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ABSTRACT

This paper discusses improved procedures for applying heuristic methods to well-known transportation and routing algorithms for solving a milk assembly problem. Miles travelled to assemble milk are reduced by up to 20 percent in a detailed case study in New York.

PROCEDURES FOR VEHICLE ROUTING PROBLEMS WITH AN APPLICATION TO MILK ASSEMBLY IN NEW YORK

Introduction

New York, unlike many other major milk producing regions, does not have large cooperatives which can coordinate milk assembly. Competition for milk supply between proprietary and cooperative handlers has resulted in a technically inefficient system, characterized by unnecessary route duplication. This paper describes procedures for reducing route overlap in farm milk pickup used as a method of measuring the impact of such a reduction in duplication for a region of central New York consisting of 478 farms served by six hauling firms.

Quantifying the magnitude of the overlap involved three steps: studying the routes actually operated during a selected base period, eliminating areas of competition and overlap by reassigning farms to milk destinations, and scheduling alternative routes for each hauler's "new" set of producers. For all three steps, a matrix of distances between all farms, plants and haulers' locations was needed.

In general, this matrix consists of $\frac{n(n-1)}{2}$ distances, where "n" equals the number of unique geographic locations. For large scale problems, this number of distances becomes extremely large. Measuring each distance by hand has obvious drawbacks in terms of time and potential for error (see Schultz, p. 13), and requires a visual and arbitrary selection of the "best path" between each pair of points. Therefore, shortcuts have been sought.

Commonly, for milk assembly problems, the number of unique locations and thereby the distances needed, are reduced by geographically segmenting the study area as Babb and Newell did or by aggregating individual farms into centralized supply centers as Lamb did. Area segmentation has negative ramifications for route scheduling, because only farms which are explicitly linked to others in that segment can be added to a route. Farm aggregation limits the practicality of the results because it precludes reorganization of the pick-up system by reassigning producers to destinations on a farm-by-farm basis and it makes actual route scheduling impossible.

The alternative employed here was to use one of a number of "shortest path" algorithms developed by the National Bureau of Standards (see Gilson and Witzgall). This algorithm was used to construct a transportation matrix of shortest distances from data that consisted of only distances (arcs) between each point (node) and the point (node) adjacent to it along each possible path. For this problem, "nodes" were farms, plants, haulers' garages, and road intersections. Use of the shortest path technique allowed us to generate the entire $\frac{n(n-1)}{2}$ distances for the matrix from a much smaller number of measurements without segmentation, aggregation or manual selection of the "shortest" path. By doing this as a distinct step, we also maximized the flexibility of using node numbering schemes to better describe the actual road network.

The next step was developing routes. Vehicle routing problems cannot be solved with optimization techniques, therefore commonly available vehicle scheduling programs use heuristics. "ROUTE," a program developed by Hallberg and Kriebel was used for this study. ROUTE has been used in similar studies, and its ability to generate "better" routes than manual methods was questioned by Strang. Because the routing problem does not have one "best" solution, the results of applying only one heuristic tool, such as using ROUTE alone, have been disappointing. ROUTE's results actually are only the first step in creating practical route systems, further manipulations, either manual or programmed, are needed to modify ROUTE's output to meet the practical constraints of vehicle availability and capacity, or multiple depots. In this analysis, manual methods and decision rules were developed and used to "massage" the systems generated by ROUTE into programmed routing schemes which outperformed entirely manually developed ones.

The Milk Assembly Problem

Cortland County, in central New York, was selected as the study region mainly because of its diversity in hauling operations. During 1980, there were six handlers receiving milk from Cortland: one proprietary firm, two independent cooperatives, and three federated cooperatives. Some routes delivered milk directly to nearby plants, the remainder returned to the hauler's facility, changed drivers, and delivered milk to distant plants. Some handlers owned and operated their own fleets, others were using independent contract haulers.

The six handlers and/or haulers operating farm pick-up routes in Cortland County were surveyed. The following data were collected for every route which included at least one Cortland farm by studying the drivers' weigh slips for eight days in May of 1980: sequence of farm stops, pounds picked up at each stop, first destination of truck load, truck used, and truck type and capacity. An eight day period was used so that a full cycle of pick-up data for every-other-day farms was collected. In total, 63 routes serving 478 farms in and around Cortland County were studied.

The Transportation Network

Locations were provided by the Federal Order #2 Market Administrator's Office which had every farm and plant spotted on U.S.G.S. topographic quadrangle maps of 1:24000 scale.

These maps were used to identify the arcs and nodes used for the shortest path network. 2907 nodes representing farms, plants, garages and road intersections were identified and 4097 arc (node-to-node) measurements were made along roads on the quadrangle maps using a map wheel. These 4097 measurements resulted in a complete matrix of 128,271 shortest distances for the 507 "nodes of interest," that is, farms, plants and garages. This road network covers a 3575 square mile area of New York State.

This process, which is much more efficient and accurate than manual ones, is also much more flexible. Nodes can be added or deleted simply by remeasuring only the adjacent arcs. Also, hand measurements could be totally eliminated by using computer graphics technology which is capable of transmitting spatial data to a computer file. This technology was not available to us at the time of this study, however.

Farm to Destination Reassignment

Our heuristic for eliminating unnecessary route overlap involved only one change in operations from what was actually happening in May of 1980--that is, each hauler was to pick up milk from a different group of farms. Farms were reassigned to haulers and/or plants on a farm-by-farm basis with the objective of minimizing farm-to-destination distance. All else remained the same. Each farm was picked up. Each hauler picked up approximately the same volume of milk, and was served by the same hauler. This basis for reassignment resulted in 44 percent of the 478 farms changing haulers. For details and a summary of this reassignment, see Table 1.

Vehicle Routing

As mentioned above, ROUTE, a vehicle scheduling program developed at Pennsylvania State University, was used to generate routes. ROUTE attempts to minimize the total distance or cost to serve a set of pick-up points of "known" location, subject to the number and capacity of trucks available and quantities at each point (see Hallberg and Kriebel).

ROUTE sequences stops to minimize mileage well, however, it does not handle other restrictions, especially vehicle availability or capacity well, nor is it capable of handling different start and delivery points (needed for routes beginning at a hauler's garage and delivering to a plant). Therefore, ROUTE was only used to sequence farm stops, the other restrictions and complications which ROUTE could not properly consider were dealt with manually by developing rules for each.

The problem of vehicle availability occurred for haulers who operated two types of trucks, for instance both straight trucks and tractors. ROUTE sequenced stops best when many more vehicles than actually were needed were input as "available." Therefore, a limitless number of one type of truck was used as input. For a hauler with more straight trucks than tractors, ROUTE was used to create only straight truck routes. These routes were then evaluated manually and visually using the maps. The longest route, the one serving the most distant farms, was combined with a second route going into or toward the same pick-up area to create a tractor-sized route by adding those farms on the second route "passed" by the first. This process was continued until the proper number of tractor routes were created. If the remaining, lower capacity routes were significantly changed by losing stops to the tractor routes, the new, smaller subset of farms was re-sequenced for small trucks by ROUTE.

ROUTE assumes a depot from which trucks originate and to which they return. However, haulers' garages are rarely at the nearby, direct delivery milk plant. In this analysis, farms were reassigned to plants and plants were to be served by the same hauler they had been prior to reassignment.

Therefore, for a hauler delivering to a plant, the garage location was input as a "dummy" farm. It could not be guaranteed, however, that ROUTE would schedule the garage as the first stop on any route. Therefore, "super" routes were created. That is, the entire set of farms, plus the garage, were sequenced as one huge route. By beginning a route at the garage's location in the super route and adding farms in sequence toward the delivery plant (implicitly the first and last stop), until truck capacities were reached, routes were created which were properly scheduled to begin at the garage and end at the plant. Two routes from the garage were created from each "super" route, and new, smaller super routes were created with the remaining unsequenced farms until a sufficient number of first trips were scheduled.

By employing the techniques outlined above, it was possible to capitalize on ROUTE's strength in sequencing farm stops and to avoid its shortcomings thereby creating practical, programmed routes.

For all routes analyzed, both those reconstructed from the weigh slip data and those generated by ROUTE, the same approach was used. Mileages from hauler's locations to farms, between farms and to plants were the shortest path distances. Route times were calculated using standard time formulae. The formula for at farm time was 11 minutes fixed time to negotiate driveways, agitate, measure, hookup and unhook the pump, and do bookkeeping, plus variable time to pump at 65 gallons per minute. For driving time, we used 40 m.p.h. for on-routes miles and 50 m.p.h. for stem miles. At-garage time was assumed to be 20 minutes for routes returning to hauler to change drivers; and, an unloading time of 60 minutes was used for routes delivering to plants. The at-farm and driving standards were not based on time studies done for this analysis, but are similar to standards developed in that manner by others, especially Chester Smith. And, they did an adequate job of estimating the actual elapsed farm-to-farm times recorded by one set of drivers in this study. Haulers interviewed consider the standards reasonable for planning purposes. The quantity of milk to be picked up at each farm was an average of the amount actually picked up during the four days the route was operated. All haulers ran "sided" routes, that is a set sequence of stops was served each odd day and another set, even ones. Everyday farms, therefore, had two "average" pick-up volumes, one for each side. The total number of routes needed and total miles travelled reflect two days of operation.

Results for May 1980

Three sets of results are presented in Table 2 to demonstrate the impact of attempting to reduce route overlap by reassigning farms to destinations of first receipt. The first column shows the characteristics of the routes generated by reconstructing the weigh slip data collected from the haulers for eight days in May.

The second column shows results for a second manipulation which was performed on these base data. For each hauler, ROUTE was used to sequence a set of routes to serve the same group of farms that he currently served, that is, before farm reassignment. This computer routing step was performed because actual routes are developed in a certain sequence for reasons in addition to minimizing distance travelled. Some real-world complications, such as when a given farmer finishes milking, driveways which can only be driven by smaller trucks, hills which only straight trucks should climb, and the like, were not considered in this study. To neutralize the effect of these variables in route scheduling for comparison purposes, computer routes were generated, these are the "Before Reassignment Programmed Routes."

The third column illustrates the effects of reassigning farms to haulers and plants. The impact of reducing route overlap by reassigning farms to destinations on a least-distance basis, simply intermingling milk, is significant in terms of miles. A total of 516 miles in two days, 20 percent of all miles, could be saved vis-a-vis the "Before Reassignment Programmed Routes." In addition, every one of the six haulers benefitted, in terms of miles, from this reassignment.

The results of sequencing current farm assignments with ROUTE, 445 miles saved in two days, or 15 percent vis-a-vis the weigh slip routes, probably stem from a number of sources: first the complexities which were not quantified here, second the ability of ROUTE to aid in vehicle scheduling as opposed to entirely manual route structuring and third the difficulty of operating "rational" routes during the peak of the flush.

These mileage savings can be translated into cost savings in a number of ways. Most obviously, fuel consumption and direct fuel cost can be reduced. Also, two routes, or truck loads, were saved, these can be translated into dollars by salvaging a vehicle, delaying the investment in a new vehicle that would otherwise be needed to serve more farms, or reducing driver labor cost. Indirectly, maintenance costs can be saved by travelling fewer miles. The savings in average route times can also reduce labor costs.

The direction of these results, that is, a savings in the number of miles travelled, was not really in question, the magnitude was. Of course, the advantage of studying a selected area and group of haulers in detail in order to create results which account for many of the actual complexities of hauling milk from real farms, down real roads, to real plants and providing savings whose magnitude could be realized by that group, has a disadvantage in that we cannot predict the same magnitude of savings for other groups. However, the approach used and the methods employed could be repeated by any group of haulers and/or handlers who agreed to cooperate in such a scheme. Again the direction of those results would not be in doubt.

Table 1. Farm Reassignment Summary

	Hauler						Entire Study
	A	B	C	D	E	F	
Number of Farms Before	21	55	63	88	92	159	478
Number of Farms After	20	51	69	69	87	182	--
Number of Farms <u>Not</u> Changing Hauler	10	38	36	30	61	94	269
2-day Volume Before (cwt.)	839	2874	3074	3878	4642	9468	24775
2-day Volume After (cwt.)	824	2914	3052	3919	4641	9425	--

Table 2. Summary of Results for a 2-Day Cycle of Routes, May 1980.

	Weigh Slip Routes	Before Reassignment Programmed Routes	After Reassignment Programmed Routes
Total Miles Travelled	3033	2588	2072
Number of Routes	63	61	61
Routes Returning to Hauler:	47	46	46
Average Number of Routes/Truck/Day:			
tractors	1.0	1.0	1.0
straights	1.8	1.9	1.9
Average Standard Time/Truck/Day:			
tractors	4h 37m	4h 47m	4h 35m
straights	6h 29m	5h 48m	5h 44m
Routes Delivering to Plants: (Straights only)	16	15	15
Average Number of Routes/Truck/Day	1.8	1.9	1.9
Average Standard Time/Truck/Day	8h 26m	8h 33m	7h 49m
Overall Fullness/Trip	93.6%	96.0%	96.0%
Farm Density (On-Route Miles/Stop)	3.1	2.6	2.0
Milk Density (Pounds/On-Route Mile)	1531	1816	2358

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