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Scheduling and Routing Milk from Farm to Processors by a Cooperative

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A milk marketing cooperative (MMC) was created by Florida dairy farmers to link the primary supply of fluid milk with the derived demand of processors in the vertical market. For any given milk supply, the revenue or return to farmers per unit of milk is the average milk price received by the MMC minus the MMC's transfer cost. An important task for the MMC is to operate the fluid milk hauling system that optimizes the MMC's milk transfer cost (routing and scheduling cost) subject to farm and plant schedules. The objective of this study is to determine if it is economically feasible to implement a more efficient routing and scheduling of farm-to-plant milk collection by the MMC.

Key Words: cooperatives, margins, milk, routing, scheduling

Florida fluid milk processors and Florida dairy farmers belonging to the Florida Milk Marketing Cooperative (MMC) recently requested that the MMC increase its efficiency in order to reduce the difference between the price paid by processors and the price received by dairy farmers. The MMC responded that the standard operating procedures of the processors and farmers were inhibiting the MMC from becoming more efficient. For example, instead of receiving the same number of loads of milk each day of the week, processors order a different number of loads of milk each day, and sometimes cancel loads of milk the day before delivery. This action raises the cost of delivering milk to the processor. On the farmer side, dairy farmers use small bulk tanks which require cooperatives to make two or more collections from the farms each day. This action increases the cost of collecting milk from farmers. Clearly, there is a need for an increased awareness of how the actions of each member of the vertical market system influence the business operations of the others. A committed effort is necessary from all three entities—the dairy farmers, the processors, and the MMC—to collectively forge a more coordinated milk marketing system (i.e., improve the vertical coordination).

With the increased emphasis on vertical coordination in the Florida milk market, competition in the marketplace forces the MMC to perform more effectively. Farmers

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and processors want milk collected and delivered on a time schedule. It is the MMC's responsibility to ensure the milk scheduling is performed efficiently. Better vertical coordination among the farmers, the MMC, and the fluid milk processors through an efficient milk collection and delivery system reduces the difference between the processor's price and the farm price. If a reduction occurs, farmers will receive a higher price. In the longer run, the savings will be divided among the processors and farmers.

The Scheduling and Routing Problem

Bodin and Golden (1981) describe the difference between vehicle routing and vehicle scheduling. They define vehicle routing as a sequence of pickup and/or delivery points through which the vehicle must travel, beginning and ending at the depot point. The vehicle schedule is defined as a sequence of pickup and/or delivery points related to departure and arrival times. When the times are not specified in the problem, the problem is a routing problem. When times are fixed in advance, the problem is a scheduling problem.

The purpose of all scheduling and routing is the same: to find the optimal assignment of the vehicle fleet to serve the demands of the pickup and/or delivery points. The difference between the scheduling and routing problems depends on a problem's characteristics and assumptions. For instance, consider the problem of picking up goods from farms by a truck fleet. If it is assumed all farm products can be picked up any time, then time constraints may be ignored. This is an example of a pure routing problem. However, if the arrival or departure times are important, the inclusion of time window constraints will be necessary.

Bodin et al. (1983) state that most scheduling and routing problems may be formulated as network problems. A measurement of the problem size is the number of nodes in the network. A polynomial-bounded algorithm can be used to determine the computational burden of a network problem. The class of all problems for which polynomial-bounded algorithms are known to exist is denoted by P problems. Class P problems generally can be solved quite efficiently. Problems in class P are solvable in polynomial time. For example, in a worst-case scenario, problem A is part of class P, and problem B is not part of class P. To solve each problem requires $1{,}000N^2$ and 2^N computations, respectively. Problem A will be more time-consuming to solve for $N = 15$. However, as problem size N increases, this situation is reversed. Also, for $N = 30$, problem B requires more than one billion computations, compared to 900,000 computations for A. Problem B is a large network and a combinatorial problem without a polynomial-bounded algorithm.

Problems in this class are categorized as NP-hard. The effort required for solving this class of problem increases exponentially with problem size. Approaches for solving these problems optimally suffer from an exponential growth in computation as problem size increases. When confronted with an NP-hard problem, researchers, rather than seek an optimal solution, frequently use a heuristic or approximation procedure to obtain near-optimal solutions. A heuristic algorithm is a procedure that uses a problem structure in a mathematical (and usually intuitive) way to provide feasible, near-optimal solutions (Bodin et al., 1983).

Formulating vehicle routing and scheduling problems as integer programming problems can be successful (Desrochers et al., 1988). Solving these problems directly with integer programming problems in a real-world situation is very difficult (or impossible for the large problem) because of the number of feasible solutions. Most computer programs can only solve small, real-world problems—such as the computer program written by Sutcliffe and Board (1990), which was successful in solving a problem consisting of 38 destinations and four vehicles. While alternative approaches have been introduced for this problem, these approaches are only approximations and cannot be used to find the global optimum solution. Instead, a near (local) optimal solution is found. Because of the size of real-world problems, most problems are solved using approaches that result in near-optimal solutions.

Methodology

According to the prevalent argument in the literature, large empirical problems involving scheduling and routing can be solved using an approximation approach, but cannot be solved directly by using a traditional mathematic programming technique (i.e., an integer programming approach). Most direct computer programs can solve only small problems [e.g., the integer programming computer program written by Sutcliffe and Board (1990) discussed above]. The ArcLogistics algorithm was selected for use in the current study and is an example of an algorithm that can solve large problems. However, ArcLogistics can only ensure a local optimum.

ArcLogistics Route (ALR) is the scheduling-routing software distributed by the Environmental Systems Research Institute, Inc. (ESRI, 1994). The algorithm used in ALR is considered a "cluster-first, route-second" method, having two steps (Weigel and Cao, 1999). These include the resource assignment algorithm (cluster) that assigns stops to vehicles, and the sequence-and-route improvement algorithm (route) that orders the route sequence within the allocated vehicles.

This procedure groups, or clusters, demand nodes into routes and then orders, or routes, the demand nodes within each of these routes by solving the problem as the Traveling Salesman Problem (TSP) (Bodin et al., 1983). Examples of cluster-first, route-second procedures used in the classical, vehicle routing problem (no time window) include works by Gillet and Miller (1974); Gillet and Johnson (1976); Karp (1977); and Chapleau, Ferland, and Rousseau (1981).

However, the algorithm used in ArcLogistics Route is not exactly a classical procedure. ALR was created based on ESRI's experience gained from the Sears projects on logistics services and product services (as detailed in Weigel and Cao, 1999). Both projects were modeled as vehicle routing problems with time windows (VRPTW), along with other relevant constraints. The VRPTW is well known among researchers for its complexity and is very difficult or impossible (for a large problem) to solve. Designed by ESRI, the algorithms embedded in ALR are the heuristics or approximation techniques separated into two sequential steps, which include the resource assignment algorithm and the route improvement algorithm (Weigel and Cao, 1999). These procedures were implemented in the C++ programming language embedded in the ALR.

The Resource Assignment Algorithm (*Cluster*)

According to Weigel and Cao (1999), the resource assignment is performed using the multiple insertion (MI) algorithm. This algorithm was modified from the generalized assignment algorithm, which is used to solve the VRPTW, as suggested by Solomon (1987). The MI algorithm incorporates multiple objectives, including travel time, the amount of time window violations, and waiting time, into adjustable weights in the objective function. The objective function (*C*) can be defined by:

$$(1) \qquad C = \mathrm{Min}\left(\beta_1 \sum d + \beta_2 \sum v + \beta_3 \sum w\right),$$

where *d* is the total traveling distance, *v* is total time window violations (e.g., hours), and *w* represents total waiting time (e.g., hours). Users can adjust the β_1, β_2, and β_3 weights, depending mainly on their business objectives.[1] However, the other constraints on a vehicle, such as a vehicle capacity and a driver's skill, are defined as hard constraints. Those constraints cannot be violated without providing infeasible results. The MI procedure minimizes the defined objective function with respect to available hard constraints.

The main objective of the MI procedure is to assign stops to vehicles. Nevertheless, there are three steps in the MI algorithm: (*a*) the initial route building, (*b*) the stop assignment, and (*c*) the optimal post-insertion improvement (Weigel and Cao, 1999).

The MI procedure begins with initial route building. This step constructs an initial route for each available truck. The initial route includes only the starting and ending points. Second, the MI procedure adds unassigned stops into the routes. As noted by Weigel and Cao (1999), for each route *r* and position *k* where a stop might be added, the insertion cost for a potential stop *i* can be defined as:

$$(2) \qquad C_{irk} = \beta_1 \Delta d_{irk} + \beta_2 \Delta v_{irk} + \beta_3 \Delta w_{irk},$$

where C_{irk} is the insertion cost associated with inserting stop *i* into position *k* in route *r*; Δd_{irk} is the change in the traveling distance; Δv_{irk} is the change in time window violations; and Δw_{irk} is the change in waiting time. A stop *x* is assigned to route *y* at position *z* when

$$(3) \qquad C_{xyz} = \mathrm{Min}\left\{C_{irk} \mid \forall\, i, r, k\right\}.$$

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[1] In this study, while β_1 is \$1.29 per mile and β_3 is \$15 per hour, β_2 is set to be the highest qualitative level allowed by the ALR (i.e., level 10).

The insertion cost is equal to infinity if any available hard constraint is violated. Meanwhile, the assignment process will continue until all unassigned stops are inserted into the routes. Then, the optional post-insertion improvement procedure transfers the allocated stops from route to route in order to balance workloads for all routes.

The Sequence-and-Route Improvement Algorithm (*Route*)

The sequence-and-route improvement process is an attempt to improve the initial route constructed from the first MI algorithm. The sequence-and-route improvement procedure consists of two heuristic procedures: the interroute and intraroute improvement algorithms (Weigel and Cao, 1999). The intraroute procedure uses the TSP heuristics to improve solutions within the assigned route, while the interroute procedure is an attempt to discover better solutions by revising the allocated routes. Both procedures employ the tabu search technique, as suggested by Glover (1986, 1992), in order to obtain an outcome beyond the local optima. This outcome cannot be achieved solely by using the interroute or intraroute improvement procedure.

The Interroute Improvement Procedure

Weigel and Cao (1999) used the interroute procedure to improve the assignment decision obtained from the MI algorithm. The interroute improvement procedure investigates multiple designed routes to gain better results. The algorithm consists of two types of moves (including transferring and exchanging moves), which are used to rearrange stops between two routes.

A transferring move is a procedure that moves a stop from the original route and inserts it into another route (the destination route) at a determined insertion position by considering the least associated transferring cost. A transferring cost is calculated based on the transferred stop, the destination route, and the insertion position. The transferring move is infeasible if any existing constraint is violated or the stop is transferred back to the original route.

An exchanging move is a procedure in which two stops from different routes are simultaneously relocated into another route. The procedure determines the insertion position for each stop in its designed destination route, based on the relevant exchange cost. An exchange cost for each potential move is calculated based on the stop exchanged, the routes involved, and the insertion positions. The move with the least exchange cost is performed. The exchanging move is infeasible if any existing constraint is violated or at least one stop is previously exchanged. The route solution obtained from this process is then applied to the intraroute improvement procedure, discussed below.

The Intraroute Improvement Procedure

As reported by Weigel and Cao (1999), the intraroute improvement procedure intends to obtain the best possible solution with the assigned routes. In theory, this problem is categorized as the Traveling Salesman Problem with time windows (TSPTW) and other available constraints. The method proposed by Or (1976) is used for this procedure. Or's procedure has proven to be effective for solving the TSPTW (Cao and Rinderle, 1992; Weigel and Cao, 1999). The result within a route is improved by the move operation, which consists of forward and backward insertions. Forward insertions improve a route by removing a stop from its current position and inserting it in a later position within the sequence. The same is true for backward insertions, except a stop is inserted in an earlier position. Given position j located later than position i in the sequence ($j > i$), the change in traveling distance associated with a forward move is determined as:

$$(4) \qquad \Delta d_{ij} = d_{i-1,i+1} + d_{j,i} + d_{i,j+1} - d_{i-1,i} - d_{i,i+1} - d_{j,j+1},$$

whereas the distance change associated with a backward move is defined as:

$$(5) \qquad \Delta d_{ij} = d_{i-1,j} + d_{j,i} + d_{j-1,j+1} - d_{i-1,i} - d_{j-1,j} - d_{j,j+1}.$$

The changes in time window violations (Δv_{ij}) and waiting time (Δw_{ij}) are calculated. Due to the forward (backward) move, the arrival times at stops after (before) $i - 1$ in the route sequence are changed. The change in total cost related to the move (ΔC_{ij}) is identified as:

$$(6) \qquad \Delta C_{ij} = \beta_1 \Delta d_{ij} + \beta_2 \Delta v_{ij} + \beta_3 \Delta w_{ij},$$

where ΔC_{ij}, Δd_{ij}, Δv_{ij}, and Δw_{ij} are changes in the total costs, traveling distance, time window violations, and waiting time, respectively, associated with moving stop i to j. The insertion algorithm seeks the least cost associated with forward or backward moves with respect to the existing constraints.

Procedures

The analysis was performed using the ArcLogistics Route 2.0 software (ALR) developed by the Environmental Systems Research Institute (ESRI) in 1999, and detailed in Weigel and Cao (1999). ALR allowed the definition of terminals and processing plants as a "location" attribute, producer farms as an "order" attribute, and tractors as a "vehicle" attribute. It also allowed time window restrictions to be assigned to farms (orders). However, this software had no option designed to accommodate the processing plant time windows for fluid milk. As a result, processing plant time windows were programmed into ALR as an "order" attribute (the same as farms), but had a volume equal to zero. They were designed to be the final destination, or the last order, visited on a route. A plant time window order was matched with a milk load demanded by the processing plant. Thus, a truck would visit the plant time window last.[2] The "specialty" option in ALR restricted a truck

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[2] There are no plant time windows in the Tallahassee or Unadilla analyses because all farm milk loads were sent to the terminal.

to a plant time window. For example, trucks destined to deliver farm milk loads to processing plant A in Lakeland could not visit the processing plant time windows corresponding to processing plant B in Tampa.

After completing the specification requirement of the software, ALR used a solver to calculate the optimal schedule and route. However, due to plant time windows, some trucks would visit the processing plant before visiting farms to pick up milk. This happened because the ALR solver wanted trucks to meet the time window constraints at the processing plant, even if there was no milk to deliver. This problem can easily be solved. For example, if the processing plant time windows are the last orders on all the truck routes (i.e., all farms were visited before the plant time window), the procedure is finished. If this does not happen, then keep the routes that had plant time windows as the last orders on the routes and rerun the solver until all the routes have a plant time window as the last stop.

Data and Assumptions

Truck scheduling data were provided by the Florida Milk Marketing Cooperative (MMC) covering the seven-day period of October 3–9, 1999, for 203 dairy farms, 13 fluid milk processing plants, and 8 truck terminals. The data showed the actual behavior of the truck fleet, including time of farm pickup, volume of farm pickup, the sequence of farms in each route, the destination of the farm milk (i.e., processing plant or terminal), the volume received by the processing plant, and the time the milk arrived at the processing plant.

The time spent at each farm was assumed equal regardless of the size of the farm; however, there were differences among farms, depending on the terminal areas in which they were located. The farm service times were 49, 68, 70, 64, 44, 67, and 44 minutes in Avon Park, Belleview-Mayo, Jacksonville, Okeechobee, Tallahassee, Tampa, and Unadilla, respectively (Florida MMC, 1999). Milk supply is assumed equal to demand (i.e., no imported milk) during the study period.

Moreover, all held-over farm milk was stored in trailers at the MMC terminals (i.e., there was no storage at processing plants or other locations). All farm milk loads stored at terminals were sent directly to fluid milk processing plants before the farm milk loads picked up on that day. However, milk could only be stored for up to 72 hours (three days) at 40EF before being delivered to the fluid milk processing plants. Each terminal served farms in its own area and performed under first-in/first-out policies. All terminals were open 24 hours a day.

According to the MMC dispatch sheet, tank trailers had a capacity of 55,000 pounds (550 cwt) in the Okeechobee and Avon Park terminal areas; 53,000 pounds (530 cwt) in the Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla areas; and 50,000 pounds (500 cwt) in the Tampa area. Tractor-trailers began a route at an MMC terminal and finished at a fluid milk processing plant or at the same terminal from which they departed. The empty-load miles traveled after unloading farm milk at the fluid milk processing plant were not considered in this analysis. The average truck speed was assumed to be 55 miles per hour (mph) for highways with limited access, 40 mph for local highways, 35 mph for primary and secondary streets, and 25 mph for local streets. Cost per mile used in this analysis was $1.29 (Florida MMC, 1999), which included the cost of fuel, maintenance, and depreciation. Cost per hour was assumed to be $15 (which included the hourly wage of the driver both in regular time and overtime).[3]

Prior to running the model, the software requires setting the service area, or the map, for the software to operate. The largest service area is 200-by-200 miles. This service area is not large enough to cover the entire area of Florida. For this reason, the service areas of the MMC containing farms and terminals are divided into six service areas and are run individually as (*a*) Avon Park and Okeechobee, (*b*) Tampa, (*c*) Belleview and Mayo, (*d*) Jacksonville, (*e*) Tallahassee, and (*f*) Unadilla.

The benchmark run was the actual milk collection and delivery performed from Sunday through Saturday for the October 3–9, 1999, period by the MMC. All information was put into the ALR program to calculate the amount of time and miles, as well as any violation of the time window constraints. A time window was violated if a truck visited a farm or processing plant before or after the scheduled time for a farm or the time interval for a processing plant. In the benchmark run, each farm had a scheduled time (i.e., the exact time without any relaxation in a time window). In contrast, each processing plant delivery requirement had a time window plus or minus 30 minutes from the required schedule.

The alternative run differs from the benchmark run in that each farm pickup in the alternative run had a time window plus or minus 120 minutes (two hours) from the scheduled pickup (allowing flexibility in the scheduling and routing process by ALR). The plus or minus 30 minutes for plant time windows was maintained. A time window was violated if a truck visited a farm or processing plant before or after the scheduled time interval of a farm or processing plant. However, the number of farm milk loads picked up and delivered to fluid milk processing plants on the same day, the number of milk loads sent back to terminals, the number of terminal milk loads, and the number of farm milk loads received by the fluid milk processing plants were the same in the benchmark and alternative runs. The benchmark and alternative run scenarios were performed and compared in all service areas.

Empirical Results

Table 1 presents total mileage comparisons between the benchmark and alternative scenarios for the six Florida service areas. The total mileage reductions ranged from 284.44 miles for the Unadilla area to 1,627.16 for the Belleview-Mayo area for the October 3–9 study period. However, when considering the mileage reduction as a percentage, results show a low of 0.74% for the Avon Park-Okeechobee area and a

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[3] The average hourly wage for Florida truck drivers (heavy and tractor-trailers) was $14.42 in 1999, as reported by the U.S. Department of Labor/Bureau of Labor Statistics (1999).

Table 1. Total Mileage Comparisons Between the Benchmark and Alternative Runs for the Six Florida Service Areas, October 3–9, 1999

	Total Weekly Miles		Reduction		
Service Area	Benchmark	Alternative	Miles	Percent (%)	Dollars ($) [a]
Avon Park-Okeechobee	57,508.99	57,083.20	425.79	0.74	549.27
Tampa	6,474.72	5,567.43	907.29	14.01	1,170.40
Belleview-Mayo	75,688.82	74,061.66	1,627.16	2.15	2,099.04
Jacksonville	16,236.32	15,079.71	1,156.61	7.12	1,492.03
Tallahassee	9,732.11	8,406.85	1,325.27	13.62	1,709.60
Unadilla	3,188.88	2,904.44	284.44	8.92	366.93
Total (Average)	168,829.84	163,103.29	5,726.56	(3.39)	7,387.26

[a] Cost reduction is based on cost of $1.29 per mile.

high of 14.01% for the Tampa area, with the Tallahassee service area receiving the second highest reduction percentage (13.62%). The percentage reduction dropped to 8.92% for Unadilla, 7.12% for Jacksonville, and 2.15% for the Belleview-Mayo area. For all service areas collectively, 5,726 miles (3.39%) were eliminated by the alternative run when compared to the benchmark run. Based on $1.29 per mile, the cost savings corresponding to mileage reduction in the combined service areas totaled $7,387.26 for the October 3–9 period.

Most farms (96.9%) in the Avon Park-Okeechobee area provided a full load of milk. More than 95% of the trucks had only one stop. Conversely, the Tampa service area had 7.29 one-stop routes on average, or 53.2% of the average total routes run. More multiple-stop routes allowed more combinations in the route construction process, which resulted in increased mileage reduction. This finding did not apply to the Tallahassee and Unadilla areas because there was no direct milk delivery from farm to processing plant for these areas. All trucks in the Tallahassee and Unadilla areas returned to their terminals after completing the pickup process. There were no time window restrictions (unlike for the processing plants).

Plant time window violations as measured in hours and number are important components of overall dispatching efficiency for handling milk at fluid milk processing plants. A labor cost of $15 per hour is used to generate cost per hour in the benchmark and alternative runs. As a result, changing the benchmark run to the alternative run yields an aggregate cost savings of $4,095.88 by decreasing the hours for the October 3–9 period (table 2).

Table 3 presents a comparison of the total plant time window violations (hours) for the benchmark and alternative runs for the six service areas. During the October 3–9 period, the total hours of plant time window violations ranged from 12.21 hours for the Jacksonville area to 180.82 hours for the Avon Park-Okeechobee area for the benchmark run. The corresponding range for the alternative run was 0.07 hours for the Jacksonville area and 17.15 hours for the Belleview-Mayo area. As observed from table 3, the percentage reduction in total hours for plant time window

Table 2. Total Route Time Comparisons (hours) Between the Benchmark and Alternative Runs for the Six Florida Service Areas, October 3–9, 1999

	Total Weekly Hours		Reduction		
Service Area	Benchmark	Alternative	Hours	Percent (%)	Dollars ($)[a]
Avon Park-Okeechobee	1,729.26	1,718.69	10.57	0.61	158.55
Tampa	340.38	319.30	21.08	6.19	316.20
Belleview-Mayo	2,259.87	2,161.42	98.45	4.36	1,476.73
Jacksonville	699.25	623.36	75.89	10.85	1,138.35
Tallahassee	370.15	315.55	54.60	14.75	819.00
Unadilla	195.75	183.28	12.47	6.37	187.05
Total (Average)	5,594.66	5,321.60	273.06	(4.88)	4,095.88

Note: Total route time each day equals the sum of the total driving time, total service time at each farm, and total wait time. Driving time is when trucks are running, service time is when trucks are at the farms, and wait time is when trucks are idle.

[a] Cost reduction is based on labor cost of $15 per hour.

Table 3. Total Plant Time Window Violations (hours) for the Benchmark and Alternative Runs for the Six Florida Service Areas, October 3–9, 1999

	Total Weekly Hours		Reduction	
Service Area	Benchmark	Alternative	Hours	Percent (%)
Avon Park-Okeechobee	180.82	13.83	166.99	92.35
Tampa	53.21	15.76	37.45	70.38
Belleview-Mayo	38.22	17.15	21.07	55.14
Jacksonville	12.21	0.07	12.14	99.43
Tallahassee	N/A	N/A	N/A	N/A
Unadilla	N/A	N/A	N/A	N/A
Total (Average)	287.33	46.81	240.53	(83.71)

violations between the benchmark and alternative runs ranged from a low of 55.14% (21.07 hours) for the Belleview-Mayo area to a high of 99.43% (12.14 hours) for the Jacksonville area. The total reduction in hours of plant time window violations between the benchmark and alternative runs was 83.71% (240.53 hours) for all service areas during the October 3–9 period.

A comparison of the number of plant time window violations for the benchmark and alternative scenarios is given in table 4. Over the October 3–9 study period, these violations for the benchmark run ranged from 6 for the Jacksonville area to 60 for the Avon Park-Okeechobee area, and for the alternative run ranged from 1 for the Jacksonville area to 29 for the Belleview-Mayo area. The percentage reduction in total number of plant time window violations between the benchmark and alternative runs varied from a low of 19.44% (7 violations) for the Belleview-Mayo area to a high of 83.33% (5 violations) for the Jacksonville area. The total percentage reduction in the number of plant time window violations between the benchmark and

Table 4. Total Plant Time Window Violations (numbers) for the Benchmark and Alternative Runs for the Six Florida Service Areas, October 3–9, 1999

	Total Weekly No. of Violations		Reduction	
Service Area	Benchmark	Alternative	Number	Percent (%)
Avon Park-Okeechobee	60	20	40	66.67
Tampa	23	6	17	73.91
Belleview-Mayo	36	29	7	19.44
Jacksonville	6	1	5	83.33
Tallahassee	N/A	N/A	N/A	N/A
Unadilla	N/A	N/A	N/A	N/A
Total (Average)	125	56	69	(55.20)

alternative runs was 55.20% (69 violations) for all service areas during the seven-day study period.

Tables 5 and 6 report the total hours and numbers, respectively, of the farm time window violations for the benchmark and alternative runs over the October 3–9 period. Total farm time window violations associated with hours ranged from 20.47 hours for the Avon Park-Okeechobee area to 125.18 hours for the Belleview-Mayo area in the benchmark run, and from 0 hours for the Unadilla area to 3.22 hours for the Belleview-Mayo area in the alternative run (table 5). The percentage reduction in hours of farm time window violations between the benchmark and alternative runs spanned from a low of 90.62% for the Avon Park-Okeechobee area to a high of 100% for the Unadilla area. As shown by table 5, the remaining reduction percentages were substantial—96.52% for Jacksonville, 97.43% for Belleview-Mayo, 99.70% for Tallahassee, and 99.90% for Tampa. The overall percentage reduction in hours of farm time window violations between the benchmark and alternative runs was 98% (representing 377.79 hours) for the combined service areas.

Under the alternative run scenario, the total number of farm time window violations (table 6) ranged from 0 for the Unadilla area to 7 for the Belleview-Mayo area, with corresponding values under the benchmark of 24 violations for the Avon Park-Okeechobee area and 149 for the Belleview-Mayo area. The percentage reduction in the number of farm window violations between the benchmark and alternative runs ranged from a low of 83.33% for the Avon Park-Okeechobee area to a high of 100% for the Unadilla area. As with the percentage reductions in hours of farm time window violations reported in table 5, the remaining reduction percentages for numbers of violations (table 6) were strong—91.67% for Jacksonville, 95.30% for Belleview-Mayo, 96.43% for Tallahassee, and 98.53% for Tampa. The overall percentage reduction in the number of farm window violations between the benchmark and alternative runs was 95.69% (representing 422 violations) for the combined service areas.

Table 5. Total Farm Time Window Violations (hours) for the Benchmark and Alternative Runs for the Six Florida Service Areas, October 3–9, 1999

	Total Weekly Hours		Reduction	
Service Area	Benchmark	Alternative	Hours	Percent (%)
Avon Park-Okeechobee	20.47	1.92	18.55	90.62
Tampa	59.03	0.06	58.97	99.90
Belleview-Mayo	125.18	3.22	121.96	97.43
Jacksonville	67.26	2.34	64.92	96.52
Tallahassee	57.62	0.17	57.45	99.70
Unadilla	55.94	0.00	55.94	100.00
Total (Average)	385.50	7.71	377.79	(98.00)

Table 6. Total Farm Time Window Violations (numbers) for the Benchmark and Alternative Runs for the Six Florida Service Areas, October 3–9, 1999

	Total Weekly No. of Violations		Reduction	
Service Area	Benchmark	Alternative	Number	Percent (%)
Avon Park-Okeechobee	24	4	20	83.33
Tampa	68	1	67	98.53
Belleview-Mayo	149	7	142	95.30
Jacksonville	60	5	55	91.67
Tallahassee	56	2	54	96.43
Unadilla	84	0	84	100.00
Total (Average)	441	19	422	(95.69)

Conclusions

Scheduling and routing are important for distributing highly perishable commodities in a vertical market system. This is especially true for fluid milk in order to maintain product quality. The objective of this analysis was to determine the most efficient way for scheduling and moving farm milk from producers to the processing plants for the Florida Milk Marketing Cooperative.

Results show the total average weekly route mileage could be improved by 3.39% (a reduction of 5,726 miles), for a savings of $7,387.26 (table 1). The routes in the Jacksonville, Tallahassee, Tampa, and Unadilla areas could be reorganized to reduce route mileage and route time. These service areas have the lowest percentages of one-stop routes and the largest reductions in route mileage between the benchmark and alternative runs. Routes in these four areas need to be reevaluated and possibly reorganized.

Plant time window violations and farm time window violations for the alternative runs in all service areas show a disparity between when milk is available from the farms and when processing plants need the milk. Total plant time window violations (56) under the alternative scenario (table 4) represent 6.46% of all loads. This means that 6.46% of the loads were not on time. For farm time window violations, 1.38% of the farm pickups were not on time. These violations occurred with time windows that were one hour (the scheduled time of delivery plus or minus 30 minutes) and four hours (the scheduled time of pickup plus or minus two hours) in length at the processing plant and the farm. There is no way to meet all the plant time window requirements and farm time window requirements with the current time windows that are even more restrictive. To increase the ability to pick up loads from the farms and deliver milk loads to the processing plants with the current delivery schedule would require an adjustment in both the farm and plant time windows.

Compared to the benchmark run, adding a four-hour time window to the scheduled farm pickup time in the alternative run significantly reduced the number of time window violations (ranging from 441 to 19 for farms, as reported in table 6), and from 125 to 56 for processing plants (table 4). Likewise, adding this four-hour time window significantly reduced the number of violation hours (ranging from 385.50 to 7.71 hours for farms, as reported in table 5), and from 287.33 to 46.81 hours for processing plants (table 3). Thus, an adjustment in time window length at the farm level reduced the time window violations at both the farm level and the processing plant level. Increasing the time window length also reduced the total route time (hours) for all service areas by an average of 4.88%, representing a weekly savings of $4,095.88 (table 2), and the total route miles by an average of 3.39% (a decrease of 5,726.56 miles), representing a weekly savings of $7,387.26 (table 1).

Implications

The vertical market system (the supply chain) is under pressure to become more efficient. Cooperatives are striving to remain competitive with proprietary firms. This study demonstrates the importance of scheduling and routing in the vertical market system, and how a cooperative can remain competitive. Scheduling is an overriding problem. Analysis results suggest current schedules need to be changed. Current farm-to-plant scheduling does not allow direct farm-to-plant delivery without delays. An efficiently routed and scheduled transportation system reduces mileage and route time. Adjusting time windows and/or the scheduled pickup and delivery times reduces both the total cost and the necessary time for moving milk from farms to processing plants. Areas with multiple-stop routes possess the potential for more route improvements than areas with mainly one-stop routes. An action taken at one level of the vertical market system has an impact on other levels of the system. Processors, farmers, and the MMC must each be aware of how their individual actions influence one another.

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