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The optimum number, size, and location of turkey processing plants in a three state area

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THE OPTIMUM NUMBER, SIZE, AND LOCATION OF TURKEY PROCESSING PLANTS IN A THREE STATE AREA

by

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I. INTRODUCTION

The turkey industry in recent years has undergone striking changes. There has been wide spread adoption of new technology at the levels of production, processing, distribution and merchandising. The use of new technology allows the producers, processors, and retailers to take advantage of substantial economies of scale.

Besides the greater use of new technology the entire production and marketing pattern has been changing. There has been a relocation of various phases of the industry such as a migration of processing plants from the cities to the country and the concentration of production in specific geographical areas. There has been an increase in the size and a simultaneous decrease in number of production and marketing firms. There has been a gradual elimination of some formerly important market institutions such as assemblers of live poultry and brokers, and the development of new markets and marketing channels. There has also been significant changes in the type and degree of interdependence between producers, marketing firms, and suppliers of feed and poults.

The interdependence of producers with input suppliers and marketing firms is exemplified by Gallimore (4, page IV) when he said, "It is estimated that in 1961-62, 60 to 70 percent of the turkeys produced were grown under some type of arrangement between growers and other firms, or were produced by firms owning both growing and other facilities." Interdependence exists among all firms from the grower to the retail level and it is increasing.

A significant shift has taken place in the location of the turkey processing plants from the cities into the areas of production. In recent years the costs per pound mile to distribute processed turkey have become lower than the costs per pound mile to assembly an equivalent amount of live weight. The relatively lower distribution costs of recent years are a result of better transportation, refrigeration, and packaging. Also, lower distribution costs are reflected in direct marketing channels from the large country processors to the large grocery chains and other large retail outlets and the emphasis on mass marketing. Better methods of assembling live poultry have been devised such as loading machines, large processor owned trucks, better coordinated pick up schedules. Also the proximity of large scale producers to plants lowers assembly costs considerably.

These changes in marketing practices - the large scale specialization of production, the large scale country processing plants, the large retail outlets - have created a degree of interdependence in the industry from the retailers to the producers that was unknown before such developments. For example, growth of large grocery chains and other large retail outlets and their mass procurement and distribution policies emphasizes the need for uniform quality standards, steady market flows and specification buying. These changes at the retail level induce changes at the other levels which are felt all the way back to the producer.

Turkey production has approximately tripled from 1946 to 1964, but the increase has moved into consumption at markedly lower prices as seen in Figure 1. It was indicated in Agricultural Statistics (21) that the per capita consumption of turkey has increased from 5.0 lbs. in 1955 to 7.4 pounds per person in 1965[1]. Instead of being considered a festive meat for consumption only at Thanksgiving and Christmas, turkey is being consumed during the rest of the year in competition with other meats. This has occurred because the price is favorable in relation to that of other meats, the development of satisfactory fryer-roaster strains and breeds, and because of less seasonality in production.

Turkey production is concentrating on a small number of farms. Although nearly 42,000 farms reported raising turkeys in 1964, 87 percent of the total turkey output was raised on 3,402 commercial poultry farms. Almost more than 94 percent of total output was on 4,531 commercial poultry farms raising 5,000 or more turkeys. The number of farms raising turkeys declined more than 50 percent from 1959 to 1964, but the

[1]Preliminary data.

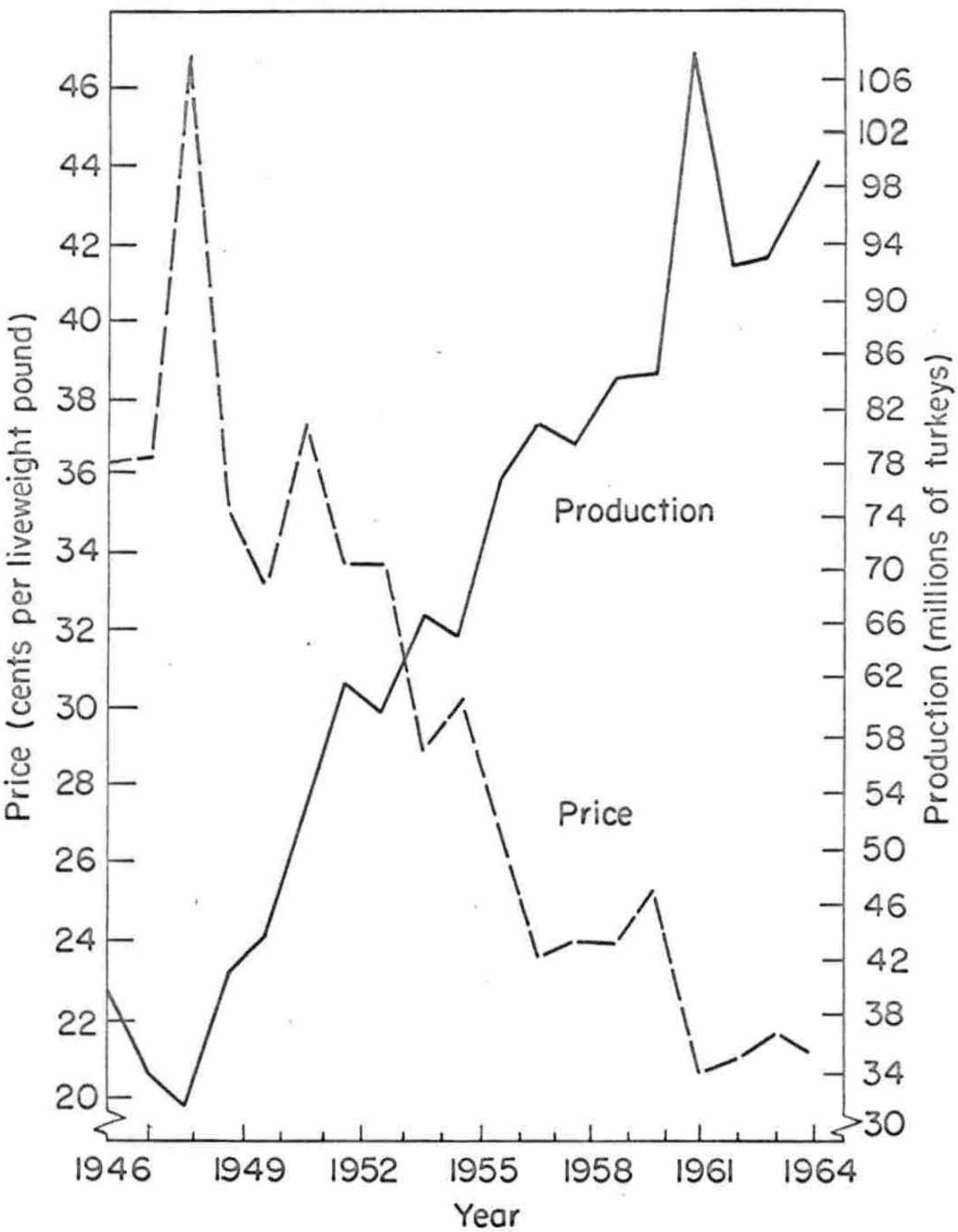

Figure 1. The production and prices of turkeys in the United States from 1946 to 1964

average number of birds raised per farm reporting was nearly three times as great. Larger lots of birds, plus more uniformity in size and quality of birds, has contributed to reduced assembly and processing costs.

Turkey production is concentrating in specific geographical areas where producers apparently enjoy a comparative advantage over other types of farming. The trend toward large commercial flocks is even more pronounced in these areas of heavy production than in the U.S. generally. Figure 2 indicates the distribution of production in the U.S. as of 1959 where each dot represents 50,000 head of turkey. It is expected that production has become more concentrated in specified areas from 1959 to the present.

The three state area of Iowa, Minnesota, and Wisconsin upon which this study focuses, is one such area of concentrated production. This three state area will hereafter be referred in this study to as Miniowisc. All the states bordering Miniowisc have relatively light production except Missouri. Missouri produced only 3.7 million head in 1959 compared to 12.4, 8.2, and 4.3 for Minnesota, Iowa, and Wisconsin. Missouri nearly doubled its annual production between 1959 and 1964 by producing 6.9 million head in 1964 as indicated in the Census of Agriculture (24). Indications are that it is continuing to increase its production from 1964 on.

The bulk of Missouri's production takes place in the

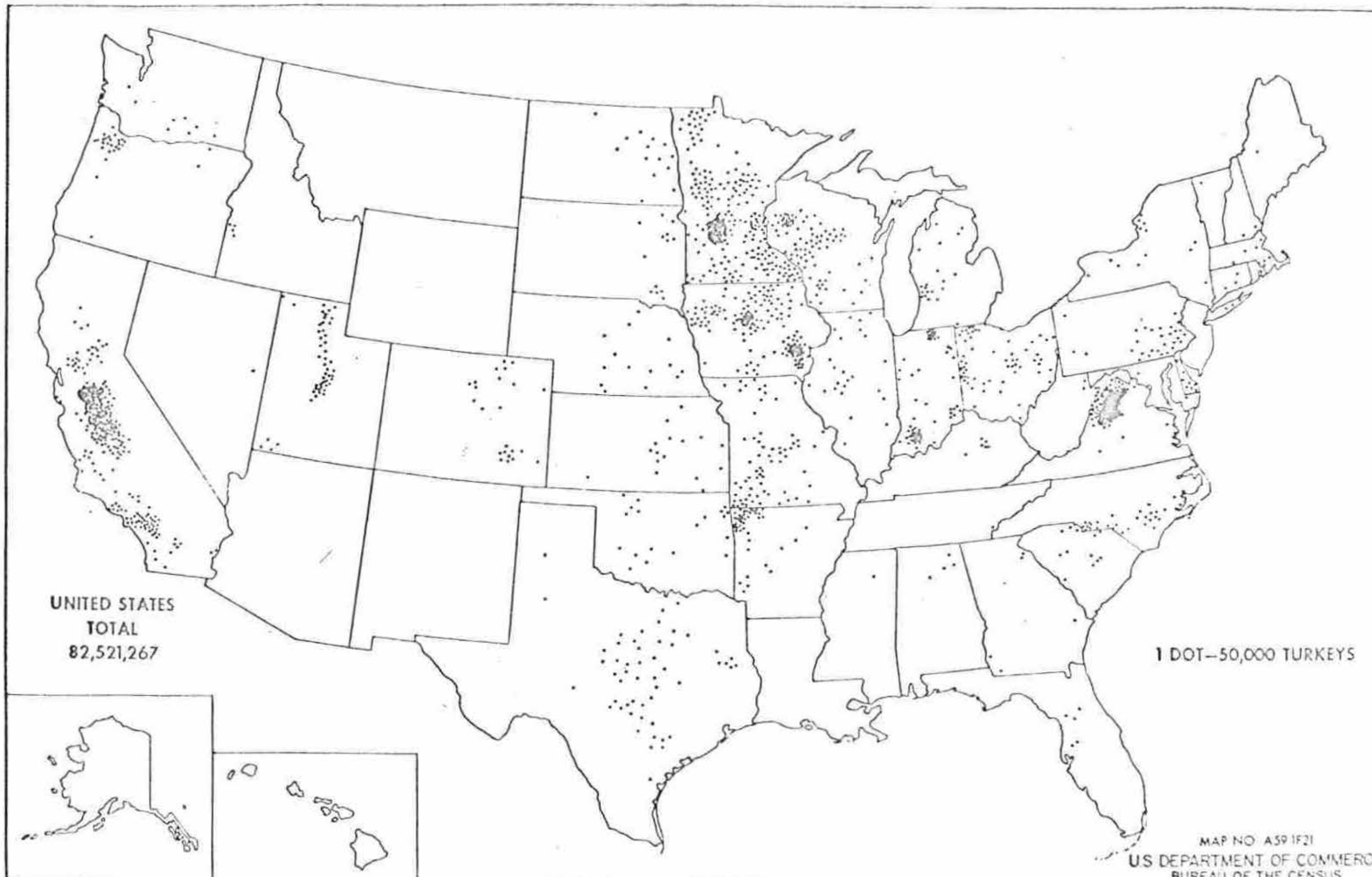

Figure 2. The concentrated areas of turkey production in the United States as of 1959

southern half of the state and this production is part of another concentrated area which covers southwestern Missouri and northwestern Arkansas. There is a band of light production in northern Missouri and southern Iowa which separates Miniowisc from the concentrated area of production just to the south.

The production by state for the north central region in 1964 is given in Table 1 as taken from the Census of Agriculture (24). The 28.6 million turkeys produced in Miniowisc was 56% of the regional production and 28% of the national production. As indicated in the table, all the states surrounding Miniowisc have light production except Missouri.

This study is a continuation of a study done by Petersen (10). Petersen had the following four objectives in mind while studying in the Iowa turkey industry:

1) determine present production density patterns for turkeys in procurement areas of turkey processing plants.

2) determine procurement costs for different classes of processing operations at various levels of production density.

3) determine alternatives to present procurement patterns that would reduce in-plant production costs as well as procurement costs.

Table 1. Turkey production in the North Central states in 1964

Minnesota		14,549,197
Iowa		8,297,234
Wisconsin		5,728,918
	Subtotal	28,575,349
Missouri		6,856,028
Indiana		4,821,459
Ohio		3,865,684
Michigan		1,383,523
Illinois		1,347,630
Nebraska		1,172,811
North Dakota		1,102,768
South Dakota		934,015
Kansas		805,687
	Total	50,864,954

4) develop a more nearly optimum pattern of plant location in light of present and possible future production patterns.

Questionnaires were developed and sent out to producers and processors in the State of Iowa in 1961. Based on the information in the questionnaires and information gathered while visiting 9 out of the 13 plants then processing turkeys in Iowa, Petersen had the following findings:

1) location of turkey processing facilities at favorable locations could reduce average per pound processing costs.

2) a more optimum procurement pattern would reduce aggregate procurement costs.

3) six existing Iowa turkey processing plants have the potential capacity (with minor changes in sharp freezing facilities) to process all of the turkeys presently grown in Iowa.

4) storage, water, sewage, and labor facilities are not limiting factors in Iowa turkey processing plants.

5) a more optimum procurement pattern would reduce farm to plant shrink of turkeys.

6) procurement costs appear to rise with the increase in procurement area and the lower production density.

7) slaughter and pick-up schedules could be more closely meshed with shorter procurement distances, thus reducing waiting time at the plant.

The present study was extended from Iowa to the three state area for several reasons. First Minoiwisc is an important concentrated area of production raising 28% of the total national production in 1964 based on 101 million turkeys reported in Agricultural Statistics (21). It was felt that the results of the analysis in terms of plant numbers and locations would have more meaning on the larger area. The two problems of cross-hauling and border effects are eliminated when the study is extended from Iowa to the three state area because Miniowisc represents a self-contained area of production. These two problems would bias the results of this type of analysis of Iowa but disappear when studying

Miniowisc. Petersen (10) found that approximately 30% of the turkeys produced in Iowa are processed out of state while approximately 20% of the turkeys processed in Iowa are purchased out of state which indicates the extent of cross-hauling over Iowa's border.

Analogous to the cross-hauling problem is the border effects problem discussed by Warrack (25). A border effect is a bias against including plants in the solution that exists near the borders of the area being studied. Both of the problems mentioned would have biased the results of a study of Iowa unless they somehow could have been compensated for.

The producers and processors of Miniowisc and the rest of the north central region are facing intensified competition from other developing turkey producing areas. In order to maintain or increase its relative competitive position, the turkey industry of Miniowisc will need to be alert to the existing changes and those which are likely to come in years ahead.

II. DESCRIPTION AND OBJECTIVES

The competitive position of the north central region has been strong as evidenced by Table 2. During the five years of 1930 - 34 the north central region production averaged 33.9% of the total United States production. It has steadily increased its proportion of U.S. production since then. In 1964 it produced 49% of the U.S. total production. Turkey growers and related businesses (hatcheries, processors, and handlers) are asking questions about how they can best adjust to the changes that are taking place in the industry by adopting new technologies and organizational arrangements to maintain or expand their business. Only if the proper adjustments are made will the north central region retain its present strong competitive position.

Miniowisc is a large contributor to the production of the north central region - it produced 56% of the region's production in 1964. The organizational efficiency and rate of adoption of new technology in Miniowisc has a large influence on the regional performance. What will be the impact of larger commercial flocks, larger capacity hatcheries and processing plants, mass procurement and distribution procedures on the small owners, the small processors and hatchery, the small independent retailer of turkeys? Should the small flock owner phase himself out? Will production be intensified around the larger processors? Where should new processing

Table 2. Percentage of total production of U.S. in each region in different periods

	1930-34[a]	1954-58[a]	1964[b]
North Central	33.9	41.4	49
North Atlantic	4.7	6.2	3
South Atlantic	9.2	13.5	13
South Central	28.3	10.7	12
Western	23.9	28.2	23

[a]"Commercial poultry slaughter plants in the U.S., number, size, location, output." USDA. Marketing Economics Research Division. AMS-379. April 1960.

[b]"Contracting and other interrating arrangements in the turkey industry." USDA. Economic Research Service. MRR-734. November 1965.

plants locate? Capital commitments are great for these installations and location decisions are crucial.

These are but a few of the questions confronting people in the turkey industry. An attempt will not be made to answer all of them. Petersen's study indicated that the average per pound processing costs can be reduced by locating the plants at favorable locations and he also found that a more optimum procurement pattern would reduce aggregate procurement costs. Based on these findings the focus of this study will be to determine the configuration of processing plant that are optimum in the sense of minimizing the total costs of assembling and processing the turkeys of Miniowisc.

The objectives of this study are to find the optimum number of processing plants for Miniowisc, the size in terms of number of pounds processed per year, and the location of each of the plants.

III. REVIEW OF LITERATURE

Only literature concerning the assembly of turkeys or poultry in general, the processing of turkeys, or application of the Stollsteimer model are reviewed here. Some studies of other aspects of the turkey industry such as pricing, integration and interregional competition, or studies indirectly related to this one are listed in the bibliography.

One study by Mortensen and two by Rogers and Rinear will be reviewed in the processing cost section. The study by Petersen plus two studies concerning the assembly of poultry in New England will be reviewed in the assembly cost section. Five previous applications of the Stollsteimer model are discussed in the optimum number, size, and location section.

A. Processing Costs

Rogers and Rinear presented two reports on turkey processing plants as part of a broad research program conducted by the Economic Research Service to improve the marketing of poultry and eggs. The first study (15) presented some preliminary results from a survey of more than 25 turkey processing plants of various sizes and types. The second report (14) examined--with more standardized accounting procedures--the potential economies of scale in turkey processing. One objective of these two studies is to provide to plant managers scientifically developed guidelines which could help them increase their efficiency.

During late 1960 and early 1961 researchers for the first study visited more than 25 commercial turkey processing plants ranging in capacity from less than 200 heavy young hens per hour to more than 2,000 per hour in Minnesota, Wisconsin, Kansas, California, Utah, Colorado, and Virginia. Preliminary results of the cost of processing turkeys into frozen ready-to-cook form showed costs for small plants to be about 6.6 cents per pound and costs declined to about 5.4 cents per pound in larger plants. However, costs may rise again in the largest plants. The major items whose costs per unit declined were utilities, ice, freezing, storage, and overhead. They found that processing plants needed to be large enough to process the crop when it is marketed -- generally from July to January -- but much of their capacity is unused the rest of the year. On an annual basis, almost half the plants studied operated at less than 30 percent of potential capacity and almost 85 percent of them at less than 50 percent of capacity. These plants could reduce their costs by operating at capacity the year round.

They found variations in costs to exist between different market classes. The lowest costs per pound were found to exist in plants processing good-quality heavy young hens and toms, and higher costs in plants processing breeders and fryer-roasters.

The study revealed several areas where plant managers could reduce costs. They were: a fuller utilization of plant capacity, emphasis on processing particular market classes, substitution of equipment and facilities for labor, good organization of the working force, and proper selection and assignment of supervisory and office personnel.

In the second study by Rogers and Rinear (14) the results of the first study were examined in more detail and the potential economies of scale in turkey processing were projected using synthetic models with standardized practices and factor cost rates for 10 plant sizes. These plant sizes ranged from 3 to 65 million pounds per year. The costs of these 10 plant and four market classes were used to obtain the individual processing cost curve used in the present study.

By studying synthetic model plants, Rogers and Rinear found substantial economies of scale to exist in turkey processing. When processing heavy young hens weighing 13 pounds ready-to-cook and operating at 100 percent of capacity for 144 days per year, costs declined from 6.9 cents per pound at 200 head per hour to 4.5 cents per pound at 4,000 head per hour. The range of 200 to 4,000 head per hour is equivalent to 3 to 65 million pounds per year. More than half the savings of 2.3 cents per pound resulted as the plant size increased from 200 to 800 head per hour and more. Three-fourths of the savings were obtained with a plant having a capacity of 1,500 head per hour.

Similar results were obtained for heavy young toms. The potential cost savings from the smallest to the largest model plant was almost 1.9 cents per pound; that is, costs declined from 5.7 cents per pound at 150 head per hour to 3.8 cents at 3,000 head per hour. The toms were assumed to weigh 22 pounds ready-to-cook. The costs for breeders at 16 pounds ready-to-cook declined from 7.8 cents to 5.0 cents when going from the smallest to the largest and costs for fryer-roasters at 7 pounds ready-to-cook went from 8.6 to 5.5 cents per pound from smallest to largest plant size.

Rogers and Rinear found that average total costs per pound are substantially affected by the rate of capacity that the plant operates under. Without exception the costs per pound of output are lower for each class as the rate of use of capacity is increased. The lowest costs in each class are achieved at 100 percent of capacity.

At 100% of capacity the costs per pound for all four market classes decline with an increase in plant size through the whole range. Therefore, a larger plant is always more efficient in this range than a smaller no matter which class is being considered. A cost curve was derived using a weighted average of the four market classes based on the percentages of each class slaughtered in 1960. The derived curve declined 2.2 cents per pound from smallest plant size to the largest.

W. P. Mortenson (8) did a study designed to point out some recent changes and the present status in turkey processing and marketing, and to analyze the important economic aspects of assembly processing, and marketing turkeys. He based the study on a sample of 67 processing plants in 11 north central states. They ranged in size from less than one half million pounds to more than 15 million pounds of turkey processed in 1957.

Some of his findings are: nine-tenths of the turkey flocks were purchased by processors directly from producers, integrators (usually feed suppliers) are assuming more and more the job of selling birds under grower contracts, and two-thirds of the turkeys were hauled from the growers in trucks owned by processors. Yields in processing were somewhat higher for mature birds than for fryer-broilers. Processing plants were limited more by the capacity of quick freezing facilities than by any other single factor. Some 93% of all heavy breed turkeys and 88% of all turkey fryers were sold by processors in frozen form. National food chains comprise almost half the market outlets for the larger processing plants. With limited changes and plant additions the processing plants in the 13 north central states could increase their present output by some 75 million pounds or four million turkeys per year, with no change in number of hours of operation per year. This assumes that the freezing capacity and/or certain other bottlenecks in facilities could be increased so that all the facilities in the plant were operating at or near optimum capacity.

Another way that annual output from the processing plants could be increased would be to operate more days per year. Mortenson calculated that if all the plants in his study operated 150 days per year the overall annual output would be increased 12.57%. Mortenson (8) goes on to say, "it appears obvious that, if certain bottlenecks of the existing plants were eliminated to increase the hourly capacity, and the plants stretched their operations over a longer season, the present processing plants and facilities would be adequate to handle the increase in turkey production that might be expected during the next several years."

B. Assembly Costs

Petersen (10) estimated that for six plants out of thirteen existing in Iowa in 1961 only 42 percent of their capacity was used in the aggregate on an annual basis. All six of these plants operated seven or more months per year. Unavailability of birds to process was the primary reason given by processors for not operating on a 12 month basis.

Over 94 percent of the birds processed by these six plants were processed from June through December. Petersen states that on the basis of the estimated potential capacity of these plants, they have the capacity to process all of the nearly 8 million birds grown in Iowa (in 1964 there were 8.3 million).

Petersen (10) found the following information pertinent to assembly costs: shrink, truck costs, capacity of trucks, pick-up schedules, competition among processors for turkeys. Thirty-seven percent of the producers completed and returned the questionnaire and 9 of the 13 processing plants responded.

From 0 to 80 miles shrink seemed to average less than 1% for all classes of turkeys and all assembling conditions such as weather and time of day. For distances greater than 100 miles shrinkage became an appreciable factor. Data on truck costs were given for two situations, a processing plant with large procurement area and low density of birds per mile, and the other with a smaller procurement area and higher density of birds per mile. The truck costs in the first instance average 35.4 cents per mile and 46.5 cents in the second case. The nine respondent plants had a total of 37 trucks between them to use for procurement. Truck capacities ranged from 576 to 1,760 mature hens. The mode was 1,760, the median 840, and the mean 989. The live weight of 1,760 mature hens figures out to 26,224 pounds live weight at 14.9 pounds per hen. The competition among processors was measured by Petersen on a county basis. On the basis of a map indicating by county how many processors purchased turkeys in all or part of the county, one can determine that competition is generally quite strong. Some counties had as many as seven competitors while only three counties had no apparent competitors and twelve had only one.

Two studies from New Hampshire are concerned with assembly costs from the point of view of a single firm. For the present thesis, however, the total assembly cost function represents the costs of assembling turkeys in a spatial area given J number of plants. The value of the function is expected to decrease as the number of plants increase. Nevertheless these two studies serve to illuminate some of the properties of assembly cost functions.

In a New England study of 75 assemblers of live poultry by Rogers and Bardwell (12) the emphasis was on density cost relationships. The unit costs of assembly declined from 0.90 cents per pound to 0.47 cents per pound when the amount to be assembled increased from 1 million to 50 million pounds at a constant density of 100 pounds per mile. At a higher density of 1,000 pounds per mile the unit cost of assembly declined from 0.60 cents per pound to 0.35 cents per pound when the amount to be assembled rose from 1 to 50 million pounds. Cost savings available from increased volume and density of the supply area would enable assemblers to offer incentives to maximize the size of nearby farm units.

The competitive advantage of large firms can be further increased by combining the assembly and processing functions under one management to effect cost savings. Since costs of assembly are small relative to processing costs, larger firms can in the short run profitably increase the size of their supply areas to secure additional volume. However in the long run, efforts to reduce assembly costs by decreasing the size of the supply area and increasing its density will most enhance the competitive position of the firm.

Henry and Burbee (5) analyzed the effects of firm size, density, and transport distance on assembly costs. Density had a marked effect on assembly costs. For a particular firm costs fell from 1.26 cents per pound at the 1,000 pound per square mile level to 0.56 cents at the 25,000 pound per mile level and the change in density caused greater absolute and percentage changes in assembly costs for larger firms than for small firms.

Assembly costs increased with hauling distance. At the 5,000 pound per square mile density level, assembly costs increased almost 0.30 cents per pound with an increase of distance from 20 to 80 miles. As firm size increased from 4.15 million pounds per year to 69.16 million pounds, assembly costs went from 0.64 cents per pound live weight to 0.92 cents per pound at the 5,000 pound per square mile density level. For less dense areas assembly costs rise more rapidly with firm size.

C. Optimum Number, Size and Location

The optimum number, size and location of processing plants for a spatial area can be determined by solving the Stollsteimer model. Although it is an efficient method of analysis, the Stollsteimer model has had only a limited number of applications to my knowledge. Stollsteimer (18) originally developed it with reference to study of pear assembly and processing in California, Mathia and King (7) analyzed the sweet potato industry of eastern North Carolina, Peeler and King (9) located egg grading and packing plants in North Carolina, Sanders (16) studied the egg marketing organization in Iowa, Polopolus (11) extended the model to multiple product processing plants of vegetables in Louisiana, and Warrack (25) studied the feed manufacturing industry of Iowa.

As far as is known Warrack's application was the first one to involve more than two plants in any one optimum solution. Warrack developed two methods for solving the model which he dubbed the iterative and the combinations methods. He obtained the same number of plants in two optimum solutions using the two methods. The optimum number of plants for the single shift solution was 25; it was 29 plants for the multi-shift solution. Both methods lead to suboptimum solutions in the sense that the optimum solution for each method is not the true solution attainable given the definition of the model. The true solution will never be calculated for Warrack's problem because prohibitive cost of calculating ${}_{40}C_{25}$ or ${}_{40}C_{29}$. ${}_{40}C_{25}$ is defined as the number of combinations of 40 things taken 25 at a time and in factorial notation would be $\frac{40!}{25!(40-25)!}$. Warrack estimated it would take 10,000 hours or more of computer time to calculate either of the two optimum solutions. The two suboptimum solutions are probably close to the true optimums.

IV. THE MODEL

The model used in this study was developed by Stollsteimer (18) while at the University of California. The model permits the determination of the number, size, and location of processing plants which, given certain restrictions, minimize the total cost of assembling and processing any given total quantity of raw material produced at scattered points in differing amounts.

First, I raw material sites or supply nodes are given; each of the i^{th} supply nodes produce X_i units of a material. Next L processing plant sites are defined from which a subset J of the L plants can be selected to process all the raw material. The problem is to determine the number, size, and location of processing plants that minimize the total cost of assembling and processing the given total quantity of raw material in the area. The total cost function stated algebraically is:

$$(1) \quad \underset{(J,L_k)}{TC} = \sum_{j=1}^{J} P_j \; X_j \mid L_k + \sum_{i=1}^{I} \sum_{j=1}^{J} X_{ij} \; C_{ij} \mid L_k$$

with respect to plant numbers ($J \leq L$) and locational pattern L_k. For a given value of J, L_k takes on $\binom{L}{J}$ values where $\binom{L}{J}$ means the number of combinations of L plants taken J at a time.

The objective is to minimize the total cost function. This will give the optimum number of plants and their locations. The sizes of each of the plants in the optimum solution are calculated from their processing cost functions. The following definitions will further explain the model:

TC = the total cost of processing and assembling the raw material

P_j = unit processing costs in plant j ($j=1,\ldots,J\leq L$) located at L_j

X_{ij} = quantity of raw material shipped from supply node i to plant j located at L_j

C_{ij} = unit cost of shipping material from supply node i to plant j located with respect to L_j

L_k = one locational pattern for J plants among the $\binom{L}{K}$ possible combinations of locations for J plants given L possible locations

L_j = a specific location for an individual plant ($j=1,\ldots,J$)

The total cost function is the sum of the total assembly cost function which is defined as:

$$\underset{(J,L_k)}{TAC} = \sum_{i=1}^{I} \sum_{j=1}^{J} X_{ij} C_{ij} \mid L_k$$

and the total processing cost function which is defined as:

$$\underset{(J,L_k)}{TPC} = \sum_{j=1}^{J} P_j X_j \mid L_k$$

The restrictions are:

$$\sum_{j=1}^{J} X_{ij} = X_i$$

= quantity of raw material available at origin i per production period

$$\sum_{i=1}^{I} X_{ij} = X_j$$

= quantity of material processed at plant j

per production period

$$\sum_{i=1}^{I} \sum_{j=1}^{J} X_{ij} = X$$

= total quantity of raw material produced

and processed

$X_{ij}, X_j \geq 0$ and $C_{ij} > 0$

In this model, long-run plant costs are assumed to be independent of plant location. At each location, the form of the long-run plant-cost function is assumed to be linear with respect to total output and to have a positive intercept. This functional form seems to be applicable to the long-run cost volume relationship in many plant operations and is theoretically supported by French, Sammet, and Bressler (3). French, Sammet, and Bressler also stressed that the economic-engineering approach to cost analysis does not necessarily produce linear functions.

The linear processing cost function implies economies of scale (declining L-shaped average cost function) and constant long-run marginal costs for any sized plant. Economies of scale in processing are assumed to exist throughout and are never exhausted. Processing technology is assumed to remain unchanged. It is assumed that one plant could possibly process all the turkeys produced in Miniowisc.

The assumption of independence of plant costs with respect to location means that the total processing cost function will be invariant with respect to plant location and also that the cost of processing the material from any origin is invariant with respect to the plant where it is processed.

The problem of minimizing equation (1) with respect to plant numbers (J) and locational pattern (L_k) can be accomplished in two steps. The first step is to obtain a total assembly cost function that has been minimized with respect to plant locations with varying numbers of plants, J. There are $\binom{L}{J}$ possible combinations of locations $L_k|J$ for any given J. As an example if there are eight plant sites, a five plant subset can have $\frac{8!}{5!\ 3!} = 56$ locational patterns. For each possible locational pattern L_k there is a submatrix, $C^*_{ij}|L_k$, of the transfer-cost matrix C_{ij}. The submatrix will be I×J with the entries in each of the J columns representing the transfer costs from each origin to a particular plant site. A I×1 vector $\overline{C}_{ij}|L_k$ is obtained by scanning $C^*_{ij}|L_k$ by rows and selecting the minimum C_{ij} in each row. The minimum total assembly costs with J plants at a specified set of locations L_k is equal to the vector X', whose entries X_i represent the quantities of material produced at each of the I origins, multiplied by the vector $\overline{C}_{ij}|L_k$. For an example problem illustrating the above procedures see Warrack (25, pp. 79).

For each value of J there are $\binom{L}{J}$ values of $(X'_i)\overline{C}_{ij}|L_k$. The minimum of these values over L_k is a point on the assembly cost function minimized with respect to plant locations. We then have J values of the following function:

$$\overline{TAC}|J = {}_{L_k}^{\min}(X'_i)\overline{C}_{ij}|L_k$$

where

$\overline{TAC}$ = total assembly cost minimized with respect to plant location for each value of $J=1,2,\ldots,L$

(X'_i) = a $(1\times I)$ vector containing elements equal to the quantities produced at each of the I origins

$\overline{C}_{ij}|L_k$ = an $(I\times 1)$ vector whose entries C_{ij} represent minimized unit transfer costs between each origin and a specified set of locations (L_k) for J plants.

As plant numbers (J) vary, the shape of the total assembly cost function minimized with respect to plant locations may be deduced from the expected signs of the first and second differences of $\overline{TAC}$ with respect to (J). Stollsteimer (19) shows that the first difference will be negative or zero; that is,

$$\frac{\Delta\ \overline{TAC}}{\Delta J} \leq 0$$

and it will be less than zero as long as there exists an entry C_{ij}^{**} which is not in $\overline{C}_{ij}|L_k$ such that $C_{ij}<\overline{C}_{ij}$ for some i.

The second difference will be positive or zero, that is

$$\frac{\Delta^2 \overline{TAC}}{\Delta \overline{J}^2} \geq 0$$

and in all empirical applications studied so far, as indicated in the Review of Literature, it was positive. This yields a total assembly cost function of the form illustrated in Figure 3. This function is the envelope curve of the set of total assembly cost curve points. The number of such points is equal to $\sum_{J=1}^{L} \binom{L}{J}$ with $\binom{L}{J}-1$ points rising vertically above the total assembly cost function for each value of J.

The next step is to define the relationship between total processing costs and the number of plants. This has been defined as

$$\underset{(J,L_k)}{TPC} = \sum_{j=1}^{J} P_j X_j | L_k$$

To find this relationship we can use the total processing cost curve with respect to volume, which is assumed linear and positively sloping with a positive intercept. This is shown in Figure 4. Since the total quantity of raw material (X) is fixed, the total processing cost when one firm is processing all the raw material will be equal to (a + bX) where (a) is the intercept value and (b) is the slope of the total processing cost function. As the number of plants increases, the total processing cost curve with respect to plant numbers will

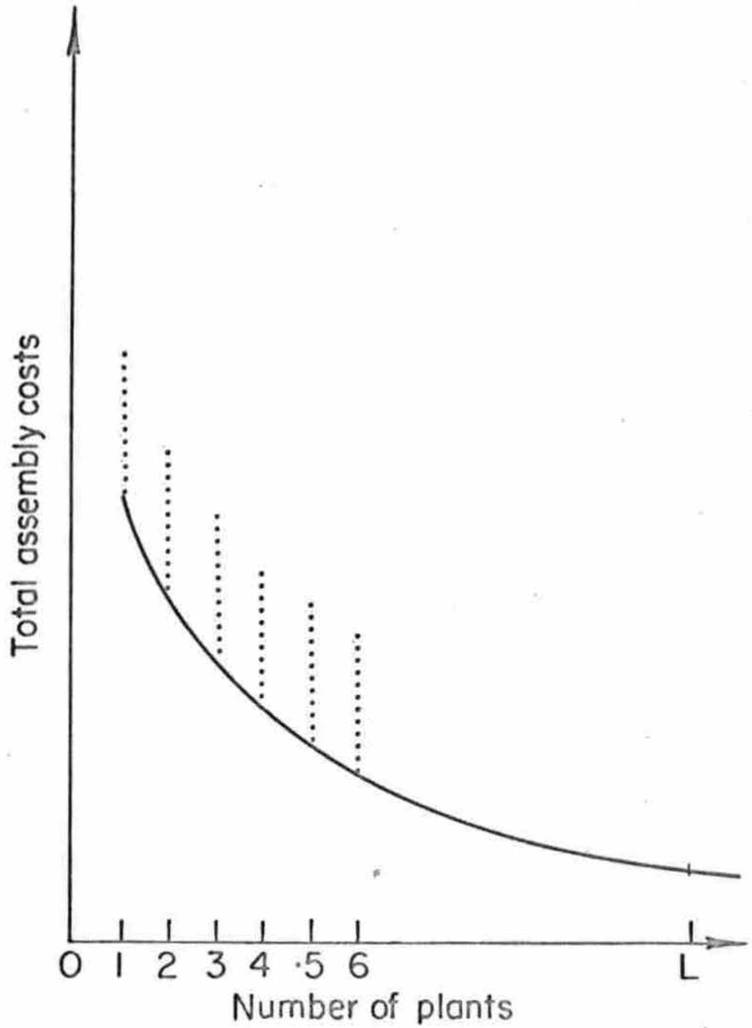

Figure 3. Total assembly cost function with respect to plant numbers

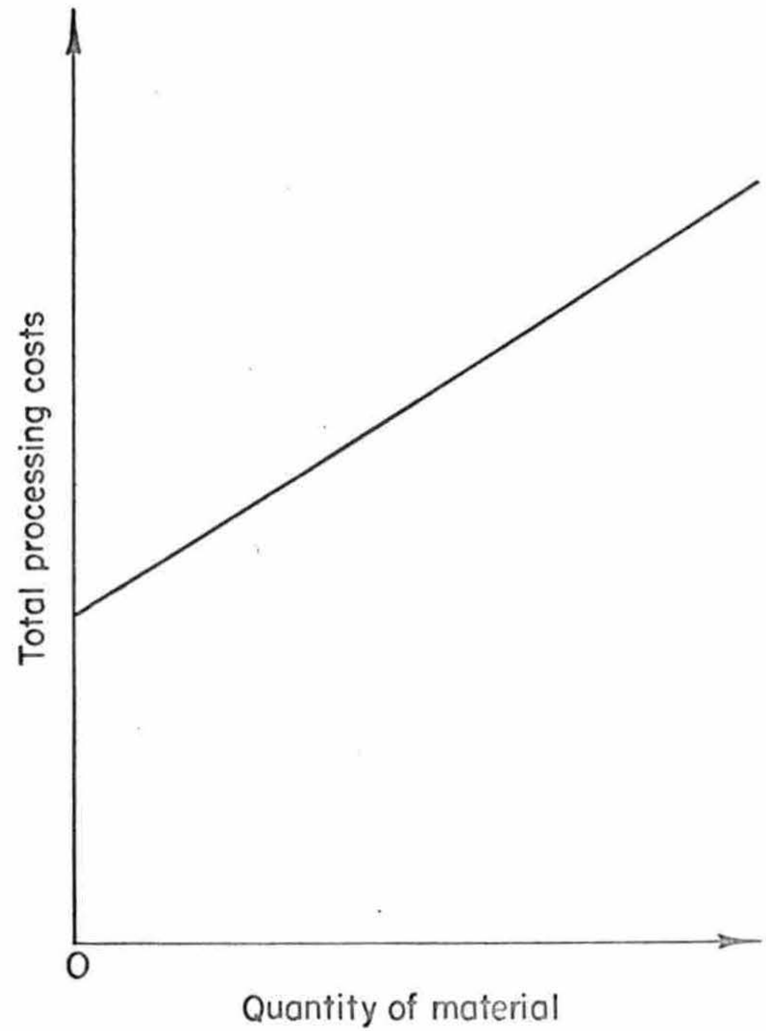

Figure 4. Total long-run processing cost function for an individual plant

increase for each additional plant by an amount equal to the minimum average annual long-run cost of establishing and maintaining a plant. This is because of the assumption of constant and equal marginal costs for all plant sizes. Thus, the minimum average annual long-run cost of establishing and maintaining a plant is equal to (a), the intercept value of the total processing cost function with respect to volume. We can then graph the total processing cost curve with respect to plant numbers (Figure 5).

The optimum solution is then found by summing the two functions with respect to plant numbers to get:

$$TC_{(J,L_k)} = \sum_{j=1}^{J} P_j X_j | L_k + \sum_{i=1}^{I} \sum_{j=1}^{J} X_{ij} C_{ij} | L_k$$

and selecting the minimum point on the total cost function. The two functions and their aggregate are illustrated in Figure 6.

The minimum point on the total combined cost function designates the optimum number of plants. From the operations performed in finding the total assembly cost function with respect to plant numbers, we can find the optimum location of the optimum number of plants. The supply area of each plant and the volume handled by each plant are also determined in the procedure. We then have the optimum size, number and location of processing plants for the given volume of production and area of assembly.

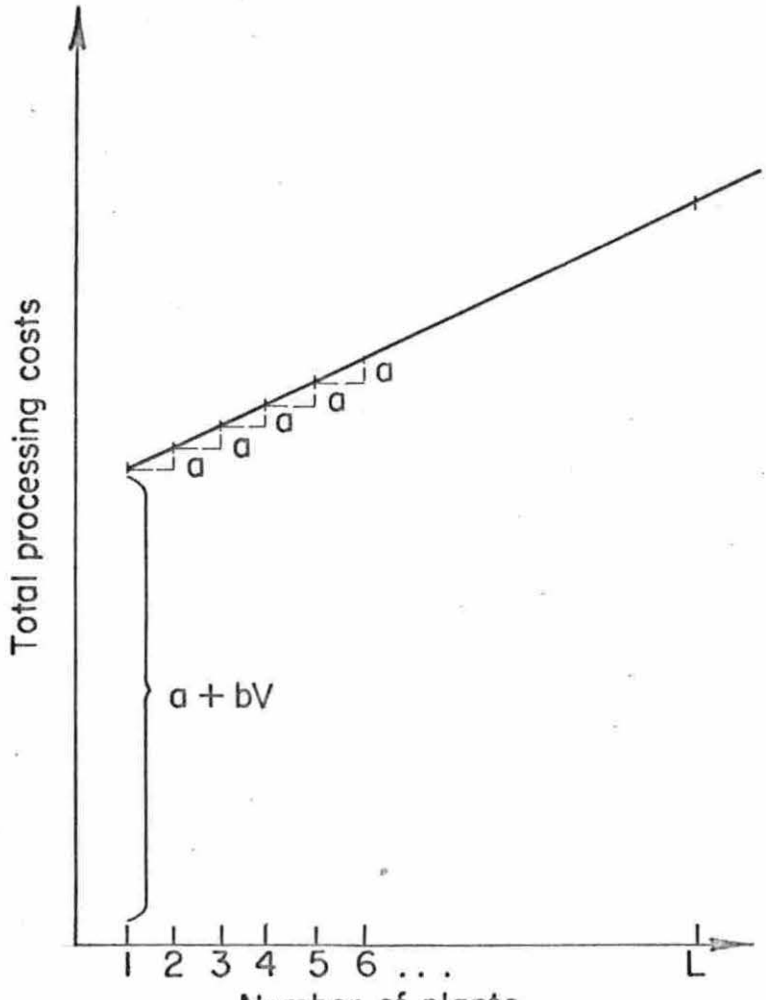

Figure 5. Total processing costs function with respect to plant numbers

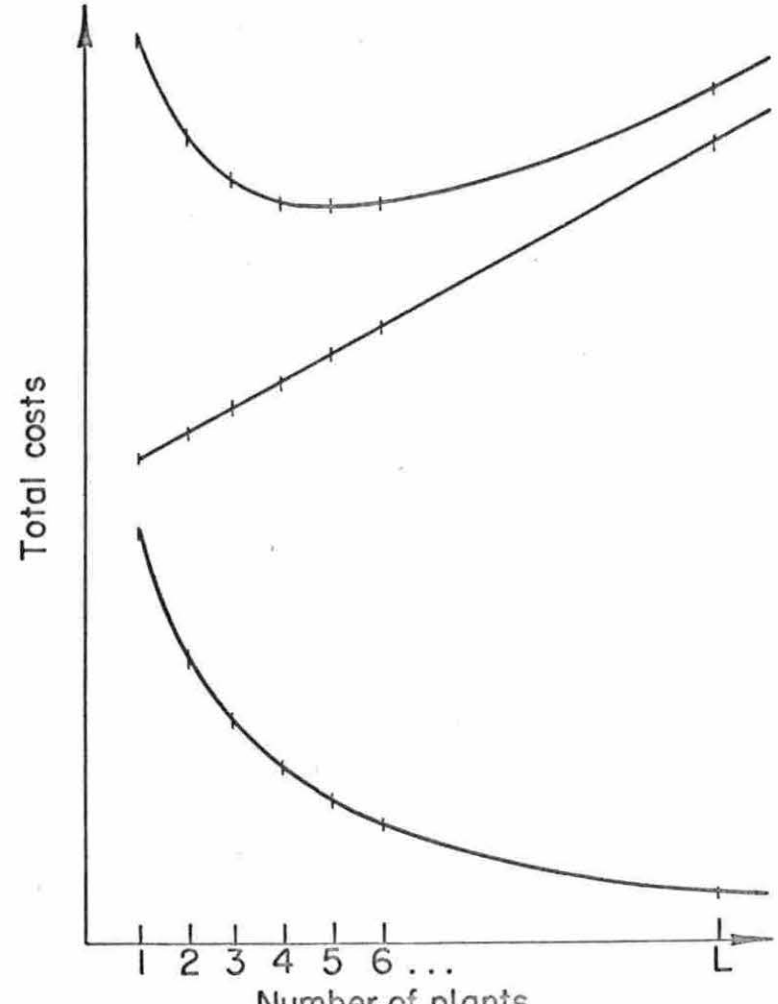

Figure 6. The total assembly costs function, total processing costs function, and the total cost function

V. COST DATA

This chapter contains two sections--one dealing with the empirical development of the processing costs and one with the empirical development of the assembly costs.

The total processing cost function with respect to plant numbers is developed in five steps. First, plant capacities in terms of number of birds per hour in each market class are converted to total pounds per year in each market class for the different sized plants. The second step is to update the average costs per pound as presented by Roger and Rinear to 1967 price levels. The third step is to multiply the updated average costs times the total pounds in each market class and take a weighted average to get the total costs per year of operating each sized plant. Likewise the same weights are used to obtain the total yearly capacity of each sized plant in pounds per year. The fourth step is to use simple linear regression to determine the individual plant's long-run processing cost function by regressing total costs for each plant size on the total pounds processed per year. The final step is derivation of the long-run total processing cost function with respect to plant numbers J.

The total assembly cost function with respect to plant numbers is developed in five steps also. The spatial area of application of the model is delineated by a specification of the supply nodes first and secondly defining a set of plant sites. Thirdly, a mileage matrix is defined representing the road mile distance between every supply node and every plant site. In the fourth step the mileage matrix is converted to a transfer cost matrix. The fifth step involves deriving the minimized total assembly cost function from the transfer cost matrix.

A. Processing Costs

Rogers and Rinear (14) in a study having general applicability in the United States synthesized 10 model plants by the economic-engineering approach for the turkey industry. The plants ranged in size from 3 to 65 million pounds per year. The number of head in each market class that the plants are capable of processing per hour is given in Table 3.

The data presented in Rogers and Rinear's study is calculated on ready-to-cook weight of the turkeys for all market classes. Table 4 gives the ready-to-cook weight and the live weight for the market classes.

Table 3. Capacity of each plant size in head per hour by market classes[a]

Market classes	Plant sizes									
	1	2	3	4	5	6	7	8	9	10
Heavy young hens	150	300	450	600	750	900	1125	1500	2250	3000
Heavy young toms	200	400	600	800	1000	1200	1500	2000	3000	4000
breeders	120	240	360	480	600	720	900	1200	1800	2400
Fryer-roasters	250	500	750	1000	1250	1500	1875	2500	3750	5000

[a]Rogers, George B. and Rinear, Earl H. Costs and economies of scale in turkey processing plants. United States Department of Agriculture Economic Research Service Market Research Report 627. p. 26. 1963.

Table 4. Average live weight and ready-to-cook weight by market classes

	Live weight	Ready-to-cook weight[a]
Heavy young hens	14.9[b]	13.0
Heavy young toms	25.4[b]	22.0
Breeders	18.1[c]	16.0
Fryer-roasters	8.7[b]	7.0

[a]Data all taken from Rogers and Rinear (14).

[b]Data taken from Agricultural Statistics, 1966 (21).

[c]The average live weight for all turkeys was used to approximate the weight of breeders. Data taken from Agricultural statistics, 1966 (21).

The assembly cost functions are calculated on the live weight basis which is the weight of the turkeys at the supply nodes. The turkeys are assumed not to lose weight in transit; that is, the shrink factor is zero. The processing cost functions are calculated on the ready-to-cook weight basis. Therefore the assembled live weight must be converted to ready-to-cook weight before the processing cost function can be calculated. The conversion factor (yield) is assumed to be 0.80: the figure used by Agricultural Statistics (21).

The capacity of each plant in pounds per hour by market class was determined by multiplying the rows of Table 3 by the respective average ready-to-cook weight of each market class as given in Table 4. The total pounds per year can be derived by multiplying by the number of hours operated in a year. Rogers and Rinear (14) assume the plants to operate 144 days per year at 100% capacity. Assuming typical 8 hour days the total number of hours per year would be 1152. This was the figure used to find the total pounds processed per year in the 10 plants by market class as presented in Table 5.

The second step consists of updating the average costs per pound of processing the different market classes in the 10 sizes of plants from 1962 price levels to the first half of 1967 price levels. The average processing costs per pound were taken from Rogers and Rinear (14) and are presented in Table 6. Rogers and Rinear had the factors that made up the average processing costs broken into five categories as follows: plant wages, supplies and materials, management, utilities and miscellaneous, capital ownership and use. Figure 7 gives the percentage contribution of each of these factors to the average processing costs per pound for each market class and each size of plant.

The plant wages and management categories were added together since management was a small percentage of average costs in all cases. An index of factor prices for all Agricultural Marketing firms taken from Marketing and Transportation Situation (23) was used to update the average

Table 5. Total pounds processed per year for each plant size by market class

Market classes	Plant sizes				
	1	2	3	4	5
Heavy young hens	2,246,400	4,492,800	6,739,200	8,985,600	11,232,000
Heavy young toms	5,068,800	10,137,600	15,206,400	20,275,200	25,344,000
Breeders	2,211,840	4,423,680	6,635,520	8,847,360	11,059,200
Fryer-roasters	2,016,000	4,032,000	6,048,000	8,064,000	10,080,000

Table 5 (Continued)

Market classes	Plant sizes				
	6	7	8	9	10
Heavy young hens	13,478,400	16,848,000	22,464,000	33,696,000	44,928,000
Heavy young toms	30,412,800	38,016,000	50,686,000	76,032,000	101,376,000
Breeders	13,271,040	16,588,800	22,118,400	33,177,600	44,236,800
Fryer-roasters	12,096,000	15,120,000	15,160,000	30,240,000	40,320,000

Table 6. The average cost per pound in processing turkeys for each plant size[a] by market classes

Market classes	Plant sizes									
	1	2	3	4	5	6	7	8	9	10
	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents
Heavy young hens	6.866	6.088	5.707	5.470	5.276	5.173	5.092	4.903	4.615	4.531
Heavy young toms	5.724	5.109	4.798	4.613	4.453	4.369	4.292	4.140	3.914	3.847
Breeders	7.760	6.775	6.313	6.032	5.815	5.714	5.627	5.411	5.115	4.973
Fryer-roasters	8.585	7.509	6.979	6.689	6.455	6.334	6.243	6.009	5.681	5.522

[a]Rogers, George B. and Rinear, Earl H. Costs and economies of scale in turkey processing plants. United States Department of Agriculture Economic Research Service Market Research Report 627. p. 41. 1963.

Market class, plant capacity, and cost item	Unit	Model plant number									
		1	2	3	4	5	6	7	8	9	10
Heavy young hens											
Capacity	Head per hour	200	400	600	800	1,000	1,200	1,500	2,000	3,000	4,000
Cost item											
Plant wages	Percent	27.4	24.8	22.8	21.0	20.4	19.9	19.1	18.2	17.4	17.0
Supplies and materials	do.	31.0	35.0	36.6	37.3	38.1	38.5	38.7	40.0	42.5	43.3
Management	do.	4.7	3.7	3.7	3.9	4.5	5.1	6.4	6.7	6.2	6.2
Utilities, miscellaneous	do.	20.4	21.6	22.0	22.4	22.2	21.9	21.4	20.9	19.6	19.4
Capital ownership and use	do.	16.5	14.9	14.9	15.4	14.8	14.6	14.4	14.2	14.3	14.1
Total costs	do.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Heavy young toms											
Capacity	Head per hour	150	300	450	600	750	900	1,125	1,500	2,250	3,000
Cost item											
Plant wages	Percent	25.9	23.2	21.3	19.6	19.1	18.5	17.8	17.0	16.2	15.8
Supplies and material	do.	34.8	39.0	40.6	41.4	42.2	42.6	42.7	44.0	46.5	47.3
Management	do.	4.4	3.5	3.5	3.7	4.2	4.8	6.0	6.2	5.7	5.8
Utilities, miscellaneous	do.	19.3	20.3	20.7	20.9	20.7	20.5	20.0	19.5	18.3	18.0
Capital ownership and use	do.	15.6	14.0	13.9	14.4	13.8	13.6	13.5	13.3	13.3	13.1
Total costs	do.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Breeders											
Capacity	Head per hour	120	240	360	480	600	720	900	1,200	1,800	2,400
Cost item											
Plant wages	Percent	32.4	29.8	27.5	25.5	24.7	24.2	23.0	21.9	20.9	20.5
Supplies and material	do.	26.0	29.8	31.5	32.2	32.7	32.9	33.0	34.2	36.2	37.2
Management	do.	5.6	4.5	4.5	4.8	5.6	6.3	7.9	8.2	7.6	7.7
Utilities, miscellaneous	do.	16.2	17.7	18.2	18.6	18.9	18.7	18.4	18.3	17.9	17.1
Capital ownership and use	do.	19.8	18.2	18.3	18.9	18.2	17.9	17.7	17.4	17.4	17.5
Total costs	do.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Fryer-roasters											
Capacity	Head per hour	250	500	750	1,000	1,250	1,500	1,875	2,500	3,750	5,000
Cost item											
Plant wages	Percent	32.1	29.5	27.2	25.3	24.4	23.9	22.7	21.6	20.6	20.3
Supplies and material	do.	26.7	30.5	32.1	32.9	33.4	33.7	33.8	34.9	37.0	38.0
Management	do.	5.5	4.5	4.5	4.7	5.5	6.2	7.8	8.1	7.5	7.6
Utilities, miscellaneous	do.	16.1	17.5	18.1	18.4	18.7	18.5	18.2	18.1	17.7	16.9
Capital ownership and use	do.	19.6	18.0	18.1	18.7	18.0	17.7	17.5	17.3	17.2	17.2
Total costs	do.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Figure 7. The percentage contribution of each factor to the average processing costs per pound for each market class by plant size

processing costs in all categories except plant wages and management. The index from marketing and transportation situation ran through June 1967.

The index figure used to update the plant wages and management category was derived from average hourly earnings for workers in poultry dressing and packing as given in Employment and Earnings Statistics for the U.S. (20)--industry code 2015. Those figures were extrapolated from May 1966--the last date available--to the first six months of 1967. The average increase in wages for the months January through June from 1962 to 1967 was 15%. Therefore an index figure of 1.15 was used for the plant wages and management category. The index for the four categories of factors of production is presented in Table 7.

Table 7. An index of factor prices for January to June 1967 for agricultural marketing firms. 1962 = 100

Factors	Index
Supplies and Materials	1.05[a]
Utilities and miscellaneous	1.02[a]
Capital ownership and use	1.08[a]
Plant wages and management	1.15[b]

[a]Data taken from Marketing and Transportation Situation (23).

[b]Data taken from Employment and Earnings Statistics (20).

The average costs of Table 6 are disaggregated into the prices for factors of production by multiplying by the corresponding elements of Figure 7. These prices are then updated to 1967 levels with the index presented in Table 7. The factor prices are then added together for each market class and plant size to obtain the updated average processing costs, which are presented in Table 8.

The third step is to determine the total yearly costs of operating each plant size. We begin by multiplying the elements of Table 5 which are total pounds processed per year and the corresponding elements of Table 8 which are the updated average processing costs. The products of the elements of these two tables give the total costs per year of processing each class in each plant size. The total costs for each plant size is found by taking a weighted average of the market classes. The weights are the percentages of each class slaughtered under federal inspection in 1960 as taken from Rogers and Rinear (14, p. 34). The same weights are used for the yearly capacities in Table 5 to obtain the yearly capacity of each plant size processing all four classes. We now have the yearly capacity of each size of plant and the corresponding total yearly cost of each size of plant. They are presented in Table 9.

The fourth step uses simple linear regression to determine the effect of plant size on the total costs for each plant size

Table 8. The updated average costs per pound of processing turkey to 1967 prices levels for plants sizes by market classes

Market classes	Plant sizes									
	1	2	3	4	5	6	7	8	9	10
	cents	cents	cents	cents	cents	cents	cents	cents	cents	cents
Heavy young hens	7.421	6.553	6.131	5.868	5.659	5.549	5.465	5.260	4.947	4.855
Heavy young toms	6.177	5.491	5.147	4.942	4.770	4.680	4.600	4.435	4.189	4.116
Breeders	8.451	7.347	6.830	6.516	6.286	6.172	6.081	5.842	5.515	5.362
Fryer-roasters	9.346	8.140	7.549	7.224	6.969	6.839	6.744	6.486	6.123	5.952

Table 9. The total yearly pounds processed and the associated total yearly costs for 10 sizes of processing plants

Plant size	Pounds/year	Total costs/year
1	3,249,677	223,384.32
2	6,499,354	395,182.08
3	9,749,030	554,584.32
4	12,998,707	708,791.04
5	16,248,384	854,853.12
6	19,497,946	1006,295.04
7	24,372,518	1237,766.40
8	32,496,653	1589,587.20
9	48,745,037	2248,439.04
10	64,993,306	2940,791.04

as they are presented in Table 9. The total costs for each plant are regressed on the total pounds of each plant to obtain the processing cost curve for a single plant which has the form:

$$PC_j = \$133,040 + .04\ V$$

where V is the pounds of turkey to be processed in ready-to-cook weight. r = .99.

The fifth step is derivation of the total processing cost function with respect to plant numbers J. This is a simple process once the individual processing cost function is defined. For each plant that is added to the solution, the total processing cost function increases by the amount necessary to establish and maintain that additional plant, which is an amount equal to the intercept of the individual processing cost curve. The total processing cost curve can be computed in the following manner:

$$TPC_J = (J)(\$133,040) + .04V$$

where V is again the pounds of turkey to be processed in ready-to-cook weight and J is the number of plants out of a total possible number of plants of L.

B. Assembly Costs

The spatial area of application of the model is Miniowisc. There are 116 supply nodes and 184 plant sites. Through the rest of the thesis potential plant sites such as the set of 184 just mentioned will be referred to as sites. A set of plant sites in a solution of the model will be referred to as plants.

Out of the 257 counties in Miniowisc, 116 were selected as supply nodes because they had greater than 50,000 head of turkey produced in 1964 as reported in the Census of Agriculture (24). The supply nodes are listed in Appendix A, and also pictured on the map of Miniowisc as the darkened areas in Figure 8. The supply node counties produced 94% of the 28.6 million turkeys grown in Miniowisc in 1964. It is believed that the results of the analysis will not be appreciably altered from what they would be if the deleted counties had been included.

Turkey producers are assumed to be homogeneously distributed throughout each supply node county. The

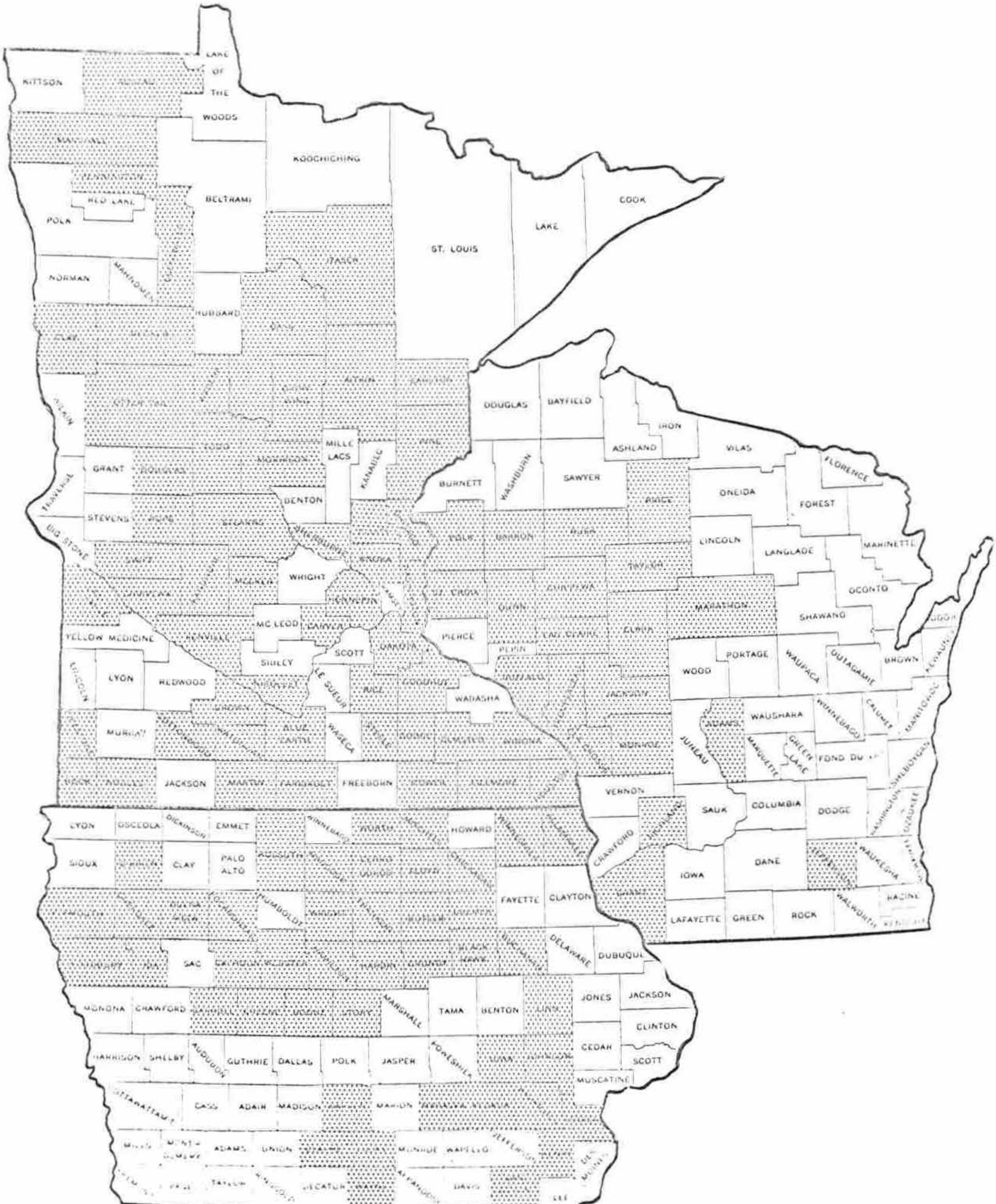

Figure 8. The 116 supply nodes of Miniowisc

geographic center is taken to represent the minimum distance to all producers within each county. In a rectangular figure the geographic center can be approximated by the point where diagonals through the opposite corners cross. In irregular shaped counties the geographic center was approximated visually. The geographic center of these counties is taken to be the supply node and is the point from which mileages are calculated.

The second step in the analysis is to determine the plant site locations. This was done in three parts. First all cities of greater than 5,000 population in Miniowisc were selected unless they happened to lie beyond the periphery of the supply nodes and would thereby never be selected as a plant site such as Milwaukee, Wisconsin which can be seen from Figure 8 to lie outside the area of the supply nodes in Wisconsin. Or, other cities of greater than 5,000 population were not selected because the city could have been part of a complex of large cities like Minneapolis-St. Paul, or because no processing plants are presently in the city and it doesn't seem likely that one would locate there due to zoning laws, difficulty of access, etc. such as Des Moines, Iowa. Smaller towns surrounding Des Moines were included to approximate the actual locations that firms might choose if they decided to locate in the area of Des Moines. Many sites on the peripheries of cities with greater than

50,000 population were included so as to give plenty of freedom of location in and around these cities.

The next part of the selection of potential plant sites involved trying to make the distribution of plant sites uniform over the spatial area of the supply nodes. Larger towns were preferred to smaller in all cases where there was competition between towns for a plant.

In the third stage of selection of the plants the criterion was the inclusion of all population centers with existing processing plants. Thirty-three processing plants were found to presently exist in Miniowisc. The set of 184 sites contains the set of 33 existing sites (plants) in the industry. The centers of cities (towns) were used as the point for measurement of mileage in all cases. The set of 184 sites and the set of 33 existing sites are both listed in Appendix A.

The third step towards the total assembly cost function is the definition of the mileage matrix representing mileages between the 116 supply nodes and 184 sites. A composite of maps were xeroxed from the Rand McNally Standard Highway Mileage Guide (17) and fitted together to form a map of Miniowisc. The three states fortunately were all in the same scale of 1 inch equals 14 miles. A transparent grid was then placed over the map scaled to 1/16 inch in each direction. Miniowisc can then be pictured as lying in the first quadrant of a rectangular coordinate system with the abscissa axis running in the east-west direction and the ordinate in the north-south direction.

The 116 supply nodes and 184 sites were then plotted on the map and the coordinates tabulated. The coordinates were measured to the nearest 1/16 of an inch which is to within less than 1 mile accuracy.

A program was then written for the IBM 360/60 computer to calculate the road mile distances between every supply node and every site. For the distance between any two points the computer found the absolute difference of the X coordinates and added to that the absolute difference of the Y coordinates. This figure was multiplied by 14 to convert it to road mile distance.

In going between any particular site and supply node the truck is assumed to travel at most in two perpendicular directions: north-south or east-west. He may not travel diagonally. There are two offsetting factors contributing to the errors of calculation. Some roads do transverse the landscape in diagonal directions which would tend to make the actual mileage less than the estimated mileage in these cases. However, some roads contain many curves, hills, and corrections which add mileage and therefore make the estimate an understatement. It so happens that the areas with predominantly diagonal roads such as Wisconsin and eastern

Minnesota also have very irregular roads while Iowa and western Minnesota tend to have straight roads that follow the section lines. These two effects, then, tend to offset each other and it is believed that they tend to make the calculation error small in most cases.

The three state area is not large enough for distortion due to the earth's curvature to have a significant effect. All map errors and measurement errors are assumed not to exist.

The fourth step involves deriving the transfer cost matrix from the mileage matrix. The transfer cost between a supply node and any site is the cost of moving a unit (one truckload of turkeys) of product from the producer to the plant. The elements of the mileage matrix are first doubled to account for the roundtrip distance between the plant and the producer. These figures are then multiplied by the unit cost per mile for assembling turkeys which is just the average cost per mile for operating the truck plus the driver's wages. Petersen (10, p. 24) had data on assembly costs for two situations. Average costs of assembly in the respective situations were 35.414 and 46.450 cents per mile. The average of these two figures was taken as the unit cost of assembly for this study which is 40.9 cents per mile. It includes the fixed and variable truck costs and the driver's wage. The truck is assumed to haul a 30,000 pound payload tandem trailer.

The transfer cost matrix is then the mileage matrix with its elements doubled and multiplied by 40.9 cents, the unit per mile cost of assembling turkeys.

The fifth step involves deriving the assembly cost function from the transfer cost matrix. We need to know the number of trips to each supply node. The number of turkeys at each supply node is multiplied by a weighted average live weight of the four market classes--toms, hens, breeders, and fryer-roasters. The average live weight of these four classes in 1964 is given in Table 4. The weights are the percentages of each class slaughtered under federal inspection in 1964 as presented in Agricultural Statistics (21). These percentages are shown in Table 10. The toms and the hens were grouped together in a young turkey category. This category was split for our purposes so that 78.7% in the young turkey category became 39.5% hens and 39.5% toms.

Table 10. Percentage by market class slaughtered under federal inspection in 1964[a]

Market class	Percentages
Heavy young toms	39.5
Heavy young hens	39.5
Breeders	3.2
Fryer-roasters	18.0

[a]U.S. Department of Agriculture. Agricultural Statistics, 1966. Washington, D.C., U.S. Department of Agriculture. 1966.

The percentages slaughtered were multiplied by the respective live weights of each class and summed to get the weighted average of 18.0362 pounds. The number of turkeys at each supply node was multiplied by the weighted average to get total pounds at each supply node. The truck is assumed to haul a 30,000 pound payload. The total pounds at each supply node is divided by 30,000 to get the number trips required which is equal to X_i, the number of units at origin i. Each truckload is a unit and partial truckloads are taken as a full load.

The total assembly cost function is then derived as the envelope of all assembly costs given J plants. For each J there are $\binom{184}{J}$ locational patterns L_k, or $\binom{184}{J}$ values of $(X_i')\overline{C}_{ij}|L_k$. The minimum of these values is a point on the total assembly cost function minimized with respect to plant location.

VI. COST ANALYSIS

Two approaches will be investigated for solving the model. They are the combinations and the iterative approaches so named by Warrack (25).

The combinations approach follows the computational procedure outlined in Chapter IV. For all possible combinations of plant locations of J plants the locational pattern which minimizes the total assembly cost function is determined. This procedure is carried through for all values of J where J=1, ..., 184 for this thesis to obtain the total assembly cost function with respect to plant numbers J minimized by locational patterns for each J. The total processing cost curve with respect to plant numbers is subsequently derived and the two functions summed to obtain the total cost function with respect to plant numbers J. The optimum solution to the problem is the minimum point of the total cost function which gives the optimum number of plants and their locations. The size of each plant in the solution is found by summing the units of raw material in all the supply nodes served by that particular plant. The supply nodes served by a particular plant are determined in the assembly cost function from the $\overline{C}_{ij}|L_k$ vector. The combinations approach then is an optimization procedure in the sense that all possible locational patterns given J plants are investigated and the minimum of these are selected as a point on the total assembly cost function. The total assembly cost function computed by the combinations approach is the lower bound of all total assembly cost functions for a given problem.

If important model assumptions hold concerning the minimized total assembly cost function and the total processing cost function, the total cost function will be convex. These assumptions are: the first differences of the minimized total assembly cost function with respect to plant numbers are negative; the second differences of the minimized total assembly cost function with respect to plant numbers are non-negative; and the total processing cost function is linear. If the total cost function is convex then a local minimum is a global minimum. These assumptions obviate computing the total cost function for all L plant numbers.

Although the combinations approach yields the optimal solution, it has the drawback for large problems of an immense computational burden. For a problem of the size undertaken in this study the computational costs of the combinations approach are prohibitively high. The IBM 360/60 computer is capable of calculating 3,000 combinations of locational patterns per minute using the programs developed by Wendell Primus and myself. For J=2 the combinations approach requires calculating 16,653 combinations, which was done. However $\binom{184}{3}$ equals 1,004,731 combinations which would take approximately 335 minutes of computer time--more than we could afford. Calculating $\binom{184}{5}$ is estimated to require 537,000 minutes of computer time. As can be seen the computational costs rise at an extremely high rate as one increases the plant numbers. Warrack found a solution using the combinations approach in reverse order starting with J=L, and with the slight modification of dropping a doubly eliminated plant out of the solution. This approach was not feasible in our case because the optimum solution was thought to be close to the low end and the iterative optimum solution substantiated this. Starting from the high end with J=184 and working backwards would have been impractical for our purposes.

The iterative approach was utilized as an alternative method of solving the model. With one important exception the basic solution procedure is the same for the iterative approach as for the combinations approach. The exception is that in iterative method, once sites are selected that minimized the total assembly cost function for ${}_{184}C_1$, ${}_{184}C_2$, ..., ${}_{184}C_{J-1}$ plants, they are retained in the solution. When solving for ${}_{184}C_J$ the problem is to find the plant from the 184 - (J-1) remaining plants that combine with the J-1 plants already in the solution to minimize assembly costs.

An example might be helpful in explaining the difference between the methods. One plant is selected from the 184 potential sites that minimizes the assembly cost function for both approaches. In the combinations method all $_{184}C_2$ locational patterns are considered when selecting the two plants that minimize the total assembly cost function. In the iterative method all 183 remaining plants are considered that when combined with the first plant selected, will minimize the total assembly cost function for two plants.

This additional constraint of the iterative method allows it to be applied to large problems to obtain a sub-optimum solution where the combinations approach would be prohibitively expensive. Instead of having to investigate all the possible locational patterns for J plants, the iterative method only requires investigating L - J + 1 plants not in the solution.

The iterative method is a suboptimal procedure because not all possible locational patterns are investigated when the solution is being calculated and the total cost function of the iterative method is always greater than or equal to the total cost function of the combinations method. When the minimum point of the total cost function of the iterative method is being referred to, it will be called the optimum solution; however it must be recognized that this is the optimum solution for the iterative method and not the true optimum solution. The greatest disparity between the total cost functions for the two methods is expected to occur at

J=2 and for the difference between them to decrease as J increases. The two total cost function will be exactly equal at J=1 and 184. The total processing cost functions of the two methods are always equal so the differences in the total cost functions can all be attributed to the total assembly cost functions. All the above conclusions are confirmed by Warrack's study. His iterative total assembly cost function was higher than the combinations on the low end but the two functions were exactly the same from J=28 to 40 plants. It is reasonable to expect in this study that the error in the iterative total cost function over the combinations should decrease and eventually equal zero as J increases from J=2 to 184.

A. Results

Two optimum solutions to the model were obtained by the iterative method for two configurations of sites. One configuration was the set of 184 sites and the other was the set of 33 existing sites in the industry. The 116 supply node configuration remained unchanged through the different solutions. For both the solutions J was allowed to range from 1 to 33 sites. The optimum number of plants in both optimum solutions was six, but the plant locations between the two optimum solutions were all different. A clear distinction must be maintained between solution and the optimum solution. The solution should be thought of as referring to the total cost function while the optimum solution will refer to the minimum point of the total cost function.

The results of the application of the model to the 184 site configuration are presented in Table 11. The plants are listed in Table 11 as they come into the solution, and their effect on the total assembly, total processing, and the total cost functions. The first plant to come into the solution was Mound with total assembly costs of \$2,356,073, total processing costs of \$15,631,485, and total costs of \$17,987,558. When J=2 the two plants in the solution are Mound and Iowa Falls. The effects of two plants in the solution is to decrease total assembly costs and total costs to \$1,753,870 and \$17,518,295 respectively, and to increase total processing costs to \$15,764,525. With the iterative method, once a plant comes into the solution it stays in. The six plants in the optimum solution are Mound, Wadena and Wilmar in Minnesota, Iowa Falls and Washington in Iowa, and Chippewa Falls in Wisconsin. The assembly costs, processing costs and size of each plant in terms of pounds of ready-to-cook turkey processed per year for the plants in the optimum solution are presented in Table 12.

The combinations approach could only be applied for J=2 plants for the set of 184 sites since calculation of J=3

Table 11. The total assembly costs, total processing costs, and total costs for the solution of 184 sites by the iterative method

Plant	Total assembly costs	Total processing costs	Total costs
Mound	2,356,073	15,631,484	17,987,557
Iowa Falls	1,753,870	15,764,524	17,518,394
Wadena	1,363,329	15,897,564	17,260,893
Chippewa Falls	1,129,021	16,030,604	17,159,625
Washington	992,441	16,163,644	17,156,085
Willmar	857,944	16,296,684	17,154,629
Caledonia	781,055	16,429,724	17,210,780
Cherokee	704,305	16,562,764	17,267,070
Thief River Falls	642,514	16,695,804	17,338,319
Barron	597,774	16,828,842	17,426,616
Aitkin	561,171	16,961,882	17,523,053
St. James	524,654	17,094,922	17,619,576
Wausau	493,385	17,227,962	17,721,347
Chariton	471,259	17,361,002	17,832,261
Spring Valley	450,316	17,494,042	17,944,358
Webster City	430,619	17,627,082	18,057,701
Richland City	413,656	17,760,122	18,173,778
Frazee	396,720	17,893,162	18,289,882
Brainerd	383,194	18,026,202	18,409,396
Stillwater	370,116	18,159,242	18,529,358
Charles City	358,547	18,292,282	18,650,829
Benson	347,488	18,425,322	18,772,810
Faribault	336,690	18,558,362	18,895,052
Augusta	326,031	18,691,402	19,017,433
Le Mars	317,760	18,824,442	19,142,202
Waterloo	310,700	18,957,482	19,268,182
Jefferson	303,744	19,090,522	19,394,266
Laverne	296,858	19,223,562	19,520,420
Iowa City	290,123	19,356,602	19,646,725
Cambridge	283,778	19,489,642	19,773,420
Mt. Pleasant	277,538	19,622,682	19,900,220
Medford	271,397	19,755,722	20,027,119
Mason City	265,400	19,888,762	20,154,162

Table 12. The assembly costs, processing costs, and total pounds processed[a] for the six plants in the optimum solution of 184 sites by the iterative method

Plants	Assembly costs	Processing costs	Total pounds/ year
	$	$	
Mound	62,155	1,283,260	28,755,500
Iowa Falls	204,607	3,229,182	77,403,550
Wadena	212,869	3,684,145	88,777,625
Chippewa Falls	244,725	3,729,200	89,904,000
Washington	47,431	1,509,716	34,416,900
Wilmar	86,160	2,861,179	68,203,475

[a]Ready-to-cook weight.

would have been too expensive. The combinations method selected Waverly and Melrose over the iterative's selection of Mound and Iowa Falls for a savings of $133,908 or .02 cents per pound. The iterative solution has a .65% error at J=2. The total assembly costs, total processing costs, and total cost are respectively $1,639,962., $15,764,524., and $17,404,486. It is interesting to note that the locations of the plants in the two solutions are not too dissimilar; that is, Mound is not many miles from Melrose in Minnesota and Iowa Falls is not many miles from Waverly in Iowa as shown on the map in Figure 9. This indicates that the iterative method should be a good approximation to the combinations method in this study even on the low end. The error of the iterative method is small probably because there are many sites to choose from and the spatial area of the supply nodes and

Figure 9. The plants in the solutions of the combinations and the iterative methods for 184 sites at J=2

is large.

The results of the iterative application to the 33 existing configuration of sites are presented in Table 13. Again there are six plants in the optimum solution and in the same breakdown with reference to states; however no plants are the same in the two solutions. The 33 existing plants are all a subset of the 184 plants.

The six plants in the optimum solution for the 33 existing sites are Faribault, Melrose and Frazee in Minnesota, Ellsworth and Kalona in Iowa, and Barron in Wisconsin. The assembly costs, processing costs, and total pounds processed for the six plants in the optimum solution are presented in Table 14.

The combinations approach could be applied for J=2,3, and 4 for the 33 existing site configuration. As expected the error of the iterative method decreased with each increase of J except going from J=1 to 2. For J=2,3, and 4 the error in the iterative solution is respectively $155,840, $120,224, and $112,799. The error of the iterative solution is larger in this application than in the other probably because there are fewer sites to choose from which means that less optimally located plants enter the solution than when there is a larger selection to choose from. The error in the iterative method seems to be related to the number of destinations relative to the number of origins with the error

Table 13. The total assembly costs, total processing costs, and total costs for the solution of the 33 existing sites by the iterative method

Plant	Total assembly costs	Total processing costs	Total costs
Faribault	2,437,866	15,631,484	18,069,350
Melrose	1,814,207	15,764,524	17,578,731
Ellsworth	1,415,380	15,897,564	17,312,944
Barron	1,207,490	16,030,604	17,238,094
Kalona	1,066,604	16,163,644	17,230,248
Frazee	928,153	16,296,684	17,224,838
Wilton	838,861	16,429,724	17,268,586
Willmar	759,846	16,562,764	17,322,610
Storm Lake	697,679	16,695,804	17,393,483
Aitkin	649,269	16,828,842	17,478,111
Thief River Falls	608,696	16,961,882	17,570,578
Decorah	574,241	17,094,922	17,669,163
Butterfield	543,810	17,227,962	17,771,772
Altura	527,587	17,361,002	17,888,589
Westfield	513,251	17,494,042	18,007,293
Sioux City	502,817	17,627,082	18,129,899
Albert Lea	494,061	17,760,122	18,254,183
Jackson Creek	487,536	17,893,162	18,380,698
Litchfield	481,607	18,026,202	18,507,809
Vinton	476,323	18,159,242	18,635,565
Eagle Grove	471,610	18,292,282	18,763,892
Carroll	467,906	18,425,322	18,893,228
Burlington	465,079	18,558,362	19,023,441
Marshall	462,948	18,691,402	19,154,350
Calmar	461,156	18,824,442	19,285,598
Postville	460,561	18,957,482	19,418,043
West Liberty	460,142	19,090,522	19,550,664
Detroit Lakes	459,788	19,223,562	19,683,350
Keokuk	459,599	19,356,602	19,816,201
Davenport	459,599	19,489,642	19,949,241
Pelican Rapids	459,599	19,622,682	20,082,281
Chilton	459,599	19,755,722	20,215,321
Endeavor	459,599	19,888,762	20,348,361

Table 14. The assembly costs, processing costs, and total pounds processed[a] for the six plants in the optimum solution of the 33 existing sites by the iterative method

Plant	Assembly costs	Processing costs	Total pounds/ year
	$	$	
Faribault	182,129	2,603,782	61,768,550
Melrose	180,661	3,781,711	91,216,775
Ellsworth	185,048	3,058,904	73,146,600
Barron	149,870	2,793,176	66,503,400
Kalona	96,989	1,737,352	40,107,800
Frazee	133,455	2,321,756	54,717,900

[a]Ready-to-cook weight.

becoming smaller when more destinations are available to be selected from.

One of the two plants selected by the combinations method for J=2 is the same as one in the iterative solution for J=2. At J=3 two of the three plants are the same and at J=4 one of the four plants are the same. Table 15 gives the total assembly costs, total processing costs, and total costs for the solutions of the combinations method. The plants in the solution for each value of J must be listed because plants in the solution from previous calculations if any may not stay in the solution. For J=1 the cost functions are the same as the iterative.

Although no plants in the two optimum solutions of the iterative methods are the same, the general locations of the six plants in the optimum solutions for the two iterative

Table 15. The total assembly costs, total processing costs, and total costs for the 33 existing sites by the combinations method

Plants	Total assembly costs	Total processing costs	Total costs
	$	$	$
Calmar Melrose	1,658,367	15,764,524	17,422,891
Ellsworth Altura Melrose	1,295,156	15,897,564	17,192,720
Ellsworth Altura Frazee Wilmar	1,095,691	16,030,604	17,126,295

applications are quite similar. Figure 10 shows the locations of the six plants in the optimum solution for the 184 site configuration and Figure 11 shows the locations of the optimum six existing plants. As can be seen from the two figures the plants of Iowa and Wisconsin are almost identically located, but the plants in Minnesota assume a somewhat different pattern. Still overall the plants in the two optimum solutions are located quite consistently.

The optimum solution based on the 184 site configuration is the least-cost configuration for assembling and processing turkey in Miniowisc found in this study. However if the combinations method could have been calculated for J=6, it could have given a lower total costs. The optimum solution of the 184 site configuration saves $70,209 or .018 cents per

Figure 10. The six plants in the optimum solution of the 184 sites by the iterative method

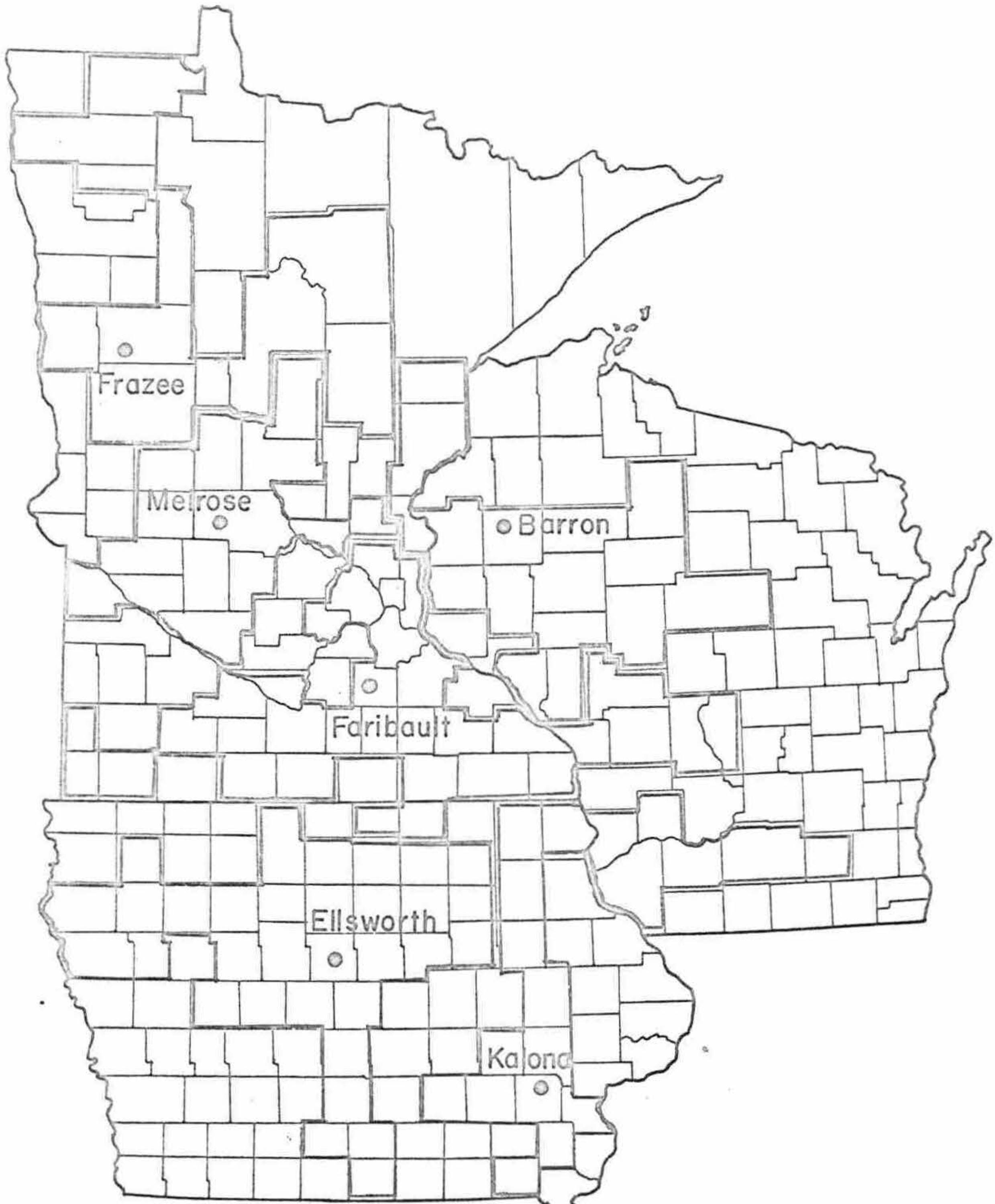

Figure 11. The six plants in the optimum solution of the 33 existing sites by the iterative method

pound over the optimum solution of the 33 site configuration. This savings is relatively insignificant to the amount that can be saved if the turkey industry went from its present 33 site configuration to the optimum solution for the 33 site configuration. In other words, merely selecting the six more optimally located plants out of the 33. According to the model the industry could save $3,123,523 or .80 cents per pound by moving to the six optimum plants. The savings are calculated as the difference between the total costs of assembling and processing turkeys with 33 plants in the solution and the total costs with six plants in the solution.

The six existing optimum plants are more uniform in size than the optimum six plants from the set of 184 as can be seen from Table 16 where the 12 optimum plants from both solutions are listed by size and average costs per pound.

It can be seen from Table 16 that the six plants in the optimum solution for the 33 existing sites are less variable in size. Using the range of 35-75 million pounds, only two of the existing six plants fall outside that range while five of the six plants from the 184 site configuration fell outside that range. The optimum solution for the existing plants has an advantage over the optimum solution for 184 sites of more uniformity for the six plants in the optimum solution.

If one plant were to process all the 387,461,100 pounds

Table 16. The sizes and average costs per pound for the plants in the two optimum solutions

Optimum solution for 184 sites			Optimum solution for 33 existing sites		
Plant	Total pounds/ year	Ave. cost in cents	Plant	Total pounds/ year	Ave. cost in cents
Mound	28,755,500	4.46	Faribault	61,768,550	4.21
Iowa Falls	77,403,550	4.17	Melrose	91,216,775	4.14
Wadena	88,777,625	4.14	Ellsworth	73,146,600	4.18
Chippewa Falls	89,904,000	4.14	Barron	66,503,400	4.20
Washington	34,416,900	4.38	Kalona	40,107,800	4.33
Wilmar	68,203,475	4.19	Frazee	54,717,900	4.24

of turkey ready-to-cook weight in Miniowisc it would have an average cost of 4.03 cents per pound. All the plants in the two optimum solutions as represented in Table 16 have average costs per pound of less than 4.50, or have average costs of within 1/2 cent of the average costs for the one large plant processing all the turkeys of Miniowisc.

Given the 33 site configuration in Miniowisc, the industry can save $3,123,523 out of a total cost of $20,348,361 by moving to the optimum solution of six plants for the existing 33 sites with a total cost of $17,224,838. However, it can save $2,576,589 of the $3,123,523, or 82.5% by moving from the 33 sites to a configuration of thirteen plants in the solution rather than moving all the way from 33 sites to 6 plants. For J=13 plants the total assembly cost curve flattens out indicating that most of the economies of assembly have been exhausted at that point for the 33 existing sites. The plant sizes at J=13 plants in the solution for the 33 existing sites are closer in size to the plants that exist in the industry today than are the plants in the optimum solution.

The 13 plants in the 33 existing sites solution are listed in Table 17 along with their assembly costs, total pounds processed and their average costs. Figure 12 shows the locations of the 13 plants, and their supply areas.

Given the state of the turkey industry today in

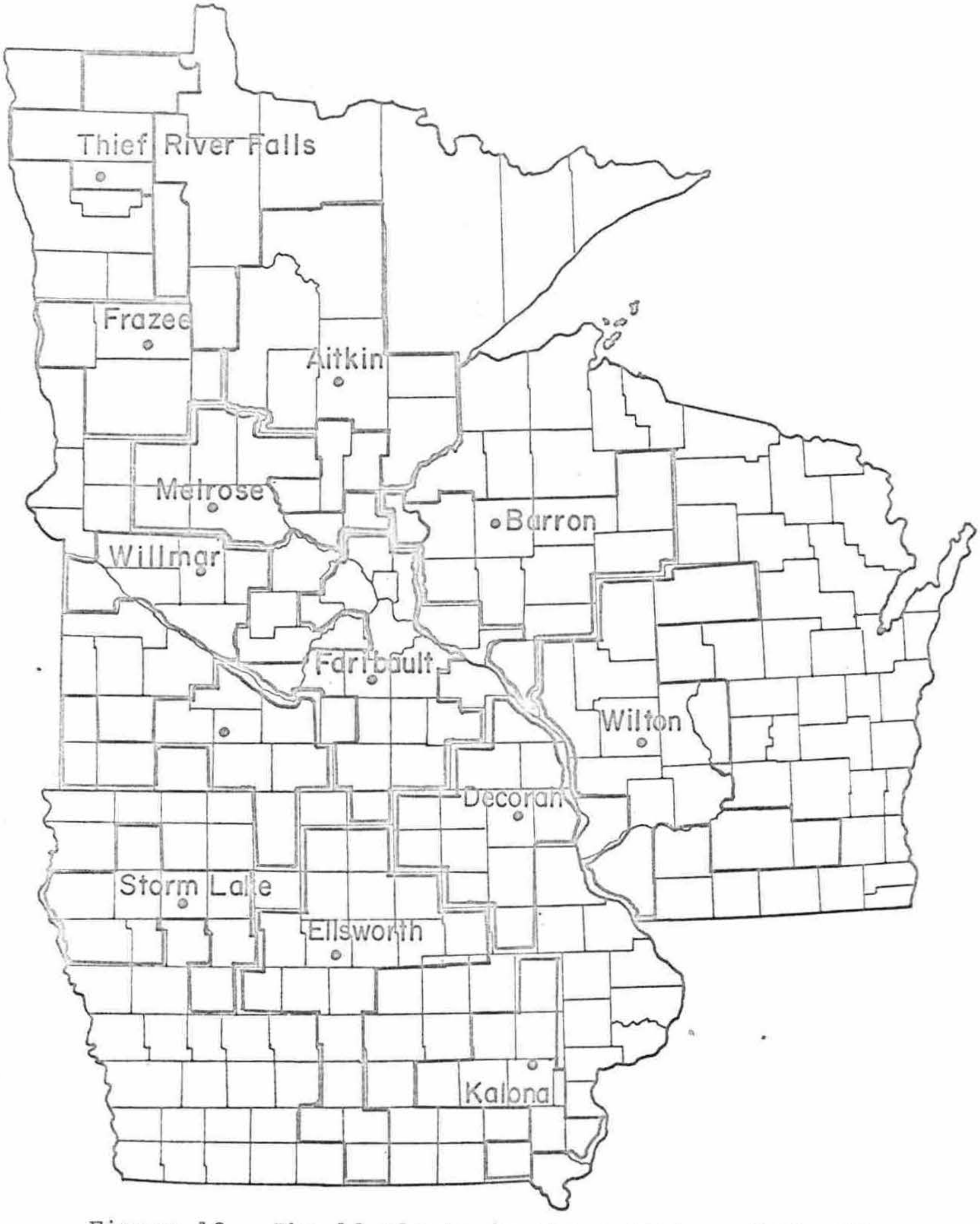

Figure 12. The 13 plants in the solution of the 33 existing sites by the iterative method and their supply areas

Table 17. The assembly costs, total pounds, and average costs per pound for 13 plants in the solution of the existing sites by the iterative method

Plants	Assembly costs in dollars	Total pounds/ year	Average costs in cents
Faribault	1,171,220	25,954,500	04.51
Melrose	732,214	14,979,350	04.88
Ellsworth	1,934,382	45,033,550	04.29
Barron	1,868,554	43,387,850	04.30
Kalona	1,294,881	29,046,025	04.45
Frazee	1,301,023	29,199,575	04.45
Wilton	1,503,504	34,261,600	04.38
Wilmar	2,247,642	52,865,050	04.25
Storm Lake	972,900	20,996,500	04.63
Aitkin	1,595,987	36,573,675	04.36
Thief River Falls	687,135	13,852,375	04.96
Decorah	1,054,399	23,033,975	04.57
Butterfield	864,116	18,276,900	04.72

Miniowisc with 33 existing sites and a total cost of assembling and processing the 28.5 million turkeys of $20,348,361, the industry can obtain considerable savings by reducing the number of processing plants. The industry could realize a savings of $3,193,732 if it assumed a six plant configuration like the one in the optimum solution of the set of 184 sites with total costs of $17,154,629. This was the maximum amount of savings the industry could obtain as calculated in this thesis.

The industry could obtain 81% of the total savings possible or $2,576,589 by reducing the number of plants from 33 to 13 in the 33 existing site solution. The total cost for the 13 existing plants are $17,771,772.

The industry could further reduce the number of plants to six as in the optimum solution of the 33 existing sites. The savings of reducing the number of plants from 13 to 6 in the 33 existing site solution is $546,934 or 17% of the total possible savings. The total costs for the optimum solution of the 33 existing sites are $17,224,838.

The industry can obtain further savings by relocating the six plants in the optimum 33 existing site solution to the configuration of the 184 site optimum solution. The savings for relocating the optimum six plants would be $70,209 or 2% of the total possible savings. The total costs for the optimum solution of the 184 sites are $17,154,629.

B. Limitations

The effectiveness of any model can be enhanced by increasing the precision of the data going into it. According to my data sources there are 33 plants operating in Miniowisc now under federal inspection. There could be others not operating under federal inspection which are not included in this study. If there are more than 33 plants operating in Miniowisc, then the industry would have greater savings by moving to a more optimum configuration than the model indicates.

Only one truck size was assumed for all plant sizes and it operated under a constant average cost per mile of 40.9 cents. Different truck sizes and costs could be assumed to allow for varying conditions of assembly to ascertain its effect on the optimum solution. Different densities of turkey production could be assumed to determine the effect on the optimum solution. The amount of shrink occurring under varying conditions of assembly could be incorporated in the costs of assembly to determine its effect on the optimum solution. These are a few of the questions that can be explored with further research in the field.

This study found the optimum number of plants for Miniowisc and the associated total costs of assembly and processing under the assumption that competition between the processing plants does not exist. In reality competition between the plants does exist and tends to make total costs higher than they would be if competition didn't exist. If the costs of competition were incorporated into the solution of the model, it would tend to make the number of plants in the optimum solution smaller.

One of the consequences of the assumption of no competition between processing plants is that all the turkeys in a particular supply node will go to the plant in the solution for which transportation costs are the smallest. This consequence of the no competition assumption is accentuated in the

33 existing plant solution of this study where the last four plants to come in the solution have zero assembly costs because other plants overshadow them. As an example Westfield and Endeavor in Wisconsin are about 13 miles apart. Westfield is evidently more favorably located in relation to the surrounding supply nodes than is Endeavor which means Westfield takes all the nearby turkeys leaving none for Endeavor. When Endeavor is finally forced into the solution as the thirty-third and final plant to enter, there are no turkeys for it to process. In reality plants close to each other compete for the surrounding turkeys with a certain percentage going to each plant. Not all the turkeys in most supply nodes go to one plant, as evidenced by Petersen (10, p. 49) where 84 out of the 99 counties in Iowa had more than one processing plant procurring turkeys in that county. The supply nodes could be defined on a smaller spatial unit such as a township to minimize the amount of competition that actually exists within the supply node.

Another source of cost to the processors that has not been considered in this study is the costs of loading the turkeys at the grower. The costs of loading is a constant factor at each supply node related to the number of turkeys produced there. Deletion of this factor from the study doesn't effect the optimum solution save only from adjusting the total assembly and processing cost function downward by a constant amount.

Another simplifying assumption that distorts reality is that of equal costs of establishing and maintaining a plant for all plants regardless of its size. This implies equal fixed costs for all plants. Under this assumption the optimum solution for the 183 plant configuration is found to contain 6 plants of which the smallest processes 28.8 million pounds and the largest 89.9 million pounds both with the same fixed costs. But trying to force that wide range of output out of the same amount of fixed costs would seem to put quite a strain on the variable factors.

In future applications of the model it might be possible to define the individual plant processing cost function in segments with each segment corresponding to a range of output that can be realistically handled by a given level of fixed investment. The assumption of constant marginal costs would have more meaning in this context.

Although marginal costs would be constant within each segment, they would not necessarily be constant between segments. This allows for different technology at different levels of output. This does not preclude the assumption of unchanging technology through the period of the model's application.

The processing cost function would be linear for each segment but the total processing cost function with respect to plant numbers would not necessarily be linear. Given a locational pattern L_k and plant numbers J, the total processing cost would be the sum of the individual plant's processing costs with respect to their output.

The procedure for solving the model would be slightly altered. The total cost function would have to be found by simultaneously determining the total assembly cost and total processing cost functions rather than first minimizing the assembly costs with respect to plant numbers and the adding total processing costs to it to obtain the total cost function. There would be $\binom{L}{J}$ total cost points for each value of J similar to the assembly costs points of Figure 3 in Chapter IV where L is the total number of plant sites and J is any subset of them. The total cost function minimized with respect to plant numbers J would then be the envelope of the set of all total cost points. The total assembly cost function and total processing cost function would be determined by the locational pattern given J plants that minimized the total cost function. The optimum number, size and location of plants would be determined from the minimum point of the total cost function.

Under this definition of the model, economies resulting from greater use of technology would have an effect on the optimum solution. In general it should tend to reduce the variation in plant size of the plants in the optimum solution.

Another shortcoming in the model used for this study is the assumption that processing costs are independent of location. In view of the fact that for this study all the plants in both optimum solutions and the solution consisting of 13 existing plants were located in smaller cities and towns, this assumption was not too unrealistic in this case. However plants in different locations could have different costs especially for those in large cities. This shortcoming can be corrected by adjusting the appropriate C_{ij}'s in the transfer cost matrix to compensate for differences in processing costs for the different locations.

VII. SUMMARY AND CONCLUSIONS

The objective of this study was to find the optimum number, size and location of turkey processing plants in the three states of Minnesota, Iowa and Wisconsin which were dubbed Miniowisc.

The production of turkeys in Miniowisc was assumed to be given and the Census of Agriculture (24) was used to determine the 1964 production by county. Only counties with greater than 50,000 head were considered as origins or supply nodes. A homogeneously distributed set of 184 destinations or plant sites were selected in Miniowisc.

A grid was placed on the map of Miniowisc and the coordinates of all supply nodes and plant sites recorded. A program was written for the IBM 360/60 computer to calculate a mileage matrix for distances between all plant sites and supply nodes. From this a transfer cost matrix was developed using a unit assembly cost of 40.9 cents per mile where a unit was defined as one 30,000 pound truckload.

The processing costs for a single plant were estimated by least squares regression from data obtained by adjusting the processing cost data presented by Rogers and Rinear (14).

Optimum solutions were obtained for two sets of plant sites--the complete set of 184, and a 33 element subset of these representing the existing processing plants in Miniowisc.

The optimum number of plants in both solutions were six but the locations and sizes for the optimum six were different between the two solutions. There was a correspondence between the locations of the plants in the two optimum solutions with three located in Minnesota, two in Iowa and one in Wisconsin. There was a large variation in the sizes of the six plants from the set of 184 sites while the six from the 33 existing sites were more uniform in size.

The turkey industry of Miniowisc could save $3,123,523 or .80 cents per pound according to the analysis if it changed from the existing 33 plant configuration to a subset of 6 of these 33. If they choose to relocate these six more optimally they could save another $70,209 or .017 cents per pound by going to the optimum solution for the 184 site configuration. The total possible savings for the turkey industry of Miniowisc is $3,193,732 according to this study.

It is recognized that industries do not change in one quick step but gradually over a period of time. It appears however that the industry could reap some short run gains by eliminating some of their marginal poorly located plants. An examination of the solution for the 33 existing sites reveals that four of them are completely over shadowed by the other plants which means they enter the solution but have nothing to process.

In the long-run however the industry can make the greatest savings by striving for the optimum solution of the 184 site configuration. It must be realized that this is a static equilibrium solution dependent on the level of technology. Given the level of technology and the assumptions of the model, the optimum solution is the best that can be attained. However as technology advances and adjustments toward the optimum are made, possibly a better solution can be attained than the one previously calculated.

The results of this study should be helpful to industry leaders in pointing out where savings can be realized for the industry as a whole. To the individual plant owners it indicates the path of adjustment needed in order to remain competitive if the industry as a whole moves toward the optimal situation. For society as a whole the optimum solution can be used as a basis for comparison to judge the efficiency or lack of efficiency in the existing structure of the industry.

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Somehow I would like to show my appreciation to all the people who through communication and example made the nearly two years at Iowa State the most productive and rewarding years yet.

X. APPENDIX A

This appendix contains three tables. The first one is Table 18 which contains the 184 plant sites of Miniowisc. These plants sites form a nearly homogeneous distribution of sites across the supply nodes of Miniowisc. Table 19 is a subset of Table 18. Table 19 is a list of the 33 existing plant sites of the industry. Table 20 is a list of the 116 supply nodes of Miniowisc. A supply node is a county with greater than 50,000 head of turkeys produced in 1964. All three tables have their entries listed by states.

Table 18. The 184 plant sites of Miniowisc by states

<u>Iowa</u>

Algona
Ames
Atlantic
Boone
Burlington
Calmar
Carroll
Cedar Rapids
Centerville
Chariton
Charles City
Cherokee
Clinton
Dallas Center
Davenport
Decorah
Dubuque
Eagle Grove
Ellsworth
Esterville
Fairfield
Forest City
Ft. Dodge
Ft. Madison
Grinnell
Ida Grove
Independence
Indianola
Iowa City
Iowa Falls
Kalona
Keokuk
Knoxville
Laurens
Le Mars
Maquoketa
Marshalltown
Mason City
Mt. Pleasant
Muscatine
Newton
Oelwein
Osage
Osceola
Oskaloosa
Ottumwa
Pella
Perry
Postville
Sibley
Sioux City
Spencer
Spirit Lake
Storm Lake
Sac City
Sheffield
Sabula
Vinton
Washington
Waterloo
Waverly
Webster City
West Liberty

<u>Minnesota</u>

Aitkin
Albert Lea
Alexandria
Altura
Anoka
Austin
Bemidji
Benson
Blue Earth
Brainerd
Buffalo
Butterfield

Table 18 (Continued)

Minnesota

Caledonia
Cambridge
Cloquet
Crookston
Detroit Lakes
Dilworth
Duluth
Farimount
Faribault
Furgus Falls
Forest Lake
Frazee
Grand Rapids
Hastings
Hibbing
Hopkins
Hutchinson
Litchfield
Little Falls
Laverne
Madelia
Mahnomen
Mankato
Marshall
Melrose
Minneapolis
Montevideo
Mora
Morris
Mound
New Ulm
Northfield
Owatona
Pork Rapids
Pelican Rapids
Pipestone
Red Wing
Redwood Falls
Rochester
Rusford
Sanstone
Sauk Center
St. Charles
St. Cloud
St. James
St. Paul
St. Peter
Shakapee
Slayton
Sleepy Eye
South St. Paul
Spring Valley
Stillwater
Thief River Falls
Wadena
Walker
Waseca
Waterville
Wells
Willmar
Warren
Windom
Winowa
Worthington

Table 18 (Continued)

Wisconsin

Arcadia	Menomonen
Augusta	Merrill
Baraboo	Monroe
Barron	Phillips
Beloit	Plattville
Black River Falls	Prarducon
Blair	Rice Lake
Chetek	Richland City
Chippewa Falls	Shawano
Clintonville	Sparta
Croix Falls	Spooner
Eau Claire	Stevens Point
Eleva	Stroughton
Endeavor	Thorp
Ft. Atkinson	Tomah
Grontsberg	Viroqua
Janesville	Wausau
Jefferson	Westfield
Johnson Creek	White Water
La Crosse	Wilton
Ladysmith	Wisconsin Rapids
Madison	
Marshfield	
Medford	

Table 19. The 33 existing plant sites of Miniowisc by states

Iowa	
Burlington	Keokuk
Calmar	Postville
Carroll	Sioux City
Davenport	Storm Lake
Decorah	Vinton
Eagle Grove	West Liberty
Ellsworth	
Kalona	
Minnesota	
Aitkin	Litchfield
Albert Lea	Marshall
Altura	Melrose
Butterfield	Pelicon Rapids
Detroit Lakes	Thief River Falls
Faribault	Willmar
Frazee	
Wisconsin	
Barron	
Chilton	
Endeavor	
Jackson Creek	
Westfield	
Wilton	

Table 20. The 116 supply nodes of Miniowisc b states

Iowa

Allamakee
Black Hawk
Boone
Bremer
Buchanan
Buena Vista
Butler
Calhoun
Carroll
Cerro Gordo
Cherokee
Chickasaw
Clark
Floyd
Franklin
Greene
Grundy
Hamilton
Hancock
Hardin
Henry
Ida
Iowa
Johnson
Keokuk
Kossuth
Linn
Louisa
Lucas
Mahaska
Mitchell
O'Brien
Plymouth
Pocahontas
Story
Warren
Washington
Wayne
Webster
Winneshiek
Woodbury
Worth
Wright
Van Buren

Minnesota

Aitkin
Anoka
Becker
Blue Earth
Brown
Carlton
Carver
Cass
Chippewa
Chisago
Clay
Clear Water
Cottonwood
Crow Wing
Dakota
Dodge
Douglas
Faribault
Fillmore
Goodhue
Hennepin
Houston

Table 20 (Continued)

Minnesota	Wisconsin
Isanti	Adams
Itasca	Barron
Kandiyohi	Buffalo
Lac Qui Porle	Chippewa
Marshall	Clark
Martin	Dunn
Meeker	Eau Claire
Morrison	Grant
Mower	Jackson
Nicollet	Jefferson
Nobles	La Crosse
Olmsted	Marathon
Otter Tail	Monroe
Pennington	Polk
Pine	Price
Pipestone	Richland
Pope	Rusk
Renville	St. Croix
Rice	Taylor
Rock	Trempealeau
Roseau	
Sherburne	
Stearns	
Steele	
Swift	
Todd	
Wadena	
Washington	
Watonwan	
Winona	

XI. APPENDIX B

This appendix contains the computer programs that lead to the calculations of the mileage matrix, the iterative solutions, and the combinations solutions. All three programs were written by Wendell Primus and myself for the IBM 360/60.

The mileage matrix is the result of a technique for which I know of no precedent. The technique which is explained in detail in Chapter V is similar to the distance formula utilized in plane geometry for the calculation of distance between two points P_1 and P_2 on a plane. The straight-line distance between P_1 and P_2 is:

$$d = \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2}$$

where x_1 and x_2 are the X coordinates of P_1 and P_2 respectively and y_1 and y_2 are the Y coordinates of P_1 and P_2 respectively.

The techniue used in this study does not calculate the straight-line distance between any two points, but the right angle distance as measured along the X and the Y axes. The absolute X distance and the absolute Y distance between any two points are summed to obtain the right angle distances.

The first step in the application of the technique in this study was to fit together a map of Miniowisc and place a transparent grid over it. Then points were plotted and the coordinates of each point recorded. The points were the 116 supply nodes and the 184 plant sites. The computer program in Figure 13 was written in order to program the computer to calculate the right angle distance between every supply node and every processing plant.

The symbols XSN and XPP designate the X coordinates of the supply nodes and plant sites respectively and YSN and YPP designates the Y coordinates of the supply nodes and plant sites respectively. The symbols ISN and IPP designate two arrays containing the names of the supply nodes and the plant sites respectively. The parameter CONF is the conversion factor from right angle map distance to road mile distance.

After the calculation of the mileage matrix is completed, the parameter COST is utilized to transform the mileage matrix to a transfer cost matrix where COST represents the average cost per mile for transporting a material. The COST figure is doubled if one wants to account for the round trip distance.

Table 21. A computer program for calculating a mileage and transfer cost matrices

```
      DIMENSION XSN(116),YSN(116),XPP(184),YPP(184),DIST(116,184)
      DOUBLE PRECISION ISN(116),IPP(184)
      READ(1,1)N,M,CONF,COST
    1 FORMAT(2I3,2F6.4)
      READ(1,2)(XSN(I),I=1,N)
      READ(1,2)YSN(I),I=1,N)
      READ(1,2)(XPP(I),I=1,M)
      READ(1,2)(YPP(I),I=1,M)
      READ(1,2)(ISN(I),I=1,N)
      READ(1,3)(IPP(I),I=1,M)
      IPOINT=0
    2 FORMAT(13F6.4)
    3 FORMAT(10A8)
      DO 4 I=1,N
      DO 4 J=1,M
      DIST(I,J)=ABS(XSN(I)-XPP(J))
      DIST(I,J)=DIST(I,J)+ABS(YSN(I)-YPP(J))
    4 DIST(I,J)=DIST(I,J)*CONF
   16 K=1
      KK=12
   12 IF(KK-N)5,5,6
    6 KK=N
    5 WRITE(3,7)(ISN(L),L=K,KK)
    7 FORMAT(1H1,10X,12(2X,A8))
      DO 8 J=1,M
    8 WRITE(3,9)IPP(J),(DIST(L,J),L=K,KK)
    9 FORMAT(1H ,2X,A8,12F10.2)
      IF (KK-N)10,11,11
   10 K=KK+1
      KK=KK+12
      GO TO 12
   11 IF (IPOINT)100,14,100
   14 IPOINT=1
      DO 15 I=1,N
      DO 15 J=1,M
   15 DIST(I,J)=DIST(I,J)*COST
      GO TO 16
  100 STOP
      END
```

The combinations approach is an optimizing procedure in the sense that its total cost function is the lower bound of all total cost functions for a particular problem. The combinations approach is discussed in greater detail at the beginning of Chapter VI.

The first few statements of the program for solving the combinations approach as presented in Figure 14 involves calculating the transfer cost matrix. Calculating the transfer cost matrix takes only a small amount of computer time on each run and it was preferred to reading in the transfer cost matrix. A small subroutine is utilized to calculate the processing costs for each plant in the solution and also the total processing costs with respect to the number of plants in the solution. The following definition of symbols will better explain the program:

ASC = an individual plant's assembly costs
PCC = an individual plant's processing costs
SASCT = total assembly costs for all plants being considered for the solution
TPC = total processing costs for all plants being considered for the solution
TTC = total costs which is the sum of the total assembly costs and the total processing costs for all plants being considered for the solution
XLBS = the total pounds of turkey at any particular supply node in live weight
V = the total pounds of turkey in Miniowisc in live weight
KJ = the number of plants in the group for which the solution is being found. KJ corresponds to J as defined in Chapter IV

Table 22. A computer program for determining the solution of the combinations method

```
      DIMENSION XSN(116),YSN(116),XPP(184),YPP(184),DIST(116,184),
     1XTRUCK(116),ISEL(50),COST(184) ,JSEL(2.120),ASC(50) ,KSEL(50)
      DOUBLE PRECISION ISN(116),IPP(184),XLBS(116),V,TPC,PCC(50),TTC
      READ (1,1) N,M,CONF,COS,KJ
    1 FORMAT (2I3,2F6.4,20I3/26I3 )
      READ(1,2)(XSN(I),I=1,N)
      READ(1,2)(YSN(I),I=1,N)
      READ(1,2)(XPP(I),I=1,M)
      READ(1,2)(YPP(I),I=1,M)
      READ(1,3)(ISN(I),I=1,N)
      READ(1,3)(IPP(I),I=1,M)
    2 FORMAT (13F6.4)
    3 FORMAT (10A8)
      READ(1,4)(XTRUCK(I),I=1,N)
    4 FORMAT(19F4.0)
    5 FORMAT(9F8.0)
      READ(1,5)(XLBS(I),I=1,N)
      V=0.0D0
      DO 6 I=1,N
      V=V+ XLBS(I)
      DO 6 J=1,M
      DIST(I,J)=ABS(XSN(I)-XPP(J))
      DIST(I,J)=DIST(I,J)+ ABS(YSN(I)-YPP(J))
    6 DIST(I,J)=DIST(I,J)*CONF *COS * 2.0
      SASCT=.1E50
      KK=KJ-2
      KI=KJ-1
      DO 111 I=1,KI
  111 ISEL(I)=I
  138 JXY=ISEL(KI)+1
      DO 112 J=JXY,M
      ISEL(KJ)=J
      DO 120 JC=1,KJ
  120 COST(JC)=0.0
      ASCT=0.0
```

Table 22 (Continued)

```
      DO 123 JD=1,N
      KL=1
      DO 124 JE=2,KJ
      IF (DIST(JD,ISEL(JE))-DIST(JD,ISEL(KL)))122,124,124
  122 KL=JE
  124 CONTINUE
      JSEL(1,JD)=ISEL(KL)
      ASCT=ASCT+DIST(JD,ISEL(KL))*XTRUCK(JD)
  123 COST(KL)=COST(KL)+DIST(JD,ISEL(KL))*XTRUCK(JD)
      IF (ASCT-SASCT)131,112,112
  131 DO 129 JJ=1,KJ
      KSEL(JJ)=ISEL(JJ)
  129 ASC(JJ)=COST(JJ)
      SASCT=ASCT
      DO 127 JD=1,N
  127 JSEL(2,JD)=JSEL(1,JD)
  112 CONTINUE
  114 ISEL(KI)=ISEL(KI)+1
      IF (ISEL(KI)-M)138,140,140
  140 JXZ=1
  143 LK=KI-JXZ
      IF (LK)150,150,141
  141 ISEL(LK)=ISEL(LK)+1
      DO 173 LL=LK,KK
  173 ISEL(LL+1)+ISEL(LL)+1
      IF (ISEL(LK)-M+JXZ)138,142,142
  142 JXZ=JXZ+1
      GO TO 143
  150 IS=KJ
      WRITE(3,15)
   15 FORMAT(1HO,'ASS COST  PLANT NUMBER  NAME    PC COST ')
      CALL PC(N,JSEL,IS,V,XLBS,PCC,TPC,KSEL)
      TTC=SASCT+TPC
      DO 18 J=1,IS
```

Table 22 (Continued)

```
  16 FORMAT(1H ,F12.2        ,14,A8,F12.2)
     JX=KXEL(J)
  18 WRITE(3,16)ASC(J),KSEL(J),IPP(JX),PCC(J)
     WRITE(3,19)SASCT,TPC,TTC
  19 FORMAT(1H ,3F12.2)
1000 STOP
     End


     SUBROUTINE PC(N,JSEL,IS,V,XLBS,PCC,TPC,ISEL)
     DIMENSION JSEL(2,120)  ,ISEL(50)
     DOUBLE PRECISION XLBS(116),PCC(50)
     DO 3 J=1,IS
   3 PCC(J)=0.0D0
     DO 1 K=1,IS
     J=ISEL(K)
     DO 2 L=1,N
     IF (JSEL(2,L)-J)2,4,2
   4 PCC(K)=PCC(K)+.032DO*XLBS(L)
   2 CONTINUE
   1 PCC(K)=PCC(K)+.133040D6
     TPC=IS*.133040D6 +.032DO*V
     RETURN
     END
```

The iterative method for solving the problem is similar to the combinations method except for one additional constraint. Once a plant comes into the solution it stays in. For this reason the iterative method produces a suboptimum solution as discussed in Chapter VI. However its relatively cheap cost of application makes it a valuable tool for solving the Stollsteimer model. Warrack applied the iterative method with success to his problem. Although the basic iterative method as developed by Warrack was used in this study, the program for the computer was rewritten to increase its efficiency. Figure 15 presents the computer program used in this study to solve the problem by the iterative method. Many of the symbols are the same and have same meaning in the program for the iterative method as in the program for the combinations method. However, KJ is not defined in the iterative program while IS is an array containing the plants already in the solution.

Table 23. The computer program for determining the solution of the iterative method

```
      DIMENSION XSN(116),YSN(116),XPP(184),YPP(184),DIST(116,184),
     1XTRUCK(116),ISEL(50),COST(184) ,JSEL(2,120),ASC(50)
      DOUBLE PRECISION ISN(116),IPP(184),SLBS(116),V,TPC,PCC(50),TTC
      IS=0
      READ (1,1) N,M,CONF,COS,IS,(ISEL(I),I=1,IS)
    1 FORMAT (2I3,2F6.4,20I3/26I3 )
      READ(1,2) (XSN(I),I=1,N)
      READ(1,2) (YSN(I),I=1,N)
      READ(1,2) (XPP(I),I=1,M)
      READ(1,2) (YPP(I),I=1,M)
      READ(1,3) (ISN(I),I=1,N)
      READ(1,3) (IPP(I),I=1,M)
    2 FORMAT (13F6.4)
    3 FORMAT (10A8)
      READ(1,4) (XTRUCK(I),I=1,N)
    4 FORMAT(19F4.0)
    5 FORMAT(9F8.0)
      READ(1,5) (XLBS(I),I=1,N)
      V=0.0D0
      DO 6 I=1,N
      V=V+ XLBS(I)
      DO 6 J=1,M
      DIST(I,J)=ABS(XSN(I)-XPP(J))
      DIST(I,J)=DIST(I,J)+ ABS(YSN(I)-YPP(J))
    6 DIST(I,J)=DIST(I,J)*CONF *COS * 2.0
       SELECT FIRST PLANT
      DO 7 I=1,M
    7 COST(I)=0.0
      K=1
      IF (IS)8,8,100
    8 DO 11 J=1,M
      DO 12 I=1,N
   12 COST(J)=COST(J) +DIST(I,J)*XTRUCK(I)
```

Table 23 (Continued)

```
      IF (COST(K)-COST(J))11,11,13
   13 K=J
   11 CONTINUE
      HAVE JUST SELECTED FIRST PLANT
      ASC(1)=COST(K)
      SASCT=COST(K)
      DO 17 J=1,N
   17 JSEL(2,J)=K
   98 IS=IS+1
      WRITE(3,15)
   15 FORMAT(1HO,'ASS COST  PLANT NUMBER  NAME      PC COST')
      ISEL(IS)=K
      CALL PC(N,JSEL,IS,V,XLBS,PCC,TPC,ISEL)
      TTC=SASCT+TPC
      DO 18 J=1,IS
   16 FORMAT(1H ,F12.2         ,14,A8,F12.2)
      JX=ISEL(J)
   18 WRITE(3,16)ASC(J),ISEL(J),IPP(JX),PCC(J)
      WRITE(3,19)SASCT,TPC,TTC
   19 FORMAT(1H ,3F12.2)
      IF (IS-33)100,1000,1000
  100 SASCI=.1E50
      DO 21 K=1,M
      DO 35 KG=1,M
   35 COST(KG)=0.0
      DO 22 I=1,IS
      IF (ISEL(I)-K)22,21,22
   22 CONTINUE
      ASCT=0.0
      DO 23 J=1,N
      KL=K
      DO 24 L=1,IS
      MM=ISEL(L)
      IF (DIST(J,MM)-DIST(J,KL))25,25,24
```

Table 23 (Continued)

```
  25 KL=MM
  24 CONTINUE
     JSEL(1,J)=KL
     ASCT=ASCT+DIST(J,KL)*XTRUCK(J)
  23 COST(KL)=COST(KL)+DIST(J,KL)*XTRUCK(J)
     IF (ASCT-SASCT)31,21,21
  31 DO 29 JJ=1,IS
     MM=ISEL(JJ)
  29 ASC(JJ)=COST(MM)
     SASCT=ASCT
     ASC(IS+1)=COST(K)
     KM=K
     DO 27 J=1,N
  27 JSEL(2,J)=JSEL(1,J)
  21 CONTINUE
     K=KM
     GO TO 98
1000 STOP
     END

     SUBROUTINE PC(n,JSEL,IS,V,XLBS,PCC,TPC,ISEL)
     DIMENSION JSEL(2,120)   ,ISEL(50)
     DOUBLE PRECISION XLBS(116),PCC(50)
     DO 3 J=1,IS
     3 PCC(J)=0.0D0
     DO 1 K=1,IS
     J=ISEL(K)
     DO 2 L=1,N
     IF (JSEL(2,L)-J)2,4,2
   4 PCC(K)=PCC(K)+.032DO*XLBS(L)
   2 CONTINUE
   1 PCC(K)=PCC(K)+.133040D6
     TPC=IS*.133040D6 +.032DO*V
     RETURN
     END
```

XII. APPENDIX C

It was originally intended that Appendix C would contain the mileage matrix representing road miles distances between the supply nodes and plant sites of Miniowisc. However due to its great size the mileage matrix was deleted from this thesis. The matrix contains 21,344 elements and would have added more than 80 pages to the thesis.

For anyone who is interested, a copy of the mileage matrix has been left with:

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