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POTENTIAL SAVINGS IN FARM MILK PICKUP COSTS FROM ELIMINATING ROUTE DUPLICATION AND USING IMPROVED SCHEDULING TECHNIQUES

by

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PREFACE

Jean Sehulster is currently an Agricultural Economist in the office of the Market Administrator, New York-New Jersey Milk Marketing Area and James Pratt is a Research Associate in the Department of Agricultural Economics at Cornell University.

The findings reported in this paper are based on Sehulster's Master's thesis research which was completed in the Department of Agricultural Economics at Cornell University. Financial support for this project was provided by the office of the Market Administrator, Order No. 2 and by the New York State Department of Agriculture and Markets, Division of Dairy Industry Services. We are grateful to Dr. Robert Story and Herbert Kling for their unwavering encouragement during this project.

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SUMMARY OF RESULTS

A case study of six hauling firms operating farm milk pickup routes in Cortland County, New York showed that assembly costs could have been reduced significantly from actual 1980 levels. Two procedures were used: using a computerized vehicle scheduling program to sequence farm stops and eliminating unnecessary duplication in farm pickup routes.

The predicted savings from using computer-based techniques, without eliminating duplication, were $54,000 in 1980 costs annually, averaging 1.2¢ per hundredweight. Mileage was reduced by 14.7 percent. Although computerized vehicle scheduling programs have received a lot of "bad press," techniques were developed in this research to modify the "computer" results, making them superior to manually designed routes and realistic for farm pickup. The methodology developed is presented in this report. Other scheduling program users probably have been disappointed because they have assumed their "computer printouts" were the end product. Actually, the computer schedules are only the first step. They need to be questioned, evaluated and improved upon in most cases.

Costs attributable solely to avoidable overlap averaged 1.1¢ per hundredweight and resulted in increased mileage of 17.6 percent. The combined impact of both methods of reducing hauling costs would be a savings of 2.3¢ per hundredweight, $104,000 annually and 30 percent of two-day mileage.

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DEFINITION OF TERMS

ARC. Part of the transportation network. Generally in network systems, arcs are the links between nodes. For this research, arcs were distances along actual roads between nodes (i.e., farms, plants, garages or road intersections). See Figure 1, page 4.

AT-FARM TIME. Standard time required for drivers to perform all functions in picking up milk at a farm which included: driving to and from milkhouse and main road, positioning truck, hooking and unhooking pump, agitating, measuring, pumping, bookkeeping and washing tank. See Appendix I, page 42.

AT-GARAGE TIME. 20 minutes. Time used in designing routes to allow for driver's duties at the hauler's garage after each route. Used for those loads which returned to garages to change drivers before distant shipment (i.e, NYC).

AT-PLANT TIME. 60 minutes. Time to wait, unload and wash at milk plants. Used in developing routes which delivered directly to local plants.

CLEARLY ATTAINABLE SAVINGS. Variable cost savings associated with predicted mileage reductions only (i.e., does not include any cost reductions associated with predicted minute savings).

DEPOT. Origin of the route--hauler's garage was the depot.

EVERYDAY FARM. Farm at which milk was picked up every day (14.5% of farms studied). The majority of farms had sufficient bulk tank capacity to hold two-days' milk production and, therefore, were served only every-other-day.

FULLY-ALLOCATED SAVINGS. Variable and fixed costs savings associated with the predicted reductions in both miles and minutes. These savings assume that the time saved will be used to serve other farms and, thereby, generate a contribution to fixed costs (or to increase the volume of business without added capital investment). See Appendix III, page 44.

NETWORK. Method of describing any kind of movement (i.e., electrical current, water, human beings, airplanes...ad infinitum) in terms of arcs and nodes. Used here to measure distances along the actual, available roads in and around Cortland County.

NODES. Decision points in a network (see above). Used here as the locations of farms, plants, garages or road intersections. See Figure 1, page 4.

NON-OVERLAPPING (NO) ROUTES. Routes developed by computer techniques on which haulers could serve farms which were assigned to them so that garage-to-farm distance was minimized and overlap was eliminated. See Figures 5 and 6, pages 27 and 29.

ON-ROUTE MILES. Mileage between stops on the route--i.e., begins at first farm and ends at last farm served.

OPERATING TIME. Total standard route time including: at-farm time, driving time and at-plant or at-garage time.

RESCHEDULED ACTUAL (RA) ROUTES. Routes developed by computer techniques on which haulers could serve exactly the same group of farms they had served on the actual routes studied.

RESIDUAL ROUTES. Computer-generated routes to nearby farms on which truck capacity was severely under-utilized. Evidence of ROUTE program's deficiency in handling capacity constraints.

STEM MILES. Mileage from origin to first stop and from last farm back to origin.

SUPER ROUTE. Device developed to schedule routes which start at garage and end, with a full load, at a milk plant. Super routes included all farms served in two days and the milk plant as a "dummy" stop.

WEIGH SLIP (WS) ROUTES. Actual routes studied. The mileage incurred on weigh slip routes was calculated by "running" the sequence of stops recorded by the drivers "through" the transportation network.

BACKGROUND

Duplication in farm pickup routes has often been cited as a major contributor to inefficiency in milk assembly. Clearly if unnecessary route overlap were eliminated, hauling costs could be reduced. Haulers could save both mileage and operating time, and perhaps use fewer trucks, to collect the same volume of milk and to provide the same level of service to farms.

Route duplication may be a more serious problem in New York than in other milk-producing states because, unlike some other dairy regions, New York does not have one (or a few) producer cooperative(s) coordinating farm pickup. Many firms, both cooperative and privately-owned, often collect milk in the same section of the milkshed. These firms operate trucks along the same set of roads but serve only some of the farms they pass.

Although these routes overlap, some duplication may be unavoidable, especially in production areas which have high farm and/or milk densities. These areas would require more than one route to pick up the milk produced along a given set of roads. On the other hand, competition for supply among firms may have led to "unnecessary" duplication and to higher costs for the haulers in that region.

Objective and Approach

This research examined the inefficiency caused by unnecessary duplication in milk assembly in one region of New York State. The cost of unnecessary overlap was quantified by calculating the savings which could be realized by a group of haulers if overlap in their farm pickup areas were eliminated.

THE DATA BASE

Cortland County, in central New York, was selected for a case study of actual hauling operations. Six hauling firms were serving farms in the county. Each hauler was surveyed to collect data about routes he was operating for eight-day periods in both May and November of 1980. 1/ Using the drivers' weigh slip records, the following information was gathered about actual routes which served at least one Cortland farm:

1) sequence of stops,
2) volume picked up at each stop,
3) frequency of pickup,
4) first destination of the load, and
5) truck capacity and type.

In total, 63 routes serving 478 farms during May and 56 routes serving 467 farms during November were studied.

Farms, plants, haulers' garages and available roads were identified on 1:24,000 scale USGS topographic maps. 2/ This information was used to determine the shortest distance from each point of interest (farm, plant or garage) to every other one.

The distances were needed for two procedures used in the study: reassigning farms to haulers and designing alternate farm pickup routes. For these operations, it is preferable to link all points of interest to one another rather than to segment the region or to aggregate farms. With

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1/ Eight days were studied to include a complete cycle of pickups at every-other-day farms and to reflect the day-to-day fluctuation in plant receipts.

2/ The maps were provided by the Federal Order No. 2 Market Administrator's office.

"n" defined as the number of locations, $\frac{n(n-1)}{2}$ distances are needed. For this study, there were 507 points (farms, plants and garages); therefore, 128,271 links were needed.

Measuring all of these distances by hand would be tedious and would also result in errors both in making the measurements and in selecting the best path to follow. Therefore, another approach was used which describes the available roads as a network of arcs and nodes. "Nodes" were farms, plants, garages and road intersections and "arcs" were the roads linking these nodes. Using a "shortest path" algorithm, the entire matrix of 128,271 distances was constructed from a much smaller number of measurements. [3/] Only distances between each node and its adjacent nodes were needed; these were measured on the USGS maps. [4/] The road network for one quadrangle is shown in Figure 1 and the scope of the network is shown in Figure 2. [5/]

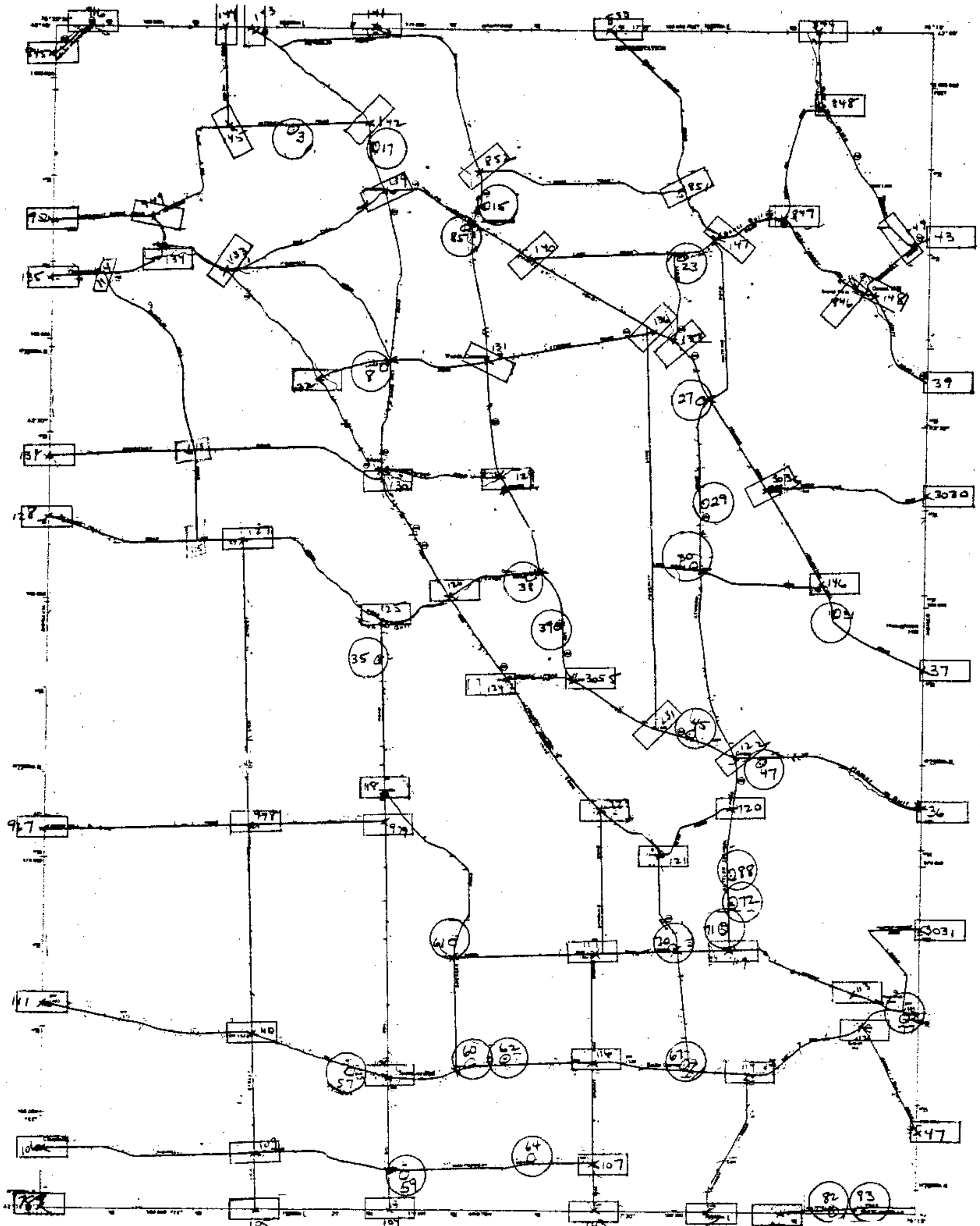
Shortest path techniques are more flexible than other methods. Nodes can be added (or deleted) easily. A new node only requires measurements to its adjacent points rather than to every other node in the network. Complexities, such as one-way streets, unsafe bridges, dangerous hills and the like, could be included in an arc and node system. However, these road restrictions were not incorporated into this network because they were not known.

3/ J. Gilson and C. Witzgall, "A Performance Comparison of Labeling Algorithms for Calculating Shortest Path Trees," NBS Technical Note 772 (Washington, DC: US Department of Commerce, National Bureau of Standards, 1973). pp. 1-12.

4/ Computer graphic techniques could save a considerable amount of the labor involved in making the arc measurements.

5/ The entire system required 2,907 nodes and 4,097 arcs, required 65 quadrangle maps and represented nearly 4,000 miles of roads.

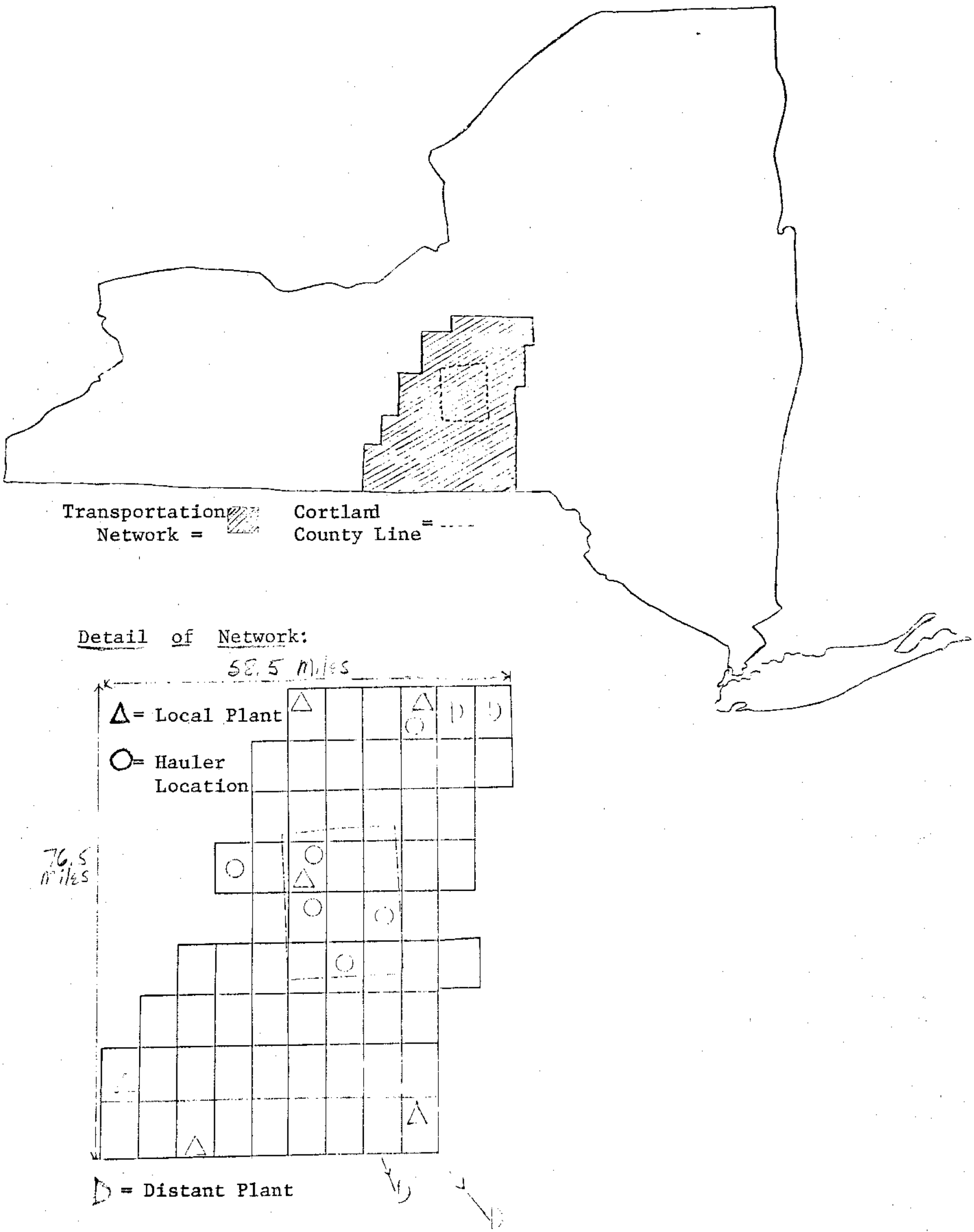
Figure 1. Transportation Network Specified for One Topographic Quadrangle



LEGEND:

○ = Farm Nodes; ▭ = Intersection Nodes; ——— = Arcs

Figure 2. Geographic Area Covered by Transportation Network



PROCEDURES

The impact of reducing unnecessary overlap was measured as follows:

1) Using the sequence of stops recorded on the weigh slips, the road network and standards for both driving and farm service time, [6/] the mileages and times incurred on the actual routes studied were calculated.

2) New routes were designed for each hauler using a computer scheduling program, ROUTE. [7/] On these new routes, haulers would serve exactly the same farms they were serving on the actual routes. This step isolated the cost of overlap from the impact of using computer techniques to sequence routes. [8/]

3) Overlap was eliminated by reassigning each farm to one of the six haulers so that farm-to-hauler distance would be minimized. [9/]

4) New routes were developed for each hauler on which he could serve the new farms assigned to him in step 3. These routes were compared to the computer-sequenced existing routes (step 2) to calculate the cost of unnecessary overlap.

6/ The time standards were based on work by Chester Smith. See Appendix I for a detailed explanation.

7/ M. C. Hallberg and W. R. Kriebel, "Designing Efficient Pickup and Delivery Route Systems by Computer," Station Bulletin 782 (University Park, PA: Pennsylvania State University, June 1972), pp. 1-32.

8/ Also, the sequences followed on the actual routes may have resulted from special milking times, inadequate driveways for large vehicles or other complexities that were not known. If these factors caused actual routes to require more mileage, a direct comparison of "weigh slip" routes to non-overlapping computer routes would have exaggerated the cost of overlap itself. Note: The program can consider both special times and vehicle restrictions, if they are known. See Appendix II.

9/ Three reassignment criteria were used. The farm-to-hauler reassignment was the more stable one and, therefore, is the one presented here. For a discussion of the results of the other criteria, see Sehulster.

COMPUTERIZED VEHICLE SCHEDULING: METHODS FOR IMPROVING THE RESULTS

Portions of ROUTE were used to design assembly systems. This program employs a heuristic (a decision aid) developed by Clarke and Wright. 10/ The technique begins with the worst solution and uses a simple rule to make improvements. For a more detailed description of the ROUTE program itself, see Appendix II.

A route solution determines both the number of routes and the sequence of stops on those routes which minimize total distance, given the locations of stops, the number of trucks and their capacities, and the quantity to pickup at each stop. The worst solution would be to have each stop served by its own route, or have "n" routes each with only one stop, so that:

Stop 1 is on route 1,

Stop 2 is on route 2,

Stop 3 is on route 3,

.

.

.

Stop N is on route N.

To improve this base solution, stops are combined so that the greatest distance is saved. Clarke and Wright developed the concept of a "savings coefficient" to rank the potential savings from each of the $\frac{n(n-1)}{2}$ possible pairs of stops. 11/ If two routes serve only one stop each,

10/ G. Clarke and J. W. Wright, "Scheduling Vehicles from a Centre Depot to a Number of Delivery Points," Operations Research 12 (1964), pp. 569-581.

11/ Ibid.

total mileage is the distance from the Depot to Stop 1 and back, plus the distance from the Depot to Stop 2 and back, as shown in Figure 3. But, when Stops 1 and 2 are served by one route, the distance from Stop 1 back to the Depot and the distance from the Depot to Stop 2 are "saved"; while, the distance from Stop 1 to Stop 2 is added (Figure 4). The savings coefficient is the distance saved by serving the two stops on one route, or: $S_{ij} = d_{oi} + d_{jo} - d_{ij}$.

Where, S_{ij} = savings coefficient for the ij pair of stops

d_{oi} = distance from Depot to Stop i

d_{jo} = distance from Stop j to Depot

d_{ij} = distance from Stop i to Stop j.

Savings coefficients are calculated for each pair of stops and arranged in descending order. Routes are developed by combining stops with the highest savings coefficients until a constraint, such as vehicle capacity, route time or cost, is encountered. This technique does not necessarily find the uniquely minimum distance route system but it clearly arrives at a better solution in logical manner.

ROUTE has been used in other studies and some researchers, especially Strang, have been disappointed with its results. 12/ The program sequences stops to minimize distance well but it does not handle route constraints well. This is especially true of vehicle capacity and availability. In addition, the program was not designed for milk pickup and does not explicitly schedule for everyday farms or for multiple depots

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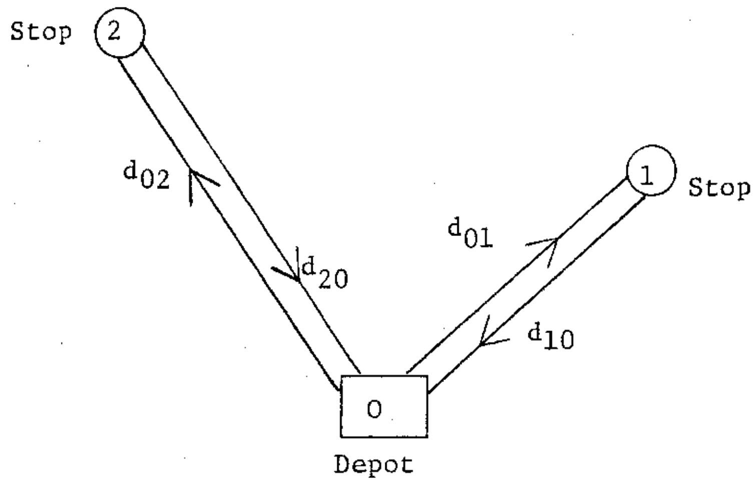
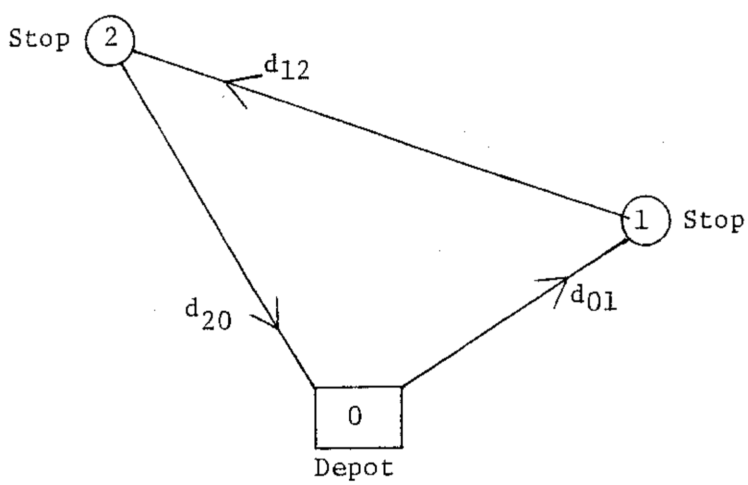
12/ D. R. Strang, "An Economic Analysis of the Sources and Magnitudes of Inefficiency in Bulk Milk Assembly in New York State," (Ph.D. thesis, Cornell University, 1975), p. 175.

Figure 3. Illustration of Route Patterns for Two Routes Each Serving One Stop



Two Route Total Distance = $(d_{01} + d_{10}) + (d_{02} + d_{20})$

Figure 4. Illustration of Route Pattern and Savings Coefficient When Two Stops Are Served By One Route



One Route Total Distance = $d_{01} + d_{12} + d_{20}$

Savings Coefficient = $[(d_{01} + d_{10}) + (d_{02} + d_{20})] - (d_{01} + d_{12} + d_{20})$

$= d_{01} + d_{20} - d_{12}$

(routes which begin at garages and deliver to plants). Therefore, ROUTE was only used for sequencing and other techniques were developed to handle these constraints.

Handling the Mixture of Everyday and Every-Other-Day Pickups

In a two day period, "everyday" farms are effectively two stops at the same location which must be put onto different routes. But, the "two" stops have the same savings coefficient and would be assigned, in sequence, to the same route. Therefore, it was necessary to "trick" ROUTE into scheduling two trips (one for each day) to everyday farms. One option available in ROUTE allows a number of different vehicle types to be "input." Another option allows a vehicle restriction at any stop, such that "vehicle Type X may not serve Stop 1." To schedule two routes to everyday stops, two vehicle "types" were used. Actually these truck types were identical, but defining them as Type X and Y created an odd day and an even day fleet. One of the "two" everyday stops was restricted to vehicle Type X only, the other to vehicle Type Y only. All every-other-day farms, which needed only one stop in two days, were unrestricted. Routes could then be sequenced so that the odd everyday stop was on a different route than the even stop, and every-other-day farms could be assigned to the "best" route in terms of minimizing distance.

Handling Multiple Depots

The ROUTE program assumes that all trucks return to the depot. However, the actual routes started at haulers' garages which were not at, or near, milk plants. One hauler was 59 miles from one plant he was serving (see Figure 2). To be realistic, routes should be designed to start at the garage and end, with a full load, at the plant. Simply adding the plant as a "dummy" farm and scheduling with ROUTE did not solve the problem because the truck would not necessarily be full when the plant stop was assigned. "Super" routes were developed to schedule garage-to-plant routes. Farms were already associated with (or were reassigned to) a hauler; therefore, the garage was assumed to be the "depot." The plant was treated as a "dummy" farm stop, and to solve the capacity problem, a truck large enough to hold the hauler's entire two-day pickup volume was "input." One route was sequenced to include all farms and the plant. Because the garage was the depot, it was implicitly the start and end point (see the left-hand side of Table 1).

Garage-to-plant routes were created manually from the super route by beginning at the garage's location in the super route and adding farms, in sequence, toward the plant until truck capacity was reached. [13/] These routes would then begin at the garage and end at the plant with a full load. Two first loads were created from each super route (as shown on the right-hand side of Table 1). Smaller super routes were created with the remaining unscheduled farms until enough first trips were designed.

Handling ROUTE's Allocation Deficiencies

Fleet utilization on "programmed" routes was disappointing. For example, one hauler picked up 247,628 pounds of milk using trucks with 52,000-pound tanks. Only five routes should be needed, but ROUTE scheduled six as follows:

13/ If the next stop in the super route was too large to be included on that route because of truck capacity, the quadrangle maps were used to identify other stops that the truck would pass on its way to the plant whose volumes would fit on the truck.

Table 1. Sample Super Route for Scheduling First Trips From Hauler's Location to Plant

Farm Stop**		Amount Picked Up (lbs.)		Time At Stop (mins.)
	Garage			
Adams		3,064		15
Bates		2,781		16
Clover Hill		4,428		15
Dixon		2,099		15
Edwards		3,746		18
Ford		4,038		13
Green		2,501		16
Howe		1,775		14
Ilford		5,948		13
Jones		2,633		14
			33,013	
Kelly		4,853		13
Leonard		820		12
Miller		3,325		17
Nowles		1,619		14
O'Hara		4,355		19
Milk Plant	*	0		0
Perry		2,431		15
Quinn		3,910		14
Rhodes		3,792		14
Smith		4,505		19
Tuttle		5,097		17
Ulster		3,029		16
Vaugh		4,825		20
White		5,108		20
	Garage			

First Garage-to-Plant Sequence

1 Adams
2 Bates
3 Clover Hill
4 Dixon
5 Edwards
6 Ford
7 Green
8 Howe
9 Ilford
10 Jones

11 Milk Plant

33,013 Pounds on Load

Second Garage-to-Plant Sequence

1 White
2 Vaughn
3 Ulster
4 Tuttle
5 Smith
6 Rhodes
7 Quinn
8 Perry

9 Milk Plant

32,697 Pounds on Load

Amount Picked Up on Route = 80,682 pounds

Distance Traveled on Route = 155.9

Route Requires a Truck With a Capacity of 300,000 pounds*

* Actual truck tank capacity is 34,400 pounds.

** Stop names are fictitious.

Route	Number of Stops	Pounds Picked Up	Total Distance (miles)	Tank Capacity Utilization (%)
1	9	51,895	67.3	99.8
2	8	28,910	8.6	55.6
3	8	44,698	20.8	86.0
4	10	51,777	42.0	99.6
5	11	51,977	24.1	100.0
6	4	18,371	15.4	35.3
	50	247,628	178.2	79.4

Tank capacity utilization would be only 79% while the actual routes this hauler was operating were 95% full. Route 6 and Route 2 were considered "residual" routes because they had only a few, nearby stops and tank capacity was under-utilized. These residual routes resulted from the method the program uses to sequence stops.

ROUTE adds stops to routes by examining savings coefficients. Therefore, the candidate farms which it considers adding to a route are limited by their placement in the savings matrix. Only stops that are close to the last one sequenced are considered. But, if the candidate farm's pickup volume is too large for the truck or if it has already been assigned to another, completed route, sequencing ends. 14/ This leaves a subset of stops which are close to the depot that are scheduled last and they are assigned to residual routes. But, because they are near the depot, these farms are located on roads used by other routes and could be added to one of them without adding any distance.

14/ Existing links cannot be broken; therefore, if the candidate stop is already assigned to a route, that entire route sequence must be added. In most cases, adding an entire route to a route being developed would exceed truck capacity; therefore, the link would not be made.

To eliminate residual routes, each "computed" route was traced on the maps to identify which farms from the residual routes could be added to another route without increasing mileage. Farms were added to routes or swapped from one route to another until the residual route was eliminated.

For the example given previously, one route was eliminated resulting in these routes:

Route	Number of Stops	Pounds Picked Up	Total Distance (miles)	Tank Capacity Utilization (%)
1	8	49,885	67.3	95.9
2	10	42,702	10.3	82.1
3	10	51,776	18.8	99.6
4	10	51,777	42.0	99.6
5	12	51,488	33.2	99.0
	50	247,628	171.6	95.2

6.6 miles would be saved and capacity utilization would increase to 95.2%.

ROUTE also did not consider the number of vehicles available properly. This problem was discovered by varying the number of trucks. For a hauler who needed only five routes, five vehicles were input and routes were scheduled. When ten vehicles were "available" to serve the same set of farms, a different, lower-mileage route system was scheduled (using only five of the ten trucks). Experimentation showed that as the number of vehicles ROUTE believed were available increased, total mileage for the routes it generated declined. The cause of this problem was not discovered, but its existence had implications for using ROUTE. The number of vehicles needed to schedule the "best" route scheme could not be predicted; therefore, 99,999 vehicles were input for ROUTE sequencing. 15/

15/ ROUTE accepts five digits for each vehicle type.

Specifying 99,999 trucks created problems when designing routes for haulers who operated both straight chassis and tractor-trailer vehicles because the difference in tank size between the two types was large enough to affect the number of routes needed. And the program would schedule routes for large trucks first; therefore, with 99,999 available only tractor-trailer sized routes would be sequenced.

Again manually-applied techniques were used to create routes for haulers with mixed fleets. For example, one hauler operated 24 routes; eight routes used tractor-trailers and the others used straight chassis trucks. Because more small capacity routes were needed, 99,999 straight chassis trucks were "input," resulting in 29 routes. Some of these 29 routes were merged to create 8 tractor-trailer routes as outlined below:

1) Each computer-generated route was traced on the maps to identify which section of the farm pickup area it served.
2) The longest route (the one serving the most distant farms) was identified. This route was enlarged by adding stops from a second and/or third route scheduled to serve that region. Farms in distant areas were "mopped up" until the larger tractor-trailer capacity was reached.
3) Longer routes were combined into large-capacity routes (as above) until the proper number of tractor-trailer routes was created.
4) If the remaining straight chassis routes were no longer properly sequenced because of "losing" stops to tractor-trailer routes, they were rescheduled.

By serving distant farms with the larger trucks, fewer long distance routes were needed and total miles were reduced.

If a hauler used more tractor-trailers than small trucks, ROUTE was used to sequence tractor-trailer routes. The shorter (or closer) of these routes were then divided into straight chassis sized routes.

All of these techniques made it possible to capitalize on ROUTE's strength in sequencing farm stops and to create practical route systems while avoiding the process' shortcomings. It is likely that other scheduling program users have been disappointed because they have assumed that their "computer printouts" were the end product. Actually, the computer schedules are only the first step, and they need to be questioned, evaluated and improved upon in most cases.

POTENTIAL SAVINGS FROM USING MODIFIED COMPUTER SCHEDULING TECHNIQUES

The six haulers were not using computers to schedule routes during 1980 but the routes they hypothetically would use to serve their reassigned, non-overlapping farms were designed by modified computer techniques. In order to isolate the inefficiency due to unnecessary duplication from other sources of inefficiency, it was also necessary to reschedule the actual routes using the same computer-based procedures. 16/

The rescheduled actual routes were compared to the weigh slip routes. The results of this comparison showed that the potential savings from using these modified computer techniques were substantial. Moreover, they could be attained whether or not duplication was reduced.

Cost savings were estimated from the predicted reductions in miles and minutes by applying 1980 per mile and per minute cost factors. The variable cost per mile was estimated to be 38.6¢, the variable cost per minute used was 11¢ and the estimated fixed cost per minute was 4.8¢.

16/ In addition, some scheduling restrictions, such as special milking times or inadequate driveways, which could have affected the sequences followed on actual routes were not known and, therefore, were ignored in the computer-based scheduling steps.

These costs were based on research conducted by Wasserman [17/] and by Anderson. [18/] For a complete and detailed discussion of these costs, see Appendix III.

Using the sequence of stops recorded by the drivers on weigh slips and the average of the recorded pickup volumes, the travel distances and hours spent on the actual routes were determined. These weigh slip (WS) mileages and times were based on the transportation network and the time standards. Similarly, the computer-generated rescheduled actual (RA) route mileages and times were based on the same average pickup volumes, transportation network and standards. All that would change on RA rather than WS routes is the sequence of stops--all farms would be served by the same hauler, everyday farms would receive everyday service, haulers would ship to the same plants and use the same fleets. Table 2 shows some of the operating characteristics of the RA and WS routes for May. Samples of the route reports and hauler summaries developed for this study are shown in Appendix IV.

If the modified computer techniques had been used and if the RA routes had been implemented in May, two routes could have been eliminated. Two-day travel distance would be reduced by 445 miles, saving 14.7% of the weigh slip miles. Operating time could be reduced by 790 minutes mainly as a result of reduced driving time. One 60 minute at-plant and one 20 minute at-garage time could be avoided. At-farm time would not change because the same volume of milk would be picked up from the same number of farms.

17/ W. Wasserman and W. Lesser, "Using the TI-59 Programmable Calculator to Estimate Operating Costs and Hauling Rates for Bulk Milk Assembly," A.E. Res. 80-12 (Ithaca, NY: Cornell University, June 1980), pp. 15-30.

18/ B. L. Anderson, "The Structure and Characteristics of the Milk Assembly System in New York State," A. E. Res. 81-16 (Ithaca, NY: Cornell University, September 1981), pp. 1-52.

Table 2. Operating Characteristics, Rescheduled Actual (RA) and Weigh Slip (WS) Routes, May 1980 2 Days of Operation

Characteristics	All Six Haulers	
Number of Farms	478	
Number of Farms Served Every Day	35	
Pounds of Milk Picked Up	2,477,516	
	RA	WS
Number of Routes	61	63
Total Miles	2,588	3,033
Total Minutes	15,530	16,320
Routes Returning to Hauler	46	47
Total Miles	1,690	2,008
Number of Routes/Truck/Day:		
Straight Chassis	1.9	2.0
Tractor-Trailer	1.0	1.0
Standard Time/Truck/Day:		
Straight Chassis	5h 48m*	7h 8m
Tractor-Trailer	4h 47m	4h 37m
Routes Delivering to Plants (straight chassis trucks only)	15	16
Total Miles	898	1,025
Number of Routes/Truck/Day	1.9	1.8
Standard Time/Truck/Day	8h 56m	8h 26m
Overall Fullness/Trip (%)	96.0**	93.6
Farm Density (on-route miles/stop)	2.6	3.1

* "h" refers to hours, "m" refers to minutes.

** The RA routes would be 96.0% full based on the average of the pickup volumes recorded for each farm on the weigh slips. This is higher utilization than other researchers have "budgeted" for routes. The variation in actual daily production was analyzed and very little day-to-day fluctuation was found; therefore, these routes should be feasible for actual operations.

Loads per truck per day for straight chasses returning to garages to change drivers before shipment to distant plants would decline because saving one load would not idle one truck (i.e., it would still be needed for at least one load each day). Average standard time on these straight truck routes could be reduced because they would be used to serve nearby farms. On the other hand, tractor-trailer routes to haulers would be slightly longer on the average because tractor-trailers would serve the more distant farms. On routes to plants, loads per truck per day would increase because "saving" one trip would allow that hauler to leave one truck idle without increasing average truck operating time significantly.

Average fullness per trip would change only for haulers who saved loads, but overall utilization would increase from 93.6 to 96.0%. Finally, average farm density, or on-route miles per stop, would improve because on-route miles would decrease while the number of stops would be the same.

Although each of the haulers would benefit from using the RA routes rather than the WS routes, there would be a wide variation in their individual savings. Table 3 shows the time and distance savings of the May RA versus May WS routes for each hauler.

The small decrease in at-farm time resulted from reducing service to "top off" farms (those served more than once a day) to only once a day, thereby saving the fixed portion of stop time. The saving in route operating time would range from 9 minutes in two days for Hauler A to 252 minutes for Hauler F. Haulers D and F could each save one route and, therefore, save one at-plant and one at-garage time, respectively. The proportion of route time spent driving would decrease for all haulers, although Hauler A would hardly be affected. On the other hand, Hauler E could save 4.4% of his driving time.

Table 4 shows the potential cost savings of using the May RA routes.

Table 3. Time and Distance Savings for Each Hauler, Rescheduled Actual (RA) vs Weigh Slip (WS) Routes, May 1980

Hauler	Savings in Minutes (WS minutes minus RA minutes)				Decrease in Driving as a % of Total Time (WS% minus RA%)
	At-Farm	Driving	Other Time*	Total	
A	0	9	0	9	0.9%
B	11	44	0	55	2.2
C	0	43	0	43	1.2
D	24	162	60	246	3.0
E	43	142	0	185	4.4
F	22	210	20	252	2.8
Total Savings	100**	610	80	790	2.6%

Hauler	Savings in Miles (WS miles minus RA miles)			Total Savings as a % of Total WS Miles
	Stem	On-Route	Total***	
A	21	(11)	10	5.7%
B	(5)	34	29	14.6
C	(13)	39	24	4.1
D	59	62	120	16.2
E	32	68	100	28.5
F	99	63	162	16.5
Total Savings	193	255	445	14.7%

* "Other Time" refers to at-plant (60 min./route) and/or at-garage (20 min./route) time.

** At-farm changed slightly because of a reduction in service to "top off" farms (farms served more than once a day). Some of those served more than once a day on WS routes were served only once a day on RA routes.

*** Parts may not add to total due to rounding.

NOTE: () indicates increases for RA routes vs WS routes.

Table 4. Estimated 1980 Cost Savings, May Rescheduled Actual vs. May Weigh Slip

	Hauler						All Six
	A	B	C	D	E	F	Haulers
Minutes Saved	9	55	43	246	185	252	790
Miles Saved	10	29	24	120	100	162	445
Fixed Saving: $.048/minute**	$.43	2.64	2.06	11.81	8.88	12.10	$37.92
Variable Savings: $.110/minute**	.99	6.05	4.73	27.06	20.35	27.72	86.90
$.386/mile	3.86	11.19	9.26	46.32	38.60	62.53	171.77
Fully-Allocated 2 Day Savings	$5.28	19.88	16.05	85.19	67.83	102.35	$296.59
2 Day Volume (cwt.)	839	2,874	3,074	3,878	4,642	9,468	24,775
Fully-Allocated Savings Per Cwt.	$.006	.007	.005	.022	.015	.011	$.012
Fully-Allocated Annual Savings	$961	3,618	2,921	15,505	12,345	18,628	$53,979
CLEARLY ACHIEVABLE SAVINGS DUE TO REDUCED MILEAGE:							
Annual Variable Mileage Saving	$703	2,037	1,685	8,430	7,025	11,380	$31,262
Mileage Saving Per Cwt.	$.005	.004	.003	.012	.008	.007	$.007

* Parts may not add to total due to rounding.

** Assumes minutes saved are used to serve other farms to generate contribution to fixed costs.

The "clearly attainable savings" are the variable costs saved from reduced mileages (see Appendix III for a detailed explanation). They would range from \$700 to \$11,000 per year. The mileage savings would translate to a cost saving of from 0.3¢ to 1.2¢ per hundredweight. The group could save at least \$31,000 annually, or 0.7¢ per hundredweight, from the 445 mile decrease in two-day route mileage.

The "fully-allocated" savings estimates assume that the per minute cost savings could be achieved (see Appendix III). These annual savings would be nearly \$54,000 for the group, averaging 1.2¢ per hundredweight picked up. Hauler C would save almost \$3,000 per year, or 0.5¢ per hundredweight; while, Hauler F could save \$18,000 annually and Hauler D could reduce his costs by 2.2¢ per hundredweight.

Weigh Slip and Rescheduled Actual Routes: November 1980

Seven fewer weigh slip routes were used to serve Cortland farms in November than in May because some haulers had consolidated their routes as volumes at farms declined. Therefore, the November and May weigh slip routes had approximately the same tank utilization, 92.3% and 93.6%, respectively. Three haulers operated the same number of weigh slip routes in both time periods, but two of these firms served more farms in November. One hauler operated exactly the same routes in both November and May.

The rescheduled actual route results suggest that four more November routes could have been eliminated, saving 457 miles, 15.2%, and 904 minutes, 6.0% (see Table 5).

Table 6 shows the cost savings from operating the November RA routes. The short-run savings from reduced mileage would be \$32,000 annually or 0.8¢ per hundredweight for the group. Annual mileage savings would range from \$770 to \$9,500 on a hauler basis, while individual haulers could clearly

Table 5. Operating Characteristics, Rescheduled Actual (RA) and Weigh Slip (WS) Routes, November 1980 2 Days of Operation

Characteristics	All Six Handlers	
Number of Farms	467	
Number of Farms Served Every Day	16	
Pounds of Milk Picked Up	2,115,934	
	RA	WS
Number of Routes	52	56
Total Miles	2,541	2,998
Total Minutes	14,160	15,064
Routes Returning to Hauler	37	40
Total Miles	1,349	1,638
Number of Routes/Truck/Day:		
Straight Chassis	1.9	2.0
Tractor-Trailer	1.0	1.0
Standard Time/Truck/Day:		
Straight Chassis	5h 42m	6h 30m
Tractor-Trailer	4h 59m	4h 27m
Routes Delivering to Plants	15	16
Total Miles	1,192	1,360
Number of Routes/Truck/Day:		
Straight Chassis	1.5	1.7
Tractor-Trailer	1.0	1.0
Standard Time/Truck/Day:		
Straight Chassis	8h 15m	8h 56m
Tractor-Trailer	5h 56m	6h 8m
Overall Fullness/Trip (%)	94.8	92.3
Farm Density (on-route miles/stop)	2.4	3.0

* "h" refers to hours, "m" to minutes.

Table 6. **Estimated 1980 Cost Savings, November Rescheduled Actual vs. November Weigh Slip Routes**

	Hauler						All Six
	A	B	C	D	E	F	Haulers
Minutes Saved	20	72	12	248	259	293	904
Miles Saved	17	38	11	130	126	135	457
Fixed Saving: $.048/minute**	$.96	3.46	.58	11.90	12.43	14.06	$43.39
Variable Savings: $.110/minute**	2.20	7.92	1.32	27.28	28.49	32.23	99.44
$.386/mile	6.56	14.67	4.25	50.18	48.64	52.11	176.40
Fully-Allocated 2 Day Savings	$9.72	26.05	6.15	89.36	89.56	98.40	$319.23
2 Day Volume (cwt.)	519	2,646	2,089	2,623	3,688	9,593	21,159
Fully-Allocated Savings Per Cwt.	$.019	.010	.003	.034	.024	.010	$.015
Fully-Allocated Annual Savings	$1,769	4,741	1,119	16,264	16,300	17,909	$58,100
CLEARLY ACHIEVABLE SAVINGS DUE TO REDUCED MILEAGE:							
Annual Variable Mileage Saving	$1,194	2,670	774	9,133	8,852	9,484	$32,105
Mileage Saving Per Cwt.	$.013	.006	.002	.019	.013	.005	$.008

* Parts may not add to total due to rounding.

** Assumes minutes saved are used to serve other farms to generate contribution to fixed costs.

save from 0.2¢ to 1.9¢ per hundredweight. In the longer run the group could realize a $58,100 annual cost reduction and save an average of 1.5¢ per hundredweight.

Before studying the November routes, it was hypothesized that the savings from the RA routes would be smaller for November than May, because it was assumed that haulers would have more flexibility to design efficient routes manually during the short season than in the flush. However, the results did not support this hypothesis. The November RA routes would require 15.2% fewer miles than November's weigh slip routes, while for May there would be a 14.7% reduction. The slightly larger November saving was largely due to Hauler E who did not change his routes at all as volume declined, resulting in a 78.2% tank utilization on his ten November weigh slip routes (vs. 98.5% for 10 May routes). On the other hand, Hauler C did consolidate routes and operated routes in November which were similiar to the "best" sequence suggested by the RA routes. These results suggest that routes should be rescheduled and consolidated as milk production declines in order to maintain high tank capacity use and to reduce mileage. The results for Hauler E demonstrate that planning routes for 80 to 85% of "normal" (neither short nor peak) milk production and operating those routes year round is inefficient and costly because trucks are full only in the peak. Two sets of routes should be used, one for the "normal-to-peak-to-normal" months and one for the "normal-to-short-to-normal" months.

Impact of the Vehicle Scheduling Techniques

The impact of using the modified computer techniques to design routes was both substantial and consistently better than the manual methods the haulers were using. Although the computed routes did not reflect some of the factors which would affect route sequences because they were not known, it is not likely that many farms actually require special pickup hours or certain truck types. [19/] Nor, is it probable that the road network included many roads and bridges which are actually unuseable. [20/] Therefore, most of these savings are realistically attainable.

The results were very similiar for May and November and two conclusions can be drawn from this similarity. First, generalizing the two-day results for either time period should provide a valid prediction of annual cost savings (if routes are rescheduled for short month production). The estimated annual cost savings for May and November, which were based on May and November two-day savings, are almost identical. The clearly attainable annual savings would be $31,000 if May's results are imputed to annual figures and $32,000 if November's results are used. The long-run fully-allocated savings for the group differ by only $4,000 per year as a result of implying May rather than November results. Further, each of the six haulers' savings ranked almost identically in the two months. Second, the results of using these vehicle scheduling techniques to design routes were consistent. The RA routes predicted a 14.7% improvement for May, and similarly, a 15.2% mileage reduction for November.

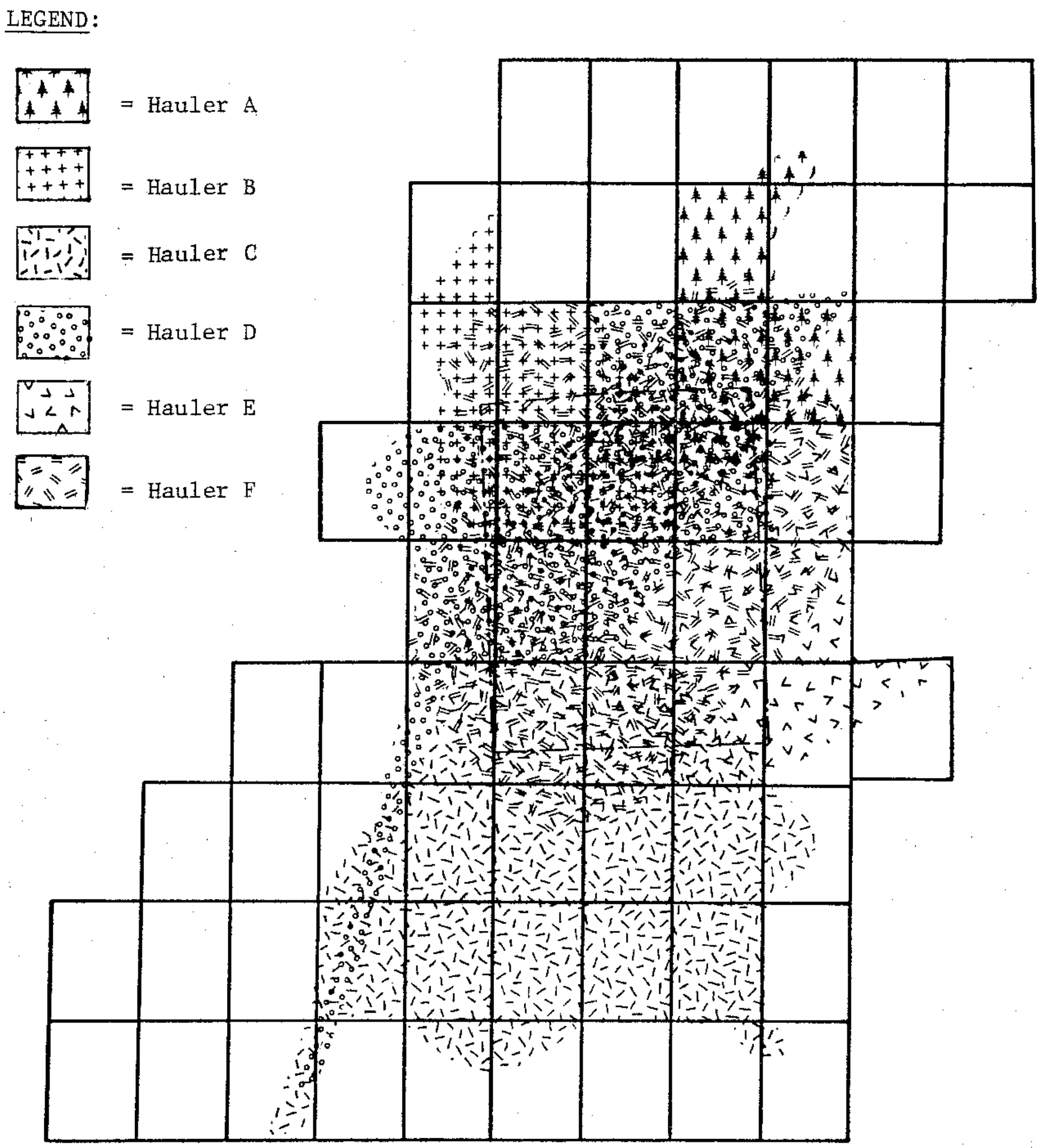
COSTS ATTRIBUTABLE TO UNNECESSARY DUPLICATION

After the existing weigh slip routes were studied, the degree of overlap on actual routes could be examined visually. Figure 5 shows the entire network area with each hauler's weigh slip pickup area superimposed. The darker area in the center indicates the region of the highest degree of overlap.

19/ Half of the farms in this study were being served by large trucks on the weigh slip routes.

20/ All of these complexities could easily be incorporated in a network if they are known.

Figure 5. Depiction of Overlap, Weigh Slip Data, May 1980



Amount of Unnecessary Duplication

Unnecessary duplication was defined as the miles and minutes, and thereby costs, which could be saved by reassigning farms to haulers' locations, so that overlap would be eliminated. Comparing routes resulting from the reassigned farm sets to the rescheduled actual (RA) routes isolated the inefficiency caused by unnecessary duplication. The RA routes would be the more efficient routes the haulers could operate to serve their existing, overlapping farm sets while the routes designed for the reassigned farm sets would be the more efficient ones for non-overlapping pickup areas. 21/

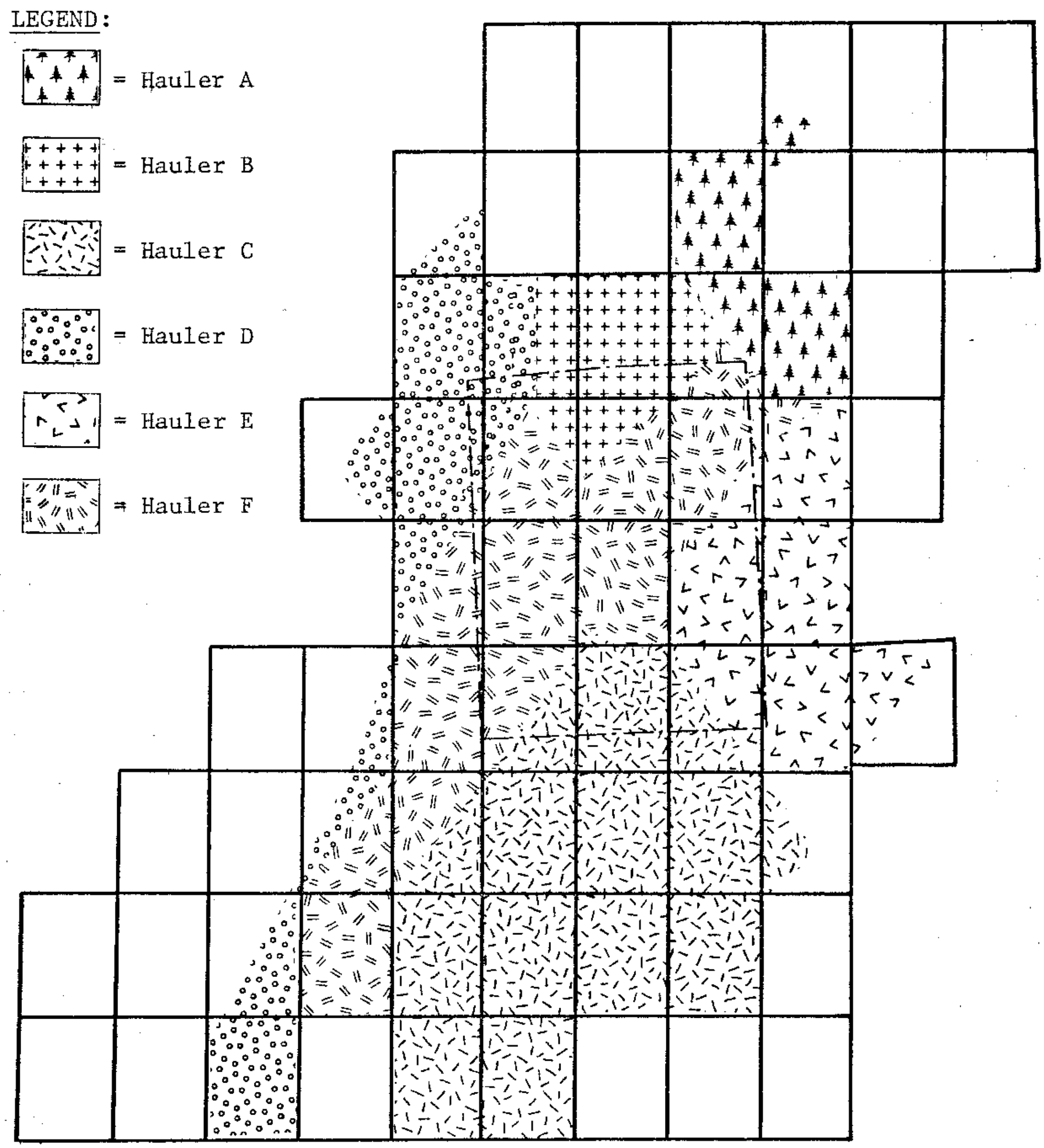
Farms were reassigned to haulers' locations so that farm-to-garage distance was minimized. 22/ As a result of this reassignment, the farm region was geographically divided among the haulers as shown in Figure 6. Areas of overlap were eliminated (compare Figures 5 and 6).

After reassignment, 45% of the farms would be served by a different hauler than had actually served them. Milk would be "comingled"; that is, milk marketed by the various firms, both cooperative and proprietary, would be loaded on the same truck and each plant would receive some milk that previously had gone to another plant. But all else would remain the same. Haulers would pick up the same volume of milk, use the same fleets and ship to the same plants. Further, plants would receive the same volume of milk and all milk would be picked up.

21/ The computed routes were developed by using heuristic procedures; therefore, it cannot be assumed that either distance or cost was minimized. These routes are efficient in the sense that they are better than the current routes and are the best that could be generated with the techniques used.

22/ As mentioned earlier, a number of reassignment criteria, or bases, were compared; the farm-to-hauler scheme was the most stable over time and the most effective in eliminating overlap in pickup areas. A network transshipment algorithm developed at the Naval Postgraduate School was used for the reassignments, see Bradley, et al.

Figure 6. Depiction of Farm Reassignments



Routes were developed for each hauler to serve his reassigned farms and to ship to the plants he served on the actual routes. Table 7 shows the operating characteristics of the routes to non-overlapping farms (NO) and rescheduled actual (RA) routes for May 1980.

Four hundred fifty six miles every two days were attributable to unnecessary duplication in farm pickup. Route time could be reduced by 613 minutes. Although duplication caused haulers to travel significantly more miles and to spend considerably more time, it did not cause them to operate more routes. This result was surprising. It was predicted that reorganization would "save" routes and trucks, as well as miles and minutes. It did not because tank capacity, rather than time, was the limiting factor in the dense Cortland area. Because the number of routes would not change, trucks would average the same number of loads per day and overall fullness per trip would be 96.0% for both NO and RA routes. However, on-route miles per stop would improve significantly with the reassignments.

Table 8 shows the cost of unnecessary duplication. Saving 17.6% of two-day RA mileage would clearly save $32,000 per year for the group. The extra miles caused by overlap cost these haulers an average of 0.7 cents per hundredweight.

In the long run, the group could save $49,000 annually, if duplication were eliminated and these haulers used the time saved to serve other farms. The fully-allocated cost of route duplication was 1.1 cents per hundredweight. These estimates of the cost of overlap are conservative because the six firms would be likely to include <u>all</u> of their farms if they participated in a reorganization scheme, not just those served on Cortland County routes. However, only Cortland routes were included in this study.

Table 7. Operating Characteristics, Non-Overlapping (NO) and Rescheduled Actual (RA) Routes, May 1980 2 Days of Operation

Characteristics	All Six Haulers	
Number of Farms	478	
Number of Farms Served Every Day	35	
Pounds of Milk Picked Up	2,477,516	
	NO	RA
Number of Routes	61	61
Total Miles	2,132	2,588
Total Minutes	14,917	15,530
Routes Returning to Hauler	46	46
Total Miles	1,275	1,690
Number of Routes/Truck/Day:		
Straight Chassis	1.9	1.9
Tractor-Trailer	1.0	1.0
Standard Time/Truck/Day:		
Straight Chassis	5h 38m*	5h 48m
Tractor-Trailer	4h 35m	4h 47m
Routes Delivering to Plants (straight chassis trucks only)	15	15
Total Miles	857	898
Number of Routes/Truck/Day	1.9	1.9
Standard Time/Truck/Day	8h 33m	8h 56m
Overall Fullness/Trip (%)	96.0	96.0
Farm Density (on-route miles/stop)	2.1	2.6

* "h" refers to hours, "m" to minutes.

Table 8. Estimated 1980 Cost Savings, Non-Overlapping (NO) vs Rescheduled Actual (RA) Routes

		All Six Haulers NO
Minutes Saved vs RA Routes		613
Miles Saved vs RA Routes		456
Fixed Saving:	$.048/minute*	$29.42
Variable Savings:	$.110/minute*	67.43
	$.386/mile	176.02
Fully-Allocated 2 Day Savings		$272.87
2 Day Volume (cwt.)		24,775
Fully-Allocated Savings Per Cwt.		$.011
Fully-Allocated Annual Savings		$49,662
CLEARLY ACHIEVABLE SAVINGS DUE TO REDUCED MILEAGE:		
Annual Variable Mileage Savings		$32,036
Mileage Saving Per Cwt.		$.007

* Assumes minutes are used to serve other farms to generate contribution to fixed costs.

Impact of Reorganization on Actual Level of Hauling Costs in 1980

Comparing the results of the reassignment (NO) to the weigh slip (WS) routes provides an estimate of the total savings which could be achieved from reassigning farms to reduce duplication compared to the actual hauling costs incurred in 1980. However, these savings would have two causes: reassignment and improved scheduling techniques.

Table 9 presents the characteristics of non-overlapping (NO) routes and the weigh slip routes. Two routes would be eliminated as a result of the improved route sequences. 23/ The two-day decrease in mileage would amount to 29.7%. And, the average distance between stops would decrease by one mile.

Reduced driving, at-plant and at-garage time would save 1,403 minutes every two days. Although tractor-trailers would be used to serve the most distant farms on NO routes, they would not be operated for longer periods of time because even the most distant farms would be more "rationally" located after the reassignments. Straight chassis trucks delivering to plants would be operated slightly longer on NO routes because they would serve farms which were assigned to the garage rather than to the plant location.

Table 10 presents the 1980 cost savings of NO routes versus the May weigh slip routes. These six haulers could clearly save at least $63,000 annually if they participated in a reassignment scheme and implemented the routes and sequences suggested. Hauling costs could be reduced by 1.4¢ per hundredweight from 1980 levels by saving 901 miles every two days. Fully-allocated costs incurred during 1980 were $104,000 higher than necessary because of poor route scheduling and overlapping pickup areas. Hauling costs could be reduced by 2.3¢ per hundredweight in the long run.

23/ The two routes could be saved without reorganization, if the RA routes were instituted.

Table 9. Operating Characteristics, Non-Overlapping (NO) and Weigh Slip (WS) Routes, May 1980 2 Days of Operation

Characteristics	All Six Haulers	
Number of Farms	478	
Number of Farms Served Every Day	35	
Pounds of Milk Picked Up	2,477,516	
	NO	WS
Number of Routes	61	63
Total Miles	2,132	3,033
Total Minutes	14,917	16,320
Routes Returning to Hauler	46	47
Total Miles	1,275	2,008
Number of Routes/Truck/Day:		
Straight Chassis	1.9	2.0
Tractor-Trailer	1.0	1.0
Standard Time/Truck/Day:		
Straight Chassis	5h 38m*	7h 8m
Tractor-Trailer	4h 35m	4h 37m
Routes Delivering to Plants (straight chassis trucks only)	15	16
Total Miles	857	1,025
Number of Routes/Truck/Day	1.9	1.8
Standard Time/Truck/Day	8h 33m	8h 26m
Overall Fullness/Trip (%)	96.0	93.6
Farm Density (on-route miles/stop)	2.1	3.1

* "h" refers to hours, "m" to minutes.

Table 10. Estimated 1980 Cost Savings, Non-Overlapping (NO) Routes vs Weigh Slip (WS) Routes

		All Six Haulers NO
Minutes Saved vs WS Routes		1,403
Miles Saved vs WS Routes		901
Fixed Saving:	$.048/minute*	$67.34
Variable Savings:	$.110/minute*	154.33
	$.386/mile	347.79
Fully-Allocated 2 Day Savings		$569.46
2 Day Volume (cwt.)		24,775
Fully-Allocated Savings Per Cwt.		$.023
Fully-Allocated Annual Savings		$103,642
CLEARLY ACHIEVABLE SAVINGS DUE TO REDUCED MILEAGE:		
Annual Variable Mileage Savings		$63,298
Mileage Saving Per Cwt.		$.014

* Assumes minutes are used to serve other farms to generate contribution to fixed costs.

Participating in a farm reassignment scheme in an attempt to eliminate route overlap would save the group a substantial amount in the long run, but the impact on each hauler individually would be quite varied. The predicted savings from each of the two sources, improved routing techniques and improved farm assignments, were compared for each hauler. This comparison is presented in Table 11. Comparing the two-day mileage reductions predicted for the RA routes versus the weigh slip routes indicates the relative efficiency of each hauler's actual operations: how efficiently was he serving the farm set he had? The relative benefits of NO versus RA indicates the "rationality" of each hauler's farms in relation to his own location. Or, assuming he was operating the best routes he could (RA), how rationally located were his farms?

Hauler C operated the most efficient routes but served the most poorly located group of farms. Conversely, Hauler E had the most rational group of farms, but operated the least efficiently designed routes. Hauler A also had an irrational set of farms; in fact, he would not operate routes in Cortland County after reassignment. The combined savings from participation in a reorganization scheme and using the suggested routes, as shown in the third column of Table 11, indicate that the haulers' incentives to participate are substantial and quite similar. Hauler D would benefit the least but could save 21% of his actual miles.

SUMMARY OF RESULTS

This research examined two possible sources of inefficiency in bulk milk assembly: poor vehicle scheduling and unnecessary overlap in farm pickup routes. To isolate the effect of using improved vehicle scheduling techniques, the actual routes studied in each time period were rescheduled using the modified scheduling techniques. On these rescheduled routes,

Table 11. Efficiency Comparisons and Incentives

Hauler	Savings Due to Rescheduling RA vs WS (Savings as % of WS Miles)	Savings Due to Reassignment NO vs RA (Savings as % of RA Miles)	Incentive to Participate NO vs WS (Savings as % of WS Miles)
A	5.7	30.7	34.9
B	14.6	11.2	24.1
C	4.1	32.1	34.9
D	16.2	5.8	21.1
E	28.5	4.0	31.3
F	16.5	19.5	32.8
All Six Haulers	14.7%	17.6%	29.7%

each hauler would serve the same farms, use the same trucks and provide the same services to farms and plants as he had on his actual routes.

Farms were then reassigned to haulers' locations so that farm-to-garage distance was minimized. The effect was to eliminate overlap in the farm areas served by the six firms. The routes developed for these reassignments were compared to the rescheduled actual routes to isolate the cost of overlap.

Costs (or possible savings) were estimated by comparing the miles and minutes incurred on actual routes, rescheduled actual routes and routes developed for the reassignments. The miles and minutes saved in each comparison were used to calculate 1980 cost impacts.

Vehicle scheduling procedures were developed which combine computerized and manual techniques. They were used to create practical routes which outperform the ones actually operated by the six participants. The estimated savings were both substantial and consistent. All six haulers would benefit from operating the computed "RA" routes rather than the routes they were using in 1980. Savings in mileage would amount to 14.7% of May's weigh slip miles and 15.2% of November's. Two of the 63 routes operated in May and four of the 56 November routes would have been eliminated if the haulers had used these routing techniques. Reduced mileage would lower hauling costs by at least $31,000 annually for the group. Most of the haulers would also spend considerably less time to provide the same farm pickup service; therefore, long-run annual savings could be as much as $54,000 for the group.

Duplication caused routes to be 456 miles longer every two days, and those extra miles cost the six haulers $32,000 in 1980. In addition, 613 minutes would be saved every two days if duplication were eliminated. The long-run annual cost of overlap was as high as $49,000 for the group, if the 10 hours saved every two days could have been used to serve other farms. The variable mileage saving would reduce average hauling costs by 0.7¢ per hundredweight, while the fully-allocated average savings per hundredweight would be 1.1¢.

If farms were reassigned and if the improved routing techniques developed for this study were used, the full impact of non-overlapping routes versus the actual routes studied would be attainable. Two-day travel distance would be reduced by 901 miles, saving 32,000 gallons of fuel in one year. Mileages would be 30% lower than actual 1980 levels, and the variable mileage savings would be $63,000 per year or 1.4¢ per hundredweight for the six haulers. In addition, two routes could be eliminated and 1,403 minutes would be saved. Long-run annual hauling costs could be reduced by $104,000 or an average of 2.3¢ per hundredweight in the Cortland area.

Table 12 presents a summary of the results of this research. The predicted savings are substantial, but they are limited to the conditions which existed in the Cortland area in 1980. The savings predicted, therefore, would not necessarily be accurate for other parts of New York or other states. The potential savings of reorganization and improved routing techniques in other regions would depend on the degree of overlap, actual route efficiency and the inherent level of hauling costs due to the density of farms and milk in those regions. However, the methodology developed here could be used by any group of firms to estimate the impact of farm pickup reorganization and improved route scheduling.

Table 12. Summary of Results, 1980

Characteristics of Study Group:	
Number of Haulers	6
Number of Farms	478
Average Pounds Picked Up in Two Days	2,477,516
Percent of Farms Served Everyday	14.5%

	Scheme 2b		
	Savings Due to Reassignment (NO vs RA)	Savings Due to Rescheduling (RA vs WS)	Total Savings* (NO vs WS)
Two-Day Minutes	613	790	1,403
Two-Day Miles	456	445	901
Annual Mileage Costs	$32,036	$31,262	$63,298
Fully-Allocated Annual Costs	$49,662	$53,979	$103,642
Fully-Allocated Costs/Cwt.	1.1¢	1.2¢	2.3¢

* Parts may not add to total due to rounding.

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Wasserman, Walter, and William Lesser. "Using the TI-59 Programmable Calculator to Estimate Operating Costs and Hauling Rates for Bulk Milk Assembly," A.E. Res. 80-12. Ithaca, New York: Cornell University, June 1980.

APPENDIX I. Time Standards Used for Route Development

The standards used for driving and farm service times in this study were based, in part, on time studies conducted by Chester Smith [1/] and, in part, on data collected in the study. It was the policy of one firm to have the drivers record the time at which they left each farm on their pickup records. Elasped farm-to-farm times (i.e., leave one farm, drive to and serve second farm) from these records were used to test the accuracy of these standards. Of course, any standards could be used. The following were used here for route development:

Driving:

On-Route (farm-to-farm), 40 mph =	1.5 minutes/mile
Stem (to and from garages and plants), 50 mph =	1.2 minutes/mile

At-farm:

Fixed time to drive up driveway, position truck, hookup pump, agitate, measure, sample, fill out records, unhook pump and drive back to main road =	11 minutes
plus	
Variable time to pump at 65 gallons per minute =	.0018 minutes/pound

Other Time: [2/]

At-plant time for waiting, unloading and cleaning =	60 minutes
At-garage time for loads returning to hauler locations before distant shipment =	20 minutes

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1/ Chester Smith, "Analysis of the Cost of 'Stop Time' in Farm Bulk Milk Pickup Routes," (Syracuse, NY: Northeast Dairy Cooperative, 1972), pp. 1-15.

2/ Haulers in the study stated these are the times they would use for these functions when planning routes. Waiting time is actually highly variable among plants.

APPENDIX II. Description of ROUTE Program

Data Needed:

1) Distances - Four possible means of supplying distance data:
   a) entire savings matrix
   b) entire distance matrix
   c) node network data, ROUTE will calculate distances
   d) coordinate network data, "x, y" axis coordinates; ROUTE will calculate distances. User can specify conversion factor.
2) Vehicles--For each of 99,999 types:
   a) number available
   b) capacity
   c) driving speed
3) Stops
   a) an identifier (with reference to savings matrix)
   b) volume
   c) time required at stop

Route Constraints

1) Truck capacity
2) Length of workday
3) Distance or Cost of Route

Stop Constraints

1) Hour in the day (e.g., serve between 8:00 and 8:30 a.m.)
2) Vehicle - type(s) which cannot serve stop.

APPENDIX III. Translating Miles and Minutes into Costs

The cost factors developed here were based on research conducted by Wasserman and Lesser, [1/] and also on consultations with Walter Wasserman, Richard Aplin and Colette Hoffman. [2/] They agreed that only one set of costs was needed, even though two types of trucks were used. The difference in the variable cost of operating tractor-trailers rather than straight chassis trucks occurs for over-the-road milk movements which were not studied here. Further, the higher investment cost of the larger tractor-trailer tanks would not increase fixed costs per minute significantly.

Table III.1 presents the calculation of fixed costs per minute for 1980 which was applied to the savings in minutes. The capital investment in trucks was expressed as a present value, annual equivalent of 1980 replacement costs. Chassis costs for straight trucks and tractors were assumed to be the same. The difference in tank replacement cost ($19,000 for 35,000 pound tanks versus $35,000 for 50,000 pound tanks) when expressed as an annual equivalent per minute was less than 1¢ (see note in Table III.1) and was ignored. An inflation-free or "real" cost of capital of 9% was used so that the interest rate on debt and the opportunity cost of equity would reflect the real, or non-inflated 1980 cost. Because, all of the other costs used in these calculations, such as fuel, tires or

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1/ W. Wasserman and W. Lesser, "Using the TI-59 Programmable Calculator to Estimate Operating Costs and Hauling Rates for Bulk Milk Assembly," A.E. Res. 80-12, (Ithaca, NY: Cornell University, June 1980), pp. 1-12.

2/ Statewide milk marketing specialist with New York State Cooperative Extension, a professor in the Department of Agricultural Economics at Cornell, and an economist with the New York-New Jersey Market Administrator's Office, respectively.

Table III.1 Calculation of 1980 Fixed Truck Costs* Per Minute

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General Assumptions:

1. Time saved for each truck is used to serve other farms to generate revenue which will contribute to fixed costs.
2. 9% inflation-free cost of capital with 50% debt and 50% equity financing.**
3. Trucks are operated 12 hours per day and 365 days per year, or 262,800 minutes annually.

1980 Vehicle Replacement Cost Assumptions:

Truck chassis cost	$46,000
Expected chassis life	7 years
Chassis salvage value	20 %
35,000 pound tank cost	$19,000*** (see NOTE below)
Expected tank life	10 years
Tank salvage value	20 %

Annual Equivalent Vehicle Replacement Costs:

Chassis: $$\frac{\$46{,}000 - [(46{,}000)(20\%)(\text{PV of } \$1 \text{ in Year } 7)]}{\text{PV of } \$1/\text{year for } 7 \text{ years}}$$

$$\frac{\$46{,}000 - [(46{,}000)(.2)(0.5470)^{a}]}{5.0330} = \frac{\$40{,}967.60}{5.0330} = \$8{,}140$$

Tank: $$\frac{\$19{,}000 - [(19{,}000)(20\%)(\text{PV of } \$1 \text{ in Year } 10)]}{\text{PV of } \$1/\text{year for } 10 \text{ years}}$$

$$\frac{\$10{,}000 - [(19{,}000)(.2)(0.4224)]}{6.4177} = \frac{\$17{,}394.88}{6.4177} = \$2{,}710$$

Annual Equivalent Cost = $10,850

Annual Fixed Costs Per Vehicle:

Annual equivalent vehicle replacement cost	$10,850
Insurance	1,400
Registration	280
Highway tax	120
	$12,650

Fixed Costs Per Minute: $12,650/262,800 minutes = $0.048 per minute

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Continued

Table III.1 (continued)

NOTE: Calculation of Difference in Annual Equivalent Replacement Cost Per Minute of 35,000 pound straight chassis tanks and 50,000 pound tractor-trailer tanks.

1980 Replacement Cost Difference: \$35,000 - 19,000 = \$16,000

Annual Equivalent Cost Difference Per Minute:

$$\frac{\$16,000 - [16,000(.2)(.4224)]}{6.4177} = \$2,282$$

\$2,282 per year/262,800 minutes = \$.009 per minute.

* Unless otherwise noted, Walter Wasserman and Colette Hoffman were consulted to confirm 1980 cost levels.

** Source: Richard Aplin.

*** Source: Anderson, *op. cit.*, p. 19.

a/ Source of PV factors: R. Aplin, G. Casler and C. Francis, *Capital Investment Analysis Using Discounted Cash Flows*, 2nd ed. (Columbus: Grid, Inc., 1977), pp. 150-154.

insurance, were "real" 1980 prices an inflation-free cost of capital also was used. [3/] The calculation of fixed costs per minute assumed a 12-hour day and 365 days of operation. To the extent that this operating assumption is optimistic, the 4.8¢ per minute cost would be conservative.

On the other hand, it is quite difficult to assume that saving operating minutes would lower fixed costs at all, because the level of fixed costs would not vary with changes in operating time. If a truck could be "saved," all or most of the fixed costs associated with that truck would clearly be avoided. But, although some haulers could avoid using one truck for their Cortland operations, it could not be assumed that that truck would not be needed for routes outside of the county. Because of the limited data base in this analysis, routes could be "saved," but trucks could not.

In applying fixed costs to minutes saved, it was assumed that the predicted savings in operating time would be used to serve other farms, and that this increased business would generate increased income. Of course, the level of fixed costs would be the same, but the revenue to cover those costs would increase. Or, viewed differently, the hauler's volume of business, the number of farms he serves, could increase without purchasing another vehicle--fleet expansion could be delayed. Therefore, the fixed savings applied to minutes should be interpreted as savings which could only be realized in the long run, if at all. For example, applying savings to the predicted reduction of 9 minutes in two days for Hauler A would be unrealistic. But, the 252 minute, or 6 hour and 12 minute, savings predicted for Hauler F could affect the operations. (See Table 3, p.20.)

3/ Nine percent seems low when prevailing 1980 interest rates are considered, but bank rates include a factor for inflation.

Table III.2 presents the calculations used for variable costs. The 15 bias-ply tires assumed were the weighted average for the large and small vehicles used on the weigh slip routes: 60% tractor-trailers with 18 wheels and 40% straight chassis with 10. Wasserman and Lesser estimated $600 annually for routine maintenance caused by farm pickup, 4/ and the 67 mile average daily figure used to calculate annual mileage was a weighted average of the miles travelled on the various types of weigh slip routes studied.

The variable cost per minute calculation assumed that drivers were paid on an hourly basis. Actually, farm pickup drivers are compensated in several ways: by the hour, on a salary basis, or on a trip basis. 5/ Therefore, assuming an hourly wage and applying variable savings per minute would not be realistic for haulers whose drivers are salaried, unless the savings were interpreted in a manner similar to fixed cost savings, as discussed above. In other words, drivers would receive the same salaries, but could serve <u>more</u> farms than they had on the weigh slip routes if they worked the same number of hours. Again, these savings would not be as clearly attainable for haulers with salaried drivers, and they would accrue over time.

4/ Wasserman and Lesser, <u>op</u>. <u>cit</u>., p. 5.

5/ The six haulers studied were <u>not</u> asked to provide data on driver compensation methods.

Table III.2 Calculation of 1980 Variable Truck Costs* Per Minute and Per Mile

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Variable Cost Per Minute:

Assuming: Drivers are paid an hourly wage and/or time saved is used to serve other farms to generate revenue which will contribute to drivers' wage and fringe costs.

Drivers Compensation: \$5.30 per hour** plus fringes at 25% = \$6.60/hr.

Variable Cost Per Minute: \$6.60 per hour/60 minutes = \$0.11/min.

Variable Costs Per Mile:	\$/mile
Diesel fuel: 5.0 miles per gallon at \$1.10 per gallon =	\$0.220
Bias-ply tires: 15 tires at \$200 each new with 60,000 mile life =	0.050
Ton mile tax:	0.017
Repairs: Parts and labor =	0.075
Routine maintenance: \$600 per year for oil, filters, belts, tuneups and the like and 24,455 miles per truck per year***=	0.024
Variable Costs Per Mile =	\$0.386

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* Unless otherwise noted, Walter Wasserman and Colette Hoffman were consulted to confirm 1980 cost levels and operating assumptions.

** Anderson, op. cit., p. 17.

*** Based on data from May weigh slip routes as follows:

	Miles/day
7.0 Straight trucks to garage X 2.0 routes/day X 41 miles/route =	574
4.5 Straight trucks to plants X 1.8 routes/day X 64 miles/route =	518
13.5 Tractor-trailers to garage X 1.0 routes/day X 44 miles/route=	594
25.0 Trucks	1,686

Weighted average miles/truck/day = 67.
Miles/truck/year = 67 X 365 = 24,455.

APPENDIX IV. Route Reporting

A report was generated for each route using the standard time formulas and the transportation network. In addition, efficiency statistics were calculated for each route. Table IV.1 shows a route report for a "weigh slip" route returning to the garage.

"Miles 'To'" are the shortest distances between each stop on the route, the first and last distances are "stem" miles. "Farm Number" is the hauler's number for each producer. The "Quad Number" indicates the farm's location. The "ED" indicates that the farm requires everyday service. "Driving Time" and "At-Farm Time" are based on the standards and "Average Pick Up Volume" is the average of the four weigh slip recordings for that "side" (odd or even operating day). The truck used, its type and size are indicated and tank capacity utilization for the load is calculated. Mileages and standard times are summarized. Farm density is calculated as on-route miles per stop to indicate the average distance between stops. Milk density is calculated as pounds picked up per on-route mile to indicate the average milk volume available per on-route mile.

Table IV.2 shows a route report for a "weigh slip" route delivering to a plant. This route has three stem mileages: garage to first farm, last farm to plant, and plant to garage. [1/] Also, there is a 60 minute unloading time rather than at-garage time.

1/ Some haulers serving plants scheduled more than one load per truck per day. For these, the first route began at the garage and delivered to the plant, and the second and third loads started at the plant not at the garage, therefore only the last load had three stem mileages.

Table IV.1 Sample Individual Route Report for Route Returning to the Hauler, from Weigh Slip Data, May 1980

Handler: (handler identifier) Route: (route identifier)
Days Operating: May 11, 13, 15, 17 Odd

Miles "To"	Driving Time (min.)	Farm Number	Name	Quad Number	Average Pickup Volume (lbs.)	At Farm Time (min.)
			Hauler's City			
2.1	3	70	...	348	4,803	20 ED
10.2	15	90	...	570	3,785	18
3.2	5	30	...	570	3,492	17 ED
1.0	2	87	...	570	5,807	21
6.8	10	89	...	441	6,510	23
2.0	3	75	...	441	4,095	18
1.1	2	20	...	441	3,041	16
2.6	4	71	...	441	4,993	20
9.0	14	33	...	570	8,126	26
0.6	1	5	...	570	4,608	19
7.7	9		Hauler's City			
46.3	68	10 Stops			49,260	198

Truck Used: #3 Tractor 51,600 lb. capacity 95.5% full this trip

Mileage Summary:

Stem: 9.8
On-Route: 36.5
Total 46.3 miles

Standard Time Summary:

At-Farm: 198
Driving: 68
At Garage: 20
Total 286 min. = 4 hr. 46 min.

Farm Density: 3.6 on-route miles/stop

Milk Density: 1,349 lbs. picked up/on-route mile

Table IV.2 Sample Individual Route Report for Route Delivering to Local Plant, from Weigh Slip Data, May 1980

Handler: (handler identifier) Route: (route identifier)
Days Operating: May 11, 13, 15, 17 Odd

Miles "To"	Driving Time (min.)	Farm Number	Name	Quad Number	Average Pickup Volume (lbs.)	At Farm Time (min.)
			Hauler's City			
1.7	2	80	...	440	2,360	15 ED
0.2	0	174	...	440	2,924	16
9.0	14	128	...	411	2,385	15
1.0	2	199	...	411	3,354	17
4.6	7	140	...	411	890	13
2.5	4	125	...	411	804	12
2.7	4	123	...	877	2,436	15
1.4	2	179	...	877	4,465	19
6.9	10	136	...	131	1,979	15
5.3	8	53	...	131	2,626	16
4.4	7	48	...	131	3,605	17 ED
8.4	10		Milk Plant's City			
29.0	35		Hauler's City			
77.1	105	11 Stops			27,828	170

Truck Used: #12 Straight 30,100 lb. capacity 92.5% full this trip

Mileage Summary:

Stem	39.1
On-Route:	38.0
Total	77.1 miles

Standard Time Summary:

At-Farm:	170
Driving:	105
Unloading:	60
Total	335 min. = 5 hr. 35 min.

Farm Density: 3.5 on-route miles/stop

Milk Density: 732 lbs. picked up/on-route mile

Summary reports were also generated. Table IV.3 shows the "Route Summary" which recaps and totals the individual route characteristics. Table IV.4 shows the "Fleet Use Summary" which recaps the routes and times for each truck. There is also a calculation of tractor-trailers as a percent of the fleet, and loads and times per truck per day are calculated. Both Tables IV.3 and IV.4 are based on "weigh slip" data.

Table IV.5 shows a "Route Operations Summary" for a hauler's weigh slip routes. "Geographic Range" is calculated as stem miles as a percentage of all miles to indicate the relative distance from farms to the garage or from farms to plants. In the example given, geographic range is 21.1% which is low, because this hauler's farms were near his garage and because he did not serve local plants directly.

Table IV.3 Sample Route Summary Report, from Weigh Slip Data, May 1980

Grouping: TUV May

Route Number	SI DE	Mileage Total	Mileage Stem	Mileage On-Route	# of Stops	Average Total Load (lbs)	Tank Capacity (lbs)	% Full	Truck Used	Std. Time (min)	Density Farm	Density Milk
1	Odd	46.3	9.8	36.5	10	49,260	51,600	95.5	4	286	3.6	1,349
2	Odd	50.7	7.6	43.1	10	48,092	51,600	93.2	2	290	4.3	1,115
3	Odd	22.2	5.1	17.1	7	47,934	51,600	92.9	5	216	2.4	2,803
4	Even	29.2	2.9	26.3	9	46,966	51,600	91.0	5	246	2.9	1,785
5	Even	29.9	10.0	19.9	11	47,195	51,600	91.5	2	267	1.8	2,371
6	Even	20.9	6.6	14.3	12	47,975	51,600	93.0	4	267	1.2	3,354
6 Routes		199.2	42.0	157.2	59	287,422	309,600	92.8		1,572		

Table IV.4 Sample Fleet Use Summary Report, from Weigh Slip Data, May 1980

			Number of Routes			Std. Operating Time (min.)		
Truck	Type	Used on Route(s)	Odd Total	Even Total	2-Day Total	Odd Total	Even Total	2-Day Total
#4	Trac	1 and 6	1	1	2	286	267	553
#2	Trac	2 and 5	1	1	2	290	267	557
#5	Trac	3 and 4	1	1	2	216	246	462
			3	3	6	792	780	1,572
Number of Trucks Used			3	3	6			

3 Different Trucks   3 Tractors   0 Straights   Tractors as % of Fleet: 100%

<u>Average Number of Routes Per Truck:</u> (No. Routes/No. Trucks Used)

Odd Day: 1.0 Routes/Day
Even Day: 1.0 Routes/Day
Overall: 1.0 Routes/Day

<u>Average Standard Operating Time Per Truck:</u> (Total Std. Time/No. Trucks Used)

Odd Day: 264 Min. = 4 hrs. 24 min. per day
Even Day: 260 Min. = 4 hrs. 20 min. per day
Overall: 262 Min. = 4 hrs. 22 min. per day

Table IV.5 Sample Route Operations Summary Report, from Weigh Slip Data, May 1980

Route Operations Summary	All 6 Routes
Number of Farms Served	55
Number of Farms Served Everyday	3 farms 5.5%
Average Farm Density	2.7 on-route miles/stop
Average Milk Density	1,828 lbs. picked up/on-route mile
Geographic Range (stem miles as % of total miles)	21.1%
Average Number of Stops	10 per route
Average Load: For Straight Truck Routes	0 lbs. per route
For Tractor-Trailer Routes	47,903 lbs. per route
Average Mileage	33 miles per route