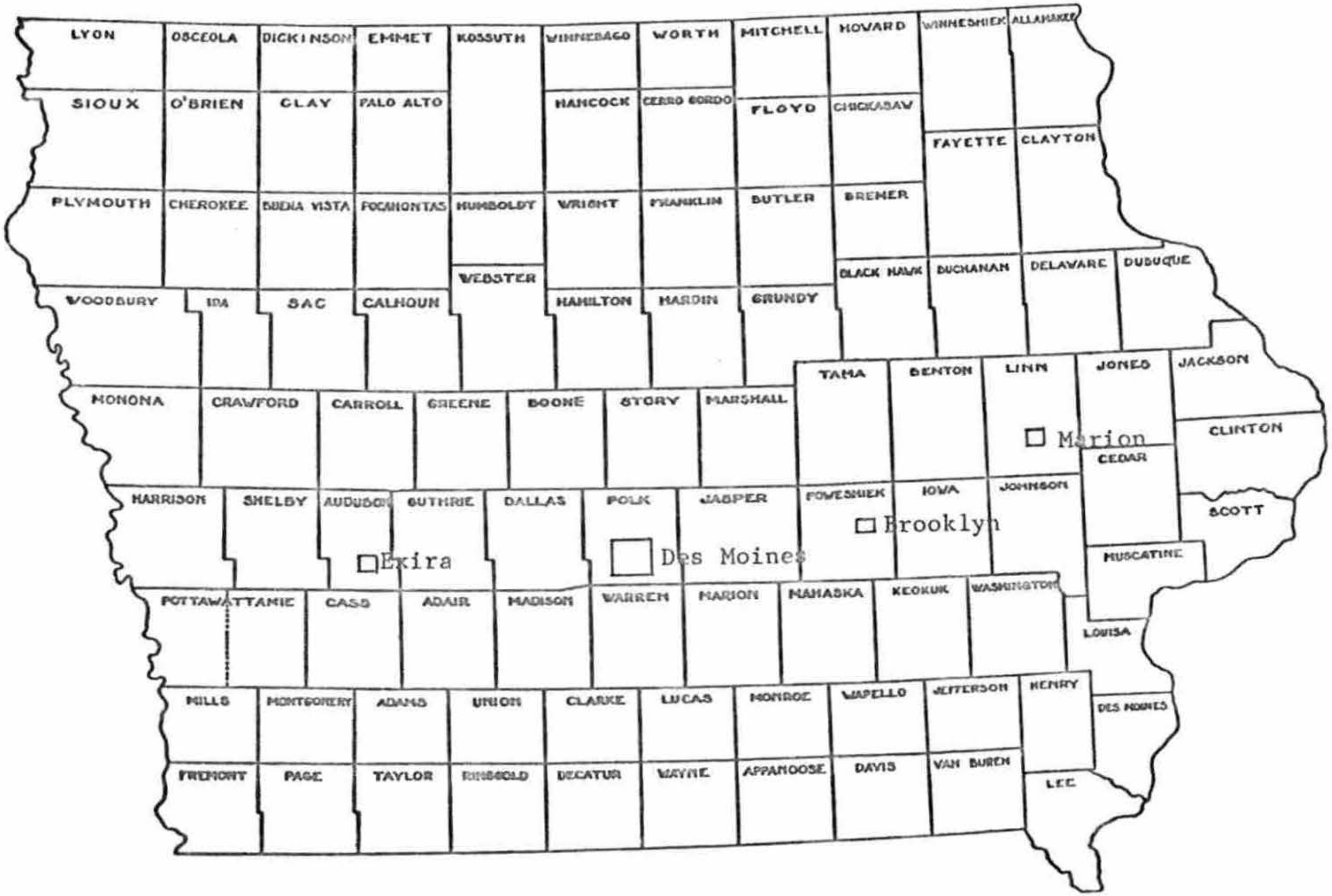

Figure 2. Locations of receiving stations

A and B bulk farm pick-up: .2385¢/cwt/mi.

B can farm pick-up: .3445¢/cwt/mi.

Over-the-road tanker: .1283¢/cwt/mi.

Transportation costs per hundredweight were determined for counties either shipping milk directly or through a receiving station. The costs per hundredweight were determined by multiplying the distance from each county to each market by the appropriate "standard" rate or rates. If milk was hauled through a receiving station, that portion of the total distance by farm pick-up was multiplied by the appropriate "standard" rate and that portion of the total distance traveled by over-the-road tanker was multiplied by the appropriate "standard" rate.

The receiving station operation was considered as part of the cost of transportation. From Cooperative records was determined a variable cost per hundredweight to account for receiving station operation. The receiving station variable cost per hundredweight was added onto transportation costs per hundredweight for routings through a receiving station.

The cheapest routing from each county to each possible destination was selected as that transportation cost used in the solution computation.

Problem set-up

The above supply, demand, and transportation data for grade A milk was placed in a matrix of the following form:

$$
\begin{array}{lccccccccccccccccccc}
 & T_{11} & T_{12} & T_{13} & \cdots & T_{1j} & T_{21} & T_{22} & \cdots & T_{2j} & T_{31} & T_{32} & \cdots & T_{3j} & \cdots & T_{ij} & & & \\
D_1 & X_{11} & X_{12} & X_{13} & \cdots & X_{1j} & & & & & & & & & \cdot & & & & \\
D_2 & & & & & & X_{21} & X_{22} & \cdots & X_{2j} & & & & & \cdot & & & & \\
D_3 & & & & & & & & & & X_{31} & X_{32} & \cdots & X_{3j} & \vdots & & & & \\
\vdots & & & & & & & & & & & & & & \cdots & & & & \\
D_i & & & & & & & & & & & & & & & X_{ij} & & & \\
S_1 & X_{11} & & & & & X_{21} & & & & X_{31} & & & & & & -y_1 & & \\
S_2 & & X_{12} & & & & & X_{22} & & & & X_{32} & & & & & & -y_2 & \\
S_3 & & & X_{13} & & & & & \cdot & & & & \cdot & \cdot & & & & & -y_3 \\
\vdots & & & & \ddots & & & & \ddots & & & & \ddots & \vdots & & & & & \vdots \\
S_j & & & & & X_{ij} & & & & X_{2j} & & & & X_{3j} & \cdots & X_{ij} & & & -y_j
\end{array}
$$

The notation is the same as that of the algebraic model. The additional symbols y_1, y_2, ... y_j are the slack vectors added for computational purposes. To be determined by solution are the X_{ij}'s, the amount of grade A milk going to the i^{th} market from the j^{th} county. The rest of the matrix is filled with zeros.

The grade A milk hauling pattern and total transportation costs were calculated on the IBM 7074 electronic computer at Iowa State University for each surplus plant location: Des Moines, Marshalltown, Brooklyn, Marion, Hudson, Maquoketa Valley, Coggon, and Jessup. The B grade milk transportation cost was hand calculated because B milk always went to the surplus plant. The overall optimum was found by adding together the total A and B transportation costs.

1975 Situation

The 1963 situation was projected to 1975 to see if the optimum location and hauling pattern changed. Demand and supply data were projected to 1975. Transportation costs were not projected but were those used in 1963 computations.

Consumption data

In order to project consumption data, it was necessary to formulate a consumption function. The choice of function was partially determined by the data available, a population profile (1) for each county broken down by sex and five year age groups and projected to 1965, 1970, 1975, and 1980. Also available were the results of a recent survey of milk beverage consumption patterns (5).

Using the population data and the milk consumption pattern data, it was possible to project consumption to 1975. From the milk consumption pattern survey it was concluded that milk consumption was mainly a function of age and sex. Contributing factors in milk consumption were type of milk product consumed and the region of the country in which a person resided.

Non-contributing consumption elements were income elasticities and urbanization. Data presented in the survey showed that there seems to be an insignificant difference in milk consumption by income groups over the income range in counties comprising the marketing area of handlers to whom the Cooperative sells milk. The survey also showed that milk consumption was not affected by urbanization.

The procedure for determining consumption figures was to determine total milk consumption in 1975 and then to determine Cooperative share by markets of the total consumption. Total consumption was found using projected 1975 population data and the table "Daily Average Ounces of Fluid Milk Used as a Beverage by Age Groups, January - March, 1962" (includes whole, skim, low fat, chocolate milk and drink, and buttermilk) from Milk Beverage Consumption Patterns. Total consumption per county was found by multiplying the number in each age group by the daily ounces ot milk consumed for that age group and by adding the results. All age groups were divided by sex. The resulting figures were multiplied by 365 for yearly consumption and changed to hundredweight units.

After determining the total milk consumption came the problem of determining the Cooperative's share. Total milk consumption by county for 1963 was determined by the same method as 1975 consumption figures. For each market was estimated the Cooperative's handlers present (1963) share (per cent) of each county's total consumption. The estimated per cents were multiplied by 1963 total county consumption and the results added by markets to give estimated 1963 Cooperative consumption. The estimated 1963 Cooperative consumption figures were compared with actual cooperative milk consumption and resulting adjustments were made in the 1963 per cent estimates of county consumption by markets. Adjustments were made by determining what per cent was the actual 1963 Cooperative milk consumption of the estimated 1963 Cooperative consumption by market and multiplying the resulting per cents by the corresponding 1963 per cent estimates of county consumption by markets. It was assumed that each market's present (1963) per cent of total consumption in each county would remain the same in 1975. In reality, Cooperative handlers will spread their sales area, but at the same time, dealers from other markets will be spreading into Cooperative handler's area. The 1963 market county shares were multiplied by 1975 total consumption estimates and the results added by county to get 1975 Cooperative Consumption estimates of markets.

The surplus plant was allocated fifteen per cent of total milk consumption. This per cent was the assumed minimum surplus necessary to provide an adequate fluid supply for daily and seasonal variations in milk production and consumption.

The 1975 Cooperative consumption estimates were adjusted upward by a percentage to fit regional consumption patterns.

<u>Production data</u>

Known was the present Cooperative milk production in each county. Assuming that the Cooperative keeps the same share of total county production, what will be the Cooperative milk production by county for 1975? Cooperative records could not be used in making projections of Cooperative milk production by county. The Cooperative's share of a county's milk production has been unstable due to mergers with other cooperatives and changing market outlets. An important consideration in making county production estimates is the trend in a county's relative standing in total state milk production.

Data available for use was Cooperative production from each county, total milk produced by each county for the years 1949 (11, pp. 60-68), 1954

(12, pp. 90-98), and 1959 (13, pp. 184-187), and yearly total state production figures through 1962 (9, p. 66; 10, p. 10).

The first step was to project the trend in each county's relative production position. For the years 1949, 1954, and 1959, each county's per cent of total state milk consumption was found. A regression line was fitted to the per cents for each county. The line fitted was the linear form $Y = a + bx$ where X represented time and Y the county's per cent of state production. Thus, for any year in the future, one could determine a county's relative production position.

A three point regression is not a good statistical practice if a county has a widely fluctuating production pattern. However, most counties had a definite upward or downward trend in production over time. With sixty-one counties involved in the Cooperative's overall production and most counties showing a definite production pattern, those counties with erratic production patterns would be a small part of total Cooperative production.

Each county's total production was determined for 1963 and 1975. From state production totals was projected state total production for the years 1963 and 1975. By taking each county's projected per cent of state totals times projected state production, each county's production was determined for 1963 and 1975.

Next, the Cooperative's share of 1975 production was determined. The Cooperative's per cent of each county's total production was determined in 1963 for grades A and B milk. To facilitate computation, it was assumed that the Cooperative share of future production would remain as in 1963. Thus, the Cooperative's 1975 production by county was found by multiplying the Cooperative's 1963 county production share by the county's 1975 total production estimate.

It was found that the Cooperative share of the total 1975 grade A supply would not fill projected market demands and allow for an operating surplus of fifteen per cent for grade A milk. It was assumed that a price rise (through either a change in Class prices or an increase in blend from higher utilization) would attract a higher proportion of the grade A milk being produced in 1975 in each county. Thus, the projected Cooperative production estimates were adjusted upward to meet projected market demands.

The solution to 1975 optimum location and hauling patterns using the projected demand and supply data proceeded as in solving the 1963 model.

DISCUSSION OF RESULTS

Consumption Data

In Table 1 is the consumption data by destinations for 1963 and 1975 used in the program solution. The grade A milk demands formed the demand constraints for computer solution. Each number in the table represents the milk requirements of handlers at a destination to which the Cooperative supplies milk.

Table 1. Handlers' consumption of Cooperative grade A milk by destinations, demand constraints of program (volumes in hundredweight)

Symbol	Destination	1963	1975
D1	Des Moines	1,930,954.84	2,184,641
D2	Marshalltown	457,735.99	472,239
D3	Grinnell	41,268.86	41,874
D4	Ottumwa	136,404.56	122,495
D5	Cedar Rapids	424,173.51	467,588
D6	Iowa City	275,574.79	365,018
	Surplus Plant	629,981.39	644,792.62
	Totals	3,896,093.94	4,298,617.62

Comparing 1963 and 1975 figures, demand for milk will increase in the Des Moines and Cedar Rapids - Iowa City markets. Milk requirements for the Marshalltown, Grinnell, and Ottumwa destinations are expected to either increase slightly or decline. The differences between the 1963 and 1975 figures are the result of demographic factors: total population growth by counties broken down by age groups and sex.

Production Data

In Table 2 are the production figures of Cooperative producers by county for 1963 and 1975. Each figure in the table represents the amount of a specific grade milk produced by Cooperative farmers within a county in the stated time period, 1963 or 1975. The 1963 and 1975 "A" figures were supply constraints in the computer solutions.

If present trends continue, the following counties will not be producing any appreciable amount of milk in 1975: Boone, Dallas, Greene, Hamilton, and Webster. The projected lack of production in certain counties is an expected result of increased specialization in farm production. This increased specialization in milk production is shown on Figures 3, 4, and 5 of density of whole milk equivalent marketed (9, p. 3). Comparing the 1959, 1963, and 1975 maps, it can be seen that milk production will become more specialized, if present trends continue, in the northeast and western sections of the state. By 1975, it is anticipated that northeast Iowa will be the greatest milk producing area in Iowa.

Total Costs

Total hauling costs and receiving station volumes are found in Table 3.

Looking at the 1963 situation for grade A milk hauling costs only, Coggon is the optimum location for the surplus plant, with Maquoketa Valley,

Table 2. Cooperative production of grades A and B milk by county, supply constraints of A milk for computer program (volumes in hundredweight)

Symbol	County	1963 A	1963 B Bulk	1963 B Can	1975 A	1975 B
01	Adair	40,656.53	11,437.10	13,723.38	50,287.51	24,505
02	Adams		5,451.78			7,162
04	Appanoose	18,113.88			20,636.77	
05	Audubon	33,929.38	17,183.09	91.474.83	53.226.55	134,304
06	Benton	166,755.58			196,267.74	
07	Black Hawk	37,118.74			36,826.87	
08	Boone	39,072.34			-0-	
09	Bremer	35,102.41			54,027.99	
10	Buchanan	91,098.97			138,593.26	
11	Buena Vista	15,154.25			15,858.61	
12	Butler	8,244.53			14,056.32	
13	Calhoun	7,078.30			6,156.23	
14	Carrol	14,147.79	14,078.26	30,308.09	21,710.01	53,703
15	Cass	245.88	27.52	26,203.09	373.41	31,400
16	Cedar	27,348.07			29,523.73	
17	Cerro Gordo	5,812.42			4,992.81	
18	Cherokee	6,319.78			8,585.95	
19	Chickasaw	5,624.17			9,581.72	
20	Clarke	32,098.39		304.56	46,850.59	358
21	Clay	3,721.92			1,502.54	
22	Clayton	68,041.34			123,283.34	
24	Crawford		786.66			1,079
25	Dallas	179,100.97			-0-	
26	Davis	9,771.47			13,947.09	
28	Delaware	251,205.74			409,350.48	
31	Dubuque	52,759.89			89,425.99	
33	Fayette	63,373.51			111,087.73	
35	Franklin	61,973.18			73,694.39	
37	Greene	33,226.16		16,296.74	-0-	
38	Grundy	36,778.81			60,574.14	

Table 2 (Continued)

Symbol	County	1963 A	1963 B Bulk	1963 B Can	1975 A	1975 B
39	Guthrie	64,485.76	7,989.51	53,025.13	72,369.67	53,924
40	Hamilton	11,608.44			-0-	
42	Hardin	59,984.31			54,055.93	
46	Humboldt	6,190.67			6,212.11	
47	Ida	3,286.47			1,186.28	
48	Iowa	88,555.28	7,388.22	6,588.28	114,772.33	14,268
49	Jackson	3,032.07			4,613.04	
50	Jasper	257,659.54	7,580.23	7,748.03	314,482.07	14,724
51	Jefferson	2,365.04			2,627.86	
52	Johnson	68,727.97			9,800.18	
53	Jones	186,355.83			259,879.99	
54	Keokuk	9,757.47			4,841.66	
57	Linn	220,119.02			325,775.90	
58	Louisa	52.41			34.29	
59	Lucas	17,455.32		6,360.25	3,259.11	934
61	Madison	60,402.97		18,795.78	49,864.57	12,221
62	Mahaska	63,380.91	20,645.40	10,311.30	58,004.71	22,299
63	Marion	140,778.70	19,185.71	4,730.12	202,383.33	27,091
64	Marshall	171,205.37			115,547.09	
68	Monroe	43,899.67			52,290.48	
76	Pocahontas	23,780.08			26,865.39	
77	Polk	233,994.15		20,784.50	167,904.89	11,741
78	Pottawattamie		4,403.93	261.06		-0-
79	Poweshiek	125,865.94	48,063.30	77,362.14	165,787.61	130,077
81	Sac	17,966.80			28,975.05	
83	Shelby		5,696.84	10,208.93		20,833
85	Story	130,292.90			163,980.24	
86	Tama	81,890.59		1,081.46	98,062.74	1,000
88	Union	2,147.27			3,062.24	

Table 2 (Continued)

Symbol	County	1963 A	1963 B Bulk	1963 B Can	1975 A	1975 B
89	Van Buren	16,460.31			18,421.69	
90	Wapello	85,973.46			73,853.16	
91	Warren	283,085.19		31,276.63	284,523.96	24,762
92	Washington	28,809.17			18,008.91	
93	Wayne	5,483.49			6,749.37	
94	Webster	37,166.97			-0-	
	Total	3,896,093.94	169,917.55	426,844.30	4,298,617.62	586,385

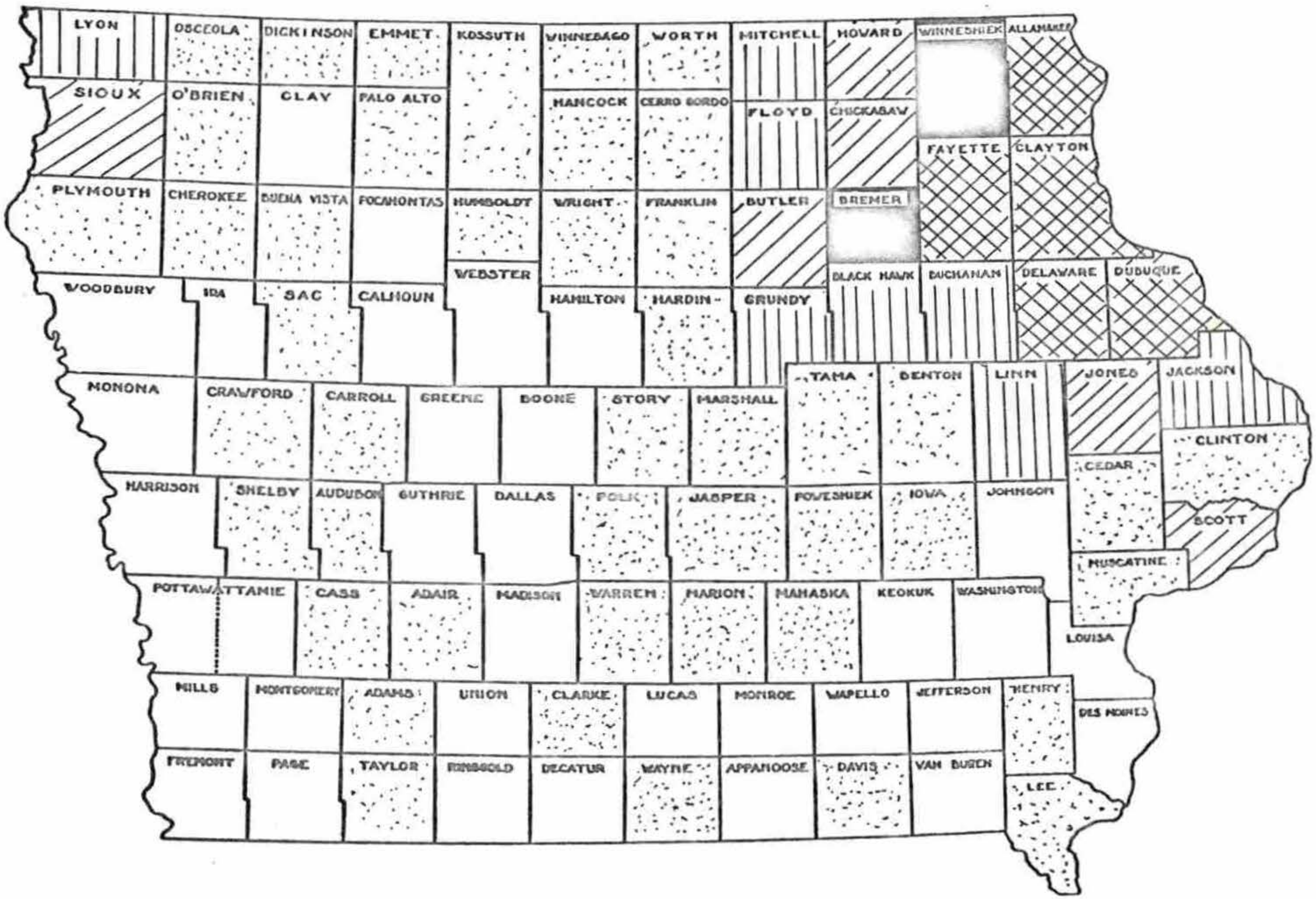

Figure 3. Whole milk equivalent marketed by county, 1959
(density in hundredweight per square mile)

Under 500

500 to 1,000

1,000 to 1,500

1,500 to 2,000

2,000 to 3,000

Over 3,000

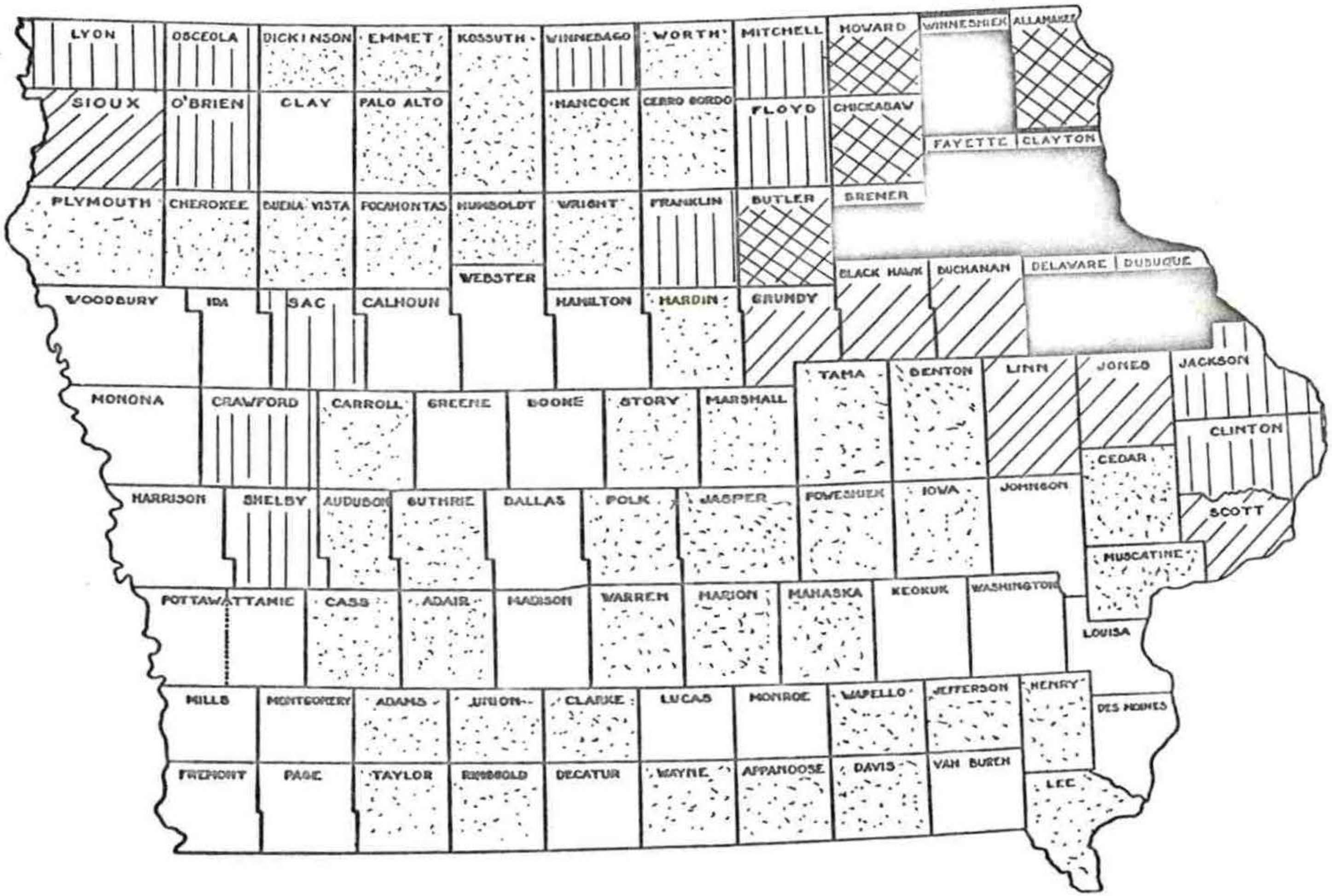

Figure 4. Whole-milk equivalent marketed by county, 1963
(density in hundredweight per square mile)

Under 500

500 to 1,000

1,000 to 1,500

1,500 to 2,000

2,000 to 3,000

Over 3,000

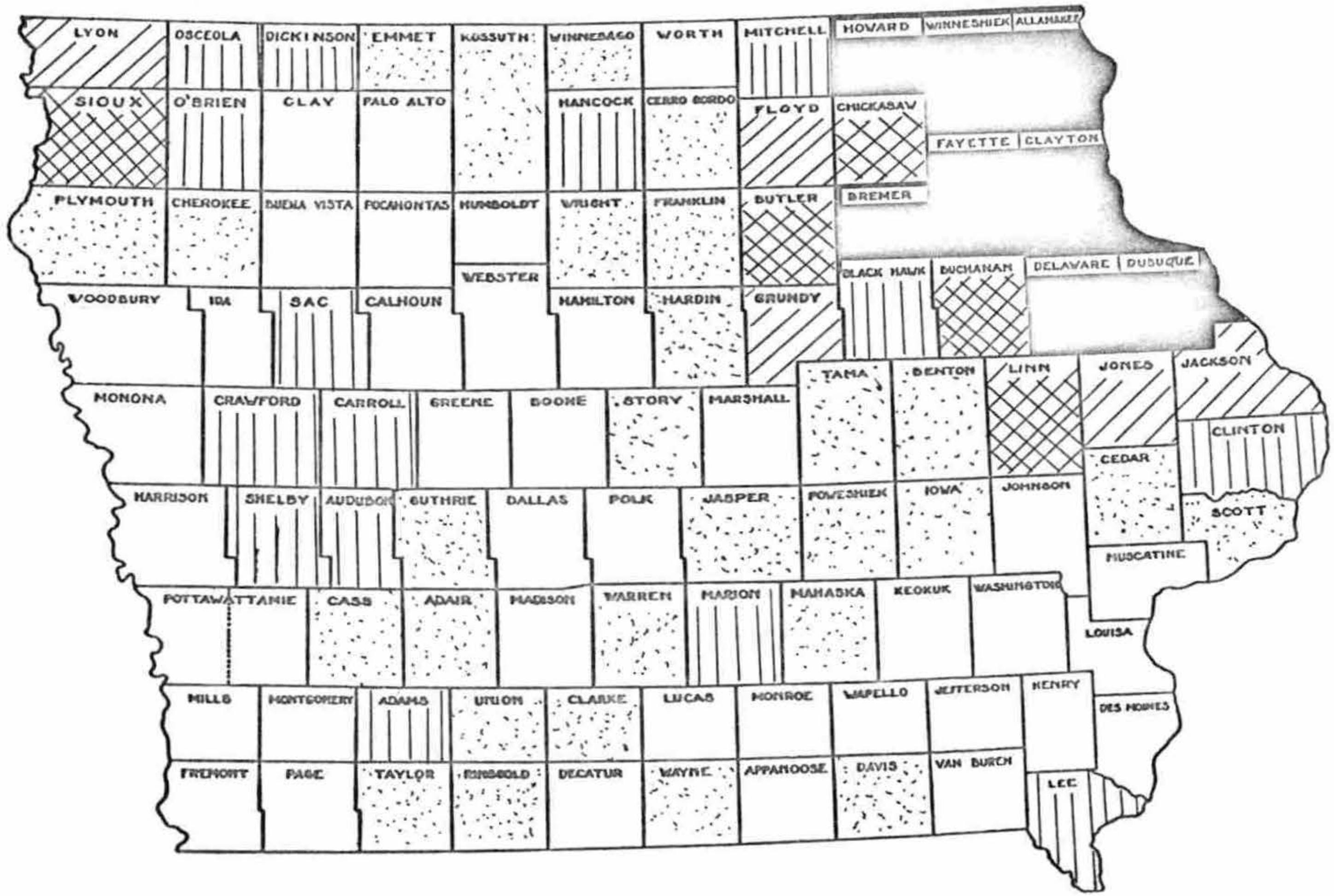

Figure 5. Estimated whole milk equivalent marketed by county, 1975 (density in hundredweight per square mile)

Under 500

500 to 1,000

1,000 to 1,500

1,500 to 2,000

2,000 to 3,000

Over 3,000

Table 3. Summary of plant location data, hauling costs and receiving station volumes

	Alternative Surplus Plant Locations	D 81 Des Moines	D 82 Marshalltown	D 83 Brooklyn	D 84 Marion	D 85 Hudson	D 86 Maquoketa Valley	D 87 Coggon	D 88 Jessup
	1963 Situation, Hauling Costs								
	Grade A Milk	$494,427.95	$441,615.02	$416,784.68	$364,890.01	$374,590.61	$344,317.32	$340,088.75	$346,725.95
	Ungraded Milk	121,520.20	145,348.18	147,757.68	215,699.79	195,828.50	254,730.73	229,932.03	224,205.52
	Combined	$615,948.15	$586,963.20	$564,542.36	$580,589.80	$570,419.11	$599,048.05	$570,020.78	$570,931.47
	Receiving Station Volumes in cwt.								
Grade A	Marion Total	194,626.20	-0-	-0-	-0-	-0-	-0-	-0-	-0-
	Annual Average/Day	533.22	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Grade B	Des Moines Total	-0-	117,125.48	154,206.72	190,175.48	162,788.37	204,151.98	190,175.48	196,763.76
	Annual Average/Day	-0-	320.89	422.48	521.03	445.99	559.32	521.03	539.08
Grade B	Exira Total	128,147.91	155,459.28	185,767.38	185,767.38	185,767.38	200,632.30	185,767.38	185,767.38
	Annual Average/Day	351.09	425.91	508.95	508.95	508.95	549.68	508.95	508.95
Grade B	Brooklyn Total	-0-	-0-	-0-	7,748.03	-0-	95,421.47	18,059.33	10,311.30
	Annual Average/Day	-0-	-0-	-0-	21.23	-0-	261.43	49.48	28.25
	1975 Situation, Hauling Costs								
	Grade A Milk	$651,212.61	$587,205.31	$562,540.16	$492,346.30	$507,213.38	$455,842.01	$462,118.51	$468,986.77
	Ungraded Milk	102,452.90	125,183.68	133,049.10	193,846.91	173,937.54	234,634.80	207,430.46	200,796.16
	Combined	$753,665.51	$712,388.99	$695,589.26	$686,193.21	$681,150.92	$690,476.81	$669,548.97	$669,782.93
	Receiving Station Volumes in cwt.								
Grade A	Marion Total	493,911.90	206,178.33	357,069.80	-0-	84,419.13	-0-	-0-	33,204.68
	Annual Average/Day	1,353.18	564.87	978.27	-0-	231.29	-0-	-0-	90.97
Grade B	Des Moines Total	-0-	-0-	-0-	134,673.00	134,673.00	148,941.00	134,673.00	134,673.00
	Annual Average/Day	-0-	-0-	-0-	368.97	368.97	408.06	368.97	368.97
Grade B	Exira Total	-0-	186,537.00	186,537.00	186,537.00	186,537.00	241,319.00	186,537.00	186,537.00
	Annual Average/Day	-0-	511.06	511.06	511.06	511.06	661.15	511.06	511.06
Grade B	Brooklyn	Not used at all.							

Jessup, Marion, Hudson, Brooklyn, Marshalltown, and Des Moines being progressively more costly sites. The numbers represent the value of the objective function, $\sum_i \sum_j X_{ij}T_{ij}$, for the computer solutions. Looking at the values for the most optimum, one notices a closeness between Coggon, Maquoketa Valley, and Jessup.

The 1963 solution of ungraded milk hauling costs is almost exactly the opposite of the 1963 order of grade A milk hauling costs. In this category Des Moines is the optimum surplus plant location with Marshalltown, Brooklyn, Hudson, Marion, Jessup, Coggon, and Maquoketa Valley following in decreasing order of desirability. Overall grade B transportation hauling costs rise as surplus plant locations are considered eastward from Des Moines. This pattern of rising hauling costs results because a large amount of grade B volume is located in western Iowa. In 1963, grade B milk procurement was in western Iowa, around Des Moines, and east to the Brooklyn area.

Putting the 1963 grade A milk and ungraded milk hauling costs together to form the combined costs, the overall optimum location is Brooklyn with Hudson, Coggon, and Jessup virtually tied at a close second. Because of the savings accrued by locating nearer ungraded production sources than grade A production sources, Brooklyn's site is an optimum. However, looking at the overall combined cost order: Brooklyn, Coggon, Hudson, Jessup, Marion, Marshalltown, Maquoketa Valley, and Des Moines; the savings of locating nearer a high density grade A production area more than offset the added cost of hauling ungraded milk.

For any given surplus plant location considered, milk was allowed to pass through any one of four receiving stations located at Marion, Des Moines, Exira, and Brooklyn. The only grade A milk in the 1963 situation which passed through a receiving station was for a Des Moines surplus plant location. The Marion receiving station was used. All other milk passing through receiving stations was ungraded. The volumes of milk passing through the Brooklyn receiving station were generally too small to justify a receiving station operation.

Looking at the 1975 situation for grade A milk hauling costs, the order follows closely the 1963 order. The optimum plant location is Maquoketa Valley with Coggon, Jessup, Marion, Hudson, Brooklyn, Marshalltown, and Des Moines following in order of descending desirability.

Looking at the 1975 situation ungraded milk hauling costs, the order is exactly like the 1963 situation ungraded milk order: Des Moines most desirable, followed by Marshalltown, Brooklyn, Hudson, Marion, Jessup, and Coggon, with Maquoketa Valley the least advantageous location.

The combined hauling cost order for 1975 is Coggon, Jessup, Hudson, Marion, Maquoketa Valley, Brooklyn, Marshalltown, and Des Moines. The optimum 1975 location was more heavily influenced than the optimum 1963 location by the savings of locating the surplus plant near a high density grade A production area.

Consideration of grade B production sources in selecting a surplus plant location in 1975 becomes less important both objectively and subjectively. Objectively, the savings of locating near a high density grade A production area are greater than the added grade B transportation costs incurred. Subjectively, it would be reasonable to assume that grade B procurement sources will change over time in response to surplus plant location. If the surplus plant were located in northeast Iowa, grade B production sources in western Iowa and around Des Moines would tend to convert to grade A production and supply the Des Moines, Marshalltown, and Grinnell markets or ship grade B milk to other manufacturing plants. The cost of transporting grade B milk to northeast Iowa surplus plant location from western and central Iowa would be prohibitive. An eastern Iowa location would probably result in increasing procurement of grade B milk in that vicinity in the future.

In all but three surplus locations considered in 1975, grade A milk was shipped from counties in the northeast Iowa milkshed area through the Marion receiving station to Des Moines. Only grade B milk passed through the Des Moines and Exira receiving stations. Brooklyn was not used at all as a receiving station.

Shipment Patterns

Figures 6, 7, 8, and 9 are samples of the routing patterns for grade A milk with the surplus plant located at selected sites. Grade B milk hauling patterns are not shown, but all "B" milk can be pictured as going to the surplus plant.

Figure 6 is a good example of high hauling costs for grade A milk. In order to satisfy the milk requirements for the Des Moines market, milk must

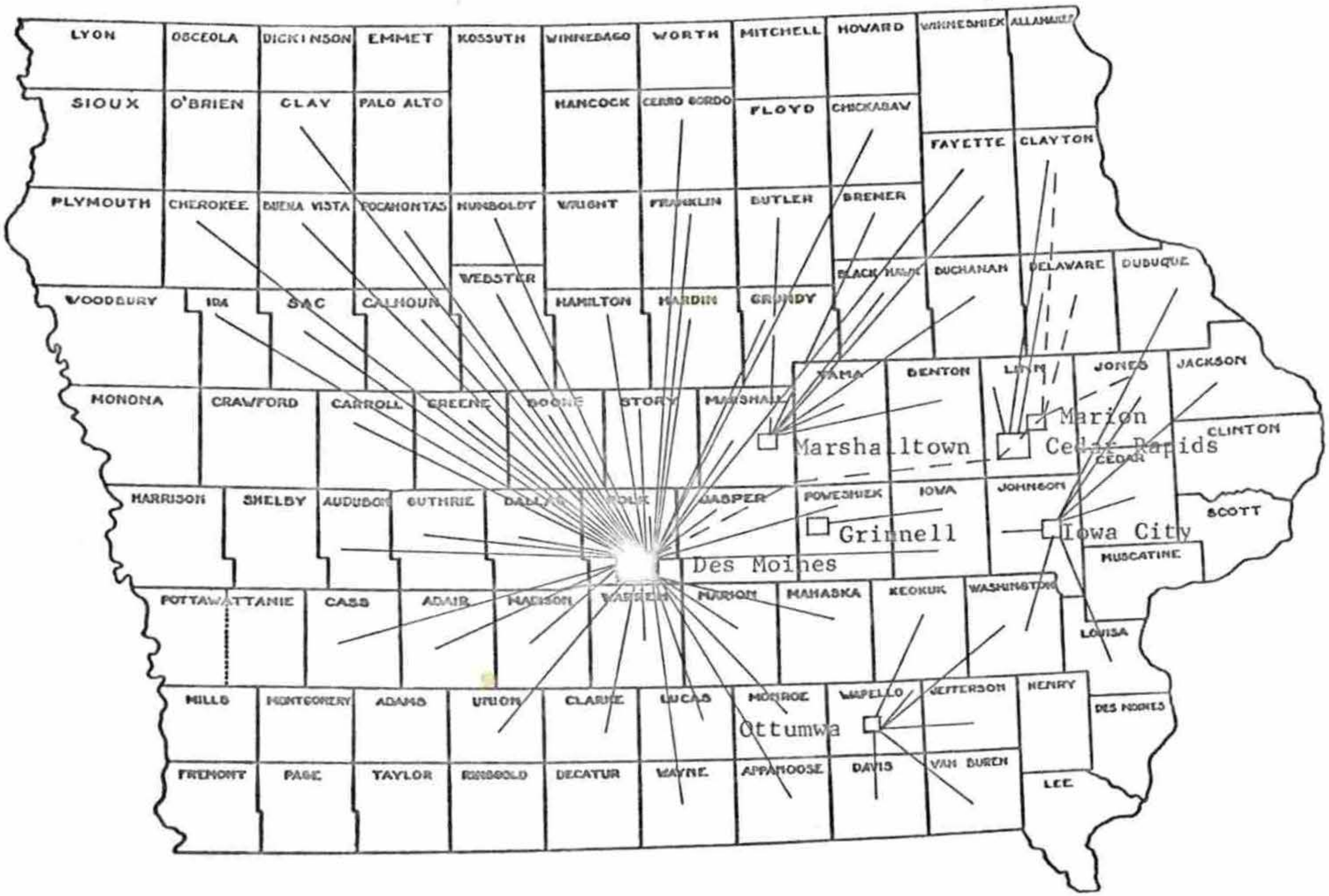

Figure 6. Optimum 1963 routing pattern for grade A milk with the surplus plant located at Des Moines, D81 (------denotes milk routed through receiving station)

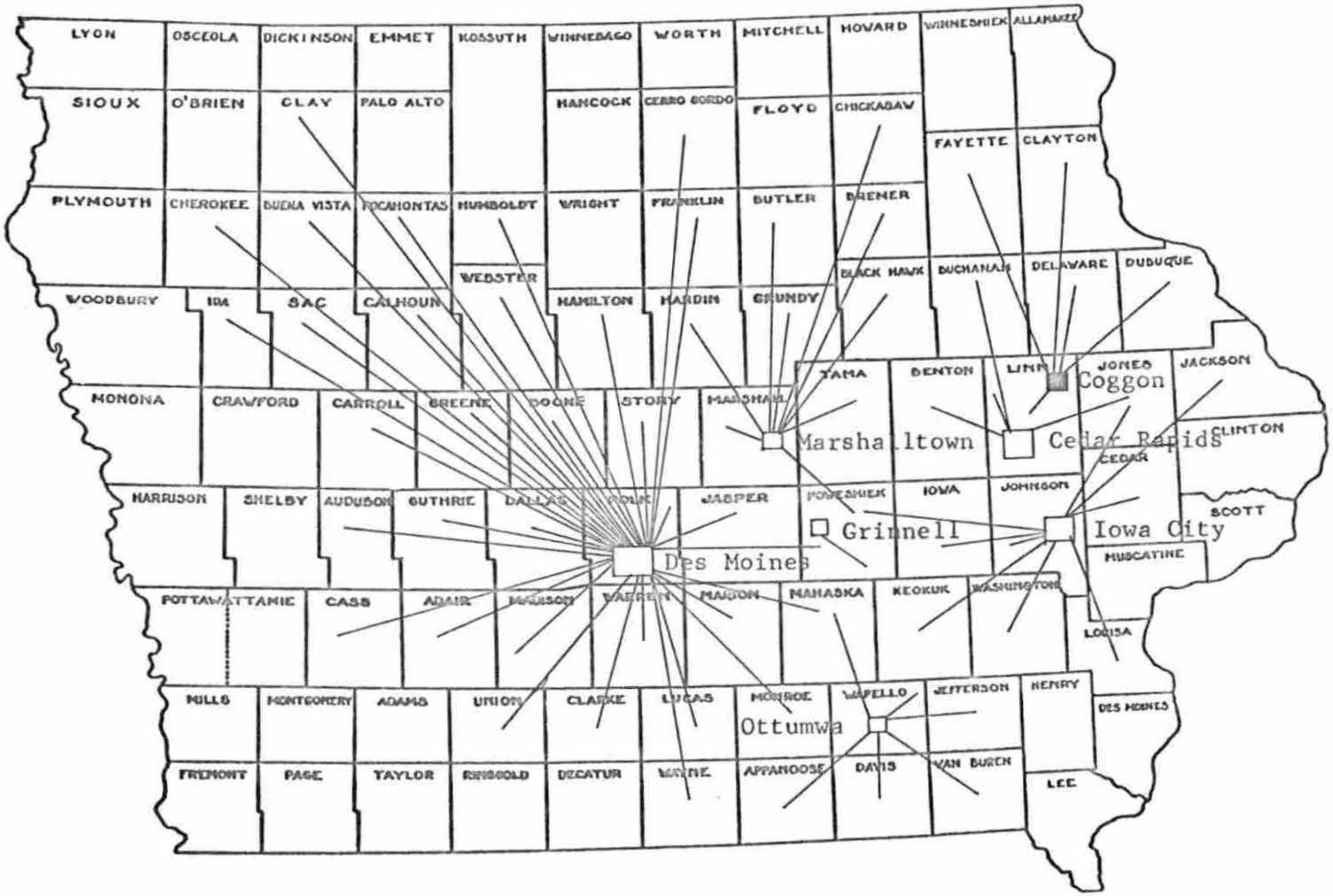

Figure 7. Optimum 1963 routing pattern for grade A milk with the surplus plant located at Coggon, D87

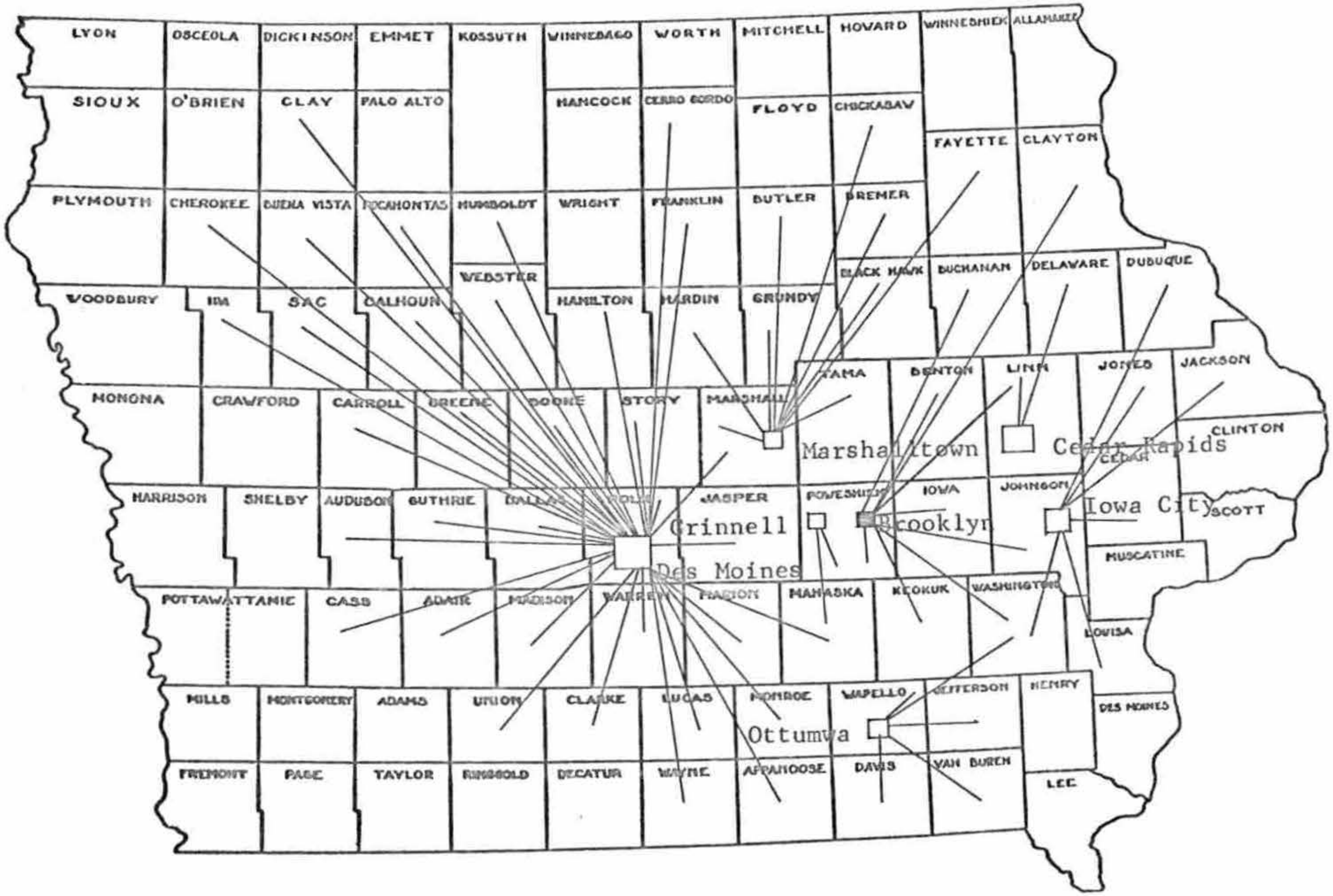

Figure 8. Optimum 1963 routing pattern for grade A milk
with the surplus plant located at Brooklyn, D83

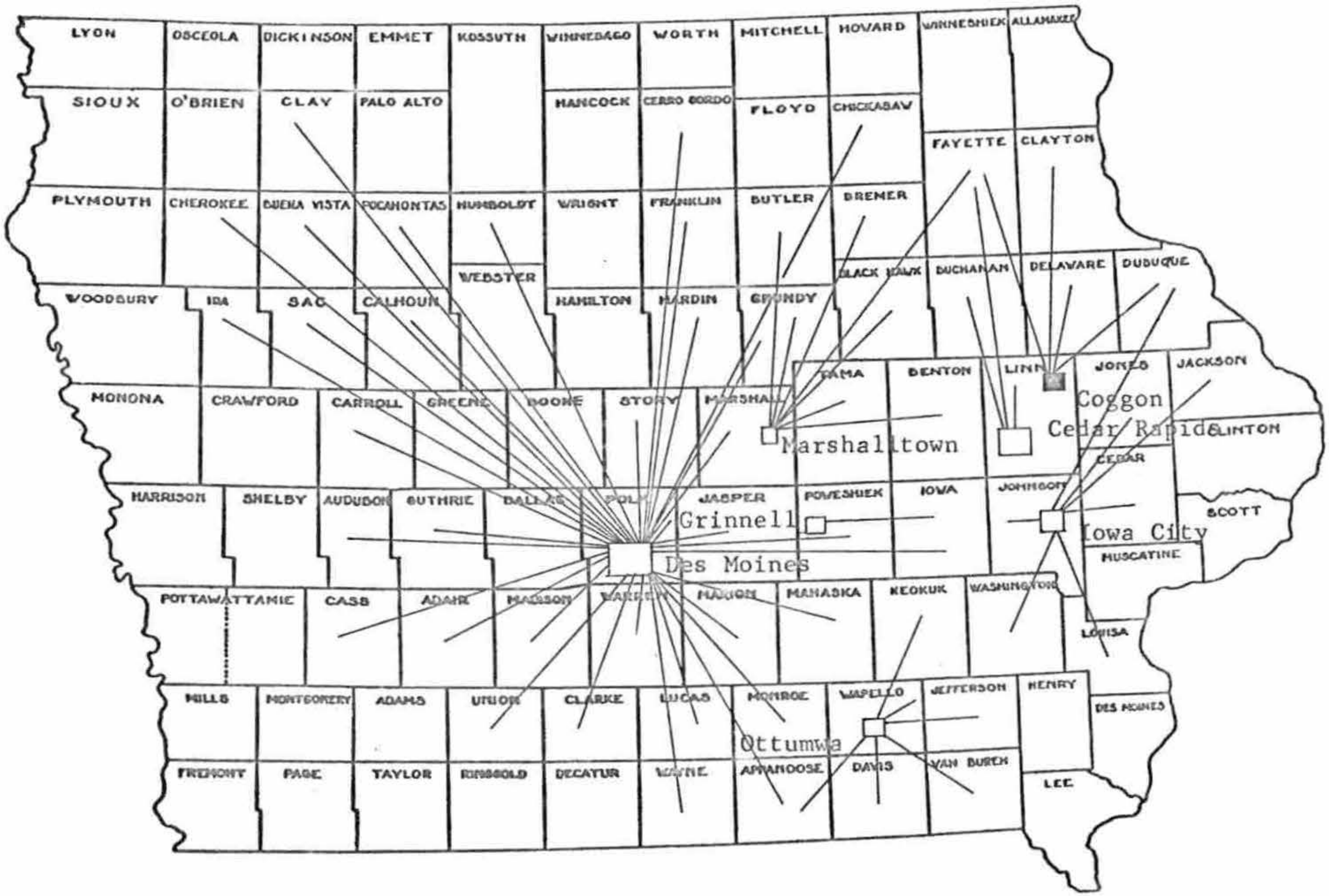

Figure 9. Optimum 1975 routing pattern for grade A milk
with the surplus plant located at Coggon, D87

be shipped from a widely dispersed area. It is costly to ship milk to Des Moines from such far-away counties as Clayton, Delaware, Fayette, and Chickasaw. When the surplus plant is located at Coggon (Figure 7), the milk requirement of the Des Moines market has been substantially reduced and Des Moines now draws milk from a less widely dispersed area. The surplus plant at Coggon is in a high density milk production area, resulting in the surplus plant drawing milk from nearby counties.

For all hauling patterns, the Des Moines market draws milk from a wide area due to a high milk requirement and due to central Iowa's not being a high density milk production area. The other markets fill their milk requirements from nearby and eastward counties depending upon the surplus plant location. The Des Moines market has a strong influence upon milk patterns.

The overall optimum location for 1963 (Figure 8), Brooklyn, draws milk from a wider area than does the optimum 1963 grade A location, Coggon. However, Brooklyn is the overall optimum due to lower ungraded milk hauling costs as a result of being closer to ungraded milk production areas.

In 1975, the overall optimum location is Coggon (Figure 9). The Coggon surplus plant site draws milk from nearer counties than does the 1963 overall optimum, Brooklyn. However, the Coggon site is further away from ungraded production areas. The savings in grade A milk hauling costs by locating the surplus plant near high density production counties has a greater influence in determining the overall optimum location in 1975 than in 1963.

It is not always least costly, from the total cost viewpoint, for a milk producer to ship milk to the nearest market. Consider the grade A producer in Monroe county. If this producer is paying his own hauling costs, it is cheapest for him to haul milk to the nearest market, Ottumwa. However, from the total cost viewpoint, it is cheaper to have the Monroe county producer ship his milk to the Des Moines market and have the Ottumwa market obtain its milk from other counties not necessarily as close to Ottumwa as Monroe.

Marginal Costs

The optimal solution of the transportation model simultaneously yields marginal cost values or "shadow prices". These marginal cost values correspond to the value of the slack vectors in the optimal solution tableau. The difference between any two marginal costs shows the increase or decrease in transportation costs of shifting one unit (hundredweight) of milk production from one county to another.

The "shadow prices" of the 1963 program solution with the surplus plant located at Coggon are shown on Figure 10. The marginal cost for Clay county is zero. The transportation coefficient ($.4436) for shipping milk from Clay county to Des Moines was the largest coefficient appearing in this optimum solution. Thus, if one hundredweight of milk production is shifted from Clay to any other county, the total transportation costs will be reduced by the marginal value of the other county. If a hundredweight is shifted from Clay to Humboldt county, the saving is $.1860 - $.000 =

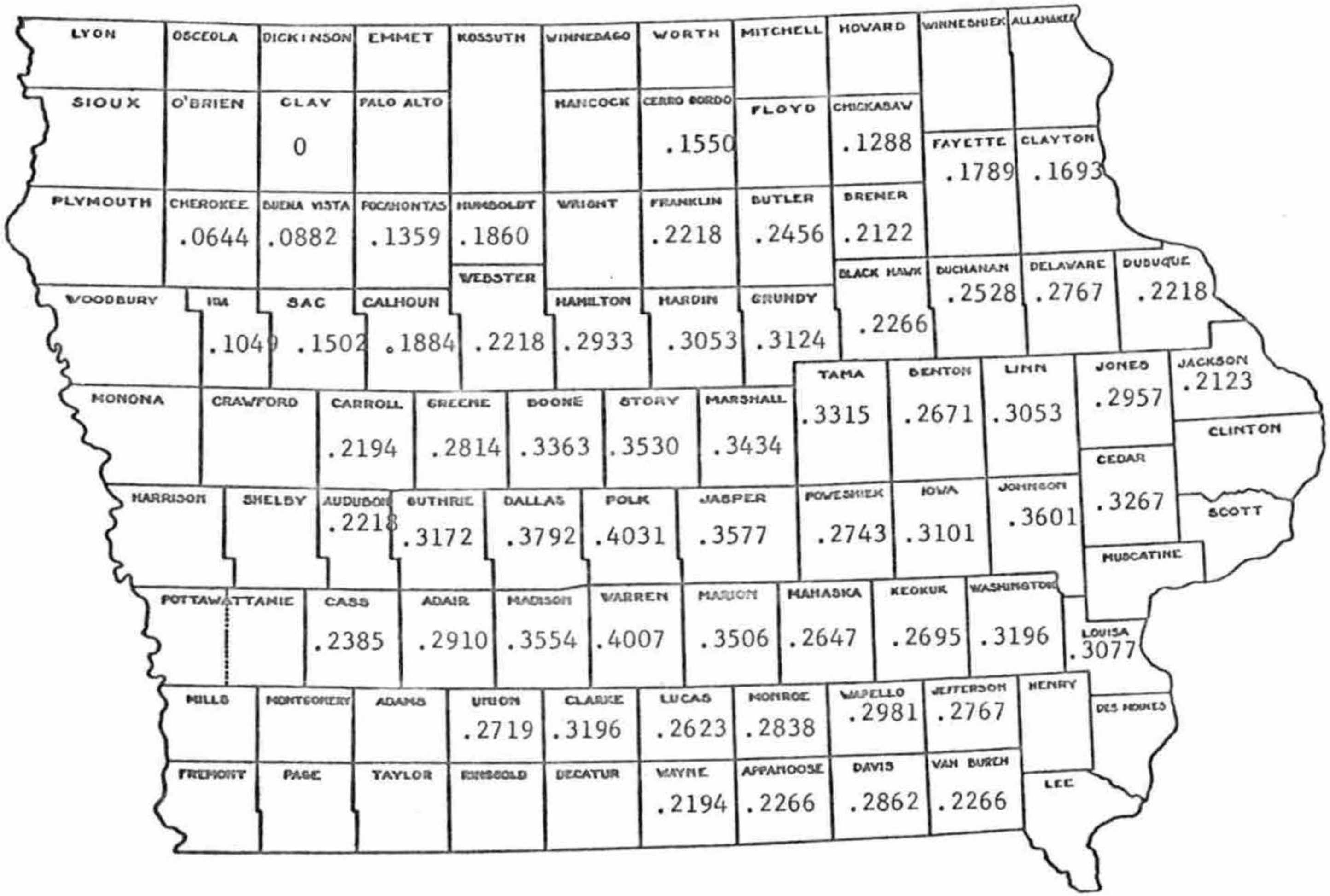

Figure 10. "Shadow prices" of 1963 solution with the surplus plant located at Coggon

$.1860. The changes in total transportation costs in shifting production between any two counties is the difference in the marginal values or "shadow prices" of the counties involved. Shifting one hundredweight of production from Poweshiek to Polk county would save $.1288 ($.4031 - $.2743). Each marginal value is in units of dollars per hundredweight.

The differences between these marginal values indicate the maximum amount that can be saved (or dissaved) by shifting a hundredweight of production. A similar reduction in costs by shifting succeeding production units between any two counties is not necessarily true. However, given that the same transportation coefficient is related to the production of its county, it is possible to shift a relatively large number of hundredweight of milk from one county to another.

By looking at the Coggon marginal values on Figure 10, it is shown that transportation costs are reduced by moving production closer to markets. The Cooperative can reduce aggregate transportation costs by shifting production from lower to higher marginal valued counties. The most profitable counties in which to increase production would be the counties near large population centers and farthest from the general surplus areas in the state. Increasing milk production in counties around Des Moines has the greatest effect in reducing aggregate transportation costs.

Pricing and Hauling Rates

The Cooperative operates in two Federal Milk Marketing orders, the Des Moines order with a marketing area covering twenty-two counties in central Iowa and the Cedar Rapids-Iowa City order covering the corporate limits of those two cities. All milk sold by handlers within the order marketing areas used for fluid or bottle uses is priced at Federal Order Class I price. All milk which is not bottled, including approved milk processed in the Cooperative surplus plant, is priced at Federal Order Class II price which is lower than the Class I rate. Handlers located in Polk county pay the Class I price for milk used for fluid purposes. Class I price to handlers in the marketing area outside Polk county is $.10 lower than the reported Class I price. Approved milk received by handlers outside the area is priced with additional reductions in Class I price depending upon their distance from the "base zone." This pricing arrangement is used to negate any advantage a handler may have by locating close to market outlets. The total values of Class I and Class II milk are added together to determine the total value of milk in the Order. Blend price for the Order is determined by dividing the total value of Order milk by the total volume of Order milk.

For the Cooperative, the total value of member milk is equal to the sum of member Class I and Class II milk values, plus or minus any gain or loss in the manufacturing operation, and payments to or from the milk market administrater. Market administrater payments to or receipts from the Cooperative cover any differences between Federal Order and Cooperative blend prices occurring because of Cooperative milk sales to dealers outside the order area and handling the surplus for the market. The Cooperative blend price equals the total value of Cooperative member milk divided by the volume of Cooperative milk. The Cooperative deducts fees and charges from the Cooperative blend price to get Cooperative producer net price. From the producer net price, the Cooperative also deducts the hauling rate ($/cwt) due the farm pick-up trucker plus any other deductions authorized by the producer to get the net payment due. The Cooperative can negotiate with handlers for additional charges or rates to be added to the Class prices.

The merger of cooperatives spoken of in the introduction may cause the merger of the Federal Milk Orders involved into one Order with market location class and blend price differentials to producers.

On Figures 11, 12, 13 and 14 are hauling rates per hundredweight (negotiated hauling rates) versus total length of route for bulk, over-the-road, and can type hauling. Also graphed are the values of "standard" rates (.2385, .3445, and .1283¢/cwt/mi) times milage, the transportation function used in determining model transportation coefficients. Looking at the graphed standard rates, one sees that the negotiated rate is not responsive to length of route. The over-the-road tanker cost per hundredweight is responsive to miles traveled. The Cooperative has a contract rate arrangement with a private trucker for over-the-road tanker operation. The contracted rates and derived transportation coefficients for over-the-road tanker are nearly identical functions of mileage. Bulk and can farm pick-up rates are negotiated between farmers and haulers.

The negotiated bulk and can farm pick-up standard rates are nearly constant with respect to length of route. The differentials in negotiated rates are possibly due to such factors as bargaining strengths of farmer and hauler and quality of service by the hauler. In general, there seems to be a lack of standard rate differentials in response to route length.

The model transportation coefficients are a linear function of length of route. By making transportation costs a function of mileage, then transportation cost differentials between counties result from their varying distances from markets. These transportation differentials are

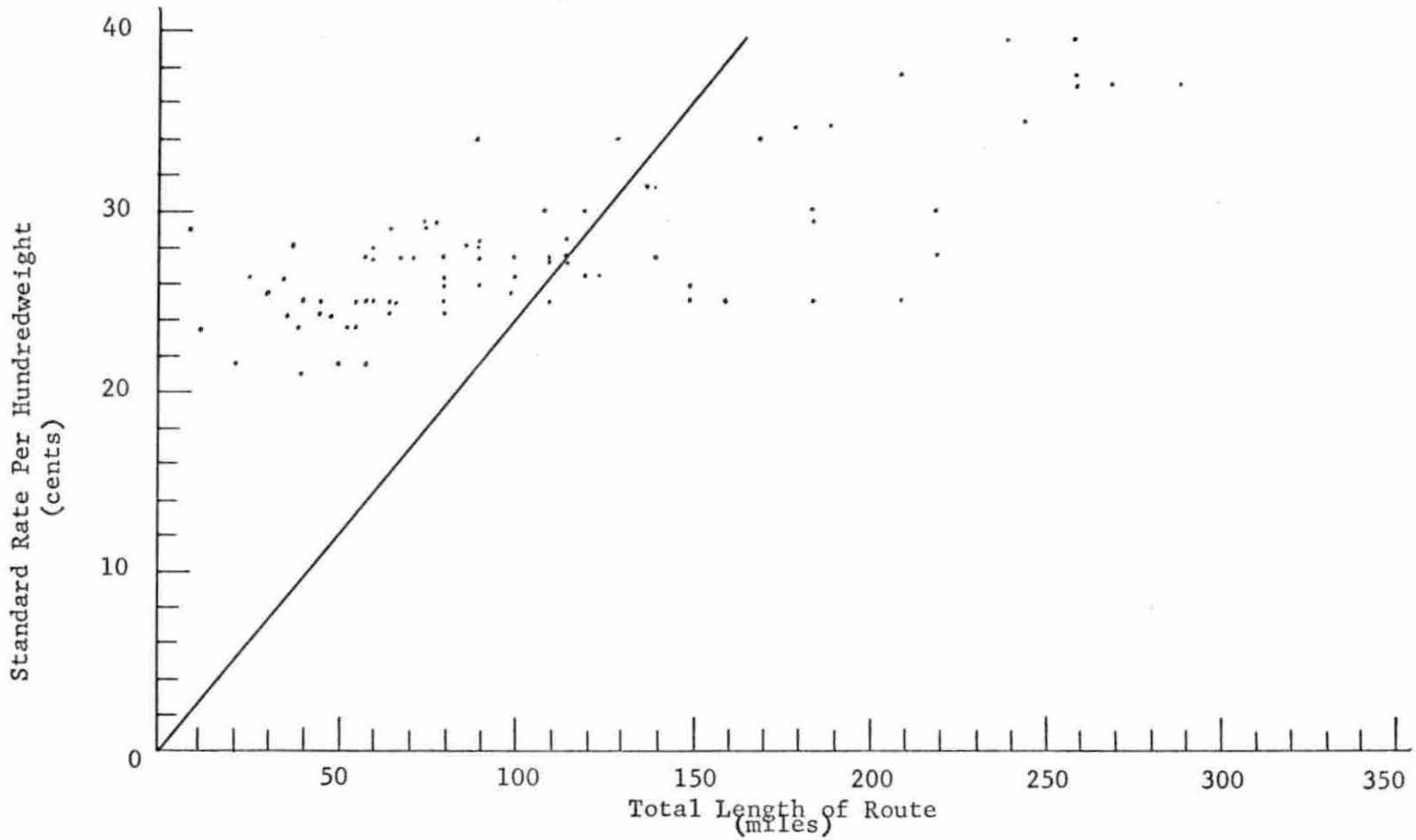

Figure 11. Des Moines area grade A and B bulk standard rates versus route length

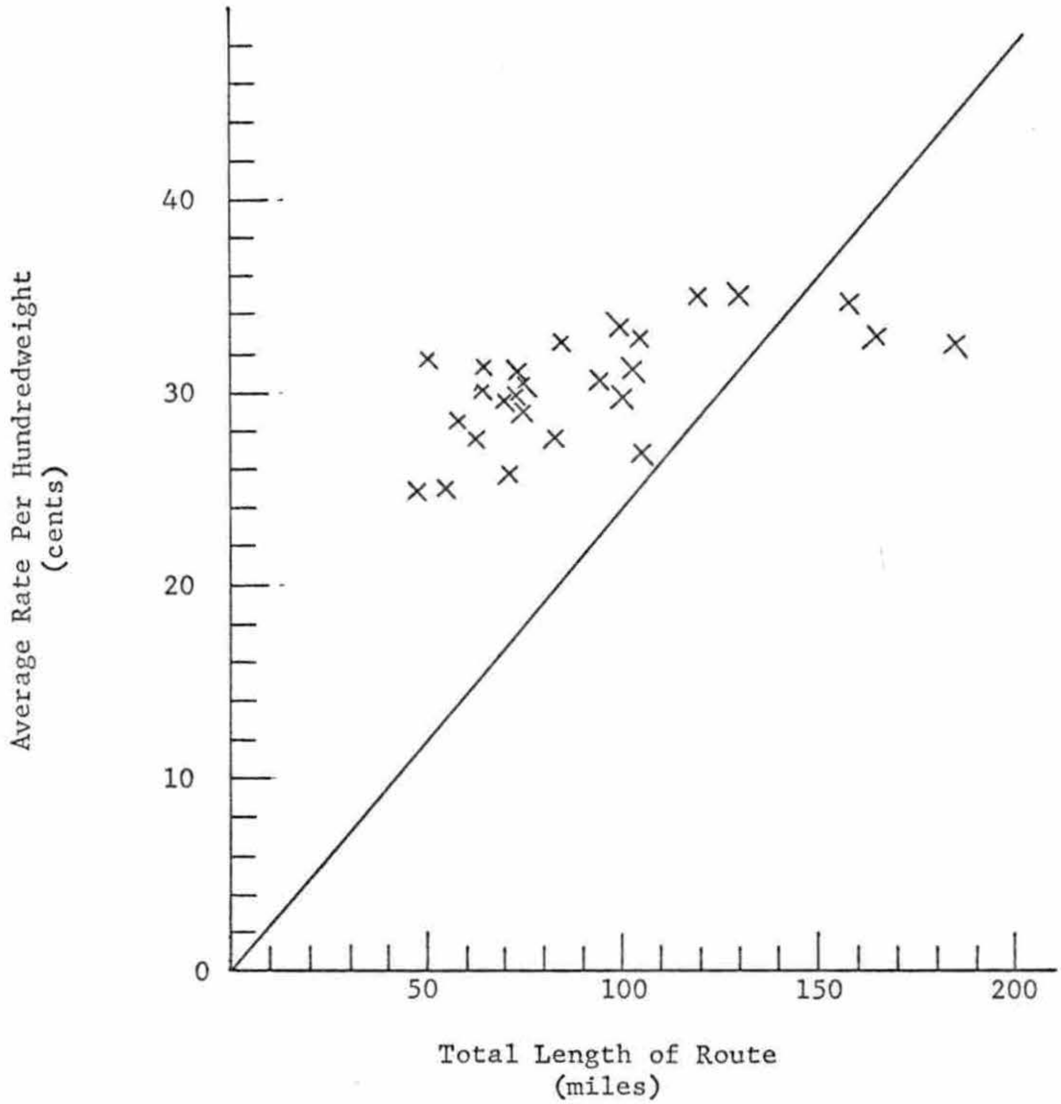

Figure 12. Cedar Rapids area grade A bulk average rate per route versus length

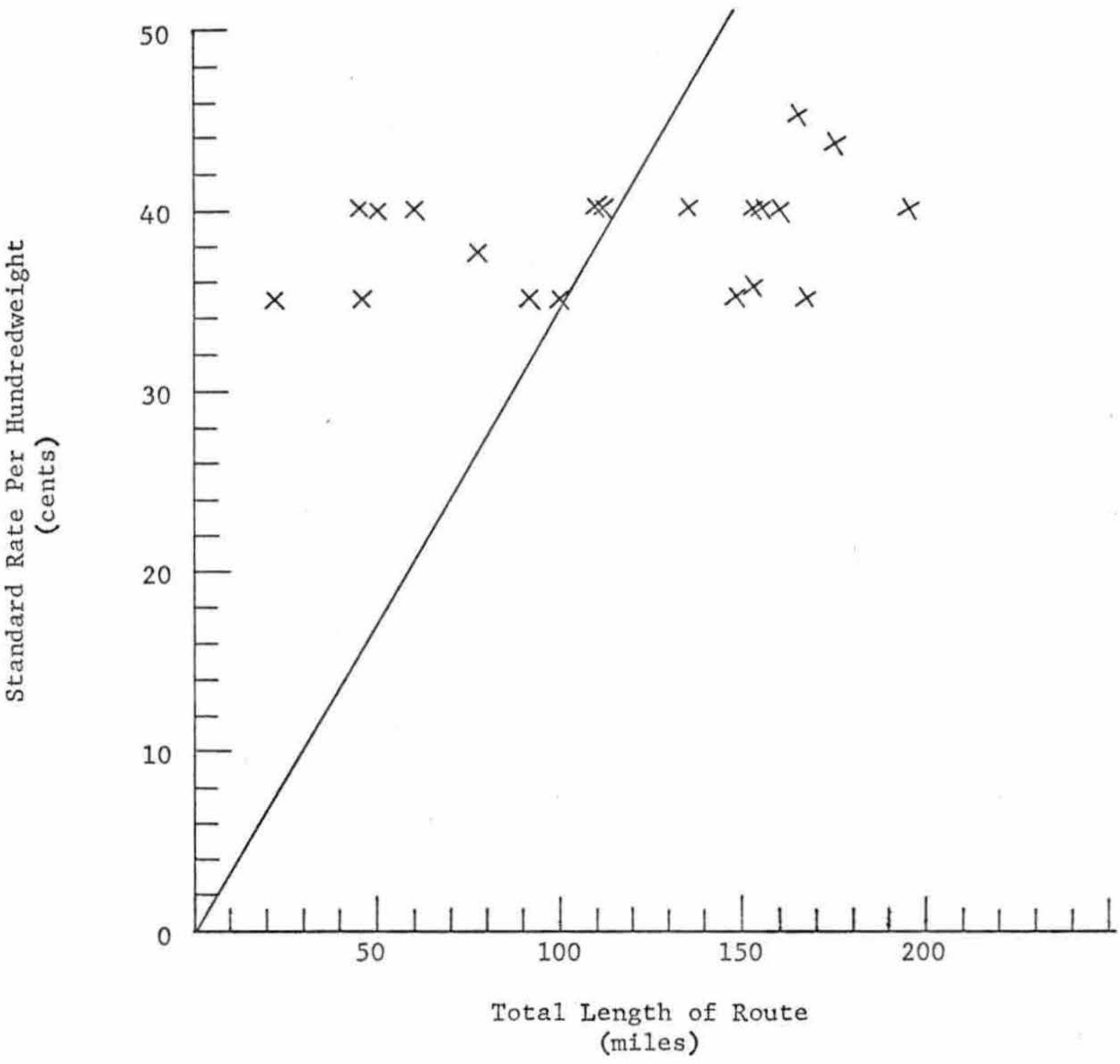

Figure 13. Des Moines area grade B can standard rate versus route length

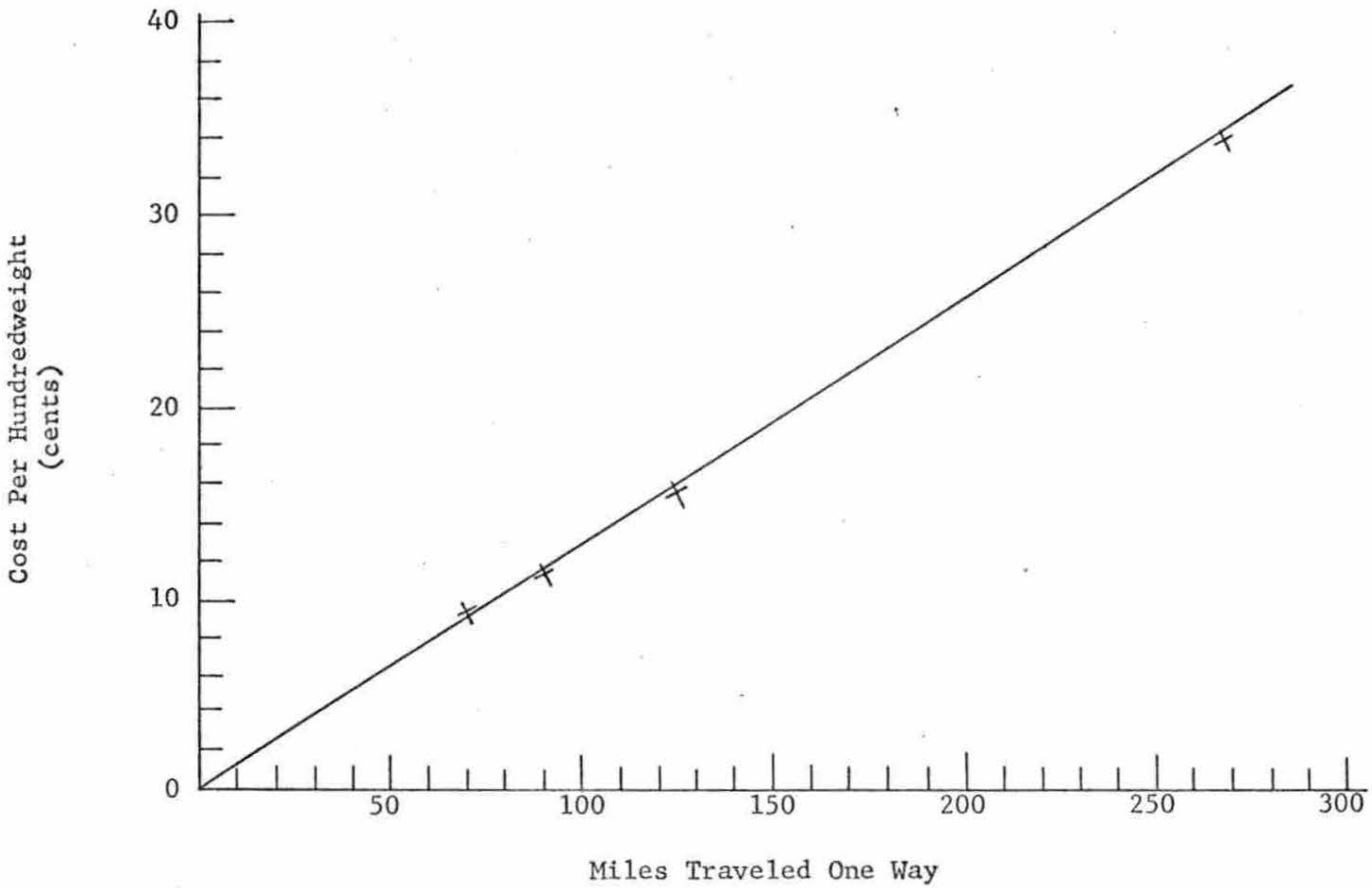

Figure 14. Over-the-road tanker hauling rate versus route length

the basis upon which the transportation model selects among possible county milk shipments to markets. The model transportation coefficients reflect the variable costs of hauling (gas, oil, etc.) while negotiated standard rates do not reflect the marginal costs of hauling the additional miles traveled.

Comparing negotiated standard rates to the model transportation function on the following graphs, there is a difference in distribution of hauling costs between the two. If it is assumed that the model transportation function is a "realistic" transportation function, then farmers paying more than the actual hauling costs and farmers paying hauling rates to the right of the model transportation function are paying less than actual hauling costs.

With negotiated standard rates ($/cwt) approximately constant with respect to miles for bulk and can hauling, then aggregate transportation costs are spread among farmers roughly equally per unit volume of milk hauled. An individual farmer's total hauling cost depends upon his volume of milk hauled. There seems to be an implicit agreement in the negotiations of haulers and farmers to avoid standard rate differentials so that Cooperative members will share equally in the transportation costs per volume. Due to such behavior, farmers closer to markets pay more than the actual transportation cost and farmers a great distance from markets will pay less than the actual transportation costs. No actual hauler cost data is available to substantiate this discrepancy between actual and negotiated transportation costs. But some discrepancy will exist due to the variable costs of hauling.

The overall result of market pricing and actual hauling costs is that individual farmers do not receive a price for their milk according to their proximity to market. Cooperative members closer to markets receive less than the true value of their milk while members at greater distance receive more than the true value of their milk. Implicit within Cooperative members' actions is the notion that they share aggregate transportation costs equally by volume.

Locating the surplus plant at a site that minimizes total aggregate transportation costs could result in increased actual price per hundred-weight, hence income, to Cooperative members. With a new minimum cost location, the process of adjustment to increase member income with present practices would be as follows. A new minimum cost location with present negotiated hauling rates would result (assuming optimum hauling pattern) in haulers as a group receiving additional income due to less hauling expense with the new location. The amount of additional income would be equal to aggregate transportation costs at the old site minus aggregate transportation costs at the new minimum cost site. To pass this additional income onto member farmers from haulers, hauling rates would have to be renegotiated in order to reflect the savings in aggregate transportation costs. These savings would be reflected in a general lowering of overall hauling rates, hence, an increase in actual net price to the farmer. In this adjustment process, farmers only benefit if the savings in aggregate transportation costs are passed from hauler to farmer in lowered hauling rates.

To insure that Cooperative members receive the benefits of a new minimum cost location, actual hauler transportation costs should be determined so that actual rates can be readjusted. This readjustment of rates may have to come about by a change in present hauling determination procedures and methods.

Implicit within Cooperative member action is avoidance of hauling cost per hundredweight differentials. It would seem that the Cooperative is truly "cooperative" in that aggregate transportation costs are spread relatively equally per hundredweight among members. If the Cooperative surplus plant is relocated to a minimum cost site, then increased income will accrue to Cooperative members as a group if there is a general lowering to members of hauling cost per hundredweight.

Limitations of Study

This study does not settle the specific problem of choosing a definite location. Several important factors in selecting a definite surplus plant location are cost of site, labor supply, local tax structure, accessibility to highways and railways, water and electricity supplies and rates, and accessibility to finished product markets.

Other Uses of the Analytical Framework

The analytical framework used in solving for the optimum location can be adapted to other problems of interest to dairy cooperatives and similar firms. For a given surplus plant site, actual hauling rates and routes can be used to determine the optimal hauling pattern for weekdays, weekends, and during specific seasons of the year. The necessary data for carrying out such computations is shown on Figure 15.

The framework can also be used to chose the most profitable market and the resulting transportation pattern. This is especially applicable in selling surplus milk and dairy products among several markets. Also, the analytical framework can be used to determine the feasibility of proposed receiving stations and storage facilities.

		Markets or Destination						
		Exira	Des Moines	Brooklyn	Marshalltown	Grinnell	Ottumwa	Etc.
Anticipated Days Requirements (cwt.)								

Route Loads & Rates

Route No.	Anticipated Size of Load							
	(cwt.)							
3.	________	____	____	____	____	____	____	____
4.	________	Enter here average rate per cwt. negotiated to each market or destination. For destinations the hauler will not or cannot reasonably be expected to drive to because of distance and the length of day he would put in, enter $.9999.						
6.	________							
7.	________							
'	________							
'	________	____	____	____	____	____	____	____
'	________	____	____	____	____	____	____	____
'	________	____	____	____	____	____	____	____
etc.	________	____	____	____	____	____	____	____

Receiving Stations

Receiving Station	Anticipated cost per cwt.							
Exira	________	____	____	____	____	____	____	____
Des Moines	________	Enter here average cost per cwt. for hauling in a tanker to each market. (Cost per load divided by average size of load hauled)						
Brooklyn	________							
Marion	________	____	____	____	____	____	____	____

Figure 15. Data form for IBM computer routing of milk

SUMMARY

The transportation model of linear programming was used to determine the optimum location of a surplus milk manufacturing plant and the resulting shipment patterns. Eight alternative sites were selected and the optimum locations were determined for 1963 and 1975.

The optimum 1963 location was Brooklyn. It was a favorable location due to its proximity to ungraded milk production.

The optimum 1975 location was Coggon. Projected production and consumption trends resulted in a definite shift in optimum site away from Brooklyn to a high density milk production area. The results of the study agree with theory that the surplus plant should be located at the point of highest density milk production.

The study showed how quantitative techniques can be applied to milk industry problems to supply information to make management decisions. Besides the use of the analytical framework for this specific study, additional possible uses in solving other dairy management problems were mentioned.

Increased income can accrue to Cooperative members if the surplus plant is located to minimize transportation costs.

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APPENDIX

Table 4. Numerical 1963 solution for grade A milk surplus plant located at Brooklyn, D83 (functional value $416,784.68; volumes in hundredweight)

No.	County	Supply (cwt.)	D1 Des Moines 1,930,954.84	D2 Marshalltown 457,735.99	D3 Grinnell 41,268.86	D4 Ottumwa 136,404.56	D5 Cedar Rapids 424,173.51	D6 Iowa City 275,574.79	D83 Brooklyn 629,981.39
01	Adair	40,656.53	40,656.53						
04	Appanoose	18,113.88	18,113.88						
05	Audubon	33,929.38	33,929.38						
06	Benton	166,755.58							166,755.58
07	Black Hawk	37,118.74		37,118.74					
08	Boone	39,072.34	39,072.34						
09	Bremer	35,102.41		35,102.41					
10	Buchanan	91,098.97							91,098.97
11	Buena Vista	15,154.25	15,154.25						
12	Butler	8,244.53		8,244.53					
13	Calhoun	7,078.30	7,078.30						
14	Carroll	14,147.79	14,147.79						
15	Cass	245.88	245.88						
16	Cedar	27,348.07						27,348.07	
17	Cerro Gordo	5,812.42	5,812.42						
18	Cherokee	6,319.78	6,319.78						
19	Chickasaw	5,624.17		5,624.17					
20	Clarke	32,098.39	32,098.39						
21	Clay	3,721.92	3,721.92						
22	Clayton	68,041.34							68,041.34
25	Dallas	179,100.97	179,100.97						
26	Davis	9,771.47				9,771.47			
28	Delaware	251,205.74					251,205.74		
31	Dubuque	52,759.89						52,759.89	
33	Fayette	63,373.51		63,373.51					
35	Franklin	61,973.18	61,973.18						
37	Greene	33,226,16	33,226.16						
38	Grundy	36,778.81		36,778.81					
39	Guthrie	64,485.76	64,485.76						
40	Hamilton	11,608.44	11,608.44						
42	Hardin	59,984.31		59,984.31					
46	Humboldt	6,190.67	6,190.67						
47	Ida	3,286.47	3,286.47						
48	Iowa	88,555.28							88,555.28
49	Jackson	3,032.07						3,032.07	
50	Jasper	257,659.54	257,659.54						
51	Jefferson	2,365.04				2,365.04			
52	Johnson	68,727.97							68,727.97
53	Jones	186,355.83						186,355.83	

Table 4 (Continued)

No.	County	Supply (cwt.)	D1 Des Moines 1,930,954.84	D2 Marshalltown 457,735.99	D3 Grinnell 41,268.86	D4 Ottumwa 136,404.56	D5 Cedar Rapids 424,173.51	D6 Iowa City 275,574.79	D83 Brooklyn 629,981.39
54	Keokuk	9,757.47							9,757.47
57	Linn	220,119.02					172,967.77		47,151.25
58	Louisa	52.41					52.41		
59	Lucas	17,455.32	17,455.32						
61	Madison	60,402.97	60,402.97						
62	Mahaska	63,380.91	59,032.83		4,348.08				
63	Marion	140,778.70	140,778.70						
64	Marshall	171,205.37	41,586.45	129,618.92					
68	Monroe	43,899.67	43,899.67						
76	Pocahontas	23,780.08	23,780.08						
77	Polk	233,994.15	233,994.15						
79	Poweshiek	125,865.94			36,920.78				88,945.16
81	Sac	17,966.80	17,966.80						
85	Story	130,292.90	130,292.90						
86	Tama	81,890.59		81,890.59					
88	Union	2,147.27	2,147.27						
89	Van Buren	16,460.31				16,460.31			
90	Wapello	85,973.46				85,973.46			
91	Warren	283,085.19	283,085.19						
92	Washington	28,809.17				21,834.28		6,026.52	948.37
93	Wayne	5,483.49	5,483.49						
94	Webster	37,166.97	37,166.97						
	Total	3,896,093.94	1,930,954.84	457,735.99	41,268.86	136,404.56	424,173.51	275,574.79	629,981.39

Table 5. Numerical 1975 solution for grade A milk surplus plant located at Coggon, D87 (functional value $462,118.51; volumes in hundredweight)

No.	County	Supply (cwt.)	D1 Des Moines 2,184,641	D2 Marshalltown 472,239	D3 Grinnell 41,874	D4 Ottumwa 122,495	D5 Cedar Rapids 467,558	D6 Iowa City 365,018	D87 Coggon 644,792.62
01	Adair	50,287.51	50,287.51						
04	Appanoose	20,636.77	11,833.23			8,803.54			
05	Audubon	53,226.55	53,226.55						
06	Benton	196,267.74		196,267.74					
07	Black Hawk	36,826.87		36,826.87					
08	Boone	-0-							
09	Bremer	54,027.99		54,027.99					
10	Buchanan	138,593.26					138,593.26		
11	Buena Vista	15,858.61	15,858.61						
12	Butler	14,056.32		14,056.32					
13	Calhoun	6,156.23	6,156.23						
14	Carroll	21,710.01	21,710.01						
15	Cass	373.41	373.41						
16	Cedar	29,523.73						29,523.73	
17	Cerro Gordo	4,992.81	4,992.81						
18	Cherokee	8,585.95	8,585.95						
19	Chickasaw	9,581.72	9,581.72						
20	Clarke	46,850.59	46,850.59						
21	Clay	1,502.54	1,502.54						
22	Clayton	123,283.34							123,283.34
25	Dallas	-0-							
26	Davis	13,947.09				13,947.09			
28	Delaware	409,350.48							409,350.48
31	Dubuque	89,425.99						43,157.86	46,268.13
33	Fayette	111,087.73		42,008.22			3,188.84		65,890.67
35	Franklin	73,694.39	73,694.39						
37	Greene	-0-							
38	Grundy	60,574.14	29,585.02	30,989.12					
39	Guthrie	72,369.67	72,369.67						
40	Hamilton	-0-							
42	Hardin	54,055.93	54,055.93						
46	Humboldt	6,212.11	6,212.11						
47	Ida	1,186.28	1,186.28						
48	Iowa	114,772.33	72,898.33		41,874.00				
49	Jackson	4,613.04						4,613.04	
50	Jasper	314,482.07	314,482.07						
51	Jefferson	2,627.86				2,627.86			
52	Johnson	9,800.18						9,800.18	
53	Jones	259,879.99						259,879.99	

Table 5 (Continued)

No.	County	Supply (cwt.)	D1 Des Moines 2,184,641	D2 Marshalltown 472,239	D3 Grinnell 41,874	D4 Ottumwa 122,495	D5 Cedar Rapids 467,558	D6 Iowa City 365,018	D87 Coggon 644,792.62
54	Keokuk	4,841.66				4,841.66			
57	Linn	325,775.90					325,775.90		
58	Louisa	34.29						34.29	
59	Lucas	3,259.11	3,259.11						
61	Madison	49,864.57	49,864.57						
62	Mahaska	58,004.71	58,004.71						
63	Marion	202,383.33	202,383.33						
64	Marshall	115,547.09	115,547.09						
68	Monroe	52,290.48	52,290.48						
76	Pocahontas	26,863.39	26,865.39						
77	Polk	167,904.89	167,904.89						
79	Poweshiek	165,787.61	165,787.61						
81	Sac	28,975.05	28,975.05						
85	Story	163,980.24	163,980.24						
86	Tama	98,062.74		98,062.74					
88	Union	3,062.24	3,062.24						
89	Van Buren	18,421.69				18,421.69			
90	Wapello	73,853.16				73,853.16			
91	Warren	284,523.96	284,523.96						
92	Washington	18,008.91						18,008.91	
93	Wayne	6,749.37	6,749.37						
94	Webster	-0-							
	Total	4,298,617.62	2,184,641.00	472,239.00	41,874.00	122,495.00	467,558.00	365,018.00	644,792.62

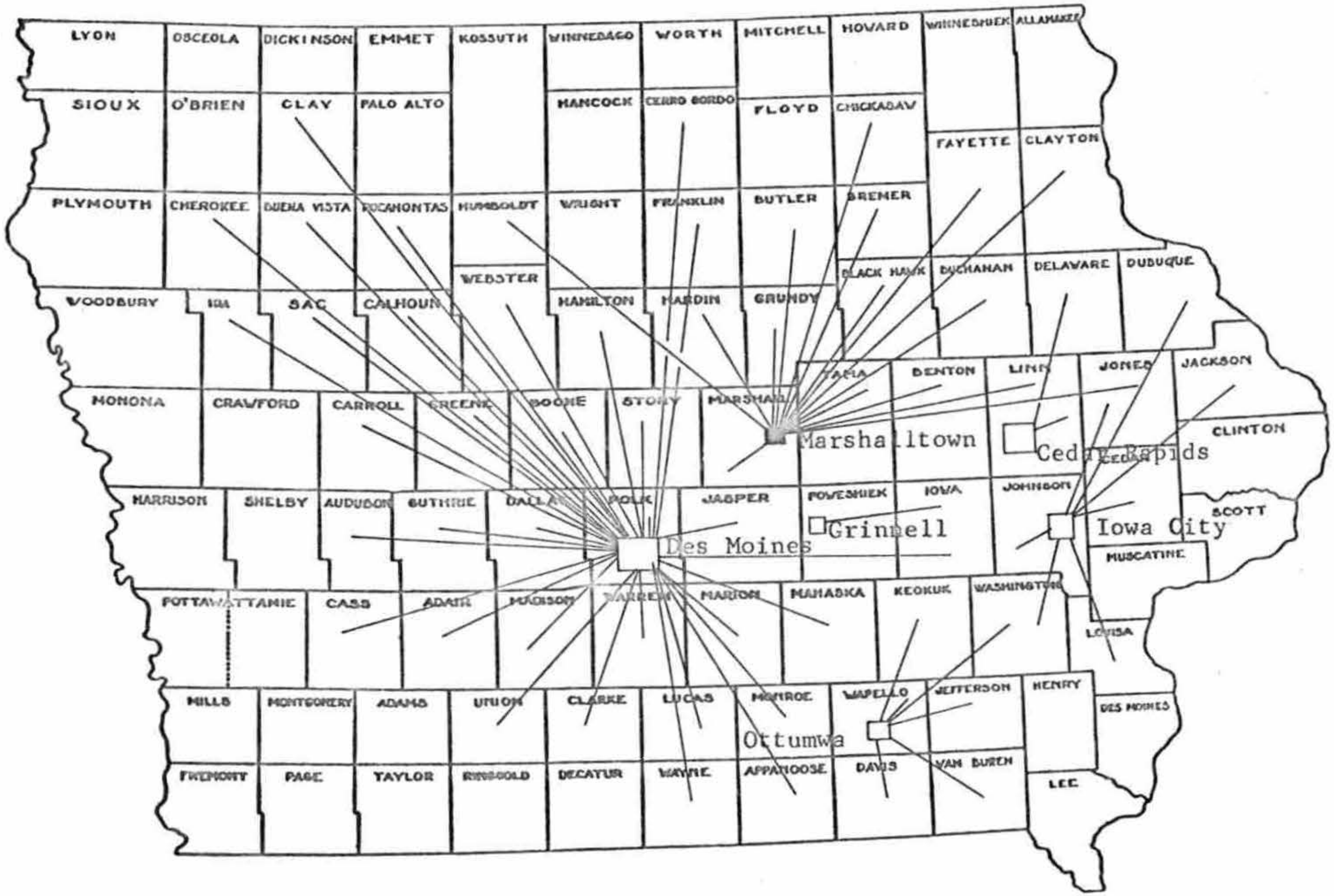

Figure 16. Optimum 1963 routing pattern for grade A milk with the surplus plant located at Marshalltown, D82

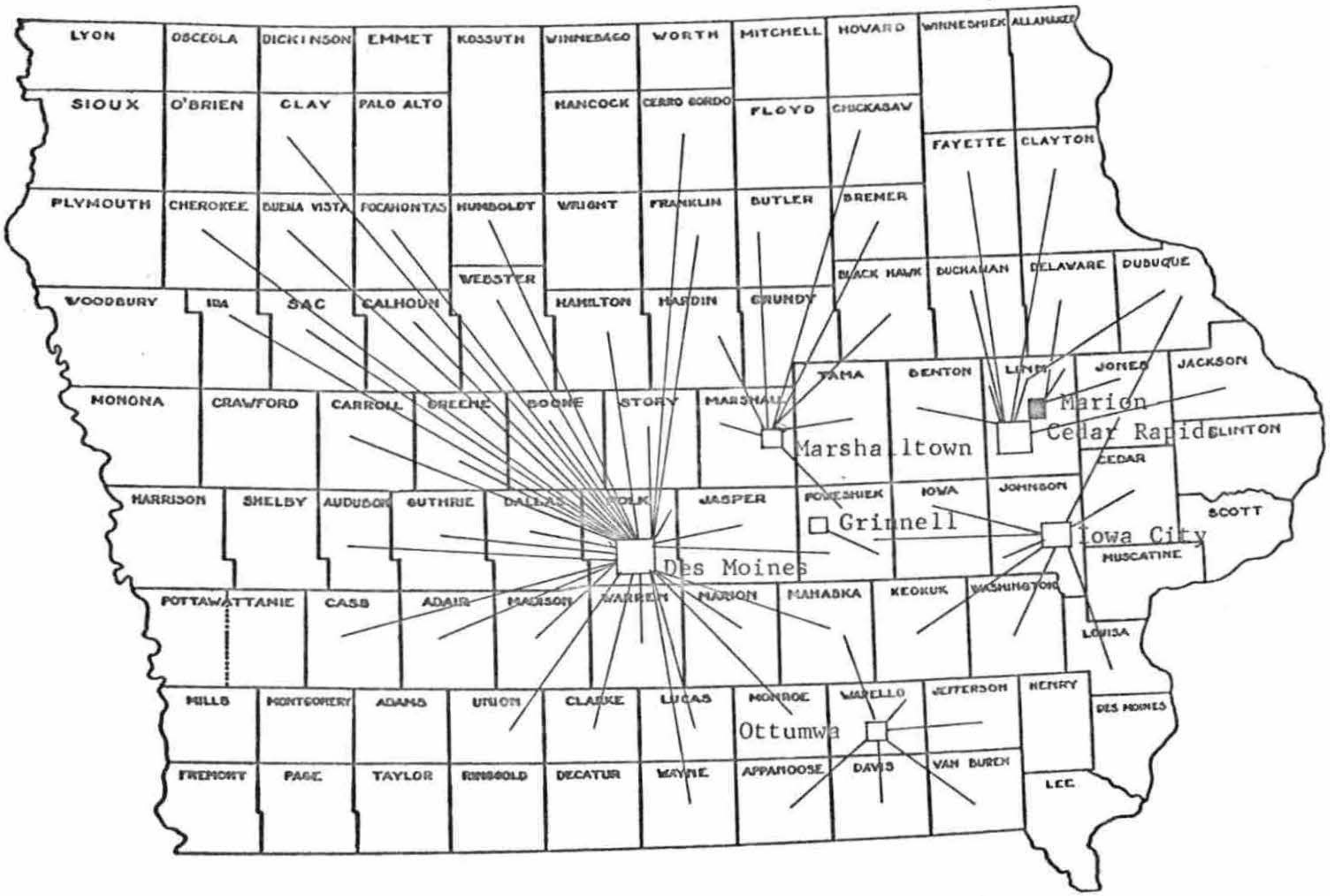

Figure 17. Optimum 1963 routing pattern for grade A milk with the surplus plant located at Marion, D84

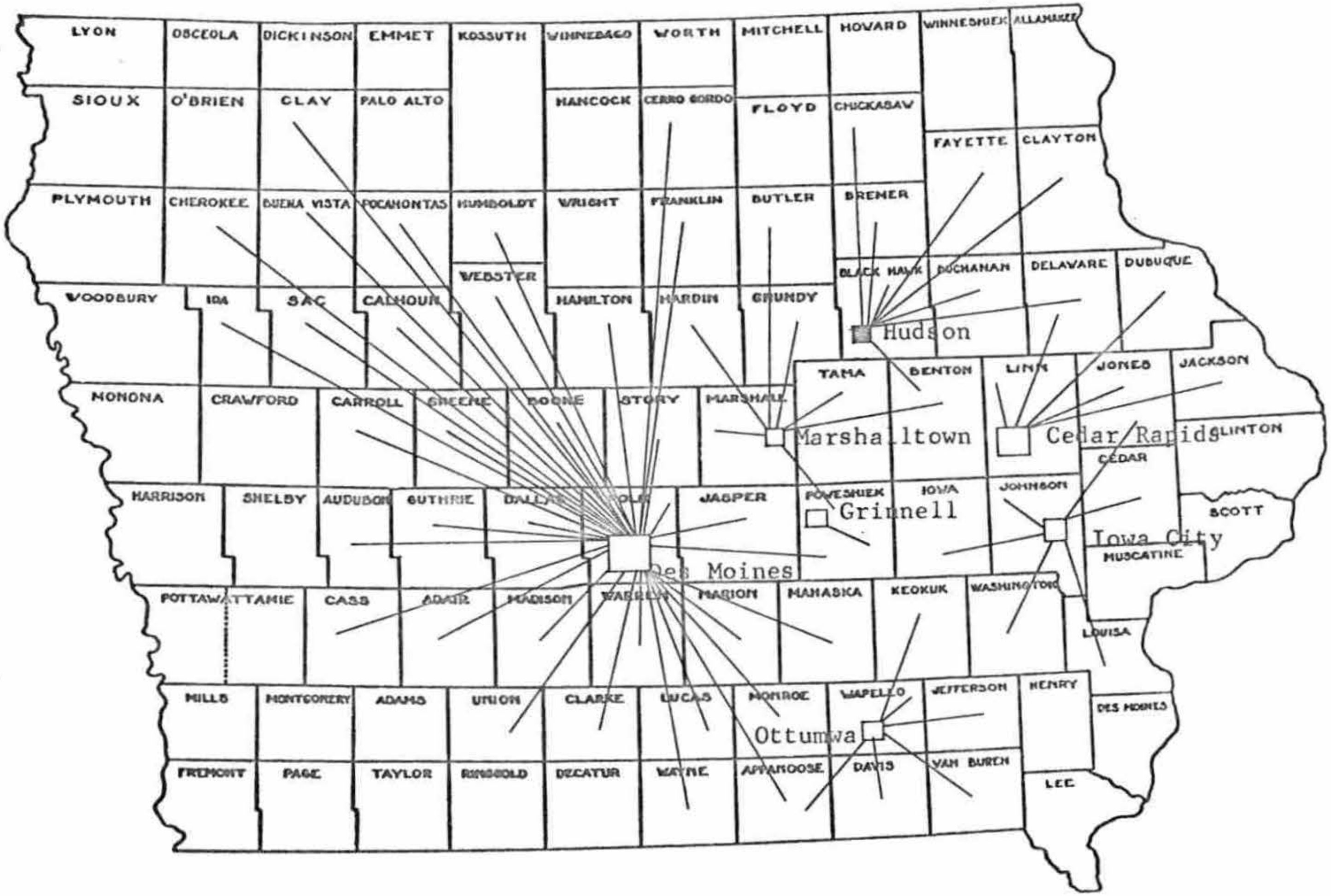

Figure 18. Optimum 1963 routing pattern for grade A milk with the surplus plant located at Hudson, D85

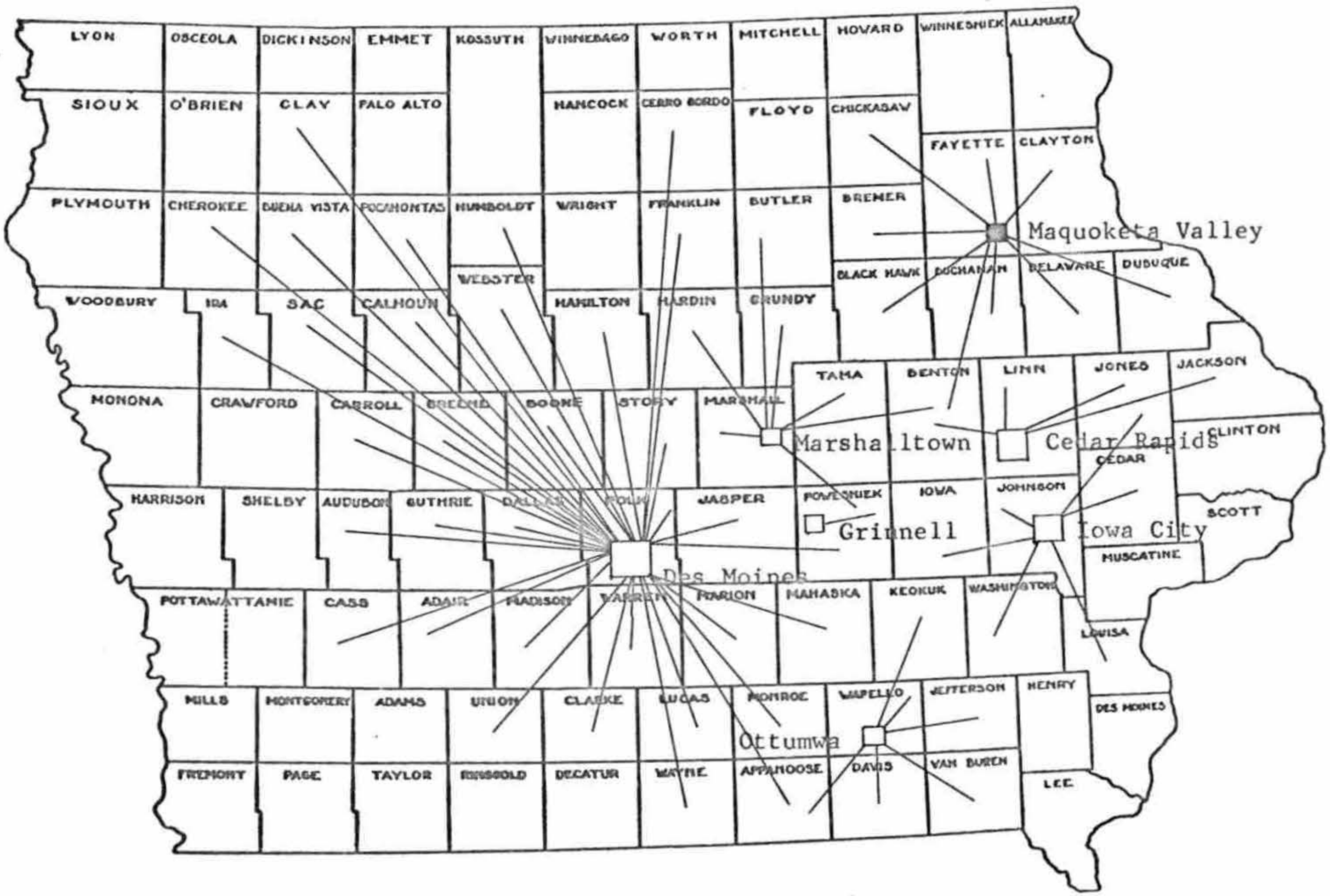

Figure 19. Optimum 1963 routing pattern for grade A milk with the surplus plant located at Maquoketa Valley, D86

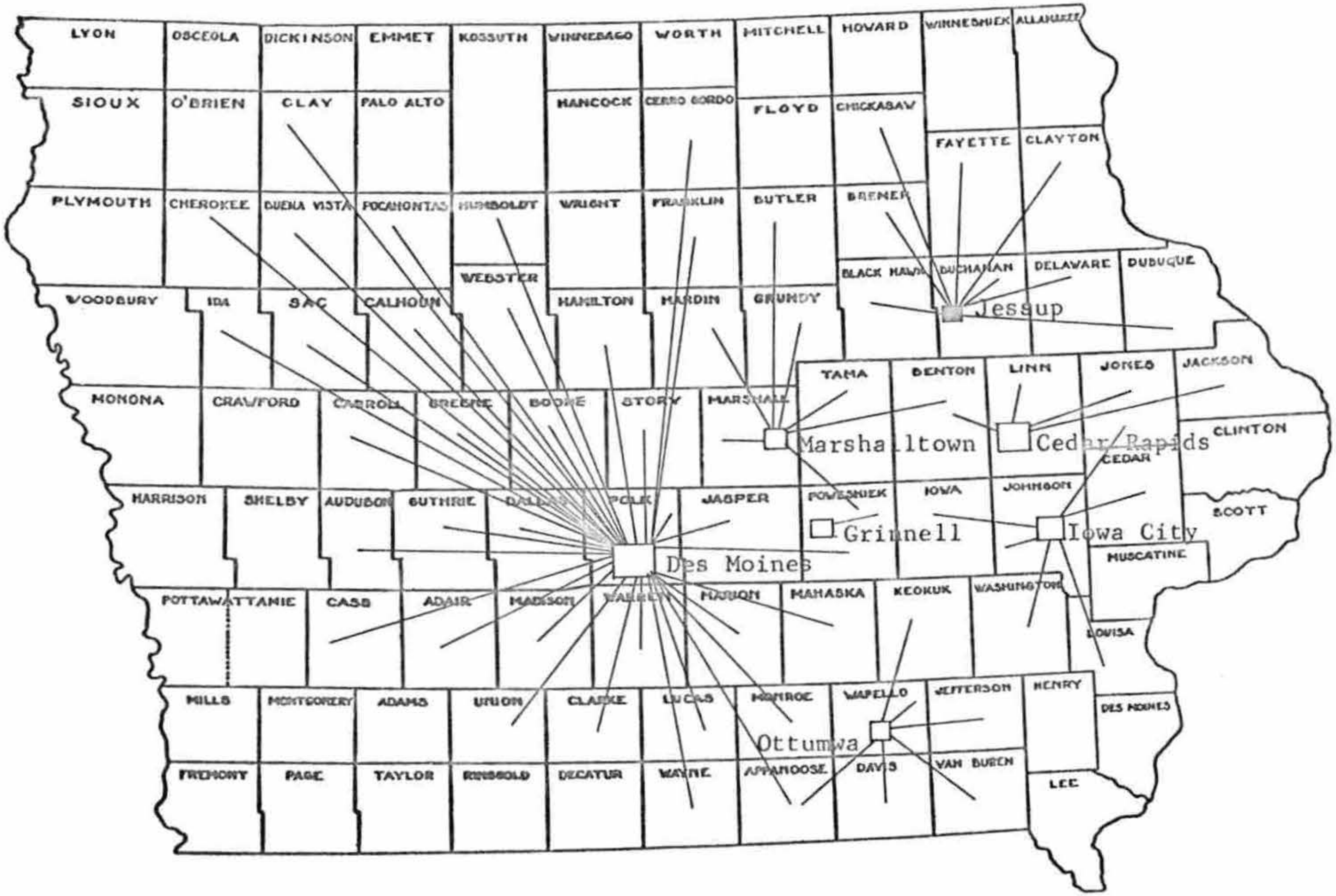

Figure 20. Optimum 1963 routing pattern for grade A milk with the surplus plant located at Jessup, D88

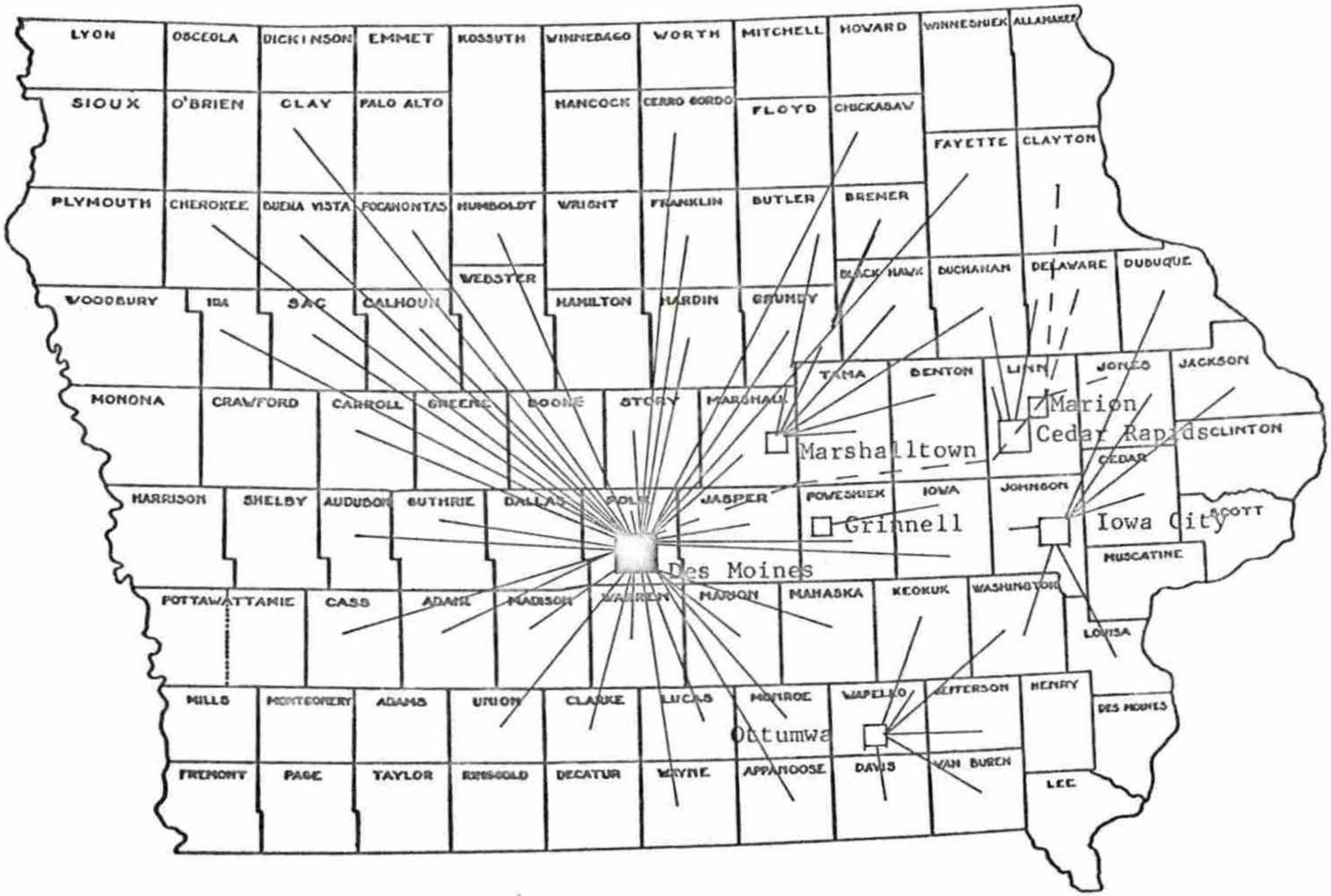

Figure 21. Optimum 1975 routing pattern for grade A milk with the surplus plant located at Des Moines, D81 (------denotes milk routed through receiving station)

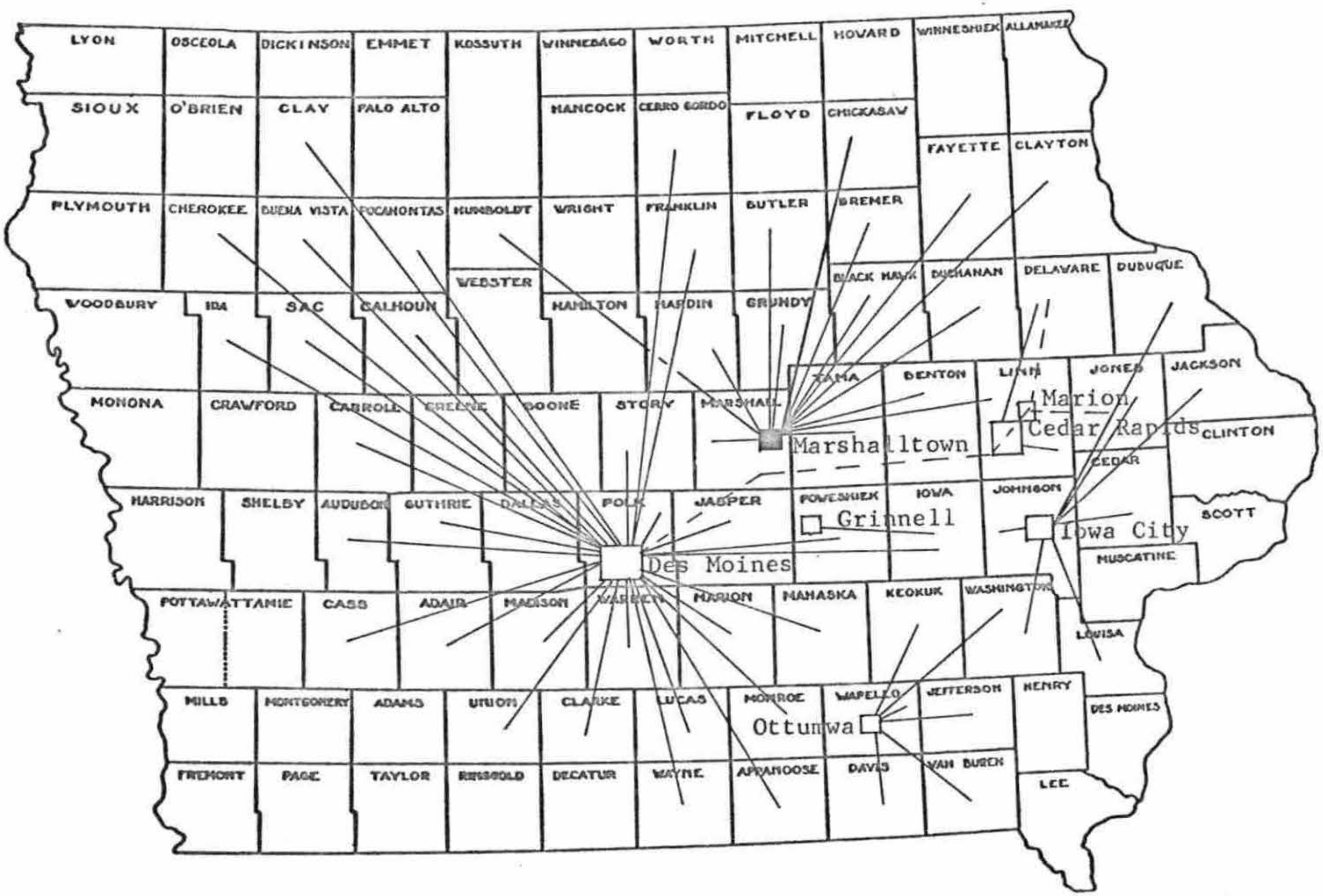

Figure 22. Optimum 1975 routing pattern for grade A milk with the surplus plant located at Marshalltown, D82 (------denotes milk routed through receiving station)

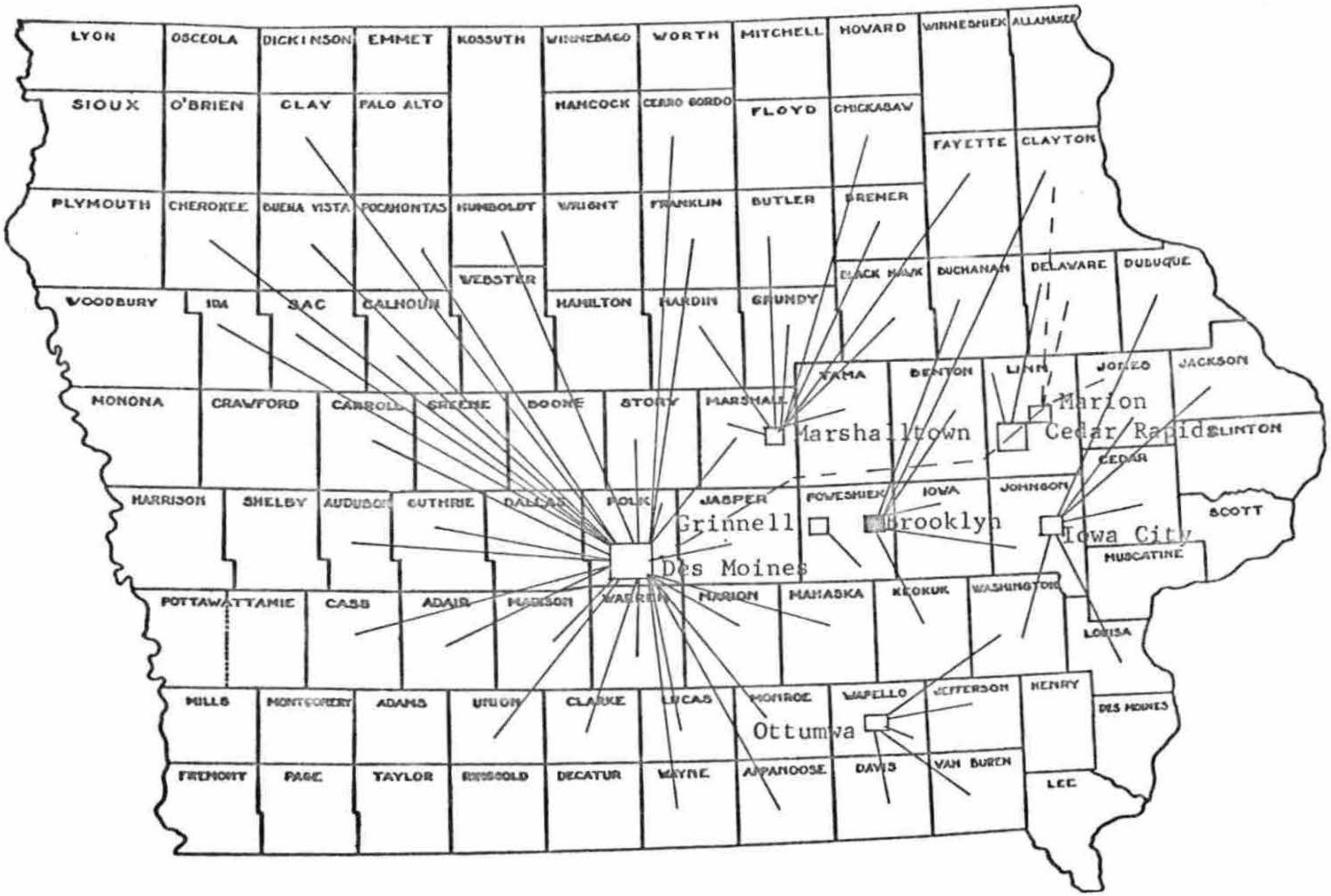

Figure 23. Optimum 1975 routing pattern for grade A milk with the surplus plant located at Brooklyn, D83 (------denotes milk routed through receiving station)

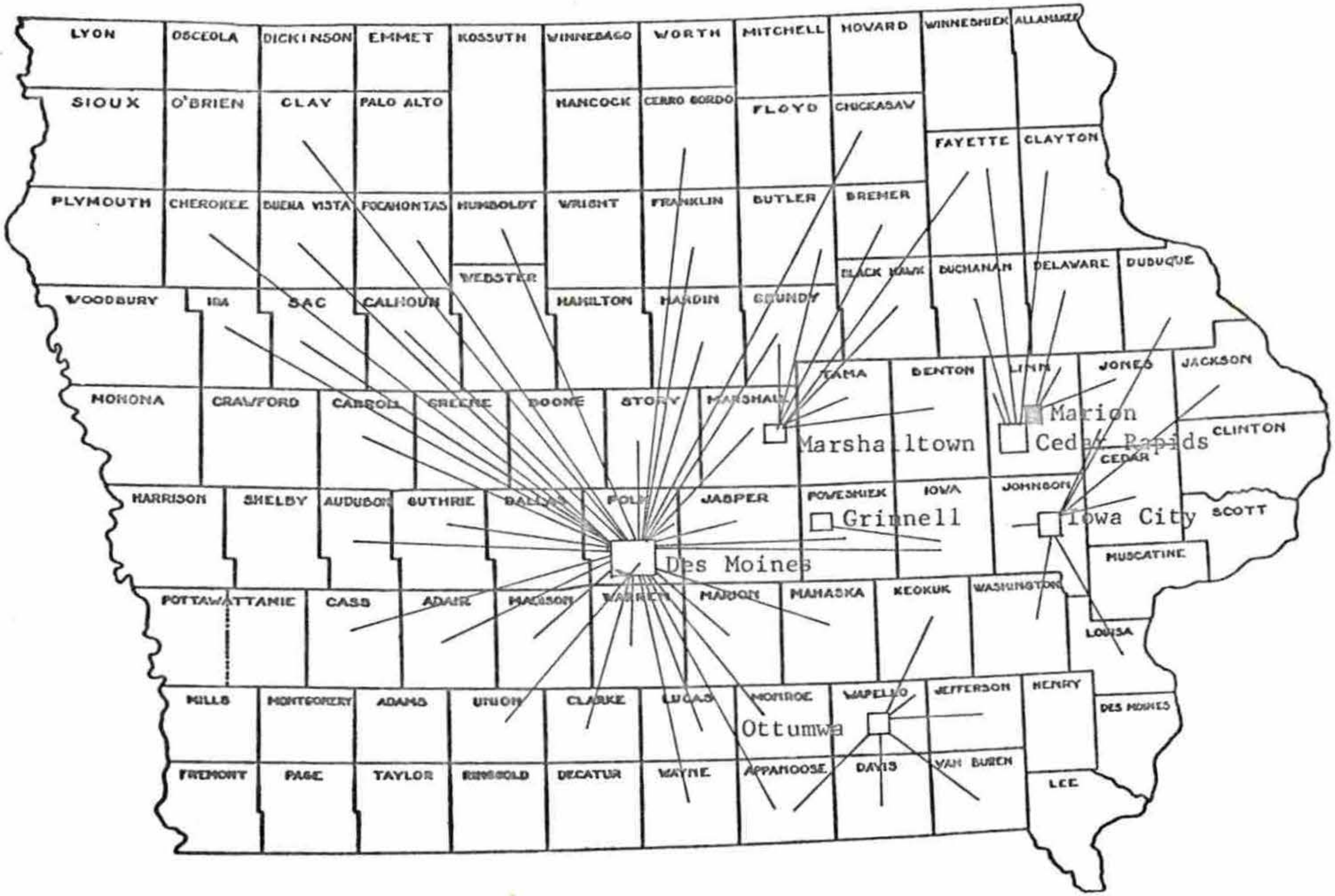

Figure 24. Optimum 1975 routing pattern for grade A milk with the surplus plant located at Marion, D84

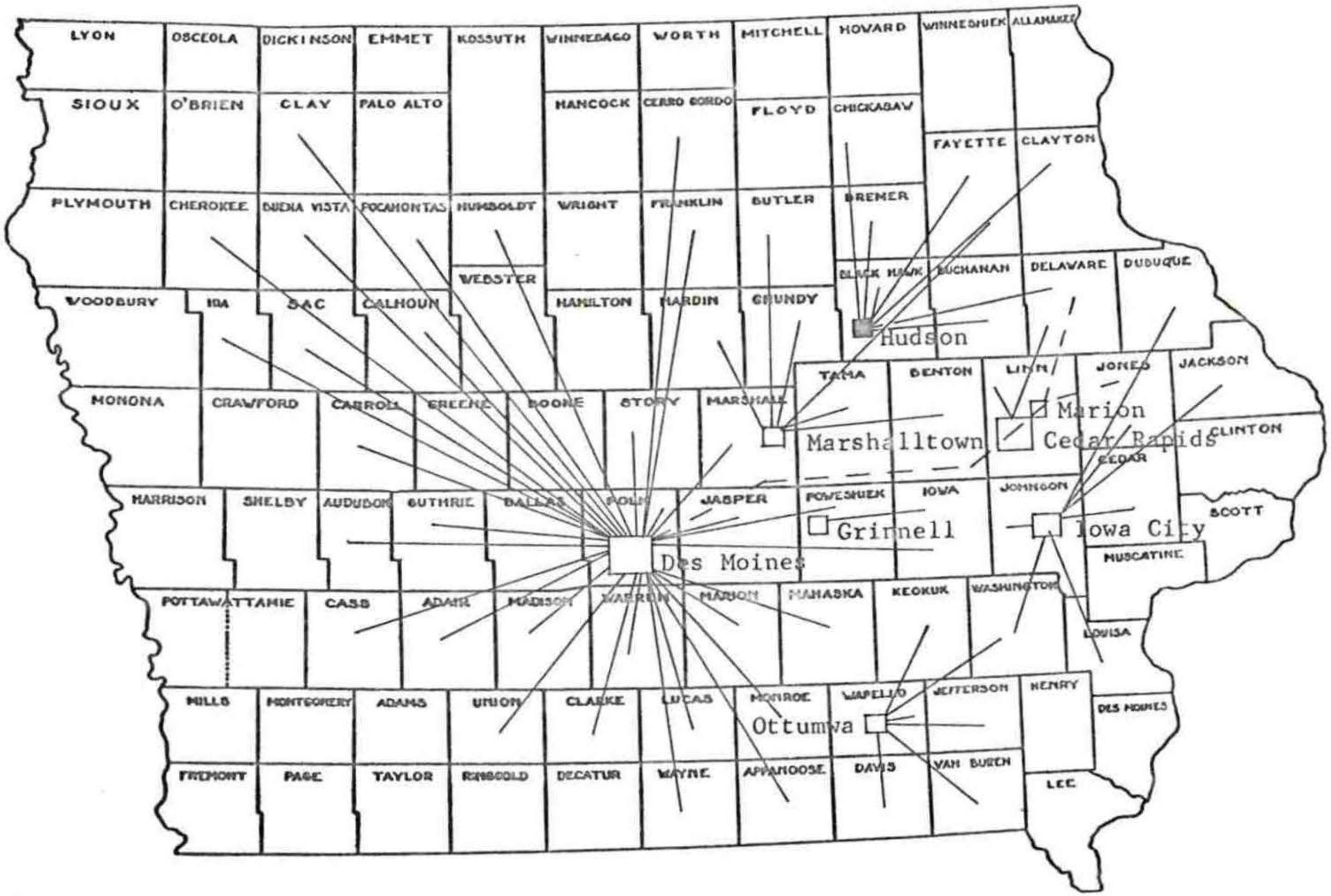

Figure 25. Optimum 1975 routing pattern for grade A milk with the surplus plant located at Hudson, D85 (------denotes milk routed through receiving station)

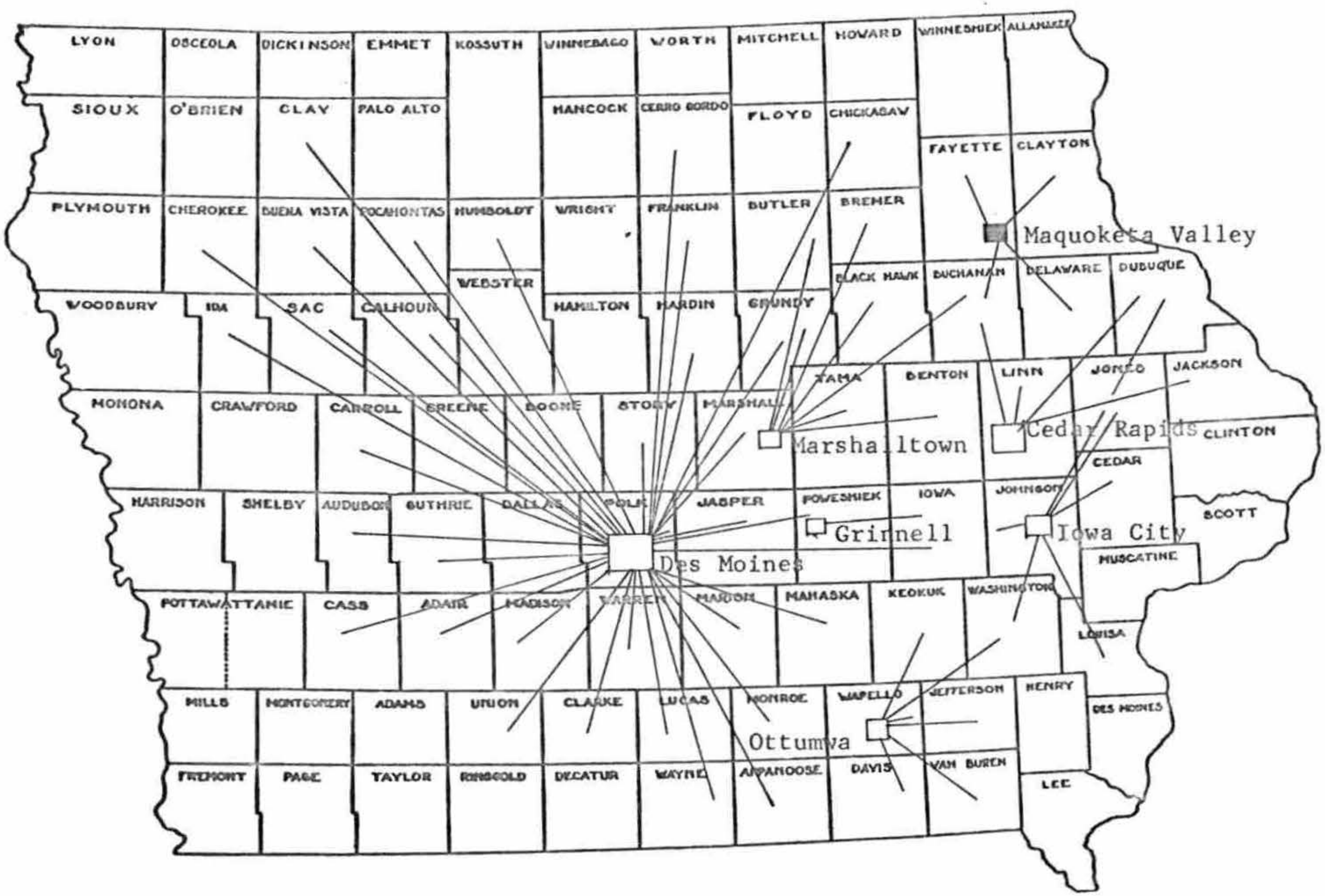

Figure 26. Optimum 1975 routing pattern for grade A milk with the surplus plant located at Maquoketa Valley, D86

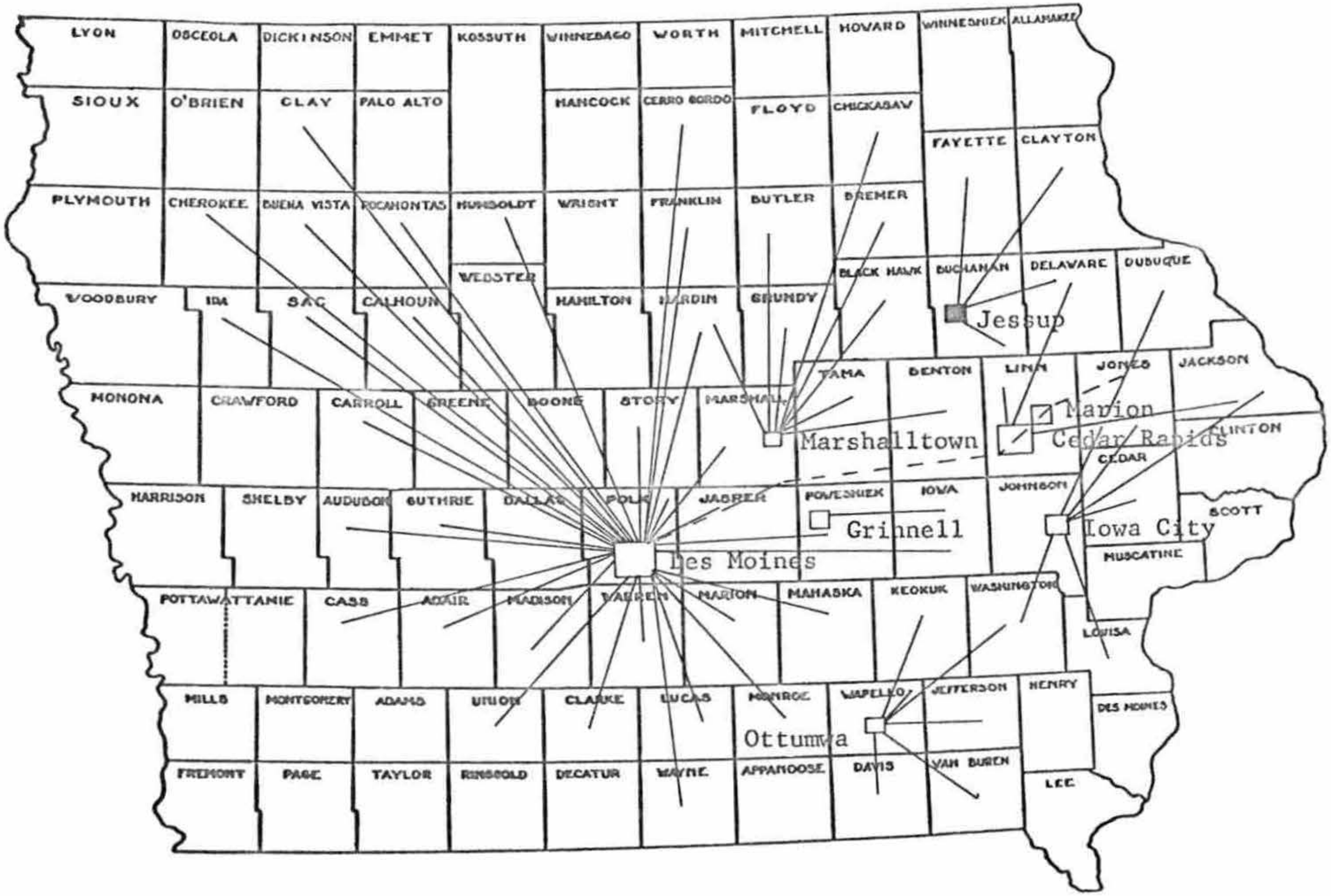

Figure 27. Optimum 1975 routing pattern for grade A milk with the surplus plant located at Jessup, D88 (------denotes milk routed through receiving station)