EFFECT OF MILK ASSEMBLING AND PROCESSING COSTS ON OPTIMAL TYPE AND SIZE OF PLANT FOR BUTTER AND NONFAT DRY MILK IN MINNESOTA

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CHAPTER I

INTRODUCTION

Statement of the Problem

The sale of dairy products is the second most important source of income to Minnesota farmers, second only to livestock sales. In 1968 10.3 billion pounds of milk were produced in the State.[1/] Of this quantity, about 74 percent was processed into butter and nonfat dry milk [NFDM]. These are the most concentrated of the major dairy products. Minnesota seems to have a comparative advantage in the production of milk but its geographic location, relative to major population centers, dictates that its milk be marketed in as concentrated form as possible. The distance to major markets and the stability of Minnesota milk production implies the continued importance of the butter-powder sector of the Minnesota dairy industry.

In general the butter and powder markets are well defined. Most of these products move from processors to consumers through one of several large regional marketing cooperatives or through several independent wholesalers. Also, the federal government under its farm price support program stands ready to purchase any

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[1/] Minnesota Crop and Livestock Reporting Service, Minnesota Agricultural Statistics 1969, 560 State Office Building, St. Paul, Minnesota, March 1969.

quantity that doesn't move through commercial channels at government quoted prices.

Marketing milk as butter and powder can be divided into three general operations: (1) assembly of wholemilk, (2) processing wholemilk into butter and powder and (3) disassembly of butter and powder to the consumer. Of these three, disassembly is set apart and faces fewer and different problems than the other two operations. Four factors contribute to this logical separation: (1) the large weight reduction that occurs in processing milk into butter and powder, (2) the relatively large distances that separate processing and consumption, (3) the well defined market channels for butter and powder and (4) the guaranteed market of the federal government.

The major problem areas of marketing milk in the butter-powder industry are found in processing the milk and in assembling the milk to the processing plants. In this area of the sector the effects of technological changes in processing and assembly have created problems related to the efficient size and type of processing plants.

A number of studies of plants processing milk into butter and powder have demonstrated economies to scale. On the other hand, studies of assembly of milk to the processing plants have demonstrated diseconomies with increases in volume assembled. This increasing cost results from the need to assemble larger volumes from areas more distant from the processing plants which results in higher average costs. The interplay of decreasing processing costs and increasing assembly costs has been instrumental in the emerging plant types and sizes.

Historical Perspective

Milk production in Minnesota started as a part of self sufficient pioneer farming. The butter marketing industry first developed as a result of farmers shipping farm separated cream in cans to city "centralizers" which processed and marketed the cream. The cream was delivered by horse and wagon to local rail stations where it was shipped to the cities. The density of cream production was too low to warrant local processing plants.

As the production of cream in the state increased, local crossroad communities found they could economically support a creamery. The local creamery processed the farm separated cream delivered by horse and wagon and shipped back packaged butter to various markets. The size of the local creamery was limited by milk assembly patterns set by horse and wagon operations. Before this system of marketing became obsolete, about 867 crossroad creameries were in operation in Minnesota.[1]

The introduction of farm trucks and better roads increased the effective economic assembly area of the local creamery. This resulted in increased size and reduced numbers of local creameries.

The introduction of skim milk drying equipment and the

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[1] Gruebele, J. W. and E. Fred Koller, "Creamery Industry: Structure and Performance," Minnesota Farm Business Notes, No. 479 Institute of Agriculture, University of Minnesota, St. Paul, Minnesota, December 1965.

development of a market for NFDM especially during and shortly after World War II created a demand for wholemilk rather than cream alone. This shifted cream separation from the farm to the local creamery. The creamery in turn sold the skim milk to specialized drying plants. The wholemilk was assembled in cans to the local creamery. The skim milk from a number of local creameries was assembled in bulk tank trucks to the specialized drying plants.

The continued improvement in roads and trucks increased the area over which it was economical to assemble milk. This prompted the specialized drying plants to take on the task of churning the cream as well as drying the skim milk, bypassing many of the local creameries. Some local creameries closed, others became receiving stations, receiving milk primarily in cans and shipping it on to the butter-powder plant in large semi-trailer tank trucks.

During this same period, on farm bulk storage tanks became a reality. The use of bulk farm pickup of milk expanded the potential assembly area of a processing plant even further. This prompted the butter-powder plants to extend their bulk assembly area to the point where it encompassed a number of local receiving stations and creameries. This resulted in further reduction in the number of local creameries and receiving stations and in general increased the size of butter-powder plants.

During this whole development, butter was shipped in bulk, 64 or 68 pound boxes, to central wholesale butter print houses where it was consumer packaged. Up to this stage of development the emerging butter-powder plants did not have the volume to justify moving the butter printroom to the point of processing.

Current Developments

In the last few years there has been introduced into the industry a high speed soft butter printer.[1/] The machine can package consumer butter prints directly from the churn, whereas the old method required the butter to be tempered in a cooler for a period of time before printing. This equipment has obvious cost saving potential if sufficient quantities of cream can be assembled at a common churning and printing plant. This raises a question about whether sufficient quantities of milk can be economically assembled at a butter-powder plant to provide sufficient quantities of butter to warrant the cost of a soft printer. Or, on the other hand, will super butter plants develop which receive cream from specialized powder plants which receive wholemilk? The answers are largely dependent upon the relative magnitude of the economies to scale of powder processing and butter processing and the relative decreasing economies of assembly of milk and cream.

This study analyzes these cost functions under various expected milk production densities in Minnesota to appraise what type and size of processing plants and what type of assembly

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1/ Printing butter refers to packaging the butter in consumer size units, usually four one quarter pound sticks in a one pound package. The term print comes from the early method of stamping out consumer portions with a mold that "imprinted" the brand name in the butter.

patterns are likely to emerge as a result of current technological changes.

The Problem

The adjustments discussed above have not always been easily accomplished. There were 867 local butter creameries and seven butter-powder plants manufacturing butter in Minnesota in 1938. In 1970 there were about 128 local butter creameries and 42 butter-powder plants manufacturing butter.[1/] Yet butter production changed little. In 1940 Minnesota plants manufactured 311.2 million pounds of butter[2/] and in 1969 315.6 million pounds.[3/]

The tremendous changes involved greatly test the invisible hand of the market place. Adjustments of the type and magnitude taking place in the butter-powder industry can be made much less painful and with a great deal more rationality if the effects of new technological developments are fully examined and decision makers informed of these consequences.

This study was made in an effort to provide the industry with knowledge about the effects of new technology. The large regional marketing cooperatives are wondering if they should plan on building

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[1/] Based on a special report of the Minnesota Department of Agriculture.

[2/] U. S. Department of Agriculture, Dairy Statistics, Statistical Bulletin No. 218, U. S. Department of Agriculture, Washington D. C. (1959), table 199.

[3/] Minnesota Agricultural Statistics 1970, Crop and Livestock Reporting Service, Minnesota Department of Agriculture, St. Paul, Minnesota, March 1970.

super (very large) butter plants in anticipation of receiving cream from specialized powder plants and other cream assemblers. Butter-powder plants are wondering if they should try to expand and add a soft butter printer or should they ship their cream production to super butter plants. The local butter plants wonder how long they can continue as butter plants and if shifting to a milk receiving station status is an economical alternative. Milk receiving stations wonder if they can continue as economical entities. They are all interested in knowing at what volume the emergine economic units should plan to operate. This study was undertaken to help the industry answer questions of this nature.

Objectives

This study has three broad objectives. The first is to determine the long run cost relationships for processing wholemilk into butter and nonfat dry milk. The second is to determine long run cost relationships for farm-to-plant transportation of raw milk and interplant milk and cream movement. The third is to determine long run cost relationships for both processing and assembly of milk under (a) alternative product processing systems and (b) various milk production density patterns.

Hypothesis

One general hypothesis and three sub-hypotheses were posited as guides to achieving the objectives of this study. The general hypothesis is as follows:

> The volume of a milk processing plant and the density of milk production in its assembly area determine if nonfat dry milk and butter manufacturing can be most economically carried on in the same plant.

The sub-hypotheses are as follows:

> (1) Plants with relatively large volumes can manufacture nonfat dry milk and/or butter at significantly lower cost than plants with small volumes.
>
> (2) The unit-cost of assembling milk increases as the size of the assembly area of given production density increases and declines as the density of the area increases.
>
> (3) The cost of transporting cream, on a wholemilk equivalent basis, is significantly less than transporting wholemilk.

Theoretical Considerations

The conceptual economic problem in this study is one in which processing firms that operate in an almost purely competitive market setting are seeking to maximize profits. Because of the assumed competitive setting this is equivalent to minimizing long run cost.[1/] Firm theory states that individual firms, seeking to maximize profit, and given sufficient time to render all factors of production variable will operate at a level where marginal cost equals average cost and these, in turn, equal marginal revenue. These traditional conditions are shown diagramatically in figure 1. The long run average cost curve is the typical U-shaped curve found in economic texts. The declining segment of the curve, or

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[1/] In this study cost minimization is stressed not only because of the assumption of the competitive market but also because of the dominance of cooperative firms in the industry. There is no historic evidence to suggest that the dairy cooperatives in Minnesota have tried to exercise market restricting practices which would call for an objective other than cost minimization.

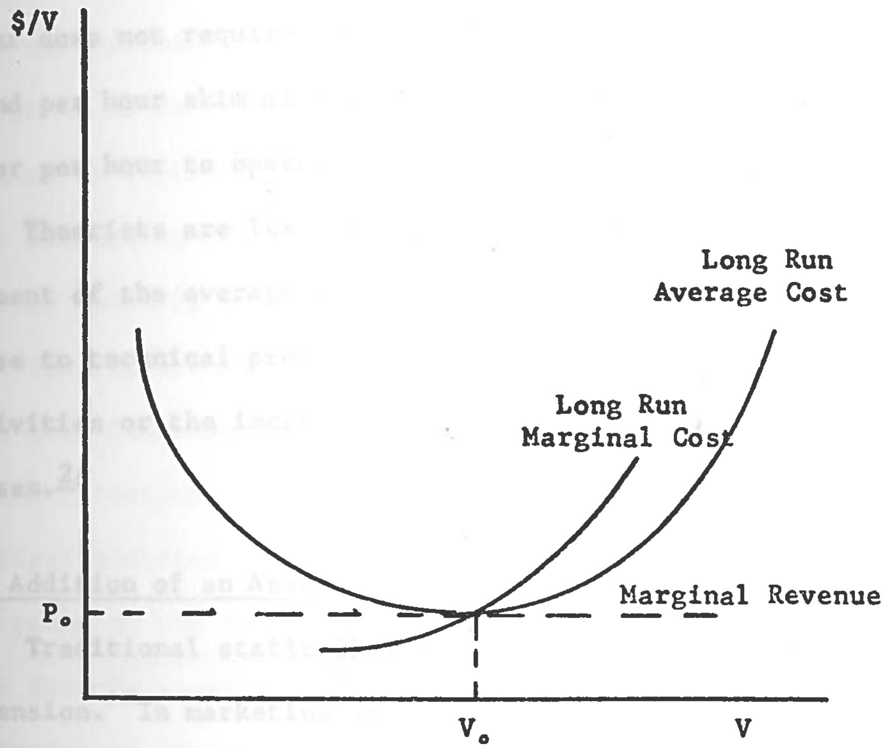

Figure 1. Traditional hypothetical long run marginal and average cost curves and equilibrium output under competitive conditions.

increasing returns to scale portion, is in general said to be caused by more efficient combinations of factors and technological efficiencies of larger pieces of equipment.[1/] For example, in the dairy industry a 4,000 pound of powder per hour capacity skim milk dryer does not require twice as much material to build as a 2,000 pound per hour skim milk dryer and in addition requires no more labor per hour to operate.

Theorists are less explicit about the cause of the rising segment of the average cost curve. Textbooks often ascribe its cause to technical problems of coordinating the various underlying activities or the increasing difficulty of managing larger enterprises.[2/]

The Addition of an Assembly Cost Function

Traditional static firm theory abstracts from the spatial dimension. In marketing agricultural products, and especially a high weight relative to value product like milk, the abstraction

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1/ There is a definitional problem in what constitutes "returns to scale." The theoretical economist defines an increase in scale as a proportional increase in all inputs. Agricultural economists, on the other hand, have been less restrictive on requiring a proportional change in all inputs and have in general referred to change in scale as a change in "plant." The complement of inputs may or may not change proportionately as the plant size changes. Boulding discussed scale and variable proportions in Economic Analysis: Microeconomics Volume I, Harper Row, New York, fourth edition 1966, pp. 544-551. In this study economies to scale refers to a change in plant size in the tradition of other agricultural economics studies.

2/ McConnell, Campbell R., Elementary Economics: Principles, Problems and Policies, McGraw Hill, New York, 1960, p. 440.

from the spatial dimension leaves the analysis wanting. The dispersed nature of agricultural production implies that any economies associated with volume in processing plants must be weighed against the possible diseconomies of assembling the larger volume from more distant production points. If farm production at any one point is relatively fixed, larger volume of milk can be assembled at a plant only by going further into the countryside at ever increasing distances. This inevitably leads to a rising average assembly cost function.[1/]

The inclusion of an assembly cost function in the standard firm cost function has a noticeable effect on the equilibrium volume of output. This can be seen graphically in figure 2. The vertical addition of the average assembly cost function causes the low point on the combined cost function to occur at a lower volume than for the processing function alone. The result is that the inclusion of the spatial dimension and the resulting cost function reduces equilibrium plant size. In figure 2, equilibrium (least cost volume) considering assembly occurs at V_1 which is less than V_2, the equilibrium volume when processing alone is considered.

The above result is especially applicable to the butter-powder industry. The assembly cost of wholemilk is a significant cost variable that plant managers must consider in determining long run optimal plant size.

[1/]The same basic principle associated with increasing assembly cost also holds for disassembly of the processed product. The reasons for excluding disassembly from the study have already been discussed.

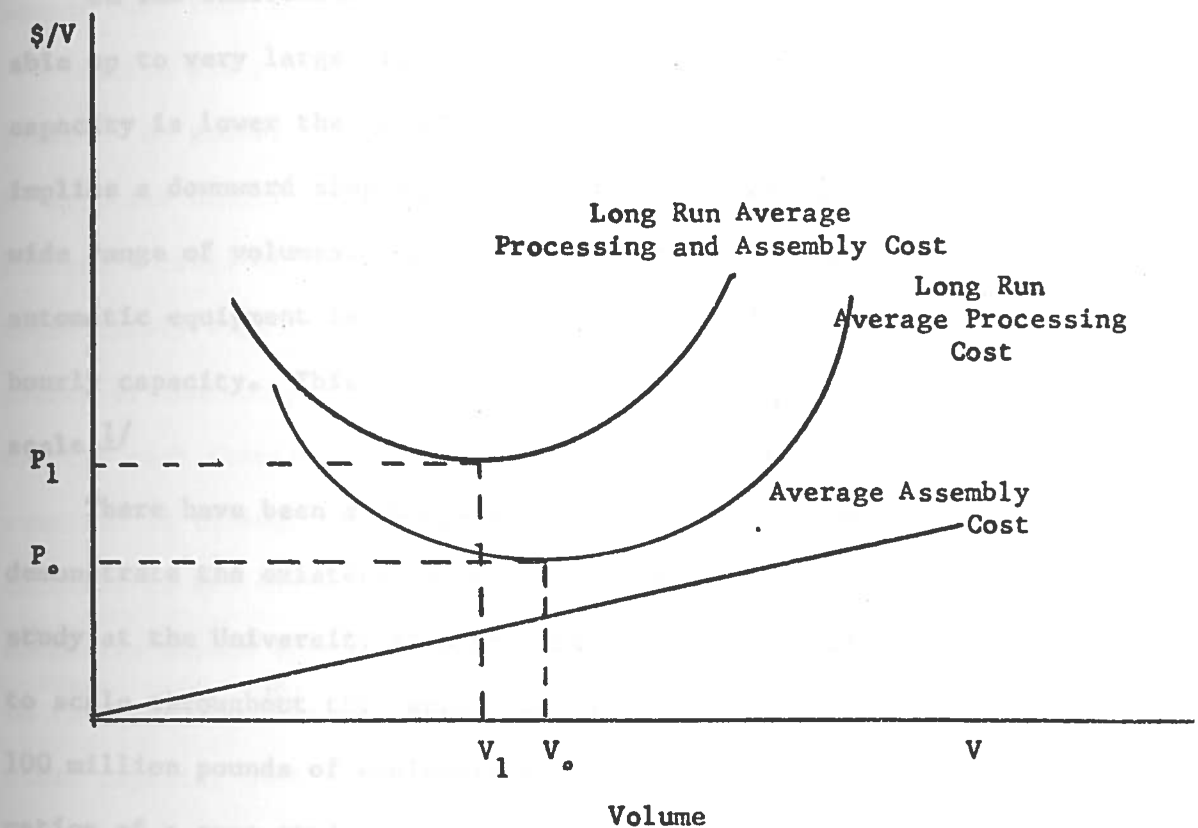

Figure 2. Hypothetical average cost functions for assembling and processing milk.

There is a large amount of evidence, both theoretical and empirical, which points to economies to scale in processing for butter-powder plants.

On the theoretical side, dairy processing equipment is available up to very large sizes and the capitalized cost per unit of capacity is lower the larger the capacity of the equipment. This implies a downward sloping average equipment cost function over a wide range of volumes. Also, the labor needed to tend this largely automatic equipment is the same regardless of the equipment's hourly capacity. This provides further evidence of economies to scale.[1/]

There have been a number of empirical studies which also demonstrate the existence of economies to scale. Juers did a study at the University of Minnesota in 1957 which showed economies to scale throughout the range studied.[2/] He considered volumes to 100 million pounds of wholemilk annually. The study was a combination of a case study and an economic engineering study. Plants were selected as models and adjustments were made based on an economic engineering approach to yield short run cost functions for the selected plants. The envelope of the plant's average cost function was called the long run cost function.

1/ It can be seen from this there is a change in the variable proportions of factors used as plant size changes. Therefore, the term "economies to scale" is not the same as that used by economic theoreticians such as Boulding.

2/ Juers, Linley E., "An Economic Analysis of the Operating Costs of Butter-Powder Plants with Particular Reference to the Problem of Joint Costs," Unpublished Ph.D. Thesis, University of Minnesota, July 1957.

This study was updated and extended by Thompson in 1962.[1/] He extended the scale curve to a volume of 250 million pounds of wholemilk annually. The curve did not turn up, although it did become very flat in the higher volume ranges.

Hanlon did a similar economies to scale study at Minnesota in 1966.[2/] He essentially used the same procedure as Juers, that is, he selected sample plants and generated cost-volume relationships through a range of volumes by the economic engineering method. He found fairly significant economies to scale up to 200 million pounds of wholemilk annually. The envelope curve or long run average cost function essentially flattened out at that volume and remained so through the remaining volume range considered, which extended to 475 million pounds of wholemilk annually. The lack of economies beyond a volume of 200 million pounds may have been due to the fact that the two largest plants used as models achieved their capacity with several small evaporators and dryers rather than larger capacity single unit equipment.

The important feature, though, is the fact that the long run average cost function does not turn up. This flatness and the absence of diseconomies hints of the importance of assembly in establishing optimal plant size for a butter-powder plant. The

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1/ Thompson, Russell G., "An Approach to Estimating Optimum Sizes of Butter-Powder Plants," Unpublished Ph.D. Thesis, University of Minnesota, August 1962.

2/ Hanlon, John William, "An Analysis of Processing Costs in Plants That Manufacture Butter and Nonfat Dry Milk," Unpublished Ph.D. Thesis, University of Minnesota, June 1966.

shape and location of the assembly cost function then becomes the limiting condition on plant size.

Procurement or Assembly

Strictly speaking milk procurement involves more than just assembly cost. It includes the purchase as well as the assembly of the milk. This implies that each farm producing milk has a supply function. This implies an intensive and an extensive marginal change in supply as a result of a change in net price paid to the farm producer.[1/] An increase in volume can be the result of a higher pay price stimulating more production from existing producers and/or the expansion of the assembly area to include more farm producers.

Ideally, then, a procurement cost function rather than an assembly cost function should be used in conjunction with a processing cost function. This has been pointed out by a number of writers, important among them is French. In a critique of an article about plant location by Olson he pointed out this weakness in Olson's model which considered only processing and assembly costs.[2/]

Williams, in another article, touched on this problem in a

[1/] Net price is the price paid for milk at the plant less any assembly charge.

[2/] Olson, Fred, "Location Theory as Applied to Milk Processing Plants," Journal of Farm Economics, Vol. XLI, December 1959, p. 1558.

slightly different way.[1/] He addressed himself to the problem of monopsony power which is the natural outcome of most spatial efficiency models. He reasoned that at the location of the processing plant the plant's monopsony power is greatest and that as the supply area expands, the processing firm encounters increasing competitive pressure from adjacent plants. He, therefore, included an average at-the-farm cost of raw product function, which is a reflection of the competition from other plants as well as the on farm production response. This cost function along with an assembly cost function and a processing cost function was included in a total cost function for marketing. The monopsony aspects are not particularly appropriate to Minnesota's butter-powder industry. The industry is overwhelmingly made up of cooperative firms. As has been mentioned previously these cooperatives have in general followed the cooperative principles of open membership and equal treatment of all patrons.

The numerous ramifications of elastic supply functions are important as well as interesting, but they are beyond the scope of this study. For the inclusion of supply response functions to be meaningful, they need to be specific to the area of a possible plant. This formidable task requires resources greater than are available. In addition, it requires an extensive study of the monopsonistic behavior of the possible plant participants. This

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1/ Williams, J. C. Jr., "The Equilibrium Size of Marketing Plants in a Spatial Market," Journal of Farm Economics, Vol. XLIV, November 1962.

again is interesting but is beyond the present scope and objectives of this study.

Yet another reason which lends credence to a study which does not include a supply response function is the generally accepted belief that milk supplies are inelastic. Halvorson estimated the price elasticity of milk in the U. S. in the two periods 1929-57 and 1941-57.[1/] He reported long run supply price elasticities in the range of .35-.50. Wipf and Houck estimated a supply function for milk in the U. S. based on time series data for the period 1945-64.[2/] They found the supply price elasticity to be about .15. With elasticities of this magnitude, a change in the assembly area is clearly more important in determining supply response than a change in net price that would result from altering processing and/or assembly costs.

A Modification of the Milk Assembly Cost Function

There are alternate assembly systems by which manufacturing milk reaches processing plants. In the manufacturing milk industry the assembly of wholemilk can be direct from the farm to the dairy processing plant or indirect via milk receiving stations and transshipment from that point. This latter method of assembly

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1/ Halvorson, Harlow W., "The Response of Milk Production to Price," Journal of Farm Economics, Vol. XL, December 1958, pp. 1101-1113.

2/ Wipf, Larry J. and James P. Houck, Milk Supply Response in the United States, an Aggregate Analysis, Department of Agricultural Economics, Report No. 532, Institute of Agriculture, University of Minnesota, St. Paul, Minnesota, July 1967.

was studied by Thompson.[1] It involves using smaller trucks to assemble milk from the farm to a local point and the local point transshipping the milk to a central processing plant in larger trucks. Farm assembly truck size is limited by road conditions, weather and farm driveway conditions. These conditions preclude the use of semi-trailer trucks for farm assembly. Semi-trailer trucks can haul a considerably larger volume than the necessarily limited size farm assembly trucks. Hence, they can transport milk between points at a lower unit-cost. This implies that as milk is assembled from points farther and farther from the processing plant a point is reached where it pays to set up a receiving station and transship the milk from far out points in semi-trailer trucks. The effect of this transshipment possibility is to flatten out the average milk assembly cost function that considers only direct assembly. The flattening out of the assembly function, in turn, increases the equilibrium (least cost) volume of the processing plant.[2] This can be seen diagramatically in figure 3. Five relationships are drawn in this diagram. P represents long-run processing costs per unit of wholemilk. A_1 depicts average assembly costs where all of the milk is assembled from farmers in relatively small trucks. A_2 represents average assembly costs where a combination of small and large truck units and a system of receiving stations are used for milk procurement. T_1 is the sum

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[1]Thompson, op. cit.

[2]Of course, this is contingent on equilibrium occurring at a volume where transshipment is taking place.

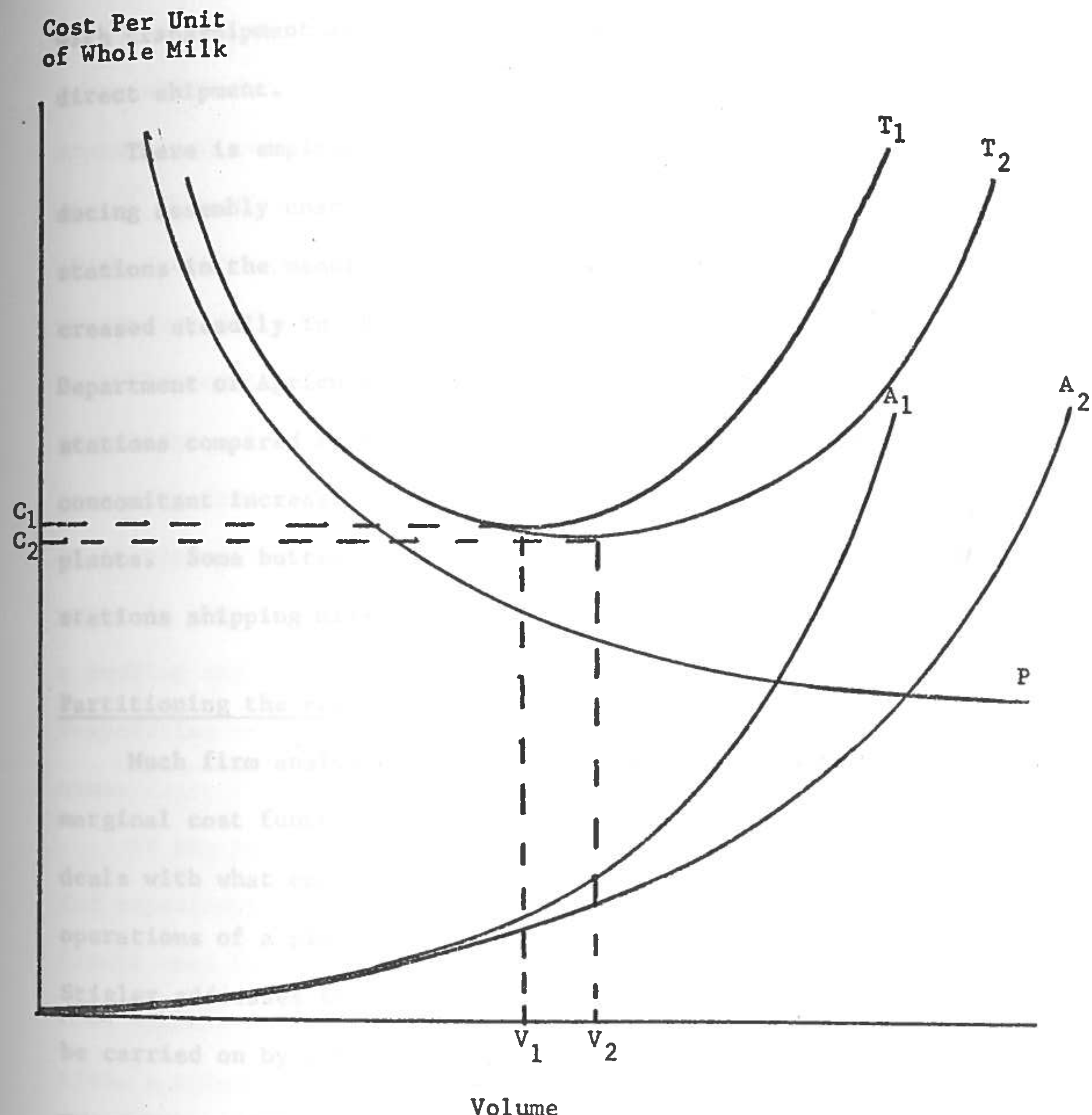

Figure 3. Average processing, assembly and total costs in a hypothetical butter-powder plant for direct assembly and indirect assembly.

of P and A_1, and T_2 is the sum of P and A_2. Minimum cost volume with transshipment is V_2 which is larger than minimum cost V_1 with direct shipment.

There is empirical evidence that supports this concept of reducing assembly cost via transshipment. The number of receiving stations in the manufacturing milk industry in Minnesota has increased steadily in the last 12 years. In 1958 the Minnesota Department of Agriculture reported 91 manufacturing milk receiving stations compared to 197 in 1970.[1/][2/] This same period has seen a concomitant increase in the size of butter-powder processing plants. Some butter-powder plants have fifteen or more receiving stations shipping milk to them.

Partitioning the Processing Cost Function

Much firm analysis centers around the total average and marginal cost functions of the firm. Analysis less frequently deals with what operations should economically be included in the operations of a plant or firm and hence these cost functions. Stigler addresses himself to the question of what activity should be carried on by a firm in his book on industrial organization.[3/]

[1/] Some of this change may be due to other considerations. It may be a short run effort of local creameries from becoming insolvent or closing.

[2/] Special reports of the Minnesota Department of Agriculture, St. Paul, Minnesota, September 1, 1958 and July 1, 1970.

[3/] Stigler, George J., The Organization of Industry, Richard D. Irwin, Homewood, Illinois, Chapter 12, pp. 129-141, also published as "The Division of Labor is Limited by the Extent of the Market," Journal of Political Economy, Vol. LIX, June 1951.

He points out that a firm can be viewed as engaging in a series of distinct operations; purchasing and storing materials; transforming materials into semifinished products and into finished products; storing and selling the outputs; extending credit to buyers; etc.[1/] The firm is partitioned among the functions or processes which constitute the scope of its activity rather than the factor or product markets it deals in.

The costs of these individual functions will be related by technology. The cost of one function may depend upon whether the preceding function took place immediately before or in the immediate vicinity, as when hot skim milk coming off the milk separator is pumped directly to the evaporator for drying. This saves a cooling and heating cost that would occur if separating and evaporating were carried on in a different place or at a different time.

If the interrelationships of the cost functions are ignored, for expository purposes, a simple geometrical construction of the firm's cost functions can be obtained. If the cost of each function depends only on the rate of output (or input) of the function, a unique cost curve can be drawn for it. If all the functions are computed on the basis of a common processing unit, say wholemilk equivalents for milk processing, they can all be represented in the same figure. The vertical sum of these cost curves will be the conventional average-cost curve of the firm.

[1/] *Ibid.*, p. 131.

Figure 4 gives a simplified example of such functions.[1/] Curves P_1, P_2 and P_3 are functions making up AC, average cost. P_1 demonstrates increasing returns, P_2 demonstrates decreasing returns and P_3 is the typical U-shaped average cost curve. The solid segment of AC is the sum of P_1, P_2, P_3. The dotted segment of AC is the sum of P_2, P_3 and C_3.

Stigler reasoned that the firm, represented by the solid AC, faced with overall decreasing returns above V_1 could not, under competitive conditions, be in a position to take advantage of the economies of P_1. A new firm might come into being and take on this specialized function. If the new firm was the only firm, it would or could have the monopoly power to charge C_3. The old firm without P_1 as a function would then, under competitive conditions, operate at V_2. If the new firm with function P_1 faced other firms with functions similar to P_1, that is, competitive conditions existed for the new firm, C_3 would be driven down to C_4 and there would be a concomitant vertical shift downward in the dotted AC curve of the old firm.

The development of a new firm in this case allowed for the exploitation of economies of size for the process of function P_1. At the same time, the spin off of function P_1 lowered the average cost, AC, for the old firm and allowed it to operate at a lower point on its decreasing cost function.

Dairy plant studies in the past have not asked what functions

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[1/] *Ibid.*, p. 132.

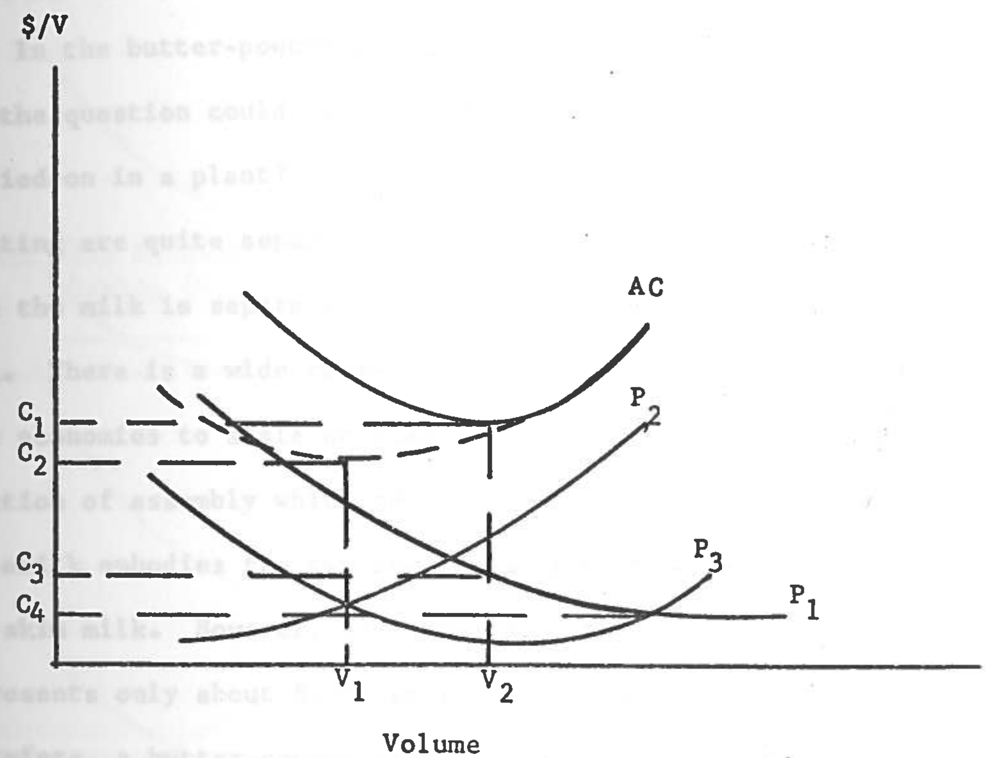

Figure 4. Average cost curves for several hypothetical functional operations necessary to process some product and ways the functions can be combined in a firm or plant.
Source: Stigler, p. 132.

should be carried on in a plant. Typically the studies have started with the products as a datum. The analysis usually centered around optimum size for the given products.

In the butter-powder sector of the manufacturing milk industry the question could well be asked, what processes should be carried on in a plant? The processes of churning and butter printing are quite separate from evaporating and drying, that is once the milk is separated into its components, cream and skim milk. There is a wide range of volumes under which both processes face economies to scale or size. There is, however, the additional function of assembly which enters the picture. The initial product wholemilk embodies the two raw products of the two processes, cream and skim milk. However, once separated the raw product cream represents only about 8.75 percent of the volume of wholemilk. Therefore, a butter-powder plant faced with an overall decreasing returns average cost curve but an increasing returns churning-printing function may find it profitable to spin off this function to a specialized firm or plant. Although the new plant would face an increasing assembly function for cream, it would be minor compared to the assembly function for wholemilk. The drying plant, in turn, without the inclusion of the downward sloping average cost curve for churning and printing, would find its minimum cost point at a lower volume. This whole idea is expressed graphically in figure 5. In this figure all curves are unit cost curves. Curve A is the unit cost function for churning and printing; curve B is the unit cost function for drying skim milk; and curve D is

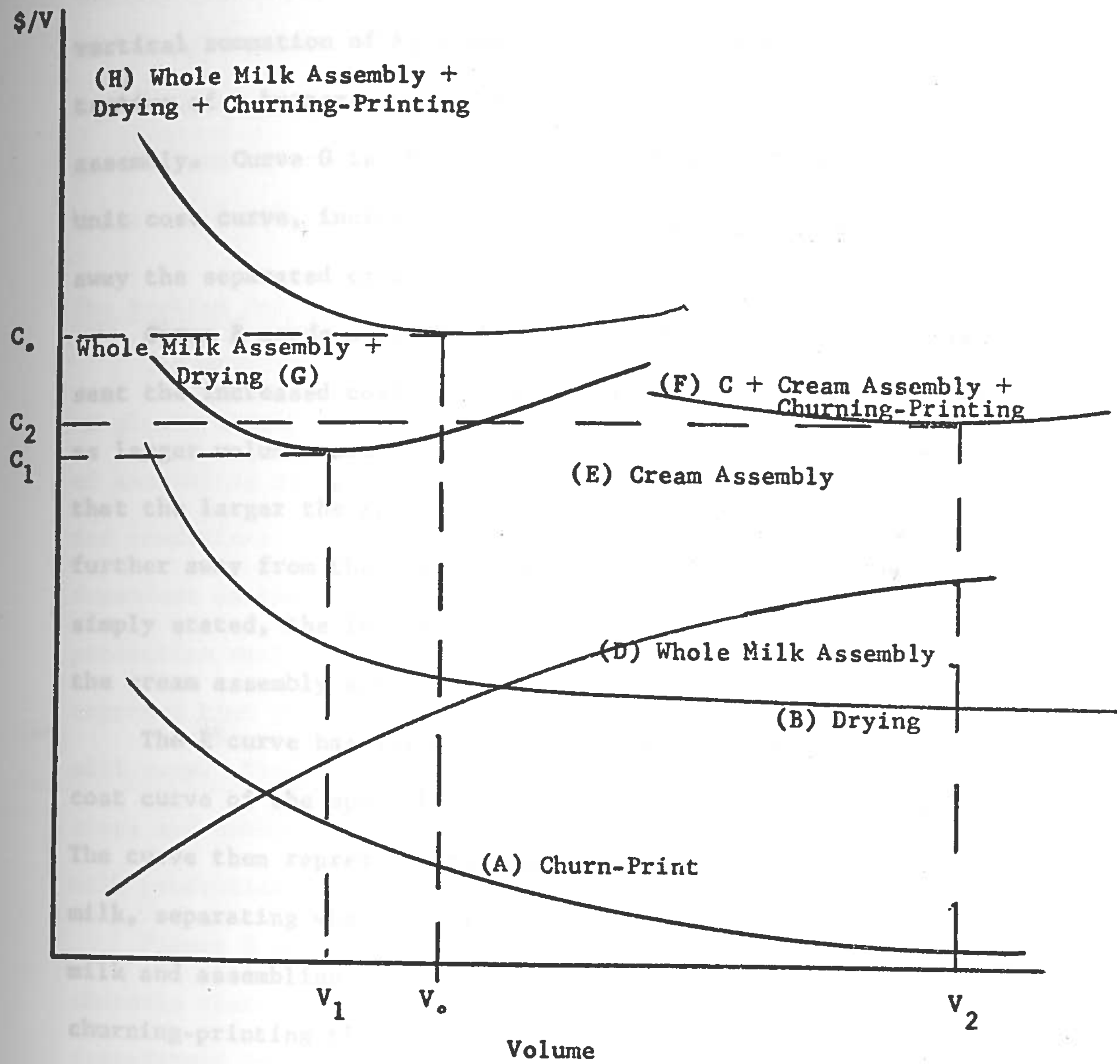

Figure 5. Hypothetical average cost curves for a butter-powder plant plus milk assembly, a specialized powder plant plus milk assembly and butter processing in a separate plant and the partitioned average cost functions making up the two systems.

the unit cost function for assembling wholemilk. Curve H is the vertical summation of A, B and D; it is, in other words, illustrative of a butter-powder plant unit cost curve which includes assembly. Curve G is the vertical summation of B and D; it is the unit cost curve, including assembly of a powder plant that ships away the separated cream.

Curve E needs a little explanation. It is included to represent the increased cost of shipping cream over greater distances as larger volumes are involved. The curve, in essence, suggests that the larger the specialized churning-printing plant is, the further away from the specialized drying plant it will be. More simply stated, the larger the churning-printing plant, the larger the cream assembly area.

The E curve has its origin at the minimum point of the unit cost curve of the specialized drying plant with wholemilk assembly. The curve then represents the minimum cost of assembling wholemilk, separating wholemilk into cream and skim milk, drying skim milk and assembling cream (from other plants) at a specialized churning-printing plant.

Curve F is the summation of curves E and A. It is the unit cost of assembling cream from several plants which includes minimum cost of assembling wholemilk, separating, drying the skim milk and churning and printing butter. The minimum point on this curve, F, is the minimum cost of assembling and processing wholemilk into butter and powder.

This is strictly a hypothetical example, the relative magnitudes of volume and cost have no basis in empirical investigation. The example should be viewed as a pictorial expression of the major thesis of this study. The subsequent chapters will investigate if and under what conditions the above results will be a least cost solution.

The Problem Restated

The problem of this study is to find the plant or combination of plants which, under competitive conditions, minimize the cost of assembling and processing milk into butter and nonfat dry milk for conditions common to Minnesota. The assembly function is very dependent on the density of milk production. The density of milk production varies from area to area in the state. Thus, it can be expected that the optimum size and type of milk processing plants will vary. The problem can be restated as that of finding the sizes and combination of plants that are least cost for specified milk production densities.

Figure 6 is a diagramatic scheme of the alternative processing channels that this study considers that milk can follow as it is transformed into butter and nonfat dry milk. Farm wholemilk sources are assumed uniformly distributed on a random basis. Bulk wholemilk from the farm has three alternative destinations. It can be assembled, via farm-to-plant bulk tank trucks, to a plant that receives, separates, churns, prints and drys the milk. It can be assembled, via farm-to-plant bulk tank trucks, to a plant that receives, separates and drys the milk. Or, it can be assembled by means of farm-to-plant bulk tank trucks, to a plant (or

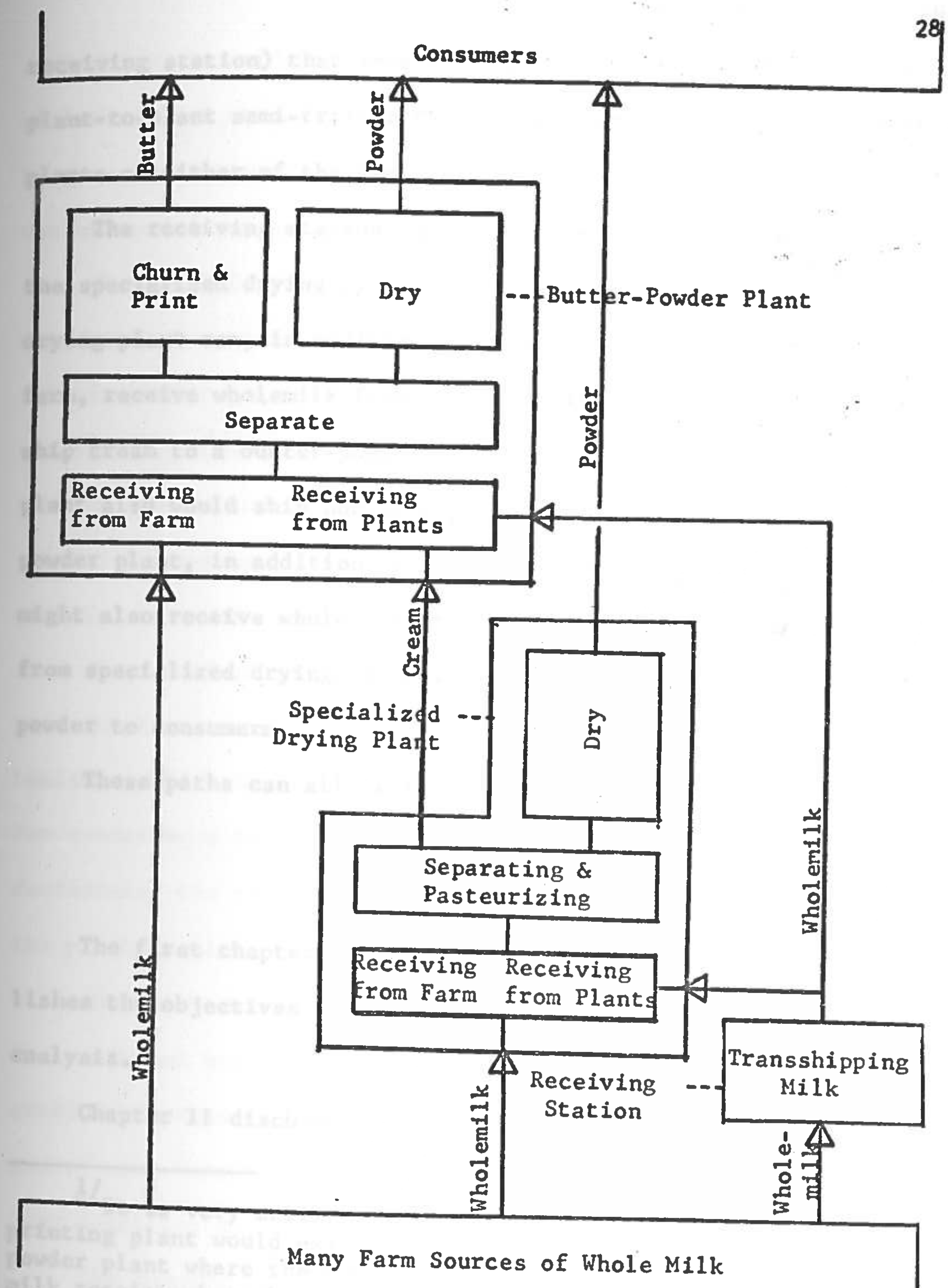

Figure 6. Patterns of milk assembly and processing into butter and nonfat dry milk.

receiving station) that merely reloads the wholemilk into larger plant-to-plant semi-trailer tank trucks for shipment to processing plants of either of the two previous types.

The receiving station, just mentioned, can ship wholemilk to the specialized drying plant or the butter-powder plant. The drying plant can, in addition to receiving wholemilk from the farm, receive wholemilk from receiving stations. It, in turn, can ship cream to a butter-powder plant.[1/] The specialized powder plant also would ship nonfat dry milk to consumers. The butter-powder plant, in addition to receiving wholemilk from the farm, might also receive wholemilk from receiving stations and/or cream from specialized drying plants. It in turn would ship butter and powder to consumers.

These paths can all be traced out in figure 6.

Chapter Delineation

The first chapter of this thesis defines the problem, establishes the objectives and develops the theoretical basis for the analysis.

Chapter II discusses the theory of production costs and the

[1/] It is very unlikely that a completely specialized churning-printing plant would exist. Rather it would be part of a butter-powder plant where the powder department was geared to the wholemilk receipts but the churn-print department would be geared to handle additional cream. It is logical to expect a large churn-print operation to be located central to cream sources. It is highly likely that the ideal location for it would be at one of the finite sources of cream, the drying plants. The further advantage of sharing some of the facilitating stages needed by both the drying operation and the butter-printing operation almost assumes that the butter-printing operation would be associated with a drying operation.

method used to estimate those costs. The economic engineering method of cost estimation, the method used, is reviewed. The reasons for using it, its rationalization with theory, its application to dairy plants and its limitation are discussed.

Chapter III presents the plant operation details and estimated cost functions. Average cost functions are first developed for six powder plants that receive wholemilk in bulk. Then the average cost functions are developed for the butter operation, with the assumption that the butter department will be in conjunction with a powder plant. The two functions are also combined to provide a traditional butter-powder plant long run cost function.

Chapter IV presents estimation techniques and the estimated cost functions for farm-to-plant and plant-to-plant bulk milk hauling. This chapter also develops the cost-volume relationship for operating a bulk milk receiving station. The receiving station facilitates the transfer of milk from the farm-to-plant trucks to the plant-to-plant trucks.

Chapter V deals with the translation of milk hauling costs into milk and cream assembly costs. It also deals with the integration of processing and assembly costs. It evaluates the integrated cost functions at various volumes and various milk production densities to determine least cost processing assembly systems.

The summary and conclusions are discussed in Chapter VII. A recap of the problem, procedure, the data, the cost functions and analysis is presented along with conclusions derived from the study.

CHAPTER II

RESEARCH PROCEDURE USED IN ESTIMATING PROCESSING COSTS

This chapter deals with the theory of production costs and the methods used to estimate those cost functions.

The first section deals with the reasons for using an economic engineering approach to estimate the processing cost functions. It also presents a brief review of some of the previous studies that have established the value of the economic engineering methods.

The next section deals with the theory of cost functions, both short and long run. It also discusses the adaptation of the theory to dairy plants and to the economic engineering techniques.

The third major section presents the procedure followed in applying the economic engineering techniques to estimating processing costs for nonfat dry milk and butter.

The fourth section presents the scope and source of data.

The last section discusses the assumptions related to product yield and the seasonal distribution of milk production.

Economic Engineering as an Estimation Technique

A cost study may be made in one of several ways. Behind the several ways are two basic approaches. They are: (1) statistical techniques using accounting data and (2) building block or economic engineering techniques.

The use of accounting data was ruled out as a major approach to estimating the cost functions for this study for several reasons. First, good accounting data is not available for many of the variables the study is concerned with. Few, if any, processing plants in the state keep detailed enough accounting records to allow the separate estimation of drying costs and butter churning costs. Also, plants do not exist for the full range of volumes considered in this study. There is yet another problem, obsolete technology is embodied in the accounting data of most plants. For example, in Hanlon's study of four processing plants, the larger plants used several small obsolete dryers to handle large volumes.[1/] Since that study was completed the equipment has been replaced by larger more efficient units. These larger more efficient units existed at the time the study was made but the modified accounting method used by Hanlon precluded their consideration in determining economies to scale.

Yet another problem with accounting data approaches is the problem associated with comparability of results between plants. Accounting data include many local plant operation idiosyncrasies which tend to mask the functional cost relationships of the basic processes.

For these reasons the economic engineering approach to cost

1/ Hanlon, _op. cit._, p. 533.

estimation was selected as the superior alternative for estimating the various cost functions of this study. This method permits the development of cost functions, embodying the latest technology and combining of these functions to arrive at alternative plant types and assembly systems.

The synthetic method is a well established method of cost analysis. It has its roots in budget analysis which has been proved effective and useful over and over again. Also, it has had wide acceptance in the construction industry and has been used by numerous economists and agricultural economists.[1/]

The literature shows that Bressler was one of the first to use the method in a systematic way in a dairy study in New England in 1942.[2/] Another early classic study using economic engineering methods was made by Chenery who used it to study gas transmission costs in pipe lines.[3/] Another important study demonstrating the application of economic engineering techniques was made by Brewster in Texas in 1954.[4/] He used this method to study size-

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1/Bressler, R. G. Jr., "Research Determination of Economies of Scale," Journal of Farm Economics, Vol. XXVII, August 1945, p. 533.

2/Bressler, R. G. Jr., Economies of Scale in the Operation of Country Milk Plants, New England Research Council with the New England Agricultural Experiment Stations and the U. S. Department of Agriculture.

3/Chenery, H. B., "Engineering Production Functions," Quarterly Journal of Economics, Vol. LXIII, November 1949, pp. 507-531.

4/Brewster, John M., Comparative Economics of Different Types of Cottonseed Oil Mills and Their Effects on Oil Supplies, Prices and Returns to Growers, Marketing Research Report No. 54, U. S. Agricultural Marketing Service, U. S. Department of Agriculture, 1954.

volume relationships in the cottonseed milling industry. He was one of the first agricultural economists to point up the appropriateness of linear cost functions for many agricultural marketing processing operations. He showed, at least in cotton seed milling, that most variations in product processed for a plant was the result of variation in time spent processing rather a rate change in processing methods.

In 1956 French, Sammet and Bressler published a study of costs of processing in the California pear industry.[1/] This report contains a detailed account of the economic engineering methodology that they refined and used in their estimation of long run cost curves for pear processing.

The use of the economic engineering approach by these researchers and others demonstrate its usefulness as a method of estimating economies to scale.

The economic engineering method of estimating cost relationships, like most economic research tools, is not without fault. The means of estimating the cost coefficients is cut loose from statistical reliability tests. This makes the accuracy of the coefficients difficult to judge.[2/] The researcher and the users of the study can only compare the coefficients with alternative

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[1/] French, B. C., L. L. Sammet and R. G. Bressler, "Economic Efficiency in Plant Operations with Special Reference to the Marketing of California Pears," Hilgardia, Volume XXIV, California Agricultural Experiment Station, July 1956.

[2/] Black, Guy, "Synthetic Method of Cost Analysis in Agricultural Marketing Firms," Journal of Farm Economics, Vol. XXXVII, May 1955.

sources, which often are not available. This problem is related to another, that is the danger of overlooking costs or oversimplifying relationships between stages and thus underestimating costs. Effort was made to minimize these problems by working closely with dairy engineers and dairy plant managers.

Another problem of the economic engineering approach to estimating economies to scale is that the method overlooks effects external to the plant.[1/] Cost effects resulting from multiplant firms or number of firms in the industry elude the basic physical approach of this technique. It is recognized that these are important issues but for this study they are considered beyond its scope.

Theoretical Considerations

Before proceeding with the estimation of the long run cost-volume relationships a brief discussion of the theoretical production process and its modification in actual dairy plants is in order.

The principles of production are the foundation of the analysis of costs, resource allocation and output. The elements of production theory are available in any number of economic texts.[2/]

1/ Smith, Cabel A., "Survey of the Empirical Evidence on Economies of Scale," Business Concentration and Price Policy, Output of the National Bureau of Economic Research, New York Princeton University Press, 1955, p. 223.

2/ See for example, Henderson, James M. and Richard E. Quant, Microeconomics, A Mathematical Approach, McGraw Hill Book Company, New York, 1958, p. 42.

Therefore, it is not necessary to restate them here. It is sufficient to state the well known fact that the precise combination of variable resources that a plant should use depends upon the marginal physical products of those resources and upon their respective prices. To minimize cost for a given amount of product, resources should be combined in a ratio such that the marginal physical product per dollar's worth of one equals the marginal physical product per dollar's worth of each resource used. If this procedure is followed for various quantities of product the resulting cost output relationship is the common cost curve. If some factors are fixed, the curve is a short run cost curve. If all factors are variable, the curve is a long run cost curve.

The theoretical long run cost function is the envelope of the theoretical short run cost function. The long run cost function is drawn as a smooth curve tangent to each short run cost curve. For economies to scale, the tangency points between the short run average cost curves [SRAC] and the long run average cost curve [LRAC] occurs above the minimum point of the short run curves, as shown in figure 2.1.[1/]

The same tangency condition should hold for estimated average cost curves. However, the estimation technique of the economic engineering approach used to develop the short run cost curves is

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[1/] For a more detailed discussion of the relationship between short and long run cost curves see a basic economics text such as Henderson and Quant, op. cit., Chapter III. For the original work see Viner, Jacob, "Cost Curves and Supply Curves" Zeitschrift für Nationalökonomie, 1931, reprinted in Readings in Price Theory, The American Economics Association, Richard D. Irwin, Homewood, 1952, pp. 198-232.

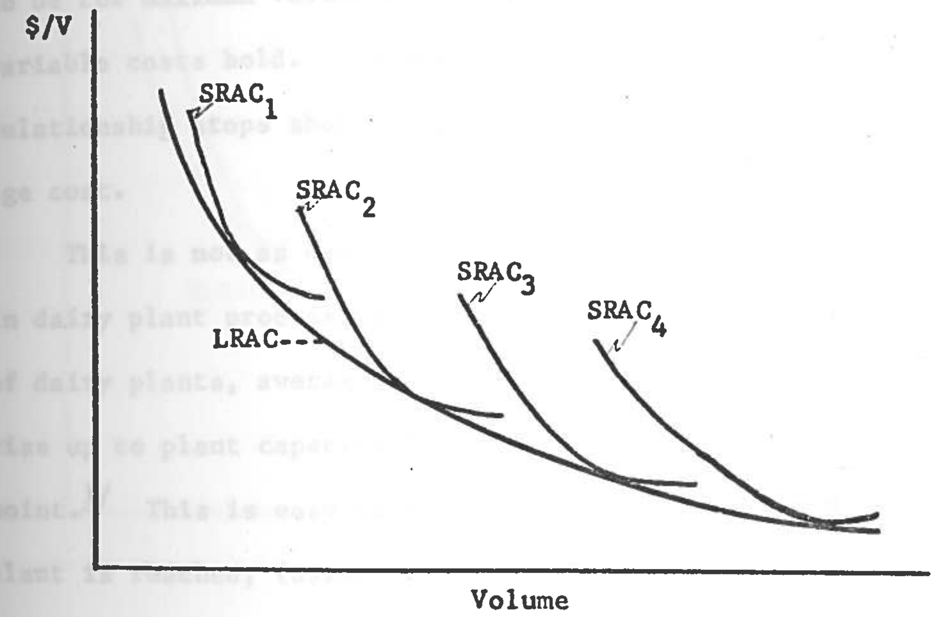

Figure 2.1. Theoretical short and long run average cost curves.

such that the envelope appears to touch the estimated short run curves at their minimum. This occurs because the linear cost functions of the economic engineering approach, at least the linear cost functions of this study, are estimated only up to the plants stated capacity. Stated capacity is estimated or defined to be the maximum volume of the plant under which the constant variable costs hold. Therefore, estimation of the cost-volume relationship stops short of a true minimum of the short run average cost.

This is not as damning as it might first appear, especially in dairy plant processing. As Bressler pointed out in his study of dairy plants, average variable cost showed little tendency to rise up to plant capacity but rose very rapidly beyond that point.[1/] This is easy to understand, once capacity in a dairy plant is reached, (using the just defined capacity), further increases in volume must come from operating the equipment at greater than technically optimum rates which results in significant product loss and quality deterioration. This has the effect of sharply raising the average variable cost of the product.

In light of rapidly rising average variable cost, the effect of extending the estimated short run average cost curve [ESRAC] beyond plant capacity is to bend the curve sharply away from the long run average cost curve [ELRAC], as shown in figure 2.2. The solid segment of the short run average cost curves is what normally

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[1/] Bressler, op. cit., p. 526.

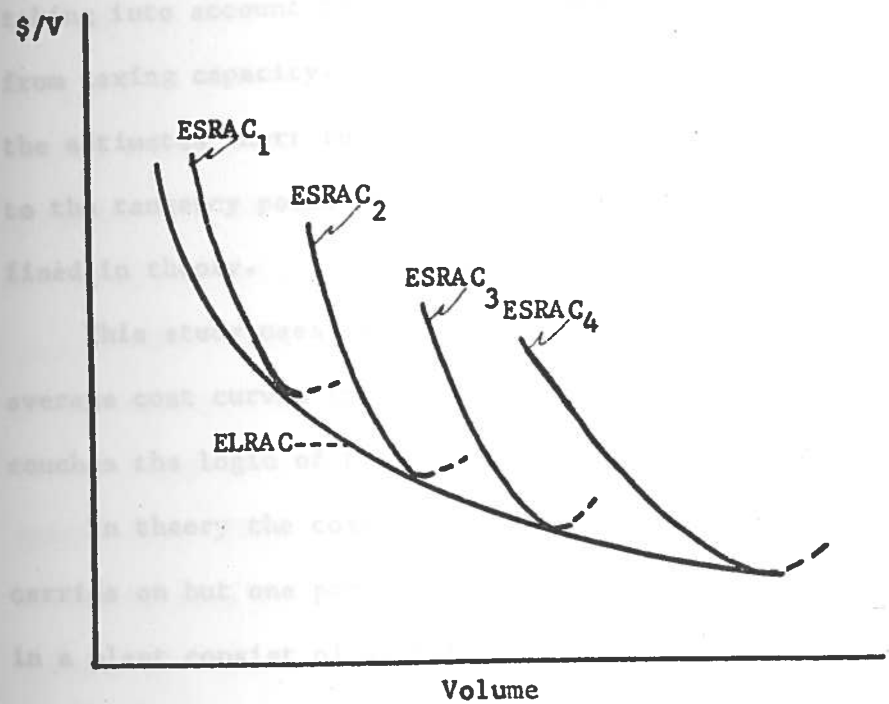

Figure 2.2. The relationship of the estimated long run average cost curve to the estimated short run average cost curves.

is estimated in an economic engineering study using linear cost estimates. The dotted portion of the short run average cost curves is the expected results of extending the estimated curve, taking into account the rising average variable cost resulting from taxing capacity. In a case such as this the minimum point on the estimated short run average cost curve is a good approximation to the tangency point with the long run average cost curves as defined in theory.

This study uses the minimum points of the estimated short run average cost curves to estimate long run average cost curves. It couches the logic of this action in the argument above.

In theory the cost curves are dealt with as if the plant carries on but one process. In reality, however, activities within a plant consist of an integration and correlation of many different "processing" stages. Each processing stage can be viewed as a center where the production function for that process can be identified. The stages are distinguished by the type of equipment used and the function performed. In each stage there are the necessary equipment, labor and facilitating elements for carrying out the process.

In most instances, the inputs of the centers are related to a flow of a single physical product. In the case of dairy plants it is usually related to the flow of wholemilk or some constant factor of proportionality of one of its derivatives. The range of rate variation is limited by technical or legal requirements and by the connecting centers in the plant. A balance of some sort must be reached with respect to rates in each center or some type of storage function provided. The "best" rate for any stage must be balanced with the other stages and the cost of storage. In the case of the plants of this study, receiving goes on at a given rate and in all other stages the rates are consistent with the drying unit's rate, in the case of the stages related to the drying process. The stages related to butter processing are operated at the same rate as the high speed soft printer.

Another important adjustment from textbook theory to dairy plant reality relates to factor substitution. The continuous factor substitution of theory does not hold in dairy plant operations. This is especially true in the short run. This can easily be seen from inspecting the factors of production found in a dairy plant: labor, equipment, buildings, raw products, power, fuel and water. Labor is not a substitute for equipment in the highly mechanized technology specific conditions of modern dairy plants. Likewise, the other factors are not substitutes. The most logical substitution is labor and equipment. However, changes in equipment that affect labor equipment ratios changes the equipment size and hence the plant size which changes the scale in the context of scale used here.

This implies that in dairy plants, in the short run, variation in plant output for a time period, that is daily, annual, etc., are a function of the hours of operation. French, Sammet and Bressler point out that the failure to distinguish between rate and time dimensions has created problems over the nature of cost curves.[1] They point out that most empirical studies observe only the time dimension and, hence, they find linear cost functions and constant marginal costs.

This is the type of functions defined in this study and the study bases its theoretical validity on this argument presented so well by French, Sammet and Bressler. Dairy plants in general and specifically the plants of this study are designed to operate at a set rate. Variations in plant volume are changed by changing the hours of operation. This gives credence to the use of constant average variable costs, as was done in this study.

The use of linear functions is admittedly dangerous if not supported by evidence that average variable costs are in fact fairly uniform in the range being considered. There is evidence, however, in the dairy industry that average variable costs are fairly uniform. Bressler in an earlier study of New England dairy plants showed that there was little tendency for average variable cost to increase up to plant capacity but that it increased very rapidly beyond that point.[2] Juers correlated daily fuel and electricity use with volume in his sample plants. In every case the correlation coefficient was in the 90's.[3] Knudtson correlated monthly electricity and fuel use with volume of butter processed

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1/ French, Sammet and Bressler, op. cit., p. 548.

2/ Bressler, op. cit., p. 526.

3/ Juers, op. cit., pp. 120-124.

for butter plants in Minnesota.[1] All his correlation coefficients were in the 90's also, except one. He also compared, in graphical form, linear labor requirements functions with actual labor use. Visual observation indicates that a linear function provides a good estimate of labor costs.[2]

Thompson correlated weekly labor costs, monthly electrical use and monthly fuel use with volume for a butter-powder plant. He also had correlation coefficients in the .90's.[3]

Hanlon correlated labor cost, electricity cost and fuel cost with volume for four butter-powder plants in Minnesota. He had linear correlation coefficients in the .90's for electricity and fuel but his labor correlation coefficients were generally in the .70's and .80's.[4]

These results give strong evidence of constant average variable costs for major cost factors in butter-powder plants.

Procedure

The economic engineering method contains three basic steps.

The first step is to record in detail every step in the production process. Then, with the help of these recorded details, the process is broken into stages or centers, each of which has a

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1/ Knudtson, Arvid C., "An Analysis of Processing Costs in Specialized Butter Plants Receiving Wholemilk," Unpublished Ph.D. thesis, University of Minnesota, October 1957, pp. 147-153.

2/ Ibid., pp. 181-186.

3/ Thompson, op. cit., pp. 18-37.

4/ Hanlon, op. cit., Chapter III.

distinguishable production function.

The second step is to evaluate the various techniques that may be used at each processing stage. This is where the engineering data, time and motion data and in some cases specific accounting data are utilized to arrive at the desired factor combinations.

The third step is to apply factor prices to determine the cost relationship at each center. The centers are then combined to arrive at total cost of the processing operation.

The specific procedures of this study, behind these three broad steps, follow closely the work of Kerchner,[1/] who in turn patterned his work closely after the technique of French, Sammet and Bressler.[2/] Kerchner synthesized a dairy plant capable of processing wholemilk into butter and nonfat dry milk or cheese and whey powder. The steps he followed were modified and extended to facilitate the cost estimates for the several different size and types of plants considered in this study. The similarity of many of the processes made Kerchner's work a useful starting point.

Scope and Source of Data

The largest part of the data underlying the estimated cost functions in this study were obtained from dairy plant engineering

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[1/] Kerchner, Orval Guy, "Economic Comparison of Flexible and Specialized Plants in the Minnesota Dairy Manufacturing Industry," Unpublished Ph.D. thesis, University of Minnesota, June 1966.

[2/] French, Sammet and Bressler, op. cit.

input-output coefficients. These input-output data were obtained from a number of sources. Dairy equipment engineers and sales personnel who service the dairy industry in Minnesota provided much of the information, especially equipment specifications and prices. Several previous studies of dairy processing plants were also valuable sources of data. Much of the labor input-output data was obtained by means of time and motion studies of many aspects of dairy plant operation. Also many processing plants in the state were visited to observe variations in processing methods and to discuss management problems with the plant managers. Other valuable sources were staff members from the University of Minnesota in the Departments of Agricultural Economics, Agricultural Engineering, and Food Science and Industries.

The milk processing plants in this study ranged in volume from about 78 million pounds of wholemilk annually to about 623 million pounds annually. This volume range was selected with the help of sales engineers of large dairy equipment suppliers and plant managers. They indicated that, under Minnesota conditions, a drying plant not capable of producing 1,000 pounds of powder per hour would be economically unfeasible. On the other hand, the largest dryer any of them had information on was an 8,000 pounds of powder per hour model. They indicated that a plant with a dryer of this capacity would be capable of using all known technical efficiencies. A plant of this size also approximates the annual volume capacity of a continuous churn-high speed butter printer combination. The four other plant sizes within the volume range were included to provide the necessary information for estimating the form of the long run cost function.

Butter churning and printing were treated as a joint operation because of the obvious cost advantage of a joint operation. Before the development of the soft butter printer these two operations were usually carried on in separate plants. By combining these operations there is a savings of the cost of the bulk containers used to hold the butter between churning and printing and most of the labor of the central printing plant. The joint operation requires only slightly more labor than bulk packaging.

Assumptions

Several assumptions were used in designing the plants and estimating their costs.

Product yield: When converting milk products into wholemilk equivalents the assumptions made in this study were:

(a) Wholemilk contained 3.5 percent milkfat and 8.5 percent nonfat solids.

(b) The yield of 40 percent cream per hundred-weight of wholemilk is 8.75 pounds.

(c) The yield of butter per hundred-weight of wholemilk is 4.31 pounds.

(d) The yield of nonfat dry milk per hundred-weight of wholemilk was 8.38 pounds. This includes .40 pounds of buttermilk powder.

Monthly Distribution of Milk Receipts

Milk production has a distinctive seasonal pattern. It rises to a peak in late spring and drops to a low in early fall. This seasonal pattern has an important effect on the utilization of labor. It also has to be taken into account in determining annual plant capacity. The annual capacity is not three hundred sixty-five times the maximum daily capacity. The peak daily capacity can only be achieved for a short period because of this seasonality effect.

In this study a five period seasonal pattern of milk production was developed as a seasonal index. All annual costs and production were based on this seasonal pattern. Table 2.1 lists the periods, the number of days in each period, the percent of the year each period represents and the index of each period with the maximum period as the base.

The seasonal index was derived from an average of milk production on farms in Minnesota for the years 1966, 1967 and 1968.[1/] Months with similar average daily production volumes of milk were grouped together. Table 2.2 indicates the average monthly production indices and how they were grouped into five periods.

In addition to the seasonal index the relationship between the volume of a maximum day and annual volume was established for this seasonal pattern. The maximum daily volume is .322 percent of annual volume. This was obtained by weighing the index by the

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[1/] Minnesota Agricultural Statistics 1969, op. cit., p. 61, table 66.

Table 2.1. Seasonal index of milk production in Minnesota, 1966-68 average.

	Days	Index of seasonal production	Percent of the year
Period 1	122	100	33
Period 2	59	91	16
Period 3	62	83	17
Period 4	61	69	17
Period 5	61	62	17
	365		. 100

Table 2.2. Monthly seasonal index and derivation to a five period index for milk production in Minnesota, 1966-68 average.

	Days in month	Index of monthly production	Five period index
January	31	90	Index at 91 [Period 2]
February	28	87	
March	31	98	Index at 100 [Period 1]
April	30	98	
May	31	100	
June	30	96	
July	31	82	Index at 83 [Period 3]
August	31	67	Index at 69 [Period 4]
September	30	58	Index at 62 [Period 5]
October	31	64	
November	30	68	Index at 69 [Period 4]
December	31	80	Index at 83 [Period 3]

Source: Minnesota Agricultural Statistics 1969, table 66.

seasonal periods, summing them and dividing this sum into 1/122 of the weighted maximum seasonal index.[1/]

The capacity of the six drying facilities were calculated on the basis of this seasonal index. It was assumed that the driers would operate a maximum of twenty hours in the peak period. This allows for cleaning and a margin of safety for unforeseen shut downs. The dryer capacities were converted to wholemilk equivalents. All volume designations in this study are expressed in these units unless otherwise specified.

The summary of hourly, daily, weekly and yearly production capacities for the six estimated drying facilities can be found in table 2.3. It is interesting to note the wide range in annual plant capacities. They range from just under 78 million pounds of milk processed annually to over 622 million pounds annually.

Six butter departments were also synthesized with comparable volumes to the six drying facilities. These butter departments and the drying facilities with similar capacities were combined into traditional butter-powder plants.

The procedure of estimating the two operations separately allowed the volume processed by the butter operation to be independent of the drying operation. It is possible to have in one plant a large butter department and a small drying department. In this study the reference to a large butter department is to this type of plant management.

[1/] There are 122 days in the maximum period.

Table 2.3. Hourly, daily, weekly and yearly capacity of six skin milk drying facilities and six matching butter departments.

Production Period	1000 lbs. powder per hr. dryer	2000 lbs. powder per hr. dryer	3000 lbs. powder per hr. dryer	4000 lbs. powder per hr. dryer	6000 lbs. powder per hr. dryer	8000 lbs. powder per hr. dryer
			(1000 lbs. of whole milk equivalents)			
Hour	12.5	25	37.6	50.1	75.2	100.2
Day 1/	250.6	501.1	751.1	1,002.2	1,503.4	2,004.5
Week	1,753.9	3,507.8	5,261.8	7,015.8	10,523.5	14,031.4
Year 2/	77,813.7	155,627.4	233,441.1	311,254.8	466,882.2	622,509.6

1/ Assumes 20 hours maximum operating time.

2/ Allows for seasonality of milk production.

The next chapter discusses the synthesized plant processing operations and the estimated cost functions derived from them.

CHAPTER III

ESTIMATION OF PROCESSING COSTS

This chapter is devoted to the estimation of individual long run average cost functions for nonfat dry milk processing and butter processing as well as these two processing cost functions combined.

The first section deals with processing wholemilk into nonfat dry milk and cream. The processing stages are outlined and the cost functions for factors of production by these stages are developed. The factor cost functions for each plant are summed to yield the short run average cost functions for the six specialized drying plants. The long run average cost function is estimated by fitting a smooth function to the minimum estimated points on the short run average cost functions.

The second section repeats this procedure for butter processing. The short run average cost functions are estimated for butter departments. The term butter department is used rather than plant because it is assumed that butter will be processed at the site where powder is processed.

The last section combines the long run average cost functions for the two products into a butter-powder plant that processes wholemilk into nonfat dry milk and butter.

Milk Drying Plants

In this section the short run average cost function for six specialized drying plants are developed along with the resulting long run average cost function. The plants are assumed to receive wholemilk in bulk and produce cream and nonfat dry milk.

The Processes of the Milk Drying Plants

There are five logical stages involved in a drying plant. They are: (1) receiving wholemilk, (2) separating-pasteurizing, (3) skim milk evaporating-drying, (4) powder packaging and warehousing and (5) facilitating processes, providing electricity, refrigeration, heat and administration. Figure 3.1 presents a schematic drawing of the stages (excluding (5)) and the flow of products through the drying plant.

The receiving process includes receiving wholemilk in farm-to-plant bulk trucks or over-the-road semi-trailer tank trucks, pumping the wholemilk to the separator or storage and providing facilities for washing the tank trucks.

The separating-pasteurizing process is integrally connected. This equipment is sized to the evaporator and dryer to provide a continuous flow of product from receiving to powder packaging. This allows for a completely automated system which minimizes labor, conserves heat energy and minimizes bacterial contamination. The wholemilk is pumped from storage or directly from the tankers to a heat exchanger which utilizes the regeneration process in

1. Receiving bulk milk from farms and other plants
2. Storage: wholemilk, cream
3a. Wholemilk plate with regeneration
3b. Cream plate with pasteurizer and regeneration
4. Separator
5. Evaporator; effects consistent with size of plant
6. Dryer
7. Powder storage

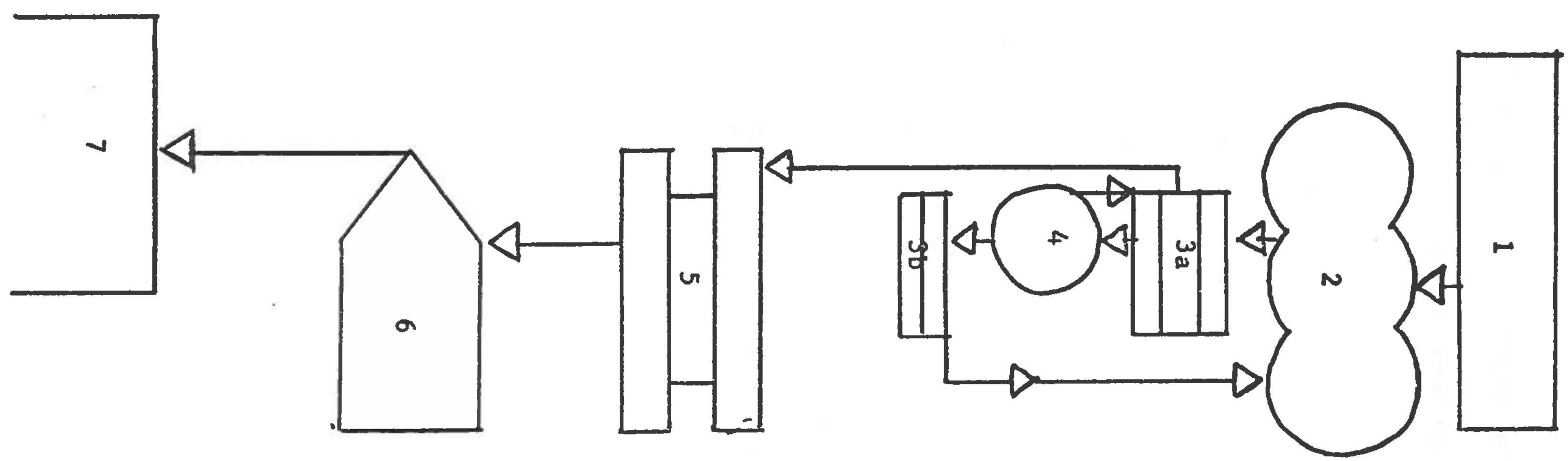

Figure 3.1. Schematic drawing of the equipment and flow of products in a specialized milk drying plant receiving wholemilk.

heating the wholemilk to separation temperature.[1/] The separated cream is further heated to pasteurization temperature and then cooled, again utilizing regeneration as much as possible. The cream is pumped to storage to condition the butterfat prior to churning in the plant's butter department or another plant's butter department.

The skim milk is pumped to the evaporator. The evaporator condenses the skim milk from about 9 percent solids to about 45 percent solids. The condensed skim milk is pumped to a vertical spray dryer where most of the remaining moisture is removed. This process results in a switch in the product from a liquid phase to a solid phase. The condensers are much more efficient at removing moisture from the product but they cannot accomplish this phase change. This explains why evaporators and dryers are both used in drying skim milk.

The nonfat dry milk is pumped or augered to hoppers for bagging in the powder packaging and warehousing process. The powder is packaged in 50 pounds type "G" bags. It is palletized and warehoused to await sale.

The facilitating stage includes providing steam or other heat, refrigeration, electricity and administration.

Factor Cost Categories

The cost functions for the drying plants were estimated by

[1/] Regeneration refers to the transfer of heat from milk or cream already separated to milk about to be separated. This partial heat transfer saves on both heating and cooling costs.

estimating the various factors of production by stages. The factors were categorized on the basis of ease of estimation. The factor cost categories are:

Labor
Equipment, buildings, land
Fuel
Electrical
Water and sewage
General plant supplies
Packaging supplies
General administrative expenses
Patron account and field service

Each of these factors was evaluated for a fixed annual cost component and a variable cost component. The variable cost component is always expressed as dollars per 1,000 pounds of wholemilk equivalents, the standard volume measure for this study. The development of each of these factor costs is presented in the following sub-sections.

Labor Costs

The labor data was obtained from several sources. Plant managers, dairy engineers, previous plant studies and time and motion studies all were utilized in arriving at labor costs.

Labor requirements were segmented into several divisions for both estimation and analytical purposes. Supervisory and administrative labor was treated as a fixed factor for each plant. These labor requirements remain constant regardless of the annual volume of milk processed. In the strictest sense this is somewhat restrictive. For example, a plant as defined here, operating at one-half capacity could reduce its administrative staff to a size comparable to a smaller plant processing a like volume but operating at capacity. It does not damage the overall analysis, however, because the major interest lies with the long run cost curve which envelopes the short run cost curves of this study at or near plant capacity for all six plants.

The general manager's salary, plant superintendent's salary and the required number and salary of office personnel were estimated with the help of plant managers. Hanlon's study of four butter-powder plants was also used as a guide to administrative salaries.[1/] The general manager's salary was based on responsibilities mainly associated with procurement and processing. It was assumed that product sales were handled by a regional marketing cooperative.

The salary of the general manager of the smallest plant, 78 million pounds annually, was estimated at $13,000 per year. It was further estimated that the manager's salary of each successively larger plant went up by $1,000. Thus, the salary of the general manager of the largest plant, 623 million pounds annually, was estimated at $18,000.

The plant superintendent's salary was estimated at $10,000 per year. In the smallest plant, the plant superintendent also has responsibilities for supervising receiving and maintenance. This is consistent with the smaller drying plants visited during the course of the study.

The office salaries were estimated at $5,200 per year.

[1/] Hanlon, op. cit.

Usually a bookkeeper receives somewhat more than this and general secretaries somewhat less. The number of office personnel was separated into those for plant operations and those for patron accounts. This allowed for easy handling of either direct patrons or receiving station accounts.

It was estimated that the smallest plant, Plant 1, required one office worker, Plants 2, 3 and 4 required two office workers and Plants 5 and 6 required three office workers for handling plant operations.

Receiving labor was also treated as a fixed factor. Receiving requires mostly supervisory labor in Minnesota plants. The bulk truck drivers do most of the actual labor involved in unloading. In Plants 1 and 2 one worker was estimated to be needed for this job. In the other plants two workers were required. Their gross salary was estimated at $6,760 annually.

Other labor treated as fixed for each plant was maintenance and engineer labor. In Plant 1 it was assumed this was done by the plant superintendent and general plant labor. In Plant 2 one worker was estimated to be needed for these two jobs. In the other four plants two workers were estimated to be needed for the two jobs.[1/] The gross salary for these workers was estimated at $9,000 annually.

The labor needed for grading and plant quality control was considered fixed. It was assumed that the plants wanted to

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[1/] In calculating these requirements it was assumed that the boilers are equipped with automatic controls.

qualify their products for government purchase, therefore, a U. S. Department of Agriculture resident grader was included as a cost for each plant. The cost of a grader was estimated at $12,000 annually. The grader was assumed to be responsible for the quality control of the plant as well as grading. In the three largest plants, Plants 4, 5 and 6, extra laboratory workers were included to assist the grader. The gross salary for a laboratory technician was estimated at $5,200 annually.

The remaining labor requirements, the actual plant production labor, has both fixed and variable components. Daily clean-up and set-up labor is fixed irrespective of volume. Operation labor and packaging and warehouse labor varies with volume. This is consistent with the earlier discussion on how volume changes in a plant are achieved by changing the length of the operating period. The actual variability of the labor is more complex than just relating it on a one to one basis with the man-hours per 1,000 pounds of volume because of seasonality of milk production.

Dairy engineer labor requirements and the data from the time and motion studies are relevant on a daily basis. The estimation of the fixed man hours for clean-up and set-up and the man-hours required to perform the several tasks that vary with volume can readily be expressed in the following functional form:

$$H_i^D = a + b\ V$$

where:

H_i^D, is the daily (D) man-hours for plant i

a, is the daily fixed man-hours

b_i is the man-hour requirements per 1,000 pounds of wholemilk equivalents

V_i is daily volume of wholemilk equivalents, in 1,000 pounds

This daily labor use function cannot simply be converted into an annual labor use function by multiplying through by 365 days. Two factors prevent this. First, milk production in Minnesota has a seasonal pattern. This already has been discussed (Chapter I, table 1). Also, dairy plants find they must hire labor on an annual basis in order to retain the quality of the labor needed in a modern dairy plant. These two factors mean that a plant manager will want a labor crew which will minimize the amount of unproductive labor in the off season but which, also, will not cost him more in overtime wages (at time and one-half) than a man's annual straight time salary. In view of this crew size problem a method was devised for converting the daily man-hour requirement function into an annual man-hour requirement function. This was done for each plant.

First, a crew size was selected which was capable of handling a daily volume which was in the volume range of the plant under consideration. Next, the annual volume of milk was calculated which provided a daily volume in the maximum period which just utilized the man hours available from that crew without overtime hours. In functional notation it is:

$$\bar{V}^A_{ij} = \frac{(Cr_j)\ (h)\ -\ F_i}{d\ \ b_i}$$

where:

$\bar{V}^A_{ij}$, is annual (A) volume of wholemilk for plant i and crew size j, in 1,000 pounds

d, is .00322, the fraction of annual volume that is received on a day in the maximum period

b_i, is the man-hours of variable labor required for processing in the i-th plant per 1,000 pounds

Cr_j, is the crew of j men

h, is 8 hours, the number of hours of straight time per man per day

F_i, is fixed daily man-hours

The next step was to determine how labor requirements increased as annual volume increased beyond the volume that just utilized the man-hours of straight time available in the maximum period. The seasonal pattern of milk production from Chapter I, table 1 was used in this estimation.

The peak period exists for 33 percent of the year. Therefore, as volume first increases above $\bar{V}^A_{ij}$, overtime labor is required for only 33 percent of the volume increase. There is unused labor in the other periods to process the volume increase in those periods. The overtime labor requirement on 33 percent of the volume increase is valid until the volume reaches 1/.91 times the initial volume, $\bar{V}^A_{ij}$. At this point the second period joins the peak period in requiring overtime labor to process increases in volume. Now 50 percent of the annual increase in volume is subject to overtime labor. Likewise, when annual volume reaches

1/.83 times the initial volume, $\vec{V}^A_{ij}$, 67 percent of further volume increases are subject to overtime labor. The pattern continues, when the annual volume reaches 1/.69 times the initial volume, $\bar{V}^A_i$, .84 percent of further volume increases are subject to overtime labor.

The same pattern holds if a volume increase reaches 1/.62 the initial volume, $\vec{V}^A_i$. However, it was assumed at this volume a man would be added to the crew. The remaining unproductive labor in the slack period is needed for vacation time.[1/]

The functional representation of this scheme is:

$$H^A_{ij} = \begin{cases} Cr_{ij}\ (8)\ (365) + (1.5)\ (.33)\ b_i\left[\vec{V}^A_{ij} - V\right] & \vec{V}^A_{ij} \leq V \leq \vec{V}^A_{ij}/.91 \\ Cr_{ij}\ (8)\ (365) + (1.5)\ (.50)\ b_i\left[\vec{V}^A_{ij} - V\right] & \vec{V}^A_{ij}/.91 \leq V \leq \vec{V}^A_{ij}/.83 \\ Cr_{ij}\ (8)\ (365) + (1.5)\ (.67)\ b_i\left[\vec{V}^A_{ij} - V\right] & \vec{V}^A_{ij}/.83 \leq V \leq \vec{V}^A_{ij}/.69 \\ Cr_{ij}\ (8)\ (365) + (1.5)\ (.84)\ b_i\left[\vec{V}^A_{ij} - V\right] & \vec{V}^A_{ij}/.69 \leq V \leq \vec{V}^A_{ij}/.62 \end{cases}$$

where:

H^A_{ij}, is the annual man-hour equivalents of labor that must be paid for the jth crew in the ith plant

Cr_{ij}, is the jth crew size in the ith plant

8, is the hours of straight time per day per man

365, is the number of processing days in a year

1.5, is the time and one-half for overtime factor

.33, .50, .67, .84, are the proportions of the annual volume change subject to overtime. Man-hour

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[1/] Vacation pay is included in the gross wage rate so there is no inconsistency or double counting in this assumption.

equivalents is used rather than just man-hours because some of the physical hours have been inflated by a factor of 1.5 because they are over-time hours and must be paid for at a time and one-half rate.

b_i, is the man-hours of variable labor required for processing in the ith plant

$\bar{V}^A_{ij}$, is the annual volume of wholemilk for the ith plant that just uses the straight time man-hours of labor available on a peak period day for the jth crew size, in 1,000 pounds

V, is volume in 1,000 pounds

The procedure outline above was followed for a number of different crew sizes for the six plants. The resulting functions for each plant were compared and the least hour cost segments of each function were combined to form an annual man-hours of production labor functions. This function was converted into a linear function based on two factors. First,

$$b_i \simeq (1.5)\ (.67)\ b_i,$$

which says that the variable man-hour coefficient is the same for the annual volume as the daily volume for the third period. It also happens that the third period dominates the least cost segments for the annual man-hour function.

The variable coefficient for the annual linear man-hour equivalent function was estimated to be the same as the variable coefficient, b_i, on a daily basis.

The intercept or fixed portion of the annual linear man-hour equivalent function was estimated in the following way. The total man-hour equivalents required for $\bar{V}^{A}_{ij}/.62$ (where j is the optimal crew size at maximum volume for the ith plant) were calculated. From this total, $\left[b \cdot V^{A}_{ij}\right]$, the estimate of variable man-hour equivalents was subtracted to leave the fixed man-hour equivalents or intercept of the function. This was done for each of the six plants.

The annual man-hour equivalent functions' parameters do not have a direct economic interpretation. The functions are a proxy for the more complex system of crews and overtime labor requirements which in turn are developed from the daily fixed and hourly variable labor requirements.

The annual man-hour equivalents functions for the six plants were converted into dollar costs by applying the appropriate hourly wage rate.

The wage rates for plant labor were obtained from the plant managers and based on the wages paid in 1969. There was little difference in rates from plant to plant. This was true whether the plants were unionized or not. Two basic wage rates were used. Machine operators and skilled workers were paid a gross wage of \$3.50 per hour and general plant labor was paid a gross wage of \$3.25 per hour. The gross wage rate includes the cost of fringe benefits, vacation pay, sick leave, unemployment compensation, payroll taxes, etc.[1/] It is the wage cost to the plant not the

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1/ See Kerchner, op. cit., p. 62 for details on fringe benefits, taxes, etc., in a representative union contract for the manufacturing milk industry in Minnesota.

rate the worker receives.

The effective wage rate for each plant was a weighted average of the two wage rates just mentioned. The average rate decreased slightly as plant size increased. This was due to the higher proportion of general plant workers in a crew in the larger plants.

The estimates of the daily fixed labor requirements for the production crews for the six plants are shown in table 3.1. The major portion of the fixed time is for clean-up and set-up. The labor requirements reflect the use of clean-in-place equipment whenever possible. With clean-in-place systems cleaning is automated and larger capacity plants require little more cleaning labor than small ones. For example Plant 2 requires 15.5 hours for clean-up and set-up and Plant 6, with four times the capacity only requires 17.5 hours.

The estimates of the variable labor coefficients are shown in table 3.2. The operator labor is based on one worker attending the evaporator-dryer complex and the separator-pasteurizer complex. This equipment is equipped with automatic controls and the operator performs mainly as a monitor over the system.

The packaging and warehouse labor coefficients are based on the recommendations of the engineers who developed the automatic bagging and weighing equipment. With the manual system a man can package and warehouse 2,320 pounds of powder per hour. With the automatic equipment a man can package and warehouse 3,000 pounds of powder per hour.

Table 3.1. Estimated daily fixed labor requirements for the production crew for six milk drying plants in Minnesota, 1970.

	Plants					
	1	2	3	4	5	6
	(man-hours)					
Receiving	3.75	2.25	2.75	3.25	3.75	4.25
Powder packaging and warehousing	2.00	2.00	2.00	2.00	2.00	2.00
Refrigeration	.25	.25	.25	.25	.25	.25
Evaporator and dryer complex	8.00	8.00	8.00	8.00	8.00	8.00
General	3.00	3.00	3.00	3.00	3.00	3.00
Total	17.00	15.50	16.00	16.50	17.00	17.50

Table 3.2. Estimated daily variable labor requirements for the production crew for six drying plants in Minnesota, 1970.

	Plants					
	1	2	3	4	5	6
	(Man-hours per 1000 lbs. whole milk equivalents)					
Operator labor	.0798	.0399	.0266	.0200	.0133	.0100
Packaging labor[1/]	.0344	.0344	.0266	.0266	.0266	.0266
Total	.1142	.0743	.0532	.0466	.0399	.0366

1/ Plants 1 and 2 manually packaged powder into 50 pound type G bags. The larger plants were assumed to have an automatic bagger for 50 pound type G bags. In both cases it was assumed that the plants were equipped with powder hoppers so that the packaging rate could be independent of the drying rate.

The analysis showed the first two plants could not justify the expense of an automatic bagger but the other four plants were equipped with them.

The daily fixed and variable production labor requirement were converted into annual production labor requirements by the method described previously. The estimated production cost functions in man-hours and in dollars for the six plants is shown in table 3.3. The distinguishing feature of these functions is the steady increase in the intercept value and steady decrease in the variable coefficient as plant size rises.

Table 3.4 contains a summary of the non-production plant personnel discussed earlier in the text. These costs were combined with the production labor cost functions of table 3.3 to form the overall plant labor cost functions. These functions are shown in table 3.5.

Figure 3.2 shows the labor cost functions plotted as average labor cost curves. The cost functions are easier to compare in this form. The average labor cost drops rapidly in the low volume ranges, especially for the volume ranges of the two smallest plants. The average labor cost to process 50 million pounds of milk is $1.65 per 1,000 pounds of wholemilk and at 233 million pounds it drops to $.59 per 1,000 pounds, a difference of $1.06. At 623 million pounds average cost is about $.35 per 1,000 pounds, a difference of $.24 compared to $.59 per 1,000 pounds at a volume of 233 million pounds.

Table 3.3. Estimated production labor cost functions in man-hour equivalents and dollars for six milk drying plants in Minnesota, 1970.

Plant	Maximum annual volume (mil. lbs.)	Cost function in man-hour equivalents	Average wage rate (dollars)	Cost function in dollars
1	78	6917 + .1142 V	3.36	23,241 + .3837 V[1/]
2	156	7169 + .0743 V	3.36	24,081 + .2496 V
3	233	7259 + .0532 V	3.34	24,245 + .1777 V
4	311	7728 + .0466 V	3.33	25,734 + .1552 V
5	467	8030 + .0399 V	3.32	26,660 + .1325 V
6	623	8468 + .0366 V	3.30	27,944 + .1208 V

1/ V is volume in 1,000 pound wholemilk equivalents

Table 3.4 Estimated annual cost of non-production plant personnel for six milk drying plants in Minnesota, 1970.

Category	1	2	3	4	5	6
			Plants (dollars)			
General manager	13,000	14,000	15,000	16,000	17,000	18,000
Office workers	5,200	10,400	10,400	10,400	15,600	15,600
Plant superintendent	10,000	10,000	10,000	10,000	10,000	10,000
Receiving - Shipping		6,760	6,760	13,520	13,520	20,280
Chief engineer				9,000	9,000	9,000
Maintenance man				9,000	9,000	9,000
USDA Grader	12,000	12,000	12,000	12,000	12,000	24,000
Laboratory technician				5,200	5,200	5,200
Total	40,200	53,160	54,160	59,360	91,320	111,080

Table 3.5. Estimated labor cost functions of production and non-production personnel combined for six milk drying plants in Minnesota, 1970.

Plant	Maximum annual volume (mil. lbs.)	Labor cost function (dollars)
1	78	63,441 + .3837 V1/
2	156	77,241 + .2496 V
3	233	96,405 + .1777 V
4	311	110,854 + .1552 V
5	467	117,980 + .1325 V
6	623	139,024 + .1208 V

1/ V is volume in 1000 pounds whole milk equivalents.

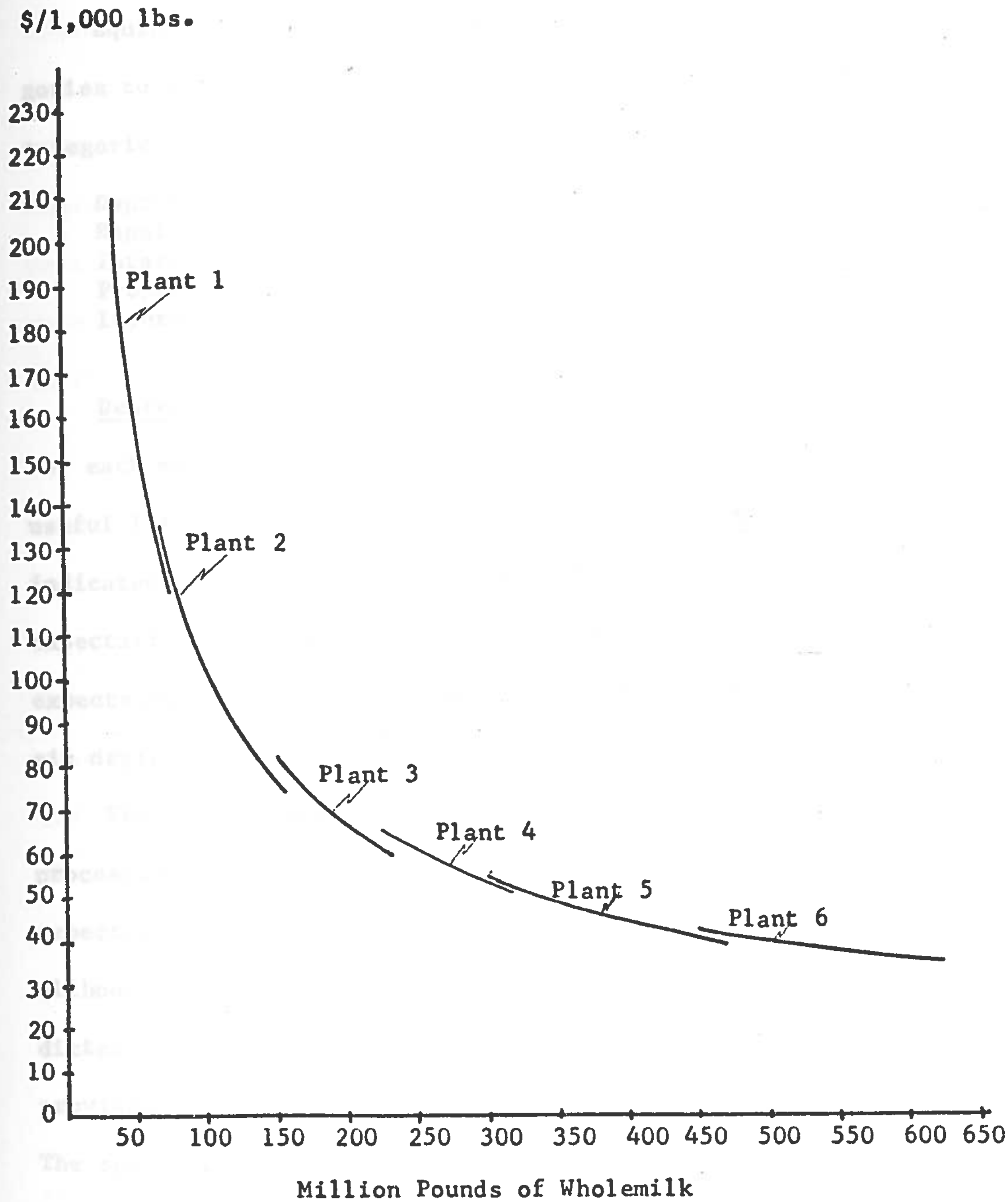

Figure 3.2. Estimated average labor cost for six specialized milk drying plants in Minnesota, 1970.

Equipment Building and Land Costs

Equipment and building costs were divided into five categories to aid in estimating annual costs for them. The five categories are:

Depreciation
Repair and maintenance
Interest on investment
Property taxes
Insurance

Depreciation. The annual depreciation charge was computed for each major piece of equipment. It was based on the estimated useful life suggested by the equipment sales personnel. They indicated their estimates of useful life were strongly weighted by expectations of obsolescence. The estimated installed cost, life expectancy and annual depreciation charge for the equipment in the six drying plants are shown in appendix table A.1.

The annual building depreciation charge was computed for each processing stage. The annual depreciation charge was based on an expected useful life of 20 years. Plant managers indicated that although the structures would last longer than this, obsolescence dictates a shorter useful life expectancy. An architectural firm provided construction costs for the various building requirements. The space requirements were based on space uses in the plants visited in the course of the study and/or physical requirements set down by the equipment manufacturers. The building space requirements by stages, unit construction cost, total construction cost and annual depreciation charge for the six drying plants are shown in appendix tables A.2 through A.7.

Repair and Maintenance. Because of strict sanitary regulations and strict mechanical performance requirements, equipment and buildings must be kept in excellent condition. Parts that tend to wear must be replaced periodically to insure top performance and to minimize possible costly shut downs. A rate of 1.5 percent of new equipment and building costs was used as an estimate of the annual cost of repair and maintenance. Rates similar to this have been used by other dairy researchers.[1/]

Interest on Investment. The opportunity cost of capital invested in equipment and buildings was based on a seven percent interest rate applied to the mid-life value. Historically dairy plants in the state have been able to borrow money for equipment and buildings at a rate between 5.5 and 6.0 percent. Currently, a period of inflation, interest rates have risen to eight percent and higher. An expert on agricultural finance in the Department of Agricultural Economics, University of Minnesota, indicated these high rates were probably transitory and that a rate of seven percent would be more appropriate given the time horizon of this study.

Property Taxes. The Minnesota Department of Taxation was consulted for property tax rates. The state average mill rate of

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[1/]Kerchner, op. cit., p. 76 used a rate of 1.5 percent. Homme and Simmons used a rate of 2.0 percent, Homme, Henry A. and Richard L. Simmons, Planning Agricultural Processing for the South: Butter and Milk Powder Manufacturing Costs, Agricultural Policy Institute, North Carolina State University, Raleigh, North Carolina, July 1965, p. 11.

299 was used as the appropriate tax rate. This was adjusted by multiplied by .33 to take account of "true value" and again by .33 to account for "assessed value."[1/] This value was then multiplied by .5 to reflect the mean value of equipment and buildings as mid-life value. This resulted in a rate of 1.6 percent to be applied to new value of equipment and buildings as the estimate of annual property tax cost.

Insurance. The annual insurance cost was based on coverage for fire and extended coverage for such items as wind, hail, and vandalism. A rate of 36 cents per $100 of equipment and building was used. This was provided by a local agent who insures a number of dairy plants. This rate was applied to 80 percent of new value. This resulted in a rate of 0.3 percent to be applied to new value of equipment and buildings as the estimate of annual insurance cost.

Land Cost. The annual cost of the land at the plant site was assumed to be the opportunity cost of the capital invested in land. Land site requirements were assumed to be five times the building area.[2/] The land was given a nominal value of $.20 per square foot. An interest rate of seven percent was used. The

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[1/]Tax assessors start with "market value" of property and then adjust its value by these factors "true value" and then assessed value. The mill rate is applied to the assessed value. For a discussion of "true value" and "assessed value" see Minnesota Statutes 1967, Vol. I, Chapter 273, Section 293.11 and 273.13.

[2/]This is a rule of thumb used by the architectural firm that provided other data in this study.

land site area, the investment cost and the annual interest charge for the six plants is shown in appendix table A.8.

Summary. The percentage rates for repair and maintenance, interest on investment, property taxes and insurance were applied to the new equipment and building values found in Appendix A tables 1 through 7. The resulting values were added to the annual depreciation charges to get the total annual cost of equipment and buildings for each of the six plants. These costs are summarized in table 3.6. The annual land cost, from appendix table 8, is also included in table 3.6.

The annual cost of equipment, buildings and land ranges from $79,026 for Plant 1, the smallest plant to $270,699 for Plant 6, the largest plant. The largest plant has eight times the capacity of the smallest plant but its annual equipment, building land cost is only 3.5 times that of the smaller plant.

Fuel Costs

Fuel is an important cost item in a drying plant. It is needed for firing the furnaces of the dryer and the boiler. The boiler provides steam for heating milk in the separator-pasteurizer process, heating skim milk in the evaporators, heating water for clean-up and heating the building.

Natural gas was selected as the fuel source. It is available in most communities in the state and generally provides the most economical source of energy. Dairy plants usually subscribe to interruptable service. This service comes at a special reduced

Table 3.6. Estimated annual equipment, building and land costs by stages for six milk drying plants in Minnesota, 1970.

Center	Plant 1	2	3	4	5	6
	(dollars)					
Receiving	4,486	4,364	11,516	15,054	20,845	28,365
Separator - pasteurizer	4,969	8,344	14,296	14,363	21,851	27,040
Evaporator - dryer	38,564	47,386	60,297	74,324	104,068	135,874
Powder packaging and warehouse	5,555	5,555	8,453	8,451	8,453	8,453
Laboratory	1,221	1,221	1,221	1,221	1,221	1,221
Refrigeration	592	592	592	638	744	1,103
Boiler	5,290	7,732	8,275	8,818	10,173	11,802
General service	794	879	1,048	1,132	1,301	1,385
Office	2,028	2,028	2,366	2,704	3,042	3,380
EQUIPMENT TOTAL	63,499	78,101	108,064	126,705	171,698	218,623
Building	14,924	18,953	25,419	29,978	40,155	49,706
Land	603	833	1,119	1,341	1,878	2,370
Total annual cost of equipment buildings and land	79,026	97,887	134,602	158,024	213,731	270,699

rate but it means the supplier can cut off service in periods of heavy community use. This means the plant must have a standby source of fuel, usually bottle gas or fuel oil. Most drying plants maintain a standby boiler as an insurance factor so the conversion in fuels may be a simple process.

A gas rate of $.37 per 1,000 cubic feet of gas was used as an estimate of the cost of interruptable service. Kerchner found this to be an appropriate rate in his study.[1/] Several gas suppliers in the state were contacted and they indicated the rate structure has not changed since his study was made.

Gas requirements were divided into fixed and variable requirements. The dryer, evaporator-pasteurizer complex, and truck washing in the receiving stage were classified as variable gas users. The fixed uses included heating the equipment to operating temperature, heating the building and heating cleaning water.

Variable Gas Costs. The variable gas use coefficients were obtained from several sources. The coefficients for the six plants are summarized in table 3.7.

The receiving and separating-pasteurizing stage gas requirements were obtained from Kerchner's dairy plant study.[2/] His requirements are based on engineering data, for translating the heat energy needed to provide hot water for cleaning the bulk trucks and to heat the wholemilk for separating and the cream for

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1/ Kerchner, op. cit., p. 64.

2/ Ibid., pp. 64, 65 and 80.

Table 3.7. Estimated variable natural gas requirements for six milk drying plants in Minnesota, 1970

Equipment use complex	Plants 1 and 2	Plants 3 and 4	Plants 5 and 6
	(cu. ft. per 1,000 lbs. W. M. E.)		
Receiving - Separating			
Pasteurizing[1/]	25.54	25.54	25.54
Evaporating[2/]	387.00	296.96	276.89
Dryer[3/]	259.45	259.45	259.45
TOTAL	671.99	581.95	561.88

1/ Based on Kerchner, op. cit., pp. 64, 65 and 80.

2/ Based on engineering data in Mojonnier Bros. Co. Bulletin No. 488-13.

3/ Based on Hanlon, op. cit., p. 67.

pasteurizing into gas requirements for the boiler. He assumed 75 percent regeneration in the separator-pasteurizer complex.

The evaporator's gas requirements were developed from the manufacturer's stated BTU requirements.[1/] This equipment supplier also provided information on the number of "effects" to use with the evaporators in the different plants.

An evaporator's thermal efficiency is dependent on the number of "effects" that it has. An "effect" can be thought of as the exposure of the skim milk to a nest of heat exchanger tubes for the purpose of evaporating moisture in the skim milk. In a single "effect" evaporator the heat exchanger tubes transfer thermal energy from the steam to the skim milk. The thermal energy causes some of the moisture in the skim milk to evaporate. In a double "effect" evaporator the second "effect" transfers some of the thermal energy in the evaporate (the evaporated moisture from the skim milk) of the first "effect" to the skim milk. In a double "effect" evaporator the second effect first removes some of the moisture with evaporate from the first effect and then in the first "effect" steam removes more moisture. Thus the more effects that an evaporator has the most efficient it is in using gas energy to concentrate skim milk.

The more "effects" that an evaporator has the more expensive it is to purchase. The engineers of one of the major suppliers of evaporators recommended double "effect" evaporators for Plants 1

[1/] Mojonnier Bros. Co., Bulletin No. 488-13.

and 2, triple "effect" evaporators for Plants 3 and 4 and quadruple "effect" evaporators for Plants 5 and 6. They also recommended that the evaporators be equipped with thermo-compressor units. These act as steam regenerators and have about the same effect on thermal efficiency as an added "effect."

The dryer's gas requirements were obtained from Hanlon's study of butter-powder plants.[1/] His data was based on actual gas meter readings of dryers operating under plant conditions. Dairy engineers indicated there were no thermal efficiency differences between the dryer's sizes used in the six plants. The coefficient from Hanlon's study was applied to all six dryers.

Fixed Gas Costs. The fixed gas requirements were more difficult to estimate than the variable coefficients. Dairy engineers have not concerned themselves very much with establishing coefficients for wash water use, equipment heat loss and its effect on building heating requirements and other similar considerations. In the absence of good engineering data, the fixed gas requirements were based on empirical evidence obtained by Hanlon.[2/] He estimated a gas use function for a butter-powder plant with a volume similar to Plant 2 of this study. The least squares estimate, based on actual gas meter observations was:

$$G_T^M = 1186 + .718205\ V_W^M$$

[1/] Hanlon, op. cit., p. 67.

[2/] Ibid., pp. 65-68.

where:

G_T^M, is estimate of total natural gas used monthly, in cubic feet

V_W^M, is volume of wholemilk processed monthly, 1,000 pounds unit

The intercept value, 1186, was interpreted as an estimate of the gas used for the fixed requirements. The fixed gas requirements for the other five plants were estimated by using this relationship for Plant 2 and adjusting it according to the building space of the other plants. The annual fixed gas requirements for the six plants are summarized in table 3.8.

Summary of Gas Costs. The fixed and variable gas requirements were converted into dollar costs by multiplying the values by $.37. The gas cost function for the six plants are summarized in table 3.9.

The economies to scale are not as great for fuel use as they were for labor and equipment, buildings and land. Plant 1's gas cost at 78 million pounds of wholemilk is about $.30 per 1,000 pounds. This cost drops only 6 cents per 1,000 pounds for Plant 4 at a volume of 311 million pounds of wholemilk. Plant 6, the largest plant, has a fuel cost of about $.22 per 1,000 pounds at a volume of 623 million pounds of wholemilk. This is $.08 per 1,000 pounds less than Plant 1, the smallest plant.

Electricity Costs

Milk drying plants rely heavily on electrical energy for the

Table 3.8. Estimated fixed natural gas requirements for six milk drying plants in Minnesota, 1970.

Plant	Maximum whole milk volume (million lbs.)	Annual fixed gas requirements (cubic ft.)
1	78	10,116
2	156	10,680
3	233	13,404
4	311	14,652
5	467	18,168
6	623	20,784

Table 3.9. Estimated gas cost functions for six milk drying plants in Minnesota, 1970.

Plant	Maximum whole milk volume (million lbs.)	Gas cost functions (dollars)	Total gas cost at maximum volume (dollars)
1	78	3743 + .2486 V[1/]	23,084
2	156	3952 + .2486 V	42,773
3	233	4959 + .2153 V	55,210
4	311	5421 + .2153 V	72,444
5	467	6722 + .2079 V	103,770
6	623	7690 + .2079 V	137,108

[1/] V is 1,000 pounds wholemilk.

numerous motors on almost every major piece of equipment and to provide light. Electrical costs were divided into three categories for estimation purposes, a demand charge cost, a fixed energy cost and a variable energy cost.

The demand charge is a monthly charge made by the electrical supplier based on the maximum kilowatt-amperes used during the month. The fixed energy cost includes the electrical energy used for plant operations that do not vary with volume processed. It includes clean-up, bringing equipment to operating temperature, laboratory use, office use, lighting, etc.

The variable energy cost includes electrical energy used by the equipment when processing and it varies directly with volume processed.

The unit cost of electricity was based on the rate schedule of a major electrical supplier in the state.[1/] The applicable rates are reproduced in tables 3.10 and 3.11. Table 3.10 shows the demand charge rates and table 3.11 shows the energy charge rates. The rates in both cases are dependent on the quantity of electrical service used per month.

Demand Charge Cost. The monthly demand charge is based on the greatest fifteen minute load during the month. This is adjusted by the average power factor for the month.[2/]

[1/] Northern States Power Company, Schedule GK025.

[2/] The power factor relates to electrical energy feedback into the suppliers lines. In this study it was assumed to be .85 based on Farrall, Arthur W., Engineering for Dairy and Food Products, John Wiley and Sons, New York, 1963, p. 41.

Table 3.10. Standard demand charge for secondary voltage service.

Kilovolt-amperes or less per month		
	First 100	$185 per month
	Next 100	$1.55 per k v a per month
	Excess	$1.27 per k v a per month

Source: Northern States Power, schedule GK025.

Table 3.11. Standard schedule of rates for electrical energy charge.

Kilowatt hours per month	Cost per kilowatt hour (cents)
First 20,000	1.55
Next 30,000	1.20
Next 50,000	1.05
Next 400,000	.94

Source: Northern States Power, schedule GK25.

The connected horse-power was used as the determining factor for estimating the demand charge.[1/] The number and horse-power of the electrical motors in the six plants were estimated from the equipment tests in appendix table A.1. It was assumed that one horse-power was equivalent to one kilowatt. This is based on the engineers rule of thumb that one horse-power-hour is equal to one kilowatt-hour under operating conditions. This conversion factor takes into account energy losses in feeder lines and operating inefficiencies.

The total kilowatts, based on connected horse-power, was converted to kilowatt amperes by multiplying kilowatts by 1.18, to account for the power factor of .85. This kilowatt-ampere value was used as an estimate of the greatest 15 minute load for a month. It was assumed to be the same for all twelve months. The appropriate rate from table 3.10 was applied to the kilowatt-ampere for each of the six plants. This monthly charge was converted to an annual charge by multiplying by twelve. The annual demand charge cost for the six plants is summarized in table 3.14. The annual demand charge costs range from $3,708 for Plant 1, the smallest plant to $11,868 for Plant 6, the largest plant.

Fixed Energy Cost. The fixed electrical energy costs were based on equipment motor operating time involved in clean-up and warm-up. They also include allowances for electrical energy used

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1/ This is the rule of thumb used by engineers. Kerchner used this method in estimating demand for a butter-powder plant, Kerchner, op. cit., p. 67.

in the office, laboratory, etc. The estimates of the fixed horse-power-hours for the six plants are shown in table 3.12. These horse-power-hours were converted to kilowatt-hours on the basis of one horse-power-hour is equivalent to one kilowatt-hour. The appropriate unit-cost was obtained from table 3.11 for each plant. The appropriate rate was based on an estimate of the total energy used in a month by each plant at near capacity volume. The energy unit-cost rate for Plants 1 through 6 were calculated to be $.0123, $.0117, $.0111, $.0108, $.0103 and $.0100, respectively. These rates were applied to the daily fixed energy requirements and multiplied by 365 to obtain the annual fixed electrical energy cost for the six plants. These costs are summarized in table 3.14.

Variable Energy Cost. The variable energy cost coefficients were based on horse-power-hours of motor use and the hourly capacity of the equipment containing the motors. The horse-power used per hour and the wholemilk equivalents processed during an hour were estimated by stages. The horse-power-hours were converted to kilowatt hours (on a 1 for 1 basis) and this divided by the hourly volume processed. These coefficients by stages and plants are summarized in table 3.13. The sum of the coefficients by stages for each plant were converted to costs by applying the appropriate unit-cost rates developed in the fixed energy cost section above. These variable electrical energy cost coefficients are also summarized in table 3.14.

There are economies to scale in all three electrical cost divisions. The annual electrical demand ranges from $3,708 for

Table 3.12 Estimated daily fixed horsepower-hours for six drying plants in Minnesota, 1970.

	-------- Plants ---------					
	1	2	3	4 (H.P.-Hrs.)	5	6
Receiving	3.00	3.00	4.00	4.00	6.00	8.00
Separator, pasteurizer	5.25	46.25	58.75	58.75	105.63	111.88
Evaporator, dryer	27.30	31.05	54.45	66.15	100.50	131.13
Powder packaging	19.50	23.00	28.75	33.50	42.75	52.00
Warehousing	9.00	9.00	9.00	9.00	9.00	9.00
Refrigeration	18.00	18.00	18.00	18.00	18.00	18.00
Boiler	30.00	32.00	38.00	40.00	48.00	54.00
Laboratory	3.00	3.00	3.00	3.00	3.00	3.00
Office	9.00	9.00	9.00	9.00	9.00	9.00
Total	124.05	171.33	222.95	241.40	341.88	396.01

Table 3.13 Estimated variable electric requirements for six milk drying plants in Minnesota, 1970.

Equipment Center	Plants 1	2	3	4	5	6
	(KWH's/1000 lbs. whole milk)					
Receiving	.2000	.2000	.2000	.2000	.2000	.2000
Refrigeration	.0061	.0061	.0061	.0061	.0061	.0061
Separator	1.7598	1.4665	1.2590	.9428	1.1523	1.0475
Boiler	1.0810	1.0810	1.0810	1.0810	1.0810	1.0810
Evaporator	1.5252	.8670	1.0140	.9239	1.1229	1.0988
Dryer	6.5365	3.8549	3.2123	2.8073	2.3883	2.1788
Warehousing	.2830	.2830	.3363	.3363	.3363	.3363
Total	11.3916	7.7585	7.1067	6.2974	6.2869	5.9485

Table 3.14. Estimated annual electric cost functions for six milk drying plants in Minnesota, 1970.

Plant	Maximum volume wholemilk	Annual cost of demand charge	Annual cost of fixed energy charge	Variable cost for energy per 1,000 lbs. W.M.E.
	(million lbs.)		(dollars)	
1	78	3,708	557	0.1139
2	156	4,080	730	0.0776
3	233	5,820	903	0.0711
4	311	6,888	950	0.0680
5	467	8,424	1286	0.0648
6	623	11,868	1445	0.0595

the smallest plant to $11,868 for the largest plant. The largest plant is eight times larger than the smallest but the cost is only three times as great. The same situation holds for the annual fixed energy cost. The largest plant's cost of $1,445 is not three times the smallest plant's cost of $557. Again the same situation holds for the variable energy cost coefficients. The largest plant's cost coefficient of $.0595 per 1,000 pounds of wholemilk is almost half the smallest plant's cost coefficient of $.1139 per 1,000 pounds of wholemilk.

Water and Sewage Costs

Water is used in a drying plant for cleaning and cooling products coming off the pasteurizer and cooling the evaporators.[1/]

A rate of 11 cents per 1,000 gallons of water was used for the unit cost of water and sewage. This is based on the assumption that the plants purchase water from a municipal source at 7 cents per 100 cubic feet and that the water is disposed of through the municipal sewage system at 1 cent per 100 cubic feet.

Water and sewage costs were divided into fixed and variable costs for estimation purposes.

Fixed Water and Sewage Costs. Plant cleaning is the main source of fixed water and sewage costs. No engineering

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[1/] In areas where water is not readily available in large quantities at economical prices, the evaporator cooling water may be reused by installing evaporative cooling towers to recool the water. Engineers indicated that at the water cost rate used in this study there is little difference in the cost of cooling with all main water or tower water.

specifications could be found for plant cleaning water requirements. Kerchner estimated fixed water costs for a butter-powder plant with the help of a plant manager.[1/] His estimates were used making adjustments in the quantity requirements for the different size plants. These costs are summarized in table 3.15.

Variable Water and Sewage Costs. The main source of variable water costs are truck washing, cooling cream and cooling the evaporators. The variable water requirements for receiving and cream cooling were estimated to be the same for all six plants. It was assumed that 14 gallons of water was needed for cleaning bulk truck tanks for each 1,000 pounds of wholemilk received. It was also assumed that cream is partially cooled with main water. It was estimated to take about 30 gallons of water per 1,000 pounds of wholemilk equivalent of cream.[2/] The evaporator water requirements depend on the size of the evaporator and the number of "effects" it has. The variable water use coefficients for the different size dryers were based on the manufacturer's engineering specifications.[3/]

The physical water use requirements were converted to costs by multiplying through 11 cents per 1,000 gallons of water. These water and sewage costs for the six plants are summarized in

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[1/] Kerchner, op. cit., p. 72.

[2/] Cream was cooled from 140° to 55° with water. It takes about 3 gallons of water per gallon of cream. Farrall, op. cit., p. 289.

[3/] Mojonnier Bros. Co., Bulletin No. 488-13.

Table 3.15. Estimated annual fixed cost and variable cost coefficient for water and sewage for six milk drying plants in Minnesota, 1970.

Plant	Fixed annual water cost (dollars)	Variable water cost per 1000 lbs. W.M.E. receiving	separating	evaporating	total
		(dollars per 1000 W. M. E.)			
1	416	.0020	.0033	.0315	.0368
2	456	.0020	.0033	.0310	.0363
3	496	.0020	.0033	.0205	.0258
4	537	.0020	.0033	.0204	.0257
5	577	.0020	.0033	.0243	.0296
6	617	.0020	.0033	.0242	.0295

table 3.15. The fixed annual water and sewage costs range from $416 for the smallest plant to $617 for the largest plant. The amount of water needed to clean a large drying plant is not much greater than that needed for a small plant and these costs reflect that. The variable cost coefficients range from $.0368 for the smallest plant to $.0295 for the largest. This is due to the greater number of effects in the evaporator of the larger plant.

There are economies to scale for water and sewage costs but they are of a minor nature compared to labor and equipment costs.

General Plant Supply Costs

General plant supplies include such items as soap, sanitizing agents, brushes, lubricants, uniforms, laundry service and a host of other miscellaneous items. It was estimated with the help of several plant managers and accounting data from their plants. First, accounting data from a number of plants was evaluated for cost volume relationships of their drying department. From these several were selected which were known to be well managed and did not have specialty dry milk powder products as a sideline. From these plants' costs the annual general supply costs of the six drying plants were estimated. These costs are summarized in table 3.16.

These estimated annual general plant supply costs demonstrate economies to scale. The costs range from $18,400 for the smallest plant to $23,000 for the largest. The major contributing cost items to general supply costs are soap and sanitizing agents. Just as cleaning water requirements go up little for larger plants

Table 3.16. Estimated annual cost of general plant supplies for six milk drying plants in Minnesota, 1970.

Plant	Maximum volume (million lbs.)	Annual general plant supply costs (dollars)
1	78	18,400
2	156	19,000
3	233	19,700
4	311	20,600
5	467	21,700
6	623	23,000

so it is with soap and sanitizing agent requirements.

Packaging Supply Costs

It was assumed that the dry milk powder was packaged in 50 pound type "G" bags. These meet the federal government's purchase specifications. The federal government is the largest buyer of milk powder.

Type "G" bags cost $241.20 per 1,000. Assuming 83.8 pounds of milk powder per 1,000 pounds of wholemilk, the cost of packaging is $.4043 per 1,000 pounds of wholemilk. This cost is applicable to all six plants. There are no economies to scale in packaging supplies.

General Administrative Costs

General administrative expenses include such items as office supplies, telephone service, meeting expenses, audit, legal fees, etc. There does not seem to be any clear-cut relationship between volume processed and these costs. A study of a number of audit records of butter-powder plants indicated that larger volume plants have higher costs than small plants. However, the major expense seems to be fixed for all plant sizes and relatively small increases for larger volume plants.

The general administrative costs were estimated by taking the audit statement of four butter-powder plants with good cost records adjusting for local conditions and extrapolating to fit the plant sizes of this study.[1/] These results were then divided

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[1/]The basic records were also used by Hanlon, op. cit., p. 112. Insurance was excluded because it was included in equipment, building and land costs and audit and unclassified was adjusted to make them more consistent with general expectations.

into butter department costs and drying plant costs. It was estimated that 80 percent of the costs were associated with drying and receiving and 20 percent associated with the butter department. The annual general administrative costs for the six drying plants are summarized in table 3.17. The annual general administrative costs vary from $8,400 for the smallest plant to $16,400 for the largest plant. The largest plant has eight times the volume of the smallest plant but only about twice the general administrative cost.

Patron Accounts and Field Service Costs

The patron account and field service costs include the costs of a field man to handle patron relations and patron quality control, commercial laboratory fees for patron quality control and secretarial and booking help for keeping patron accounts.

Plant managers were consulted about the number of patrons a field man could service. There was general agreement that a field man could service 250 to 300 manufacturing grade patrons. This was translated into a cost per volume relationship by assuming that a field man was needed for 78 million pounds of milk. It was further assumed that if a full-time field man was not needed, part-time help was available for this position. At an annual salary of $8,000 gross the cost for field man service was calculated to be $.1028 per 1,000 pounds of milk.

Most dairies have their patron milk quality work done by commercial laboratories. This basically involves simple bacteria plate counts. A commercial laboratory indicated the annual cost

Table 3.17. Estimated general administrative expenses for six milk drying plants in Minnesota, 1970.

Plant	Maximum milk capacity (million lbs.)	Annual general administration expenses (dollars)
1	78	8,400
2	156	9,400
3	233	10,400
4	311	11,800
5	467	14,000
6	623	16,400

of this was about $.1080 per sample. Using the same patron to volume relation used above, this amounted to $.0361 per 1,000 pounds of milk.

There is a considerable amount of book work required in keeping patron accounts. Records must be kept of each day's receipts for each patron and summarized bi-weekly or monthly. In addition annual records must be kept for patronage refunds and other patron details. It was assumed one person was needed for each 78 million pounds of milk (250 to 300 patrons) at an annual salary of $5,200 gross, this amounted to $.0668 per 1,000 pounds of wholemilk.

The sum of the field service and patron accounts cost amounts to $.2009 per 1,000 pounds of wholemilk. There are no economies to scale for patron accounts or field service costs.

Summary of Milk Drying Plant Costs

The nine cost categories just described and estimated for the six milk drying plants are summarized in table 3.18. The categories are labor costs, equipment, building and land costs, fuel costs, electrical costs, water and sewage costs, general administrative costs and patron accounts and field service costs. The annual fixed costs and the variable cost coefficients for each cost category are summarized for the six milk drying plants.

The short run cost functions (total annual average cost) were derived from the sum of the fixed annual costs and the sum of the variable cost coefficients for each plant are listed in table 3.18. The average costs for the six plants for selected volumes are shown in table 3.19. The average cost functions for the six plants are

Table 3.18. Estimated fixed and variable costs by major factor cost categories for six milk drying plants in Minnesota, 1970.

Cost Categories	Plant 1 Fixed cost	Plant 1 Variable cost per 1,000 lbs. W.M.E.	Plant 2 Fixed cost	Plant 2 Variable cost per 1,000 lbs. W.M.E.	Plant 3 Fixed cost	Plant 3 Variable cost per 1,000 lbs. W.M.E.	Plant 4 Fixed cost	Plant 4 Variable cost per 1,000 lbs. W.M.E.	Plant 5 Fixed cost	Plant 5 Variable cost per 1,000 lbs. W.M.E.	Plant 6 Fixed cost	Plant 6 Variable cost per 1,000 lbs. W.M.E.
	(dollars)											
Labor	63,441	.3837	77,241	.2496	96,405	.1777	110,854	.1552	117,980	.1325	139,024	.1208
Building and equipment	79,026		97,887		134,602		158,024		213,731		270,699	
Fuel	3,743	.2486	3,952	.2486	4,959	.2153	5,421	.2153	6,722	.2079	7,690	.2079
Electricity	4,265	.1139	4,810	.0776	6,723	.0711	7,838	.0680	9,710	.0648	12,313	.0595
Water	416	.0368	456	.0363	496	.0258	537	.0257	577	.0296	617	.0295
General plant supplies	18,400		19,000		19,700		20,600		21,700		23,000	
Packaging supplies		.4043		.4043		.4043		.4043		.4043		.4043
General administrative	8,400		9,400		10,400		11,800		14,000		16,400	
Patron account & field serv.		.2009		.2009		.2009		.2009		.2009		.2009
Total	177,691	1.3882	212,746	1.2173	273,285	1.0951	315,074	1.0694	384,420	1.0400	469,743	1.0229

Table 3.19. Estimated short run average costs for selected volume of wholemilk for six milk drying plants manufacturing nonfat dry milk and cream in Minnesota, 1970.

Wholemilk Volume (mil. lbs.)	Average Cost (dollars/1,000 lbs.) Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
40	5.831					
50	4.942					
60	4.350					
70	3.927	4.257				
78	3.666	3.952				
95		3.457				
110		3.151				
125		2.919				
140		2.737	3.047			
156		2.581	2.851			
170			2.703			
190			2.533			
210			2.397	2.570		
233			2.268	2.419		
250				2.330		
270				2.236		
290				2.156	2.366	
311				2.082	2.275	
330					2.205	
350					2.138	
370					2.079	
390					2.026	
410					1.978	
430					1.934	
450					1.894	2.067
467					1.863	2.029
490						1.982
510						1.944
530						1.909
550						1.877
570						1.847
590						1.819
610						1.793
623						1.777

also plotted in figure 3.3.

Figure 3.3 also shows the long run average cost curve for the volume range of the six plants. The long run cost function was estimated to be:

$$LRAC^{P} = 1.522 + 167.458V^{-1}$$

where:

$LRAC^{P}$, is the long run average cost for milk drying plants per 1,000 pounds of wholemilk processed

V, is volume of wholemilk processed in 1,000 pounds

The estimated long run average cost function for milk drying plants demonstrates economies to scale throughout the volume range estimated. At a volume of 78 million pounds of wholemilk the average cost of processing wholemilk into nonfat dry milk and cream is $3.67 per 1,000 pounds. This average cost drops to $1.78 per 1,000 pounds at 623 million pounds, the maximum volume estimated. The economies to scale are greatest in the lower volume ranges. The average cost drops $1.59 per 1,000 pounds in going from 78 million pounds of milk annually at an average cost of $3.67 per 1,000 pounds to 311 million pounds with an average cost of $2.08 per 1,000 pounds. As plant volume is increased from 78 million pounds to 623 million pounds average cost declines $1.78 per 1,000 pounds. About 90 percent of this savings in average cost is achieved when volume reaches 311 million pounds a year.

In addition to the economies of scale exhibited by the six plants in figure 3.3, the slope of the six short run average cost curves also provides some interesting insights. The larger the

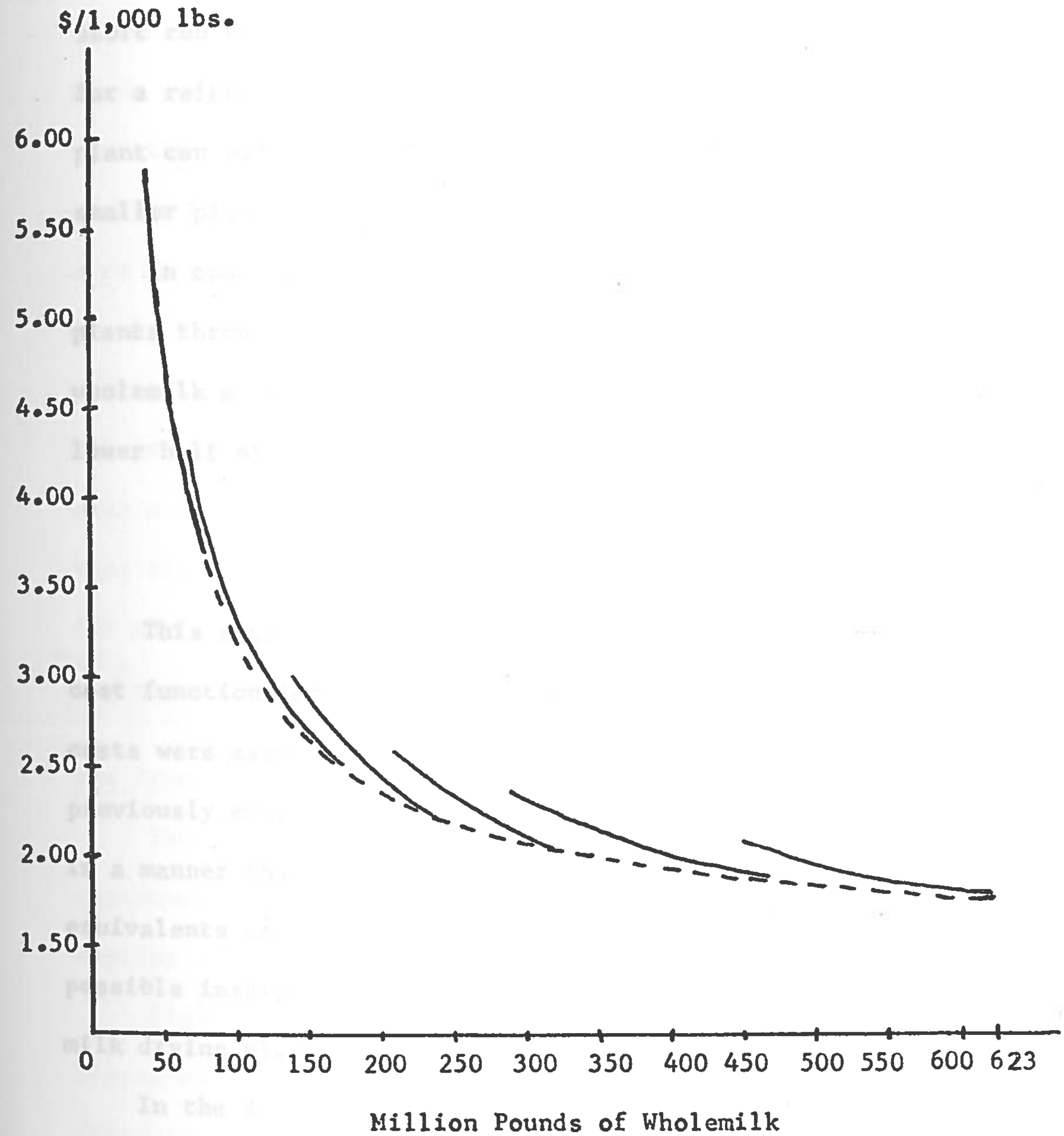

Figure 3.3. Short run and long run average costs, six milk drying plants in Minnesota, 1970.

plant's capacity the less steep the slope of the short run average cost curve.[1/] This implies that a reduction in volume in the short run results in a smaller rise in average processing cost for a relatively larger plant than a smaller plant. A larger plant can adjust to a given shift in milk production better than a smaller plant.

In conclusion, there are economies to scale for milk drying plants throughout the volume range 78 to 623 million pounds of wholemilk a year. The major economies are demonstrated in the lower half of the volume range.

Butter Departments

This section presents the development of the long run average cost function for butter departments. The butter departments costs were assumed to be additions to the milk drying plant costs previously estimated. The butter department costs were estimated in a manner that did not restrict them to the same milk volume equivalents as the milk drying plants. This allows for the possible inshipments of cream to the butter department from other milk drying plants without a butter department.

In the development of the long run cost function for the milk drying plants, six different sets of major equipment complexes were used to define scale of plant. In butter processing over the same range of volumes one churn and printer size was used. There

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[1/] Absolute value of slope.

is only one size of high speed soft butter printer manufactured for large volume operations. There are different size batch butter churns but the continuous churn is manufactured in only one basic size. A recent study by Nolte and Koller indicated there is very little difference in the operating cost of batch churn and continuous churn in the volume range of this study.[1/] The difference in scale for the six departments is little more than the size of the butter cooler and the amount of cream storage. These two storage items were estimated at a constant unit cost over the volume range so that there are no economies to scale. There is also a little difference in administrative costs for the difference size departments but this is minor. The economies to scale for the butter departments is more nearly an economies to size in the use of the churn-printer complex.

The Processes of the Butter Department

There are three logical operating stages envolved in a butter department. They are: (1) churning-printing stage, (2) butter cooling stage and (3) facilitating stage.

Figure 3.4 presents a schematic drawing of the two processing stages and the flow of products through the butter department. Cream is received into storage from the drying department in the same plant or from specialized drying plants. The cream is pumped from storage to the continuous churn. The buttermilk from the

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[1/] Nolte, G. M. and E. Fred Koller, "Continuous Churns Introduced Into Minnesota Creamery Industry," Minnesota Farm Business Notes, No. 509, Institute of Agriculture, University of Minnesota, August 1968.

1. Source--may be drying department in same plant or other plant (if other plant, receiving is handled by drying department of this plant).
2. Cream and buttermilk storage.
3. Churn.
4. Bulk butter packaging unit.
5. High speed soft butter printer (¼ pound prints).
6. High speed soft butter printer (1 pound prints).
7. Butter cooler.

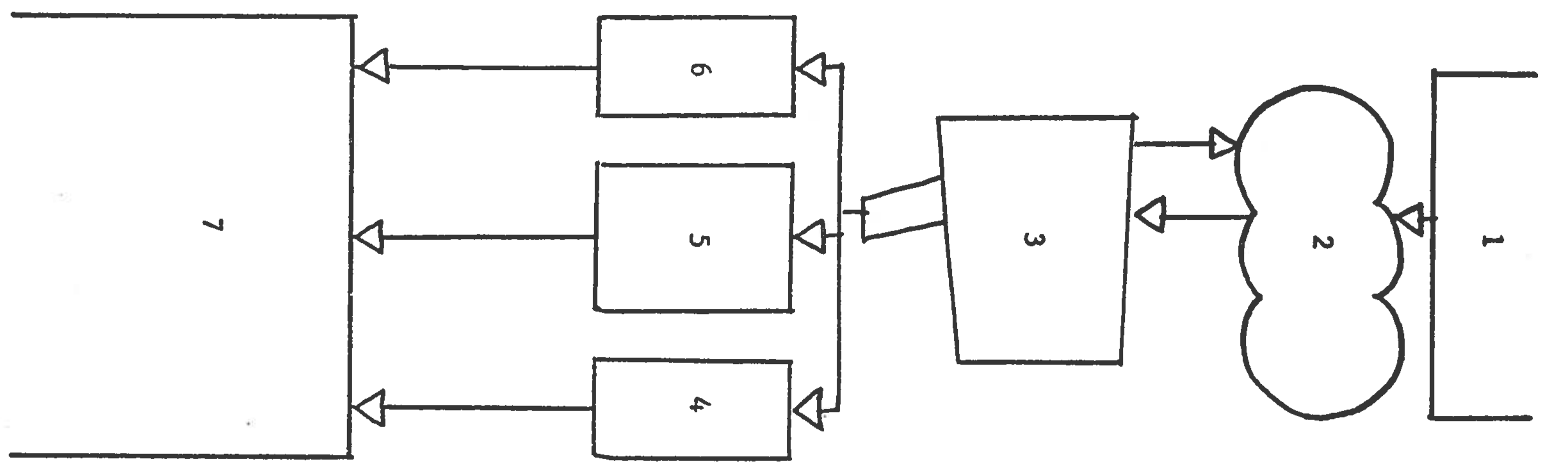

Figure 3.4. Schematic drawing of butter churning-printing operation.

churning operation is pumped back to storage to await movement back to the drying operation. The butter from the churning operation is deposited directly or pumped to one of three packaging units, a one-fourth pound print high speed soft printer, a one pound print soft printer or a 68 pound bulk packaging unit. The packaged butter is palletized and transported to the cooler to await shipment to consumers.

In this study it was assumed that all butter flowed through the one-fourth pound print high speed soft printer. Plants with high speed soft printers try to maximize the quantity marketed as one-fourth pound prints. This assumption does not restrict the analysis. The only change in costs from considering other packaging configurations is a slight decrease in labor costs for bulk packaging. This does not affect the analysis of type or size of plant unless different size departments are assumed to have different packaging configurations.

<u>Factor Cost Categories</u>

The cost functions for the butter departments were estimated by estimating the various factors of production by stages. Like the estimating procedure used in the milk drying plants, the factors were categorized to facilitate the estimation procedure. The factors categories are:

Labor
Equipment, buildings and land
Fuel
Electricity
Water and sewage
General plant supplies
General administration

Each of these factors was evaluated for a fixed annual cost component and a variable cost coefficient. The development of each of these factors is taken up in the following sub-sections.

Labor Costs

The labor cost data was developed in a similar manner to that used in the milk drying plants. Labor requirements were divided into supervisory and administrative labor and production labor. Supervisory and administrative labor was treated as fixed for each department. The estimates were based on the recommendation of plant managers. The estimates were made on the basis of the departments being additions to the drying plants previously estimated. This means, for example, that a general manager is not needed. The general managers of the drying plants were allocated an addition to their salary for the additional responsibility of managing the butter departments.

The processing labor requirements were treated as variable. The production requirements without considering seasonality or crew shift-problems, were first estimated based on time and motion data. These estimates were then adjusted to allow for seasonality and the numbers of crew shifts per day.

Production Labor Costs. The churning-printing process requires a crew of three, a churn operator, a printer operator and a worker boxing the one pound butter packages by hand or with a semi-automatic boxer. The rate of processing is limited by one of two things. If a semi-automatic boxer is used, the printer is the limiting factor at an effective rate of 4,000 pounds of butter produced per hour.[1/] If the butter is boxed by hand this operation becomes the limiting factor at an effective rate of 3,500 pounds per hour.

The particular method of boxing does not have significant effect on labor cost. Women are used in the hand boxing operation and their lower wage rate practically compensates for the lower production rate. At a gross wage rate of $3.50 per hour for males and $2.50 per hour for females and abstracting from seasonality and shift problems, the operating cost for churning-printing and hand boxing is 11.7 cents per 1,000 pounds of wholemilk equivalents, and for semi-automatic boxing it is 11.3 cents per 1,000 pounds of wholemilk equivalents. When seasonality and shift problems are considered there are some advantages to the use of women and hand boxing. In many rural communities women can be hired on a part-time or seasonal basis. This means that in the slack periods the women workers need not be guaranteed a 40-hour work week. On the other hand, plant managers indicate they must practice year around employment for male workers to insure a quality labor force. Male workers are usually kept on the payroll in the slack periods.

The use of women to box butter also may have an advantage in organizing shifts. It is easier to schedule crews when only two

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[1/] The butter printer is engineered to operate at a rate up to 4,500 pounds per hour but the records of plants surveyed indicated an effective rate of 4,000 pounds of butter per hour was consistent with plant operations. This rate allows for occasional stops for adjustments, etc.

workers on a three-man crew need to be guaranteed 40 hours of work per week, but the work week is more than five days.

In addition to the actual processing labor requirements, clean-up and set-up of the churn and printer was estimated to require two man hours per run.[1/]

Production labor costs for the butter department were estimated from these facts. The hourly requirements were converted into shifts and shifts into work weeks. Several different volumes in the range up to 623 million pounds of wholemilk equivalents were evaluated for crew size, extra overtime changes, and specifically average labor costs. From this analysis average production labor costs were estimated at 14 cents per 1,000 pounds of wholemilk equivalents. The shift analysis showed that at certain volumes the average labor cost deviated a penny per 1,000 pounds on one side or the other of the 14 cent average. This was not related to size of butter department but rather to efficient use of a particular crew size. It was not considered significant enough to go to a complex labor cost function which would include these minor variations.

Indirect Labor Costs. In addition to the direct processing labor costs, the additional costs of management, supervisory labor and miscellaneous help was estimated as fixed for each butter department.

1/The "run" concept was used instead of daily operation because the larger plants operate continuously for 70 hours or more before stopping for a clean-up.

Butter Department No. 1, the smallest department, was estimated to need a part-time office worker and an additional plant worker. It was assumed the plant worker released the plant superintendent of the milk drying plant from some of his work responsibilities to allow him to supervise the butter department. It was further estimated that the general manager of the associated drying plant would receive an additional $1,000 for the management responsibilities of a butter department. The annual indirect labor costs for Department 1 were estimated as follows:

Part-time office worker	$ 2,600
General plant worker	6,820
Addition to manager's salary	1,000
TOTAL	$10,420

Department 2 was estimated to need an office worker and a working butter foreman. The associated drying plant's general manager was allocated an addition to his salary of $1,500. The annual indirect labor costs for Department 2 were estimated as follows:

Office worker	$ 5,200
Working butter foreman	8,000
Addition to manager's salary	1,500
TOTAL	$14,700

Department 3 was estimated to need an office worker and a working butter foreman. The associated drying plant's manager was allocated an additional $2,000 to his salary. The annual indirect labor costs were estimated as follows:

Office worker	$ 5,200
Working butter foreman	8,600
Addition to manager's salary	2,000
TOTAL	$15,800

Department 4 was estimated to need an office worker plus a part-time helper. This department also needed a butter foreman and a general plant worker. It was assumed this worker would assist the U.S.D.A. resident grader. The associated drying plant's manager was allocated an additional $2,500 to his salary. The annual indirect labor costs for Department 4 were estimated as follows:

Office workers	$ 7,800
Butter foreman	9,000
General plant worker	6,820
Addition to manager's salary	2,500
TOTAL	$26,120

Department 5 was estimated to need two office workers, a butter foreman, a general plant worker and a part-time laboratory helper. The associated drying plant's general manager was allocated an additional $3,000 to his salary. The annual indirect labor costs for Department 5 were estimated as follows:

Office workers	$10,400
Butter foreman	9,500
General plant worker	6,820
Part-time laboratory helper	3,000
Addition to manager's salary	3,500
TOTAL	$33,220

Department 6, the largest department, was estimated to need two office workers, a butter foreman, a general plant worker and a laboratory helper. The associated drying plant's general manager was allocated an additional $4,500 to his salary. The annual labor costs for Department 6 were estimated as follows:

Office workers	$10,400
Butter foreman	10,000
General plant worker	6,820
Laboratory assistant	6,000
Addition to manager's salary	4,500
TOTAL	$37,720

<u>Summary of Labor Costs</u>. The estimated production labor cost of 14 cents per 1,000 pounds of wholemilk equivalents was applied to all six butter departments. There are no economies to scale in this estimate.

The indirect annual labor cost for the smallest butter department was estimated at $10,420. The indirect annual labor cost for the largest butter department was estimated at $37,720. The largest department is eight times larger than the smallest one but indirect labor costs are less than four times as great. There are some economies to scale for indirect labor costs.

Equipment, Building and Land Costs

Equipment, building and land costs for the butter departments were estimated in the same manner used for the drying plants. Depreciation was based on the recommendations of dairy equipment sales, engineers, annual repair and maintenance costs were calculated at the rate of 1.5 percent of purchase value, annual interest on investment costs were calculated at the rate of 7 percent of mid-life value (3.5 percent of purchase value), annual property tax costs were calculated at the rate of 1.6 percent of purchase value and annual insurance costs were calculated at the rate of 0.3 percent of purchase value.

The estimated installed cost, life expectancy and annual depreciation charge for the butter department equipment are shown in appendix table A.9. The estimated annual depreciation cost for the equipment in the butter department is $22,412.

The percentage rates for repair and maintenance, interest on investment, property taxes, and insurance were applied to the new equipment values found in appendix table A.9. The resulting values were added to the $22,412 depreciation charge to give an estimated annual equipment cost of $38,315.

The building and storage requirements varied for the six butter departments. The size requirements, purchase value and annual cost are shown in appendix table A.10.

Enough cream storage was provided for one day's receipts during the peak period. It was assumed earlier that the drying plant also provided one day's cream storage.

Enough butter storage was provided to store 14 days of production during the peak period. This allows the resident grader to complete all the quality tests on the butter before it has to be shipped. The butter cooler costs were based on a self contained free standing prefabricated model. It was assumed to be equipped with pallet racks to allow for floor to ceiling storage. It was also assumed that the cooler was capable of storing butter at zero degrees, a common practice with print butter. The unit-cost of the butter cooler was based on the recommendations of a major manufacture of coolers.

The building requirements for the churn-print room were based on the size of the best organized churn-print room visited during the course of the study. The building requirements for the office and personnel services area were based on estimated additional needs to the existing facilities in the associated drying plant. The same unit costs were used as were used in the drying plant for comparable areas.

The churn-print room is the same size for all departments. This implies economies to scale. The butter cooler and cream storage are directly proportional to value. There are no economies to scale for these.

Fuel Costs

Fuel requirements of a butter department are minimal. Fuel is required to heat the building and to heat cleaning water. The only cost estimated for fuel requirements was the gas cost of providing these two heating tasks. It was assumed the boiler of the associated drying plant provided the steam. The wear on the boiler of providing this marginal quantity of steam is so small it was not estimated.

A dairy engineer's rule of thumb was used to estimate the gas requirements for heating the building. The rule is the volume of the building times 10 equals the BTU loss per hour during the winter months. This applies to building areas where there is no great heat loss from processing equipment such as the churn-print room. The complete formula used to generate the annual cost of gas for building heating is as follows:

$$G^B = [V \times 10 \times .001 \times 1.4 \times .00037 \times 3600]$$
$$= .0186V$$

where:

G^B, is annual cost of heating the butter department

V, is building volume of the butter department

.001, is the cubic feet of gas needed to generate a BTU

1.4, is the efficiency factor of converting gas to BTU's

.00037, is the cost of a cubic foot of gas

3600, is the number of hours of winter weather

The application of this formula resulted in the following annual gas costs for heating the butter department:

Department 1	$591
Department 2	614
Department 3	636
Department 4	658
Department 5	688
Department 6	718

It was assumed that all size departments used the same amount of hot water for clean-up. Eighteen hundred gallons of water was heated 120° each day. Using the same transformation factors as above this amounted to $.703 per day or $257 per year.

There are economies to scale for fuel costs but fuel is a minor cost factor in the butter departments.

Electrical Costs

Electrical energy is used in the butter department to pump cream, operate the churn and printer, run the compressors on the butter cooler as well as some lesser uses. The electrical cost functions were estimated in three parts, just as was done for the drying plant. The three parts are, a demand charge cost, a fixed energy cost and a variable energy cost. The first two were estimated as fixed annual costs and the latter was a variable cost coefficient of volume churned.

The demand charge cost was based on the connected horse-power, just as in the drying plants. The connected horse-power was estimated at 85 based on the equipment list in appendix table A.9.

The connected horse-power was converted to kilowatts at a 1 to 1 rate and the kilowatts to kilovolt-amperes by dividing by .85, the power factor. A unit cost rate of $1.27 per kilovolt-ampere was used to convert the physical value to cost.

The monthly demand charge cost for the butter department is $119.38 per month or $1,433 annually.

The main contributor to the fixed energy cost in the butter department is the electrical energy used to maintain a zero temperature in the butter cooler. This cost was determined by estimating the BTU's lost through the cooler walls and converting that into electrical energy equivalents. The formula used to estimate the kilowatt-hours /KWH/ of electrical energy is:

$$KWH^{B} = P\,(T^{\circ} - T^{I}) \cdot 0.0295 \cdot 8760$$

where:

- KWH^{B}, is kilowatt-hours of electrical energy
- P, is the peripheral area of the butter cooler
- T°, is 44.2°F, the average outside temperature in Central Minnesota
- T^{I}, is .0°F, the average inside temperature of the butter cooler
- 0.0295, is the "A" value of 4 inch urethane, the cooler insulation
- 8760, is the number of hours in a year

The application of this formula resulted in the following annual kilowatt hours of electrical energy requirements for the six butter coolers:

Department 1	34,310
Department 2	59,860
Department 3	74,095
Department 4	91,615
Department 5	125,925
Department 6	174,470

The variable electrical energy requirements were estimated for cooling the butter and for operating the several electric motors associated with the churn and butter printer.

It was assumed that butter was cooled from 50° to 0° and that the specific heat of butter is .63. There are 43.1 pounds of butter per 1,000 pounds of wholemilk, therefore, 1,358 BTU's of sensible heat must be removed from 1,000 pounds of wholemilk equivalents of butter. In addition, it was assumed to take 1,024 BTU's per 1,000 pounds of wholemilk equivalents of butter to remove the latent heat of fusion. Therefore, it was estimated that 2,382 BTU's of heat had to be removed per 1,000 pounds of wholemilk equivalents. The relationship of 12,000 BTU's per hour is about equal to 1.5 kilowatt-hours was used to convert the BTU's to kilowatt-hours.

The variable electrical cost for refrigeration is .2978 kilowatts per 1,000 pounds of wholemilk equivalents of butter.

The churn and printer plus the several small auxiliary motors were estimated to require 63 kilowatts per hour. At the hourly production rate of 4,000 pounds of butter, this amounted to 0.0151 KWH's per pound of butter or 0.6508 KWH's per 1,000 pounds of wholemilk equivalents of butter.

Electrical energy for the butter departments was priced at

0.94 cents per kilowatt hour.[1] This rate was applied to the annual fixed energy requirements of the cooler and the two variable cost coefficients just estimated. These were added to the annual demand charge cost to give the electrical cost functions for the six butter departments. The electrical costs are summarized in table 3.20.

There are only minor economies to scale for electrical costs.

Water and Sewage Costs

Water is used primarily for cleaning in the butter department. It was estimated to take 3,000 gallons of water per day for butter departments. The same unit cost of 11 cents per 1,000 gallons was used that was used in the drying plant.

The estimated annual cost of water and sewage for all butter departments is $120.

General Plant Supply Costs

General plant supplies include soap, salt, sanitizers, brushes, uniforms, laundry service and other miscellaneous small items. These items were all treated as fixed costs except salt. The collective cost of these items was estimated with the help of plant managers and accounting data from a number of butter plants.

The general plant supply cost estimates for the six departments are:

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[1] See table 3.11.

Table 3.20. Estimated annual demand charge cost, annual fixed energy cost and variable energy cost coefficient for electrical service for six butter departments in Minnesota, 1970.

Department	Maximum volume W.M.E.	Annual demand charge	Annual fixed energy cost	Variable energy cost coefficient per 1,000 lbs. W.M.E.
		dollars		
1	78	1433	211	.0089
2	156	1433	452	.0089
3	233	1433	586	.0089
4	311	1433	750	.0089
5	467	1433	1083	.0089
6	623	1433	1530	.0089

Department 1	$2,125
Department 2	2,375
Department 3	2,500
Department 4	2,875
Department 5	3,250
Department 6	3,500

Salt cost was estimated to be 1.78 cents per 1,000 pounds of wholemilk equivalents. This is based on a micro flour sale price of $2.06 per 100 pounds and 2 percent salt in the butter.

There are some minor economies to scale for plant supply costs.

Packaging Supply Costs

It was assumed that the butter was formed into one-fourth pound sticks and packaged in one pound cartons. The one pound cartons were packaged in 32 pound pasteboard boxes for shipment.

The price of packaging supplies was obtained from a local paper products distributor. The parchment paper costs .0010 per one-fourth pound wrap, the carton costs .0148 cents per pound of butter and the 32 pound pasteboard box costs .0022 cents per pound of butter. This summed to .018 cents per pound of butter or 0.78 cents per 1,000 pounds of wholemilk equivalents.

General Administrative Costs

General administrative costs are similar to those listed for a drying plant. These costs were estimated as 20 percent of the general expenses of a butter-powder plant. The butter-powder plant costs were the same as those used in estimating similar costs of the drying plants.[1/]

The estimated annual general administration costs for the six butter departments are summarized in table 3.21.

There are economies to scale for general administrative costs. Annual costs only double while volume increases eight-fold in going from the smallest volume department to the largest.

Summary of Butter Department Costs

The eight cost categories just described and estimated are summarized in table 3.22. The categories are labor, equipment, buildings and land, fuel, electricity, water and sewage, general plant supplies and general administration costs. The annual fixed costs and the variable cost coefficient for each cost category are listed for the six butter departments. The volume of the six departments coincide with the six milk drying plants.

The production process and the churn and printer are the same size for all departments. This explains the constant variable cost coefficient for all six plants.

The different fixed costs are the result of more indirect labor, more and larger storage facilities in the larger departments. The other equipment is the same for all plants. The fixed costs for the larger departments do not rise as fast as capacity increases.

The major purpose in developing the six butter departments and their cost function was to generate a long run average cost

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[1/] See page 99, Chapter III.

Table 3.21. Estimated general administrative expenses for six butter departments in Minnesota, 1970.

Department	Maximum volume of W.M.E. (million lbs.)	Annual general administrative expenses (dollars)
1	78	2100
2	156	2350
3	233	2600
4	311	2950
5	467	3500
6	623	4100

Table 3.22. Estimated fixed and variable costs by major factor categories for six butter departments in Minnesota, 1970.

Factors	Department 1 Annual fixed cost	Department 1 Variable cost per 1,000 lbs. W.M.E.	Department 2 Annual fixed cost	Department 2 Variable cost per 1,000 lbs. W.M.E.	Department 3 Annual fixed cost	Department 3 Variable cost per 1,000 lbs. W.M.E.	Department 4 Annual fixed cost	Department 4 Variable cost per 1,000 lbs. W.M.E.	Department 5 Annual fixed cost	Department 5 Variable cost per 1,000 lbs. W.M.E.	Department 6 Annual fixed cost	Department 6 Variable cost per 1,000 lbs. W.M.E.
	(dollars)											
Labor	10,420	.1400	14,700	.1400	15,700	.1400	26,120	.1400	32,720		37,720	.1400
Building & equipment	27,803		29,682		31,012		32,618		35,632		38,644	
Fuel	848		871		893		915		945		975	
Electricity	1,644	.0089	1,885	.0089	2,019	.0089	2,183	.0089	2,516	.0089	2,963	.0089
Water	120		120		120		120		120		120	
General plant supplies	2,125	.0178	2,375	.0178	2,500	.0178	2,875	.0178	3,250	.0178	3,500	.0178
Packaging supplies		.0078		.0078		.0078		.0078		.0078		.0078
General administrative expenses	2,100		2,350		2,600		2,950		3,500		4,100	
Total	45,060	.1745	51,983	.1745	54,844	.1745	67,781	.1745	78,683	.1745	88,022	.1745

function for butter departments. This function was assumed to be the smooth curve fitted to the minimum point of the short run average cost functions. This function was estimated to be:

$$LRAC^{B} = .2575 + 38,621\ V^{-1} \qquad R^{2} = .997$$

where:

$LRAC^{B}$, is the long run average cost for butter departments adjoining milk drying plants per 1,000 pounds of wholemilk equivalent

V, is the volume of wholemilk equivalents of cream processed in 1,000 pounds.

This average cost function is drawn in figure 3.5.

Referring to figure 3.5, at a volume of 78 million pounds of wholemilk equivalents, the average long run cost of the butter department is $.753 per 1,000 pounds and at 623 million pounds, the maximum volume estimated, the average cost drops to $.330 per 1,000 pounds. This amounts to a savings of $.417 per 1,000 pounds. Like the drying plant's long run average cost, the major savings in average cost occurs in the lower half of the volume range. The average cost at 311 million pounds of wholemilk equivalents, half the maximum volume, is $.382 per 1,000 pounds. This amounts to a savings in average cost of $.371 per 1,000 pounds over $.753 per 1,000 pounds at 78 million pounds. On the other hand, increasing the volume from 311 to 623 million pounds results in only a savings of $.052 per 1,000 pounds of wholemilk equivalents.

In summary there are economies to scale in butter processing in the range 78 to 623 million pounds of wholemilk equivalents of cream. The major economies are obtained in the lower half of this

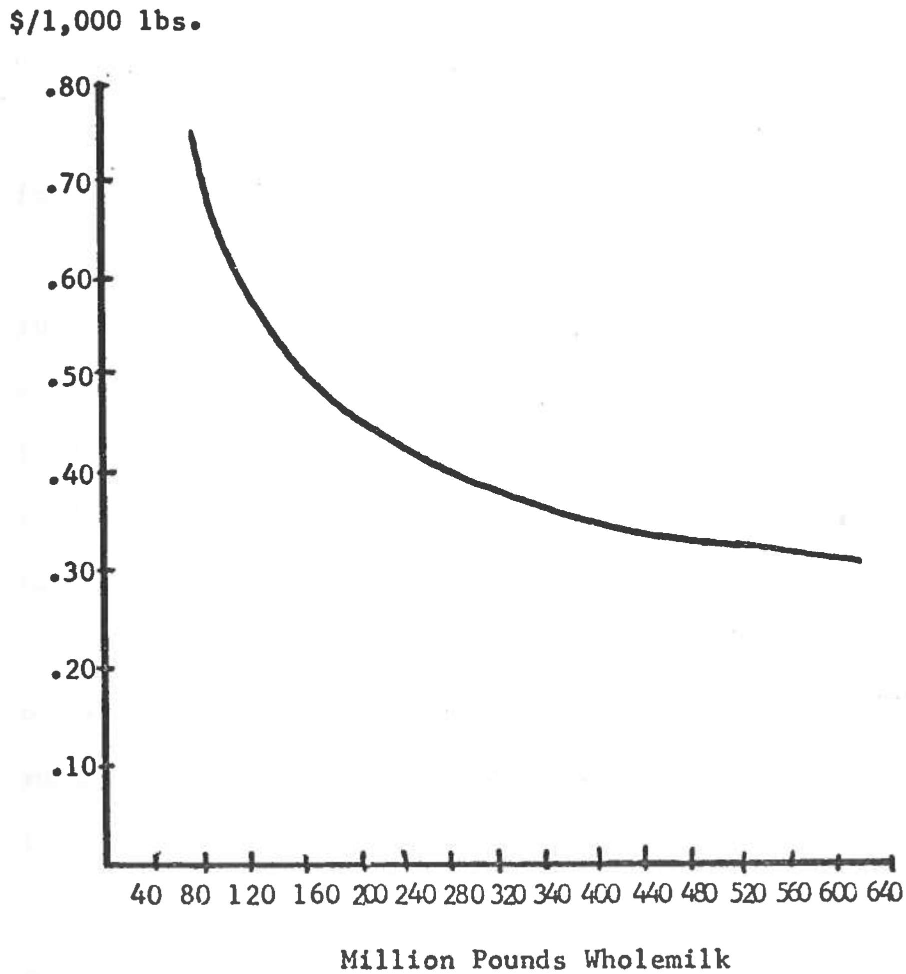

Figure 3.5. Long run average cost curve for butter churning and printing departments in Minnesota, 1970.

volume range.

Butter-Powder Plants

In this section the milk drying plant long run average cost function and the butter department long run average cost function are combined to give a butter-powder plant long run average cost function. This combined long run cost function is representative of the costs of plants which process all their milk receipts into butter and nonfat dry milk. It differs from the cost functions of earlier butter-powder plant studies by the addition of soft printing of the butter rather than bulk packaging.

The milk drying plant long run average cost function and the butter department long run average cost function were combined by summing the average cost of the two for a given volume. The three functions are plotted in figure 3.6.

Several interesting observations can be made from a comparison of these three functions. First there is a sizable difference in the magnitude of the long run average cost of processing for milk drying plants and costs of processing for butter departments. The average cost of the butter department is only about 16 percent of the total average cost of a butter-powder plant. This implies a second observation, the cost savings associated with scale of operation are greater for the drying plant than for the butter department. In going from 78 million pounds of wholemilk equivalents to 623 million pounds, there is an average cost savings of $1.89 per 1,000 pounds for the drying plant. This compares to an

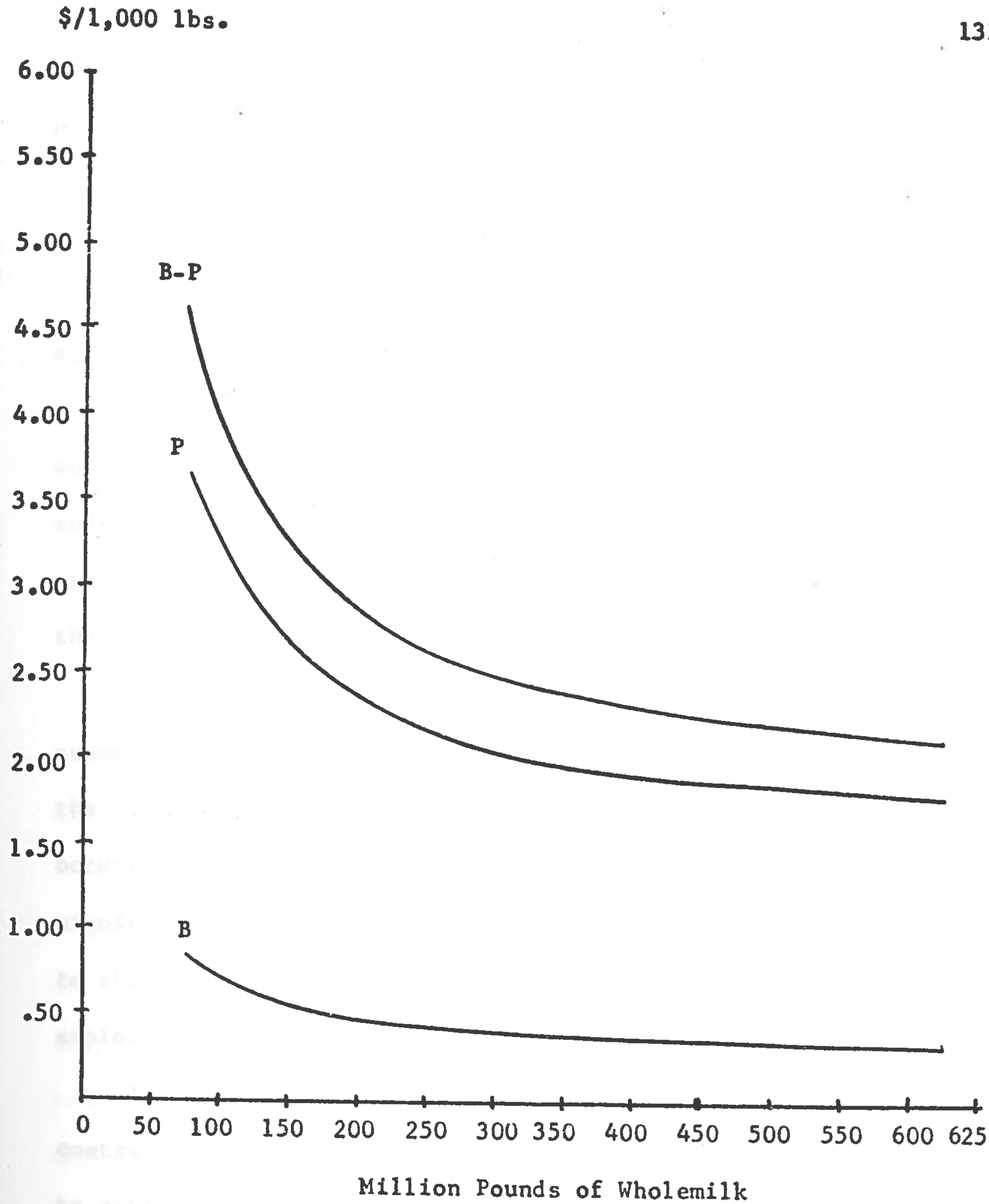

Figure 3.6. The long run cost curves for a drying plant, the butter department and the combination of the two, a butter-powder plant.

average cost savings of $.43 per 1,000 pounds for the butter department for a similar volume increase.

Summary

In this chapter the long run average cost functions were estimated for milk drying plants, for butter departments located at powder plants but not necessarily processing the equivalent volume of product, and for butter-powder plants where milk powder and butter are processed in fixed proportions. The functions all exhibit economies to scale but the major economies are achieved in the first half of the estimated volume range.

The question left to be answered is at what point will rising assembly costs offset the decreasing processing costs and cause the overall assembly-processing average cost to rise. If this occurs at a low enough volume, a volume low enough to still have significant increased economies in butter processing, it will pay to ship the cream to a plant that can assumulate enough cream to exploit the economies to scale in butter processing.

The next chapter deals with the estimation of milk hauling costs. In the subsequent chapter the milk hauling costs are used to estimate assembly cost functions. The assembly cost functions are combined with the processing cost functions of this chapter to answer the questions just posed.

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CHAPTER IV

ESTIMATION OF MILK COLLECTING AND HAULING COSTS

The cost of collecting and hauling milk is a function of many variable factors.[1/] This chapter discusses these factors and presents the estimated functional relationship of them to the cost of collecting and hauling milk. In Chapter V these functional relationships are applied to factor conditions found in Minnesota to estimate cost-volume assembly functions.

There are three distinct types of operations involved in collecting and hauling milk. They are: (1) farm-to-plant milk collecting and hauling, (2) milk receiving station operations and (3) plant-to-plant milk or cream hauling. Farm-to-plant milk collection involves relatively small bulk trucks collecting milk from a number of farmers, a route, and hauling it to a processing plant or receiving station. Milk receiving stations receive milk from farm-to-plant bulk trucks and transfer the milk to plant-to-plant semi-trailer tank trucks. The plant-to-plant milk hauling involves transporting milk from milk receiving stations to processing plants. Plant-to-plant cream hauling involves the same semi-

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[1/] Collecting and hauling milk is used as a generic term to represent movement of milk from place to place in general. The term assembly is used to characterize the movement of milk from place to place but there the places have geographical reference to one another. For example, assembly of the milk from the 20 farms in a five-mile radius of the plant.

trailer tank trucks hauling cream from milk drying plants to large butter departments.

The economic engineering method was used to estimate the costs of farm-to-plant milk hauling. This method was also used to estimate the costs of operating the receiving station. The plant-to-plant hauling costs were estimated by using estimated physical and cost data from a study by Thompson[1/] and a study by Kerchner.[2/]

The next three sections take up in turn farm-to-plant collecting and hauling cost functions, the milk receiving station operating cost function and plant-to-plant hauling cost functions.

Farm-to-Plant Milk Collecting and Hauling Costs

In this study it is assumed that milk is collected from farms and hauled to plants or receiving stations in bulk trucks. Currently manufacturing grade milk is also collected in cans. This method is rapidly declining and it is expected to soon be obsolete. New quality standards for milk currently being discussed, will, if adopted, set requirements at a level that will make it virtually impossible to meet with can milk. For this reason collecting and hauling can milk was excluded from this study.

In general bulk milk is collected from the farm every other day. Each truck usually collects the milk from a number of farms in a single load. Because of road conditions, the winter and

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[1/] Thompson, op. cit.

[2/] Kerchner, Orval, Costs of Transporting Bulk and Packaged Milk by Truck, Marketing Research Report No. 791, Economic Research Service, U. S. Department of Agriculture, May 1967.

spring weather conditions and the size of farmers' driveways, the trucks are limited to single unit models [semi-trailer models are infeasible]. Both single driving axle and tandem driving axle straight trucks are used to assemble manufacturing grade milk in Minnesota. Single axle models are the most popular. Tandem axle models are most often found on grade A milk routes where producers are large and/or the assembly area is extensive.

At the present time the majority of trucks haul two loads per day. This facilitates spreading the fixed cost of the truck over a large volume of milk and provides a reasonable work day for the driver. There are exceptions to this. If the routes are particularly long because of: (1) the distance the routes are from the plant, (2) the distance between farm stops [density of producers], or (3) the number of farm stops [many small producers] then time may limit a truck to one load per day. It will be seen in the next chapter that as the assembly area expands, a distance from the plant is reached beyond which it pays to switch from a single axle truck hauling two loads per day to a tandem axle hauling one load per day.

There are a number of published cost studies dealing with farm-to-plant milk collecting and hauling which were helpful in estimating the milk collecting and hauling costs functions. The technique and results of previous studies were used whenever possible. No previous study was acceptable by itself, however, because of technological changes, price changes and/or geographic differences.

Cost estimates have been made for farm-to-plant assembly of bulk milk by many researchers in various parts of the country. Miller conducted a study in Wisconsin,[1/] Baum and Pauls in Washington,[2/] Clark in California,[3/] McKinney and Stelly in Texas,[4/] Morris and Thompson in Missouri,[5/] Sinclair in Vermont,[6/] Bowring and Taylor in New Hampshire,[7/] Ishee and Barr in Pennsylvania,[8/] Pritchard and Cope in Indiana,[9/] Cotton in North

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[1/] Miller, Arthur H., Bulk Handling of Wisconsin Milk--Farm to Plant, Wisconsin Agricultural Experiment Station Bulletin No. 192, 1956.

[2/] Baum, E. L. and D. E. Pauls, A Comparative Analysis of Costs of Farm Collection of Milk by Can and Tank in Western Washington, 1952, Washington Agricultural Experiment Station Technical Bulletin No. 10, May 1953.

[3/] Clarke, D. A. Jr., A Comparative Analysis of the Costs of Operating Milk Collection Routes by Can and Tank in California, Mimeo Report No. 91, California Agricultural Experiment Station, October 1947.

[4/] McKinney, Kenneth and Randall Stelly, Farm-to-Plant Hauling and Receiving Bulk Milk, Texas Agricultural Experiment Station MP-377, October 1959.

[5/] Morris O. Richard and Russell G. Thompson, Costs of Hauling Bulk Milk From Farm to Plant, Missouri Agricultural Experiment Technical Bulletin No. 873, November 1964.

[6/] Sinclair, Robert O., Economic Effect of Bulk Milk Hauling in Vermont, Vermont Agricultural Experiment Station Bulletin No. 581, June 1955.

[7/] Bowring, James R. and Kenneth A. Taylor, Transition to Bulk Assembly of Milk in Northern New England, New Hampshire Agricultural Experiment Station Bulletin 453, October 1958.

[8/] Ishee, Sidney and W. L. Barr, Effects of Bulk Milk Assembly on Hauling Costs, Pennsylvania State University, Agricultural Experiment Station Bulletin 641, December 1958.

[9/] Pritchard, Norris T. and William H. Cope, Milk Assembly in the Fort Wayne Milkshed, Purdue Agricultural Experiment Station Bulletin 559, February 1951.

Carolina,[1] Groves and Cook in Wisconsin,[2] Cowden for the U. S. Department of Agriculture[3] and Jacobson and Fairchild in Ohio.[4] Most of these studies were initiated as a result of the rapid shift to bulk milk hauling during the 1950's. There are some exceptions to this. Groves and Cook sought to reconcile the differences in costs of the many previous milk hauling studies.[5] The authors were largely successful in their efforts; most of the differences in costs between studies could be explained by changes in general price levels or location. Morris and Thompson looked at the effect of size of bulk truck, size of patron and length of haul on costs.[6] And Jacobson and Fairchild looked at equitable ways of dividing milk hauling costs between producers of various size and distance from the bottler.[7]

These studies provided a valuable background from which to

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[1] Cotton, Walter P., Farm to Plant Milk Assembly Rates and Problems in North Carolina, North Carolina State College, Department of Agricultural Economics AE Information Series 23, December 1950.

[2] Groves, F. W. and H. L. Cook, Hauling and Transportation Cost Functions for Wisconsin Milk, University of Wisconsin, Agricultural Economics 31, April 1961.

[3] Cowden, J. W., Farm-to-Plant Bulk and Can Milk Hauling Costs, U.S.D.A., Farmers Coop. Service Report 18, March 1956.

[4] Jacobson, Robert E. and Gary F. Fairchild, Hauling Costs and Rates in Bulk Milk Assembly, Ohio Agricultural Research and Development Center, Research Circular No. 162, February 1969.

[5] Groves and Cook, op. cit.

[6] Morris and Thompson, op. cit.

[7] Jacobson and Fairchild, op. cit.

pattern this portion of the study. In some cases data was even used; when it was felt the data was applicable and original data was not easily available.

Procedure

The approach used to estimate cost functions for farm-to-plant milk collecting and hauling is similar to the approach used to estimate processing cost functions. The total operation was partitioned into easily estimable parts (stages), the physical relationships were estimated for each part and factor prices were applied to the physical estimates.[1/]

The economic engineering method was selected as the appropriate estimating technique for the same basic reasons that it was used to estimate processing costs. Good accounting data was not available for some costs and didn't exist at all for some of the alternative hauling systems. This method allowed the synthesizing of cost relationships for systems not commonly found in current use.

The farm-to-plant hauling costs were first divided into truck costs, labor costs and administrative costs. Administrative costs were handled separately for estimation reasons. The truck cost and labor cost categories were each separated into a set of fixed costs and a set of variable cost sub-divisions. The fixed and variable sub-divisions were further partitioned into plant and route costs. The following diagram illustrates this division,

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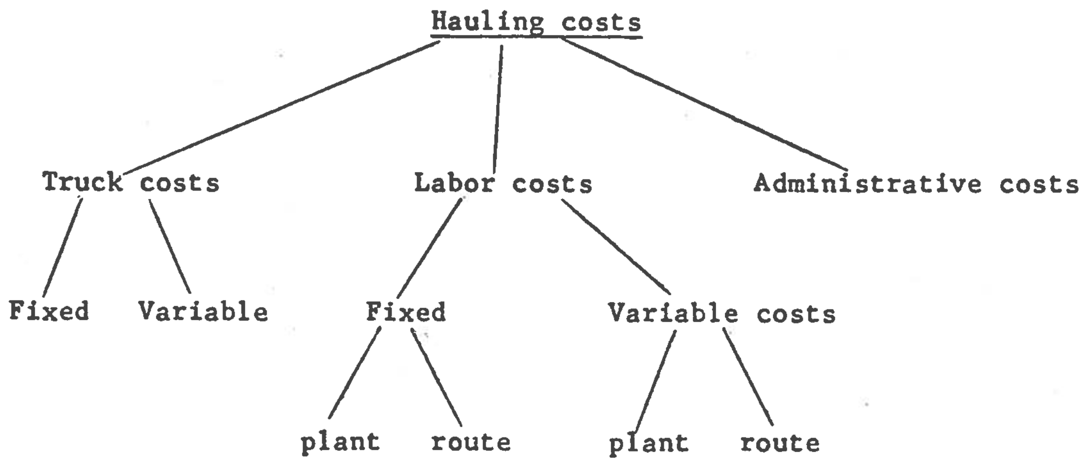
[1/] In a few cases direct dollar estimates were made.

sub-division and partitioning:



Truck Costs

There are a number of different size bulk trucks used in Minnesota for hauling milk from farm to plant. In this study the costs of four sizes were estimated. They have hauling capacities of 1,800, 2,200, 2,700 and 3,200 gallons of milk. The 1,800 and 2,200 gallon tanks are used on single driving axle trucks. The 2,700 and 3,200 gallon tanks are used on tandem axle trucks. The 2,200 and 3,200 gallon models are of major interest in this study. They represent the maximum size or near maximum size that can be used by these two truck types. State weight regulations restricts larger weights. In addition, dairy equipment dealers indicated that most current sales are of these size tanks.

The truck costs were divided into fixed and variable cost categories. The fixed category includes depreciation of equipment, interest on investment, insurance and license fees. The variable cost category includes fuel, oil and grease, tires and repair and maintenance. The classification of these costs are summarized in table 4.1.

Table 4.1. Classification of farm-to-plant bulk milk truck costs.

Truck Costs	
Fixed	Variable
(a) Depreciation	(a) Fuel, oil and grease
(b) Interest on investment	(b) Tires
(c) Insurance	(c) Repair and maintenance
(d) License fee	

Truck Fixed Costs

Depreciation. A bulk truck is made up of two major equipment components, a cab and chassis and a bulk tank. These items are usually purchased separately and have different life expectancies. Equipment sales personnel and truck owners were consulted in estimating the annual depreciation charge.

A cab and chassis was estimated to last four years. At the end of the four years it was estimated to have a salvage value of 20 percent of purchase value. Thus, the annual depreciation rate is 20 percent of purchase value.

The purchase value of the cab and chassis was based on prices quoted by several truck sales agencies. They were asked to provide "bargained for" prices for cab and chassis appropriate for the four size tanks. These purchase values are listed in table 4.2.

The purchase value of the bulk tanks were based on the prices listed by several local manufacturers of bulk tanks. These manufacturers indicated that tanks are not a bargained for item like a cab and chassis. The purchase value of the four bulk tanks is also listed in table 4.2.

The cab and chassis and the bulk tanks purchase values were added together to get total purchase value of the truck units. The purchase values of the 1,800, 2,200, 2,700 and 3,200 gallons of milk capacity trucks are $11,480, $12,815, $17,325 and $18,890, respectively.

The bulk tanks were estimated to have a useful life of twelve years with no salvage value. Bulk tanks are not regularly traded

Table 4.2. Estimated investment costs of several size bulk milk trucks in Minnesota, 1970.

Milk hauling capacity (gallons)	Cost of tank	Cost of truck (dollars)	Total cost
1,800	6,500	4,980	11,480
2,200	7,125	5,690	12,815
2,700	7,775	9,550	17,325
3,000	7,850	10,790	18,890

and there is little alternative use for the tanks once they are not suited for hauling milk any longer. The twelve year estimate was based on the recommendation of the manager of the transportation department of a large regional dairy cooperative. This amounts to an annual depreciation rate of 8.33 percent of purchase value. The annual depreciation costs for the bulk tanks and the cab and chassis are summarized in table 4.3.

The annual depreciation cost for the 1,800, 2,200, 2,700 and 3,200 gallon capacity trucks are $1,925, $2,121, $3,555 and $3,926, respectively.

Interest on Investment. Interest on investment is the opportunity cost of the capital invested in the equipment. It was calculated at an interest rate of seven percent applied to the midlife value of the cab and chassis and the bulk tanks. The formula used is:

$$I_A^I = 0.07 \frac{[P-S]}{2} + 0.07 S$$

where:

I_A^I, is the annual investment cost, in dollars

P, is the purchase value of the cab and chassis and the bulk tanks

S, is the salvage values

The annual interest on investment costs for the four trucks are also summarized in table 4.3. They are $436, $488, $1,000 and $1,067 for the 1,800, 2,200, 2,700 and 3,200 gallon capacity trucks, respectively.

Table 4.3. Annual depreciation, interest, license, insurance and total fixed cost for four sizes of bulk milk trucks in Minnesota, 1970.

Milk Hauling Capacity	Depre-ciation	Interest	License	Insurance	Total Fixed Cost
(gallons)			------------- dollars --------------		
1,800	996.00	436.10	45.85	447.30[a]	1925.25
2,200	1138.00	488.39	47.10	477.46	2120.95
2,700	1910.00	999.81	76.10	569.19	3555.10
3,200	2179.00	1066.38	79.90	600.94	3926.22

a/ Based on liability limits of $25,000/$50,000/$10,000 full coverage comprehensive and $50 deductible collision and universal driver coverage.

License Fees. The annual license fee is a minor cost in Minnesota. Milk hauling vehicles are within the license classification of "farm truck" which has a very low cost rate. The annual license fees for the 1,800, 2,200, 2,700 and 3,200 gallon capacity trucks are $45.85, $47.10, $76.10 and $79.90, respectively. These values are also summarized in table 4.3.

Insurance. Insurance costs were estimated with the help of a local insurance company. The annual insurance costs for the 1,800, 2,200, 2,700 and 3,200 gallon capacity trucks are $447, $477, $569 and $596, respectively. These costs are also summarized in table 4.3.

Summary. The four costs categories, depreciation, interest on investment, license fees and insurance, were summed as shown in table 4.3 to give total annual fixed truck costs. The estimated annual fixed costs for the 1,800, 2,200, 2,700 and 3,200 gallon capacity trucks are $1,925, $2,121, $3,555 and $3,891, respectively.

Expressed on a cost per unit of capacity, the annual fixed costs are $107, $97, $132 and $122 per 100 gallons of truck tank capacity for the 1,800, 2,200, 2,700 and 3,200 gallon capacity trucks, respectively. The 2,200 gallon capacity truck has the lowest annual fixed cost per gallon of capacity followed by the 1,800 gallon capacity truck. These are the single driving axle trucks. The 3,200 gallon capacity truck has the third lowest annual fixed costs per gallon of capacity and the 2,700 gallon capacity truck has the highest annual fixed costs per gallon of capacity. The capacity gained by adding a second axle is not great enough to absorb the annual fixed cost of the added axle at the costs per gallon obtained by the single axle trucks.

Truck Variable Costs

Variable truck costs vary with miles driven and number of driving axles. Variable truck costs were estimated in three parts: (1) fuel, oil and grease, (2) tires and (3) repair and maintenance.

Fuel, Oil and Grease. The fuel used by most farm-to-plant trucks is gasoline. Gasoline consumption was estimated with the help of the drivers surveyed and truck sales agencies. None of the haulers surveyed kept detailed enough accounting records to allow fuel costs to be estimated from their records. Some of them said they occasionally tested their trucks for gasoline consumption rates. Based on this type of evidence, the single axle trucks were estimated to get 6.5 miles per gallon and the tandem axle trucks six miles per gallon.

Gasoline price was estimated at $.328 per gallon. This is based on the suggestion of a local distributor and includes a six percent discount for volume.

This price was applied to the gasoline use rates to obtain a cost of $.0505 per mile for the single axle trucks and $.0547 per mile for the tandem axle trucks.

Oil and grease costs were based on the service recommendations of the truck manufacturers and the service charge experienced by several of the haulers who followed the recommendations. A service charge for the single axle truck was $20 and for the tandem axle truck it was $22. The manufacturer recommended servicing every 3,000 miles. Based on this information, the estimated cost of oil and grease is $.0067 per mile for the single axle trucks and $.0073 per mile for the tandem axle trucks.

Tires. Physical tire requirements were based on the replacement rate of the haulers surveyed. It was estimated that a set of tires lasted 50,000 miles. The haulers indicated they usually traded trucks with poor tires on them. Therefore, it was assumed that two sets of tires are used in 135,000 miles of service [in addition to the truck's original tires].

Tires were priced at $100 per tire. This price was recommended by a local tire distributor for the size and quality usually used by farm-to-plant milk haulers. New tire prices were used. Recapped tires do not stand up under harsh road conditions of rural Minnesota.

The single axle truck required 12 tires per 135,000 miles. At $100 per tire, the estimated tire cost for the single axle trucks is $.0089 per mile. The tandem axle trucks required 20 tires per 135,000 miles. At $100 per tire, the estimated tire cost for the tandem axle trucks is $.0148 per mile.

Repair and Maintenance. This was a difficult cost to estimate. This is not a regularly occurring expense. None of the haulers surveyed could provide the quantity or quality of records to give a realistic estimate of repair and maintenance costs. The manager of the transportation department of a large regional dairy cooperative recommended the use of general motor overhaul every 35,000 miles as a proxy for repair and maintenance costs. He emphasized the point that farm-to-plant trucks require considerably higher maintenance and repair service than plant-to-plant trucks. Based on the transportation manager's recommendation, the single axle truck was estimated to require $1,160 for repair and maintenance and the tandem axle truck $1,260 for repair and maintenance every 35,000 miles. On a per mile basis, the estimated cost of repair and maintenance is $.0331 per mile for the single axle trucks and $.0360 for the tandem axle trucks.

Because of the lack of data on repair and maintenance costs, the estimated values were compared to the results of Groves and Cooks estimated repair and maintenance costs in Wisconsin.[1/] They reported a repair and maintenance cost of $.0285 per mile based on accounting data provided by the Wisconsin Milk Haulers Association. This value was adjusted for price change by the B.L.S. Consumer Price Index. The adjusted value is $.0342 per mile. This compares favorably with the estimates of this study.

Summary. The three categories of variable cost were summed to give total variable cost as is shown in table 4.4. The variable truck cost per mile for the single axle trucks is $.0992 and for the tandem axle trucks $.1128.

[1/] Groves and Cook, op. cit., p. 10.

Table 4.4. Estimated variable truck costs, gasoline, oil and grease costs, tire costs, and repair and maintenance costs of single and tandem axle bulk milk trucks in Minnesota, 1970.

Category	Variable cost per mile	
	single axle	tandem axle
	(dollars)	
Gasoline, oil and grease	0.0572	0.0620
Tires	0.0089	0.0148
Repair and maintenance	0.0331	0.0360
Total variable cost	0.0992	0.1128

Labor Costs

Labor costs were estimated as a function of miles driven, volume hauled, number of loads hauled and number of farm stops. Labor costs were divided into fixed and variable categories. Each of these categories in turn were divided into plant and route subdivisions. The classification scheme for labor costs is summarized in table 4.5.

The labor data was obtained in several ways. The route time data, with the exception of pumping time, was obtained from time studies of fifteen bulk milk routes with 132 farm stops. The bulk trucks use a standard pump, therefore, it was not necessary to time this phase of the operation.

The plant time data was partially based on the time studies of the fifteen routes and partially on engineering data and plant manager's recommendations. The milk receiving stage at the plants to which the milk was delivered from the observed routes had unique characteristics which made some of the time study results unusable. Therefore, it was necessary to use engineering data and plant manager's recommendations.

The wage rate for labor was estimated at $3.50 per hour. This was the approximate gross wage rate[1/] paid by several of the large regional dairy cooperatives in Minnesota. Plant managers indicated that truck drivers receive about the same wage as skilled plant

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[1/] The gross wage includes about 50 cents of taxes, fringe benefits, etc. See Kerchner, op. cit., p. 62, for the approximate breakdown of the gross wage rate.

Table 4.5. Classification of farm-to-plant milk collecting and hauling labor costs for bulk milk truck in Minnesota, 1970.

Labor Costs	
Variable	Fixed
(1) Plant	(1) Plant
(a) Unloading	(a) Route preparation
	(b) Truck cleaning
	(c) Waiting and positioning to unload
(2) Route	(2) Route
(a) Driving	(a) Farm positioning, milk sampling and tank rinsing
(b) Loading	

workers.

Route Fixed Costs. The fixed labor requirements on the route include positioning the truck on the farm, sampling and measuring the milk in the farm bulk tank and rinsing the farm bulk tank after it is emptied. In addition, the small amount of pumping time used to drain the last milk from the farm bulk tank was estimated as a fixed time to simplify the summing of the several cost functions.

The fixed time per farm stop was estimated to be 0.126 hours. This is based on the average time of the 132 observations of the time study. The standard error is .04 hours. The fixed time for drawing the last milk from the farm bulk tank was estimated at .01 hours per farm stop. The total fixed time per farm stop is then 0.136 hours. At a wage rate of $3.50 per hour, the estimated fixed cost on the route per farm stop is $.476.

Although these costs are fixed for a farm stop, the number of farm stops is also a variable. The fixed time on a route is the product of the fixed time per farm stop and the number of farm stops. The number of farm stops is limited by the size of the truck and the volume of milk of the farm stops. The number of farm stops per route is dealt with further in the planning of routes in the next chapter.

Route Variable Costs. Variable labor requirements on the route include driving time and pumping time on the farm [transferring the milk from the farm bulk tank to the truck bulk tank].

Driving time was estimated as a function of miles driven. The distance traveled and the time required to drive between each farm stop and/or plant was obtained in the time studies of milk routes. This data is plotted on a graph in figure 4.1. Examination of it shows that a linear function is a good estimate of the relationship between driving time and distance driven.

A linear function was fitted to the driving time data. The least squares estimate is:[1/]

$$T^D = .023 + .024\ M \qquad R^2 = .93$$

where:

T^D, is hours of driving time

M, is miles driven

At a wage rate of $3.50 per hour the driving time function became the cost function:

$$C^D_S = .0805 + .0840\ M$$

where:

C^D_S, is the cost of driving labor between stops for a farm-to-plant bulk milk truck, in dollars

M, is the miles driven between stops

The driving cost for collecting and hauling a load of milk for a farm-to-plant bulk milk truck is:

$$C^D_L = .0805\ (n + 1) + .0840\ M$$

[1/] For a discussion of the methodology of least squares estimation see for example Dixion, Wildred J. and Frank J. Massey, Introduction to Statistical Analysis, McGraw Hill Book Company, New York, 1957, Chapter II, pp. 189-208.

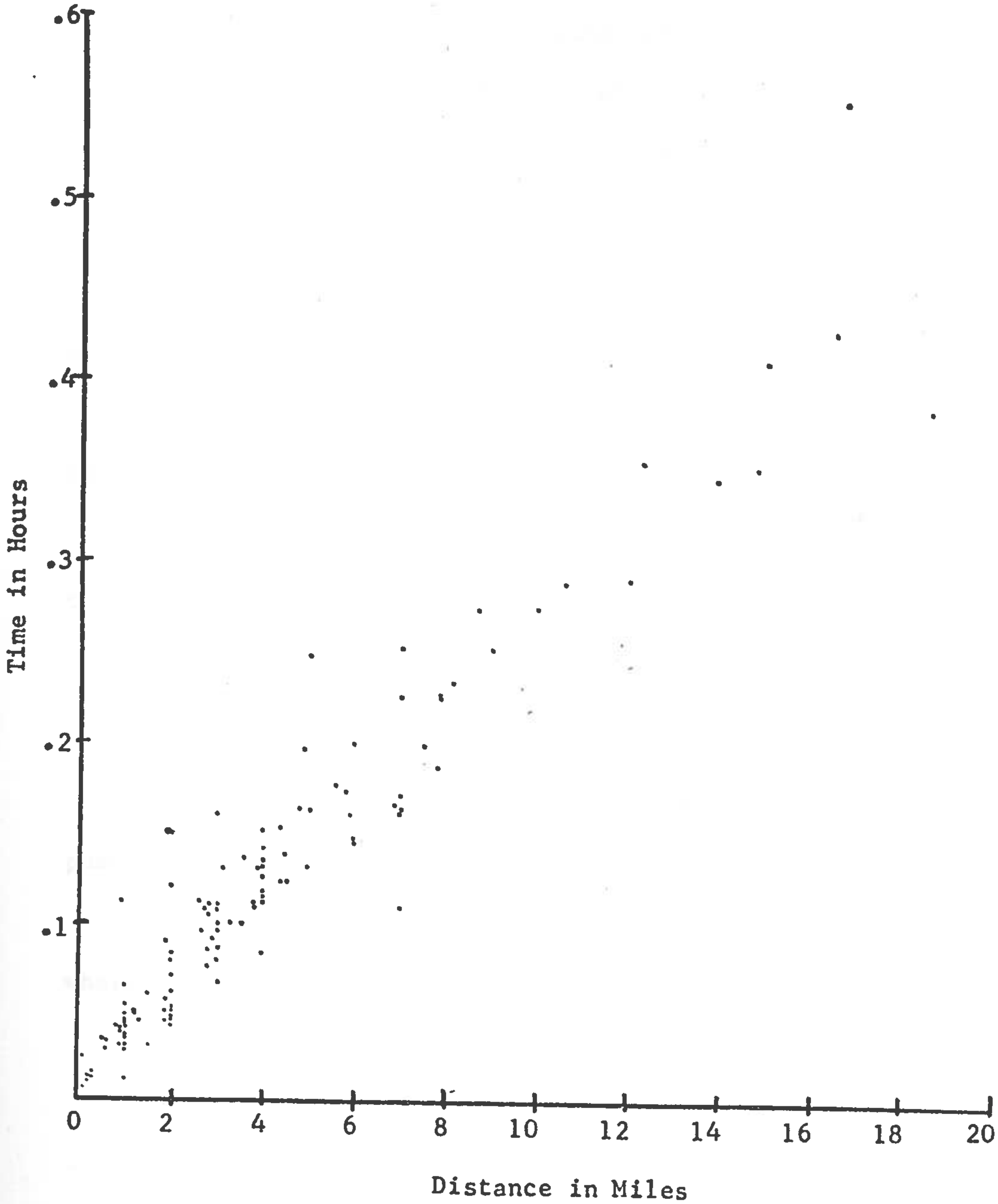

Figure 4.1. Driving time versus miles driven between farm stops and/or dairy plant for bulk milk trucks in Minnesota, 1970.

where:

C_L^D, is the cost of driving labor (in dollars) for a load of milk in a farm-to-plant bulk milk truck

n, is the number of farm stops per load

M, is total miles driven per load

Pumping time on the farm was estimated as a function of volume of milk pumped. The standard pump on most farm pickup bulk trucks is rated at 60 gallons per minute. This is equivalent to the function:

$$T_F^P = 0.0032 \text{ V}$$

where:

T_F^P, is hours of milk pumping time on the farm

V, is volume of milk pumped, in 100 pounds

At a wage rate of $3.50 per hour, the cost of labor for pumping milk on the farm is:

$$C_F^P = .0112 \text{ V}$$

where:

C_F^P, is the cost of labor for pumping milk on the farm, in dollars

V, is the volume of milk pumped, in 100 pounds

The time required to drain the last milk from the tank was included in the fixed time on the farm. Therefore, the time spent pumping on the farm for the whole route is found by simply inserting the volume of the route in the above function.

<u>Plant Fixed Costs</u>. The fixed labor requirements at the plant

include: (1) preparing for the route, (2) washing the truck bulk tank and (3) weighing, positioning and waiting to unload.

Route preparation was estimated to take 15 minutes. Eight usable observations from the milk route time studies average 14.5 minutes.

Washing time was estimated at 25 minutes. This was the average of seven usable observations from the milk route time studies. Most tanks were washed with an automatic tank washer. This requires a 20 minute cycle plus time for attaching the mechanism and rinsing the outside of the truck. The truck pump and small parts were washed while the washer was cycling. In several cases the automatic washer was not used. This method took the same amount of time as the automatic washer. The automatic washer has sanitary advantages rather than time saving features.

Weighing, positioning and waiting to unload was estimated at 12 minutes per load of milk. This was the average of fifteen observations from the milk route time studies.

The three categories of fixed time at the plant were summed as shown in table 4.6. A truck delivering one load per day requires 52 minutes per day and a truck delivering two loads per day requires 64 minutes for the fixed time at the plant.

At a wage of $3.50 per hour, the fixed labor cost per day at the plant for one load is $3.03 and for two loads it is $3.73.

<u>Plant Variable Cost</u>. The only variable labor requirement at the plant is for pumping the milk from the bulk truck into storage. Labor time was estimated as a function of volume pumped. The

Table 4.6. Estimated fixed time at the plant for bulk milk trucks hauling one and two loads per day in Minnesota, 1970.

Classification	1 load	2 loads
	----------(minutes)-------	
Route preparation	15	15
Truck tank washing	25	25
Weighing, positioning and waiting	12	24
Total	52	64

estimate was based on engineering data provided by a sales engineer. Plants are in the process of adopting much higher capacity pumps for loading and unloading milk. It was assumed that plants were equipped with high capacity twenty-five horse-power, 125,000 pound per hour pumps. At this capacity rate the variable plant labor function was estimated to be:

$$T_P^P = 0.0008 \text{ V}$$

where:

T_P^P, is hours of pumping time at the plant

V, is hundred weight of milk pumped

At a wage rate of $3.50 per hour, the cost of labor for pumping milk at the plant is:

$$C_P^P = .0028 \text{ V}$$

where:

C_P^P, is the cost of labor for pumping milk at the plant, in dollars

V, is volume of milk pumped, in 100 pounds

The labor cost relationships just described and estimated are applied to specific Minnesota situations in arriving at assembly cost functions in Chapter V.

Administrative Cost

This cost is for items such as accounting, bookkeeping and other administrative functions. This cost often is not identifiable under Minnesota conditions. In Minnesota most of the haulers are small entrepreneurs with only one or two trucks.

These haulers usually do not keep formal enough accounting records to identify this cost. In fact for a small operator it may not even occur. If the dairy plant operates its own trucks, however, this cost will occur. If this cost occurs for alternatives other than a small contract hauler then the small hauler can capture those costs as a rent.

Data to estimate the value of this administrative cost was not available. As was mentioned, the small haulers surveyed did not keep records of such items and the large haulers, although they had records, did not have them in a usable form.

In absence of data in Minnesota, the results of a recent study in Ohio was used to estimate administrative office costs.[1/] The authors reported a cost of $.1092 per stop which, following their procedure in reverse, amounted to about $530 per truck per year. This value was used as an administrative charge for all trucks.

The truck, labor and administrative cost relationships just estimated are applied to specific Minnesota conditions in the next chapter to estimate direct farm to plant cost-volume assemble functions for milk.

Receiving Station

A receiving station as used in this study is a dairy facility that receives milk from farm-to-plant bulk milk trucks and trans-

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[1/] Jacobson and Fairchild, op. cit., p. 6.

ships the milk in large semi-trailer bulk tank trucks. The estimated facility is basically a garage-like structure with an attached service area for office, supply storage and laboratory.

The same economic engineering techniques used in developing processing costs were used in estimating the costs of the milk receiving station. The reasons for using this method are also the same.

The operation of a receiving station is much less complex than the operation of a processing plant. This simplified the estimation of the cost function.

Costs for the milk receiving station were divided into five categories for estimation purposes. The five cost categories are:

Building and land
Equipment
Labor
Utilities
Plant supplies

The physical requirements for each of these categories was estimated and factor prices applied to get estimates of the cost functions.

The data used in developing the costs functions for milk receiving plants were obtained from receiving facilities at the butter-powder plants visited during the course of the study and another study of bulk milk receiving stations made by Aplin in New York in 1958.[1/]

[1/] Aplin, R. D., Country Reload Plants for Bulk Milk, Department of Agricultural Economics, Cornell University Agricultural Experiment Station, New York State College of Agriculture, Ithica, New York, 1958.

Building and Land Cost

The building was broken into two sections, the truck receiving and shipping area and the service area.

The truck receiving and shipping area was estimated to handle four straight trucks or two semi-trailer trucks at one time. It was assumed this could be done with two drive through lanes 58 feet long and 13 feet wide. This amounts to 1,508 square feet. Based on this area and a unit-cost of $10 per square foot construction cost, the estimated purchase value of the shipping and receiving area is $15,080.

The service area was assumed to include an office, laboratory and general storage area. This was estimated to take 875 square feet. At a unit cost of $15 per square foot for construction, the estimated purchase cost of the service area is $13,121.

The estimated cost of the building, the combined cost of receiving and shipping, and service area, is $28,205. The building was assumed to last 20 years. This is based on the 20 year building expectation used in estimating processing costs. The estimated annual depreciation charge for the milk receiving station building facilities is $1,410.

The other annual costs, repair and maintenance, interest on investment, property taxes and insurance were calculated at the rates used for the processing costs.[1/]

Based on those rates the estimated annual cost of repair and

[1/] For a discussion of these rates see Chapter III, pages 74-77 of this study.

maintenance, interest on investment, property taxes and insurance is $946.

The building site area was calculated at five times the building area. At $.20 per square foot, this amounts to a purchase value of $2,383. The annual interest cost of the building site area for the milk receiving station, based on an interest rate of seven percent, is $167.

Equipment Cost

Equipment requirements were based on the equipment in the receiving departments of plants visited in the course of the study. The laboratory and office equipment cost was based on Aplin.[1/] The estimated life, installed cost and annual depreciation cost for the equipment is summarized in appendix table A.11. The estimated annual depreciation charge for equipment in the milk receiving station is $1,308.

The other annual costs were calculated at the rates used for estimating processing costs.[2/] Based on those rates, the estimated annual cost of repair and maintenance, interest on investment, property taxes and insurance is $1,282.

The estimated annual cost of equipment buildings and land for the milk receiving station is $5,113.

[1/] Aplin, op. cit.

[2/] For a discussion of these rates see Chapter III, pages 74-77 of this study.

Labor Cost

The labor requirements for the milk receiving station were based on the experiences of receiving departments of butter-powder plants. A person is needed to supervise milk intake and loadout, general cleaning, some laboratory work and a little record keeping. It was assumed that these daily tasks could be handled by one worker. Therefore, the labor requirements were estimated to be one man per day.

A gross wage of $3.50 per hour was assumed to be the wage rate. This is equivalent to the wage rate for skilled plant workers used in estimating processing costs. Based on this wage rate, and an eight hour day 365 days a year, the estimated straight time labor cost is $10,192. In addition, it was assumed that the worker would work one hour a day overtime for 120 days during the peak period of milk production. At a time and one-half wage rate, this adds $630 to the labor cost. The estimated total annual labor cost for the milk receiving station is $10,822.

In calculating the labor cost in this way, it was assumed that swing shift-labor was available two days per week. It was assumed that this could be done by stationing a fieldman at the receiving station and utilizing him two days per week as a plant worker.

Utilities

The utilities were divided into three categories. The three cost categories are:

Water and sewage
Electrical
Fuel

The physical requirements were developed primarily from Aplin.[1/]

Water and Sewage. Water is used primarily for cleaning. Cleaning includes the building and storage tanks as well as the farm-to-plant trucks' tanks.

The trucks' tanks are cleaned once per day. Kerchner estimated that it takes 14 gallons of water per 1,000 pounds of milk for cleaning the truck's tank.[2/] Oplin's water estimate of 3,910 gallons of water per day was adjusted to reflect this variable water use for cleaning trucks. The adjusted water use function is:

$$G_D^W = 1,621 + 14\ V$$

where:

G_D^W, is gallons of water used

V, is volume of milk received, in 1,000 pounds

This water use function was converted into a cost function by applying a water cost rate of $.11 per 1,000 gallons of water. This rate was estimated in the processing cost chapter. It assumes the water is purchased from a municipal source and that it is returned to the municipal sewage system. The estimated daily

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[1/] Aplin, op. cit., p. 35.

[2/] Kerchner, op. cit., p. 72.

cost of water and sewage is:

$$C_D^W = .178 + .0015\ V$$

where:

C_D^W, is the daily cost of water and sewage, in dollars

V, is the volume of milk received, in 1,000 pounds

The plant operates 365 days per year. Therefore, the fixed factor was expanded by 365. The estimated annual water and sewage cost function for the milk receiving station is:

$$C_A^W = 65 + .0015\ V$$

where:

C_A^W, is the annual cost of water and sewage, in dollars

V, is the volume of milk received, in 1,000 pounds

Electricity. Electricity is a minor cost item in a milk receiving station. It is used for pumping and general service. Aplin's estimate for a similar receiving station is 107 kilowatt-hours [KWH] per day. This was adjusted to reflect the variable electrical use of the milk pumps. A milk pump was estimated to use .2 KWH per 1,000 pounds of milk pumped. Milk must be pumped twice, therefore, the plant used .4 KWH per 1,000 pounds of milk pumped. Based on this, the adjusted daily electrical use function is:

$$K_D^E = 65.4 + .4V$$

where:

K_D^E, is the daily kilowatt-hours of electricity used

V, is volume of milk received, in 1,000 pounds

The electricity use function was converted into a cost function by using an electrical energy cost rate of $.03 per kilowatt-hour.[1/] This resulted in the following cost function:

$$C_D^E = 1.962 + .012V$$

where:

C_D^E, is the daily electrical cost, in dollars

V, is the volume of milk received, in 1,000 pounds

This function was converted into an annual cost function by expanding the fixed coefficient by 365. The estimated annual cost of electricity for the milk receiving station is:

$$C_A^E = 716 + .012V$$

where:

C_A^E, is the annual cost of electricity, in dollars

V, is the volume of milk received, in 1,000 pounds

Fuel. Fuel is used in a receiving station to heat the building and to heat cleaning water. Aplin estimated that a plant similar to the one of this study required 57 gallons of fuel oil per day.[2/] This fuel use was adjusted to reflect fuel used for heating truck cleaning water. It was estimated that 60 percent of the 14 gallons of water per 1,000 pounds of milk for cleaning trucks was heated from 50° to 180°. This is equivalent to about 12,500 BTU's of energy per 1,000 pounds of milk or 0.082 gallons

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1/ This is based on Northern States Power general service rate (DC204). The demand charge was so small it was ignored in calculating the electrical cost function.

2/ Aplin, *op. cit.*, p. 35.

of fuel oil.[1/] Based on these assumptions, the estimated fuel oil use function is:

$$G_D^F = 43.6 + 0.082V$$

where:

G_D^F, is gallons of fuel oil used daily

V, is volume of milk received, in 1,000 pounds

This function was converted to a daily fuel cost function by applying a fuel oil cost of $.149 per gallon.[2/] This resulted in the following daily fuel oil cost function:

$$C_D^F = 6.50 + 0.0122V$$

where:

C_D^F, is daily fuel oil cost, in dollars

V, is volume of milk received, in 1,000 pounds

This function was converted into an annual fuel oil cost function by expanding the fixed coefficient by 365. The estimated annual cost function for fuel in the milk receiving station is:

$$C_A^F = 2372 + 0.0122V$$

where:

C_A^F, is annual cost of fuel, in dollars

V, is volume of milk received, in 1,000 pounds

Plant Supply Cost

Plant supplies include office supplies, soaps, sanitizing

1/ Farrall, op. cit., p. 654.

2/ This is based on a local petroleum distributor's price for No. 2 furnace oil.

agents, laundry service and miscellaneous items such as brushes, gaskets, etc. These are a small cost item in a milk receiving station. Aplin's estimate for a receiving station similar to the one of this study was used. The value was adjusted to reflect less laundry because of less labor and to reflect current prices. The estimated annual cost of plant supplies for the milk receiving station is $1,887.

Summary

The several individual costs and cost functions just discussed are summarized in table 4.7. The summation of these functions is the total annual cost function. It is:

$$C_A^T = 21,965 + .0257V$$

where:

C_A^T, is total annual cost of a milk receiving station, in dollars

V, is the volume of milk received, in 1,000 pounds

The large fixed cost is the dominant feature of this cost function. This implies economies to size; additional milk receipts add little to cost at the margin. The economies to size are illustrated graphically in figure 4.2. The average cost curve is plotted there. It falls dramatically, especially in the lower volume range. In going from 10 million pounds of milk received annually to 40 million pounds, average cost drops $1.65 per 1,000 pounds of milk received. The addition of another 30 million pounds of milk reduces average cost an additional $.23 per 1,000 pounds of milk.

Table 4.7. Estimated fixed and variable costs for a bulk milk receiving station in Minnesota, 1970.

Cost Item	Fixed Cost	Variable Cost per 1,000 lbs. Milk Received
Building and Land	3,523	
Equipment	2,590	
Labor	10,822	
Water	65	0.0015
Electricity	716	0.0120
Fuel	2,372	0.0122
General Supplies	1,887	———
Total	21,965	.0257

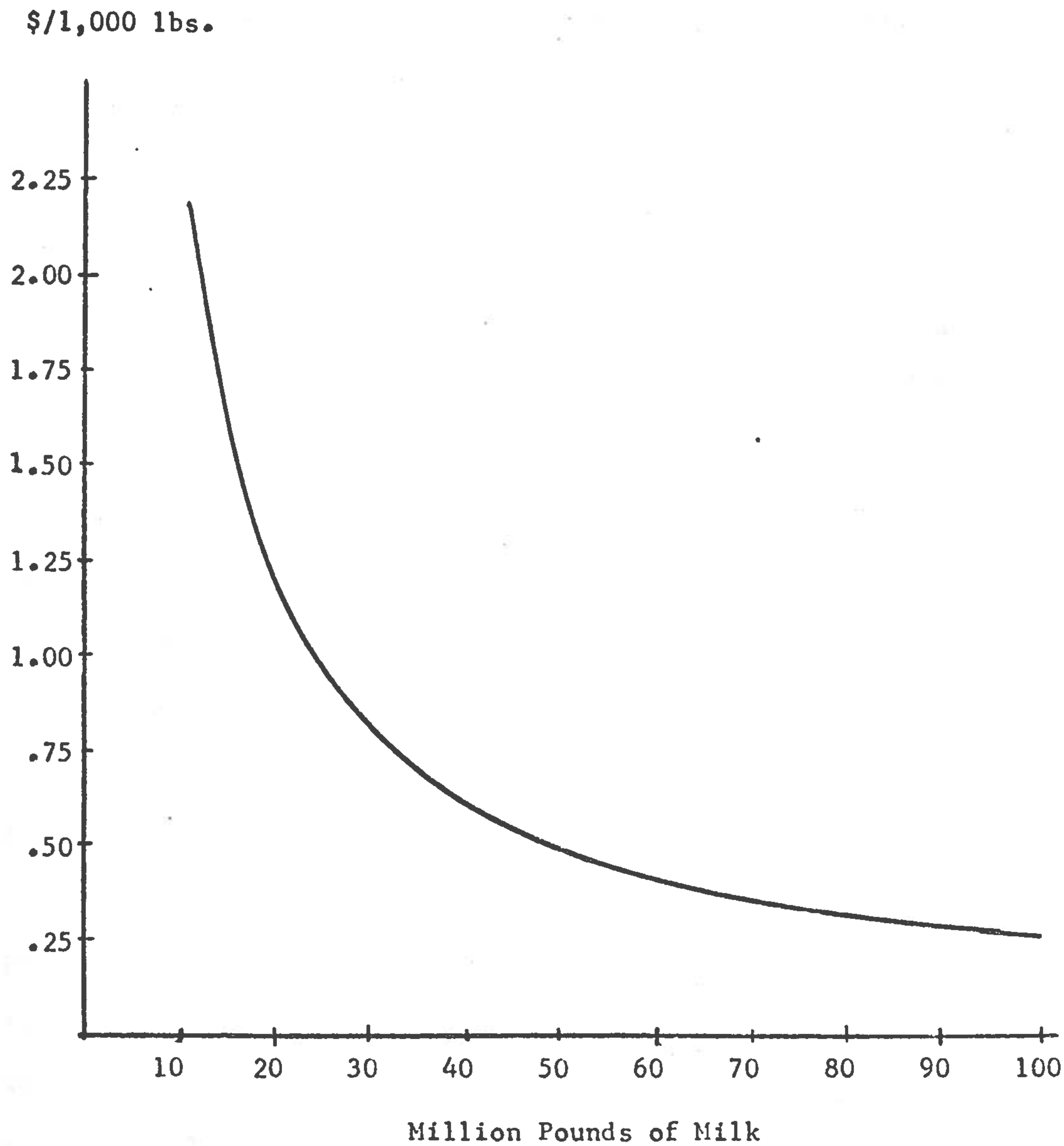

Figure 4.2. Estimated average cost of operating a bulk milk receiving station in Minnesota, 1970.

The falling average cost function implies the size of the receiving station, and its assembly area, is an important cost factor in determining its use in overall assembly patterns for milk as well as determining its distance from the processing plant. The problem of an optimal size receiving station is dealt with in the next chapter.

The average cost of operating a receiving station, just estimated, is combined with the farm-to-plant (or receiving station) assembly function and the plant-to-plant milk hauling function to estimate an indirect cost-volume assembly function in Chapter V.

Plant-to-Plant Hauling Costs

Semi-trailer tank trucks are used in this study to haul milk from receiving stations to processing plants and/or cream from specialized drying plants to large butter departments.

The data for estimating plant-to-plant hauling costs was obtained primarily from two recent studies of plant-to-plant milk hauling costs.

The labor data was obtained from Thompson.[1/] This study reported the results of an intensive time and motion study of plant-to-plant milk hauling labor requirements. Eighty-eight drivers were timed on all tasks that they performed on 214 plant-to-plant routes.[2/]

[1/] Thompson, op. cit.

[2/] Ibid.

The truck costs were developed from data obtained from Kerchner.[1/][2/] His truck costs were estimated by the economic engineering method using data obtained from trucking firms, several milk haulers, and equipment dealers throughout the U. S. His data for the Midwest was used, with some modifications, for estimating the fixed and variable truck costs.

Truck Costs

It was assumed that 5,700 gallon (49,000 pounds) capacity semi-trailer tank trucks are used for plant-to-plant hauling. Thompson's research has shown that the largest semi-trailer tankers provide plant-to-plant milk hauling service at the lowest average cost.[3/] He found this to be true even though in using the larger size units a great deal of excess capacity existed. The 5,700 gallon semi-trailer tankers are about as large as the legal limits allow in Minnesota.

Kerchner divided truck costs into fixed and variable costs in a manner similar to the cost categories used for estimating farm-to-plant truck costs.

Fixed Costs. The fixed costs included depreciation of equipment and garage facilities, insurance, interest in investment, highway use-tax, license and miscellaneous tax, management and

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1/ Kerchner, Orval, Costs of Transporting Bulk and Packaged Milk by Truck, op. cit.

2/ Kerchner's truck costs include administrative costs which were treated as a separate category in the farm-to-plant estimation.

3/ Thompson, op. cit., p. 94.

office salaries and administrative costs. These costs are summarized in table 4.8.[1] Kerchner's depreciation was based on an estimated purchase price for a diesel truck tractor of $17,000 and a tank trailer of $14,000. These costs were based on information from haulers and equipment dealers. A salvage value of $1,000 each was assumed for the tractor and trailer, with a life of seven years for the tractor and ten years for the trailer.

Building depreciation, estimated from building, office and shop equipment costs as supplied by haulers, was assigned on a per truck basis. The building was assumed to have a life expectancy of 33 years. These costs are also shown in table 4.8. Interest on investment cost was based on a rate of seven percent of mid-life value of the equipment and buildings. This was adjusted from six percent used by Kerchner. This cost is summarized in table 4.8.

Insurance, licensing, and taxes were synthesized by Kerchner from information obtained from haulers, state licensing and insurance regulations and insurance companies. They are also summarized in table 4.8.

Costs for management and office salaries and administration were developed from data obtained in a 1970 survey by Hunter.[2]

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[1] Kerchner, Costs of Transporting Bulk and Packaged Milk by Truck, op. cit., p. 4.

[2] Hunter, J. H., Jr., Costs of Operating Exempt for Hire Motor Carriers of Agricultural Commodities, A Pilot Study in Delaware, Maryland and Virginia, U. S. Department of Agriculture, ERS-109, 1963 as reported in Kerchner, Costs of Transporting Bulk and Packaged Milk by Truck, op. cit., p. 12.

Table 4.8. Estimated annual fixed costs for a 49,000 pound capacity plant-to-plant bulk milk truck in Minnesota, 1970.

Cost Item	Cost
	(dollars)
Depreciation	
Equipment[1/]	3,586
Building and Tools[2/]	250
Insurance	1,000
Interest[3/]	1,120
Federal Highway Use Tax	180
License and Miscellaneous Tax	800
Management and Office Salary[4/]	973
Administrative Costs[5/]	649
	8,558

[1/] Tandem tractor and tandem trailer.

[2/] Maintenance shop and office space.

[3/] Rate of 7 percent adjusted from Kerchner's 6 percent.

[4/] Supervision and clerical personnel plus a return to management.

[5/] Includes office supplies, utilities, legal fees and miscellaneous office expenses.

Source: Kerchner, Cost of Transporting Bulk and Packaged Milk by Truck, p. 4.

The estimated total annual fixed truck cost for a 5,700 gallon plant-to-plant semi-trailer truck is $8,558. This is based on the summarization of costs in table 4.8.

Variable Costs. Kerchner developed variable costs on a mileage basis. Variable costs include fuel, tires, maintenance and miscellaneous tiems. Kerchner estimated diesel fuel consumption at 5.5 miles per gallon. Fuel price was based on the current quoted price of a major distributor in central Minnesota. It was quoted at 28.4 cents per gallon. Based on this information, fuel cost was estimated at $.0516 per mile as shown in table 4.9.

Kerchner based his estimate of tire cost on data provided by haulers. Tire life was estimated at 200,000 miles, 100,000 miles on the original tread and two recapps of 50,000 miles each. New tire price was estimated at $115 per tire and recapps at $70 per recapp. A truck unit requires 18 tires. Based on this information, the estimated cost of tires is $.0166 per mile as shown in table 4.9.

Kerchner obtained maintenance records on 75 tractors over a 6 month period from a regional trucking organization. These records were used to compute the cost of grease and oil, repair and maintenance labor per truck. The records showed an average cost of maintenance of $.0319 per mile. This cost is also shown in table 4.9.

The other variable cost category, miscellaneous items, was used by Kerchner as an estimate of the many little things that are difficult to enumerate. His estimate is $.0100 per mile and is

Table 4.9. Estimated variable costs per mile for a 49,000 pound capacity plant-to-plant bulk milk truck in Minnesota, 1970.

Item	Cost
	(dollars)
Fuel, diesel[1/]	$.0516
Tires	$.0166
Maintenance	$.0319
Miscellaneous	$.0100
Total	$.1101

[1/] Adjusted from Kerchner to reflect change in fuel price. It is based on 5.5 miles per gallon and 28.4 cents per gallon.

Source: Kerchner, Cost of Transporting Bulk and Packaged Milk by Truck, p. 6.

summarized with the other variable costs in table 4.9.

The four variable costs were summed as shown in table 4.9. The estimated variable cost for operating a 5,700 gallon capacity plant-to-plant semi-trailer tank truck is $.1101 per mile.

The combination of these fixed and variable truck costs gives the linear cost function:

$$C_A^T = 8558 + .1101\ M$$

where:

C_A^T, is total annual truck cost for a 5,700 gallon capacity plant-to-plant semi-trailer tank truck, in dollars

M, is miles driven per year

Labor Costs

Labor costs were estimated by applying a standard gross wage rate of $3.50 per hour[1/] to the physical labor requirements reported by Thompson. This wage rate is consistent with the wage rate of several large dairies and that used in other parts of this study.

Thompson divided labor requirements into fixed and variable categories.[2/]

Fixed Costs. The fixed labor requirements estimated by Thompson include route preparation, local hookup and unhook,

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1/ See Kerchner page 62 for a relative breakdown of the gross wage.

2/ Thompson, op. cit., pp. 73-94.

waiting time, personal time and miscellaneous time. The estimates of these labor requirements are summarized in table 4.10.[1/]

Thirty minutes per day for cleaning the truck's milk tank was assumed to be needed as an addition to Thompson's fixed labor requirements. This estimate was based on data obtained for the farm-to-plant portion of this study.

Based on a wage rate of $3.50 per hour, the fixed cost per load for plant-to-plant milk hauling is $2.11 plus $1.75 per day for cleaning.

Variable Cost. Thompson divided variable labor into three categories, driving time, local pumping time (loading) and central pumping time (unloading).

Thompson found that driving time between plants was closely correlated with the road distance between those plants. He estimated the following function, using least squares estimation:

$$L^D = .078 + .024\ M \qquad R^2 = 98$$

where:

L^D, is hours of driving time

M, is miles driven between plants

Based on a wage of $3.50 per hour, this driving time function is the cost function:

$$C^D = .2730 + .0840\ M$$

where:

C^D, is cost of driving labor

[1/] Ibid., p. 87.

Table 4.10. Estimated labor requirements for fixed plant-to-plant milk hauling tasks in Minnesota, 1970.

Classification	Time Per Load
	(minutes)
Route preparation	5.0
Local hookup and unhook	7.2
Central hookup and unhook	7.3
Wait	11.0
Personal	2.9
Miscellaneous	3.1
Total	36.1

Source: Thompson, *op. cit.*, p. 87.

M, is miles driven between plants

It is of more than passing interest to compare the driving time function above with the driving time function for farm-to-plant hauling. They both have the same variable coefficient, .024. This implies that once a truck gets on the road and rolling, it travels about the same speed, 42 miles per hour, irrespective of size or type of truck.

Thompson's estimated pumping time is a function of volume of milk pumped and the size of pump. The receiving station and the processing plants estimated in this study were assumed to have higher capacity pumps than were included in Thompson's study. Pumping time therefore, was estimated on the basis of engineering data. A 125,000 pound per hour a pump requires .008 hours per 1,000 pounds of milk pumped. At a wage rate of $3.50, the pumping cost function is:

$$C^P = .028\ V$$

where:

C^P, is the cost of pumping milk in or out of the semi-trailer tank trucks

V, is the volume of milk pumped, in 1,000 pounds

The truck and labor cost functions just estimated are applied to specific Minnesota conditions in the next chapter to estimate the average cost of hauling milk or cream on a per mile basis between plants. The average cost of hauling milk between plants is combined with farm-to-plant average cost and the average cost of operating the receiving station to give an indirect cost-volume assembly function for milk. The average cost of hauling cream is used as a contributing cost to assembling and processing cream in large butter departments.

CHAPTER V

INTEGRATION AND ANALYSIS OF ASSEMBLY AND PROCESSING COST FUNCTIONS

In this chapter the farm-to-plant cost estimates prepared in Chapter IV are used to develop cost-volume assembly functions for collecting milk direct from farm to plant. The receiving station cost function and the plant-to-plant hauling cost functions, also prepared in Chapter IV, are used to modify direct assembly to include indirect assembly by means of transshipment through receiving stations. The plant-to-plant costs are also used to develop a cream shipment cost function.

The assembly and processing cost function are combined and evaluated for least cost processing and assembly systems at various volumes and various milk production densities. Specifically, the combined cost functions are evaluated at various volumes of milk up to 623 million pounds a year and at milk production densities of 260,000, 130,000, 65,000 and 32,500 pounds of milk per square mile annually to determine which of the following systems is least cost:

1. Plants processing direct received milk into butter and powder.
2. Plants processing direct and indirect received milk into butter and powder.

3. Plants processing direct received milk into powder and cream and shipping the cream to large butter departments for processing.

4. Plants processing direct and indirect received milk into powder and cream and shipping the cream to large butter departments for processing.

Rationalizing the Assembly Cost Function

Assembly costs rise as volume assembled to a plant increases because the increase in volume must come from a widening supply area.[1/] By making certain simplifying, but reasonable assumptions, a volume-geometric area relationship can be specified. The collecting and hauling cost functions can be applied to the geometric area to estimate the cost of assembling the milk to one point in the area. By repeating this for various size areas, a cost-volume milk assembly function can be estimated.

The use of a regularly shaped geometric supply area such as a square or circle is well documented in the literature. Its popularity in estimating assembly costs comes mainly from the unwieldy task of trying to deal with every farm source of raw product supply.[2/] One of the earliest studies of processing and assembly that made use of a regular shaped geometric supply area was a

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[1/] The alternative of more production per farm has been excluded as a possible way of increasing volume. It was pointed out earlier in this study that farm production of milk is inelastic.

[2/] French, Ben C., "Some Considerations in Estimating Assembly Cost Functions for Agricultural Processing Operations," Journal of Farm Economics, Vol. XLII, November 1960, p. 767.

dairy study by Bressler and Hammerberg.[1/] This study used a circular shaped assembly area and converted air miles, radius, to road miles with an adjustment factor. Another often sighted study of processing and assembly costs that made use of a circular supply area was made by Henry and Seagraves.[2/] They were interested in looking at the cost differences of expanding the supply area versus intensifying production near the plant for broilers. They also relied on the functional relationship between the radius and the area of a circle to link cost and volume together in a manageable fashion.

The specific problem of handling assembly costs where collection routes are involved was discussed in an article by Olsen.[3/] He went beyond just using a circular supply area. He divided assembly costs into fixed and variable costs on the basis of whether the cost item varied with location of the route to the plant. He reasoned that even travel between farm stops is fixed because this task must be performed irrespective of where (to what plant) the milk is assembled. This idea is employed in this study.

French enlarged on the framework used by these authors and

[1/] Bressler, R. G. Jr., and D. O. Hammerberg, Efficiency of Milk Marketing in Connecticut, 3: Economics of the Assembly of Milk, Storrs Agricultural Experiment Station Bulletin 239, University of Connecticut, Storrs Connecticut, 1942.

[2/] Henry, William R. and James A. Seagraves, "Economic Aspects of Broiler Production Density," Journal of Farm Economics, Vol. XLII, pp. 1-17, February 1960.

[3/] Olsen, op. cit.

set down some logical procedures and formulations for developing assembly cost functions where a regular shaped supply area is the link between cost and volume.[1/] The fixed and variable costs as defined by Olsen, were used along with the equational form of unit costs suggested by French in developing average assembly cost functions.

The total cost of transporting the required supplies of a single product from any point to a processing plant depends on the equipment used, the labor used with each piece of transport equipment, the work methods employed by the labor, the distance from the supply point or route to the plant, the speed of travel, the prices of inputs, the total volume of product handled per trip and per period, waiting time at the plant and at the farm and minor environmental factors that may vary from time to time.[2/] Most of these are fixed or approximately linear functions. If the volume per trip and the truck speed are treated as constants, a reasonable assumption for milk hauling, the variable cost per unit of commodity can be represented by: (1) a constant part b_o, associated with fixed truck costs, loading, unloading and waiting time and (2) a constant cost per unit of volume per unit of distance traveled b_1, which includes variable truck cost and driving labor. For a single supply source the total variable cost of hauling any given volume, S, is

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[1/] French, op. cit.

[2/] Ibid., p. 769.

$$C = S\,(b_o + b_1\,D)$$ [1]

where:

C, is total cost of hauling from one point to a plant

D, is road distance traveled

S, the supply assembled

With several discrete supply sources the total variable cost per period is a sum of the cost from each distance, weighted by the volume transported from that distance. That is,

$$C = \sum_{i=1}^{n} (b_o\,S_i + b_1\,S_i\,D_i)$$

The average total assembly cost is simply

C/S

The milk assembly functions were estimated by using the above function with the collecting and hauling cost data developed in the previous chapter. In order to do this some further assumptions had to be made about average production per farm and the average density of farms in a region.

The density of milk production varies considerably from place to place in the state. The density of milk production by counties is shown in figure 5.1. These are actual densities of production; the effective densities for butter-powder plants is less. This is especially true in the higher density counties. There is competition from fluid markets and several large cheese

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[1] *Ibid*., p. 770.

Figure 5.1. Pounds of milk produced per square mile for selected counties in Minnesota, 1968.

Source: Minnesota Agricultural Statistics 1969.

plants. The tendency for overlapping assembly areas for butter-powder plants is also greater in the more dense areas.

In absence of any good method of determining the effective density for a given region, four densities were selected for the analysis. The four densities selected are 260,000, 130,000, 65,000 and 32,500 pounds of milk production annually per square mile. It was assumed that 260,000 pounds per square mile was a practical high for effective density in an area. At the other end of the range, it was assumed that below 32,500 pounds per square mile the general approach used in the study is ineffective; the assumption of uniform density breaks down and special local situations become more important.

Production per farm varies a great deal from farm to farm. However, it is reasonable to talk about average size farms when they are aggregated into groups serviced by a bulk milk truck.

The average size farm was estimated at 260,000 pounds of milk per year. This is approximately the average size of farms shipping manufacturing grade milk in bulk in Minnesota in 1969.[1/] On the basis of this assumption, the production per square mile was translated into farms per square mile. The 260,000 pounds per square mile density is equivalent to one farm per square mile. Likewise, the 130,000 pounds per square mile density is equivalent to one farm per two square miles, the 65,000 pounds per square

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[1/] This was based on data taken from the Minnesota Dairy Summary, June 5, 1970, Minnesota Crop and Livestock Reporting Service, St. Paul, Minnesota.

mile density is equivalent to one farm per four square miles and the 32,500 pounds per square mile density is equivalent to one farm per eight square miles.

By specifying the average production per farm, the average number of stops per load can be calculated and by specifying the average density the average distance traveled between farms can be estimated as well as the number of routes in a given area. It thus becomes possible to treat loads of milk as originating at a point. The fixed costs per unit of product, b_o is made up of: (1) fixed truck cost, (2) fixed and variable time at the plant, (3) fixed time on the farm, summed over the number of farms in a load, (4) pumping time on the farm and (5) variable truck cost and driving time traveling from the first farm stop to the last farm stop of the load. (From here on this will be called the route, it excludes travel from the plant to the first farm stop and travel from the last farm stop to the plant. This will be called travel to and from the route.) The constant cost per unit of volume per unit of distance traveled, b_1, is made up of the variable truck cost and driving labor; it applies to travel to and from the route. All collecting and hauling costs are treated as fixed, for a truck size, except those associated with travel to and from the route. It follows that average assembly cost increase as routes are added at further and further distances from the plant. The routes radiate out from the plant to form a regularly shaped supply area.

The supply area was assumed to be a diamond shaped area tilted 45° to the road system as shown in figure 5.2. In much of the dairy area of Minnesota the road system approximates a square grid system. If the road system is thought of as a rectangular coordinate system with a plant at the origin, then the road distance to any point is X + Y. It follows that the road distance from the plant to any point on the edge of the diamond shaped supply area is the same. If routes have their origins along such a diamond then all such routes will have the same variable cost value, b_1. The unit-costs of assembly, b_o and b_1, were developed on an average daily basis. Collecting and hauling costs were converted into assembly costs on the basis of the volume of milk assembled by each truck size on a daily basis. The assembly cost functions for direct assembly are presented first. The indirect assembly via transshipping through receiving stations is then presented.

Direct Assembly Cost Functions

The average daily load volume of a truck is dependent on the number of farm stops and the average daily volume of production of each farm. Bulk milk in Minnesota is picked up on an every-other-day basis. Therefore, considering seasonality (a peak day is .322 percent of annual volume) a 2,200 gallon capacity truck can service 22 farm stops per day, two eleven stop loads. A 3,200 gallon capacity truck can service 16 farm stops per day, all in one load. The average volume assembled on an average day for a 2,200 gallon capacity truck servicing 22 farms is 31,328 pounds. The unit costs were derived by dividing costs by this value. This

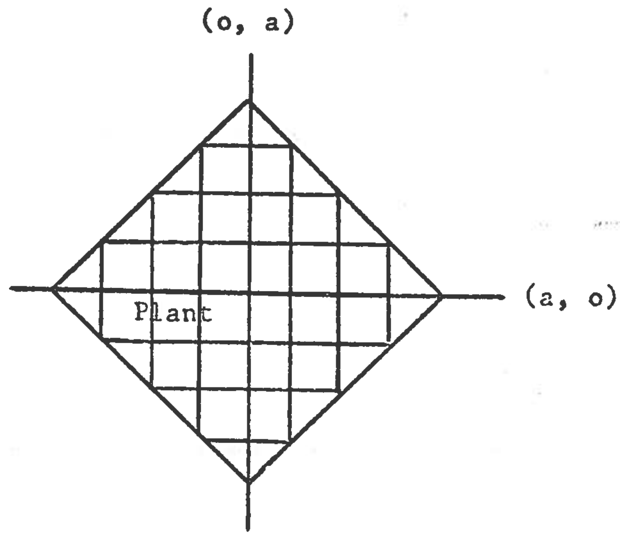

Figure 5.2. Supply area for a square grid road system.

also was done with the 2,200 gallon capacity truck. Its average volume assembled on an average day servicing 16 farms is 22,795 pounds of milk.

Although farm-to-plant hauling cost data was estimated for four truck sizes, only two were used in estimating farm-to-plant assembly cost functions. The 2,200 gallon capacity truck, hauling two loads per day, was included for close in routes. The 3,200 gallon unit, hauling one load per day, was included for more far distant routes. These two size trucks each provide hauling at a lower cost than the other truck in its axle class.

The number of miles on a route and the general shape of the routes was based on results obtained by plotting a series of sample assembly routes for the four densities, the two truck sizes and various width assembly areas. Farms were randomly allocated on a square grid road network for network for each of the four densities. Minimum travel distance routes were worked out by trial and error. Effort was made to use Kreuser's computerized version of Dantzig and Ramser's route minimizing programme.[1/][2/] The number of alternative farm combinations per route ran computer time so high the programme was impractical, especially considering the general nature of the analysis. In addition, the exact length

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[1/] G. B. Dantzig and J. H. Ramser, "The Truck Dispatching Problem," Management Science, Vol. VI, pp. 80-91, 1959.

[2/] Kreuser, Jerome L., Mira: A Method for Solving the Truck Dispatching Problem, Data and Computation Center, Social Systems Research Institute, University of Wisconsin, Madison, Wisconsin, 1968.

of the routes is not crucial to the results. Costs associated with route length are fixed.

From these sample routes, average distance between farm stops was estimated for each of the four densities. Also the depth of the routes was estimated. Depth of a route is defined as the distance between the start and finish location of a route (routes were in general U shaped) and the farthest out farm stop [the distance between the top and bottom of the U].

The diamond shaped assembly area was divided into tiers of routes. Figure 5.3 shows one quadrant of an assembly area for the 260,000 pound per square mile density and how the tiers divide up the area. The width of the tiers was based on the depth of the routes. For a density of 260,000 pounds per square mile and 11 stop loads the depth of route was estimated to be 7 miles. One additional mile was added to this to allow for the distance between the end of one route and the beginning of the next. Every eight miles a new tier of routes was added as shown in figure 5.3. The average miles per route, the route depths and the tier width for the four densities and the two truck sizes are shown in table 5.1.

The first tier for all four densities was calculated in a slightly different manner. It was assumed that two 11 stop loads per quadrant was the minimum or base. In other words, these two loads in a quadrant (eight loads in the diamond shaped area) essentially required only fixed costs of assembly. The first tier has no, or very little, cost required for traveling to and from

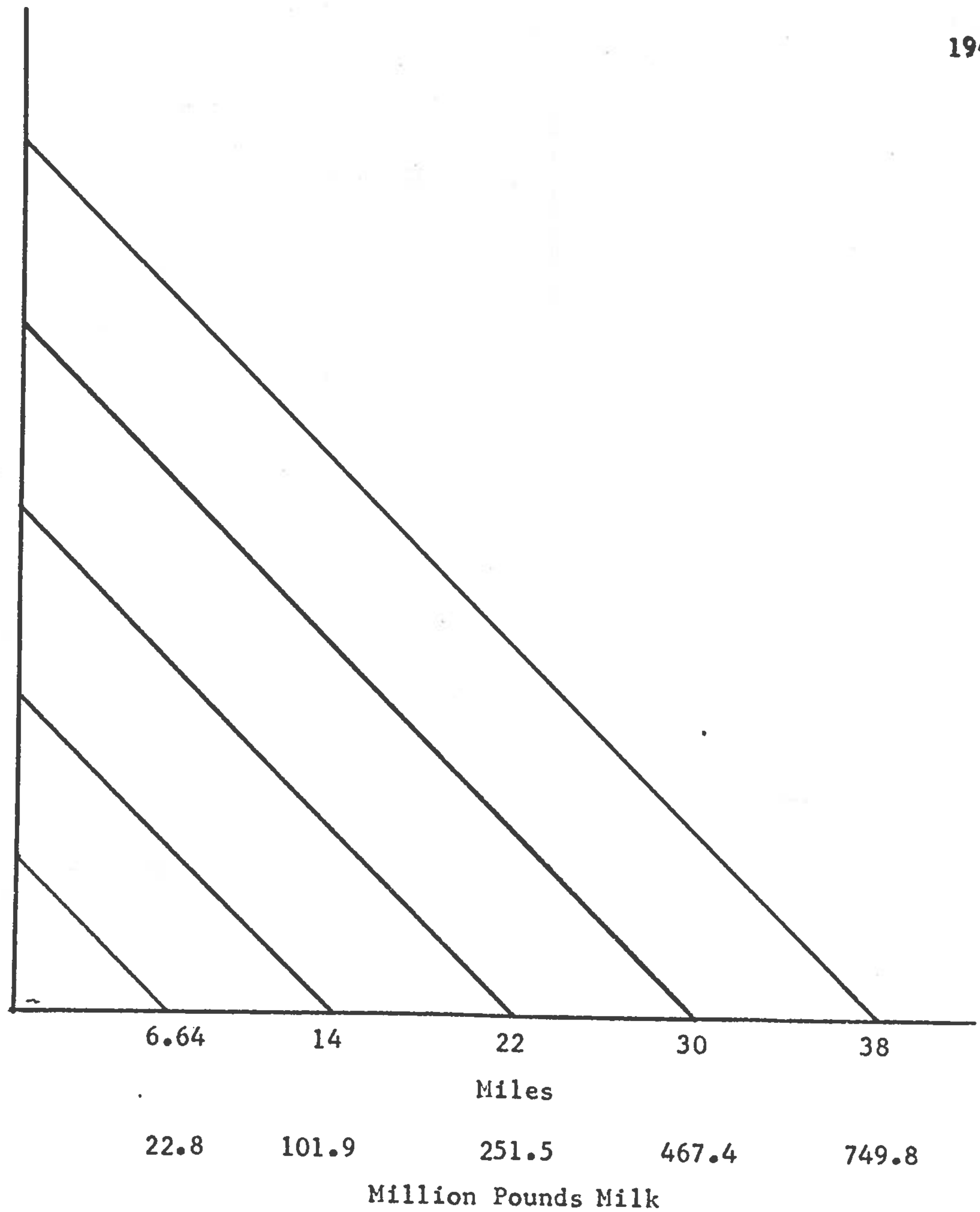

Figure 5.3. One quadrant from a diamond shaped assembly area with a density of 260,000 pounds per square mile divided into tiers of 11 farm-stop-load routes.

Table 5.1. The average miles per route, the route depths and the tier widths for four densities and two trucks' sizes.

	260,000 pounds per square mile		130,000 pounds per square mile		65,000 pounds per square mile		32,500 pounds per square mile	
	2200 gal.	3200 gal.	2200 gal.	3200 gal.	2200 gal.	3200 gal.	2200 gal.	3200 gal.
	(miles)							
Average miles per day on route[1/]	32	--	44	32	62	45	96	70
Average depth of route	7	--	9	10.5	11	13	18	21
Width of a route tier	8	--	11	12.5	14	16	22	25

[1/] For the 2,200 gallon truck size the miles are for 2-11 stop loads.

the routes.

Once the tiers were defined it was a simple matter to calculate the unit cost of assembling milk from each of the tiers. It is the route costs and plant costs, which are fixed per truck, b_o, plus the cost of traveling to and from the tier, b_1. The leading edge of a tier is everywhere equal distance from the plant, therefore, all milk is hauled from the tier at the same unit cost.

With this information on route size and length, number and size of farm stops, size of trucks and the density assumptions coupled with the farm-to-plant hauling cost data, it was possible to estimate average cost functions for assembling milk as a function of volume assembled. Both marginal assembly cost functions, the unit cost of assembling from the periphery of the supply area, and the average assembly cost functions, the average unit cost of assembling from the whole supply area, were estimated.[1/] The average cost of assembly is the weighted unit cost of assembling milk from each tier in a specified size assembly area. The weights are the volume of milk in each tier.

[1/] Average cost of assembly is the relevant function to combine with the processing cost function to determine least cost size of plant and the size of the assembly area. Farmers who must pay the marketing cost are interested in minimizing the marketing cost they face. They are interested in minimizing the combined cost of processing and assembly. Therefore, farmers near a plant are willing to subsidize the cost of assembling milk from further out farmers so long as the savings in processing cost due to the larger volume of the further out farmers are greater than the assembly subsidy they must pay. The cooperatives affect this transfer payment by owning the trucks or by payment schemes to contract haulers.

The tier system of route location provides only a few point estimates of the average and/or marginal cost-volume relationships. These point estimates were used to estimate a continuous cost-volume function by fitting a smooth curve to the point estimates. The reasonableness of this was tested by comparing the estimated values obtained from the continuous function against the costs obtained from the hand plotted routes.

The problem of specifically defining the volume at which truck sizes changed to get minimum average cost of assembly was only dealt with in a limited way. The hauling cost data of Chapter III indicated that for near in assembly the 2,200 gallon truck, making two loads per day, is the least cost method of assembly. As the assembly area expands with volume increases, a point is reached where the larger 3,200 gallon truck, making one load per day, becomes the least cost method of assembly. Break even analysis indicated that this occurs when the periphery of the assembly area is about 50 or 60 miles from a plant. With this in mind truck type, and hence truck cost, (fixed and variable) was switched with the tier that approximated this distance.

The unit cost of assembling milk, less travel to and from the route, is treated as a constant for each of the four densities in this analysis. The farm-to-plant hauling cost items developed in Chapter III and treated as fixed for assembly analysis are:

1. Fixed truck cost
2. Fixed labor at the plant, summed over the number of loads hauled per day.

3. Fixed labor on the farm, summed over the number of farm stops per day.
4. Fixed driving labor, the intercept value of the farm-to-plant driving time function summed over the number of farm stops per day.
5. Pumping labor, plant and farm, based on average volume pumped per day.
6. Travel on the route, based on the miles driven daily on the route proper varies with the four densities.

The daily costs of the six cost categories above were calculated for the two truck sizes and the four densities. The results are summarized in table 5.2. These daily total costs were converted into unit-costs (dollars per thousand pounds of milk) by dividing through by the average milk hauled per day. For the 2,200 gallon truck this was 31,328 pounds and for the 3,200 gallon truck it was 22,795 pounds. These unit-costs for the two truck sizes and the four densities are shown in table 5.3. The unit cost (remember this does not include travel to and from the route) of the 2,200 gallon truck ranges from $1.074 per thousand pounds of milk at the 260,000 pounds per square mile density to $1.449 per thousand at the 32,500 pounds per square mile density. The increase in cost as density goes down is due to the greater distance that must be traveled between farm stops.

The unit cost of the 3,200 gallon truck ranges from $1.357 per thousand pounds of milk at the 260,000 pounds per square mile density to $1.754 per pound at the 32,500 pounds per square mile

Table 5.2. Daily assembly costs of two truck sizes and four densities, excluding cost of travel to and from the routes.

Cost Item	Daily Cost	
	2200 gal. truck	3200 gal. truck
	(dollars)	
Fixed truck cost	7.26	12.21
Fixed labor at the plant	3.75	1.82
Fixed labor on the farm	10.47	7.62
Fixed driving labor	1.93	1.37
Pumping labor	4.39	3.19
Sub Total	27.80	26.21
Travel cost on the route for density of:		
260,000 pounds/square mile	5.86	4.72
130,000 pounds/square mile	8.06	6.30
65,000 pounds/square mile	11.36	8.86
32,500 pounds/square mile	17.59	13.78

Table 5.3. Unit cost of assembling milk for two truck sizes and four densities excluding unit cost of travel to and from the routes.

Density per square mile	2200 gal. truck	3200 gal. truck
	------ (dollars/thousand pounds)----	
260,000	1.074	1.357
130,000	1.145	1.426
65,000	1.250	1.538
32,500	1.449	1.754

density. The higher unit-cost of the 3,200 gallon truck compared to the 2,200 gallon truck at the same densities due to higher truck costs.

The other cost element of assembling milk is the cost of going and coming from the routes. In the analysis here it is based on the distance from the plant to the first or last farm stop in each tier of routes.

The variable truck cost per mile and driving labor cost per miles were summed and divided by the quantity of milk hauled. This yielded a unit-cost per mile (dollars per thousand pound mile). This, in turn, was multiplied by the number of miles driven going and coming from the routes in each tier and added to the fixed cost to give the average cost of assembling milk from each tier.

The variable truck cost per mile for the 2,200 gallon truck is $.0992 and the driving labor cost per mile is $.0840. These were combined and divided by 31,328 pounds to yield a unit-cost of $.00585 per thousand pound-mile. The 31,328 pounds represents two loads so the distance traveled is four times the distance to the route or $.02340 per thousand pound per mile of distance to the route.

The variable truck cost per mile for the 3,200 gallon truck is $.1128 and the driving labor cost per mile is $.0840. These were combined and divided by 22,794 pounds to yield a unit-cost of $.00863 per thousand pound-mile. The 22,975 pounds is for one load so the distance traveled is two times the distance to the route or $.01726 per thousand pound-mile of distance to the route.

These unit-costs per mile were applied to the distance to the route values given in table 5.1. The unit-cost of assembling milk from successively further out tiers is shown in table 5.4, as marginal cost. Marginal cost here refers to the unit-cost of assembling milk from the outer tier or periphery of the assembly area.

The average cost of assembly, also shown in table 5.4, is the weighted average unit-cost of assembling from each tier. The weights being the volume of milk assembled from each tier.

These point estimates of average and marginal assembly cost-volume relationships were fitted with functions of the form $C = AV^b$ to generate continuous functions for each density. The following functional relationships were estimated:

260,000 pounds per square mile density

$$MC_{260} = .2287 \ V^{.1510}$$

$$AC_{260} = .3349 \ V^{.1138}$$

130,000 pounds per square mile density

$$MC_{130} = .1576 \ V^{.1954}$$

$$AC_{130} = .2452 \ V^{.1524}$$

65,500 pounds per square mile density

$$MC_{65} = .1333 \ V^{.2231}$$

$$AC_{65} = .2131 \ V^{.1767}$$

32,500 pounds per square mile density

$$MC_{32.5} = .1228 \ V^{.2461}$$

Table 5.4. Volume of milk, distance to assembly area periphery, marginal cost and average cost of assembly for four densities.

Volume (thousand pounds)	Distance to Periphery (miles)	Marginal Cost (dollars/thousand)	Average Cost (dollars/thousand)	Truck Size (gallons)
	Density of 260,000 pounds/square mile			
22,823	6.6	1.087	1.087	2,200
101,920	14.0	1.268	1.230	2,200
251,474	22.0	1.454	1.360	2,200
467,417	30.0	1.657	1.495	2,200
749,759	38.0	1.895	1.631	2,200
	Density of 130,000 pounds/square mile			
22,823	9.4	1.170	1.170	2,200
104,116	20.0	1.433	1.377	2,200
257,972	31.0	1.703	1.565	2,200
491,693	43.5	2.091	1.822	3,200
815,443	56.0	2.341	2.027	3,200
	Density of 65,000 pounds/square mile			
22,823	13.3	1.288	1.288	2,200
916,330	27.3	1.662	1.573	2,200
221,130	41.3	2.017	1.823	2,200
426,465	57.3	2.429	2.114	3,200
697,645	72.3	2.751	2.362	3,200
	Density of 32,500 pounds/square mile			
22,823	18.8	1.500	1.500	2,200
109,330	41.0	2.026	1.911	3,200
282,913	66.0	2.660	2.379	3,200
538,330	91.0	3.163	2.754	3,200
874,120	116.0	3.666	3.106	3,200

$$AC_{32.5} = .1951 \; V^{.2004}$$

where:

MC, is marginal assembly cost, the unit-cost of assembling milk from the periphery of the area required to generate the called for volume of the function

AC, is the average cost of assembly, the average unit-cost of assembling from the total area required to generate the called for volume of the function

V, is the volume of milk assembled in thousand pounds

The above equations are estimates of the functional relationship of marginal and average cost of assembling milk to volume assembled for direct farm-to-plant assembly.

The possibility of indirect assembly via milk receiving stations with transshipment of milk in over-the-road tankers is considered next.

Indirect Assembly Cost Functions

Milk receiving stations will become part of the overall assembly pattern if the marginal cost of adding a receiving station is less than the marginal cost of extending the periphery of the direct assembly area.

The marginal cost of adding a receiving station requires some explanation. As can be seen from Chapter IV, the operation of the receiving station is subject to economies to size over the range considered (to about 100,000,000 pounds of milk annually). Marginal cost of indirect shipment includes average assembly cost to the receiving station and the average cost of transshipping the milk to the main processing center. Average assembly cost to the receiving station and average transshipment costs increase with volume, while average cost of operating the receiving station decrease with volume. Thus, just as there is a minimum cost volume of assembling and processing, there is a minimum cost size receiving station.

As a first approximation, the marginal cost of adding a receiving station was based on the average cost of adding a least cost volume receiving station. It is a first approximation because it assumes that the total least cost volume of the receiving station is consistent with an overall least cost volume. If it isn't, the average cost of indirect shipment must be adjusted to reflect some lesser volume and the marginal cost decision criteria reapplied to see if the receiving station with less (or more) than least cost volume is still part of the least cost assembly set.

The average cost of operating a receiving station was estimated in Chapter IV. The average cost function was estimated to be:

$$AC^{RS} = .0257 + 21965\ V^{-1}$$

where:

AC^{RS}, is the average cost of operating a receiving station per 1,000 pounds of milk handled annually

V, is the volume of milk handled annually in 1,000 pounds

The average cost functions of assembling milk to the milk receiving station were taken to be the same as those for direct shipment to processing plants. They are listed on page 195.

The average cost of transshipping milk was developed from the data on plant-to-plant hauling costs given in Chapter III. Like the farm-to-plant assembly functions, the plant-to-plant hauling costs of Chapter IV were all treated as given and fixed except for those that varied with distance. The relevant distance of transshipment of milk for determining receiving station size is the distance to the periphery of the receiving station's assembly area. The unit cost of transporting the milk the remaining distance to the central processing plant contributes to marginal cost but not to the least cost volume receiving station. Its determination is taken up separately.

The annual fixed truck cost for the semi-trailer truck unit was estimated to be $8,858 in Chapter IV. This is equivalent to 23.45 per day. It was assumed that the average volume of a load was 42,000 pounds, 86 percent of the 49,000 pounds of capacity. This allowed for seasonality. It was further assumed that the tanker would haul three loads per day. Dividing the daily cost by 126,000 pounds yielded a fixed unit-cost for the tanker of $.186 per thousand pounds of milk.

The labor costs treated as fixed per load included fixed time at the processing plant and receiving station, pumping time, both loading and unloading, tank cleaning time and fixed driving time, the intercept portion of the plant-to-plant driving time function. The sum of the five cost factors is $.314 per thousand pounds of milk. It is the average fixed cost of transporting milk from a receiving station to a central processing plant. This does not include the variable cost of the truck or driver for actually transporting the milk over the road.

The variable truck cost per mile for the plant-to-plant tanker was estimated to be \$.1101 in Chapter IV. Variable driving labor per mile was estimated to be \$.0480 per mile. The sum of these two divided by 4,200 pounds per load yields a unit-cost of \$.00462 per thousand pound-mile.

The assumption has previously been made that the assembly area is diamond shaped and imposed on a square road grid system. The distance from the center of the area, the receiving plant location, to the periphery is related to volume by the equation:

$$\text{distance} = \frac{V^{.5}}{[(2)\ \text{density}]^{.5}}$$

This expression facilitated expressing the variable portion of transshipping costs to the periphery of the receiving station area, as a function of volume of the receiving station

$$VC = (2)\ (.00462)\ \frac{V^{.5}}{[(2)\ \text{density}]^{.5}}$$

where:

VC, is the variable unit-cost to the periphery of the area

V, is volume of milk assembled to the receiving station, in 1,000 pounds

The four densities were inserted into this function to get the following functions:

$$VC^{T}_{260} = .000405\ V^{.5}$$

$$VC^{T}_{130} = .000573\ V^{.5}$$

$$VC^{T}_{65} = .000809\ V^{.5}$$

$$VC^{T}_{32.5} = .001146\ V^{.5}$$

where:

VC^{T}, is the variable unit cost of transporting milk in plant-to-plant tankers to the periphery of the assembly area, in dollars per 1,000 pounds of milk

V, is volume of milk assembled to the receiving station, in 1,000 pounds

The combined average assembly cost, average receiving station operation cost and average transshipment to the periphery of the assembly area for the four densities are:

$$AC_{260} = \underbrace{.0257 + 21965\ V^{-1}}_{\text{receiving station}} + \underbrace{.3349\ V^{.1138}}_{\text{assembly}} + \underbrace{.314 + .000405\ V^{.5}}_{\text{transshipment to periphery}}$$

$$AC_{130} = .0257 + 21965\ V^{-1} + .2452\ V^{.1524} + .314 + .000573\ V^{.5}$$

$$AC_{65} = .0257 + 21965\ V^{-1} + .2131\ V^{.1767} + .314 + .000809\ V^{.5}$$

$$AC_{32.5} = .0257 + 21965\ V^{-1} + .1951\ V^{.2004} + .314 + .001146\ V^{.5}$$

where:

AC, is average cost assembling to the receiving station plus average cost of operating the receiving station plus transporting the milk to the periphery of the receiving station assembly area, in dollars

V, is the volume of the receiving station in 1,000 pounds of milk

The least cost point on a cost curve can be formed analytically by taking the first derivative, setting it to zero and solving for volume.[1/] With the above functions, however, there are complications in solving for volume once the derivative is taken. The method of solving for variables raised to an odd power is to take the log transforms. However, the functions are additive in the variable, volume, which precludes the use of log transforms.

As an alternative, the least cost volume was estimated by generating a series of solutions over a range of volumes and selecting that volume that had the lowest average cost associated with it. The approximate least cost volume and the accompanying average cost of the combined functions is shown in table 5.5.

The total average cost of indirect assembly also includes the cost of transporting the milk from the edge of the receiving station assembly area (which is assumed to be coincidental with the periphery of the direct assembly area) to the central processing plant. The same functions used to define the variable average cost of transshipping milk to the edge of the receiving station assembly area apply except that the appropriate volume, V, is the volume of the direct assembly area.

[1/] Assuming second order conditions hold.

Table 5.5. Least cost volume of milk and average cost of assembling milk to the receiving station plus average cost of operating the receiving station plus average cost of transporting the milk to the periphery of the receiving station assembly area.

Density (lbs./ sq. mile)	Least cost volume (thousand lbs.	Average cost (dollar/ thousand lbs.)
260,000	100,000	1.932
130,000	80,000	2.148
65,000	70,000	2.392
32,500	50,000	2.743

The first approximation to the marginal cost of indirect assembly for the four was estimated to be:

$$MC^{I.A.}_{260} = 1.932 + .000405\ V^{.5}$$

$$MC^{I.A.}_{130} = 2.148 + .000573\ V^{.5}$$

$$MC^{I.A.}_{65} = 2.392 + .000809\ V^{.5}$$

$$MC^{I.A.}_{32.5} = 2.743 + .001146\ V^{.5}$$

where:

$MC^{I.A.}$, is the marginal cost per 1,000 pounds of milk of adding indirect assembly[1/]

V, is the volume of the direct assembly area, in 1,000 pounds

Direct Versus Indirect Assembly

The marginal cost of direct assembly of milk was compared with the marginal cost of indirect assembly of milk for each of the four densities. In all four cases the marginal cost of extending the direct assembly area is less than the marginal cost of adding receiving stations for volumes of milk through 623 million pounds. In mathematical terms the following inequalities hold:

[1/] It should be remembered that this is the appropriate marginal cost only when the receiving station is operating at least cost volume.

260,000 density

$$1.932 + .000405\, V^{.5} > .2287\, V^{.1524}$$

130,000 density

$$2.148 + .000573\, V^{.5} > .1576\, V^{.1954}$$

65,000 density

$$2.392 + .000809\, V^{.5} > .1333\, V^{.2231}$$

32,500 density

$$2.743 + .001146\, V^{.5} > .1228\, V^{.2461}$$

$$0 \leq V \leq 623{,}000$$

That the inequalities hold, can be seen by comparing the marginal costs of direct and indirect assembly for the four densities summarized for various volumes in table 5.6. Even in the least dense case, 32,500 pounds per square mile, direct assembly of milk is clearly less costly than indirect assembly via receiving stations. At 623 million pounds of milk the marginal cost of expanding the direct assembly area is $3.275 per thousand pounds of milk where as the addition of a receiving station has a marginal cost $3.651 per thousand pounds of milk. Thus even for areas of low densities of milk production in Minnesota the use of receiving stations does not seem to be a practical alternative for least cost assembly of bulk handled milk.

Because of the infeasibility of indirect assembly of milk over the range of volumes considered in this study, the appropriate assembly patterns are all direct assembly. Yet to be analyzed is the feasibility of specialized milk drying plants that ship their cream production to large butter departments in other dairy plants

Table 5.6. Marginal cost of direct and indirect assembly of milk for four densities of milk production in Minnesota, 1970.

Volume	260,000 density M.C. direct	260,000 density M.C. indirect	130,000 density M.C. direct	130,000 density M.C. indirect	65,000 density M.C. direct	65,000 density M.C. indirect	32,500 density M.C. direct	32,500 density M.C. indirect
(thousand lbs.)	(dollars/thousand lbs.)							
50,000	1.175	2.023	1.305	2.276	1.478	2.573	1.761	3.000
100,000	1.322	2.060	1.495	2.329	1.724	2.648	2.088	3.107
150,000	1.406	2.089	1.617	2.370	1.740	2.705	2.306	3.189
200,000	1.469	2.113	1.712	2.404	2.030	2.754	2.476	3.258
250,000	1.520	2.135	1.787	2.435	2.114	2.797	2.616	3.373
300,000	1.563	2.154	1.853	2.462	2.222	2.835	2.736	3.373
350,000	1.600	2.172	1.909	2.487	2.299	2.871	2.842	3.424
400,000	1.634	2.188	1.959	2.510	2.370	2.904	2.939	2.371
450,000	1.663	2.204	2.005	2.532	2.433	2.935	3.023	3.515
500,000	1.690	2.218	2.036	2.553	2.490	2.964	3.102	3.557
550,000	1.714	2.232	2.085	2.573	2.543	2.992	3.176	3.596
600,000	1.737	2.246	2.121	2.592	2.594	3.019	3.246	3.634
623,000	1.747	2.252	2.137	2.600	2.615	3.030	3.275	2.651

and the least cost volume of processing and assembling of milk.

All of the functions have been developed to do this except a function to define the cost of shipping cream. This is considered in the next section.

Cream Shipment Costs

It was assumed that the same plant-to-plant tankers used to haul milk are used to haul cream. Therefore, the cream hauling costs are simply a transformation of the plant-to-plant milk hauling cost functions to reflect greater quantity of wholemilk equivalents of cream hauled in a tanker load. A 42,000 pound load of milk is about equivalent to a 480,000 pound load of wholemilk equivalents of cream.

The fixed unit cost of transporting milk in plant-to-plant tankers was calculated to be $.314 per thousand pounds of milk, assuming 42,000 pounds of milk per load. At 480,000 pounds of wholemilk equivalents of cream per load this becomes $.0275 per thousand pounds of wholemilk equivalents of cream.

The variable unit cost per mile for transporting milk in plant-to-plant tankers was estimated to be $.00462 per thousand pound-mile, assuming 42,000 pounds of milk per load. At 480,000 pounds of wholemilk equivalents of cream per load, this becomes $.000404 per thousand pound-mile of wholemilk equivalents of cream.

It was assumed that if cream is shipped to a butter department in another plant it travels twice as far as the distance from the powder plant to the periphery of its assembly area. The tanker then travels four times the distance from the plant to the periphery. The variable unit cost per mile was transformed into a cost-volume relationship by applying the following equation:

$$\text{Average cost of travel} = (4)\ (.000404)\ \frac{V^{.5}}{[(2)\ \text{density}]^{.5}}$$

For the four densities the specific functions for shipping cream are:

260,000 pounds/square mile density

$$AC^{S.C.}_{260} = .0275 + .0000709\ V^{.5}$$

130,000 pounds/square mile density

$$AC^{S.C.}_{130} = .0275 + .0001002\ V^{.5}$$

65,000 pounds/square mile density

$$AC^{S.C.}_{65} = .0275 + .0001417\ V^{.5}$$

32,500 pounds/square mile density

$$AC^{S.C.}_{32.5} = .0275 + .0002004\ V^{.5}$$

where:

$AC^{S.C.}$, is average cost per 1,000 pounds of wholemilk equivalents of cream, in dollars

V, is volume of milk received at the milk drying plant shipping cream, in 1,000 pounds

With the development of these functions, milk assembly and cream shipment, sufficient information exists to compare the average cost curves for the two processing systems postulated in Chapter I.

Combined Assembly and Processing Cost Functions

Direct assembly cost functions for the four densities were combined with the cost functions of two processing systems:

1. Plants processing milk receipts into butter and powder [B-P].
2. Plants processing milk receipts into powder and cream, shipping the cream to large butter departments where it is processed into butter [P-S_B-B].

The first system above is straight forward. The average assembly cost functions for the four densities were combined with the butter-powder plant long run average cost function estimated in Chapter III. The total long run average cost of assembling and processing of this system for selected volumes for the four densities is listed in table 5.7. This total long run average cost function for processing and assembly is also plotted in figures 5.4-5.7 for the four densities.

The second processing system, the specialized milk drying plant shipping cream to a large butter department involves several cost functions. The milk drying plant long run average cost function, estimated in Chapter III, was used for the specialized drying plant. The cream shipment functions, just estimated, were used for the appropriate density situation. The butter processing costs were assumed to the minimum processing cost estimated for a butter department in Chapter III. The total long run average cost of assembling and selected volumes for the

Table 5.7. The combined assembly and processing long run average costs for specialized milk drying plants with the butter department in another plant and for butter-powder plants for four densities of milk production in Minnesota, 1970.

Volume	260,000 lbs./ sq. mi.		130,000 lbs./ sq. mi.		65,000 lbs./ sq. mi.		32,500 lbs./ sq. mi.	
	A-P-S_c-B	A-B-P	A-P-S_c-B	A-B-P	A-P-S_c-B	A-B-P	A-P-S_c-B	A-B-P
(thousand lbs.)	(dollars/thousand lbs.)							
50,000	6.382	7.049	6.515	7.176	6.692	7.343	6.969	7.607
100,000	4.808	5.082	4.993	5.258	5.218	5.470	5.567	5.801
150,000	4.313	4.454	4.532	4.661	4.791	4.904	5.188	5.278
200,000	4.081	4.153	4.326	4.385	4.612	4.652	5.047	5.062
250,000	3.962	3.982	4.218	4.233	4.529	4.620	4.994	4.959
300,000	3.873	3.873	4.157	4.142	4.484	4.445	4.980	4.909
350,000	3.821	3.800	4.122	4.083	4.464	4.401	4.985	4.887
400,000	3.736	3.748	4.101	4.045	4.459	4.377	5.002	4.882
450,000	3.762	3.708	4.090	4.019	4.462	4.363	5.025	4.887
500,000	3.745	3.683	4.086	4.003	4.470	4.357	5.044	4.890
550,000	3.733	3.661	4.085	3.992	4.481	4.357	5.081	4.913
600,000	3.725	3.646	4.088	3.985	4.490	4.355	5.111	4.931
623,000	3.723	3.639	4.090	3.969	4.506	4.367	5.124	4.939

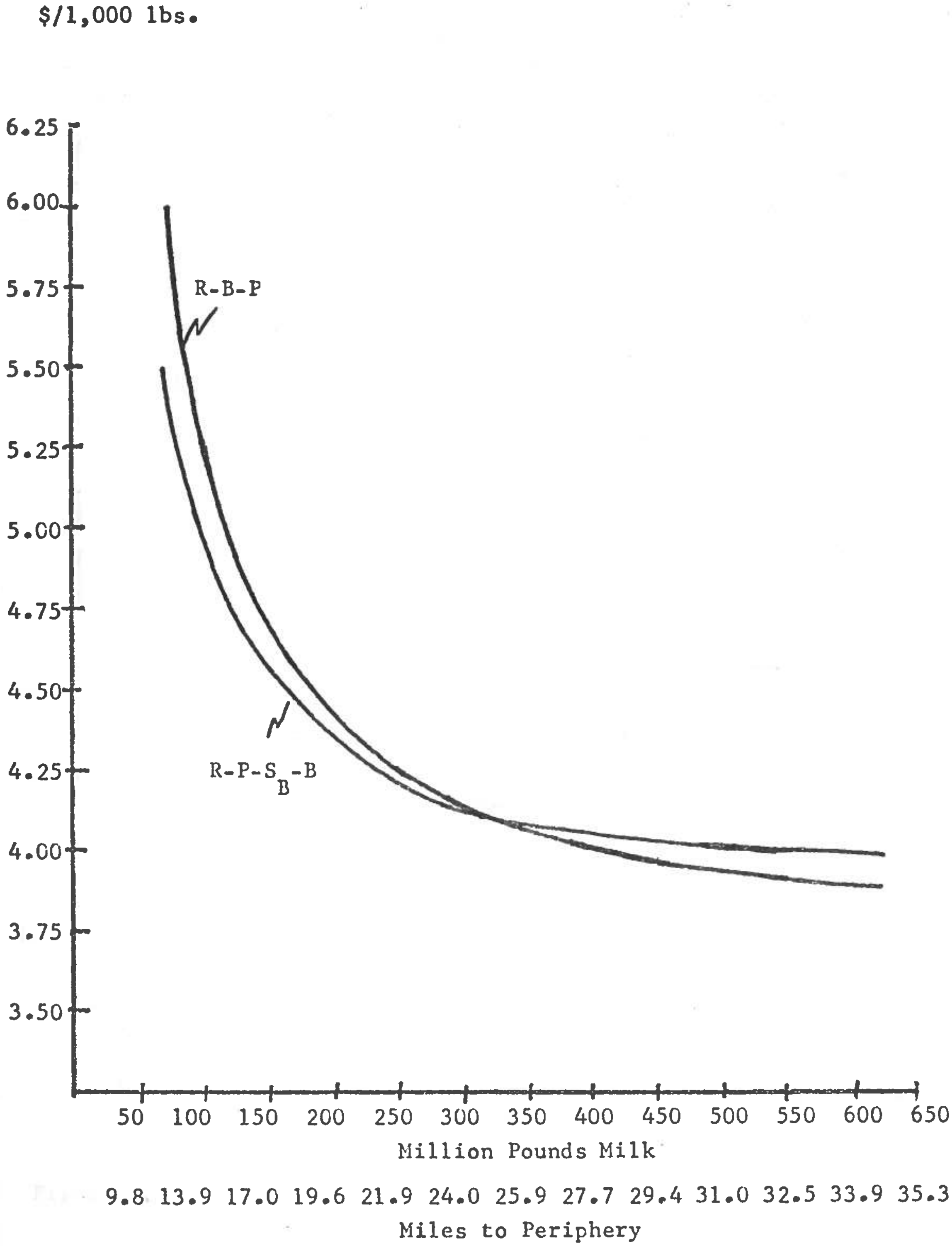

Figure 5.4. The combined assembly and processing average cost curves for specialized powder plants plus butter processing in least cost butter departments and for butter-powder plants for a density of 260,000 pounds of milk per square mile.

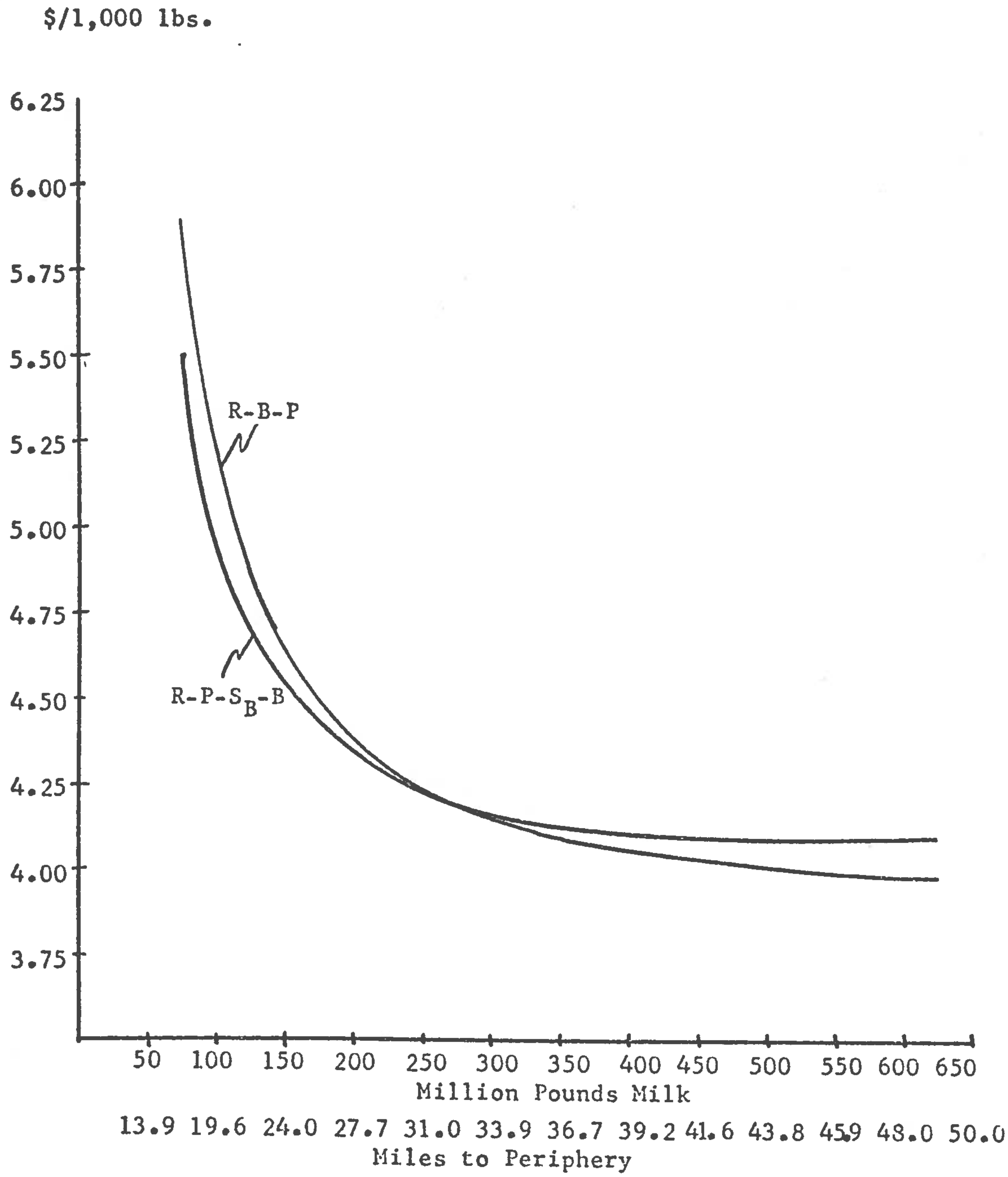

Figure 5.5. The combined assembly and processing average cost curves for specialized powder plants plus butter processing in least cost butter departments and for butter-powder plants for a density of 130,000 pounds of milk per square mile.

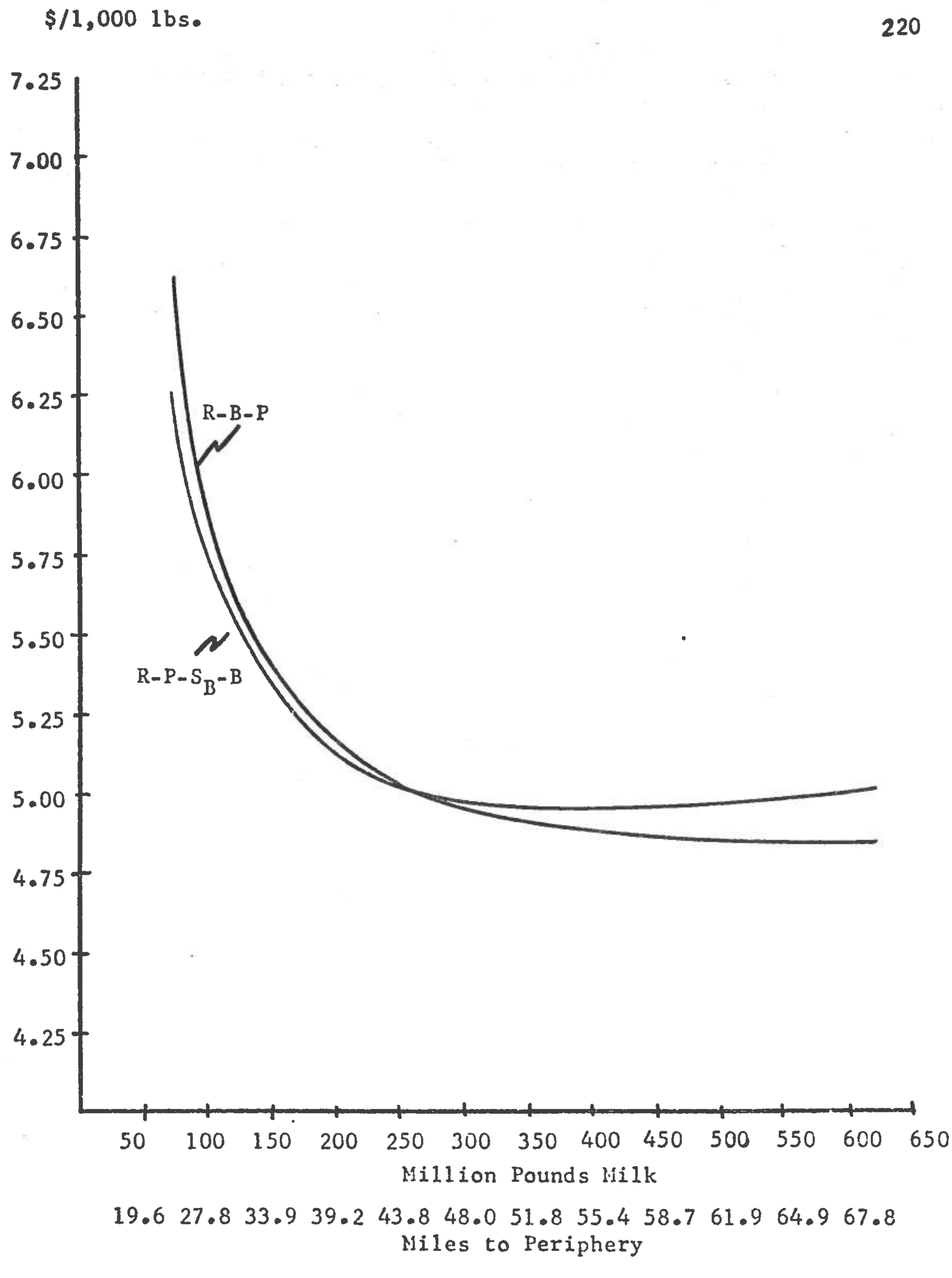

Figure 5.6. The combined assembly and processing average cost curves for specialized powder plants plus butter processing in least cost butter departments and for butter-powder plants for a density of 65,000 pounds of milk per square mile.

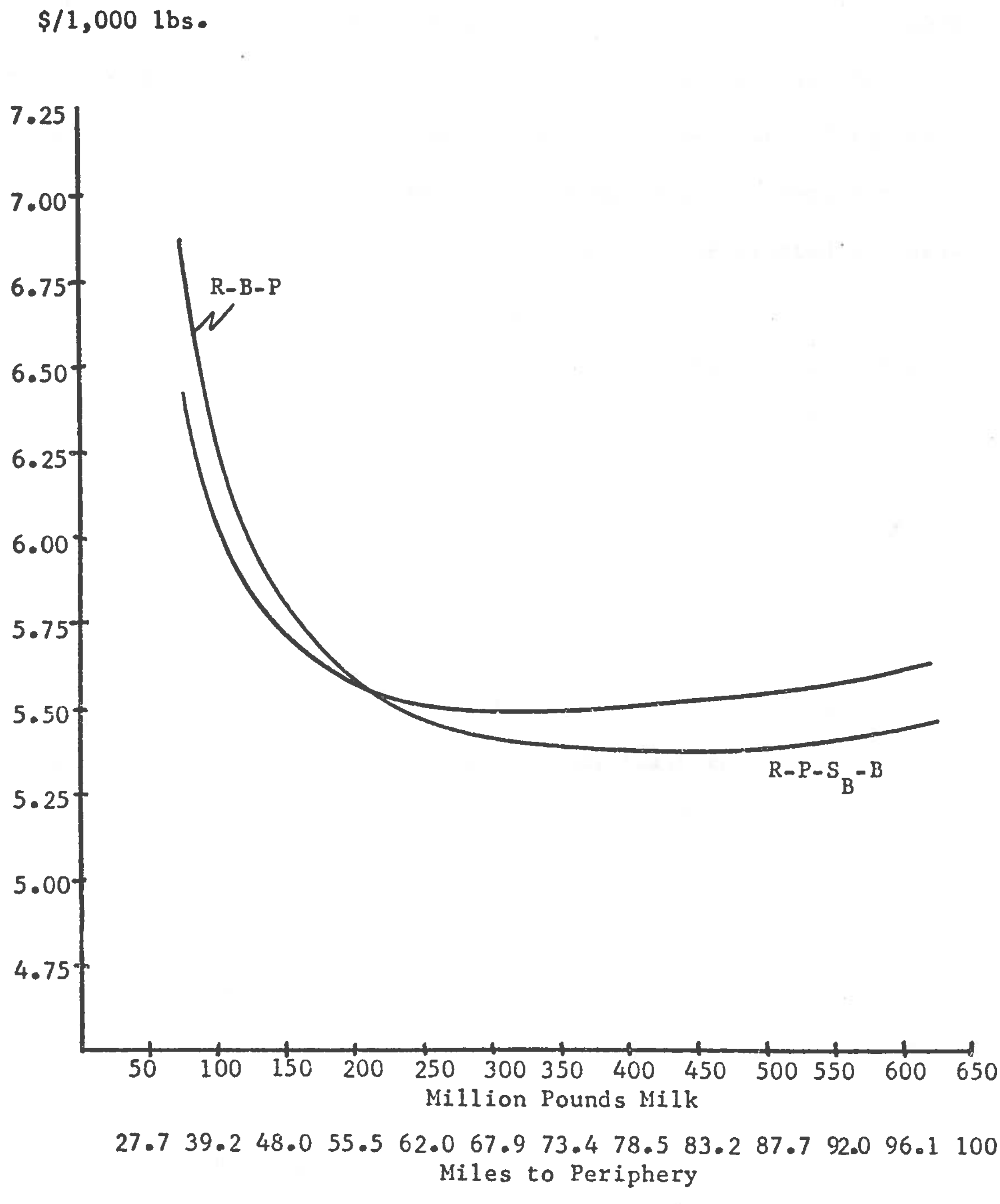

Figure 5.7. The combined assembly and processing average cost curves for specialized powder plants plus butter processing in least cost butter departments and for butter-powder plants for a density of 32,500 pounds of milk per square mile.

four densities is listed in table 5.7 along with the butter-powder plant costs. This total long run average cost function for processing and assembly is also plotted in figures 5.4-5.7 for the four densities. The assembly-processing long run average cost functions for the butter-powder plants are also plotted on these same graphs for comparative purposes.

Figures 5.4-5.7 also show the volume-distance from the plant to the edge of the assembly area relationships. The four graphs show the average assembly-processing cost-volume relationships for the two processing systems, they show the size of the assembly area for given volumes and they show the comparative total average cost of the two systems.

These four figures and table 5.7 show that the butter-powder plant system of processing achieves the least cost over a volume range of milk to 623 million pounds for all four milk production densities considered. In none of the four density cases does the assembly cost of milk rise fast enough to turn the assembly-processing average cost curves up at a low enough volume to justify shipping cream to a plant that can capture unused economies to scale in churning and printing.

The least cost volume for a butter-powder plant system in a 32,500 pounds of milk per square mile density region is about 400 million pounds of milk annually. The total average cost of assembling and processing at that volume is $4.882 per 1,000 pounds of milk. The distance from the plant to the periphery of the assembly area is about 78 miles. If the processing is organized with a specialized milk drying plant instead, the least cost volume for the drying plant occurs at a volume around 300 million pounds of milk annually. The average cost of this system at 300 million pounds is $4.980 per 1,000 pounds of milk. The minimum average cost of assembly and processing for the specialized drying plant system is $.098 per 1,000 pounds higher than the minimum average cost of assembly and processing for the butter-powder plant system.

The least cost volume for a butter-powder plant system in a 65,000 pounds of milk per square mile density region is about 600 million pounds of milk annually. The total average cost of assembling and processing at the volume is $4.355 per 1,000 pounds of milk. The distance from the plant to the periphery of the assembly area is about 68 miles. If the processing is organized with a specialized milk drying plant instead, the least cost volume for the drying plant occurs at a volume around 400 million pounds of milk annually. The average cost of this system at 400 million pounds is $4.459 per 1,000 pounds of milk. The minimum average cost of assembling and processing for the specialized drying plant system is $.104 per 1,000 pounds higher than the minimum average cost of assembly and processing for the butter-powder plant system.

The least cost volume for a butter-powder plant system in a 130,000 pounds of milk per square mile density region is about 623 million pounds of milk, the maximum volume considered in this study. The total average cost of assembling and processing at that volume is $3.969 per 1,000 pounds of milk. The distance from the plant to the periphery of the assembly area is about 49 miles. If the processing is organized with a specialized milk drying plant instead, the least cost volume for the drying plant occurs at a volume around 550 million pounds of milk annually. The average cost of this system at 550 million pounds is $4.085 per 1,000 pounds of milk. The minimum average cost of assembling and processing for the specialized drying plant system is $.119 per 1,000 pounds higher than the minimum average cost of assembly and processing for the butter-powder plant system.

The least cost volume for a butter-powder plant system in a 260,000 pounds of milk per square mile density region is at 623 million pounds of milk, the maximum volume considered in this study. The greatly increasing average assembly cost at this density level is not great enough to offset the decreasing cost of processing even at the maximum volume estimated. The total average cost of assembly and processing at that volume is $3.639 per 1,000 pounds of milk. The distance from the plant to the periphery of the assembly area is about 34 miles. The total average cost of assembly and processing for a system with specialized drying plants is also still falling at a maximum volume of 623 million pounds of milk. This type of system costs $.04 per 1,000 pounds more than the butter-powder system. This is the cost of transporting the cream.

Although the butter-powder plant system is the least cost system at the optimum volume, there is a volume range where the specialized milk drying plant system has lower average costs than the butter-powder plant system. For the 32,500 pounds per square mile density region, the specialized milk drying system is lower cost than the butter-powder plant system at volumes below 200 million pounds annually. For the 65,000 pounds of milk per square mile this is true below volumes of 250 million pounds of milk annually. For the 130,000 pounds of milk per square mile density it is true below 275 million pounds of milk annually and for the 160,000 pounds of milk per square mile density it is true below 300 million pounds of milk annually. Plants that fall in these volume ranges and cannot expand their volume for one reason or another may want to consider shipping their cream rather than installing churning and printing equipment.

Another important characteristic of these total average cost functions for assembly and processing is their almost flat shape over a wide volume range in the vicinity of the least cost volume. For at least the lower three density regions there is a volume range of about 250-300 million pounds over which cost does not vary five cents per 1,000 pounds at the most. This flatness means that local conditions assumed away in this analysis will be important in making decisions about size and type of plant in specific situations.

The shape of the overall combined average cost functions also provide some insights. The total average cost functions for assembly and processing for both types of processing organization fall rapidly in the lower volume ranges for all densities. The economies to scale considering both processing and assembly are substantial at least to volumes around 300 million for both processing systems and all four densities. The least dense region, 32,500 pounds of milk per square mile, can effect at most a savings of two cents per 1,000 pounds for some volumes over 300 million pounds. The next density region, 65,000 pounds of milk per square mile, can achieve at most a savings of seven cents per 1,000 pounds for some volumes over 300 million pounds. The second most dense region, 130,000 pounds of milk per square mile, can achieve a savings of only nine cents per 1,000 pounds by doubling its volume from 300 million pounds. The most dense region, 260,000 pounds of milk per square mile, shows moderate savings beyond 300 million pounds of milk. At the maximum volume considered the butter-powder plant system shows savings of 24 cents per 1,000 pounds over 300 million pounds.

This analysis points strongly to the fact that plants with an annual volume much below 300 million pounds annually are too small to achieve competitive processing costs under most Minnesota milk production densities. For plants over 300 million pounds annually, the density of the assembly area becomes important in determining the economically efficient size butter-powder plant. For many densities there is a wide volume range above 300 million pounds of milk annually within which average cost of assembly and processing is at a practical minimum.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The butter-powder sector of the manufacturing milk industry of Minnesota is undergoing adjustment to a series of technological improvements. The introduction of new high speed soft butter printers and continuous butter churns has made it highly desirable to combine churning and printing in the same plant and continuous operation. Other milk processing equipment, especially milk evaporators and dryers, have become more automated and better engineered. This in turn has encouraged the adoption of higher capacity, more efficient, more dependable processing equipment. The switch from can handling of milk on the farm to bulk handling, which has experienced a steady upward trend, is expected to increase further because of impending new milk sanitation regulations. In addition to an increase in bulk handling, higher capacity bulk trucks are being adapted for use in assembling bulk handled milk.

In light of these technological changes and possible effect on the structure of the industry three broad objectives were established and dealt with in this study. The first was to determine the long run cost relationships for processing milk into butter and nonfat dry milk. The second was to estimate the long run cost relationships for collecting milk in bulk trucks and transporting milk and cream between plants. The third was to determine the combined long run cost relationships for assembly and processing of milk into butter and nonfat dry milk for: (a) alternative processing systems and (b) various milk production density patterns.

Two processing systems were evaluated. One is the traditional butter-powder plant where milk receipts are processed into butter and nonfat dry milk in the same plant. The other is a system involving a specialized milk drying plant where the milk receipts are processed into nonfat dry milk and cream. The cream is shipped to a large butter department in another plant where economies to scale in churning and printing are achieved in processing the cream.

Four milk production density patterns were used in evaluating the above two processing systems. They are annual milk production densities of 260,000, 130,000, 65,000 and 32,500 pounds of whole-milk per square mile.

The processing costs were estimated by the economic engineering method. This method was selected because of a lack of good plant operating cost data and the value of this method in synthesizing alternative processing and assembly systems.

Six specialized milk drying plants were synthesized within the volume range of 78 to 623 million pounds of milk annually. Six butter departments designed as additions to milk drying plants were estimated for similar volumes. The butter departments were designed and the costs estimated in a manner such that their processing capacity could be independent of the milk receipts of the accompanying drying operation. The butter departments could receive cream from specialized milk drying plants.

An envelope function was fitted to the short run average cost functions for the six drying plants to estimate the long run average cost function for milk drying plants. The same procedure was followed for the six butter departments in estimating the long run average cost function for butter departments. These two long run average cost functions were appropriately combined to form the long run average cost function for butter-powder plants.

The cost of assembly of bulk milk to processing plants was estimated by synthesizing the costs of milk collection routes radiating out from the plant in various size diamond shaped assembly areas. Both direct farm-to-plant assembly and indirect assembly via transshipping milk through milk receiving stations and transporting it in plant-to-plant semi-trailer tank trucks were estimated. The cost relationships for the many factors required in milk collecting and hauling for farm-to-plant trucks, receiving stations and plant-to-plant trucks were estimated to provide the needed cost relationships for determining direct and indirect cost-volume milk assembly functions.

The farm-to-plant collecting and hauling costs were divided into truck costs, labor costs and administrative costs. Cost relationships were estimated separately for each of these categories. The physical data for the labor costs were obtained from a detailed time and motion study of fifteen different country milk routes.

The cost-volume relationship for the receiving station was estimated by synthesizing a bulk milk receiving station. The plant-to-plant hauling cost estimates were developed from two previous studies.

For farm-to-plant milk assembly, the costs at the plant and on the route were fixed. The variable costs were those created in going and coming from the routes. The size and shape of routes for four densities were determined by plotting a series of sample routes. The average shaped route for each density was added in tiers around the plant in a diamond shaped pattern. The unit cost of assembling from each tier was determined as well as the cumulation volume by tiers. Power functions were fitted to the cost-volume relationships for the successive tiers of routes to estimate continuous assembly cost-volume relationships for direct, farm-to-plant, assembly of milk. This was done for each of the four densities.

The indirect cost of assembly was estimated for a least cost-volume receiving station. The farm-to-plant average cost-volume assembly function, the receiving station average cost-volume function and the plant-to-plant average cost-volume functions were appropriately summed to give a total average cost-volume function for assembling milk to a receiving station and transporting it to the processing plant.

The assembly average cost-volume functions, the processing average cost-volume functions and the cream shipment average cost-volume functions were appropriately combined to produce total average cost functions for milk assembly and processing for the two processing systems under the farm milk production density patterns. From these functions the least cost type of plants, size of plants and size of assembly areas for the farm density patterns were determined.

Summary of Results

The estimated long run average cost functions for processing operations all showed economies to scale.

The long run average cost function for milk drying plants ranged from $3.67 per 1,000 pounds of milk at a volume of 78 million pounds annually to $1.79 per 1,000 pounds at a volume of 623 million pounds annually. The major economies to scale occurred in the lower half of the volume range. The average cost at 300 million pounds is $2.08 per 1,000 pounds of milk. This is $1.59 less per 1,000 than $3.67, the average cost at 78 million pounds, and only $.29 per 1,000 greater than $1.79, the average cost at 623 million pounds.

The long run average cost function for butter departments ranged from $.75 per 1,000 pounds of wholemilk equivalents of cream at 78 million pounds annually to $.32 per 1,000 pounds at 623 million pounds annually. The major economies to scale for the butter departments also occur in the lower half of the volume range. The average cost at 300 million pounds is $.39 per 1,000 pounds of wholemilk equivalents of cream. This is $.36 per 1,000 less than $.75, the average cost at 78 million pounds, and only

$.07 per 1,000 greater than $.32, the average cost at 623 million pounds.

The long run average cost function for butter-powder plants is simply the combination of the two long run average cost functions above. The same characteristics are exhibited by it that are exhibited by the two functions separately.

The estimated farm-to-plant average cost-volume functions for assembling milk exhibit increasing costs but at a decreasing rate. They also exhibit increasing costs with decreases in milk production densities. The average costs of farm-to-plant assembly for 100 million pounds of milk annually were estimated at $1.24, $1.42, $1.63 and $1.96 per 1,000 pounds of milk for milk production densities of 260,000, 130,000, 65,000 and 32,500 pounds per square mile, respectively. The average costs for 350 million pounds of milk were estimated at $1.43, $1.71, $2.03 and $2.52 per 1,000 pounds of milk for the same four densities. At the maximum volume considered, 623 million pounds, the average costs of assembly were estimated at $1.53, $1.87, $2.26 and $2.83 per 1,000 pounds of milk for the same four densities.

The marginal cost of adding a receiving station was greater than the marginal cost of direct-assembly at all volumes considered in this study. The marginal cost of direct assembly at 623 million pounds if $3.28 per 1,000 pounds of milk for the least dense pattern. The marginal cost of adding a receiving station with a least cost volume of 50 million pounds annually to the periphery of the assembly area of 600 million pounds was estimated at $3.63

per 1,000 pounds. The same relationship between direct and indirect marginal assembly costs hold for the more dense milk production patterns but the difference is even stronger in favor of direct assembly.

The least cost processing system of the two evaluated is the butter-powder plant system for all four densities. The potential unused economies in churning and printing that remain at the least cost volume of specialized drying is not great enough to pay the cost of shipping cream and still show a savings over the costs of a comparable butter-powder plant system.

The long run average cost of assembly and processing is $4.88 per 1,000 pounds of milk for a butter-powder plant processing 400 million pounds of milk annually, the approximate least cost volume, in a milk production area of 32,500 pounds per square mile. In a milk density area of 65,000 pounds per square mile, the average cost is $4.36 per 1,000 pounds at the approximate least cost volume of 600 million pounds. In a milk density area of 130,000 pounds per square mile the average cost is $3.97 per 1,000 pounds at the approximate least cost volume of 622 million pounds. In a milk density area of 260,000 pounds per square mile the average cost of assembly and processing doesn't turn up in the volume range through 623 million pounds. The function is relatively shallow in this volume range indicating there are only modest potential economies remaining. The average cost of assembly and processing at 623 million pounds is $3.64 per 1,000 pounds of milk.

Hypothesis Testing

This study was guided by a general hypothesis and three sub-hypotheses. The general hypothesis relies on the sub-hypotheses so they are discussed first. Sub-hypothesis one was:

> Plants with relatively large volumes of wholemilk can manufacture nonfat dry milk and/or butter at significantly lower costs than plants with small volumes.

This sub-hypothesis was substantiated by this study. The long run average cost functions for milk drying plants, butter departments and butter-powder plants declined throughout the volume range of 78 million to 623 million pounds of wholemilk equivalents annually. The decline was greatest in the lower volume range.

Sub-hypothesis two was:

> The unit cost of assembling milk increases as the size of the assembly area increases and declines as the density of milk production in the area increases.

This sub-hypothesis was substantiated by this study. The average cost of assembling milk increased at a decreasing rate through a volume of 623 million pounds annually. This was on the basis of uniform density in the region, an approximate square grid road system and an assembly area that expanded away from the plant in a diamond shape as volume increased.

Assembly functions were estimated for four different densities. The results show that higher densities have lower costs for assembling milk than lower densities at any given volume.

Sub-hypothesis three is:

> The cost of transporting cream, on a wholemilk equivalent basis, is significantly less than transporting wholemilk.

The results of this study are unclear with respect to this hypothesis. The study did show that the unit cost of shipping cream is considerably less than shipping wholemilk when the same unit, 1,000 pounds of wholemilk equivalents is used. However, for the densities considered it wasn't significant because shipping cream wasn't included in the least cost set of solutions which brings us to the general hypothesis.

The general hypothesis was:

> The volume of a milk processing plant and the density of milk production in its assembly area determine if nonfat dry milk and butter manufacturing can be most economically carried on in the same plant.

The results of this study failed to prove or disprove this hypothesis. The proof of the sub-hypotheses provide evidence of the truth of this hypothesis, economies to scale for processing for both nonfat dry milk and butter, rising average costs assembly with increases in volume and decreases in density of milk production and the substantially lower cost of transporting cream than wholemilk on an equivalency basis. However, for the range of densities considered realistic to Minnesota, the same type of processing plants were always butter-powder plants, in the least cost solution set. However, there is a volume range below the least cost volume where a system of specialized milk drying plants and large butter departments is less costly than combined butter-powder plants. To fully prove this hypothesis, assembly functions for milk production densities below those used in this study would have to be estimated and integrated into the processing cost functions. This will be left as a challenge to some researcher in the future.

General Conclusions

Based on the specific results already stated some broad general conclusions can be stated:

1. Indirect milk assembly via bulk milk receiving stations is a more costly method of assembling milk than direct assembly under most Minnesota milk production conditions.
2. In the long run butter-powder plant systems processing milk into butter and nonfat dry milk are the least cost type plants under most Minnesota milk production conditions.
3. In the long run careful consideration should be given to all factors before building a processing plant with a capacity below 300 million pounds of milk annually.
4. Dairy cooperative management should give attention to cost efficiencies in both processing and assembly. Increasing processing volume by increasing the effective density of a supply area through mergers of cooperatives with overlapping supply areas is economically superior to increasing processing volume by merging cooperatives with non-overlapping supply areas.

These conclusions have important implications to the dairy industry of Minnesota. The cost saving potential of large butter-powder plants, large relative to what exist currently, will all but eliminate the "local" dairy processing plant from the Minnesota scene. The members of the "local" creameries, receiving stations or small butter-powder plants will find the foregone cost savings of shipping direct to a large regional plant, perhaps up to 70 miles or more away, too great a price to pay for maintaining their "local" plant, even taking into account the strong sentiment in favor of the "locals." Based on the results of this study 15 to 20 butter-powder plants will be able to provide an efficient milk assembly and processing system for the state. This will still allow for some assembly area overlap.

This structure can only be achieved by the merger and consolidation of the approximately 300 plants of one type or another that currently exist. This consolidation will require a great deal of administrative skill and energy. Butter-powder plant volume increases in the past have tended to result from the purchase of the milk supply of independent receiving stations with little regard for assembly efficiency. This cannot continue without damaging the performance of the industry. Further mergers, and there will be many, will have to be made on the basis of both assembly and processing cost efficiencies.

Plant managers will have to give more attention to assembly costs than they have in the past, even beyond merger considerations. The problems of coordinating a large fleet of farm-to-plant bulk trucks has not existed in the manufacturing milk industry of Minnesota before. Managers will have to work hard at accumulating the background of experiences which will allow them to efficiently manage large assembly systems.

Managers will also have to give more attention to patron relationships and education. The short informal communication lines that exist for the small "locals" require little or no special effort on the part of management to communicate with the patrons. With the development of plants and assembly patterns of the size recommended by this study, the short informal communication lines will no longer exist. Managers will have to develop special skills and programs for communicating with the member patrons.

The conclusions of this study have implications beyond the manufacturing milk industry to the rural communities in general. The local dairy plants are usually a vital economic force in the many small rural communities in which they are located. The elimination of the vast majority of these will seriously impare the economic health of the small communities that lose them. On the other hand, those communities in which the large remaining plants are located will benefit greatly from their presence.

The effects of technological change on the manufacturing milk industry of Minnesota and the communities in which the processing plants operate will continue to have great structural consequences. The economic forces discussed in this study are sure to bring larger and fewer butter-powder plants.

APPENDIX

Appendix Table A.1 Estimated life, installed cost, and annual depreciation for equipment in six drying plants in Minnesota, 1970.

Plant 1, maximum volume 78.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
Receiving center			
Pump for unloading tank trucks	10	920	92
Platform scale for weighing trucks	20	6,000	300
Circulating tank truck washer	10	1,200	120
Spray ball and accessories	10	860	86
Milk and cream storage, silo tanks @.80 per gallon	20	25,360	1,258
Miscellaneous	10	1,480	148
Separator pasteurizer center			
Separator, 20,000 lbs./bu.	10	12,650	1,265
Pump	10	410	41
Pasteurizer, plate complex	10	11,345	1,135
CIP system	10	5,000	500
Evaporator-dryer center			
Double effect evaporator (12,000 lbs./hour skim in feed)	10	96,800	9,680
Vertical spray dryer (1000 lbs. powder per hour)	10	130,000	13,000
Miscellaneous (hoses, testers etc.)	10	1,385	139

Appendix Table A.1 (continued)

Plant 1, maximum volume 78.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
General service center			
Complement of shop equipment	10	1,200	120
Spare parts	10	2,500	250
Personal convenience, includes lockers, chains, tables, etc.	10	1,000	100
Office center			
Complement of office equipment	10	12,000	1,200

Appendix Table A.1 (continued)

Plant 2, maximum volume of 156.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost	Annual Depreciation
		(dollars)	
Receiving center			
Pump for unloading	10	920	92
Platform scale for weighing trucks	20	6,000	300
Circulating tank truck washer	10	1,200	120
Spray ball and accessories	10	860	86
Milk and cream storage, silo tanks @.80 per gallon	20	50,640	2,532
Miscellaneous	10	1,480	148
Separator pasteurizer center			
Separator, 27,000 lbs./hour	10	29,000	2,900
Pump	10	410	41
Pasteurizer, plate complex	10	14,560	1,456
CIP system	10	5,400	540
Evaporator-dryer center			
Double effect evaporator (25,000 lbs./hour skim in feed)	10	129,000	12,900
Vertical spray dryer (2,000 lbs. powder/hour)	10	150,000	15,000
Miscellaneous (hoses, testers, etc.)	10	1,385	139

Appendix Table A.1 (continued)

Plant 2, maximum volume of 156.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
Powder packaging and warehouse center			
Air compressor	10	800	80
Scale	10	857	86
Vacuum cleaner	10	366	37
Powder pump	10	6,846	685
Powder hopper	15	9,420	628
Powder packer	15	5,460	364
Automatic sewing machine	5	2,553	510
Lock lift truck	10	7,527	753
Hand lift truck	10	463	46
Laboratory center			
Standard complement of dairy laboratory equipment	15	9,000	600
Refrigeration center			
Self contained ice builder and chest, 1.5 H.P.	10	3,500	350
Boiler center			
Gas fired boiler, 300 H.P. (2)	15	50,000	3,333
Condensed cow water storage tank	15	5,384	359
Pressure supply tank, hot water pump and chemical feed unit	15	1,612	107

Appendix Table A.1 (continued)

Plant 2, maximum volume of 156.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
General service center			
Complement of shop equipment	10	1,200	120
Spare parts	10	3,000	300
Personal convenience	10	1,000	100
Office			
Complement of office equipment	10	12,000	1,200

Appendix Table A.1 (continued)

Plant 3, maximum volume of 233.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation
Receiving center			
Pump for unloading trucks (2)	10	1,840	184
Platform scale for weighing trucks	20	10,000	500
Circulating tank truck washer (2)	10	2,400	240
Spray ball and accessories (2)	10	1,720	172
Milk and cream storage, silo tanks, @.80 per gallon	20	75,920	3,796
Miscellaneous	10	1,680	168
Separator pasteurizer center			
Separator, 50,000 lbs./hour	10	57,500	5,750
Pump	10	410	41
Pasteurizer, plate complex	10	20,880	2,088
CIP system	10	5,800	580
Evaporator-dryer center			
Triple effect evaporator (35,000 lbs. / hour skim in feed)	10	180,400	18,040
Vertical spray dryer (3000 lbs. powder per hour)	10	175,000	17,500
Miscellaneous (hoses, testers, etc.)	10	1,385	139

Appendix Table A.1 (continued)

Plant 3, maximum volume of 233.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
Powder packaging and warehouse center			
Air compressor	10	800	80
Scale	10	857	86
Vacuum cleaner	10	366	37
Fork lift truck	10	7,527	753
Hand fork truck	10	463	46
Automatic bagger, includes hoppers, scales, bag conveyor, sewing machine	10	40,000	4,000
Laboratory center			
Standard complement of dairy laboratory equipment	15	9,000	600
Refrigeration center			
Self contained ice builder and chest, 1.5 H.P.	10	3,500	350
Boiler center			
Gas fired boiler, 350 H.P. (2)	15	54,000	3,600
Condensed cow water storage tank	15	5,384	359
Pressure supply tank, hot water pump and chemical feed unit	15	1,612	107

Appendix Table A.1 (continued)

Plant 3, maximum volume of 233.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation
General service center			
Complement of shop equipment	10	1,200	120
Spare parts	10	3,500	350
Personal convenience, includes lockers, tables chairs, etc.	10	1,500	150
Office center			
Complement of office equipment	10	14,000	1,400

Appendix Table A.1 (continued)

Plant 4, maximum volume of 311.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
Receiving center			
Pumps for unloading tank trucks (3)	10	2,760	276
Platform scale for weighing trucks	20	10,000	500
Circulating tank truck washer (3)	10	3,600	360
Spray ball and accessories (3)	10	2,580	258
Milk and cream storage, silo tanks @.80 per gallon	20	101,280	5,064
Miscellaneous	10	1,780	178
Separator pasteurizer center			
Separator, 50,000 lbs./hour	10	57,500	5,750
Pump	10	410	41
Pasteurizer, plate complex	10	20,880	2,088
CIP system	10	6,200	620
Evaporator-dryer center			
Triple effect evaporator (40,000 lbs./hour skim in feed)	10	213,400	21,340
Vertical spray dryer (4000 lbs. powder per hour)	10	225,000	22,500
Miscellaneous (hoses, testers, etc.)	10	1,385	139

Appendix Table A.1 (continued)

Plant 4, maximum volume of 311.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
Powder packaging and warehousing center			
Air compressor	10	800	80
Scale	10	857	86
Vacuum cleaner	10	336	37
Fork lift truck	10	7,527	753
Hand fork truck	10	463	46
Automatic bagger includes hoppers, scales, bag conveyor, sewing machine	10	40,000	4,000
Laboratory center			
Standard complement of dairy laboratory equipment	15	9,000	600
Refrigeration center			
Self contained ice builder and chest 2 H.P.	10	3,775	378
Boiler center			
Gas fired boiler, 400 H.P. (2)	15	58,000	3,867
Condensed cow water storage tank	15	5,384	359
Pressure supply tank, hot water pump and chemical feed unit	15	1,612	107

Appendix Table A.1 (continued)

Plant 4, maximum volume of 311.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
General service center			
Complement of shop equipment	10	1,200	120
Spare parts	10	4,000	400
Personal convenience, includes lockers, chairs, tables, etc.	10	1,500	150
Office center			
Complement of office equipment	10	16,000	1,600

Appendix Table A.1 (continued)

Plant 5, maximum volume 467.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation
Receiving center			
Pumps for unloading tank trucks (5)	10	4,600	460
Platform scale for weighing trucks	20	10,000	500
Circulating tank truck washer (4)	10	4,800	480
Spray ball and accessories (4)	10	3,640	364
Milk and cream storage, silo tanks ¢ .80 per gallon	20	143,840	7,192
Miscellaneous	10	1,980	198
Separator pasteurizer center			
Separators, 50,000 lbs./ hour and 33,000 lbs./bu.	10	90,500	9,050
Pump	10	476	48
Pasteurizer, plate complex	10	31,320	3,132
CIP system	10	7,000	700
Evaporator-dryer center			
Quadruple effect evaporator (75,000 lbs./hour skim in feed)	10	334,400	33,440
Vertical spray dryer (6000 Lbs. powder per hour)	10	280,000	28,000
Miscellaneous	10	1,385	139

Appendix Table A.1 (continued)

Plant 5, maximum volume 467.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
Powder packaging and warehouse center			
Air compressor	10	800	80
Scale	10	857	86
Vacuum cleaner	10	366	37
Fork lift truck	10	7,527	753
Hand fork truck	10	463	46
Automatic bagger, includes hoppers scales, bag conveyor, sewing machine	10	40,000	4,000
Laboratory center			
Standard complement of dairy laboratory equipment	15	9,000	600
Refrigeration center			
Self contained ice builder and chest 3 H.P.	10	4,400	440
Boiler center			
Gas fired boiler, 600 H.P. (2)	15	68,000	4,533
Condensed cow water storage tank	15	5,384	359
Pressure supply tank, hot water pump and chemical feed unit	15	1,612	107

Appendix Table A.1 (continued)

Plant 5, maximum volume 467.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
General service center			
Complement of shop equipment	10	1,200	120
Spare parts	10	4,500	450
Personal convenience, includes lockers, chairs, tables, etc.	10	2,000	200
Office center			
Complement of office equipment	10	18,000	1,800

Appendix Table A.1 (continued)

Plant 6, maximum volume 623.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation
Powder packaging and warehouse center			
Air compressor	10	800	80
Scale	10	857	86
Vacuum cleaner	10	366	37
Fork lift truck	10	7,527	753
Hand fork truck	10	463	46
Automatic bagger, includes hoppers bag conveyor, sewing machine	10	40,000	4,000
Laboratory center			
Standard complement of dairy laboratory equipment	10	9,000	600
Refrigeration center			
Self contained ice builder and chest 7.5 H.P.	10	6,525	653
Boiler center			
Gas fired boiler, 750 H.P. (2)	15	80,000	5,333
Condensed cow water storage tank	15	5,384	359
Pressure supply tank, hot water pump and chemical feed unit	15	1,612	107

Appendix Table A.1 (continued)

Plant 6, maximum volume 623.0 million pounds whole milk

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
General service center			
Complement of shop equipment	10	1,200	120
Spare parts	10	5,000	500
Personal convenience, includes lockers, chairs, tables, etc.	10	2,000	200
Office center			
Complement of office equipment	10	20,000	2,000

Appendix Table A.2. Construction costs by centers for drying plant of 78 million pounds wholemilk capacity.

Center	Area (sq. ft.)	Unit Cost	Total Cost	Annual Depre. Cost (dollars)	Other Annual Bldg. Costs	Annual Bldg. Costs
Receiving	700	10.00	7,000	350	483	833
Separating-Pasteurizing	400	20.00	8,000	400	552	952
Evaporating-Drying	1,413		40,650	2,033	2,799	4,832
Powder Warehousing	3,000	10.00	30,000	1,500	2,070	3,570
Laboratory	240	20.00	4,800	240	331	571
Boiler	1,400	10.00	14,000	700	966	1,666
Office	500	20.00	10,000	500	690	1,190
General Service	680	10.00	6,800	340	470	810
Locker and Lunch	280	15.00	4,200	210	290	500
Total	8,613					14,924

Appendix Table A.3. Construction costs by centers for drying plant of 156 million pounds wholemilk capacity.

Center	Area (sq. ft.)	Unit Cost	Total Cost	Annual Depre. Cost (dollars)	Other Annual Bldg. Costs	Annual Bldg. Costs
Receiving	700	10.00	7,000	350	483	833
Separating-Pasteurizing	400	20.00	8,000	400	552	952
Evaporating-Drying	1,498		46,145	2,307	3,184	5,491
Powder Warehousing	6,000	9.50	57,000	2,800	4,140	6,940
Laboratory	240	20.00	4,800	240	331	571
Boiler	1,400	10.00	14,000	700	966	1,666
Office	500	20.00	10,000	500	690	1,190
General Service	680	10.00	6,800	340	470	810
Locker and Lunch	280	15.00	4,200	210	290	500
Total	11,898					18,953

Appendix Table A.4. Construction costs by centers for drying plant of 233 million pounds wholemilk capacity.

Center	Area (sq. ft.)	Unit Cost	Total Cost	Annual Depre. Cost (dollars)	Other Annual Bldg. Costs	Annual Bldg. Costs
Receiving	1,392	10.00	13,920	696	960	1,656
Separating-Pasteurizing	500	20.00	10,000	500	690	1,190
Evaporating-Drying	1,613		56,780	2,839	3,918	6,757
Powder Warehousing	9,000	9.00	81,000	4,050	6,210	10,460
Laboratory	240	20.00	4,800	240	331	571
Boiler	1,600	10.00	16,000	800	1,104	1,904
Office	600	20.00	12,000	600	828	1,428
General Service	680	10.00	6,800	340	470	810
Locker and Lunch	360	15.00	5,400	270	373	643
Total	15,985					25,419

Appendix Table A.5. Construction costs by centers for drying plant of 311 million pounds wholemilk capacity.

Center	Area (sq. ft.)	Unit Cost	Total Cost	Annual Depre. Cost (dollars)	Other Annual Bldg. Costs	Annual Bldg. Costs
Receiving	1,392	10.00	13,920	696	960	1,656
Separating-Pasteurizing	500	20.00	10,000	500	690	1,190
Evaporating-Drying	1,740		69,950	3,498	4,827	8,325
Powder Warehousing	12,000	8.50	102,000	5.100	8,280	13,380
Laboratory	240	20.00	4,800	240	331	571
Boiler	1,600	10.00	16,000	800	1,104	1,904
Office	600	20.00	12,000	600	828	1,428
General Service	680	10.00	6,800	340	470	810
Locker and Lunch	400	15.00	6,000	300	414	714
Total	19,152					29,978

Appendix Table A.6. Construction costs by centers for drying plant of 467 million pounds wholemilk capacity.

Center	Area (sq. ft.)	Unit Cost	Total Cost	Annual Depre. Cost (dollars)	Other Annual Bldg. Costs	Annual Bldg. Costs
Receiving	2,088	10.00	20,880	1,044	1,440	2,484
Separating-Pasteurizing	600	20.00	12,000	600	828	1,428
Evaporating-Drying	1,817		82,296	4,115	5,678	9,793
Powder Warehousing	18,000	8.00	144,000	7,200	12,400	19,600
Laboratory	480	20.00	9,600	480	662	1,142
Boiler	2,000	10.00	20,000	1,000	1,380	2,380
Office	720	20.00	14,400	720	994	1,714
General Service	680	10.00	6,800	340	470	810
Locker and Lunch	450	15.00	6,750	338	466	804
Total	26,835					40,155

Appendix Table A.7. Construction costs by centers for drying plant of 623 million pounds wholemilk capacity.

Center	Area (sq. ft.)	Unit Cost	Total Cost	Annual Depre. Cost (dollars)	Other Annual Bldg. Costs	Annual Bldg. Costs
Receiving	2,784	10.00	27,840	1,392	1,921	3,313
Separating-Pasteurizing	650	20.00	13,000	660	897	1,547
Evaporating-Drying	1,925	20.00	96,313	4,816	6,646	11,462
Powder Warehousing	24,000	8.00	192,000	9,600	16,560	26,160
Laboratory	480	20.00	9,600	480	662	1,142
Boiler	2,000	10.00	20,000	1,000	1,380	2,380
Office	840	20.00	16,800	840	1,157	1,999
General Service	680	10.00	6,800	340	470	810
Locker and Lunch	500	15.00	7,500	375	518	893
Total	33,859					49,706

Appendix Table A.8. Land site area, investment cost and annual opportunity cost of the capital for six drying plants in Minnesota, 1970.

Plant	Site area	Investment cost	Annual opportunity cost
	(sq. feet)	--------- (dollars)	----------
1	43,065	8,613	603
2	59,490	11,898	833
3	79,925	15,985	1,119
4	95,760	19,152	1,341
5	134,175	26,835	1,878
6	169,295	33,859	2,370

Appendix Table A.9. Estimated life, installed cost and annual depreciation for churning-printing equipment in a butter department, Minnesota, 1970.

Equipment	Estimated life	Installed cost	Annual depreciation
	(years)	------- (dollars) -------	
Continuous churn	10	54,000	5,400
Bulk packaging unit	15	13,400	894
Soft butter printer (¼ lb. prints)	10	100,440	10,044
Soft butter printer (1 lb. prints)	10	34,339	3,434
Pasteboard box gluer	15	4,801	320
Semi-automatic boxer	10	11,000	1,100
Scale	15	900	60
Micro scale and light package rejector	10	3,000	300
Fork lift truck	10	6,600	660
Butter test equipment and miscellaneous	10	2,000	200
Total		230,480	22,412

Appendix A.10 Estimate of the size, purchase value and annual cost of buildings and storage facilities for six butter departments in Minnesota, 1970.

	Units	Cost per unit	Purchase value	Annual cost
		(dollars)		
Plant 1				
Cream storage	2,500 gallon	.80	2,000	238
Lockers, lunch rooms, etc.	100 sq. ft.	15.00	1,500	179
Office space	80 sq. ft.	20.00	1,600	190
Butter cooler	400 sq. ft.	22.45	8,980	1,068
Churn room	1,500 sq. ft.	20.00	30,000	3,570
Land site	10,400 sq. ft.	.20	2,080	146
				5,391
Plant 2				
Cream storage	5,000 gallon	.80	4,000	476
Lockers, lunch room, etc.	140 sq. ft.	15.00	2,100	250
Office space	160 sq. ft.	20.00	3,200	381
Butter cooler	900 sq. ft.	22.45	20,205	2,404
Churn room	1,500 sq. ft.	20.00	30,000	3,570
Land site	13,500 sq. ft.	.20	2,700	189
				7,270

Appendix A.10 (continued)

	Units	Cost per unit	Purchase value	Annual cost
		(dollars)		
Plant 3				
Cream storage	7,500 gallon	.80	6,000	714
Lockers, lunch room, etc.	180 sq. ft.	15.00	2,700	321
Office space	240 sq. ft.	20.00	4,800	571
Butter cooler	1,200 sq. ft.	22.45	26,940	3,206
Churn room	1,500 sq. ft.	20.00	30,000	3,570
Land site	15,600 sq. ft.	.20	3,120	218
				8,600
Plant 4				
Cream storage	10,000 gallon	.80	8,000	952
Lockers, lunch room, etc.	220 sq. ft.	15.00	3,300	393
Office space	320 sq. ft.	20.00	6,400	762
Butter cooler	1,600 sq. ft.	22.45	35,920	4,274
Churn room	1,500 sq. ft.	20.00	30,000	3,570
Land site	18,200 sq. ft.	.20	3,540	255
				10,206

Appendix A.10 (continued)

	Units	Cost per unit (dollars)	Purchase value	Annual cost
Plant 5				
Cream storage	15,000 gallon	.80	12,000	1,428
Lockers, lunch room, etc.	300 sq. ft.	15.00	4,500	536
Office space	400 sq. ft.	20.00	8,000	952
Butter cooler	2,400 sq. ft.	22.45	53,880	6,412
Churn room	1,500 sq. ft.	20.00	30,000	3,570
Land site	23,000 sq. ft.	.20	4,600	322
				13,220
Plant 6				
Cream storage	20,000 gallon	.80	1,600	1,904
Locker, lunch room, etc.	380 sq. ft.	15.00	5,700	678
Office space	480 sq. ft.	20.00	9,600	1,142
Butter cooler	3,200 sq. ft.	22.45	71,840	8,549
Churn room	1,500 sq. ft.	20.00	30,000	3,570
Land site	27,800 sq. ft.	.20	5,560	389
				16,232

Appendix Table A.11 Estimated life, installed cost and annual depreciation for equipment in a bulk receiving station in Minnesota, 1970.

Equipment	Estimated Life (years)	Installed Cost (dollars)	Annual Depreciation (dollars)
Pump for loading and unloading tank trucks (2)	10	1,840	184
Platform scale for weighing trucks	20	6,000	300
Circulating tank truck washer	10	1,200	120
Spray ball and accessories	10	860	86
Sample cabinet	10	1,080	108
Storage tanks (5000 gallon @ $1.00/gallon)	20	5,000	250
Office equipment	10	1,000	100
Laboratory equipment	10	600	60
Miscellaneous	10	1,000	100
Total		18,580	1,308

BIBLIOGRAPHY

Aplin, R. D., Country Reload Plants for Bulk Milk, Department of Agricultural Economics, Cornell University Agricultural Experiment Station, New York State College of Agriculture, Ithica, New York, 1958.

Baum, E. L., and D. E. Pauls, A Comparative Analysis of Costs of Farm Collection of Milk by Can and Tank in Western Washington, 1952, Washington Agricultural Experiment Station Technical Bulletin No. 10, May 1953.

Black, Guy, "Synthetic Method of Cost Analysis in Agricultural Marketing Firms," Journal of Farm Economics, Vol. XXXVII, May 1955.

Boulding, K. E., Economic Analysis: Microeconomics Volume I, Harper and Row, New York, 1966.

Bowing, James R., and Kenneth Taylor, A Transition to Bulk Assembly of Milk in Northern New England, New Hampshire Agricultural Experiment Station, Bulletin 453, October 1958.

Bressler, R. G. Jr., Economics of Scale in the Operation of County Milk Plants, New England Research Council with the New England Agricultural Experiment Stations and the United States Department of Agriculture.

_____, "Research Determination of Economies of Scale," Journal of Farm Economics, Vol. XXVII, August 1945.

_____, and D. O. Hammerberg, Efficiency of Milk Marketing in Connecticut: III. Economies of the Assembly of Milk, Storrs Agricultural Experiment Station Bulletin 239, University of Connecticut, Storrs, Connecticut, 1942.

Brewster, John M., Comparative Economics of Different Types of Cottonseed Oil Mills and Their Effects on Oil Supplies, Prices and Returns to Growers, Marketing Research Report No. 54, U. S. Agricultural Marketing Service, U. S. Department of Agriculture, 1954.

Chenery, H. B., "Engineering Production Functions," Quarterly Journal of Economics, Vol. LXII, November 1949, pp. 507-531.

Clarke, D. A. Jr., A Comparative Analysis of the Costs of Operating Milk Collection Routes by Can and Tank in California, Mimeograph Report No. 91, California Agricultural Experiment Station, October 1947.

Cotton, Walter P., Farm to Plant Milk Assembly Rates and Problems in North Carolina, North Carolina State College, Department of Agricultural Economics, AE Information Series 28, December 1950.

Cowden, J. W., Farm-to-Plant Bulk and Can Milk Hauling Costs, United States Department of Agriculture, Farmers Co-op Service, Service Report 18, March 1956.

Dairy Statistics, Statistical Bulletin No. 218, U. S. Department of Agriculture, Washington, D. C., 1959.

Dantzig, G. B., and J. H. Ramser, "The Truck Dispatching Problem," Management Science, Vol. VI, pp. 80-91, 1959.

Dixion, Wilfred J. and Frank J. Massey, Introduction to Statistical Analysis, McGraw Hill Book Company, New York, 1957.

Farrall, Arthur W., Engineering for Dairy and Food Products, John Wiley and Sons, New York, 1963.

French, Ben C., "Some Considerations in Estimating Assembly Cost Functions for Agricultural Processing Operations," Journal of Farm Economics, Vol. XLII, November 1960.

______, L. L. Sammet and R. G. Bressler, "Economic Efficiency in Plant Operations with Special Reference to the Marketing of California Pears," Hilgardia, Vol. XXIV, California Agricultural Experiment Station, July 1956.

Groves, F. W. and H. L. Cook, Hauling and Transportation Cost Functions for Wisconsin Milk, University of Wisconsin, Agricultural Economics 31, April 1961.

Gruebele, J. W. and E. Fred Koller, "Creamery Industry: Structure and Performance," Minnesota Farm Business Notes, No. 479, Institute of Agriculture, University of Minnesota, St. Paul, Minnesota, December 1965.

Halvorson, Harlow W., "The Response of Milk Production to Price," Journal of Farm Economics, Vol. XL, December 1958.

Hanlon, John William, "An Analysis of Processing Costs in Plants That Manufacture Butter and Nonfat Dry Milk," Unpublished Ph.D. Thesis, University of Minnesota, June 1966.

Henderson, James M. and Richard E. Quant, Microeconomics, A Mathematical Approach, McGraw Hill Book Company, New York, 1958.

Henry, William R. and James A. Seagraves, "Economic Aspects of Broiler Production Density," Journal of Farm Economics, Vol. XLII, February 1960, pp. 1-17.

Homme, Henry A. and Richard L. Simmons, Planning Agricultural Processing for the South: Butter and Milk Powder Manufacturing Costs, Agricultural Policy Institute, North Carolina State University, Raleigh, North Carolina, July 1965.

Hunter, J. H. Jr., Costs of Operating Exempt For-Hire Motor Carriers of Agricultural Commodities, A Pilot Study in Delaware, Maryland and Virginia, U. S. Department of Agriculture, ERS-109, 1963.

Ishee, Sidney and W. L. Barr, Effects of Bulk Milk Assembly on Hauling Costs, Pennsylvania State University Agricultural Experiment Station Bulletin 641, December 1958.

Jacobson, Robert E. and Gary F. Fairchild, Hauling Costs and Rates in Bulk Milk Assembly, Ohio Agricultural Research and Development Center, Research Circular No. 162, February 1969.

Juers, Linley E., "An Economic Analysis of the Operating Costs of Butter-Powder Plants with Particular Reference to the Problem of Joint-Costs," Unpublished Ph.D. Thesis, University of Minnesota, July 1957.

Kerchner, Orval Guy, Costs of Transporting Bulk and Packaged Milk by Truck, Marketing Research Report No. 791, Economic Research Service, U. S. Department of Agriculture, May 1967.

_____, "Economic Comparison of Flexible and Specialized Plants in the Minnesota Dairy Manufacturing Industry," Unpublished Ph.D. Thesis, University of Minnesota, June 1966.

Knudtson, Arvid C., "An Analysis of Processing Costs in Specialized Butter Plants Receiving Wholemilk," Unpublished Ph.D. Thesis, University of Minnesota, October 1957.

Krenser, Jerome L., Mira: A Method for Solving the Truck Dispatching Problem, Data and Computation Center, Social Systems Research Institute, University of Wisconsin, Madison, Wisconsin, 1968.

McConnell, Cambell R., Elementary Economics: Principles, Problems and Policies, McGraw Hill, New York, 1960.

McKinney, Kenneth and Randall Stelly, Farm to Plant Hauling and Receiving Bulk Milk, Texas Agricultural Experiment Station MP-377, October 1959.

Miller, Arthur H., Bulk Handling of Wisconsin Milk-Farm to Plant, Wisconsin Agricultural Experiment Station Bulletin No. 192, 1956.

Minnesota Agricultural Statistics, 1969, Minnesota Crop and Livestock Reporting Service, 560 State Office Building, St. Paul, Minnesota, March 1969.

Minnesota Agricultural Statistics, 1970, Minnesota Crop and Livestock Reporting Service, 560 State Office Building, St. Paul, Minnesota, March 1970.

Minnesota Dairy Summary, June 5, 1970, Minnesota Co-op and Livestock Reporting Service, St. Paul, Minnesota.

Minnesota Statutes 1967, Volume I, Minnesota State Department of Administration, State Capitol, St. Paul, Minnesota, 1967.

Mojonnier Bros. Co., Bulletin No. 488-13, Chicago, Illinois.

Morris, O. Richard and Russell G. Thompson, Costs of Hauling Bulk Milk from Farm to Plant, Missouri Agricultural Experiment Technical Bulletin No. 873, November 1964.

Nolte, G. M. and E. Fred Koller, "Continuous Churns Introduced into Minnesota Creamery Industry," Minnesota Farm Business Notes, No. 509, Institute of Agriculture, University of Minnesota, August 1968.

Northern States Power Company General Service Rate Schecule DC 204.

Northern States Power Company Schedule GK025.

Olson, Fred, "Location Theory as Applied to Milk Processing Plants," Journal of Farm Economics, Vol. XLI, December 1959.

Pritchard, Norris T. and William H. Cope, Milk Assembly in the Fort Wayne Milkshed, Purdue Agricultural Experiment Station Bulletin 559, February 1951.

Sinclair, Robert O., Economic Effect of Bulk Milk Hauling in Vermont, Vermont Agricultural Experiment Station, Bulletin No. 581, June 1955.

Smith, Cabel A., "Survey of the Empirical Evidence Economics of Scale," Business Concentration and Price Policy, a report of the National Bureau of Economic Research, New York, Princeton University Press, 1955.

Stigler, George J., "The Division of Labor is Limited by the Extent of the Market," Journal of Political Economy, Vol. LIX, June 1951.

_____, The Organization of Industry, Richard D. Irwin, Homewood, Illinois, 1968.

Thompson, Russell G., "An Approach to Estimating Optimum Sizes of Butter-Powder Plants," Unpublished Ph.D. Thesis, University of Minnesota, August 1962.

Viner, Jacob, "Cost Curves and Supply Curves," Zeitschrift fur Nationalokonomie, 1931, reprinted in Readings in Price Theory, The American Economics Association, Richard D. Irwin, Homewood, 1952, pp. 198-232.

William, J. C. Jr., "The Equilibrium Size of Marketing Plants in a Spatial Market," Journal of Farm Economics, Vol. XLIV, November 1962.

Wipf, Larry J. and James P. Houck, Milk Supply Response in the United States, An Aggregate Analysis, Department of Agricultural Economics, Report No. 532, Institute of Agriculture, University of Minnesota, St. Paul, Minnesota, July 1967.