September 1983 A.E. Res. 83-35

POTENTIAL IMPACTS OF ROUTING MILK TO DAIRY PROCESSING PLANTS ON THE BASIS OF ASSEMBLY COST AND PROTEIN CONTENT:

A CASE STUDY IN NEW YORK

by

M.E. Warner

J.E. Pratt

A.M. Novakovic

Department of Agricultural Economics
Cornell University Agricultural Experiment Station
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York, 14853

PREFACE

M.E. Warner, J.E. Pratt, and A.M. Novakovic are, respectively, Graduate Research Assistant, Research Associate, and Assistant Professor in the Department of Agricultural Economics at Cornell University.

This study draws heavily from the vehicle scheduling work done by Jean Sehulster on her master's thesis research in the Department of Agricultural Economics at Cornell.

Financial support for this project was provided by the New York State Department of Agriculture and Markets. We wish to thank the Office of the Market Administrator, Order No. 2 for providing the transportation network, David Barbano for providing the farm level data on protein and fat, and Craig Alexander, Robert Boynton, David Lee, Jean Sehulster and Walt Wasserman, for their helpful reviews. We also express our sincere thanks to Robin Greenhall for her patience in processing the successive drafts.

Requests for copies of this bulletin can be directed to:

Publications Office
Department of Agricultural Economics
Cornell University
442 Warren Hall
Ithaca, NY 14853

ABSTRACT

Cheese yields are directly related to the level of protein in raw milk. Multiple goal programming and heuristic vehicle routing techniques are used to evaluate the trade-offs between revenues and farm-to-plant hauling costs resulting from protein-based assignments of milk producers to cheese and fluid processing plants. Increased assembly costs are shown to be minor in comparison with the revenue gains from increased cheese yields.

TABLE OF CONTENTS

Page

Introduction....1

General Procedures....2

Milk Production and Composition Data....2

148 Farm Data....5

Farm Assignment and Route Generation....5

Routing....7

Changes in Hauling Time and Distance....9

Hauling Cost Assumptions....9

Changes in Cheese Yield....12

Revenue Changes....12

Changes in Processing Costs and Net Revenue....15

Seasonal Variability....16

Conclusion....18

References....20

Appendices

Appendix 1: Summary Statistics of Milk Production, Butterfat, and Protein Data for 93 Farms in a Western New York Dairy Cooperative in 1979....22

Appendix 2. Description of the Vehicle Scheduling Heuristic....28

Appendix 3. Source of Fixed and Variable Hauling Costs....33

Appendix 4. Monthly Variations in Protein and Butterfat Levels at Each Plant for all Assignments....36

Introduction

The economic values of raw milk components (fat and protein) vary with the composition and price of finished dairy products. In recent years, segments of the dairy industry have been advocating the use of a multiple component pricing system which, it is argued, would price milk components according to their value in finished products. The price of raw milk is currently differentiated only on the basis of butterfat content, with higher butterfat milk receiving a higher price. This has been the predominant pricing system since the 1920s. With the advent of lower cost protein testing equipment, some cheese manufacturers believe that a system which similarly prices milk on the basis of protein content can effectively attract higher protein milk to their plants.* This would increase their cheese yields per pound of milk and, presumably, their net revenues.

A number of studies have analyzed multiple component pricing plans and their impact on producers and/or plants (Brown; Ernstrom; Hillers et al; Ladd and Dunn). Such studies have usually emphasized the determination of component values in the manufacture of various products. In their analysis, Ladd and Dunn strengthen this approach by considering changes in processing costs resulting from the receipt of higher protein milk at a cheddar cheese plant. These studies, however, either implicitly or explicitly assume that assembly costs (the cost of hauling milk from farms to plants of first receipt) remain constant and only consider a reallocation of payments to a given group of producers.

Any shift to a protein-based payment system will give producers incentives to increase the protein content of their milk.** However, a system used only by cheese plants will change the allocation of producers among cheese and fluid plants in that milkshed (Osman). This will have impacts on assembly costs as well as the protein content of raw milk receipts at plants. These changes in shipping patterns may not only affect assembly costs for the plants offering protein incentives, but also for other plants operating in the same milkshed.

This analysis considers the impacts on both a cheddar cheese plant and a fluid milk plant as farms are assigned to the cheese plant on the basis of the protein content of raw milk rather than farm-to-plant distance. The analysis determines changes in milk assembly costs across the entire milkshed as more distant, high-protein farms are assigned to the cheese plant. Cheddar cheese processing costs and net revenues that result from alternative protein-based farm assignments to the cheese plant are also discussed.

---

* The particular protein responsible for cheese yield, casein, is not as easily measured as total protein. In this paper, the casein content of raw milk is assumed to be 78% of the protein level.

** Indications are that genetic selection for protein content may progress more slowly than for butterfat. After 20 years of component pricing in California, little change in the component characteristics of fluid milk has taken place (Quinn, Novakovic, and Wasserman).

General Procedures

The problem is analyzed as a simulated case study of a transportation network modeling the relationships among 148 farms in and near Cortland County, New York, a cheddar cheese plant and a fluid milk plant. Since complete protein data were not available for these Cortland farms, known production, protein and butterfat levels from a set of 93 farms in western New York were randomly assigned to the farms in the transportation network.

Farms were assigned to the cheese and fluid plants on the basis of their distance from each plant and the protein content of each farm's milk, given the constraint that half the total production of the 148 farms be delivered to each plant. Reassigning the high and low-protein herds in these hypothetical farm-to-plant assignments was chosen as the means to raise the protein level of raw milk delivered to the cheese plant. While it is true that there is more variation between individual cows than between breeds or between herds, it is also true that in the aggregate, some herds produce higher protein milk than other herds due to the breed of the herd and a variety of management factors such as breeding, feeding and herd health. This study focuses on an analysis of the cost effectiveness of separate assignment of high and low-protein herds to cheese and fluid plants, respectively.

This is done by developing least-cost routes to pick up all farms assigned to each plant in the minimum distance base case and in the subsequent farm-to-plant reassignments to achieve higher protein levels at the cheese plant. As protein targets at the cheese plant are raised, more distant high-protein farms are assigned to the cheese plant and time and mileage on milk assembly routes to both plants increase. The additional hauling costs indicate the relative costs of attaining higher levels of protein at the cheese plant.

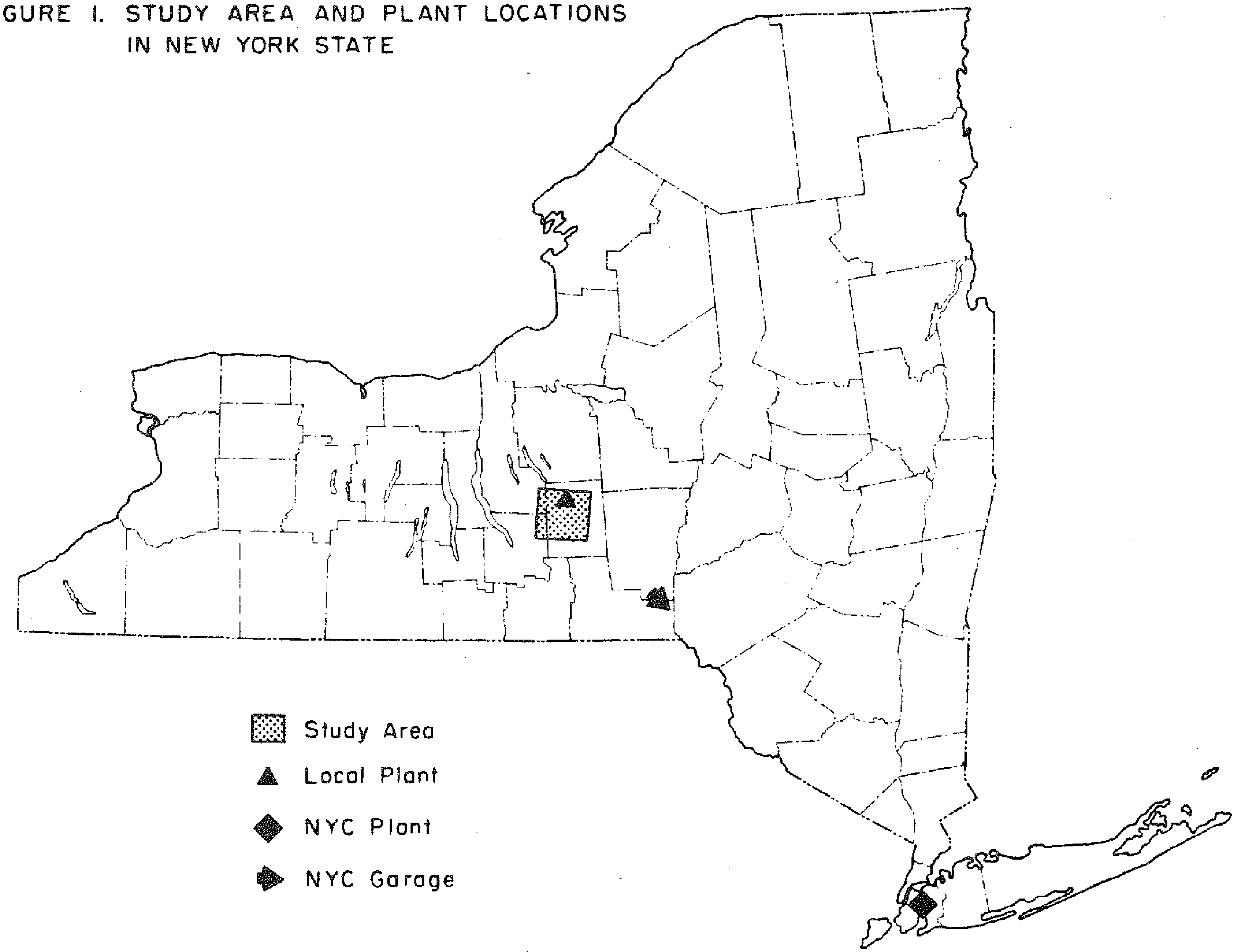
For each farm-to-plant assignment, cheese yields and changes in cheese revenues are calculated based on the protein content of milk assigned to the cheese plant. For simplicity, it is assumed that the cheese plant only produces cheddar cheese and the fluid plant only produces fluid milk products. While cheese yields, revenues, and processing costs per hundredweight increase for the cheese plant, revenues and processing costs at the fluid plant remain unchanged since the quantity of milk shipped to each plant is constant from assignment to assignment. Changes in net revenues at both plants are calculated as changes in revenues minus changes in hauling and processing costs. Although it is not plants but farmers who actually pay hauling costs, net revenue changes are calculated in this way to evaluate the combined impact on assembly costs and net revenue of delivering successively higher levels of protein to the cheese plant.

To compare the differential impact on local versus distant plants, two scenarios are used. The first assumes a local cheese plant located near the center of the study area and a distant fluid plant located in New York City (NYC) (see Figure 1). The second scenario assumes that the cheese and fluid plants are locally juxtaposed.

Milk Production and Composition Data

The milk data used in this study were gathered by the Cornell Food Science research team that studied the protein, butterfat and production levels of all farms in a western New York dairy cooperative for each month during 1979

FIGURE I. STUDY AREA AND PLANT LOCATIONS IN NEW YORK STATE



(Barbano).* These data were combined with the farm/plant transportation network to form a realistic, but simulated, set of dairy farms for this study.

The food science team studied 93 small to medium-sized dairy farms whose two-day milk production averaged 3,260 pounds per farm with a range of 1,295 to 10,681 pounds. The relative protein content of the individual farms' milk supply over the months of the year ranged from 2.6% to 3.8% and butterfat content ranged from 2.7% to 4.4%. However, the individual farms which ranked high in either butterfat or protein content changed somewhat from month to month as herds entered different stages of lactation.

Spearman rank order correlations for the 93 farms ranked by protein level across the months ranged from a high of .814 between April and May to a low of .173 between January and June, with an overall average correlation of .440 (See Appendix 1, Table 2).** Spearman rank order correlations between farms ranked by butterfat level from month to month ranged from a low of .312 between April and October to a high of .883 between February and March, with an overall average correlation of .556 (See Appendix 1, Table 3). The month-to-month correlation between high ranking farms in butterfat was somewhat stronger than the month-to-month correlation of ranking between individual high-protein farms, but in neither case was there a high correlation between the highest farms from month to month. The lack of a consistently strong correlation between high-protein farms from month to month suggests the possible need to reorganize routes more frequently during the year to capture the highest protein milk.

The mean protein level for the entire set of farms ranged from 3.01% in May to 3.34% in November (See Appendix 1, Table 1). This variation could affect the overall profitability of an assembly scheme determined by protein distribution and transportation cost. Mean butterfat for all farms ranged from 3.53% in July to 3.76% in November. The month of September was chosen for farm assignment and route generation because September's values were closest to mean milk weight, protein and butterfat levels.

Within each month, correlations of farms ranked for butterfat and farms ranked for protein ranged from a low of .183 in September to a high of .653 in December (See Appendix 1, Table 4). To determine the relationship between the herds' butterfat and protein levels, cross-sectional farm data were used to run simple monthly regressions of percent protein on percent butterfat. These simple regressions yielded corrected R^2s ranging from 4.8% in September to 42.8% in March. Although the t-ratios for the butterfat coefficients suggest that butterfat is a significant predictor of protein within each month, the magnitude of the coefficient ranged from a low of .186 in September to a high of .529 in April (for regression equations see Appendix 1, Table 5).*** Thus, it appears

---

* The New York Dairy Herd Improvement Cooperative also has protein test data; however its testing service is too new to provide a full year's worth of data for the specific farms in the locality of the transportation network.

** Spearman's rho is a measure of correlation from a nonparametric procedure which uses the ranks of the data rather then the actual values to determine the consistency in rank order of individual observations over time.

*** These low $\bar{R}^2$ values and percent butterfat coefficients are similar to the values obtained by Brog in a study of 1182 herds in Utah, North Dakota and Wisconsin and by Grippin in a study of 1435 samples in Minnesota, Wisconsin and South Dakota.

that percent butterfat is neither a strong nor consistent predictor of percent protein from month to month for the farms in this sample. This demonstrates the need for a pricing system based specifically on protein since mere compensation of high-butterfat producers will not ensure that high-protein producers are justly compensated for the true value of their milk.

148 Farm Data

Protein, production, and butterfat data for herds in the 93 farm data set were sampled and randomly assigned to the 148 farm sites in the transportation network. Although not identical, this 148 farm sample exhibits characteristics similar to those discussed above for the 93 farm data set.

Because there was no consistently strong correlation between butterfat and protein, the farm assignments made on the basis of protein level did not affect aggregate butterfat levels in milk delivered to either the cheese or the fluid plant. Protein levels were highest in November and lowest in August. These months were included in the analysis to give an indication of the range in magnitude of the costs and benefits of the protein-based milk assembly schemes. The farms chosen to serve the cheese plant in September were assumed to serve that plant in August and November.

Farm Assignment and Route Generation

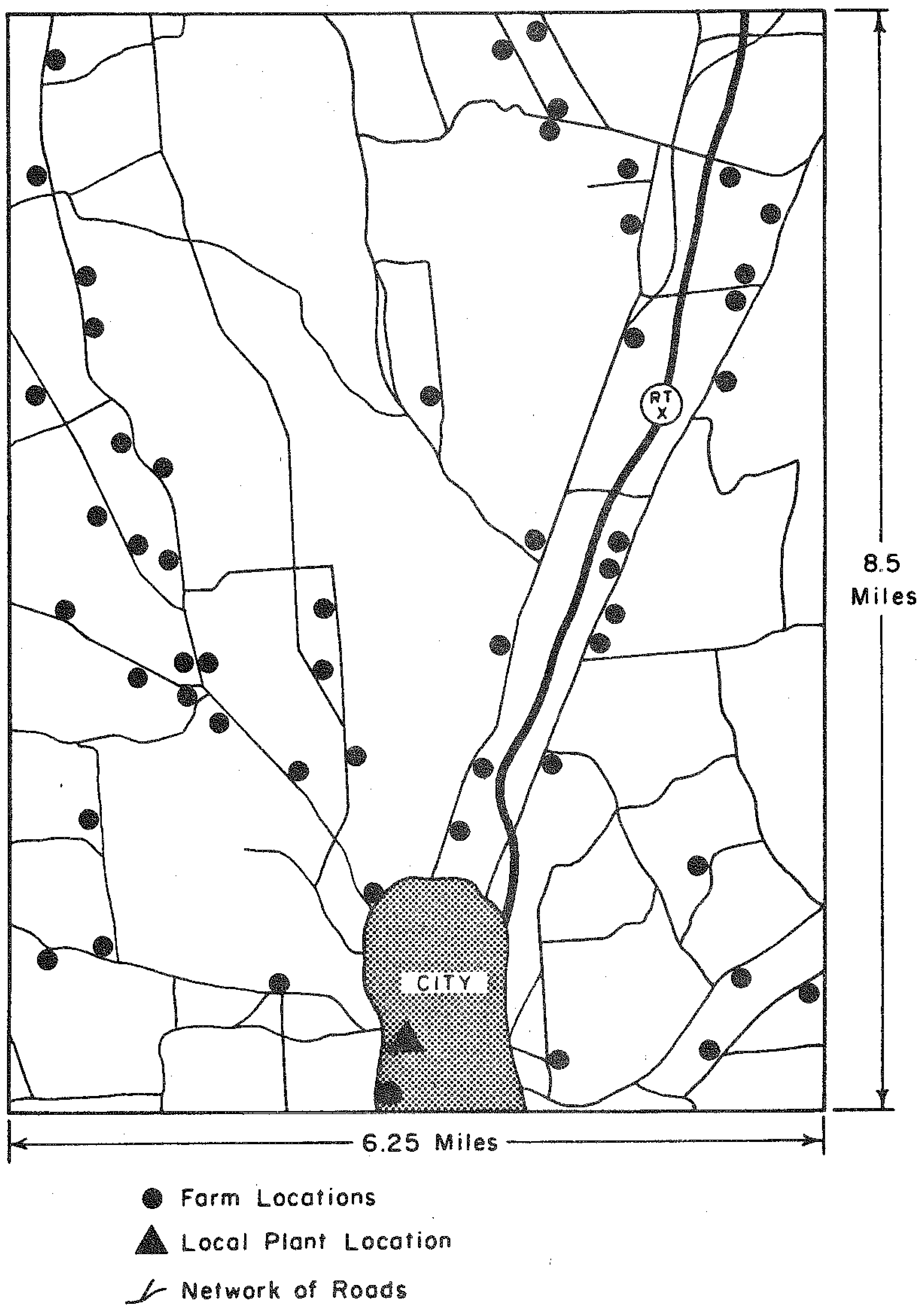
The farm/plant transportation network consisted of 148 farms and was a subregion (covering approximately 220 square miles) of a larger geographic area used by Sehulster in a study of efficiency in milk assembly. In this subregion there were 150 nodes representing dairy farms and dairy plants and over 400 nodes representing road intersections. Individual connections, or arcs, between adjacent nodes numbered over 700. A shortest path algorithm (Gilson and Witzgall) was used to determine quickly and precisely, the 11,175 shortest distances and associated paths between each of the 150 nodes of interest and all the other 149 farms and plants (see Figure 2).

In the base case where no protein target was specified, the problem was a simple transportation problem of minimizing farm-to-plant distances. In the subsequent farm-to-plant reassignments, goal programming was used to assign the farms to plants. The prioritized objectives of 1) minimizing the deviation from a specified target level of total protein delivered to the cheese plant and, 2) minimizing the sum of plant distances from the assigned farms were formulated as a multiple objective transportation problem (Lee and Moore; Arthur and Ravindran).

These two goals are incommensurable, since higher protein deliveries to the cheese plant can only be gained at the expense of increased farm-to-plant distances. By establishing a hierarchy of priorities, e.g. 1) the protein target and, 2) minimizing distance, the goal solution procedure successively seeks to achieve each goal in the order of its priority without diminishing the achievement level of any previously considered goal. Thus, the program attempts to meet the protein target first and then minimizes farm-to-plant distances.

In the base case, the protein levels at the cheese and fluid plants were 3.09% and 3.12% respectively. The second assignment increased the protein level

FIGURE 2. EXAMPLE NETWORK OF FARMS, ROADS, AND LOCAL PLANT LOCATION, 1 QUADRANGLE



at the cheese plant by .05 percentage points to 3.14%. A similar increase to 3.19% was targeted for the third assignment. The fourth assignment achieved the maximum protein level possible from half the farms, 3.22%, for the cheese plant. The protein level for the fluid plant in this assignment fell to a low of 2.99%. In the second scenario of locally juxtaposed cheese and fluid plants, only two assignments were made: the base case and the maximum protein assignment. Protein levels at both plants in each of these assignments were identical to the protein levels obtained in the base case and maximum protein assignment in the first scenario of a local cheese plant and a distant fluid plant (see Table 1).

Routing

After farm-to-plant assignments were made, routes were generated to schedule milk pickup for all farms in an efficient manner. A vehicle scheduling heuristic, ROUTE, written by Hallberg and Kriebel was used to generate the simulated routes. ROUTE attempts to minimize the total distance, time or cost of serving a set of pickup (farm) and delivery (plant) points of known location, given a fixed number of capacitated vehicles and service demands at each pickup and delivery point.*

Although minimizing distance is the primary criterion for the routing heuristic, the computer routes were manually enhanced so that each truck would be filled to at least 90% and no more than 99% of capacity. This was done following procedures developed by Sehulster.

Three simplifying assumptions were made. First, it was assumed that all farms had sufficient on-farm storage for every-other-day milk pickup service.** Second, haulers were assumed to operate only one type of pickup vehicle--a tractor trailer having a tank capacity of 51,600 pounds of milk. Third, it was assumed that plants represented both starting and stopping points on all local routes.*** For the distant New York City plant, a truck garage was assumed to be located outside the far southeastern corner of the study area. At this location trailers from pickup vehicles would be transferred to other tractors used for the long haul to the metropolitan area.

---

* See Appendix 2 for a more detailed description of networks, shortest path algorithms, and vehicle scheduling.

** Sehulster's analysis of the 478 farms in and around Cortland County New York, of which the 148 farms in this transportation network are a subregion, showed that 8% did not have sufficient on-farm storage to be picked up every-other-day. These "everyday" farms complicate routing but were not considered in the present problem. With even less simplifying assumptions, both Sehulster and Strang have shown that ROUTE is an acceptable heuristic for sequencing farm stops on routes.

*** Sehulster notes that contract haulers typically begin their first route and end their last route at their home garage which may be nowhere near the plant(s) being served. This possibility was ignored here to simplify the problem.

TABLE 1. Protein Levels for Various Farm/Plant Assignments

Scenario 1	Local Cheese Plant Protein Target (percent)	Distant (NYC) Fluid Plant Protein Level (percent)
Base Case (minimum distance)	3.09	3.12
Assignment 2	3.14	3.07
Assignment 3	3.19	3.02
Assignment 4 (maximum protein)	3.22	2.99

Scenario 2	Local Cheese Plant Protein Target (percent)	Local Fluid Plant Protein Level (percent)
Base Case (minimum distance)	3.09	3.12
Assignment 2 (maximum protein)	3.22	2.99

Changes in Hauling Time and Distance

As expected, overlap of routes to the cheese and fluid plant increased as higher protein levels were assigned to the cheese plant. Consequently, the mileage and time spent on each route increased. In the first scenario, the maximum mileage increase, 49.8 miles, occurred under the maximum protein assignment and added over an hour to the cheese plant hauler's driving time (see Table 2). For the distant fluid plant, mileage and time increases were greatest for the third assignment, with increases of 46.9 miles and 107 minutes. This is explained by the fact that 77 farms were assigned to the NYC plant in this assignment whereas only 72 to 74 farms were assigned in the other cases. Because at-farm-time is calculated as 11 minutes fixed time per farm plus a variable pumping time of 65 gallons per minute, the extra farms could make a significant difference in the time spent on-route.*

Overall, the NYC fluid plant had greater increases in time and mileage than the local cheese plant because the garage for the NYC plant was located outside the far southeastern corner rather than in the center of the study area. As higher levels of protein were attained at the cheese plant, routes for the NYC plant had to go to the northern portion of the study area to pick up the low-protein farms. The local cheese plant also experienced increased routing distances but due to its central location, not of the same magnitude as the NYC plant.

In the second scenario, where the cheese and fluid plants were locally juxtaposed, reassignment for maximum protein resulted in mileage increases for the fluid plant which were three times greater than the mileage increases for the cheese plant. Time increases, however, were almost equal (see Table 3).

Hauling Cost Assumptions

In order to assess the cost of these time and mileage increases, a formula for calculating variable and fixed costs was developed for the local and distant plant situations based on information provided by Wasserman. Each plant had five routes which needed to be picked up in a two day period. For the local plant, it was assumed that a truck could pick up two routes per day, since the average on-route time per route was about six hours. In order to pick up five routes in a two day period, a second truck would be needed but would be significantly underutilized. Thus, variable ($.156/minute and $.50/mile) and fixed ($.135/minute) costs for the local hauling situation were calculated assuming operation of two tractor trailers (see Appendix 3).

Since the routes to NYC required two types of trucks--tractors for the long haul to NYC and tractor trailers for on-route farm pickup--all cost figures were calculated separately for on-route and stem mileage. For the on-route pickup, variable costs were $.156/minute and $.482/mile and fixed costs were $.145/minute. For the longer haul from the garage, located 215 miles from NYC, three trucks were needed since a truck could only make one round trip per day.

* Other components of the total time calculation were driving speeds of 40 miles per hour for on-route miles, and 50 miles per hour for stem miles (from the garage to NYC). Standard plant unloading time was 60 minutes per load and for the NYC routes, a fixed truck transfer time of 20 minutes was allotted at the garage.

TABLE 2. Assembly Cost Comparisons (2 Day Period), Scenario 1

	Base Case		Assignment 2		Assignment 3		Assignment 4	
	Cheese	Fluid*	Cheese	Fluid*	Cheese	Fluid*	Cheese	Fluid*
Number of Farms Served	75	73	76	72	71	77	74	74
DISTANCE								
Total miles	117.0	2353.7	123.2	2363.9	141.5	2400.6	166.8	2398.3
Change from Base								
miles	--	--	6.2	10.2	24.5	46.9	49.8	44.6
%	--	--	5.3	0.4	20.9	2.0	42.6	1.9
Variable Cost ($)	58.50	975.31	61.60	980.23	70.75	997.92	83.40	996.81
TIME								
Total minutes	1,733	4,501	1,763	4,502	1,734	4,608	1,797	4,574
Change from Base								
minutes	--	--	30	1	1	107	64	73
%	--	--	1.7	.02	.06	2.4	3.7	1.6
Variable Cost ($)	270.35	702.16	275.03	702.31	270.50	718.85	280.33	713.54
Fixed Cost ($)	233.96	750.60	238.01	750.75	234.09	766.12	242.60	761.19
ASSEMBLY COSTS								
Total ($)	562.81	2428.07	574.64	2433.29	575.34	2482.89	606.33	2471.54
Change from Base								
($)	--	--	11.83	5.22	12.53	54.82	43.52	43.47
(%)	--	--	2.10	.215	2.23	2.26	7.73	1.79

* Stem Miles from the garage to NYC (215.1 miles x 5 routes x 2 days = 2151 miles) are calculated at the appropriate rates and the totals are included in the figures for variable and fixed mileage and time costs. The only changes in time and distance are on the on-route portion and are calculated at the on-route pickup rates.

TABLE 3. Assembly Cost Comparisons (2 Day Period), Scenario 2

	Base Case		Assignment 2	
	Cheese	Fluid	Cheese	Fluid
Number of Farms Served	71	77	73	75
DISTANCE				
Total miles	144.1	134.3	159.5	183.7
Change from Base				
miles	--	--	15.4	49.4
%	--	--	10.7	36.8
Variable Cost ($)	72.05	67.15	79.75	91.85
TIME				
Total minutes	1,729	1,774	1,776	1,825
Change from Base				
minutes	--	--	47	51
%	--	--	2.7	2.9
Variable Cost ($)	269.72	276.74	277.06	284.70
Fixed Cost ($)	233.42	239.49	239.76	246.38
ASSEMBLY COSTS				
Total ($)	575.19	583.38	596.57	622.93
Change from Base				
($)	--	--	21.38	39.55
(%)	--	--	3.72	6.78

Although some cost savings were gained from better fuel mileage, other costs increased due to the shorter truck life (3 years instead of 7) and higher yearly maintenance. Fixed costs, due to faster depreciation, were \$.179/minute and variable costs were \$.156/minute and \$.408/mile.

Based on the above assumptions concerning fleet size and truck use, total hauling costs were calculated for each assignment. Absolute increases in the total costs for the two day route cycles for the local cheese plant in scenario 1 ranged for \$11.83 to \$43.52 for the higher protein assignments. For the maximum protein assignment, these costs represented an increase of less than eight percent of total assembly costs (see Table 2). Although stem miles in all NYC fluid plant assignments remained unchanged, increases in on-route time and mileage yielded total cost increases ranging from \$5.22 to \$54.82. In no case did these cost increases exceed 2.3 percent of total assembly costs.

In scenario 2, increases in total hauling costs after reassignment for maximum protein were higher both in absolute value and in percentage terms for the local fluid plant, but they only amounted to \$39.55 (see Table 3).

Changes in Cheese Yield

To determine the trade-off between increased hauling costs and increased revenue from higher cheese yields, the modified Van Slyke and Price formula for cheddar cheese was used (Kosikowski):

$$\frac{\text{lbs. of cheddar cheese}}{\text{cwt. raw milk}} = \frac{[.9(\%\text{ butterfat}) + .78(\%\text{ protein}) - 0.1]\ 1.09}{1 - .38}$$

(.38 = moisture content in cheddar cheese)

This formula assumes casein, the protein responsible for changes in cheese yield, to be 78 percent of the protein content. Although casein content does vary between farms with the same protein percent, the lack of a quick, inexpensive test for casein requires use of an estimate based on the average casein level.

In the first scenario, cheese yields increased from a low of 9.7 to a high of 9.89 pounds per hundredweight, a 1.96% increase. Curiously, the cheese yield increment from the third to the fourth assignment was very small, but this can be explained by a .02 percentage point drop in the butterfat percent level (see Table 4). A similar increase in cheese yield (1.75%) occurred in the second scenario (see Table 5).

Revenue Changes

For simplicity it was assumed that only cheddar cheese was a valued end product for the cheese plant. In this way, differences in revenue due to increased cheese yield could be measured unambiguously. Determination of revenue for the fluid plant was deemed unnecessary since milk weight and butterfat content delivered remained approximately the same with each assignment, and protein percentages were always well above the minimum standards set for fluid milk. If, however, the fluid plant produced other products such as cottage cheese and cream cheese, which require casein in their manufacture, the negative

TABLE 4. Summary of Results for Scenario 1: Local Cheese Plant and Distant Fluid Plant

	Base Case		Assignment 2		Assignment 3		Assignment 4	
	Cheese Plant	Fluid Plant	Cheese Plant	Fluid Plant	Cheese Plant	Fluid Plant	Cheese Plant	Fluid Plant
Percent Protein	3.09	3.12	3.14	3.07	3.19	3.02	3.22	2.99
Percent Fat	3.56	3.60	3.58	3.58	3.59	3.57	3.57	3.58
Cheese Yield Per Cwt. * (lbs./cwt.)	9.70	--	9.79	--	9.88	--	9.89	--
Revenue Per Cwt. of Milk ($/cwt.) *	13.580	--	13.706	--	13.832	--	13.846	--
Increase From Base ($)	--	--	.126	--	.252	--	.266	--
(%)	--	--	.93	--	1.86	--	1.96	--
Transportation Cost Per Cwt. ($/cwt.)	.230	.978	.232	.993	.232	1.01	.246	1.00
Increase From Base ($)	--	--	.002	.015	.002	.032	.016	.022
(%)	--	--	.87	1.56	.87	3.27	6.96	2.25
Net Gain/Loss(-) From Base ($/cwt)								
($)	--	--	.124	-.015	.250	-.032	.250	-.022
(%)	--	--	.929	--	1.87	--	1.87	--

* The changes in fluid product yields per cwt. of raw milk delivered are insignificant for all cases. Consequently, revenues per cwt. for the fluid plant do not change for any assignment.

TABLE 5. Summary of Results for Scenario 2: Local Cheese and Fluid Plants

	Base Case		Assignment 2	
	Cheese Plant	Fluid Plant	Cheese Plant	Fluid Plant
Percent Protein	3.09	3.12	3.22	2.99
Percent Fat	3.58	3.58	3.58	3.58
Cheese Yield Per Cwt.* (lbs./cwt.)	9.73	--	9.90	--
Revenue Per Cwt. of Milk ($/cwt.)*	13.622	--	13.860	--
Increase From Base				
($)	--	--	.238	--
(%)	--	--	1.75	--
Transportation Cost Per Cwt. ($/cwt.)	.232	.238	.241	.254
Increase From Base				
($)	--	--	.009	.016
(%)	--	--	3.88	6.72
Net Gain/Loss(-) From Base ($/cwt.)				
($)	--	--	.229	-.016
(%)	--	--	1.71	--

* The changes in fluid product yields per cwt. of raw milk delivered are insignificant for all cases. Consequently, revenues per cwt. for the fluid plant do not change for any assignment.

impact of lower protein raw milk would have to be assessed in accordance with the importance of these products in a plant's total production and the products' protein levels. The production of products such as yogurt, sour cream and butter was assumed to be unaffected since butterfat did not vary significantly between assignments to the cheese and fluid plants (range 3.56% to 3.6%). Thus, differences in butterfat were not included in the revenue assumptions except as they affected cheese yield.

The effect of butterfat on cheese yield, however, was an important consideration. The legal minimum of 50% fat in the dry matter for cheddar cheese is attained when the casein/butterfat ratio is 0.7. Usually, cheese plants get more butterfat than they need which lowers the casein/butterfat ratio in the milk. This lower ratio produces a higher fat content in the cheese, which depresses the moisture content and yield (Barbano). Since high-protein and high-butterfat farms were not strongly correlated in the data used in this study, as higher protein target levels were reached, casein/butterfat ratios improved (i.e. attained the 0.7 level). Attainment of this optimal ratio compensated for the inability to adjust for imbalances in the casein/butterfat ratio when using the Van Slyke and Price cheese yield formula and increased the formula's yield-predicting accuracy with the higher protein assignments.

Changes in Processing Costs and Net Revenue

The effect of higher protein levels in raw milk on the processing and distribution costs of cheese is difficult to determine. Total revenue, and distribution and processing costs per hundredweight of raw milk input all can be expected to increase as higher cheese yields are obtained. Average gross revenue per pound of cheese is assumed to be constant, i.e. the price of cheese is constant. It is unclear whether average processing and distribution costs per pound of cheese will decrease or not, but it is expected that total net revenues will increase.

Unfortunately, there is little reliable information on actual processing costs for cheese plants and these figures are known to vary significantly from plant to plant. Different studies measure costs in different ways and draw disparate conclusions. In 1978-79 Hillers et al. conducted a survey of large, efficient cheese plants in Iowa. They separated processing costs into fixed and variable costs and assumed that fixed costs remained constant per hundredweight of milk regardless of its solids content but decreased per pound of cheese output as raw milk protein increased. Variable costs per hundredweight of raw milk could be expected to increase but were assumed to remain constant per pound of cheese output. Ladd and Dunn, however, found that variable processing costs per unit of cheese output fell as cheese yield per hundredweight of raw milk rose.

Since the focus of this study is to determine changes in assembly costs (a cost which Hillers et al. assume remains constant for a fixed volume of milk), an attempt to measure in-plant cost changes is avoided. This study simply calculates the increase in revenue per hundredweight of raw milk and compares it with the increase in assembly costs per hundredweight. Assuming a pound of cheddar cheese is valued at $1.40 (approximate 1982 wholesale price), revenue increases due to higher cheese yields ranged from 12.6 to 26.6 cents per hundredweight of raw milk, (or .93% to 1.96%) over the base case in both scenarios. After subtracting the increased hauling costs per hundredweight, net gains ranging from 12.4 cents to 25.0 cents per hundredweight were obtained. In every case, increased revenue offset increased hauling costs by a factor of at least 16 for the cheese plant. Although the hauling costs for the fluid plant also increased, in no case did they increase by more than 3.2 cents per hundredweight or 3.27% over the base case.

This simple calculation shows clearly that the increase in total revenue is greater than the increase in assembly costs required to deliver the higher protein milk to the cheese plant. As calculated, the change in net revenue also suggests that there is a "cushion" to absorb possible increases in processing and distribution costs and still leave the cheese plant with a net gain. Indeed, if processing and distribution costs per pound of cheese are constant and range from 10 to 15 cents, then increasing cheese yield per hundredweight by .19 pounds (as in the maximum protein assignment), would only increase processing and distribution costs per hundredweight of milk by 2 to 3 cents.

The net revenues above suggest that it is possible to compensate the fluid plant for its increased assembly costs as well as producers for providing higher protein milk. Indeed, net gains at the cheese plant offset increased fluid plant hauling costs seven to ten times over.

In regard to assembly costs it is important to note that at present most producers pay their own hauling costs. By comparing increased revenues with increased assembly costs for all milk delivered to each plant, it has been shown that the potential for compensating producers for their increased hauling costs exists. For a cooperative which owns its own manufacturing plant and pools members' hauling costs, the mechanism to implement a system of compensation for increased producer hauling costs already exists. For proprietary firms, producer compensation would not be as simple, but some system of rebates or higher prices could be developed.

It must also be noted that comparing the assembly costs for the protein-based farm-to-plant assignments with the minimum distance base case is not the same as comparing protein-based assignments with actual hauling costs. Actual milk assembly is undoubtedly not as efficient as in the calculated minimum distance base case. For the larger 478 farm transportation network of which this 148 farm study area is a part, Sehulster found mileage savings over the existing hauling system of 30 percent after reorganizing routes to remove overlap and sequencing farm stops in a way which minimized on-route mileage. Since the highest increase in assembly mileage under protein-based farm-to-plant assignment was 42.6 percent, reorganization of routes for protein-based milk assembly might increase assembly costs very little as compared to the present relatively inefficient hauling system.

Seasonal Variability

Protein level is generally higher just after calving and in the late fall, and lower in the winter months and hot summer months (see Appendix 1, Table 1). If plants or farmers are going to incur increased hauling costs for high protein milk, seasonal variability should be considered.

To get an idea of the range in these cheese yield benefits over the year, the months with the highest and lowest protein levels were analyzed for each assignment (see Table 6). In the highest month, November, cheese yields ranged

TABLE 6. Seasonal Variation in Cheese Yield and Net Revenue Gains for the Cheese Plant.

	Scenario 1				Scenario 2	
	Base	Assign 2	Assign 3	Assign 4	Base	Assign 2
High-Protein Month - November						
% Protein	3.36	3.37	3.39	3.38	3.33	3.39
% Butterfat	3.73	3.75	3.77	3.78	3.72	3.78
Cheese Yield lbs. per cwt. milk	10.34	10.38	10.44	10.44	10.27	10.45
Revenue $ per cwt. milk	14.476	14.532	14.616	14.616	14.378	14.630
Change from Base $/cwt	--	.056	.14	.14	--	.252
Net Gain from Base* $/cwt	--	.054	.138	.124	--	.243
%	--	.379	.969	.870	--	1.72
Low-Protein Month - August						
% Protein	3.03	3.05	3.09	3.09	3.02	3.11
% Butterfat	3.55	3.57	3.59	3.58	3.55	3.58
Cheese Yield lbs. per cwt. milk	9.60	9.67	9.73	9.73	9.59	9.75
Revenue $ per cwt. milk	13.440	13.538	13.622	13.622	13.426	13.650
Change from Base $/cwt	--	.098	.182	.182	--	.224
Net Gain from Base* $/cwt	--	.096	.180	.166	--	.215
%	--	.727	1.36	1.26	--	1.63

* This figure is net of hauling costs.

from 10.34 lbs./cwt. in the base case to 10.44 lbs./cwt. in the maximum protein assignment in the first scenario and from 10.27 lbs./cwt. to 10.45 lbs./cwt. in the second scenario. These yields represented net revenue gains ranging from 5.4 cents to 24.3 cents per hundredweight. In the lowest protein percent month, August, cheese yields ranged from 9.60 lbs./cwt. to 9.73 lbs./cwt. in the first scenario and from 9.59 lbs./cwt. to 9.75 lbs./cwt. in the second scenario. Net revenue gains per hundredweight ranged from 9.6 cents to 21.5 cents.

In both these months, net revenue gains for scenario 2 were similar to the basic results in the month of September. For the first scenario however, the benefits were only half of those estimated for September. These increases were less in August and November due to a narrowing of the difference between the fat and protein percent levels of the base case and of the subsequent protein assignments.

For all assignments except the base case, the cheese plant maintained higher protein levels than the fluid plant in both months. However, the assignment of farms which maximized the relative amount of protein going to the cheese plant in September was not the maximum assignment in November and August. This reflects the low consistency in protein ranking of farms throughout the year, as discussed earlier.

The component of greater interest to the fluid plant, butterfat, was slightly lower at the fluid plant than the cheese plant in the latter assignments but in no case fell by more than .08 percentage points. In August, butterfat levels at the fluid plant ranged from 3.53 to 3.56 percent for the different assignments. In November, the range was slightly wider, but the values were significantly higher--3.69% to 3.73% butterfat (see Appendix 4).

The above results are based on the assumption that the same farms that were assigned to each plant in September, continued to ship to that plant for the rest of the year. Naturally, if assignments were made more frequently, higher protein levels at the cheese plant could be obtained. However, since route reorganization is costly, frequent reassignments are not likely to occur. Nevertheless, it does appear that there is enough consistency among high protein farms so that a one time reorganization of routes would continue to provide net benefits throughout the entire year.

Conclusion

Given the protein, butterfat and production data and the physical network of farms, roads and plants, it appears that a coordinated effort to increase the protein level of milk shipped to cheese plants may be physically and economically feasible at all target protein levels studied and throughout all months of the year. In all cases, the cheese plant's net revenue gains outweighed the hauling cost increases. Compensation for the increased hauling costs of all farms shipping to either the cheese or the fluid plant could be made and still leave the cheese plant with a net gain under each scenario analyzed.

It is clear from the above results that cheese plants have strong monetary incentives to procure high-protein milk and that compensation of high-protein producers and of producers shipping to competing fluid plants is possible. However, this conclusion is based on the assumption that the fluid plant is indifferent to the protein content of the milk it receives. If the fluid plant were a multiple product operation that could benefit from high-protein milk, the results would overstate the benefits, although benefits could still occur. The effect on consumer preference of lower protein fluid milk (though still above minimum federal standards) was also ignored. More research on changes in cheese processing costs as higher protein milk is used is also needed. If processing costs do fall as the protein level in raw milk rises as Ladd and Dunn suggest, then the net gains listed in this study may be underestimated.

Finally, more research is needed on a pricing system which accounts for the multiple impacts on all users of raw milk. Changes in assembly costs represent only one of the effects of having a protein-based assembly system. Past discussions of multiple component pricing have dealt primarily with issues of equity among producers, given a fixed total value of raw milk components. Due to the greater attainable efficiencies under the scenarios developed above, determination of equity would now involve cheese plants, milk producers and other users of raw milk. The analysis suggests that the coordinated routing of raw milk based on its end use is feasible and that a pricing system could be found to compensate the affected parties. The overall increase in market economies that this portends could ultimately benefit consumers in the form of lower prices.

References

Aplin, Richard D., George L. Casler and Cheryl P. Francis, Capital Investment Analysis, Grid Publishing, Inc., Columbus, Ohio, 1977, pp. 153-154.

Arthur, J. and A. Ravindran, "PAGP, A Partitioning Algorithm for (Linear) Goal Programming Problems," ACM Transactions on Math Software, Sept., 1980.

Barbano, David, personal interviews, Dept. of Food Science, Cornell University, Ithaca, NY, Fall, 1982.

__________, unpublished research data, Dept. of Food Science, Cornell University, 1980.

Brog, Roy A., "Economic Incentives for Cheese Processors Using a Protein-Fat Milk Pricing Model", Journal of Dairy Science, Vol. 54, 1971, pp. 1006-1013.

Brown, Rodney J., "Computerized Cheese Yield Pricing of Milk," paper presented at the Marschall International Cheese Conference, Dane County Exposition Center, Madison, Wisc., Sept. 15-18, 1981.

Ernstrom, C.A., "A Workable Milk Pricing System Based on Cheese Yields," paper presented at the International Brown Swiss Conference, Madison, Wisconsin, Oct. 1, 1980.

Gilson, J. and C. Witzgall, A Performance Comparison of Labeling Algorithms for Calculating Shortest Path Trees, National Bureau of Standards, NBS Technical Note 772, May, 1973.

Grippin, R., V.S. Packard, and R.E. Ginn, "Variability and Interrelationship of Various Herd Milk Components," Journal of Food Production, Vol. 44, No. 1, Jan. 1981, pp. 69-72.

Hallberg, M.C. and W. Kriebel, Designing Efficient Pickup and Delivery Route Systems by Computer, Bulletin 782, Penn. State University Agricultural Experiment Station, June, 1972.

Hillers, J.K., V.H. Nielsen, A.E. Freeman, J. Dommerholt and R.E. Deiter, "Value of Fat and Protein in Producer Milk," Journal of Dairy Science, Vol. 63, 1980, pp. 322-327.

Kolata, Gina Bari, "Trial and Error Game That Puzzles Fast Computers," Smithsonian, Washington, D.C., Oct. 1979.

Kosikowski, Frank V., "Getting Top Yields and the Highest Quality," Dairy Field, August, 1982, pp. 51-53.

Ladd, G. and J. Dunn, "Estimating Values of Milk Components to a Dairy Manufacturer," Journal of Dairy Science, Vol. 62, 1979, pp. 1705-1712.

Lee, S. and L. Moore, "Optimizing Transportation Problems with Multiple Objectives," AIIE Transactions, Dec., 1973.

Osman, Loren H., "End Product Pricing On the Move," Hoard's Dairyman, May 25, 1983, p. 707.

Quinn, W., A. Novakovic and W. Wasserman, "Component Pricing," Cooperative Extension Milk Marketing Letter Series, No. 18, Cooperative Extension, Cornell University, Ithaca, NY.

Sehulster, Jean, "The Potential For Increasing Efficiency in Milk Assembly: A Case Study in Cortland County, New York," M.S. thesis, Dept. of Agr. Econ., Cornell University, Ithaca, NY, January, 1983.

Sehulster, Jean M., and James E. Pratt, Potential Savings in Farm Milk Pickup Costs from Eliminating Route Duplication and Using Improved Scheduling Techniques, A.E. Res. 83-26, Dept. of Agr. Econ., Cornell University, Ithaca, NY, 1983.

Strang, D., "An Economic Analysis of the Sources and Magnitudes in Inefficiency in Bulk Milk Assembly in New York State," Ph.D. thesis, Dept. of Agr. Econ., Cornell University, Ithaca, NY, 1975.

Wasserman, Walter, personal interview, NY State Extension Specialist for Milk Marketing, Cornell University, Ithaca, NY, January, 1983.

Zall, R., "In the Future We May Be Processing Milk on the Farm," Hoard's Dairyman, Oct. 25, 1982, p. 1330.

APPENDIX 1

Summary Statistics of
Milk Production, Butterfat, and Protein Data
for 93 Farms in a Western New York Dairy Cooperative in 1979

TABLE 1. Monthly Means and Standard Deviations for Production, Protein and Butterfat Data, 93 Farms, Western New York, 1979.

Months	Milk Weight		Protein		Butterfat	
	Mean (pounds)	Standard Deviation	Mean (percent)	Standard Deviation	Mean (percent)	Standard Deviation
January	47,514	34,617	3.1917	.176	3.6971	.205
February	49,383	34,964	3.1840	.169	3.7028	.220
March	45,313	31,369	3.1610	.151	3.6937	.217
April	52,498	33,144	3.0828	.169	3.6705	.196
May	53,781	32,253	3.0113	.163	3.6749	.223
June	57,766	32,009	3.1629	.143	3.5599	.210
July	52,846	28,041	3.1095	.143	3.5347	.194
August	50,970	29,189	3.0372	.146	3.5639	.146
September	50,234	31,130	3.1281	.159	3.6057	.207
October	48,261	30,032	3.2589	.155	3.7104	.198
November	47,186	30,180	3.3463	.163	3.7588	.202
December	44,412	29,816	3.2240	.160	3.7157	.209

TABLE 2. Spearman Rank Order Correlations Between Months for Farms Ranked by Percent Protein, 93 Farms, Western New York, 1979

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
February	0.596										
March	0.754	0.790									
April	0.409	0.623	0.665								
May	0.360	0.535	0.508	0.814							
June	0.173	0.346	0.397	0.512	0.516						
July	0.227	0.417	0.379	0.559	0.501	0.633					
August	0.196	0.349	0.330	0.553	0.574	0.594	0.735				
September	0.215	0.298	0.250	0.322	0.369	0.528	0.587	0.693			
October	0.347	0.250	0.309	0.277	0.284	0.430	0.420	0.512	0.652		
November	0.485	0.387	0.455	0.279	0.353	0.294	0.318	0.486	0.439	0.656	
December	0.503	0.432	0.462	0.255	0.253	0.198	0.241	0.361	0.230	0.466	0.723

TABLE 3. Spearman Rank Order Correlations Between Months for Farms Ranked by Percent Butterfat, 93 Farms, Western New York, 1979

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
February	0.822										
March	0.706	0.883									
April	0.558	0.677	0.737								
May	0.471	0.581	0.651	0.701							
June	0.440	0.522	0.609	0.585	0.769						
July	0.487	0.554	0.613	0.561	0.592	0.747					
August	0.531	0.590	0.580	0.523	0.568	0.662	0.755				
September	0.478	0.473	0.426	0.412	0.458	0.585	0.669	0.732			
October	0.478	0.447	0.376	0.312	0.401	0.597	0.600	0.689	0.710		
November	0.579	0.583	0.499	0.363	0.424	0.515	0.524	0.569	0.528	0.726	
December	0.531	0.492	0.400	0.318	0.327	0.342	0.442	0.510	0.444	0.547	0.708

TABLE 4. Spearman Rank Order Correlations Within Each Month of Farms Ranked by Percent Butterfat and Percent Protein, 93 Farms, Western New York, 1979.

Month	Correlation
January	0.457
February	0.404
March	0.594
April	0.563
May	0.329
June	0.344
July	0.519
August	0.307
September	0.183
October	0.420
November	0.558
December	0.653

TABLE 5. Results of Simple Regressions of Percent Protein on Percent Butterfat by Month, 93 Farms, Western New York, 1979.

Month	Intercept	Butterfat Coefficient	t-ratio	$\bar{R}^2$
January	1.32	.506	6.98	34.2
February	1.69	.403	5.87	26.7
March	1.47	.459	8.36	42.8
April	1.14	.529	7.41	37.0
May	1.85	.315	4.53	17.5
June	2.17	.279	4.29	15.9
July	1.67	.407	6.34	29.6
August	2.07	.271	3.20	9.1
September	2.46	.186	2.37	4.8
October	1.99	.341	4.60	18.0
November	1.65	.452	6.48	30.8
December	1.35	.505	8.35	42.7

A P P E N D I X 2

Description of the Vehicle Scheduling Heuristic

A network can be described by a system of lines connecting a set of points. "Node" is the term which is used to refer to the points in a network and "arc" is the term used to refer to the lines which connect the nodes. In network models of a transportation system, specific commodities are sent from certain "supply" nodes to certain "demand" nodes. Unit costs on arcs as well as restrictions on flows may also be stipulated.

In the network pictured in Figure 1, the circles labeled "Plant," Farm i," and "Farm j" represent nodes and the lines labeled "D_{oi}," "D_{oj}," and "D_{ij}," represent arcs. Arcs may be directed (allowing only one-way traversing) and/or, they may be capacitated, i.e., have a limit on the flow that passes over them. Associated with each arc is a unit cost which may represent such things as time, dollars, or distances.

Many different types of problems may be solved using networks:

1) The "Minimum Spanning Tree" Problem. This problem seeks to find the least cost path (set of arcs) which gives at least one path from any node to any other node. This could be the determination of the least expensive system of telephone or high voltage powerlines or a pipeline (arcs) which give service to all customers (nodes).

2) The "Transportation" or "Transshipment" Problem. Given a directed network with cost and capacity assigned to each arc, commodity supplies at certain nodes, and commodity demands at certain other nodes, this problem finds the set of flows which satisfy demands from the given supplies at minimum cost without exceeding any arc capacities.

3) The "Travelling Salesman" Problem. Given a network this problem finds the minimum cost sequence of traversing arcs which passes through each node at least once.

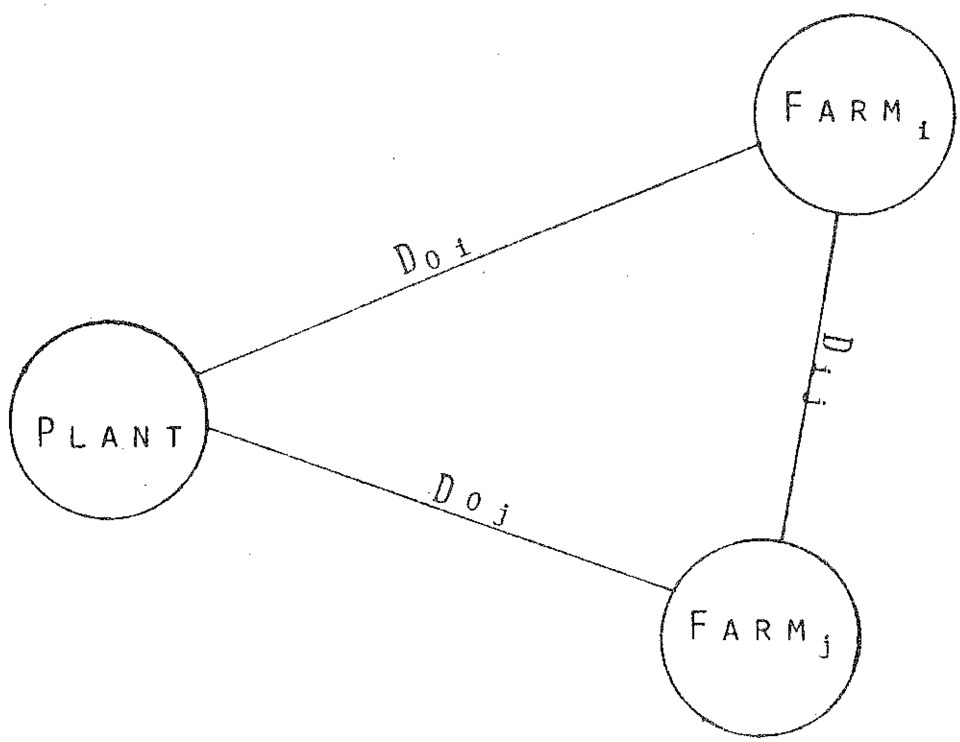
4) The "Chinese Postman" Problem. This problem finds the minimum cost sequence of traversing arcs which crosses each arc at least once.

5) The "Shortest Path" Problem. This problem finds the sequence of arcs which minimizes the cost of going from one node to another.

6) The "Vehicle Scheduling" Problem. This problem seeks to find the minimum cost sets of arcs, each set passing through a set of nodes which has less than a given total supply.

Some of these problems (1, 2, 5) can be efficiently solved even for large problems involving hundreds of thousands of arcs. Others (3,4) cannot be solved optimally for most reasonably-sized problems and, unfortunately, scheduling vehicles of limited capacity to service a number of stops (6) cannot be solved optimally for even small problems (Kolata).

Figure 1. Example Network



In the traveling salesman problem (3), when there are N nodes, there are N!/2 potential optimal solutions. Thus:

$N = 5 \longrightarrow$ 60 Potential Solutions

$N = 6 \longrightarrow$ 360 Potential Solutions

$N = 10 \longrightarrow$ 1,814,300 Potential Solutions

In the vehicle scheduling problem (6), where there may be as many as N possible routes, depending on vehicle capacity and supplies at the nodes, there are:

$N = 5 \longrightarrow$ 196 Potential Solutions

$N = 6 \longrightarrow$ 2,076 Potential Solutions

$N = 10 \longrightarrow$ over 14 million Potential Solutions

Fortunately, several heuristic* methods have been developed to provide "good" solutions to this difficult class of problem.

ROUTE, a computer program written at Pennsylvania State University by M. Hallberg and W. Kriebel, utilizes a heuristic to solve vehicle scheduling problems. ROUTE assumes a single assembly point (plant) at a known location, a known number of nodes with given supplies to be picked-up (or delivered), and a fleet of vehicles of known capacity. It must also be given distances from each node to every other node and to the plant.

Generally there are $(N^2-N)/2$ distances which must be derived in some way. For a problem of the size used in this analysis, where N equals 150, there are 11,175 such distances. To determine all of these distances by hand would be a formidable task, prone to significant errors. Fortunately, shortest path algorithms (Gilson and Witzgall) can quickly and efficiently determine these distances from the basic network information of nodes and arcs.

Using this distance information, ROUTE begins its process by initially assuming the "worst possible" solution, i.e. that each node is serviced by its own route. Then it begins to combine nodes on routes by using the concept of a "Savings Coefficient," S_{ij}.

$$S_{ij} = D_{oi} + D_{oj} - D_{ij}$$

Where: S_{ij} = Savings coefficient associated with linking stops i and j on the same route.

D_{oi} = The distance from the plant to node i.

---

* The word heuristic is a derivative of the Greek work "heuriskein" which means to discover. A heuristic approach involves methods or rules which are meant to provide guidance in the path toward discovery of the optimal solution.

D_{oj} = The distance from the plant to node j.

D_{ij} = The distance between node i and node j (see Figure 1).

S_{ij} tells what could be saved if node i and node j were combined on the same route. In this manner, S_{ij}'s are calculated for all nodes and arrayed in descending order. Nodes which have the largest savings coefficients are then linked together, forming routes.

The ROUTE program also tries to handle the restriction on vehicle capacities. Sehulster and Pratt, and Strang observed that, while ROUTE does a very good job of sequencing the nodes on routes, it does not do a very good job of handling vehicle capacity restrictions. However, by capitalizing on its sequencing strengths and using other procedures to augment its scheduling weaknesses, ROUTE can be used as an effective vehicle scheduling heuristic (Sehulster).

A P P E N D I X 3

Source of Fixed
and Variable Hauling Costs

TABLE 1. Fixed Hauling Costs, 1982

	Local Plant	On-Route Pickup NYC Plant	Long Haul NYC Plant
Assumptions			
A) Truck Chassis Cost	\$60,000	\$60,000	\$60,000
B) Expected Chassis Life	7 years	7 years	3 years
C) Chassis Salvage Value	25%	25%	25%
D) 50,000 lb Tank Cost	\$35,000	\$35,000	\$35,000
E) Expected Tank Life	10 years	10 years	7 years
F) Tank Salvage Value	25%	25%	25%
Annual Equivalent Vehicle Replacement Costs (\$)			
Chassis (a)	12,125	12,125	21,009
Tank (b)	5,975	5,975	7,073
Annual Fixed Costs Per Vehicle (\$)			
Insurance	2,500	2,500	2,500
Registration	520	520	520
Highway Tax	240	240	240
GRAND TOTAL ANNUAL FIXED COSTS (\$) PER VEHICLE	21,360	21,360	31,342
FIXED COSTS PER MINUTE (\$)	.135[c]	.145[d]	.179[e]

(a) Formula: $\dfrac{A - [(A)(C)(\text{Present Value of \$1 in year n})]}{\text{Present Value of \$1 per year for n years}}$

from Aplin et al.:

Present Value of \$1 in year n is $\dfrac{\$1}{(1+r)^n}$ assumes interest rate of 13%

Present Value of $\dfrac{\$1}{\text{year}}$ for n years is $\dfrac{[1 - (1+r)^{-n}]}{r}$

(b) Formula $\dfrac{D - [(D)(F)(\text{Present Value of \$1 in year n})]}{\text{Present Value of \$1 per year for n years}}$

(c) $\dfrac{\text{1733 min. per 2 day period x 182 days}}{\text{2 trucks}}$ = 157,703 min per truck per year
\$21,360/157,703 min. = \$.135/min.

(d) $\dfrac{\text{1620 min. per 2 day period x 182 days}}{\text{2 trucks}}$ = 147,420 min per truck per year
\$21,360/147,420 min. = \$.145/min.

(e) $\dfrac{\text{2881 min. per 2 day period x 182 days}}{\text{3 trucks}}$ = 174,781 min per truck per year
\$31,342/174,781 min. = \$.179/min.

TABLE 2. Variable Hauling Costs, 1982

	Local Plant	On-Route Pickup NYC Plant	Long Haul NYC Plant
VARIABLE COST PER MINUTE ($)			
Driver's Compensation			
Wages	7.50	7.50	7.50
Fringes	25%	25%	25%
Wage Per Hour	9.375	9.375	9.375
Variable Cost Per Minute	.156	.156	.156
VARIABLE COSTS PER MILE ($)			
Diesel Fuel	.24[A]	.24[A]	.20[B]
18 Bias Ply Tires	.08	.08	.065
Ton Mile Tax	.024	.024	.024
Repairs: Parts and Labor	.10	.10	.10
Routine Maintenance	.056[C]	.038[D]	.019[E]
Total Variable Costs Per Mile ($)	.50	.482	.408

A) 5.0 miles per gallon at $1.20/gallon
B) 6.0 miles per gallon at $1.20/gallon

C) $\frac{\text{117 miles in 2 days x 182 days}}{\text{2 trucks}}$ = 10,647 miles per truck per year, Routine Maintenance per truck $600/yr

D) $\frac{\text{202.7 miles in 2 days x 182 days}}{\text{2 trucks}}$ = 18,446 miles per truck per year, Routine Maintenance per truck, $700/yr

E) $\frac{\text{2,151 miles in 2 days x 182 days}}{\text{3 trucks}}$ = 130,494 miles per truck per year, Routine Maintenance per truck, $2,500/yr

A P P E N D I X 4

Monthly Variations in
Protein and Butterfat Levels
at Each Plant for all Assignments

TABLE 1. Monthly Variations in Protein and Butterfat Levels for All Assignments of the 148 Farms to the Cheese and Fluid Plants

	Scenario 1								Scenario 2			
	Base		Assign 2		Assign 3		Assign 4		Base		Assign 2	
	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid
January												
Protein %	3.24	3.21	3.25	3.19	3.26	3.18	3.27	3.17	3.23	3.21	3.28	3.16
Butterfat %	3.70	3.68	3.72	3.66	3.73	3.65	3.72	3.67	3.70	3.68	3.73	3.65
February												
Protein %	3.23	3.22	3.26	3.20	3.27	3.18	3.29	3.17	3.22	3.23	3.30	3.16
Butterfat %	3.70	3.69	3.74	3.65	3.74	3.65	3.73	3.66	3.70	3.69	3.75	3.64
March												
Protein %	3.19	3.18	3.20	3.16	3.20	3.16	3.22	3.15	3.19	3.17	3.23	3.14
Butterfat %	3.71	3.70	3.74	3.67	3.75	3.66	3.74	3.67	3.70	3.70	3.75	3.65
April												
Protein %	3.11	3.11	3.13	3.09	3.16	3.07	3.15	3.07	3.12	3.10	3.17	3.06
Butterfat %	3.66	3.68	3.68	3.65	3.70	3.64	3.68	3.65	3.66	3.67	3.69	3.64
May												
Protein %	3.04	3.04	3.06	3.02	3.10	2.98	3.11	2.98	3.05	3.03	3.12	2.96
Butterfat %	3.67	3.68	3.69	3.66	3.70	3.65	3.70	3.65	3.67	3.69	3.71	3.65
June												
Protein %	3.15	3.14	3.17	3.11	3.19	3.09	3.18	3.11	3.12	3.16	3.19	3.10
Butterfat %	3.55	3.56	3.56	3.54	3.57	3.54	3.56	3.55	3.54	3.57	3.56	3.54

TABLE 1. (continued)

	Scenario 1								Scenario 2			
	Base		Assign 2		Assign 3		Assign 4		Base		Assign 2	
	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid	Cheese	Fluid
July												
Protein %	3.10	3.12	3.13	3.10	3.15	3.07	3.16	3.06	3.10	3.12	3.17	3.05
Butterfat %	3.53	3.52	3.53	3.51	3.55	3.50	3.54	3.51	3.51	3.54	3.54	3.51
August												
Protein %	3.03	3.04	3.05	3.02	3.09	2.98	3.09	2.98	3.02	3.05	3.11	2.97
Butterfat %	3.55	3.56	3.57	3.54	3.59	3.53	3.58	3.54	3.55	3.56	3.58	3.53
September												
Protein %	3.09	3.12	3.14	3.07	3.19	3.02	3.22	2.99	3.09	3.12	3.22	2.99
Butterfat %	3.56	3.60	3.58	3.58	3.59	3.57	3.57	3.58	3.58	3.58	3.58	3.58
October												
Protein %	3.24	3.23	3.27	3.20	3.30	3.17	3.31	3.16	3.23	3.24	3.31	3.16
Butterfat %	3.66	3.68	3.68	3.67	3.69	3.66	3.69	3.65	3.65	3.69	3.69	3.65
November												
Protein %	3.36	3.33	3.37	3.32	3.39	3.30	3.38	3.30	3.33	3.35	3.39	3.30
Butterfat %	3.73	3.73	3.75	3.71	3.77	3.69	3.78	3.69	3.72	3.75	3.78	3.68
December												
Protein %	3.25	3.23	3.26	3.22	3.28	3.20	3.29	3.19	3.23	3.25	3.30	3.18
Butterfat %	3.71	3.64	3.73	3.68	3.76	3.65	3.75	3.66	3.69	3.72	3.76	3.65